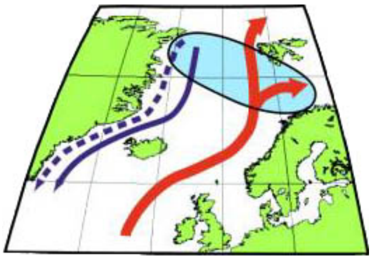
ASOF-N

Arctic-Subarctic Ocean Flux Array for European Climate: North

Contract No: EVK2-CT-2002-00139

FINAL REPORT

1 January 2003 to 31 March 2006



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Project web site:
http://www.awi-bremerhaven.de/Research/IntCoop/Oce/ASOF/index.htm

Energy,
Environment
and Sustainable Development

Fifth
Framework
Programm

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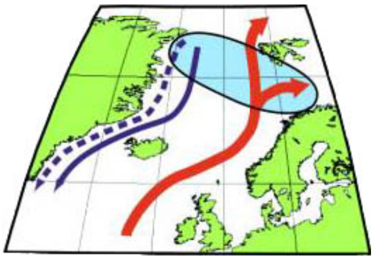

Section 1
Management and Resources Usage Summary
(months 25 - 39)

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1.1 Objectives of the reporting period

The overall ASOF-N objective is:

> To establish the appropriate components of the global observing system in the choke points of the Nordic Seas necessary to obtain the long term consolidated data set required to determine the variability of dense water, freshwater, and heat fluxes between the Arctic Ocean and the North Atlantic, to understand and predict how the fluxes respond to climatic forcing, and to provide the tools needed to asses the risks of abrupt changes.

This objective stands for the full period of ASOF. However, it could only be reached by steps and had to be broken up in components. Therefore sub-objectives were defined for the work packages. Most of those sub-objectives held for the full period. The following list comprises the most prominent ones during the third phase of the project, which covers the last 15 months (third year and 3 months of the fourth year).

The detailed objectives addressed in the individual work packages during the last period were:

WP 1 'Atlantic water pathways'

- Make measurements of track lines of Atlantic water flow by floats.
- Derive relation between variations of water mass properties and changes in the flow pattern.

To achieve these objectives the following tasks were performed during the reported period:
- processing float data and computing track lines for the floats deployed in 2004,
- processing data and compute the water mass distribution from the cruises carried out in 2004 and 2005,
- processing ADCP and LADCP data from the cruises in 2004 and 2005 to recognize the flow pattern and its year-to-year changes,
- comparison of the observed variations of track lines, water mass properties and flow patterns with model results.

WP 2 'Fluxes across the western Barents Sea'

- Determine transport time series, spatial structure and temporal variability on seasonal and interannual variability.
- Establish quantitative relations between the variations of fluxes in different sections and propagation of water characteristics.
- Asses the importance of processes and parameters responsible for the transport variability, like boundary currents, eddies and meanders, bottom topography, winter cooling and meteorological parameters.

To achieve these objectives the following tasks were performed during the reported period:
- recovery and redeployment of moorings,
- repeated sections with CTD and ADCP,
- data calibration and analysis of the time series from recent mooring recovery,
- estimation of the fluxes of volume, heat and salt from previous and last year’s data,
- comparison of the measured and modeled variability.

WP 3 'Heat flux through Fram Strait'

- Make frequent measurements (1/2h) of currents and temperature at fixed locations (11 horizontal and 4 vertical) across Fram Strait.
- Calculate volume and heat transport from above.
- Compare intensity and structure of heat flux in model and observations.

To achieve these objectives following tasks were performed during the reported period:
- data acquisition by moored current meter array deployed in 2004 and 2005,
- deployment of the moored array for the next one-year period of measurements,
- calibrating data, computing volume and heat fluxes and providing data reports on data from mooring recovery in 2004 and 2005,
- analysis of the high resolution model output for 1995-2005 and comparison with the results from the moored array in 1997-2005.

WP 4 'Freshwater flux through Fram Strait'

- Make frequent measurements (1/2h) of currents and temperature at fixed locations (4 horizontal and 4 vertical) across Fram Strait.
- Calculate volume and freshwater transport from above.

To achieve these objectives the following tasks were performed during the reported period:
- data acquisition by moored current meter array deployed in 2004 and 2005,
- calibrate data, calculate freshwater fluxes, provide data reports on data from mooring recovery in 2004 in 2005,
- process and merge historical data to new data to create and interpret time series of fluxes,
- comparison of flux variations in model and observations.

WP 5 'Data Management'

- To archive a consistent, quality-controlled set of direct observations and principle model outputs.
- To provide project data to the project scientists.
- To monitor and report to the Steering Committee on data flow.
- To achieve access for all project participants and – for the general parts – for the scientific community to electronic information on the project and its aims, on the actual status of field and modeling work and on the data inventory.

To achieve these objectives the following tasks were performed during the reported period:
- maintaining the ASOF-N homepage,
- providing the reference material on data matters to ASOF-N participants,
- compile ASOF-N data set with observations and model results on CD-ROM.

WP 6 'Integration and Synthesis'

- To determine water mass transformations in the Arctic Mediterranean that are the means by which the oceanic heat transported to the Arctic becomes available to the Arctic environment.
- To combine the measurements of property changes at choke points which give evidence of how and how strongly the ocean transports influence the Arctic and how this influence varies with time and atmospheric forcing.
- To evaluate the performance of deployed moorings.
- To design an array of minimum effort and assess the uncertainty.

To achieve these objectives the following tasks were performed during the reported period:
- analysis of the relationships between the property changes and processes, based on estimates of transport obtained by combination of hydrography, moored instruments and models and determining their strength and impact from both transport observations and model results,
- evaluate technical performance of innovative arrays, define minimum data set to describe measured variability and test results from reduced data sets from regional model outputs.

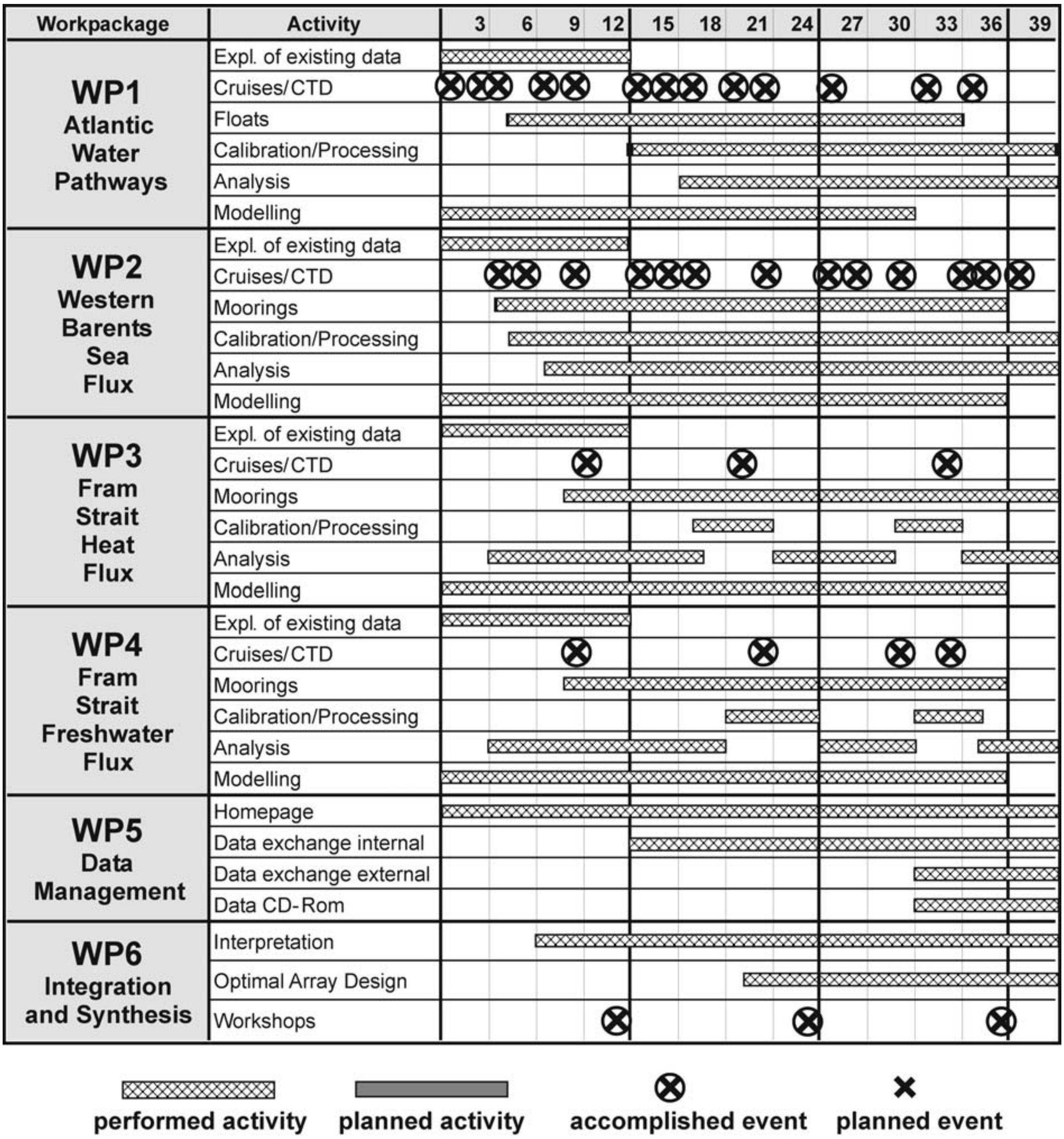
1.2 Scientific/technical progress in different work packages

The scientific/technical progress in the different work packages is summarized in the following.

The basis of progress during the project is the ongoing field work which provided the data needed to address the ASOF objectives. The third year of the project also comprised a great load of work on the data achieved from the previous year's cruises and to prepare and accomplish the field work planned for 2005 and 2006. From the Gantt chart it can be seen that all cruises took place according to the planned schedule. It can be seen further that moorings were recovered and redeployed and that data from earlier field work had been worked up and was submitted to analysis. The experiences in the field obtained during last year of the project confirm mostly the technical progress made with further development of the applied material. However progress in the field of technology suggests that further modifications may optimize the system beyond the scope envisaged during the planning phase of ASOF-N. In the final phase of the project, three-years of observations were also analysed together as complete time series and the obtained results were compared to the outputs from a wide range of numerical models runs, dedicated to the specific of the ASOF-N objective.

The comparison between the planned and the used man power and financial resources is summarized in Tables 1 and 2. They were compiled in accordance with the cost statements and give evidence that most partners dedicated more manpower and financial resources to the project as expected during the planning phase. However, it has to be taken into account that the planned numbers in the tables represent only the EU contribution. In short, the tables assure that the time and resources requested by the contract were provided. Additional time and resources were invested by the partners to assure that the objectives are met. The summary of manpower and financial resources over the full duration of the project is given in Tables 3 and 4. It appears that the lesser use of personal and resources during the last 15 months of the project in comparison to the plan (Tab. 1 and 2) was widely compensated by much larger efforts during the first two years. One obvious reason for this shift is that fieldwork in the first part of the project required higher efforts than analysis and synthesis in the second.

- **Updated Gantt chart.**



- **Comparison between planned and used manpower and financial resources by work packages and partners.**

Tab. 1: Planned and used manpower in person hours per year 2005 and 2006 according to cost statements and CPFs.

		WP1	WP2	WP3	WP4	WP5	WP6	Coord	Sum
1-AWI	Planned			2860		1361	437	607	5265
	Used			2355		1119	441	954	4869
2-IFMH (AC)	Planned				0				0
	Used				0				0
3-IMR	Planned		950				300		1250
	Used		316				352		668
4-FIMR	Planned						2000		2000
	Used						1592		1592
5-IOPAS (AC)	Planned	1890					405		2295
	Used	3404					580		3984
6-LODYC UPMC	Planned	593					407		1000
	Used	3100					594		3694
7-NPI	Planned		157		1234		396		1787
	Used		329		2733		924		3987
Sum	Planned	2483	1107	2860	1234	1361	3945	607	13597
	Used	6504	645	2355	2733	1119	4483	954	18793

Tab. 2: EU contribution to planned and used costs per year 2005 and 2006 according to cost statements and CPFs.

		WP1	WP2	WP3	WP4	WP5	WP6	Coord	Sum
1-AWI	Planned			95.093		41.439	15.719	29.196	181.447
	Used			85.278		34.623	15.815	20.862	156.578
2-IFMH (AC)	Planned				4.800				4.800
	Used				0				0
3-IMR	Planned		96.564				31.499		128.063
	Used		62.568				39.476		102.044
4-FIMR	Planned						55.146		55.146
	Used						49.507		49.507
5-IOPAS (AC)	Planned	39.440					8.349		47.789
	Used	48.188					8.700		56.888
6- LODYC UPMC	Planned	20.403					21.165		41.568
	Used	99.155					21.170		120.325
7- NPI	Planned		6.086		70.041		27.748		103.875
	Used		20.737		105.457		56.584		182.778
	Planned	59.843	102.650		74.841	41.439	159.626	29.196	562.688
	Used	147.343	83.305		105.457	34.623	191.252	20.862	668.120

Tab. 3: Planned and used manpower in person hours per year during full project duration according to cost statements and CPFs.

		Year 1	Year 2	Year 3	Year 4	Years 4+5	Sum
1-AWI	Planned	2835	4050	4050	1215	5265	12.150
	Used	3443	4050			4869	12.362
2-IFMH (AC)	Planned	0	0	0	0	0	0
	Used	0	0	0	0	0	0
3-IMR	Planned	1250	1250	1200	50	1250	3.750
	Used	2342	1391	668		668	4.401
4-FIMR	Planned	1200	1600	1600	400	2000	4.790
	Used	2097	1590			1592	5.919
5-IOPAS (AC)	Planned	2230	2230	2295	0	2295	6.755
	Used	2459	3216			3984	9.659
6-LODYC UPMC	Planned	3070	2720	1000	0	1000	6.790
	Used	3498	2700			3694	9.892
7-NPI	Planned	1512	1650	1650	137	1787	4.949
	Used	3537	4031			3987	11.555
Sum	Planned	12.097	13.500	11.795	1.802	13.597	39.194
	Used	17.376	16.978	668	0	18.794	53.148

Tab. 4: EU contribution to planned and used costs per year during the full project duration according to cost statements and CPFs

		Year 1	Year 2	Year 3	Year 4	Years 3+4	Sum
1-AWI	Planned	116.452	146.533	134.503	46.944	181.447	444.432
	Used	148.640	133.542			156.578	438.760
2-IFMH (AC)	Planned	59.408	14.400	4.800	0	4.800	78.608
	Used	44.101	79	0	0	0	44.180
3-IMR	Planned	137.869	127.807	109.729	18.334	128.063	393.739
	Used	232.362	159.043			102.044	493.449
4-FIMR	Planned	31.741	42.626	43.449	11.697	55.146	129.513
	Used	49.086	37.668			49.507	136.261
5-IOPAS (AC)	Planned	45.990	45.374	47.789	0	47.789	139.153
	Used	37.476	50.643			56.888	145.007
6- LODYC UPMC	Planned	226.306	84.877	41.568	0	41.568	352.751
	Used	153.361	79.147			120.325	352.833
7- NPI	Planned	67.314	175.662	81.046	22.829	103.875	346.851
	Used	205.689	318.837			182.778	707.304
Sum	Planned	685.080	637.279	462.884	99.804	562.688	1.885.046
	Used	870.715	778.959			668.120	2.317.793

1.3 Milestones and deliverables obtained

- **Deliverables**

The deliverables which were due during the third and a part of fourth year of the project were all delivered. They are summarized in Table 5.

Tab. 5: Deliverables requested in months 25 to 39 of ASOF-N.

Work package	Delive-rable No	Deliverable title	Due in month	Status
WP1	D. 1.2	Status report of float deployment	36	Delivered
WP1	D 1.3	Calibrated float data, current field	36	Delivered
WP1	D 1.4	Preliminary data from hydrographic surveys: CTD and ADCP	27, 37	Delivered
WP1	D 1.5	Calibrated data, T/S and ADCP current fields	30, 39	Delivered
WP1	D 1.6	Merged modelled and observed fields of currents and water mass properties	39	See below
WP2	D 2.2	Preliminary data from CM	27	Delivered
WP2	D 2.3	Preliminary data from repeated sections with CTD and ADCP	27, 37	Delivered
WP2	D 2.4	Calibrated data, analysis of time series and historical data	30, 39	Delivered
WP2	D 2.5	Estimates of fluxes of volume, heat and salt	36	Delivered
WP2	D 2.6	Comparison of modelled and measured fluxes	39	Delivered
WP3	D 3.2	Preliminary data from moored array and repeated sections (CM, ADCP, CTD)	28, 37	Delivered
WP3	D 3.3	Calibrated data, calculated fluxes and data reports	30, 39	Delivered
WP3	D 3.4	Time series of models and observations, analysis and interpretation of flux variability	39	Delivered
WP3	D 3.5	Comparison between model and observed statistics of the heat flux	39	Delivered
WP4	D 4.2	Preliminary data from moored array and repeated sections (CM, ULS, ADCP, CTD)	28, 37	Delivered
WP4	D 4.3	Calibrated data, calculated fluxes and data reports	30, 39	Delivered
WP4	D 4.4	Time series of models and observations, analysis and interpretation of flux variability	39	Delivered
WP4	D 4.5	Comparison of model and observations	39	Delivered
WP5	D 5.3	Data inventories, project data, historical data (organized in the project database)	24, 39	Delivered
WP5	D 5.4	Project CD-ROM	39	Delivered
WP6	D 6.2	Identification of active processes and estimates of their strength and time dependence	39	Delivered
WP6	D 6.3	Report with the description of array performance	26	Delivered
WP6	D 6.4	Report with description of variability characteristics	39	Delivered
WP6	D 6.5	Report with results from sensibility study to instrument reduction	39	Delivered

Remark to deliverable D1.6 “Merged modelled and observed fields of currents and water mass properties” could not be achieved in a strict sense which would mean the assimilation of the data in one of the models. However, in a wider sense model results and observations were merged by a joint analysis of pattern and fluxes in models and observations. First results were presented at the Ocean Sciences Meeting, Honolulu, Hawaii in 2006.

- **Milestones**

The milestones common for all work packages were reached in month 26 and 39 in a form of the annual oversights on WPs’ progress available. They are the basis of Section 3. These annual reports include a detailed description of the each WP progress together with information about the completed tasks and deliverables. Additionally, the information on the project progress is periodically updated on the ASOF-N webpage in a form of the cruise reports, comprising the details of performed measurements and used instrumentation.

Common milestones in WP1, WP2, WP3 and WP4 (due in month 36):

- Annual oversight on WP progress available - obtained.
- Annual water mass distributions available - obtained.
- Annual flow pattern available - obtained.

Annual oversights of the WPs are included in Section 3 of the annual report. Annual water mass distributions and flow patterns are presented in the respective deliverables in a form of short reports or published papers. The results obtained during the third year of the project are also included into the papers which are under preparation and talks and posters presented during the international conferences and meetings.

Milestones specific for each WP:

- WP1 Analysis of variability in space and time completed (month 39) - obtained
- WP2 Fluxes of volume, heat and salt across western Barents shelf available with analysis of variability in space and time, including results form statistics on significance of longer-term measurements in selected locations (month 39) - obtained.
- WP3 Volume and heat flux estimates with analysis of variability in time completed (month 39) - obtained.
- WP4 Freshwater flux estimates with analysis of variability in space and time completed (month 39) - obtained.
- WP5 Summaries on data flow provided to co-ordinator and steering committee (months 26 and 39) - obtained.
- WP5 Project CD-ROM distributed (month 39) - work in progress due to required data preparations and arrangements for large data sets.
- WP6 Technical performance evaluated (month 39) - obtained.
- WP6 Array design optimised (month 39) - obtained.

All milestones planned for the reporting period except of finalizing the project CD were reached in the planned month.

1.4 Deviation from the work plan and/or time schedule and their impact on the project

During the reporting period no significant deviations from the work plan and time schedule occurred which could have seriously impacted the project progress. Minor deviations occurred in the cruise plans or data availability in particular due to lost moorings and floats. However, they did not affect the progress and success of the project. With the exception of the last batch of floats , all field measurements planned for the period reported were carried out as expected in the work plan (see updated Gantt chart). All planned ASOF-N meetings were held in Bremerhaven as planned.

In WP1 the significant losses of deployed floats resulted in a loss of time and space coverage of float trajectories. The last float deployment will not be exploited since none of these floats resurfaced after six months drifting in 300 m depth. This failure is more likely due to a technical problem of the floats release mechanism. However, this loss should not modify fundamentally the conclusions gained from the first four floats deployments.

In WP2 one of the key persons involved in the project was on pregnancy and maternity leave in 2004 and 2005. This created a small delay in some respect. However, it could be mostly recovered and did not affect the project progress.

In WP3 the shift of the mooring duration from a 2 years deployment to 1 year due to corrosion problems occurred as planned. This issue is one of changes in the array design resulting from optimisation of the existing moorings. Due to technical problems, lack of reliability and insolvency of the manufacturer, the planned use of pop-up buoys for data recovery was not possible during the project period. A new manufacturer (OPTIMARE) redesigned and improved the instrument and started new field tests after the end of the ASOF-N funding period. By means of the achieved experience recommendations for the near-real time data transmission in Fram Strait have been worked out and other possibilities are taken into account.

In WP4 a large number of instrumentation (including complete moorings) was lost in 2005 due to unfavourable ice conditions and probably the increased activity of icebergs at the East Greenland Shelf. Mooring losses have been a major problem in this WP during the whole project. The 2004-2005 deployment was a particularly bad year. Moorings F12-7 and F13-7 in the East Greenland Current was lost, as was F19-2 on the shelf. In previous reports we have speculated about causes, in this report it suffices to say that collisions with icebergs from the disintegrating Northeast Greenland glaciers is a likely cause for at least some of the losses. Due to a positioning error F18-2 was not recovered, but may have survived and will then be recovered during the 2006 maintenance cruise. However, estimates of freshwater fluxes could be achieved on a basis of the recovered instrumentation.

In WP5 a short delay in preparation and distributing the project CD is related to the large amount and variety of different data sets, being delivered to the database continuously until the end of the project. In some cases detailed information on metadata has to be included in the project CD instead complete data sets. The CD ROM will be finalized within a few months after the project ends.

1.5 Co-ordination of the information between partners and communication activities

- Exchange of information by the e-mail.

The complete information relevant to the project was distributed among the project participants by the project coordinator via e-mails. This reduced the need of meetings and workshops.

- ASOF-N webpage.

A full description of the project with detailed information on the work plan, deliverables and milestones for each work packages is available for the project participants from ASOF-N web site. A webpage presenting the cruise reports and preliminary reports on the collected data was frequently updated. Examples of the instrument sheets are also accessible. Information on the important events relevant to the project is presented there with special attention to the other ASOF activities (ASOF-W, ASOF-E) and the conferences where the project results will be presented. The annual reports as well as ASOF-N seminar reports are also available on the webpage.

- Third ASOF-N Seminar, December 8-9, 2005, Bremerhaven, Germany.

The third ASOF-N meeting was held on December 8-9, 2005 in Bremerhaven, Germany. The seminar was organized by the Alfred Wegener Institute for Polar and Marine Research and all workpackages were represented by the involved scientists. A general overview on the overall objectives of the ASOF-N project and its particular workpackages and tasks was presented by the project coordinator with a special focus on the achieved progress. The results of the ASOF-N third year and on-going activities in all workpackages were reported by the responsible scientists during the mini-symposium on the first day of meeting. A wide range of talks presented also a summary of results achieved during the whole project. An open discussion on future plans, especially the field work and details of the planned measurements, was held during the second day. The report from the third ASOF-N meeting comprises a detailed description of the presented topics and can be found as an attachment to this report. A complete version of the report is also available from the ASOF-N webpage.

- ASOF book and ASOF Conference, June 28 -July 1, 2006, Thorshavn, Faroe Islands

The compilation of the ASOF-N results will be included in the "International ASOF Book", which is under preparation and planned to be published in the beginning of 2007. According to the preliminary draft, the separate chapters will be devoted to achievements of WP1, WP2, WP3 and WP4 with a synthesis chapter based on results of WP6. An overview of the content of the book was presented as scientific talks during the ASOF Conference on Faroe Islands. The results of all ASOF-N workpackages were displayed by project partners and intensively discussed in the context of the whole ASOF cluster. The ASOF book will be one of the main means to communicate project results to community.

- Co-operation with other projects

The results achieved in the ASOF-N workpackages were presented at the forum of ICES Ocean Hydrography Working Group during its annual meetings in April 2005 at the Rhode Island University and in April 2006 in at the University of Ireland in Galway. The ASOF-N results were also included in the 'Annual ICES Ocean Climate Status Summaries' for 2003/2004 and 2004/2005 (IAOCSS 2003/2004 and IAOCSS 2003/2004) which are prepared on a yearly basis by OHWG and published by ICES. Also project data collected during the third year of field measurements in WP1, WP2, WP3 and WP4 were transferred to the ICES data center and the World Data Center for Marine Environmental Sciences.

The knowledge achieved during the ASOF-N project was extensively used in preparation of the EU-DAMOCLES (Developing Arctic Modelling and Observing Capabilities for Long-term Environment Studies) project which was launched in December 2005. A design of the observing system in the main gateways to the Arctic Ocean used the experience of ASOF-N observatories in Fram Strait and Barents Sea Opening and was based on the results of optimization of existing arrays.

- Conference attendance.

The ASOF-N results were presented or at following scientific conferences and meetings:

- ICES Ocean Hydrography Working Group, Rhode Island, April 11-14, 2005.
- EGU General Assembly, Vienna, Austria, April 24-29, 2005.
- 2005 International Ocean Research Conference organized by TOS/UNESCO, Paris, France, June 6-10, 2005.
- Norwegian Coastal Current Conference, Bergen, Norway, August 31 - September 2, 2005.
- Second International Conference on Arctic Research Planning ICARP II, Copenhagen, Denmark, November 10-12, 2005.
- 5th ASOF ISSG Meeting, Villefranche, France, November 16-18, 2005.
- NORCAN (Norway-Canada Comparison of Marine Ecosystems) Workshop, Bergen, Norway, December 5-7, 2005.
- 2006 Ocean Sciences Meeting, Honolulu, Hawaii, February 20-24, 2006.
- Arctic Summit Science Week, Potsdam, Germany, March 22-29, 2006.
- EGU General Assembly, Vienna, Austria, April 2-7, 2006.
- ICES Ocean Hydrography Working Group, Galway, Ireland, April 11-14, 2006.
- International ASOF Conference, Thorshavn, Faroe Islands, June 28 - July 1, 2006.

1.6 Difficulties encountered at management and co-ordination level and proposed solutions

Difficulties which were encountered at the management and co-ordination level are of the same nature as during the first two years of the project and reflect the fact that the project is very ambitious. Therefore the involved scientists are highly committed to assure the supporting background for the project. The need of that becomes immediately obvious when unexpected resources are needed. The need and the successful use of additional resources was a serious issue for ASOF-N as displayed in tables 1 to 4.

Intensive commitments make it sometimes difficult to attend meetings or keep deadlines. We therefore relied very much on email communication and kept the number of project meetings small. This strategy worked out well. During the three ASOF-N meetings all workpackages were well represented and in addition ASOF-N could use the occasion of many other scientific conferences to display the results.

Problems occurred by unexpected changes or unavailability of personal, e.g. by change of appointments or maternity leave. Since qualified personal is difficult to find due to a shortage in our field, free positions could not be reoccupied without delay. This delayed the progress in part of the workpackages and on the project management level e.g. by delaying the maintenance of the website.

Since high commitment is a general problem, no particular solution can be proposed here except of the wish to keep the reporting etc. efforts as small as possible. However, as can be seen from the report the above indicated problems did not affect the progress of work.

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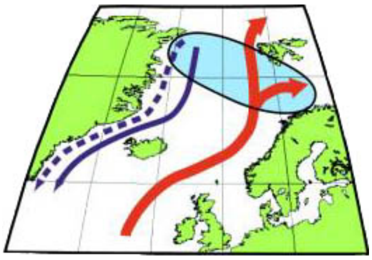
EVK2-CT-2002-00139

FINAL REPORT



Section 2

Executive Publishable Summary for the Reported Period (months 25 - 39)

Energy,
Environment
and Sustainable Development

Fifth
Framework
Programm

2. Executive publishable summary related to reporting period

Contract n°:	EVK2-CT-2002-00139	Reporting period:	1.01.2005 - 31.3.2006
Title:	Arctic-Subarctic Ocean Flux Array for European Climate: North (ASOF-N)		

Objectives:

The main ASOF-N objective is to establish the components of the global observing system in choke points of the Nordic Seas to determine the fluxes between the Arctic Ocean and the North Atlantic and to understand and predict how they respond to climatic forcing. To achieve this goal long time series are needed. For this purpose the main tasks were to perform the field measurements with a special focus on setting up of the long term measuring arrays of moored instruments and floats:

- WP 1 'Atlantic water pathways' - measurements of track lines of Atlantic water flow by floats and mapping horizontal distributions of the Atlantic water properties;
- WP 2 'Fluxes across the western Barents Sea' - measurements by a mooring array in the Barents Sea opening and carrying out hydrographic sections;
- WP 3 'Heat flux through Fram Strait' - currents and temperature measurements by a mooring array in the eastern and central Fram Strait and a high resolution vertical section of temperature and salinity across the strait;
- WP 4 'Freshwater flux through Fram Strait' - currents and temperature measurements by a mooring array in the western Fram Strait and high resolution vertical sections of temperature and salinity across and along the strait.

The following set of tasks included analysis of data sets, obtained during field measurements in WP1, WP2, WP3 and WP4. The objective of WP5 'Data Management' was to provide access to the project data and the actual status of field and modelling work and to organize the data flow to the project data centre from all partners. The WP6 'Integration and Synthesis' aimed to develop the adequate water mass classification for Fram Strait including also a description of time evolution of the water mass properties and regional correlations between the observed variables.

Scientific achievements:

The field work carried out during the third year of ASOF-N provided repeated hydrographic surveys including vertical sections of temperature and salinity in the observation area (Barents Sea, Greenland Sea, Fram Strait). The ASOF-N mooring arrays deployed during the second year of the project were recovered and redeployed in the Barents Sea opening and across Fram Strait. The analysis of the data obtained during the third year of the project together with earlier data sets permitted to describe the longer term variability of the oceanic conditions in the ASOF-N area. On this basis time variability of the water mass properties, heat and volume fluxes were estimated for the three-year long period. In combination with historical data a nearly decadal time series of fluxes resulted. The variability of volume, heat and freshwater fluxes was analyzed on different time scales from daily to interannual and nearly decadal ones. The contributions of local and remote forcing to the temporal and spatial changes of flow and temperature fields were estimated, giving the insight into the relationship between variability of forcing and of fluxes. High resolution numerical models for the western Barents Sea (NPI) and the Greenland Sea, Fram Strait and Arctic Ocean (AWI) were implemented and runs covering the ASOF-N period were completed. A refined water mass classification for Fram Strait was derived and the possibility was explored to compute the time evolution of heat and salt fluxes through Fram Strait, using variable reference salinities and temperatures. The adjustments of the measuring arrays based on the assessment of the observational system performance during the deployments resulted in a data return of about 90% during the final phase of the project.

Socio-economic relevance and policy implications:

Variability of the ocean circulation and the water mass distribution in the Nordic Seas lead to changes in the volume, heat and freshwater fluxes between the Arctic Ocean and North Atlantic. Changes in these fluxes can have a strong influence on the role of the ocean in the climate system which includes the potential of abrupt climate changes. The climate variability in particular in the northern North Atlantic has a strong impact on the living conditions in Northwest Europe. This includes energy consumption, sea traffic and marine living resources. Therefore a reliable prediction system is of high value to maintain the present living conditions. Prediction requires understanding and modelling of the relevant processes and monitoring key parameters to validate and constrain the models. Since variability of the relevant time scales can be only studied on the base of the long-term time series, ASOF-N aimed to pave the way towards an observing system consisting of a cost-effective array of instruments in the key areas for the exchanges between the North Atlantic and Arctic Ocean. The results of ASOF-N will help to design such a system, to give advice for its implementation and consequently contribute to maintain the quality of life in Northwest Europe.

Conclusions:

The evaluation of the available historical data together with the results of the ASOF-N third year field measurements suggests that variations of the fluxes between the North Atlantic and the Arctic Ocean occur on a wide range of time scales and are interlinked between the main passages. The volume and heat fluxes are also controlled by local and remote atmospheric forcing. Both in the Barents Sea Opening and Fram Strait variability of temperature is independent of the variations in the volume flux. The former is dominated by advective processes and depends mostly on the upstream conditions while the latter is related to the local atmospheric forcing. Observed variations in the Atlantic Water pathways (namely intensification/weakening of the branches of the Norwegian-Atlantic Current) result in the redistribution of the Atlantic Water in Fram Strait and strongly influence the heat flux into the Arctic Ocean. All these changes occur over long time scales and only quasi-continuous measurements over a decade and more give a chance to identify the nature of these fluctuations. Lacking spatial resolution is a problem in spite that the major parts of the transports occur in relatively narrow boundary currents. Technical problems with the present day equipment require redundancy. New technology available to replace conventional instruments on an operational basis is under development and a design of optimized observational array has been worked out on the basis of the ASOF-N experience.

Keywords:

Fram Strait, Barents Sea, heat flux, freshwater flux, Atlantic water inflow, Arctic Ocean-North Atlantic exchange, moorings, floats, CTD sections

Peer Reviewed Articles:

Authors	Date	Title	Journal	Reference
Olsson, K.A., Jeansson, E., Tanhua, T., Gascard, J.-C.	2005	The East Greenland Current studied with CFCs and released sulphur hexafluoride	Journal of Marine Systems	55 (1-2), 77-95
Holfort, J., Meincke, J.	2005	Time series of freshwater-transport on the East Greenland Shelf at 74°N	Meteorologische Zeitschrift	14 (6), 703-710, doi: 10.1127/0941-2948/2005/0079
Holfort, J., Hansen, E.	2005	Timeseries of Polar Water properties in Fram Strait	Geophysical Research Letters	32 (19), 1-4, doi: 10.1029/ 2005GL022957
Polyakov, I.V., Beszczynska, A., Carmack, E.C., Dmitrenko, I.A., Fahrbach, E., Frolov, I.E., Gerdes, R., Hansen, E., Holfort, J., Ivanov, V.V., Johnson, M.A., Karcher, M., Kauker, F., Morison, J., Orvik, K.A., Schauer, U., Simmons, H.L., Skagseth, O., Sokolov, V.T., Steele, M., Timokhov, L.A., Walsh, D., Walsh, J.E.	2005	One more step toward a warmer Arctic	Geophysical Research Letters	32(17), 1-4, doi: 10.1029/ 2005GL023740
Clement, J.L., Maslowski, W., Cooper, L.W., Grebmeier, J.M., Walczowski, W.	2005	Ocean circulation and exchanges through the northern Bering Sea - 1979-2001 Model results	Deep-Sea Research Part II: Topical Studies in Oceanography	52 (24-26), 3509-3540
Rudels, B., Björk, G., Nilsson, J., Winsor, P., Lake, I. And Nohr, C.	2005	The interaction between waters from the Arctic Ocean and the Nordic Seas north of Fram Strait and along the East Greenland Current: results from the Arctic Ocean – 02 Oden expedition	Journal of Marine Systems	55, 1-30, doi:10.1016/ 2004.06.008
Schlichtholz P.	2005	Climatological baroclinic forcing of the barotropic flow in the East Greenland Current in Fram Strait	Journal of Geophysical Research	110, C08013, doi:10.1029/ 2004JC002701.
Walczowski, W., Piechura, J., Osinski R.	2005	The West Spitsbergen Current volume and heat transport from synoptic observations in summer	Deep-Sea Research Part I: Oceanographic Research Papers	52 (8), 1374-1391, doi: 10.1016/ j.dsr.2005.03.009
Walczowski W., J. Piechura	2006	New evidence of warming propagating toward the Arctic Ocean	Geophysical Research Letters	33, L12601, doi:10.1029/ 2006GL025872.
Schlichtholz P., Goszczko I.	2006	Interannual variability of the Atlantic water layer in the West Spitsbergen Current at 76.5N in summer 1991–2003	Deep-Sea Research Part I: Oceanographic Research Papers	53, 608–626

Manuscripts in preparation:			
Carmack, E., Barber, D., Christensen, J., Macdonald, R., Rudels, B. and Sakshaug, E.	Climate Variability and Physical Forcing of the Food Webs and the Carbon Budget on Panarctic shelves	Progress in Oceanography	submitted
Jeansson, E., Jutterström, S., Rudels, B., Anderson, L.G., Olsson, K.A., Jones, E.P., Smethie Jr., W.H. and Swift, J.H.	Sources to the East Greenland Current and its contribution to the Denmark Strait overflow	Progress in Oceanography	submitted
Marnela, M., Rudels, B, Olsson, K.A., Anderson, L.G., Jeansson, E., Torres, D.J., Messias, M.-J., Swift, J.H. and Watson, A.J.	Transports of Nordic Seas water masses and excess SF_6 through Fram Strait to the Arctic Ocean	Progress in Oceanography	submitted
Nilsson, J., Björk, G., Rudels, B., Winsor, P., Torres, D.J.	Late winter conditions and freshwater transport in the East Greenland Current: result from an icebreaker-based survey.		submitted
Rudels, B., Anderson, L.G., Eriksson, P., Fahrbach, E., Jakobsson, M., Jones, E.P., Melling, H., Prinsenberg, S., Schauer, U. and Yao, T.	Observations in the Ocean.	Chapter 4 in "ARCTIC Climate Change – The ACSYS Decade and Beyond", Editors: P. Lemke, T. Fichefet, C. Dick	submitted
Wassmann, P., Reigstad, M., Haug, T., Rudels, B., Carroll, M.L., Hop, H., Gabrielsen, G.W., Falk-Petersen, S., Denisenko, S.G., Arashkevich, E., Slagstad, D. and Pavlova, O.	Food webs and carbon flux in the Barents Sea.	Progress in Oceanography	submitted
Carmack, E., Barber, D., Christensen, J., Macdonald, R., Rudels, B. and Sakshaug, E.	Climate Variability and Physical Forcing of the Food Webs and the Carbon Budget on Panarctic shelves	Progress in Oceanography	submitted
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		Lemke, T. Fichefet, C. Dick	
Wassmann, P., Reigstad, M., Haug, T., Rudels, B., Carroll, M.L., Hop, H., Gabrielsen, G.W., Falk-Petersen, S., Denisenko, S.G., Arashkevich, E., Slagstad, D. and Pavlova, O.	Food webs and carbon flux in the Barents Sea.	Progress in Oceanography	submitted
Fieg K, R. Gerdes. et al.	High resolution model results in Fram Strait	Peer revied literature	in preparation
Beszczynska-Möller A., U. Schauer, E. Fachrbach, G. Rohardt	Variablity of flow and fluxes through Fram Srait	Peer revied literature	in preparation
Loeng H., B. Aadlandsvik, T. Furevik, J.-C. Gascard, R. Ingvaldsen, K.-A. Orvik, Ø. Skagseth	Flux of heat, salt and mass to the Arctic Ocean via Norway Coast and Barents Sea	ASOF Book 2007 (peer revied book chapter)	in preparation
Fahrbach E., U. Schauer, A. Beszczynska-Möller, E. Hansen, J. Piechura, W. Walczowski	Flux of heat, salt and mass to the Arctic Ocean via Fram Strait.	ASOF Book 2007 (peer revied book chapter)	in preparation
Holfort J., E. Hansen, S. Østerhus, S. Dye, S. Jonsson, J. Meincke, J. Mortensen, M. Meredith	Freshwater fluxes east of Greenland	ASOF Book 2007 (peer revied book chapter)	in preparation
Rudels B.	Constraints on calculating the balances of heat, mass and salt for the Arctic Mediterranean	ASOF Book 2007 (peer revied book chapter)	in preparation
Gerdes R., Karcher M., Koeberle C..	Long term variability of the freshwater export from the Arctic Ocean as seen in model results	ASOF Book 2007 (peer revied book chapter)	in preparation

Non refereed literature: (R - Report, O - Oral, P - Poster, CP - Conference proceedings, B - Book chapter, A - non revieed article)

Authors/Editors	Date	Title	Event	Reference	Type
W. Walczowski , J. Piechura,	2005	Polish National Report (Area 10, 11, 12)	Report of the Working Group on Oceanic Hydrography ICES ICES CM 2005/C:06.		**R**
Walczowski, W., Piechura, J., Osinski, R	2005	Atlantic Water pathways and transport in the Fram Strait during summer	European Geosciences Union Assembly, Vienna, Austria,		**P, CP**
W. Walczowski, S. Kwasniewski	2005	Interaction between deep basin and west Spitsbergen shelf and slope.	TOS meeting, Paris		**O**
W. Walczowski, J. Piechura, W. Maslowski	2005	The Baltic Sea: freshwater source for the pan-Arctic region – in situ observations and high-resolution modeling approach	Norwegian Coastal Current Conference,		**O**

			Bergen		
A. Beszczynska-Möller, W. Walczowski, W. Maslowski	2006	Pathways of Atlantic Water through Fram Strait and its inflow into the Arctic Ocean: A synthesis of observations and model results	2006 Ocean Sciences Meeting, Honolulu, Hawaii		**O, CP**
W. Walczowski, J. Piechura	2006	Variability of the Atlantic Water properties and heat content in the West Spitsbergen Current during summers 2000 – 2005,	European Geosciences Union Assembly, Vienna, Austria		**P, CP**
Ingvaldsen, R., Loeng, H., Mork, K.A., Svendsen, E., Danielssen, D	2005	Norwegian waters.	Report on the Working Group on Oceanic Hydrography	ICES CM 2005/C:06.	**R**
Mork, K. A., Skagseth, Ø.	2005	Annual sea surface height variability in the Nordic Seas. In: The Nordic Seas, An integrated Perspective.	American Geophysical Union (AGU), Washington.	AGU Geophysical Monograph Series, 158.	**B**
Ingvaldsen R., H. Loeng, K.-A. Mork, E. Svendsen, P. Budgell, D. Danielssen	2006	Norwegian waters.	Report on the Working Group on Oceanic Hydrography.	ICES CM 2006/ OCC:08	**R**
Drinkwater, K.F., Loeng, H., Ingvaldsen, R	2005	The Physical Oceanography of the Barents Sea and Vicinity	NORCAN Workshop, 5-7 Dec 2005.		**O**
Loeng, H	2005	Igangværende forskning innen klima ved Havforskningsinstituttet. NORKLIMA - programstyremøte	Lysebu, Oslo, March 2006		**O**
Loeng, H.	2005	Klima i endring. Ukens orientering,	Havforskningsinstitutte, Bergen, Januar 2005.		**O**
Loeng, H., Ingvaldsen, R.	2005	Oceanographic conditions in the Barents Sea during 2004	Meeting with PINRO, Archangelsk, March 2005.		**O**
Loeng, H., K.A. Mork and Ø. Skagseth	2005	Some recent current measurements in Norwegian Waters: Preliminary results from bottom mounted ADCPs in the Fugløy – Bear Island and from measurements in the Norwegian Sea.	ASOF annual meeting, Villefranche, November 2005		**O**
Loeng, H. and Ingvaldsen, R.	2006	Oceanographic conditions in the Barents Sea during 2005.	IMR/PINRO meeting at "Hurgigruta", March 2006		**O**
Loeng, H	2006	Norwegian Research in Arctic and IMR involvement.	IMR/PINRO meeting at "Hurgigruta", March 2006		**O**
Loeng, H.	2006	Hydrographic conditions in Norwegian waters 2005	ICES WGOH Meeting, Galway, Ireland, April 2006		**O**
Beszczynska-Möller A., E. Fahrbach, A. Wisotzki, G. Budeus	2005	Hydrographic conditions in the Greenland Sea and Fram Strait (Area 12)	Report of the Working Group on Oceanic Hydrography ICES	ICES CM 2005/C:06	**R**

Beszczynska-Möller A., E. Fahrbach, U, Schauer, A. Wisotzki, O. Skagseth	2005	Warming events in Fram Strait and their consequences for the heat transport	ICES OHWG Annual Meeting 2005, Rhode Island, US		**O**
Beszczynska-Möller A., E. Fahrbach, A. Wisotzki, G. Budeus	2006	Hydrographic conditions in the Greenland Sea and Fram Strait in 2005	Report on the Working Group on Oceanic Hydrography.	ICES CM 2006/ OCC:08	**R**
Beszczynska-Möller A.,W. Walczowski	2006	Recent changes in the AW pathways and heat flux through Fram Strait	ICES OHWG Annual Meeting 2006, Galway, Ireland		**O**
Beszczynska-Möller A., E. Fahrbach, A. Wisotzki, G. Budeus	2005	Area 12 - Greenland Sea and Fram Strait	IAOCSS 2004-2005	ICES Cooperative Research Report No. 275	**R**
Beszczynska-Möller A., E. Fahrbach, A. Wisotzki, G. Budeus	2006	Area 12 - Greenland Sea and Fram Strait	IROC 2005 (The ICES Report on Ocean Climate 2005)	ICES Cooperative Research Report No.	**R**
Beszczynska-Möller A., E. Fahrbach, U, Schauer, O, Skagseth, K.-A. Orvik, M. Karcher, F. kauker, R. Gerdes	2005	Warm anomalies and heat flux variability in Fram Strait in 1997-2004: A comparison between observations and model results	European Geosciences Union Assembly 2005, Vienna, Austria		**O, CP**
Beszczynska-Möller A., E. Fahrbach, U, Schauer, A. Wisotzki, G. Rohardt	2006	Variability of heat flux toward the Arctic Ocean from nearly decadal measurements by the array of moorings in Fram Strait	European Geosciences Union Assembly 2006 Vienna, Austria		**O, CP**
Beszczynska-Möller A., E. Fahrbach	2005	ASOF-N Results	ASOF ISSG Annual Meeting 2005, Villefranche, France		**O**
Beszczynska-Möller A., E. Fahrbach	2005	Warming events and heat flux variability in Fram Strait	ASOF ISSG Annual Meeting 2005, Villefranche, France		**O**
Beszczynska-Möller A., E. Fahrbach, U. Schauer	2005	Variability of heat transport through Fram Stait - observations	ASOF-N Annual Seminar 2005, Bremerhaven, Germany		**O**
Beszczynska-Möller A., E. Fahrbach, U. Schauer, C. Haas, K. Fieg, M. Karcher, F. Kauker	2006	Exchanges through Fram Strairt: A link between North Atlantic conditions and Arctic sea ice ?	AWI Begutachtung		**O**
Beszczynska-Möller A., K. Fieg, W. Hayek, M. Marnela, M. Monsees, H. Rohr, E. Schütt, H. Schwegler, A. Wisotzki, O. Zenk	2005	Flow through Fram Strait - ARKXX/2 cruise report.	Berichte zur Polar- und Meeresforschung		**R**

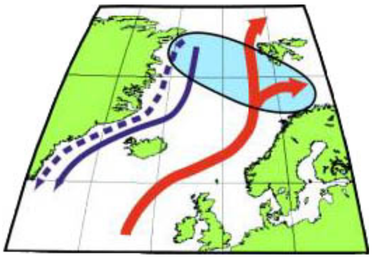
Beszczynska-Möller A., Graupner R., Greil F., Hans K., Hayek W., Monsees M., Schütt E., Wisotzki A.	2006	Flow through Fram Strait and in the entrance to the Arctic Ocean - ARKXXI/1b cruise report.	Berichte zur Polar- und Meeresforschung		**R**
Holfort J., E. Hansen		Freshwater in the East Greenland Current	European Geosciences Union Assembly 2005, Vienna, Austria		**P, CP**
Holfort J., E. Hansen	2005	The freshwater transport within the East Greenland Current	European Geosciences Union Assembly 2005, Vienna, Austria		**P, CP**
Holfort J., J. Mortensen, M. Karcher, G. Wieczorek	2005	The characteristics of Polar Water on the East Greenland Shelf as viewed in measurements, climatology and a numerical model	European Geosciences Union Assembly 2005, Vienna, Austria		**P, CP**
Marnela, M., Rudels, B, Anderson, L.G., Jeansson, E., Messias, M.-J., Olsson, A., Swift, J.H. and Watson, A.J.	2005	Exchanges of Arctic Intermediate Water and SF-6 between the Nordic Seas and the Arctic Ocean.	European Geosciences Union Assembly 2005, Vienna, Austria		**P, CP**
Rudels, B., Marnela, M, Eriksson, P.	2005	Varibility in fluxes of liquid freshwater and heat through Fram Strait.	First CliC International Science Conference, Beijing, April 2005		**P, CP**
Rudels, B., Marnela, M, Eriksson,	2005	Estimates of liquid freshwater and heat transports through Fram Strait using varying reference salinity & temperature	EGU Vienna 2005		**P, CP**
Rudels, B.	2005	Arctic Ocean Hydrography	Geophysikalische Kolloquium, Hamburg, 12 Januar, 2006		**O**
Rudels, B	2006	Oden-Healy TransArctic Ocean Expedition. The variations in theAtlantic, deep and bottom waters as seen in the Oden ct observations.	ICES OHWG Annual Meeting 2006, Galway, Ireland		**O**
Rudels, B.	2006	The Arctic Ocean and changing climate.	Helsinki Environmental Research Centre Symposium on Arctic in Changing Climate – Past, Present and Future, Helsinki		**O**
Eriksson, P. & Vainio, J.	2005	Med Aranda I arktidka vatten.		Skärgård, 28, 3, 18-21	**A**
Rudels, B.	2005	Polynior, isbildning och termohalin cirkulation.		Skärgård, 28, 3, 11-17 (in swedish).	**A**

ASOF-N

Arctic-Subarctic Ocean Flux Array for European Climate: North

Contract No:
EVK2-CT-2002-00139

FINAL REPORT



Section 3

Detailed report organized by work packages including data on individual contributions from each partner (months 25 - 39)

Energy,
Environment
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WP 1 'ATLANTIC WATER PATHWAYS'

1. Objectives

The relevant objectives of WP1 'Atlantic water pathways' during the third reporting period were focused on the last phase of the planned field work and analysis of data sets collected during the whole project. The following tasks were realized to accomplish the planned objectives:

1. Make measurements of track lines of Atlantic water flow by floats.
2. Mapping horizontal distributions of properties of Atlantic water and flow patterns once per year by hydrographic measurements (CTD, ADCP, LADCP).
3. From (1) and (2) derive relations between variations of water mass properties and changes in the flow pattern.
4. Compare the observed variations of track lines, water mass properties and flow patterns with model results.

2. Methodology and scientific achievements related to WP1 including contributions from partners

WP1 consists in a dedicated study of Atlantic water pathways across the Lofoten and Boreas basins (Fig. 1). The fluxes across the western Barents Slope which represent approximately half of Atlantic water inflow towards the Arctic Ocean, are not part of this WP1, but are covered in WP2. Heat and fresh water flows through Fram Strait are part of WP3 and WP4 respectively. In the ASOF-N 3 groups participated to WP1: LODYC (Paris) mainly in charge of Lagrangian (floats) and Eulerian (moorings) observations in cooperation with IMR (Bergen) and IOPAS (Sopot) in charge of hydrography, ADCP and LADCP observations.

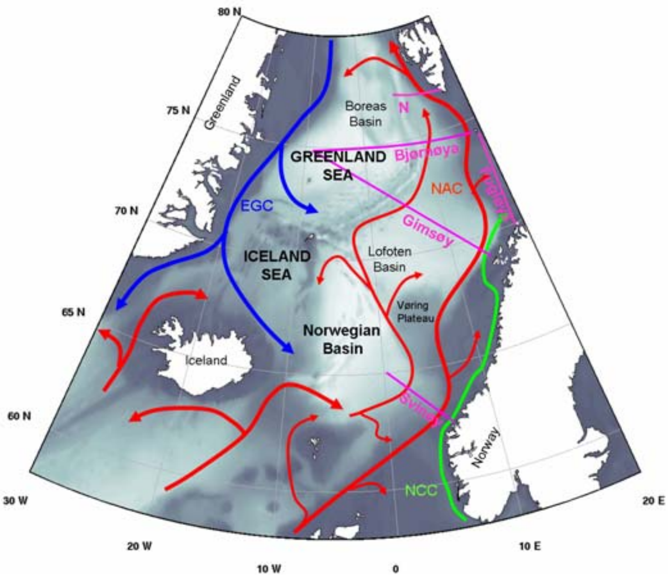


Fig. 1.1: Location of the main sections measured in WP1

Measurements by floats

Series of floats deployments occurred between April 2003 and November 2004 in the context of the ASOF-N program. In total 42 floats have been deployed for periods of 6 months approximately and on five occasions in April 2003, October 2003, April 2004, June 2004 and November 2004 respectively. The two first ASOF-N experiments have now been fully exploited and floats trajectories are shown on figure 1.2 in addition to an earlier floats experiment occurring from May 2001 until October 2001 during the MAIA project. Floats were drifting at depths of about 300 m for most of the floats (34) and 8 deep floats (1000 m depth). Most of the deployments occurred west of the Lofoten Islands across the Norwegian Atlantic Current and above the continental slope where bottom depths vary from 1000 m down to 2500 m. Figure 1.3 indicates the location of floats deployment (circles) and at the end (crosses) where the floats were released and surfaced for starting to transmit data to satellites during the following months. These operations occurred during the first 3 ASOF-N cruises made in cooperation with the Institute of Marine Research (IMR) in Bergen on board the

Norwegian research vessels 'Sarsen' (April 13 to 21, 2003), 'Johan Hjort' (October 3 to 8, 2003) and 'G.O. Sars' (April 6 to 12, 2004) respectively. To track the floats underwater by sound fixing and ranging (SOFAR) moorings equipped with sound sources were used during the project. Five moorings (M1, M2, M3, M4 and M7) were deployed in the Lofoten Basin from the Norwegian RV Sarsen in April 2003. Then four moorings (M8 to M11) were deployed in the Greenland Sea from Johan Hjort in June 2003.The two northernmost moorings (M12 and M13) had been deployed at last from the Norwegian RV Lance on September 2003 and from the German icebreaker Polarstern on October 2003 in Fram Strait. All the moorings including 13 sound sources and 16 current meters were recovered from RV Johan Hjort between May 13 and May 22, 2005 and from G.O. Sars between May 23 and June 6, 2005. Figure 1.3 indicates the locations of the 13 moorings (stars) equipped with sound sources and current meters. The detailed description of floats deployments is provided as the Deliverable 1.2.

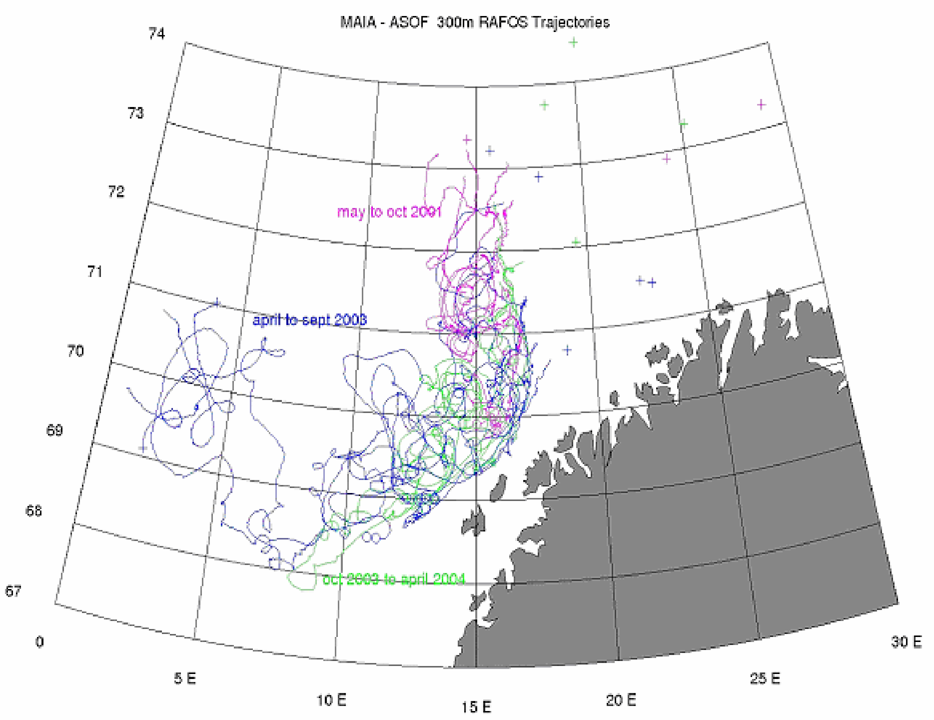


Fig. 1.2: Detailed trajectories of each ASOF floats during the two first periods (blue and green respectively) in addition to MAIA floats trajectories (pink)

Compared to MAIA results covering the 2001 summer season (May-October 2001), it seems like during ASOF summer 2003 (April to September), the Norwegian Atlantic Current slowed down if we consider meridional (northward) speeds (Fig.1.4). But MAIA floats were deployed more to the North where the continental slope is oriented North-South. So we have to consider both latitudinal and longitudinal floats displacements in order to calculate the total average speeds. Due to the predominant mesoscale variability which was discussed in earlier reports and is in each float’s trajectory superimposed on the mean displacement, this requires significant efforts.

A second general comment, concerns the seasonal variability when comparing the structure of the floats trajectories in summer and in winter. But at this stage, we only have 3 summer situations to compare with in 2003, 2004 and MAIA in 2001 and only one winter situation in 2004. The seasonal variability leads apparently to a more intense eastward Atlantic flow entering the Barents Sea in winter time and a more intense northward Atlantic flow progressing northward towards Fram Strait in summer time. But at this stage, this needs to be confirmed. Beyond the variations it became obvious that the Norwegian Atlantic current which is not restricted to a swift narrow boundary current as it is often described from observations and/or even from numerical models in the literature. The ASOF floats experiment revealed some unexpected results such as the 6 months trajectory of one float that popped up few miles (only 15 miles) from where it had been deployed 6 months before (Fig. 1.5) illustrating the profound nature of the Norwegian Atlantic Current which is not at all comparable with what is usually described in the literature.

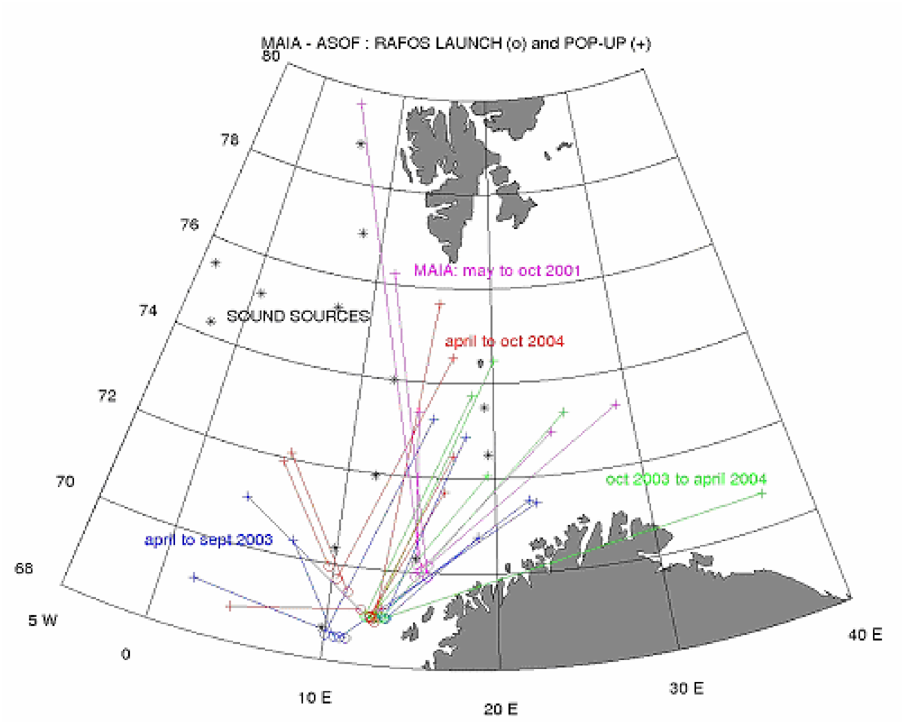


Fig. 1.3: Two end points of each float mission shown: the deployment sites (circles) and the floats located by Argos when returning to the surface (crosses) following a 6 months drift at a depth of about 300m.
Four sets of deployment are represented:
April to September 2003, October 2003 to April 2004 and April to October 2004.

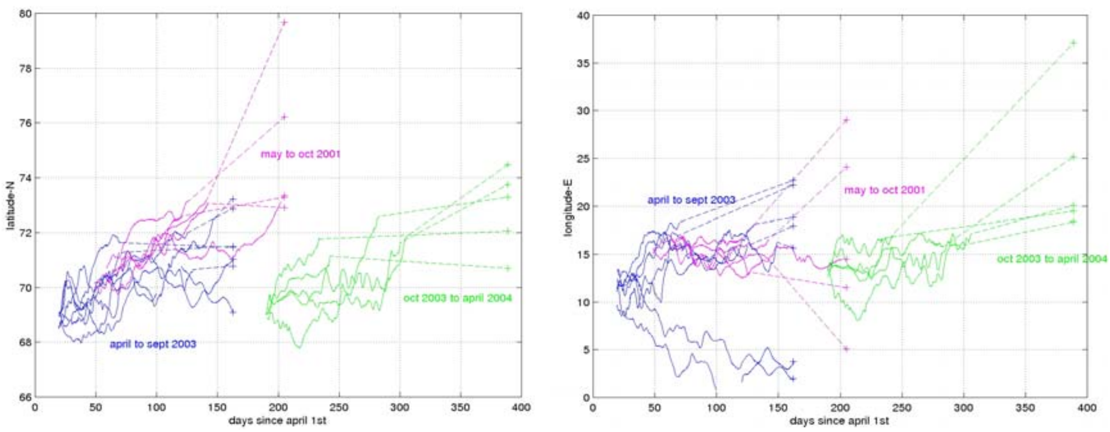


Fig. 1.4: Meridional (left panel) and zonal (right panel) speeds of floats from three sets of deployment are included: May to October 2001, April to September 2003, October 2003 to April 2004.

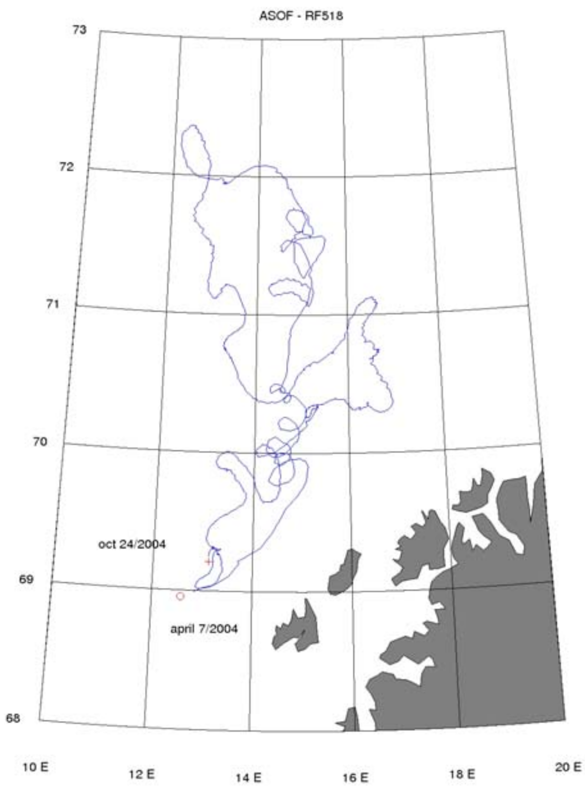


Fig. 1.5: Trajectory of float #RF518 from April 7, 2004 until October 24, 2004.
The deployment and recovery locations of the float #RF 518 occurred within 15 miles but 6 months apart.

<u>Hydrographic measurements by IOPAS</u>

The AREX2005 cruise of Institute of Oceanology Polish Academy of Sciences (IOPAS) vessel R.V Oceania was performed in period of June 08 2005 – July 19 2005. 200 CTD profiles along 13 sections were done (Fig. 1.6). The sections were situated perpendicular to the supposed direction of the Atlantic Water flow. Most of the measurements were repeated along the same sections as in 2003 and 2004 cruises. The ice conditions allowed to perform hydrographic measurements north of 80°N, in the region of the north-western Spitsbergen slope. The section Fugloya-Bear Island was omitted, because Norwegian partners (IMR) conducted measurements along the section at the same time. Also in cooperation with the Norwegian partners the southernmost section was shifted southward in 2005 and covered the Norwegian 'Gimsoy' section.

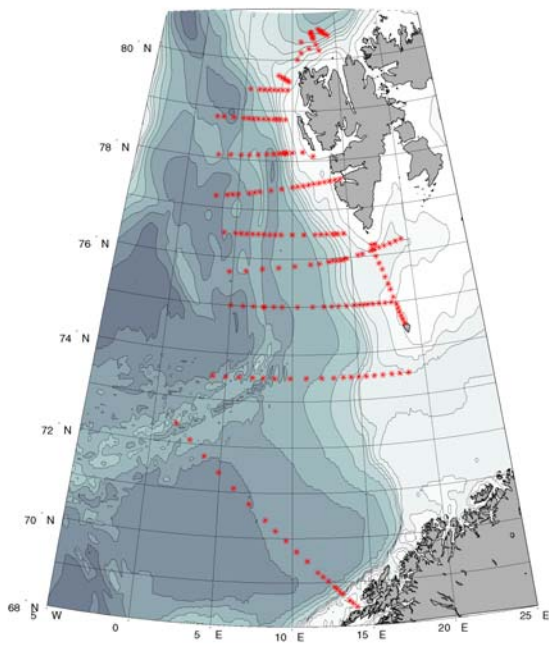


Fig. 1.6: Stations grid performed during R.V 'Oceania' cruise, summer 2005

The time schedule of the cruise was the same as in previous years. It allows the exact comparison and excludes the effects of seasonal variability. For CTD measurements the Seabird SBI9/11plus probe was used. The probe was serviced before the cruise. Water samples collected by means of the rosette water sampler SBE32 were analysed at the ship and in IOPAS laboratory with the Guildline Autosal 8400A. Measurements of currents were performed by means of lowered Acoustic Doppler Current Profiler (LADCP). The self-recording 300 kHz RDI device was used to profile the entire water column during the standard CTD casts. During the whole cruise continuous currents measurements by the ship-mounted ADCP, RDI 150 kHz were conducted. All CTD, ADCP and LADCP data obtained in 2005 were processed. Preliminary CTD and LADCP data were delivered to the ASOF database. Vertical distributions of potential temperature, salinity, potential density, specific volume anomaly and geopotential anomaly were computed. Horizontal distributions of potential temperature, salinity, potential density, geopotential anomaly and geostrophic currents (referenced to 1000 dbar) at several levels were computed. Also Atlantic Water (AW) thickness, AW heat content and other properties were calculated. Spatially nonuniform data were interpolated into rectangular grid using kriging. Due to the spatial distribution of the measurements– less dens grid in the southern part of polygon and better coverage in the Fram Strait region, horizontal structures of property distributions in the northern part of measurements area are more reliable than in the southern one.

Temperature and salinity of AW in summer 2005 was higher than in 2004 (which was considered as very warm). The mean AW temperature and salinity along the 76°30’ N section was the highest for the entire period of summer observations conducted by IOPAS (Fig. 1.7). The mean temperature and salinity at 200 dbar between 9° and 12°E was in 2005 respectively 3.78°C and 35.103 in comparison to 3.37°C and 35.061 in 2004.

The local temperature in the core of AW over the Spitsbergen slope was higher in summer 2004 (Fig 1.8, red line), but temperature averaged along the section was higher in 2005, because of higher temperature in the central and western part of the investigated section (Fig 1.8, upper panel, blue line). For the entire section, between 3° and 15°E in 2005, the mean temperature and salinity at 200 dbar was respectively 3.71°C and 35.090 in comparison to 3.30°C and 35.047 in 2004. The warm signal was broad and shifted westward. It is probably related to the observed West Spitsbergen Current two-branches structure.

As in previous cruises, in 2005 two northward flowing streams of Atlantic Water were observed. (Fig. 1.9). The main branch of the West Spitsbergen Current flows along the Barents Sea continental slope and western slope of Spitsbergen shelf break. The second, colder and less saline branch continues along the Mohns and Knipovich Ridges as a jet stream of the Arctic Front. Between both branches a zone of counter currents and mesoscale activity exists. Due to the bottom topography, both branches of AW converge west of the Spitsbergen coast, between 77°30- 77°00 N and diverge again producing a multi-path structure of AW flow in the Fram Strait.

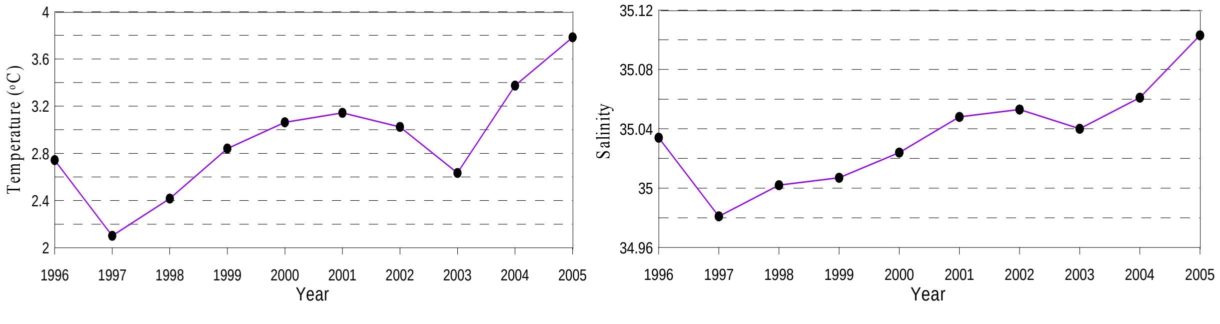


Fig. 1.7: Mean temperature and mean salinity at section ‘N’ (76°30’ N) at 200 m, between 9° and 12° E

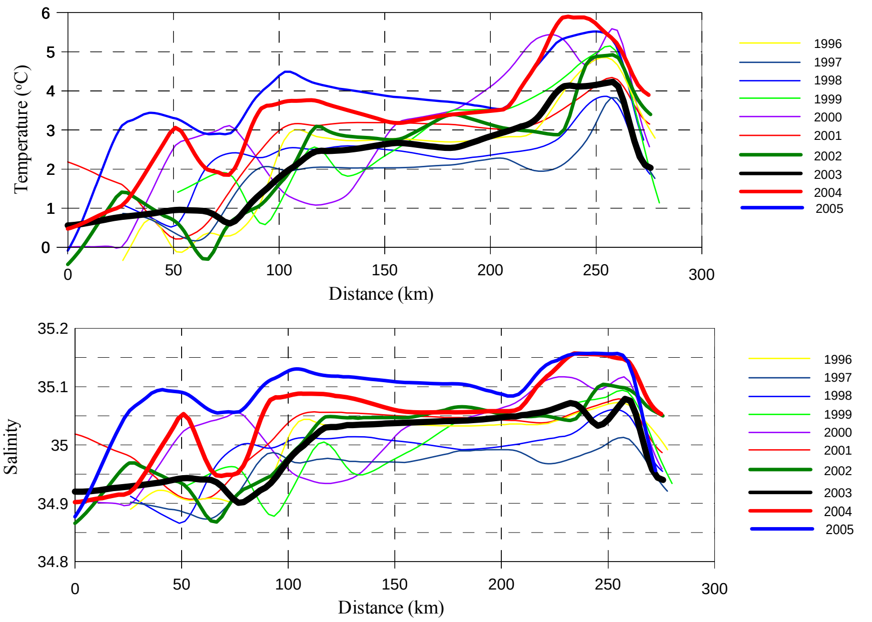


Fig. 1.8: Salinity (left panel) and temperature (right panel) at section 'N' along 76°30' N, from 4°E to 15°E at 200 m.
0-50 km –recirculation region, 100 km - the western branch, 240 km – the core of WSC.

This structure is confirmed by horizontal properties and geostrophic currents distribution (Fig. 1.9). Considerable part of AW flowing along the Norwegian coast proceeds eastward into the Barents Sea. Strict description of currents pattern in the southern part of polygon is impossible due to the spare data distribution and lack of Norwegian data from Fugloya-Bear Island section. The rest of AW inflow continues northward as two separated branches. The main core is related to the Barents Sea and Spitsbergen shelf break and slope, the western one is related to the submarine ridges system. Both branches converged at 77°30 -78°N and separated again downstream. Part of the AW flowing along the shelf break (the Svalbard Branch) enters the Arctic Ocean (AO) along the slope. In 2005 the western branch was warmer than usually. Also salinity of the western branch was the highest since 1996. The recirculation region west of the Arctic Front was broader, shifted westward, more saline and warmer (Fig 1.9). Intensive mesoscale activity in the western branch was observed. The biggest observed structures was a mesoscale eddy of 150 km in diameter at 73°20'N and frontal a meander or an eddy at 76°10'N. Both structures were the source of large temperature and heat content anomalies. When passing Fram Strait both structures could transport a vast amount of heat to the Arctic Ocean.

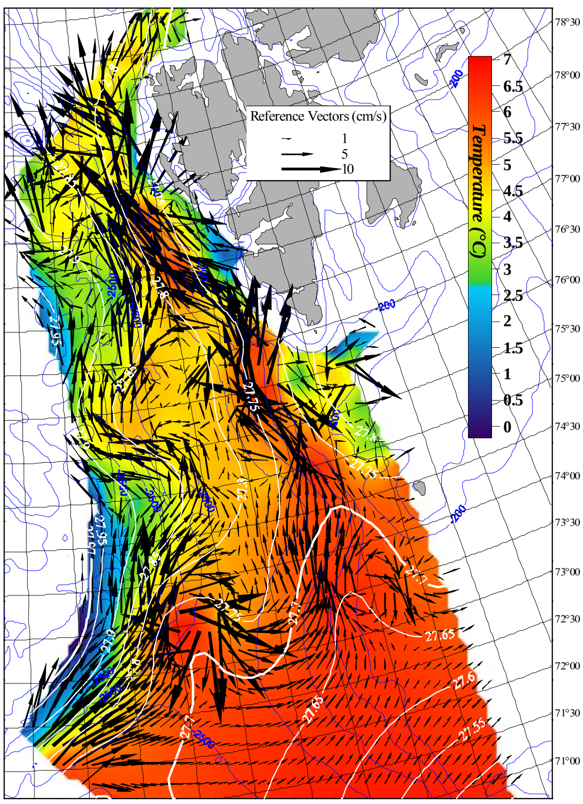


Fig. 1.9: Temperature distribution (colour scale), σ_Θ (white lines) and baroclinic currents at 100 m. June/July 2005, reference level 1000 m

The LADCP measurements confirm the complicated structure of the West Spitsbergen Current (WSC) flow. Currents measured by means of LADCP were usually stronger than calculated from geostrophy, due to the barotropic component of the flow. The baroclinic calculations show in summer 2005 a little less intensive flow of AW across the Fram Strait than in summer 2004 (0.94 Sv of AW in 2005 in comparison to 1.01 Sv in 2004). Also the heat transport was smaller (17.82 TW in 2005, 18.72 TW in 2004). However the heat transport across the section 'N' (76° 30'N) was in 2005 higher than in 2004. It probably means that in summer 2005 the warm signal did not yet reach Fram Strait

3. The socio-economic relevance and policy implication

The socio-economic relevance and policy implication of the WP1 tasks, concerns mainly three aspects. The first aspect is related to climate variability and the impact that the ocean circulation might have on climate in northern Europe. The second aspect is related to biological productivity and how ocean circulation might affect fisheries in the Barents Sea and the Lofoten basin which are among the most productive oceanic regions in the world. The third aspect concerns ships traffic and navigation in ice infested waters north of Europe (Barents Sea and Kara Sea). Regarding these three aspects, WP1 is leading us to understand and possibly predict major changes of the inflow of warm and salty Atlantic waters into the Barents Sea and/or in the Lofoten Basin. These changes might impact on regional climate, fisheries and ships navigation which have a strong socioeconomic relevance. Relevant to these three aspects, one might foresee policy implications for transports, domestic heating, energy consumption, fisheries regulations and ship routing.

On the basis of upstream observations it is possible – in the time range of one year – to predict changes of the heat transport through the Fram Strait. Better understanding of the variability mechanism will allow the prediction of changes of AW properties and transports in longer time periods.

4. Discussion and conclusion

Preliminary conclusions from float deployments

As for the MAIA floats experiment conducted in 2001, the ASOF floats experiment so far confirms the very high and ubiquitous activity of the Norwegian Atlantic Current west and north of the Lofoten islands. The Norwegian Atlantic Current is not restricted to a narrow swift boundary current along the continental margin west of northern Norway but rather to a broad (100 km) and slow (less than 5 cm/s) current progressing to the North and/or recirculating to the west in the Lofoten basin or heading east towards the Barents Sea.

Compare to MAIA results covering the 2001 summer season (May-October), it seems like during ASOF summer 2003 (April to September), the Norwegian Atlantic Current slowed down if we consider meridional (northward) speeds. But MAIA floats were deployed more to the North where the continental slope is more oriented North-South. So latitudinal and longitudinal floats displacements have to be combined and the total average speeds have to be calculated taking into account the predominant mesoscale variability which is superimposed on the mean displacement.

A second general but preliminary result, concerns the seasonal variability when comparing the behaviour of the floats trajectories in summer and in winter. But at this stage, we only have 3 summer situations to compare with in 2003, 2004 and MAIA in 2001 and only one in winter situation in 2004. During the second winter season (2005) no data could be obtained. All ten floats deployed in November 2004 were lost. The best explanation to account for this strange loss is that they got transported northward by a current surge and got stuck under the ice cover. This would then indicate that in winter 2004 none of floats got transported into the

Barents Sea, where they would have been safe but all ten floats got transported into Fram Strait.

Due to this loss we are not able to confirm that the seasonal variability leads apparently to a more intense eastward Atlantic flow entering the Barents Sea in winter time and a more intense northward Atlantic flow progressing northward towards Fram Strait in summer time which at this stage, this is still a speculation. However, we can confirm that the Norwegian Atlantic Current is not restricted to a swift narrow boundary current as it is often described from observations and/or even from numerical models in the literature. An unexpected result came up of the third ASOF floats experiment concerns the 6 months trajectory of one float that popped up few miles (only 35 nm) from where it had been deployed 6 months before illustrating the profound nature of the Norwegian Atlantic Current which is not at all comparable with what is usually described in the literature.

Conclusions from hydrographic measurements

During 3 summers of the ASOF-N program measurements, variable conditions of AW properties and transport pathways were observed. In summer 2003 Atlantic Water was relative cold and fresh, 2004 and 2005 characterise rapid rising of temperature and salinity (Fig. 1.7). Horizontal distributions of temperature anomalies during these years (Fig. 1.10) clearly show the temperature changes. Because the IOPAS observations have covered the same polygon since 2000, all anomalies were calculated in reference to the 2000-2005 mean.

In summer 2005 the AW was the warmest and most saline. The warm signal was mostly related to the western side of observed polygon (western branch of the WSC). Observed mesoscale eddies carried a large amount of heat. Assuming the 3 cm/s of mean advection speed, observed in 2005 the northern anomaly that carried about $2.4 \cdot 10^{20}$ J of heat may produce 47 TW of heat flux during two months. Eddies were able to carry this heat partly due to increased AW temperature, and due to larger AW thickness (Fig. 1.11). This result shows that the role of mesoscale eddies in the heat transport is important, and that the transport is not continuous but pulsating.

Different sizes and pathways of AW transport were observed during the 2003-2005 cruises. In cold 2003 summer the WSC flow were concentrated along the Spitsbergen slope, transports of AW and heat were much lower than in warm years (Tab. 1, Tab. 2). In 2004 and 2005 higher activity of the western branch was observed. Especially in 2005 the western branch was the source of large positive heat anomalies. The along-slope flow was also in 2004 and 2005 higher than in 2003. In warm years northward shifting of the southern ice limit in the Fram Strait region was observed.

Table 1: Atlantic Water properties at section ‘N’ along the 76°30’ parallel

	2003	**2004**	**2005**
AW mean salinity	35.005	35.034	35.063
AW mean temperature (°C)	2.427	3.086	3.462
AW volume transport (SV)	1.472	2.871	3.031
AW heat transport (TW)	18.874	47.842	53.143

Table 2: Atlantic Water properties at section ‘EB’ along the 79°50’ parallel

	2003	**2004**	**2005**
AW mean salinity	35.007	35.007	35.020
AW mean temperature (°C)	2.601	2.667	2.699
AW volume transport (SV)	-0.146	1.014	0.940
AW heat transport (TW)	3.117	18.727	17.820

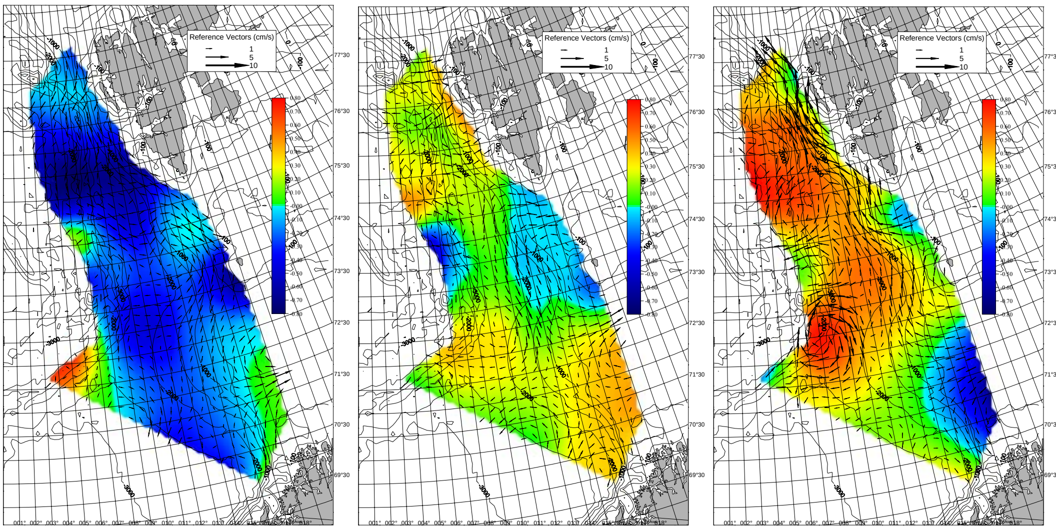


Fig. 1.10: Summer 2003-2005. Temperature anomalies at 100 dbar.
Anomalies of geostrophic currents (calculated in reference to 1000 dbar) in background.
All anomalies calculated in reference to summer 2000-2005 mean.

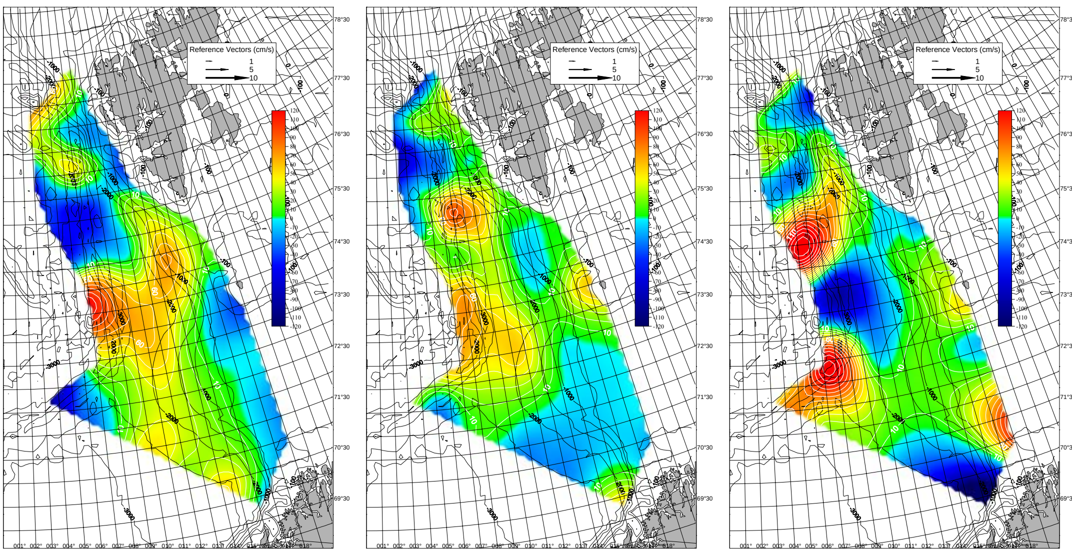


Fig. 1.11: Summers 2003-2005. AW layer thickness anomalies

The differences of the water mass properties presented in tables 1 and 2 may be partly caused by mentioned mesoscale activity and the pulse-like transport, but also integrated over the whole measurement area properties as AW heat content show meaningful differences between years.

WP 2 'FLUXES ACROSS THE WESTERN BARENTS SLOPE'

1. Objectives

The objectives of WP2 "Fluxes across the western Barents slope" are as follows:

1. To determine transport series, spatial structure and temporal variability on seasonal and interannual scales.
2. To establish quantitative relations between the variations of fluxes in different sections and propagation of water characteristics.

These objectives were pursued by the analysis of the existing data from previous and other projects (Task 2.1), a new deployment of the moorings (Task 2.2) and CTD and ADCP sections (Task 2.3). To accomplish the assumed objectives an implementation of the high resolution regional model (Task 2.6) was also done.

2. Methodology and scientific achievements related to WP2 including contributions from partners

Five moorings with current meters were recovered and deployed again in August 2005. These moorings were also successfully recovered after the end of the ASOF-N project. In addition to the ASOF moorings, two bottom-mounted ADCPs have been deployed along the section in order to measure the inflow of coastal water in the southern part of the section and the outflow of Arctic water in the Northern part of the sections. These two moorings received financial support from the Research Council of Norway and will together with the ASOF moorings make an almost complete array across the section between Norway and Bear Island. However, the ADCP close to Bear Island has not measured in 2005 due to a failure during the deployment process. All cruises with CTD sections were carried out according to the plan.

Since the ocean climate shows a great variability, we have in the following compared the situation during the two years of observations with the previous years in order to where we are in the climate development.

2.1 Hydrographic observations and results

The hydrographic observations were carried out according to the plan. Figure 2.1 shows the temperature and salinity anomalies in the Fugløya-Bear Island section in the period from 1977 to January 2006. Temperatures in the Barents Sea were relatively high during most of the 1990s, and with a continuous warm period from 1989-1995. During 1996-1997, the temperature was just below the long-term average before it turned warm again at the end of the decade. Even the whole decade was warm, it was only the third warmest decade in the 20th century (Ingvaldsen *et al.* 2002).

At the end of 2004 and beginning of 2005, the temperature was more than 1°C higher than average, and the average temperature in the core of the Atlantic inflow passed 7°C for first time at the end of 2004. During spring and summer 2005 the temperature anomalies decreased to 0.5°C above average. In October 2005, the anomalies increased rapidly, and in January 2006, a positive temperature anomaly of 1.44°C was observed, which is all time high (Fig. 2.1). High positive temperature anomalies were also observed in the entire Barents Sea at the end of 2005 and beginning of 2006. The salinity variations are similar to those in temperature, and there has been a high salinity during the last 3 years.

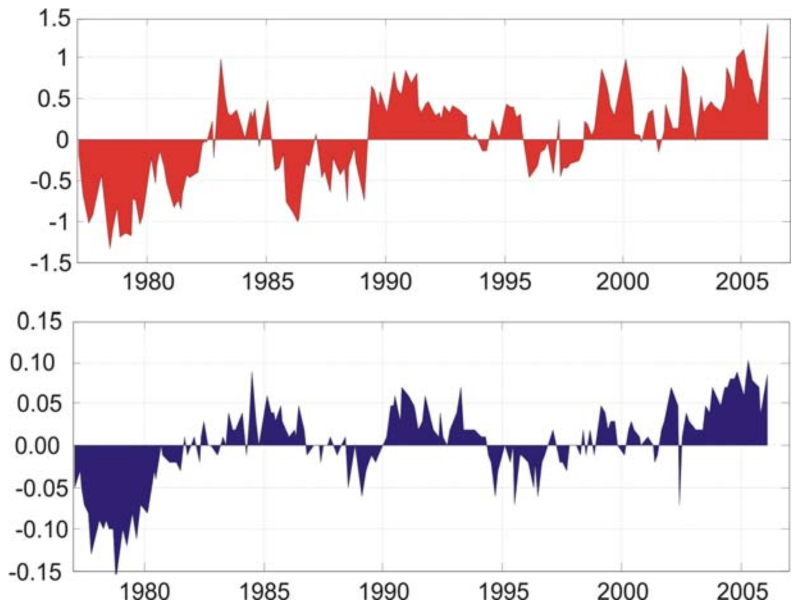


Fig. 2.1: Temperature anomalies (upper panel) and salinity anomalies (lower panel) in the section Fugløya – Bear Island section

2.2 Current conditions

The observed current in the section Fugløya-Bjørnøya is predominantly barotropic, and reveals large fluctuations in both current speed and lateral structure (Ingvaldsen *et al.,* 1999, 2000).

The time series of volume and heat transports reveal fluxes with strong variability on time scales ranging from one to several months (Fig. 2.2). The monthly mean volume flux is fluctuating between about 5.5 Sv into and 6 Sv out of the Barents Sea, and with a standard deviation of 2 Sv. The strongest fluctuations, especially in the inflow, occur in late winter and early spring, with both maximum and minimum in this period. The recirculation seems to be more stable at a value of something near 1 Sv, but with interruptions of high outflow episodes. High outflows occurred in April both in 1998 and 1999 and in 2000 there were two periods with strong outflow, one in January and a second one in June. In the first half of 2003 the inflow was high, which may explain the rapid temperature increase between January and March. The intensity of the flow was reduced during spring and summer.

The time series of volume transports shows a relatively high inflow during 1997 and 1998, before the transport decreased and reached a minimum in end of 2000. Then there was a strong increase in the transport until beginning of 2003. Earlier it has been believed that the temperature and the volume transport varied in a similar manner; that is that high temperature was linked to high volume transport and lower temperature was linked to reduced inflow of Atlantic water. However, figure 6 shows that there seems to be no correlation between the fluxes and the temperature of the inflowing water. In fact, in periods the temperature increases while the volume flux decreases, and high positive anomalies observed in 2004 are not due to an increased inflow, as we did believe earlier. This shows that in the Fugløya-Bear Island section the temperature is independent of the volume flux into the Barents Sea. The reason is simply that while the temperature of the inflowing water depends on the temperatures upstream in the Norwegian Sea, the volume flux depends mainly on the local wind field. This shows the importance of measuring both volume transport and temperature, since they not always are varying in the same manner. This is a new discovery that we can relate to the ASOF-N measurements.

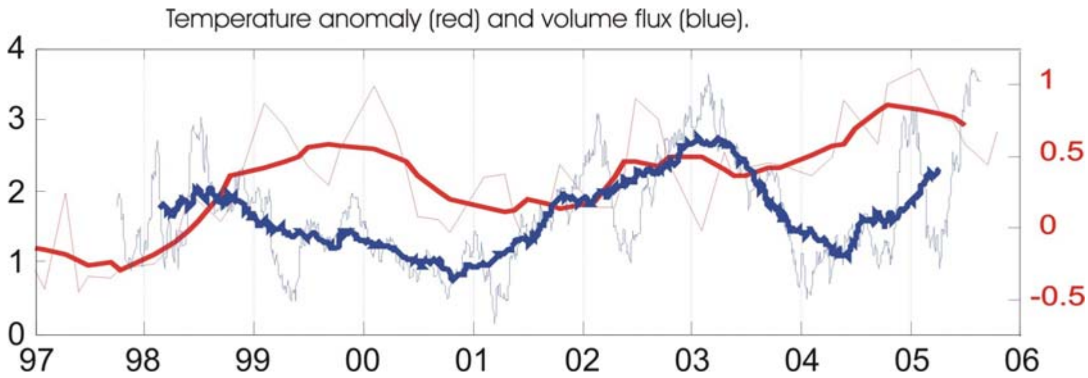
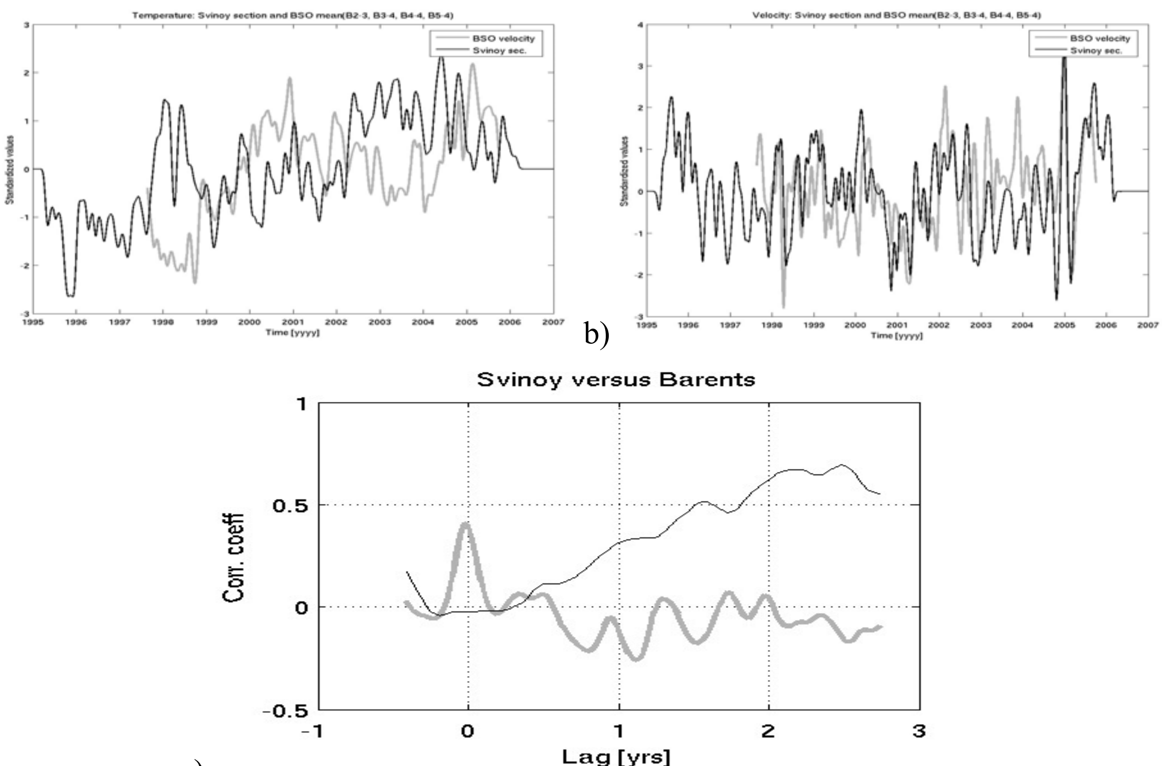


Fig. 2.2: The blue lines show Atlantic Water volume flux across the section Norway-Bear Island. Time series are 3 and 12 months running means. The red lines show temperature anomalies the section Fugløya – Bear Island section. Time series are actual values and 12 months running means.

The measurements at BSO are compared with hydrographic observations and current measurements at the Svinøy section (at approximately 62ºN). The results are presented at figure 2.3. The upper panel shows temperature observation at the two sections, and it looks like there is no relation. Looking at the current velocity, however, there seems to be some co-variation. If we make a correlation analysis of the time series from the two sections, the results are shown in the lower panel. We can see that for velocity, the correlation is best when there is no time lag between the observations. For temperature, however, the correlation is highest when we have a time lag of two years, which mean that changes in temperature occurs two years earlier in the Svinøy section than at BSO. This is the same time lag as observed between transport and temperature at BSO.



a) b) c)

Fig. 2.3: (a) Temperature and (b) velocity at the Svinøy section (black) and BSO (grey).
The lower panel (c) shows the correlations coefficient
for temperature and velocity between the two sections.

2.3 Numerical modelling of the western Barents Sea and the inflow of Atlantic water

A dynamic-thermodynamic sea ice model has been coupled to a three-dimensional ocean circulation model for the Barents Sea region (Budgell, 2004). The ocean model component is based on ROMS (Regional Ocean Modelling System) version 2.1. ROMS is a three-dimensional baroclinic general ocean model. It uses a topography-following coordinate system in the vertical, with 32 σ-coordinate levels. Orthogonal curvilinear coordinates are used in the horizontal. The average horizontal grid size is 9.3 km. The present model forcing includes surface forcing (wind and radiation) from the NCEP/NCAR Reanalysis and open boundary conditions from a large scale implementation of ROMS covering the area from the southern Atlantic to the Polar Ocean.

A report by Asplin et al. entitled "Comparison of modelled and measured fluxes at the western Barents Slope" was delivered to meet Deliverable D2.6, WP 2.

3. Socio-economic relevance and policy implication

The socio-economic relevance and policy implication of the individual work package can only be seen in the context of the full project. Since ASOF-N addresses the role of the ocean in the climate system its relevance has to be seen in the context of understanding and predicting climate variability. In particular the northern North Atlantic has a strong impact on the living conditions in Northwest Europe. This includes energy consumption, sea traffic and marine living resources. This holds in particular for WP2 because the Barents Sea is of great importance to fisheries and WP2 addresses the inflow of warm and salty Atlantic water which has a strong impact on the life in the ocean. Therefore the observations provided by this work package are of particular importance and a reliable prediction system is of high value. The results from the ASOF-N are used in an ecosystem project at IMR, and information on variations in volume transport and heat transport is frequently used in comparisons changes in the marine ecosystem. Prediction requires understanding and modelling of the relevant processes and monitoring key parameters to validate and constrain the models. Since variability of the relevant time scales can be only studied on the base of the long-term time series, ASOF-N aims to develop an observing system consisting of a cost-effective array of instruments in the key areas for the exchanges between the North Atlantic and Arctic Ocean. The results of ASOF-N will help to design such a system, to give advice for its implementation and consequently contribute to maintain the quality of life in Northwest Europe.

4. Discussion and conclusion

The entire WP has progressed after the plan. The deployment and recovery of moorings have followed the plan, and the same is valid for the hydrographic observations, but there is used more manpower than described in the proposal. However, the extra costs are paid by IMR.

The ASOF-N measuring period is carried out under a warm (or may be warming) period. It is important to have that in mind when considering the results. The main outcome so far is that the temperature in the Fugløya-Bear Island section is independent of the volume flux into the Barents Sea. The reason is simply that while the temperature of the inflowing water depends on the temperatures upstream in the Norwegian Sea, the volume flux depends mainly on the local wind field. This shows the importance of measuring both volume transport and temperature, since they not always are varying in the same manner. This is a new discovery that we can relate to ASOF-N.

WP 3 'HEAT FLOW THROUGH FRAM STRAIT'

1. Objectives

The objectives of WP3 “Heat flow through Fram Strait” during the third reporting period comprised following items:

1. Make frequent (1/2 h) measurements of currents, temperature and salinity at fixed locations (11 horizontal and 4-5 vertical) across Fram Strait.
2. Measure vertical transects of T and S across Fram Strait with high horizontal resolution.
3. Calculate volume and heat transports from (1) and (2)
4. Compare results from the moored array with output of the high resolution numerical model.

The objectives are related to Task 3.2 (data acquisition) and 3.3 (data calibration and computing the heat and volume fluxes). Work on a comparison of the heat fluxes through Fram Strait and the Barents Sea Opening (Task 3.4) was also done. Comparison of model and measurements results was performed in Task 3.5.

2. Methodology and scientific achievements related to WP3 including contributions from partners

<u>Objective 1:</u>

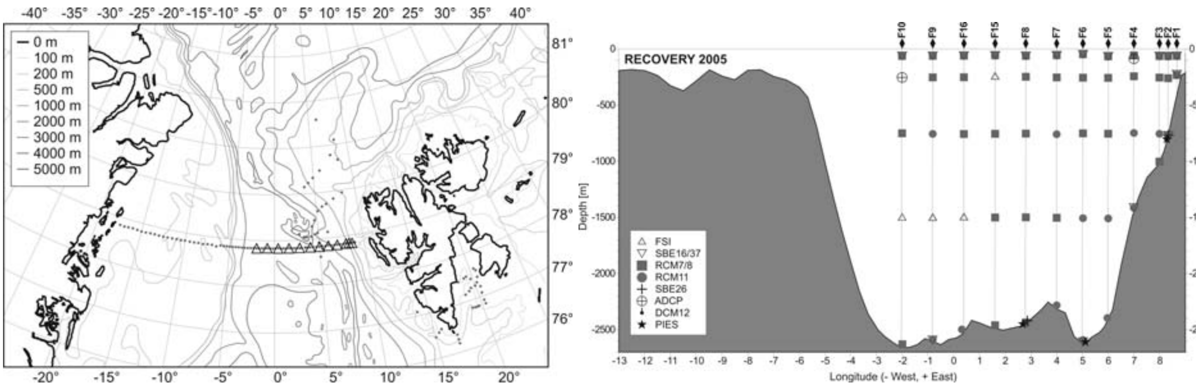


Fig. 3.1: Location of CTD stations and moorings (left) and distribution of instruments at the mooring array (right) recovered and redeployed in 2004.

The deployment of the mooring array in Fram Strait took place during R.V. Polarstern cruise in August-September 2005. The mooring section covers the West Spitsbergen Current, the main flow of Atlantic water transported into the Arctic Ocean as well as the recirculation area in the deep part of Fram Strait. Twelve moorings with a total number of 80 instruments (current meters, temperature and salinity sensors, acoustic Doppler current profilers ADCP, bottom pressure recorders, inverted echo sounders PIES and a sound source) were installed at 78°50'N between 2°W (central part of Fram Strait) and 8°40'E (West Spitsbergen shelf) - see figure 3.1. The distribution of the recovered instruments is shown on the right panel of figure 3.1.

The positions of the redeployed moorings were kept as closely as possible. The instrumentation agrees in general to the one of the recovered moorings. Some additional instruments were added in order to obtain better vertical resolution and additional information by new sensor types. Each mooring carried 3 to 8 instruments. Five moorings were equipped with bottom pressure recorders from Sea-Bird Electronics to obtain changes of the sea level inclination indicative of barotropic velocity changes, two of them with the sea level gauges SBE26 and next three with SBE16 with the pressure sensor. Two moorings are equipped with the upper looking ADCPs (Acoustic Doppler Current Profiler). During 2005 deployment of moorings, all FSI current meters, which had been used in previous years and proved to be extremely unreliable were replaced by the Aanderaa acoustic current meters.

The mooring work was split into two parts to avoid the tight time schedule for the preparing of new deployments. During the first part of the cruise 7 of 12 moorings were recovered and redeployed in the eastern and middle part of Fram Strait together with recovery and redeployment of two Pressure Inverted Echo Sounders (PIES). The remaining 5 western moorings and one PIES were recovered and deployed during the second part of the cruise. All work occurred under favourable weather conditions and in ice-free waters. The use of the POSIDONIA system for those moorings, which were equipped with POSIDONIA capable releases was of a great help and assured a safe recovery. The mooring recovery rate was 100%. 78 of 80 prior deployed instruments including PIES delivered the data what makes the obtained data rate of 97%.

In 2004 three pressure inverted echo sounders (PIES Model 6.1E) from the University of Rhode Island were deployed for the second time at the mooring section. By combining historical hydrography with the acoustic travel time measurements they give the opportunity to obtain time series of full water column profiles of temperature and specific volume anomaly. Due to that they can be used to estimate the baroclinic flow and the heat transport. In 2005 all three PIES were recovered. All instruments provided full data sets although bottom temperature records seem to be out of the correct range. During the last year deployment all PIES were equipped with the POSIDONIA transponders ET861G what made recovery in 2005 much easier as compared to the standard procedure. Using the POSIDONIA transponders allowed also obtaining the accurate positions and depths of deployed instruments.

The next array of moorings is under preparation at the moment. The instruments are calibrated and set-up for the deployment. All FSI current meters were replaced with the Aanderaa instruments to achieve the best consistency of measured properties. Twelve moorings with ca. 80 measuring instruments will be deployed in August-September 2006 at the same locations as in 2005.

Objective 2:

The standard cross-section through Fram Strait which is repeated on the annual basis was performed in two parts in August and September 2005 (Fig. 3.1). The CTD measurements at the Fram Strait section occurred mostly between mooring work and similarly to the mooring work were split into two periods. Therefore the sequence of stations was rather irregular. Altogether 144 CTD profiles were taken at 135 stations and water samples were collected during all casts. Underway measurements with a vessel-mounted narrow band 150 kHz ADCP from RD Instruments and a Sea-Bird SBE45 thermosalinograph measurements were conducted along the transect to supply temperature, salinity and current data at a much higher spatial resolution than given through the moorings.

In Fram Strait three characteristic areas can be distinguished in relation to the main flows (Fig. 3.2): the West Spitsbergen Current (WSC) between the shelf edge and 5°E, the Return Atlantic Current (RAC) between 3°W and 5°E, and Polar Water in the East Greenland Current (EGC) between 3°W and the Greenland Shelf. In 2005 warming and salinification continued in the entire Fram Strait and especially in the RAC domain. The Atlantic layer in the off-shore branch of the WSC was warmer than in 2004 and the strongest warming was found in the recirculation area in the western, deep part of the strait. This warm anomaly spread down to the bottom and to the west it reached the edge of the East Greenland shelf. A temperature difference at the section between 2004 and 2005 reveals the strong warming in the western part of the deep area extending not only in the AW layer but much down to the bottom. In the WSC an increase of temperature was found mostly in the off-shore branch and was confined to the AW layer. Comparisons between temperature measured in Fram Strait in

2005 and available climatologies (WOA2001, EGW, PHC; picture not shown) in all cases shows the strong warm anomaly in 2005. Mean temperature and salinity in the layer 50 to 500 m in three domains (WSC, RAC, EGC) were all higher than the long period average and continued the increase observed already in 2003. The strongest increase of salinity occurred in the East Greenland Current while in the WSC and RAC the observed values were the highest since the beginning of time-series.

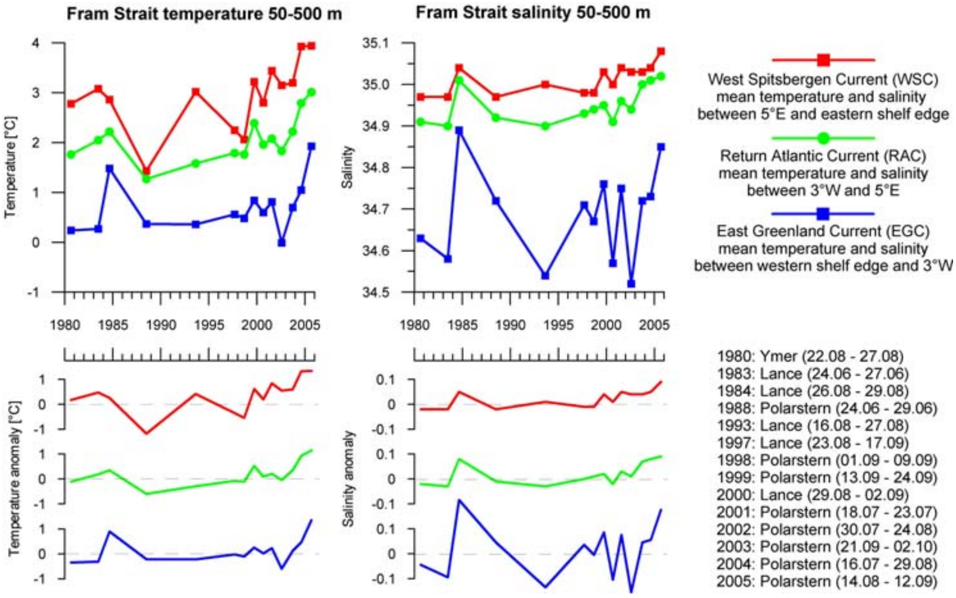


Fig. 3.2: Time series of mean temperature and salinity in the upper layer 50-500 m (upper panels) in the West Spitsbergen Current, Return Atlantic Current and East Greenland Current with anomalies from long term mean (lower panels) based on CTD sections

Hydrographic properties of the Atlantic water (Fig. 3.3) in the whole Fram Strait (defined as water mass with T>2°C and S>34.92) reveal the clear trend for last seven years. While the area of the cross-section occupied by AW varied strongly between years, the mean temperature and salinity of Atlantic Water have been increasing since 1997. In 2005 the mean temperature and salinity of the AW were higher than in 2004 (Fig. 3.3). In addition to high temperature and salinity, the areal coverage of the section by the AW occupied also increased as compared with 2004 (Fig. 3.4), indicating the largest heat content since the beginning of time-series.

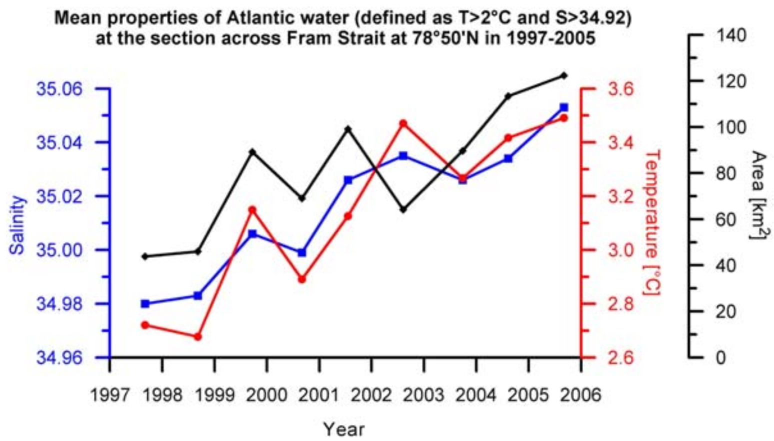


Fig. 3.3: Mean properties of Atlantic water in Fram Strait based on summer hydrographic sections

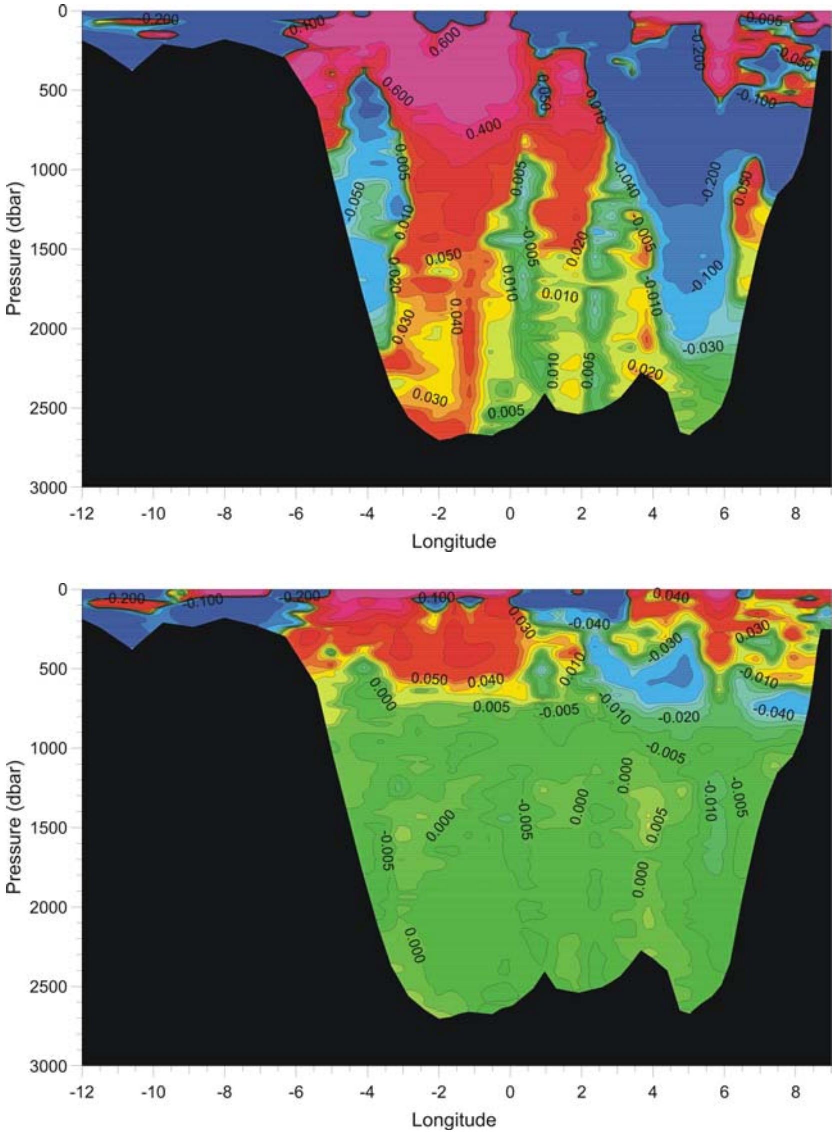


Fig. 3.4: Temperature (upper panel) and salinity (lower panel) differences at the section across Fram Strait between 2005 and 2004

Objective 3:

The heat and volume fluxes were calculated on the basis of data collected during the second ASOF-N deployment in 2004/05. These data were combined with the time series from pre-ASOF measurements in 2002/03 and first ASOF deployment in 2003/04. This three-year long time series includes periods of measurements with the extended mooring set-up. The locations of all moorings and distribution of instruments at the array have been uniform during all three years, providing consistent set of observations. Prior to the calculations of fluxes the raw data including temperature and current components were despiked, low-pass filtered with cut-off period of 40 h and averaged over the 6 h intervals. Missing data due to loss or failure of instruments were reconstructed using the linear regression method based on the correlation with the neighbouring instrument. The daily and monthly means of all variables were calculated and interpolated over the regular grid with a resolution of 1 km in the horizontal and 5 m in the vertical using linear interpolation with the kriging method which means that all neighbour values are included weighted by their respective distances. With regard to the different horizontal and vertical scales, an anisotropy ratio, scaling horizontal vs. vertical weights, was applied for the velocity and temperature fields. Volume transports were calculated as a double integral of the current component perpendicular to the section over the section area. Heat flux was calculated for the reference temperature -0.1°C. Variability of fluxes on the different time scales has been investigated by comparing the fluxes calculated first on a basis of daily averaged data and subsequently calculated with the basic data set filtered with weekly, 2-weekly, monthly, 3-monthly and yearly low pass Butterworth filters.

The volume flux (Fig. 3.5a) was characterized by the strong minimum in summer and early autumn 2004, followed by the maximum in winter and early spring 2005. However the heat flux (Fig. 3.5b) in summer and autumn was still higher than the seasonal average due to higher temperatures (warm anomaly), while in the winter months it was comparable to the previous year. The net winter-centered yearly averaged volume transport through the whole section was southward and stronger in 2004-2005 than in 2003-2004 (3.4 and 2.6 Sv southward respectively). Despite of that, the yearly averaged heat transport through the whole section was comparable for both deployment periods (52 versus 51 TW). The winter-centered annual average of the volume flux in the WSC was higher in 2005 than in 2004 (7.5 Sv as compared to 5.6 Sv) while the annual averaged of the heat flux was comparable in both years (55 TW and 52 TW respectively). In the recirculation domain the net volume flux was southward and increased in 2005 as compared in 2004 but the net heat flux (northward) was similar in both years.

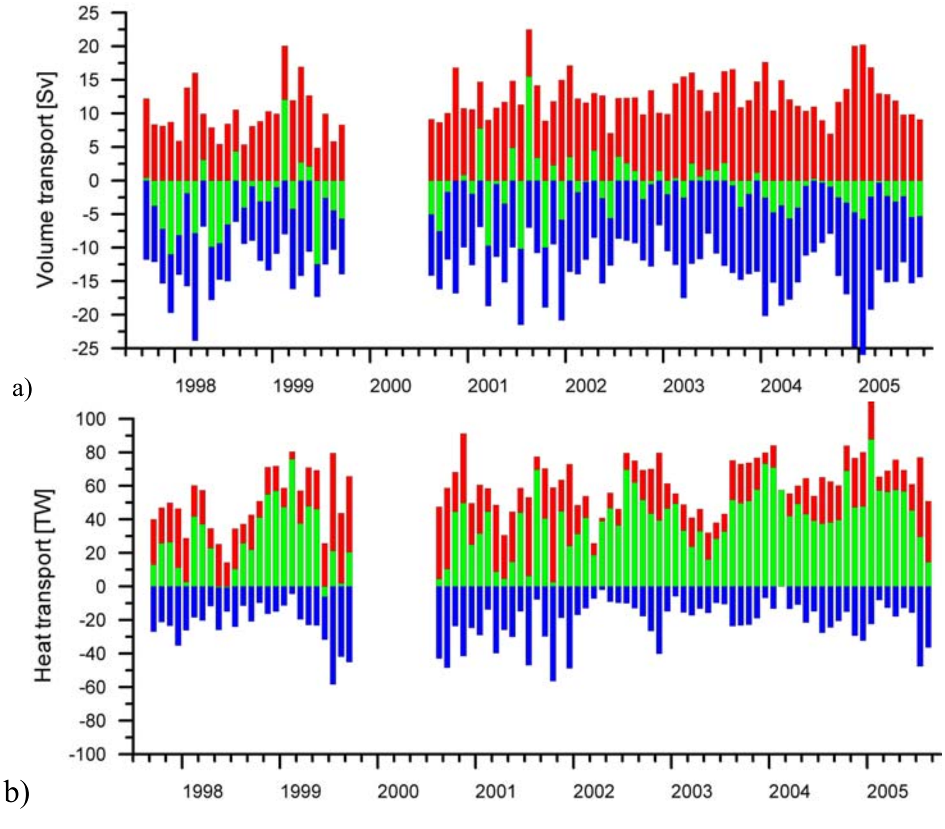


Fig. 3.5: Monthly means of the (a) volume and (b) heat transport through the whole Fram Strait section (green bars - net transport, red bars - northward transport and blue bars - southward transport) in 1997-2005

Temperature and cross-section current velocity at the depth of 250 m (the AW layer) plotted versus time and longitude (Fig. 3.6) show that since summer 2004 the warm AW water has been spreading westward and seasonal temperature decrease in spring and early summer was nearly absent both in the WSC and the recirculation area. Since summer 2003 the isotherm 3°C has been constantly shifted westward. The cross-section current distribution reveals that winter peak in the volume flux in 2005 resulted not from higher velocities in the WSC core but from the larger area of the northward flow in the entire WSC, particularly the stronger than average northward flow in the off-shore branch. Preliminary results from Fram Strait array suggest that the observed warming is less visible as an absolute value (extreme temperature) but rather as deviation from the strong seasonal cycle towards the higher temperature in spring and early summer. Observed changes in the flow field supported the upstream observations of the stronger activity in the western branch of the Norwegian Atlantic Current and/or can be also related to a shift in the position of the recirculating AW branch in Fram Strait.

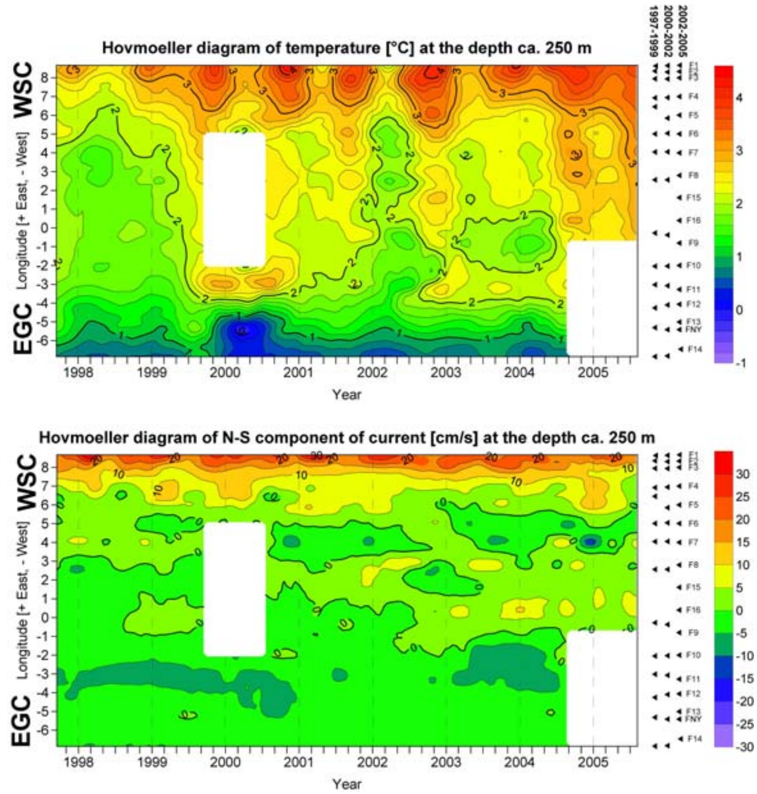


Fig. 3.6: Hovmöller time-space diagrams of temperature (upper panel) and cross-section current velocity (lower panel) measured at the mooring array in 1997-2005

Objective 4:

The high resolution ocean-sea ice model was developed with a focus on the deepwater exchange between the Greenland Sea and the Arctic Ocean through Fram Strait. The horizontal resolution is 1/12° or approx. 8 km in the Fram Strait area. The model has 50 unevenly spaced levels in the vertical. The high resolution of the model required speeding up the existing ocean-sea ice model by a factor of 20 to 30 by adjusting it to the fastest available computer. The code thus has been parallelised using MPI and has been tuned for the NEC computer at the German Climate Computing Center (DKRZ) at Hamburg.

After converting an existing coarser ocean model version (1/4°) onto a finer grid (1/12°), changing the parallelising scheme and transposing the system to a faster computer, we made first sensitivity experiments. The aim was to find an optimal set of parameterisations for the fine model grid. Using the resulting configuration we started a hindcast experiment starting 1990 with a spin up period from 1990 to 1995 and an analysis period from 1995 to 2005. We compared the results of the finer and the coarser model version and found on the one hand a sufficient agreement of general tracer and circulation pattern and on the other hand a much more detailed simulation of the local features as recirculation patterns in Fram Strait.

Figure 3.7 presents the annual mean sea surface temperature of 2001 in the finer (FRM) and the coarser (HRM) model: there was a good agreement in general pattern but differences in local details. In 300 m we expect to see a wide tongue of Atlantic water flowing west of Svalbard from the North Atlantic (West Spitsbergen Current, WSC) into the Arctic as well as the lower boundary of cold polar water, flowing east of Greenland from the Arctic into the

Atlantic (East Greenland Current, EGC). Both model results show WSC as well as EGC, but the simulated EGC in the FRM is narrower and less deep than in the HRM, whereas the WSC is warmer and wider in FRM. In FRM more energy is transported across Fram Strait and clearly more energy is recirculating. In HRM the WSC is recirculating south of Fram Strait, so a smaller amount of warm water crosses the sill. Furthermore, the different representations of the Greenland Sea are remarkable: while HRM shows a mainly isolated, substantially too cold core, in FRM the Greenland Sea is warmer and less isolated, which matches better with observations.

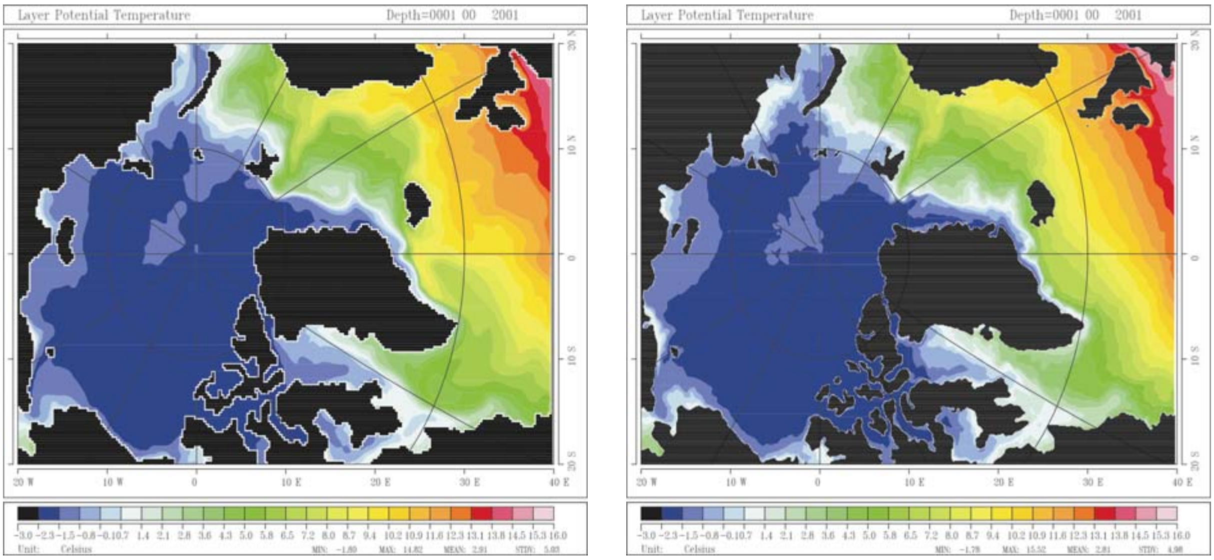


Fig. 3.7: Annual mean sea surface temperature in 2001. Results from the coarser 1/4° model (left) and the fine resolution 1/12° model (right)

To compare mooring observations and model results the vertically integrated monthly mean volume transport rates derived from the mooring line (red), from the FRM (blue) and the HRM (green) experiment are completed by two more data sets (Fig. 3.8): the FRMgap (magenta) and FRMasof (black). FRMgap sums up the vertical integrated monthly mean volume flux of FRM, but restricts the calculations to approximately a third of the available horizontal information. As a result, we end up with an information density, which is comparable to HRM. The positions chosen are where the mooring line is collecting its data. For FRMasof we subsample this dataset furthermore by using only those vertical levels, where the mooring line is instrumented, i.a. 70 m, 200 m, 800 m, 1300 m and 2000 m (versus respectively 50 m, 250 m, 750 m, 1500 m and bottom depths at the real moored array). We argue, that FRMgap has a comparable set of information as HRM, and FRMasof as the mooring line.

Tab. 3.1: Mean and standard deviations of volume transport for different model realizations

	Mean net volume transport [Sv]	Std. Dev. of volume transport
FRM	-2.0	1.26
HRM	-2.16	1.09
Mooring	-1.75	4.02
FRMgap	-2.04	1.31
FRMasof	-3.40	1.42

The time series of FRM (blue), FRMgap (magenta) and FRMasof are very similar. Neglecting a reasonable part of the available model information – horizontally, as for FRMgap and horizontally and vertically as for FRMasof - results in very similar flux rates and flux pattern as by using the complete data set. Comparing measured and modelled values of the net volume transport, differences are obvious. While the net balance modelled by HRM (green) and FRM (blue), FRMgap (magenta) and FRMasof (black) are negative and of similar values, the data from the mooring line (red) are fluctuating strongly and show nearly no systematic agreement with model data. This can be underlined by the standard deviation of the flux data (Tab. 3.1): all model data are similar while the standard deviation of the measured time series is four times bigger. Nevertheless, comparing the 10-year mean net flux values of models and observations, the difference between model results and values from observations is small, again an argument for our finding above.

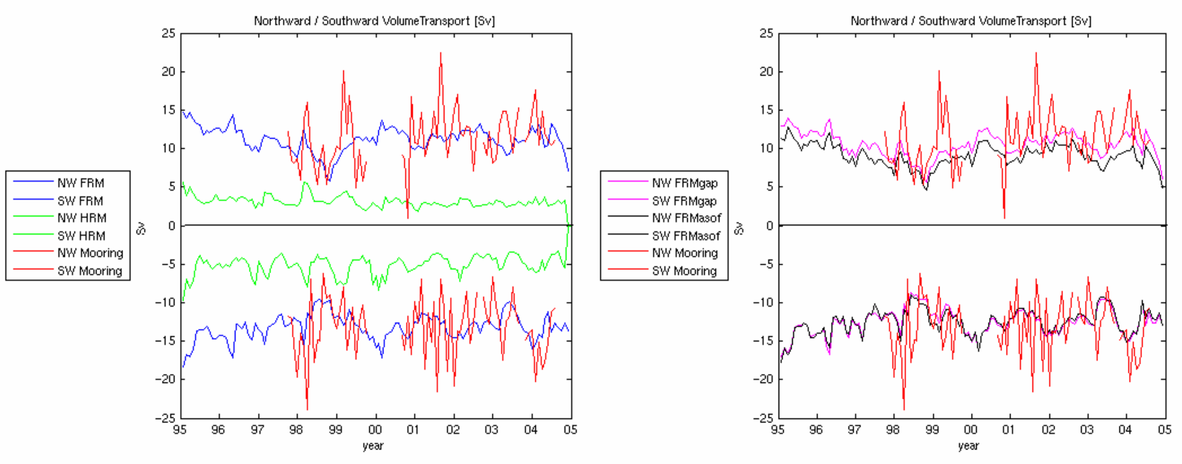


Fig. 3.8: Vertical integrated northward and southward volume flux on [Sv] across 79°N through Fram Strait
Left: FRM(blue), HRM(green), mooring line(red)
Right: FRMgap(magenta), FRMasof(black), mooring line(red)

The comparison of the vertical integrated northward and southward component of the heat transport from measurements and model results (Fig. 3.9), that the values derived from the moorings (red) ranges between the results of HRM (green), FRM (blue) and FRMgap (magenta). If we believe the measurements to be true, we have to argue, that the 1/12 ° model overestimates the heat transport into the Arctic, the ¼ ° model underestimates it. This matches with our finding, that the inflow of northern north Atlantic water seems to be too warm in FRM and the recirculation of EGC in HRM takes place south of Fram Strait. Nevertheless, comparing the mooring data to FRMasof (black) we come to a different conclusion. If we reduce our information density in the FRM horizontally and vertically to the positions where we have measurements, we can simulate the measured northward and southward transport rates quite well. Therefore we argue, that the transport rates and pattern simulated by the 1/12 ° model in principle can be in agreement with the rates derived from the moorings. The upper levels of FRMasof are in 70 m and 200 m and therefore are missing a reasonable amount of the 'too warm' EGC. In contrast of the net volume flux, the resulting net heat fluxes of HRM, FRM, FRMgap, FRMasof and data from the moorings are in the same order of magnitude. The figure suggests, that there might be a correlation at certain times and single events between model and observation. The 10-year mean heat flux rates are similar in all cases, as well as the standard deviations. Two periods of increased heat flux observed in 1998-99 and 2004-2005 are also reproduced by model results.

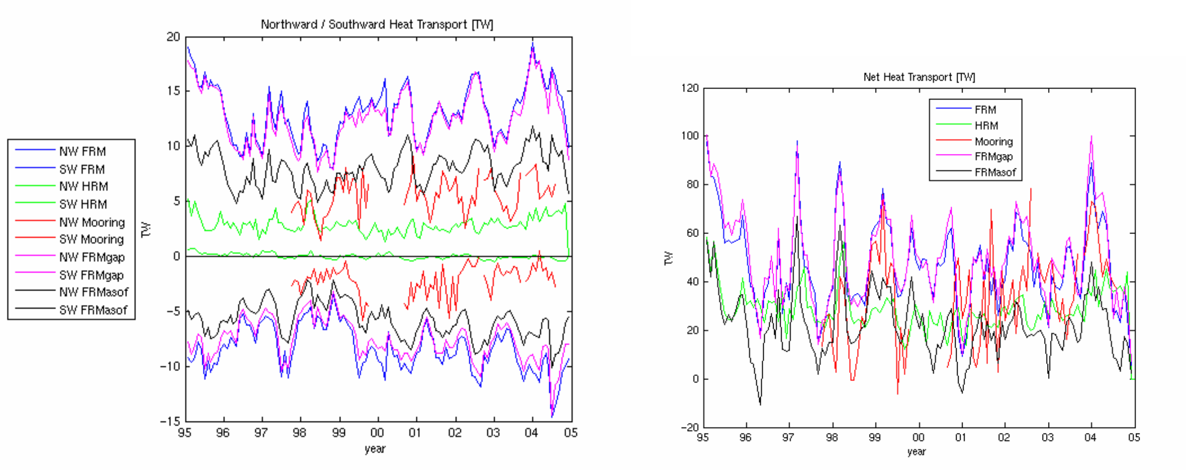


Fig. 3.9: Vertical integrated northward and southward heat flux [TW] across 79°N through Fram Strait
Left panel: Northward vs. southward heat transport, right panel – net heat transport

3. Socio-economic relevance and policy implication

In the North Atlantic the warm water flows through the Nordic Seas and finally reaches the Arctic Ocean through the Barents Sea and Fram Strait where it significantly affects the conditions which determine the properties of polar water and sea ice flowing from the Arctic to the south. The strength of the thermohaline circulation has a direct impact on the European sector climate. The changes in the volume and heat fluxes into the Arctic Ocean lead to variability of the ocean circulation between the high Arctic and North Atlantic and thus can have a strong influence on climate and on potential abrupt climate changes.

Variability with the time scales related to the climate changes can be only studied on a base of the long-term observing systems. The efforts in ASOF-N and specifically in WP3 aim on the development of a consistent, potential and cost-effective observing array in the key area for the exchanges between the North Atlantic and Arctic Ocean. Until now the status report on existing data in Fram Strait has been prepared to give a base for the long-period estimates of the heat and volume transport variability and first time series of volume and heat fluxes with a new instrument set-up have been collected. Some adjustments of the observing array were made accordingly to the obtained results. The established long term time series reveal the response of the heat and volume fluxes to the climate forcings, give an insight into the variability over the different time scales and thus they are the main tool to validate and improve the predictions by the numerical models. The first results from the high resolution model were also obtained in the reporting period and will be validated by a comparison with moorings observations.

4. Discussion and conclusion

The objectives of WP3 planned for the third phase of the project were achieved according to the schedule and the required deliverables were prepared.

First results from the bottom pressure recorders (BPR) and pressure inverted echo sounders (PIES) showed that they are able to capture the relevant range of the pressure variations and thus the resulting changes in the barotropic flow. Due to the highly barotropic character of the currents in Fram Strait, the bottom pressure recorders can be used to derive bottom pressure gradients between moorings (Fig. 3.10) and further to estimate barotropic currents. A simple scaling shows that bottom pressure gradient of order O(1.5·10^{-6}db·m^{-1}) at the latitude of 78°50'N and with mean density of seawater 1028 kg·m^{-3} results in cross -section velocity of the barotropic flow of order O(10 cm·s^{-1}). This value is in good agreement with a range of the barotropic currents derived as vertical averages of current profiles measured at the array moorings. Taking into account the dominating barotropic component of the flow in the eastern Fram Strait, the volume transport variability could be estimated from integral measurements of bottom pressure. Variations of the vertical mean temperature, which are reflected in the sound velocity, result in variations of the acoustic two-way travel time (Fig. 3.11). From a deployment of three PIES in 2004, three were successfully recovered and data were processed. First results obtained from comparison of mean temperature measured at the mooring and travel time measured by PIES revealed strong correlations for all three locations. Since changes in mean temperature are closely related to changes of the heat content, thus it is expected that changes in the heat transport can be captured by use of PIES. At the same time changes in the density structure revealed in the sound speed variations can be used for estimation of the baroclinic flow. In 2005 two bottom pressure recorders and five SBE16 with pressure sensors were deployed and three PIES were installed at the moorings array.

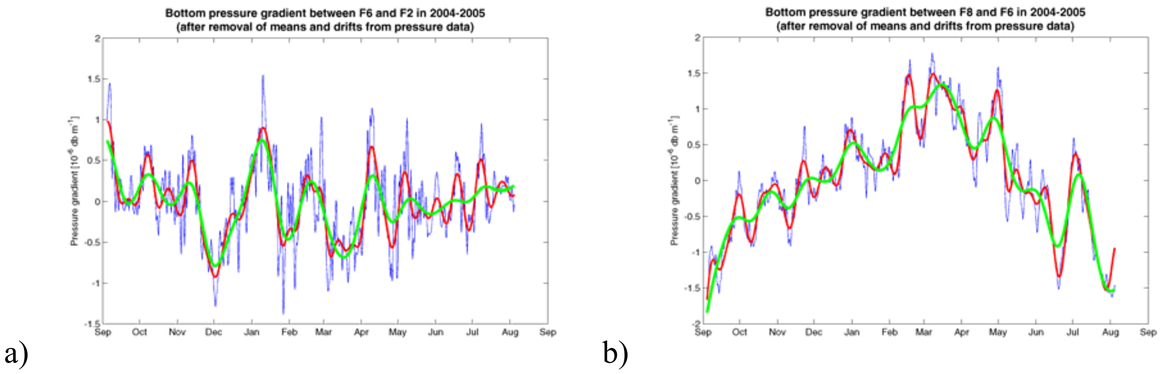


Fig. 3.10: Time series of bottom pressure gradients between (a) moorings F2 and F6 and (b) moorings F6 and F8 measured by PIES in 2004-2005. The pressure gradient were derived from measured bottom pressure after removal of mean and drift and based on 6 hour data (blue) and low-pass filtered data with 2-weeks (red) and 1 month (green) cut-off periods.

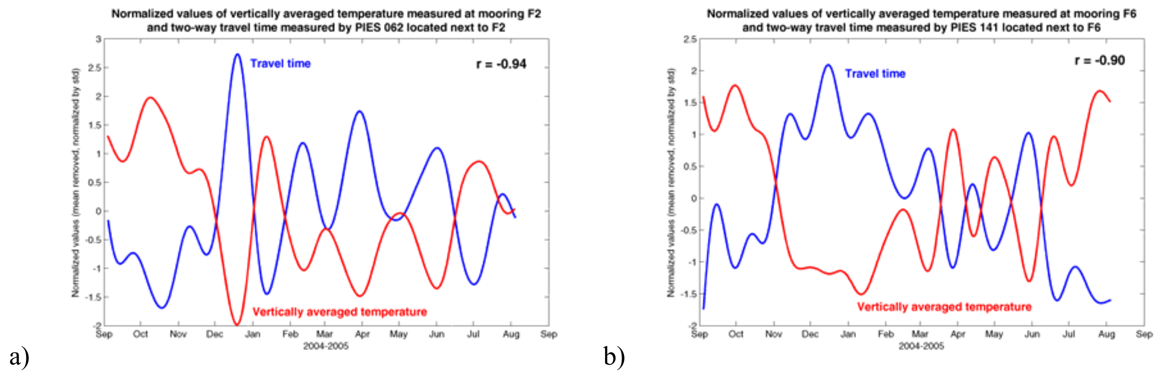


Fig. 3.11 Time series of normalized values of acoustic two-way travel time measured by PIES and vertically averaged temperature measured by temperature sensors at the mooring next to PIES in 2004-2005 for locations (a) F2 in the WSC and (b) F6 in the central Fram Strait. Both travel time and temperature time series are low-pass monthly filtered. Correlation coefficients between travel time and mean temperature are given.

Mean volume and heat transports based on monthly means for the whole period of observations (8 years) and separately for the preASOF (1997-2002) and ASOF (2002 - 2005) periods are given in table 3.2. Transports were computed for the complete Fram Strait section as well as for separate domains of the West Spitsbergen Current, central recirculation area and East Greenland Current. Long-term means of net volume and heat transports through Fram Strait were estimated on 1.9 Sv southward (with standard deviation of 4.7 Sv) and 37 TW northward (with standard deviation 20 TW) respectively. Decrease of net volume transport and increase of net heat transport were found as a difference between preASOF and ASOF periods. All transport measured during the ASOF period were characterized by significantly lower standard deviations. This can be clearly attributed to optimizing the observing array in terms of additional moorings and additional depths instrumented during the ASOF project.

Tab. 3.2: Mean volume and heat transports (calculated from monthly means) for the whole period of observations (8 years) and with distinguishing between preASOF (1997-2002) and ASOF (2002-2005) observations. Transports are given for the complete Fram Strait section and for different domains (as in Fig. 3.2).

Mean & standard deviation	Volume northward [Sv]	Volume southward [Sv]	Volume net [Sv]	Heat northward [TW]	Heat southward [TW]	Heat net [TW]
Complete section (Moorings F1-F14: 006°27'W - 008°40'E)						
Mean 97-05	**11.6**	**-13.5**	**-1.9**	**58.6**	**-21.8**	**36.8**
STD 97-05	**3.5**	**4.1**	**4.7**	**17.2**	**12.7**	**20.1**
preASOF						
Mean 97-02	**11.1**	**-13.2**	**-2.1**	**53.6**	**-24.3**	**29.3**
STD 97-02	**3.7**	**4.1**	**5.9**	**16.8**	**13.9**	**20.2**
ASOF						
Mean 02-05	**12.2**	**-13.9**	**-1.6**	**65.1**	**-18.4**	**46.7**
STD 02-05	**3.0**	**4.2**	**2.5**	**15.4**	**10.0**	**15.4**
West Spitsbergen Current (WSC) domain (Moorings F1-F6: 005° - 008°40'E)						
Mean 97-05	**7.9**	**-0.7**	**7.2**	**53.1**	**-2.8**	**50.3**
STD 97-05	**2.6**	**0.7**	**3.0**	**15.4**	**3.8**	**16.4**
preASOF						
Mean 97-02	**8.6**	**-0.5**	**8.1**	**53.2**	**-2.5**	**50.7**
STD 97-02	**2.5**	**0.6**	**2.8**	**16.4**	**3.6**	**17.2**
ASOF						
Mean 02-05	**6.8**	**-1.0**	**5.8**	**52.9**	**-3.3**	**49.7**
STD 02-05	**2.3**	**0.7**	**2.7**	**13.9**	**4.0**	**15.1**
Recirculation (REC) domain (Moorings F6-F10: 002°W - 005°E)						
Mean 97-05	**3.7**	**-6.9**	**-3.2**	**7.4**	**-11.8**	**-4.4**
STD 97-05	**2.7**	**3.7**	**5.1**	**8.0**	**10.5**	**13.4**
preASOF						
Mean 97-02	**2.6**	**-7.4**	**-4.8**	**3.9**	**-14.9**	**-11.0**
STD 97-02	**2.6**	**4.1**	**5.8**	**6.8**	**11.5**	**13.6**
ASOF						
Mean 02-05	**5.3**	**-6.2**	**-1.0**	**12.1**	**-7.5**	**4.6**
STD 02-05	**1.9**	**2.9**	**3.0**	**7.1**	**7.0**	**5.4**
East Greenland Current (EGC) domain (Moorings F10-F14: 006°27' - 002°W)						
Mean 97-05	**0.2**	**-5.9**	**-5.7**	**-0.3**	**-7.2**	**-7.5**
STD 97-05	**0.4**	**2.0**	**2.2**	**0.7**	**4.8**	**4.9**
preASOF						
Mean 97-02	**0.3**	**-5.3**	**-5.1**	**-0.4**	**-6.8**	**-7.2**
STD 97-02	**0.4**	**1.3**	**1.5**	**0.8**	**5.0**	**5.1**
ASOF						
Mean 02-05	**0.2**	**-6.8**	**-6.6**	**-0.1**	**-7.9**	**-7.9**
STD 02-05	**0.4**	**2.5**	**2.7**	**0.4**	**4.6**	**4.7**

In the West Spitsbergen Current domain the differences in standard deviations between preASOF and ASOF measurements are negligible due to comparable set of instrumentation. Decrease of net volume transport in the WSC was found between preASOF and ASOF periods but net heat transport remained the same (within the error bars). The strongest differences between both observing periods were found in the deepest, central part of Fram Strait which is referred to as the recirculation domain. The main reason is related to changes in the design of the moored array. The broad gap between central moorings in the deep part of Fram Strait which existed until 2002 resulted in the interpolation of values measured at the side moorings over the vast area, missing the spatial structure of the flow and leading to overestimated northward/southward transports. After adding two additional moorings in the central Fram Strait during ASOF, the standard deviation of volume transport decreased by half while standard deviation of heat transport dropped by factor of 2.5. The net volume transport in the central part was southward but decreased by nearly 4 Sv between preASOF and ASOF periods what can be attributed both to changes in the observational array design as to changes in the flow pattern which were also observed. The net volume transport in the East Greenland Current was southward and increased slightly between preASOF and ASOF periods. Only in this case standard deviations in volume transport were higher during ASOF measurements what may reflect the significant losses of instruments in last three years and a necessity of less reliable interpolation within the East Greenland Current. However a contribution of the recirculation domain and East Greenland Current to the total heat transport is of one order of magnitude smaller than contribution of the West Spitsbergen Current domain. This ensures that uncertainties in the volume transport in the recirculation and western domains do not influence significantly the heat transport estimates.

Spatial variability of the volume and heat transport through the Fram Strait on the monthly time scale is presented on the figures 3.12a,b as time series of vertically integrated transports per unit distance along the section. The strong northward volume flux is visible in the West Spitsbergen Current, reaching until the shelf slope base. The core of the WSC (its inner part covered by moorings F1-F3) is continuous and rather stable while an intensification of the off-shore branch of the WSC can be observed in some years (the strongest in 1999 and 2005). The volume transports in the core and the off-shore branches of the WSC seem to be inversely correlated, the maxima of the volume transport in the latter are coupled with significantly weaker volume flux in the WSC core. Since the beginning of the ASOF measurements in summer 2002, the bidirectional bands of northward and southward flow have been registered in the deepest part of the strait. Due to the great depths in this area, even weak currents of barotropic character as observed there, result in significant volume transports. These flow bands are closely related to the bottom topography. However EOF analysis (not shown here) reveals two dominating patterns with a lateral shift of northward and southward flows. Due to more baroclinic character of the East Greenland Current, the flow integrated over the shelf slope of the similar width as in the WSC results in a lower volume transport. The winter-centered annual averages of vertically integrated volume transport (Fig. 3.12c) show spatial structures of both fluxes in a relation to the bottom topography. Two branches of the WSC are clearly distinguished over the shelf slope west of Svalbard. For selected periods (1999-2000 and 2004-2005) the volume transport in the off-shore branch is higher than within the WSC core. However, the winter-centered annual averages of vertically integrated heat transport (Fig. 3.12d) clearly depict that the biggest share of the heat transport is confined within the WSC core. A contribution from the off-shore branch varied in different years from nearly null to approximately a half of heat transport in the inner part. The heat transport in the eastern part of Fram Strait is characterized by autumn and winter maxima with intensification of the heat flux by the off-shore branch. In the central part of Fram Strait, the annual averages of the volume transport show a clear difference between preASOF period with southward transport and the ASOF period when a significant northward volume transport was found over some distances. These differences are to some extent reflected in the annual averages of heat transport but their spatial variations in the central Fram Strait result in negligible contribution to the heat transport in the eastern part of the strait.

A detailed analysis of temporal variability on different time scales was focused on the most consistent data set from ASOF-N period. In this case the uniform distribution of instruments during all three deployment periods allowed to avoid any uncertainties due to changes in the observational array. (An influence of changes in the array design on transport estimates is discussed in the Deliverable 6.3). Volume and heat transports were calculated from daily averaged temperature and cross-section current data and from low-pass filtered data with cut-off periods of one week, 2 weeks, one month, 3 months and one year (Fig. 3.13).

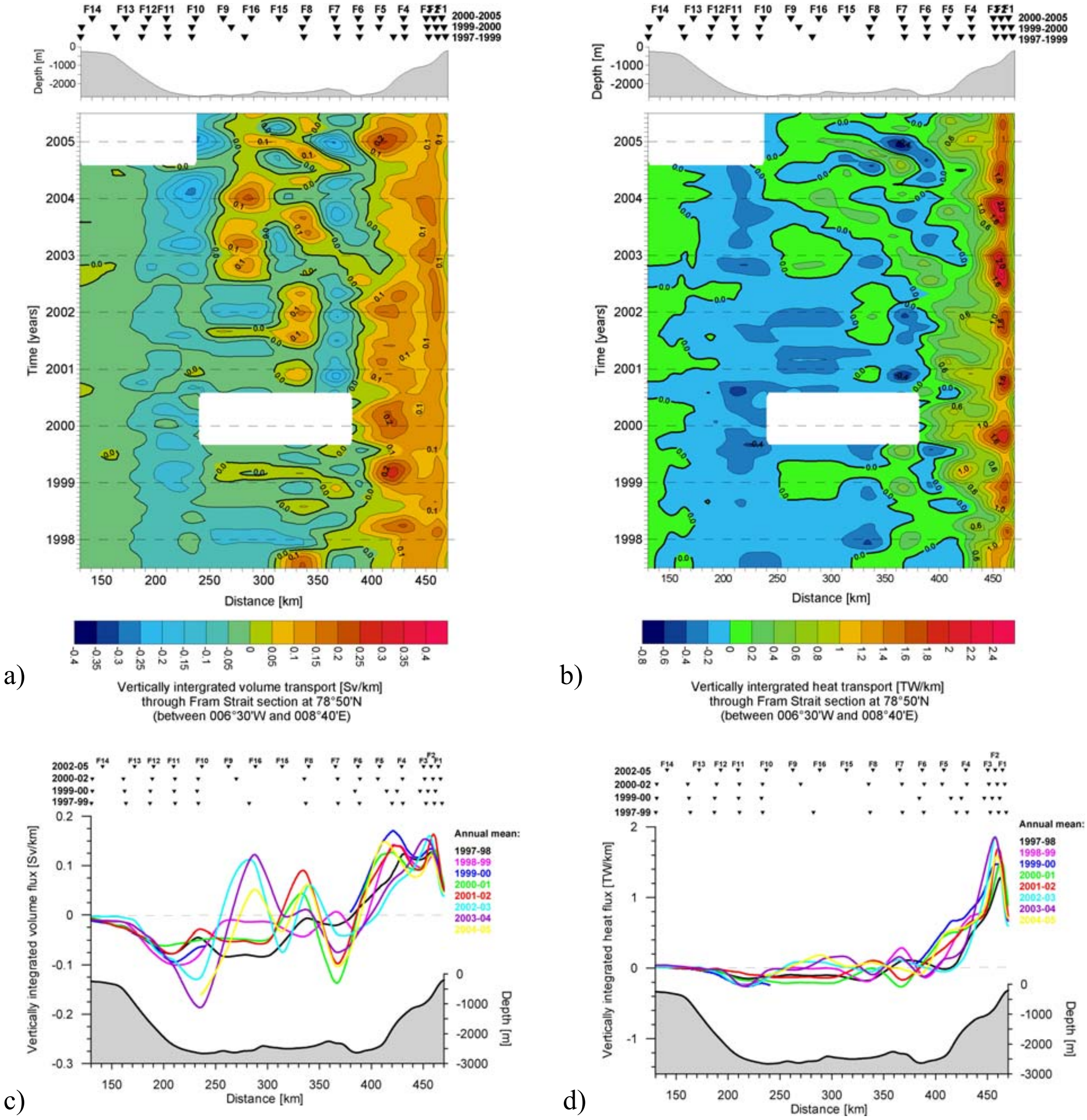
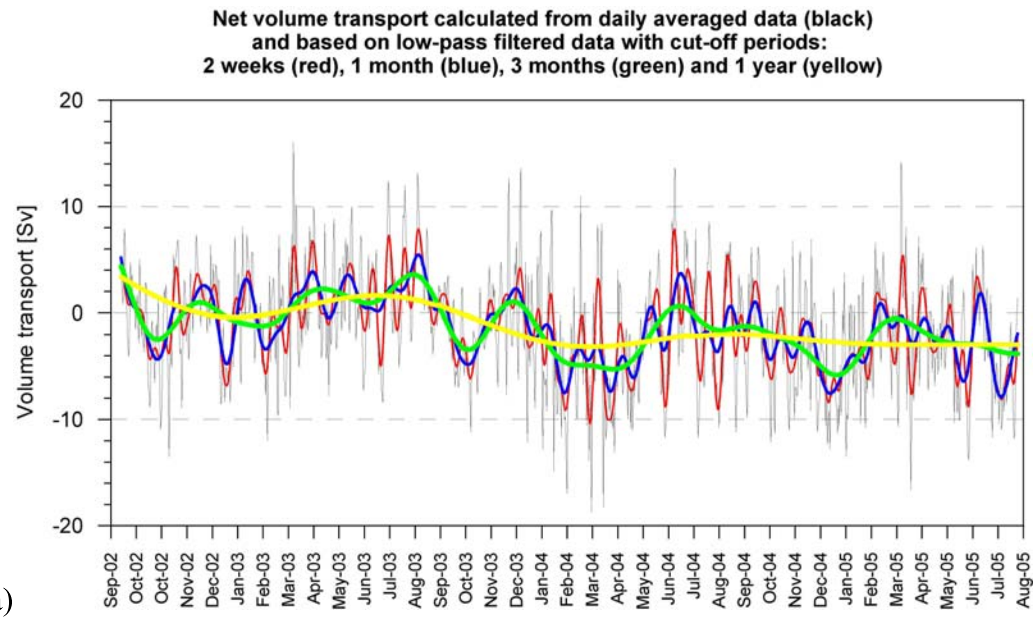


Fig. 3.12: Time-space diagram of the vertically integrated volume (a) and heat (b) transports through Fram Strait and their winter-centered annual means for (c) volume and (d) heat transports in 1997-2005. Transports are calculated from monthly mean data.

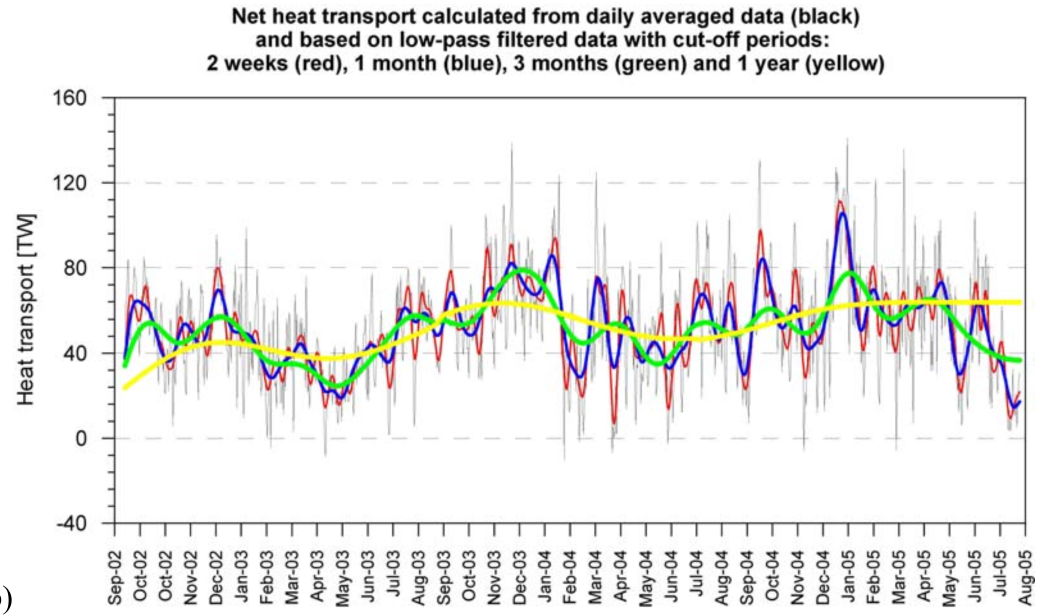
The statistics of the northward, southward and net transports are presented in table 3.3. The net volume transport on daily time scale varies between maximum values of 16 Sv northward and 18 Sv southward with a mean of 1.4 Sv southward and a standard deviation of 5 Sv. Mean day-to-day changes in volume transport were 3.4 Sv with maximum day-to-day changes reaching 19 Sv. On the daily scale the net heat transport varied in range 10 TW southward to 141 TW northward with a mean value of 52 TW and a standard deviation of 25 TW. Mean day-to-day changes of the net heat transport were 15 TW with an observed maximum of 81 TW. On the interannual time scale the net volume transport varies between maxima 3 Sv southward and 3 Sv northward with a mean of 1.2 Sv southward and a standard deviation of 1.8 Sv. The net heat transport changes within the range of 24 to 64 TW with a mean of 52 TW. It results that even if the northward and southward transports vary significantly on shorter time-scales (the difference between daily based mean and annually based mean is of the order of 6 Sv for northward and southward volume transports and of 18 TW for northward and southward heat transport), net transports are similar on scales from daily to interannual.

Tab. 3.3: Statistics of the volume and heat transports calculated from daily averaged temperature and cross-section current data and from low-pass Butterworth filtered data with cut-off periods of one week, 2 weeks, one month, 3 months and one year

Based on temperature and cross-section current data which were:		North. Volume Transport [Sv]	South. Volume Transport [Sv]	Net Volume Transport [Sv]	North. Heat Transport [TW]	South. Heat Transport [TW]	Net Heat Transport [TW]	North. Flow Area [km²]	South. Flow Area [km²]
Daily averaged	**Mean**	**16.6**	**18.0**	**-1.4**	**78.7**	**-26.5**	**52.2**	**289.0**	**361.3**
	STD	4.4	5.8	5.3	22.9	17.1	24.6	43.1	43.1
	Min	7.5	5.6	-18.7	24.2	-86.6	-10.1	154.9	218.4
	Max	32.4	38.0	16.1	161.7	17.6	141.1	432.0	495.5
1 week filtered	**Mean**	**15.9**	**17.3**	**-1.4**	**76.9**	**-24.6**	**52.3**	**287.8**	**362.6**
	STD	3.9	5.3	4.4	20.8	15.3	20.8	40.2	40.2
	Min	7.2	6.0	-13.2	25.4	-78.3	-0.6	142.4	237.8
	Max	28.0	35.0	11.4	147.8	8.7	121.9	412.5	507.9
2 weeks filtered	**Mean**	**15.0**	**16.4**	**-1.4**	**74.5**	**-22.3**	**52.2**	**284.9**	**365.4**
	STD	3.7	4.9	3.7	19.5	13.7	18.5	38.2	38.2
	Min	6.7	6.5	-10.4	30.8	-71.7	6.9	157.1	242.7
	Max	25.1	31.1	7.9	139.8	5.5	111.2	407.7	493.2
1 month filtered	**Mean**	**13.7**	**15.1**	**-1.4**	**70.7**	**-18.7**	**52.1**	**278.3**	**372.1**
	STD	3.4	4.6	2.9	17.8	12.1	16.2	32.0	32.0
	Min	5.4	4.6	-7.9	30.9	-63.5	14.6	183.2	281.7
	Max	23.0	30.3	5.5	132.0	8.1	105.7	368.7	467.2
3 months filtered	**Mean**	**12.0**	**13.4**	**-1.3**	**65.3**	**-13.9**	**51.4**	**271.9**	**378.4**
	STD	2.8	4.0	2.3	14.5	8.6	12.2	32.2	32.2
	Min	7.2	7.3	-5.8	32.4	-35.1	24.6	193.7	311.1
	Max	20.7	26.5	4.4	95.5	0.8	78.8	339.3	456.7
1 year filtered	**Mean**	**11.1**	**12.3**	**-1.2**	**60.5**	**-8.7**	**51.8**	**275.7**	**374.6**
	STD	1.5	2.0	1.8	9.3	5.3	10.0	20.0	20.0
	Min	8.2	9.1	-3.2	42.1	-34.4	23.7	246.4	329.5
	Max	16.0	15.3	3.4	73.1	-3.5	63.8	320.9	404.0



a)



b)

Fig. 3.13: Variability of (a) net volume transport and (b) net heat transport on different time scales from daily to interannual in 2002-2005

A transport of the Atlantic Water (AW) through the Fram Strait section was analysed for two cases: with reference temperature of Atlantic water 2°C (case TAW2) and 3°C (case TAW3). The former criterion is used (together with density range which cannot be applied in a case of mooring measurements) for the detailed classification of water masses proposed in WP6 as Atlantic Water in the Norwegian Sea and West Spitsbergen Current. The latter reference temperature of AW was used in WP2 for the Barents Sea opening and was applied in Fram Strait to permit the comparison between two main gateways. The time series of AW volume transport, AW mean temperature and areal coverage by AW during the ASOF period are presented on figure 3.14 (a - for AW with T>2°C and b - for AW with T>3°C). The warm AW with temperature higher than 3°C was absent at the Fram Strait section in winter 2003 (from January to May) and in February 2004. For both cases there is a strong correlation between AW heat transport and AW volume transport (0.97 for TAW3 and 0.88 for TAW2).

The mean AW temperature and areal coverage by AW are also closely correlated (0.78 for TAW 3 and 0.73 for TAW2) but there is no correlation neither between AW volume transport and AW mean temperature nor between AW volume transport and AW areal coverage. In both cases the northward and southward AW volume and heat fluxes are positively correlated (for volume northward/southward transports: 0.58 for TAW3 and 0.61 for TAW2 and for heat northward/southward transports 0.65 in both cases). There is a weak correlation between AW heat transport and AW mean temperature for the warm AW (TAW3) but not for the TAW2 case. All correlations higher than 0.52 are significant on a 99% level.

AW volume transports in the Barents Sea Opening and in Fram Strait seem to be oppositely correlated. On the interannual time scale the maxima in AW volume flux observed in the BSO in 1998 and 2003 were coupled with minima in AW volume transport through Fram Strait. On the other hand the increase in AW transport found in Fram Strait in 2000 and 2004 was accompanied by significant decrease of AW volume transport through the Barents Sea Opening.

a)

b)

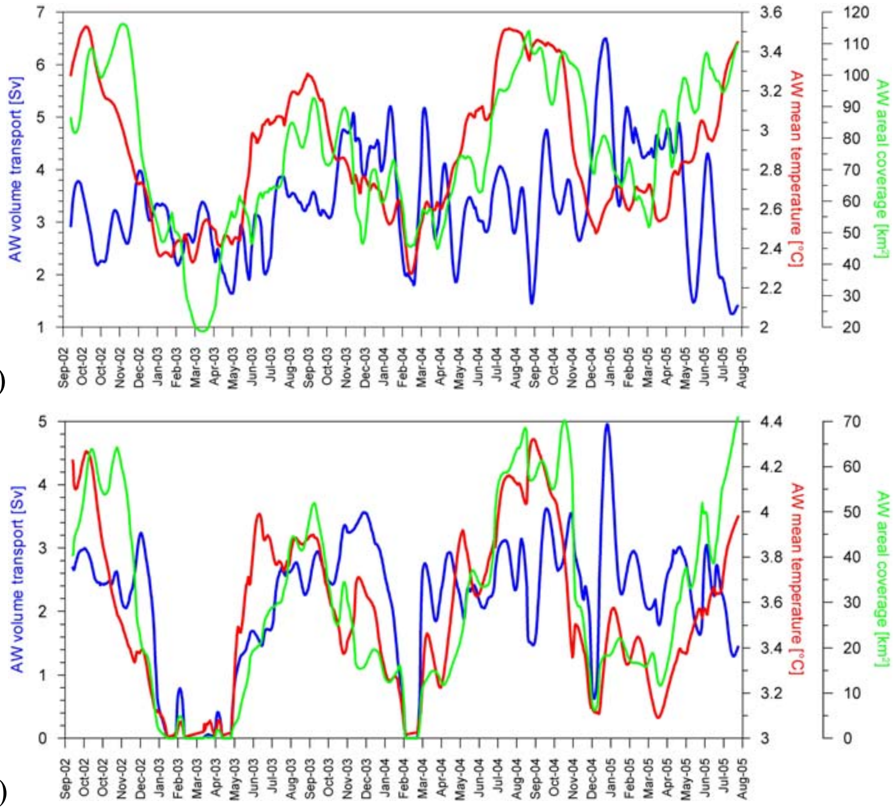


Fig. 3.14: Volume transport of Atlantic water, mean temperature of AW and AW areal coverage at the Fram Strait section in 2002-2005 for (a) AW with T>2°C and (b) AW with T>3°C

A role of the local atmospheric fields and advective temperature anomalies as forcings in the variability of volume and heat fluxes has been investigated with a closer focus on the West Spitsbergen Current domain and AW transports. Different contributions to the heat transport from temperature anomalies (T'), cross-section current anomalies (v') and nonlinear term resulting from interaction between temperature and velocity anomalies (v'T') were identified for the whole period of observations for monthly and annual means (Fig. 3.15). The strongest correlation was found between heat transport and velocity anomalies (and thus the volume transport) on both time scales while variability of heat transport was less coherent with temperature anomalies variability (but still the correlation was significant). The contributions from temperature and velocity anomalies are not correlated. It results that in years of decreased heat transport (ca 2001-2003) the contribution form temperature anomalies was higher than that from velocity fluctuations while for both periods of increased heat transport (1999-2000 and 2004-2005) the velocity related component was much larger than the temperature related one. The nonlinear component v'T' is of one order of magnitude lower than the others and thus can be neglected in analysis of different forcings.

The volume transport in the West Spitsbergen Current was compared with time series of atmospheric pressure gradients along and across Fram Strait (meridional between 85-75°N and zonal between 16°W-9°E, Fig. 3.16) as well as with meridional and zonal wind components. Significant correlations of the volume transport in WSC were obtained both for meridional (maximum correlation of 0.74 for time lag of 1 month) and zonal (maximum correlation of 0.7 for time lag 1-2 months) atmospheric pressure gradients. It can be concluded that the volume transport in the WSC is closely related to the local forcing by the atmospheric pressure field over Fram Strait. The barotropic flow generated by the inclination of the sea surface and the surface Ekman transport due to local winds are the most likely mechanisms.

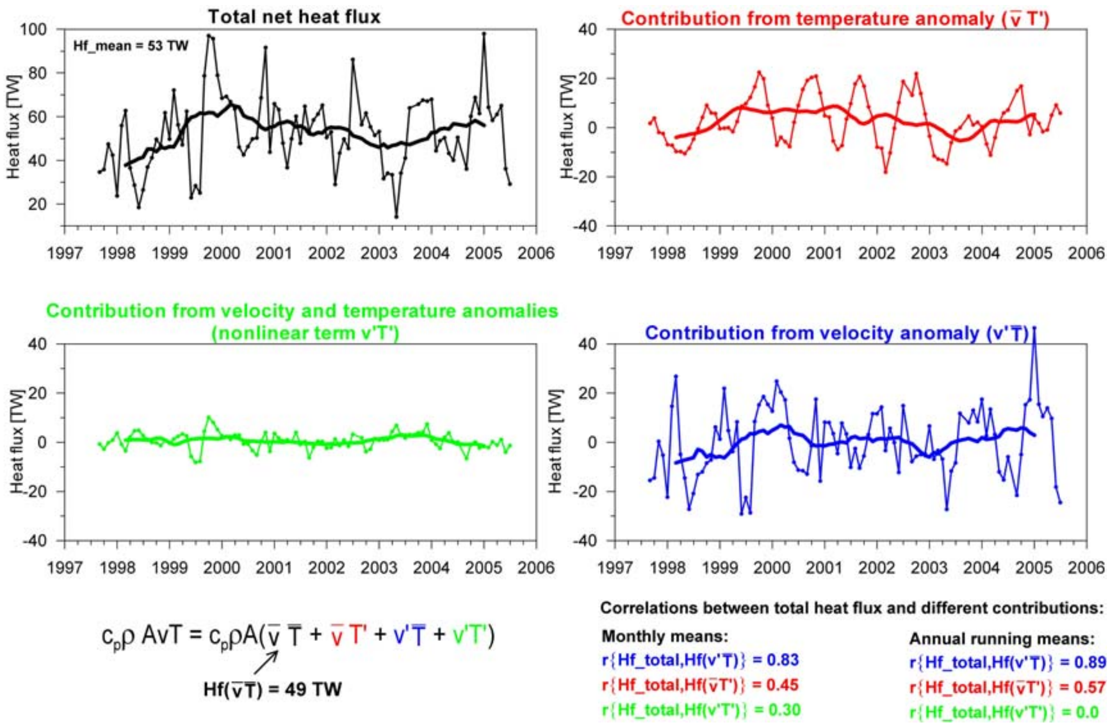


Fig. 3.15: Contributions of means and anomalies of temperature and velocity to the heat transport in the West Spitsbergen Current. The formula defining different contributions is given at the left lower panel, correlation coefficients between the net heat flux and separate contributions are shown on right lower panel for monthly and annual time scales.

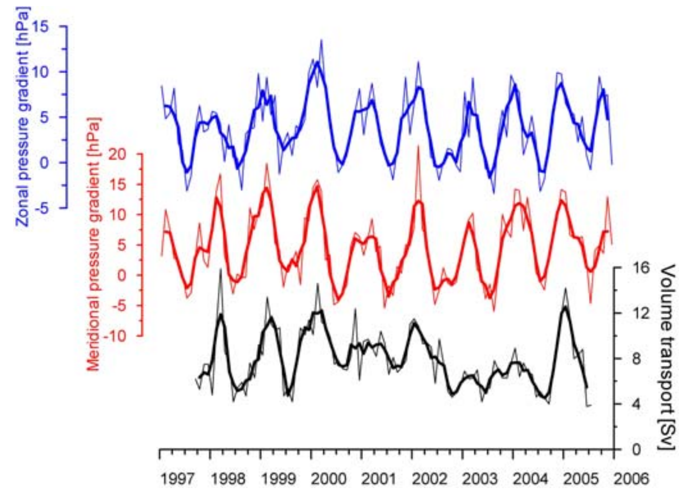


Fig. 3.16: Time series of zonal and meridional atmospheric pressure gradients over Fram Strait and the northward volume transport in the West Spitsbergen Current in 1997-2005

Variations of temperature other than due to the seasonal cycle proved to be advected from the upstream basin. A comparison of the temperature anomalies (based on deseasoned time series) from the Svinoy section located in the North Atlantic in the Lofoten basin (at the latitude of 62°N) and Fram Strait section (Fig. 3.17a) revealed a close correlation between two locations with a time lag of ca. 18 months. The velocity of propagating temperature anomalies was estimated on 3.8 cm/s what in a good agreement with earlier estimate by Furevik (2001) for anomaly observed in 1983-84 (3.6 cm/s). The propagation of temperature anomalies from the North Atlantic to Fram Strait was also confirmed by results of the numerical model (the high resolution NAOSIM ice-ocean coupled model). However a comparison of the mean temperature in the Atlantic water layer (230-280 m) between the Svinoy section and Fram Strait section suggests somehow longer time shift of about 22 months (Fig. 3.17b). Results of WP1 combined together with observations in WP3 indicate that warming events observed in Fram Strait are related not only to the temperature increase in the core of the Norwegian-Atlantic Current but also to intensification of its western branch.

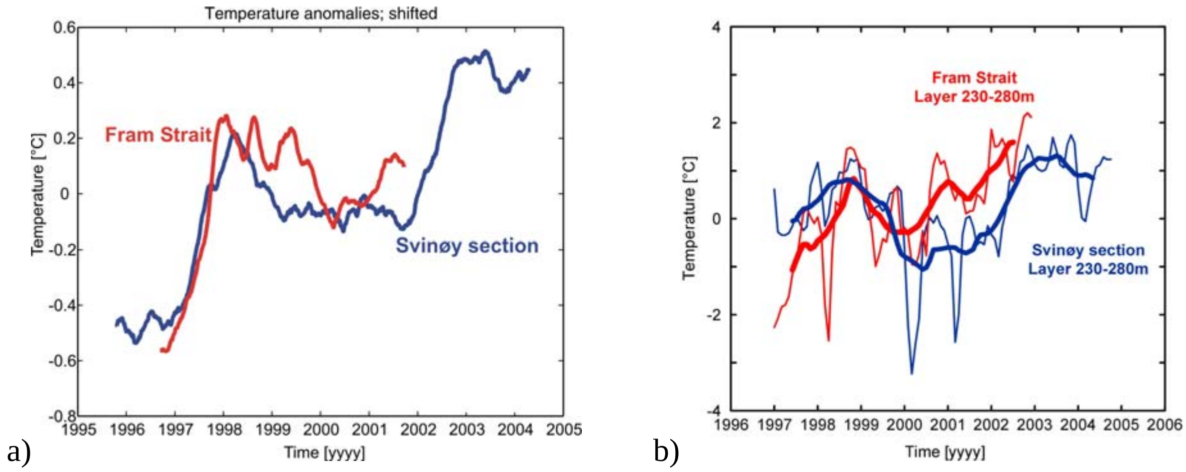


Fig. 3.17: Comparison of temperature anomalies between the Svinoy section (62°N) and the Fram Strait section (78°50'N) from (a) observations at the moored arrays and (b) NAOSIM models results.
Time series are shifted by 18 months for observations and 22 months for model data respectively.

We conclude this report on progress by addressing the deliverables and milestones specified in the "Description of work":

- Deliverable 3.2 (due in month 37): Preliminary data from moored array and repeated sections. Data were acquired from moorings and CTD section in 2005 and processed.
- Deliverable 3.3 (due in month 39): Calibrated data, calculated fluxes, data reports. Statistics of the calibrated data were calculated. Monthly and daily means of measured temperature and currents were used to calculate the heat and volume fluxes.Deliverable 3.4 (due in month 39): Time series of models and observations, analysis and interpretation of fluxes. Volume and heat fluxes were calculated from observations and model results and analysed with respect to temporal and spatial variability. A role of different types of forcing has been also investigated.
- Deliverable 3.5 (due in month 39): Comparison between model and observed statistics of the heat flux. Obtained.

5. Plans for the next period.

The array of mooring in Fram Strait will be continued during next 4 years in a frame of EU DAMOCLES project. During this period the observational array in Fram Strait will be redesigned according to recommendations based on the ASOF-N results. The next summer cruise to serve the Fram Strait moored array will take place in August and September 2006 on board RV 'Maria S. Merian'. During this cruise the mooring array in the eastern and central part of Fram Strait will be maintained with the recovering of existing moorings, downloading the recorded data and deploying the new, calibrated set of instruments. CTD and ADCP measurements will be performed at the standard section across Fram Strait. After the cruise the collected data will be processed as the existing data and time series of the heat and volume fluxes will be extended to the 9 years long period.

WP 4 'FRESH WATER FLOW THROUGH FRAM STRAIT'

1. Objectives

The objectives of WP4 “Fresh water flow through Fram Strait” during this third reporting period were as follows:

1. Make frequent (1 h) measurements of currents, temperature, salinity, sea ice draft and drift velocities at fixed locations (4 horizontal and 4 vertical) across the western part of Fram Strait
2. Measure a transect of T and S across the western part of Fram Strait with high horizontal resolution (10 nm)
3. Calculate volume transports from (1)
4. Calculate freshwater transports from (1), (2) and (3)

2. Methodology and scientific achievements related to Work Packages including contribution from partners

Objective 1: In September 2004 a total of seven moorings were installed across the East Greenland Current (EGC) and the shelf region at 78°50’N. Four moorings were installed across the EGC, instrumented with a total of twelve current meters, four temperature/salinity (TS) sensors, four upward looking sonars (ULS) measuring sea ice draft and four Doppler Current Meters (DCMs) measuring ice drift velocity. In addition three moorings were deployed on the East Greenland Shelf, as an effort to measure the freshwater flux there. Of these moorings two were tube moorings instrumented with a total of four TS sensors. One of the tubes was also instrumented with an RDCP600 that measures the transport in the upper 50 meters and the sea ice drift. A third mooring, close to the other tube, was instrumented with an Acoustic Doppler Current Profiler (ADCP) measuring the currents over a range of 150 meter. In this way T, S and currents should be measured on two sites on the shelf, in this second year of deployments of moorings on the East Greenland Shelf. This setup was the basis for the final data collection of WP4 during ASOF-N, and is illustrated in figure 4.1 with the salinity field in the background. This version of the array, in our opinion, represents the optimal setup for observing freshwater fluxes through Fram Strait with conventional moorings. It captures the bulk of the freshwater in a cost effective way. The moorings were recovered and data downloaded on the RV Lance September 2005 cruise.

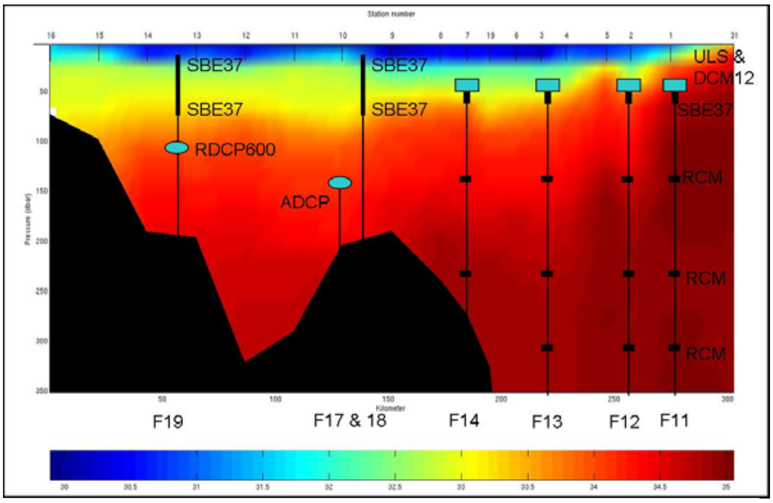


Fig. 4.1: Freshwater observation array 2004-2005

Mooring losses have been a major problem during the project. The 2004-2005 deployment was a particularly bad year. Mooring F12-7 and F13-7 in the EGC was lost, as was F19-2 on the shelf. In previous reports we have speculated in causes, in this report it suffices to say that collisions with icebergs from the disintegrating Northeast Greenland glaciers is a likely cause for at least some of the losses. Due to a positioning error F18-2 was not recovered, but may have survived and will then be recovered on the 2006 maintenance cruise.

The recovered data was added to the time series constructed during the previous project years. At the end of 2005 the time series counts eight years, which patiently have been sampled during the VEINS and ASOF-N EU funded projects. Figure 4.2 shows the salinity time series of the upper 47-74 m layer at mooring F11 (outer fringe of EGC) and F14 (inner fringe). These salinity time series are used to calculate the freshwater fluxes of Objective 4.

The features of these time series, how they compare to existing climatology from the region and their variability and seasonal cycle is discussed in Holfort. J. and E. Hansen (2005).

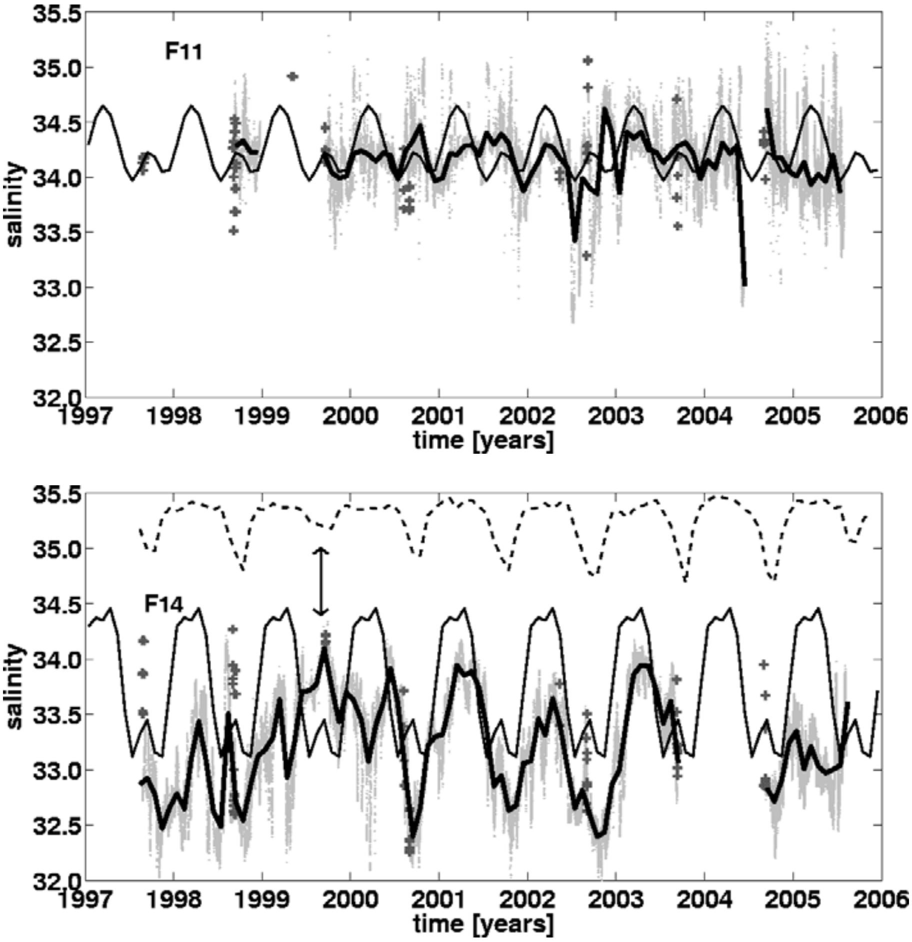


Fig. 4.2: Time series of salinity in the 47-74 dbar layer of the EGC. Mooring F11 (upper panel) represents the outer fringe of the EGC, while F11 is located in the inner (shelfward) fringe. Light grey points are the unfiltered hourly values, while the thick black line is the monthly mean. Dark grey crosses represent the mean salinity values from CTD casts in the immediate region around the moorings. The thin black line shows the salinity of the World Ocean Atlas (WOA) at 50 m in the point nearest to the moorings.

We continue to pursue the objective by continuing the maintenance of the freshwater observation array across the EGC and shelf region. On the September 2005 cruise five new moorings were deployed; the standard F11-F14 array of moorings across the EGC and one mooring on the shelf. Due to the losses no surface layer observing tube moorings could be installed on the shelf this year. This final ASOF-N deployment secured the continuation of the time series into the IPY years.

Objective 2: The annual transect was performed during the September 2005 R/V Lance cruise, measuring T and S with a CTD and the near surface currents with a vessel mounted ADCP. During the ASOF-N years we have added more transects across the EGC and the West Spitsbergen Current, and one meridional transect running along the Fram Strait. But due to heavy ice conditions only the standard section across Fram Strait at 79°N was performed on the 2005 cruise, in addition to a few additional stations in the EGC and on the East Greenland shelf. The section with station positions is shown in figure 4.3.

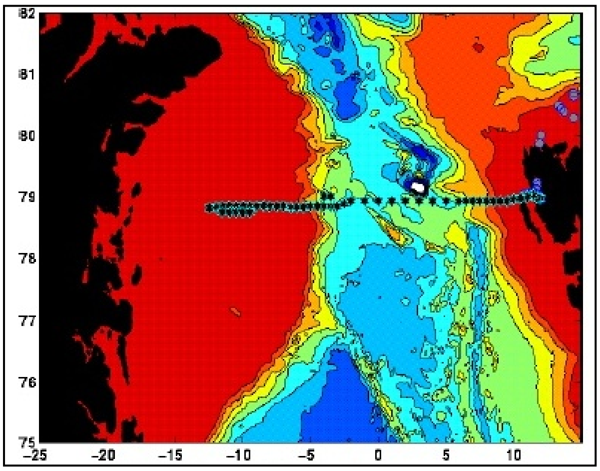


Fig. 4.3: CTD stations for the high resolution (10 nm) transect across Fram Strait

Objective 3: The volume transports were calculated from the current meters on the moorings. Several steps of data processing are required, but in short this was done by interpolating the point measurements in the horizontal and vertical directions. Multiplying with the appropriate area of each interpolation cell yields the volume transport of the EGC. For this WP the volume transport calculation is an intermediate step in the procedure of calculating freshwater fluxes. The mean annual cycle of the volume transport is shown in figure 4.4, as a reference for the freshwater flux seasonal cycle shown later.

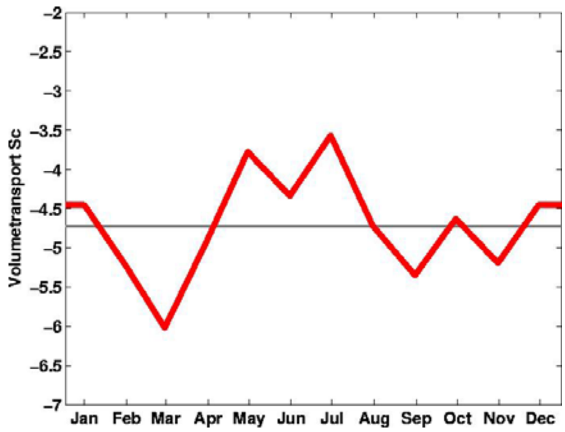


Fig 4.4: The seasonal cycle of the volume transport in the EGC. Negative value means southward transport.

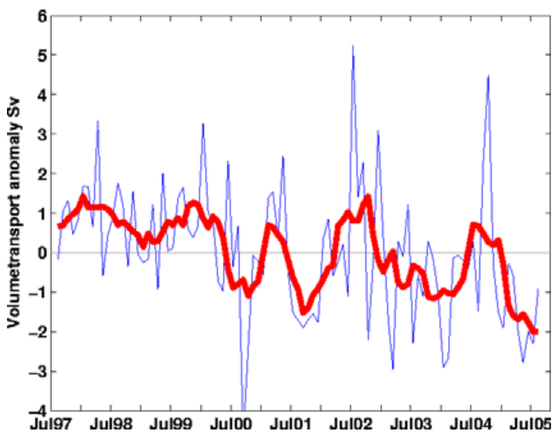


Fig. 4.5: Volume transport anomaly. I.e. volume transport time series with the average seasonal cycle

Maximum southward transport occurs in March (-6 Sv). There is a transition into the summer months, reaching minimum transport in July (-3.5 Sv). The mean annual transport over the 1997-2005 period is -4.7 Sv. The anomaly of the volume transport provides an impression of the interannual variability. The anomaly time series, i.e the volume transport time series with the average seasonal cycle subtracted, is shown in Figure 4.5.

The interannual variability is in the range +/- 1.5 Sv, superimposed on a sinking trend over the period. The average level of the volume transport appears to have dropped with a value of about 1 Sv during the eight years the observations have been maintained.

Objective 4:

The liquid freshwater fluxes were calculated using different estimates of the velocity and salinity fields, using a reference salinity of 34.90. The velocity fields were calculated by defining representative boxes around the current meters, with interpolation and extrapolation in regions not covered by instruments, and by geostrophic calculations from the summertime CTD sections. The salinity fields used as input were either the summertime salinity from the CTD sections, salinity observed by moorings, World Ocean Atlas (WOA) climatology, or a combination of these sources. The most representative estimates we assume are found by using WOA climatologies corrected with the salinity observations from the moorings. This ensures a correct salinity value at the depth of the observation, with a stratification according to the climatological mean. The freshwater transport time series as calculated with the WOA corrected salinity field is plotted in figure 4.6.

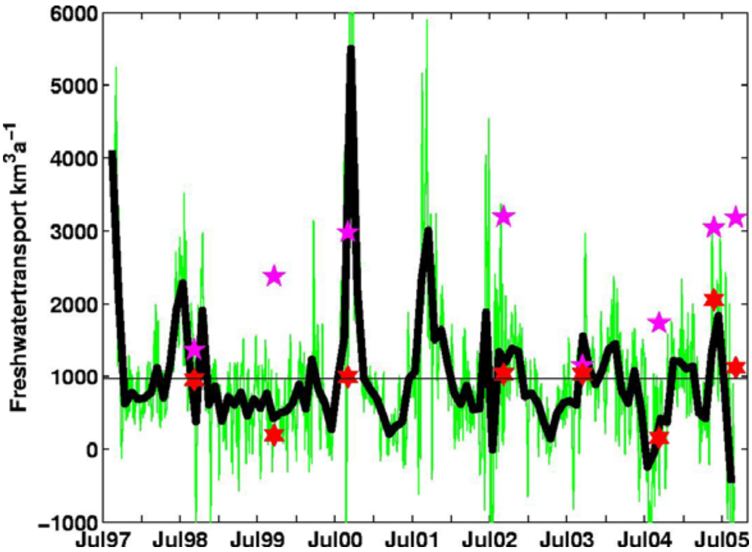


Fig 4.6: Time series of freshwater (fw) transport in the EGC. Black line: monthly mean fw transport from moorings (velocity, salinity) and corrected WOA. Green line: Daily values. Red stars: fw transport from CTD sections across the EGC using geostrophy with the level of no motion at bottom. Magenta stars: fw transport for the entire 79°N section, including the shelf region, using CTD sections and geostrophic calculations, level of no motion at bottom.

Combining the different estimates of the velocity and salinity fields, upper and lower estimates of the liquid fresh water fluxes is found. Our best estimate is that the average fresh water flux through Fram Strait in the EGC is approximately 1000 km^3/year (31.7 mSv). We should note from figure 4.6 that the CTD sections with geostrophic calculations for the entire 79°N section (magenta stars) indicate that significant amounts of the freshwater transport occurs over the shelf region, which is not captured by our present mooring setup.

There is a pronounced seasonal cycle in the freshwater transport. The average seasonal cycle of the liquid freshwater transport in the EGC is plotted in figure 4.7. The transport is at the lowest in April, dropping below 600 km^3/y (19.0 mSv). In this period much of the freshwater is in solid state (sea ice). With the onset of melt in May the freshwater transport increases, but the increasing liquid freshwater content is counteracted by the decreasing volume transport during early summer (Fig. 4.4). With sea ice melt continuing throughout summer the liquid freshwater transport reaches its maximum in September (minimum ice cover), reaching nearly 2000 km^3/y (63 mSv). The annual mean is close to 1000 km^3/year (31.7 mSv).

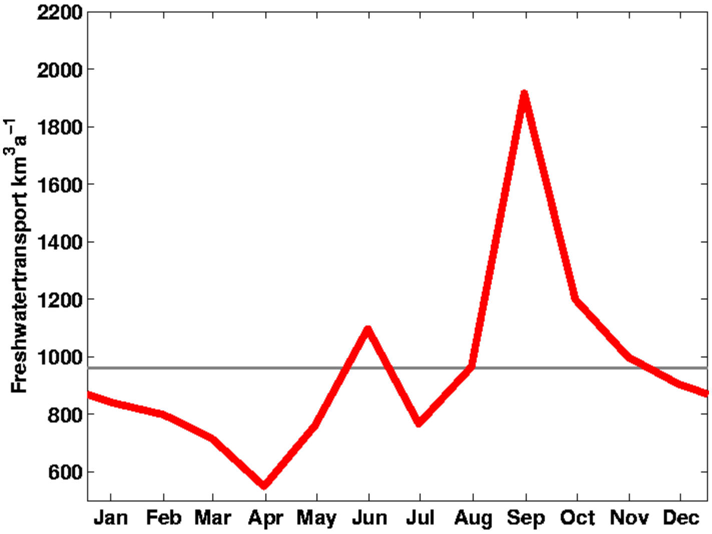


Fig. 4.7: The seasonal cycle of the EGC freshwater transport

The freshwater transport anomalies were calculated by subtracting the average seasonal cycle in figure 4.7 from the transport time series. The anomaly time series is shown in figure 4.8, where we observe interannual variability of about +/- 500 km^3/y (15.9 mSv). This is half of the annual mean. There is no significant trend in the freshwater transport in the EGC over this eight year long period; we conclude that the freshwater transport in the EGC is 1000 +/-500 km^3/y (31.7 +/- 15.9 mSv).

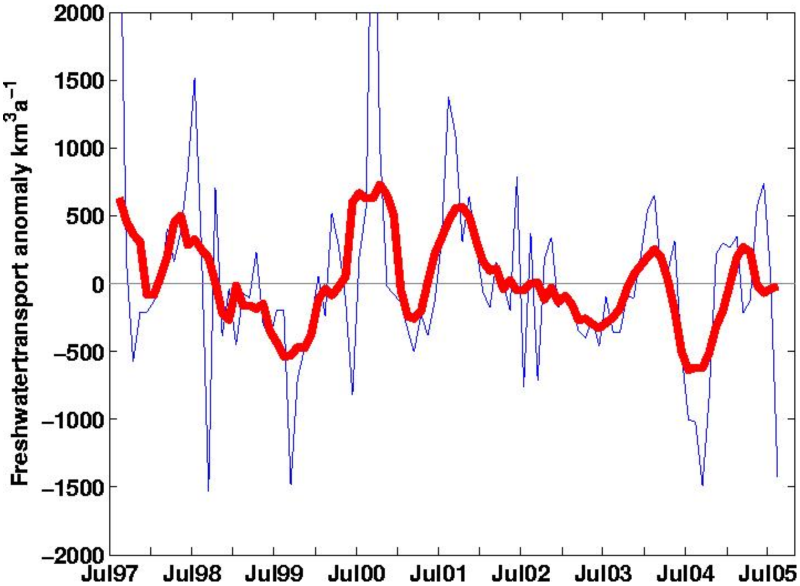


Fig 4.8: Freshwater transport anomaly. I.e. freshwater transport time series with the seasonal cycle subtracted

Comparing with model results:

Observations of the kind presented here are expensive. Still they may fail to resolve the full freshwater transport, such as the missing transport on the shelf indicated in figure 4.6.

Numerical models are very useful tools for extrapolation of the observations, extending the time series and for examining the role of the freshwater fluxes in a larger context. To do so one must ensure that the model performance is acceptable in certain key regions such as the Fram Strait. For this reason the freshwater flux estimates obtained under WP4 was compared with NAOSIM modelled fluxes. The comparison is shown in figure 4.9.

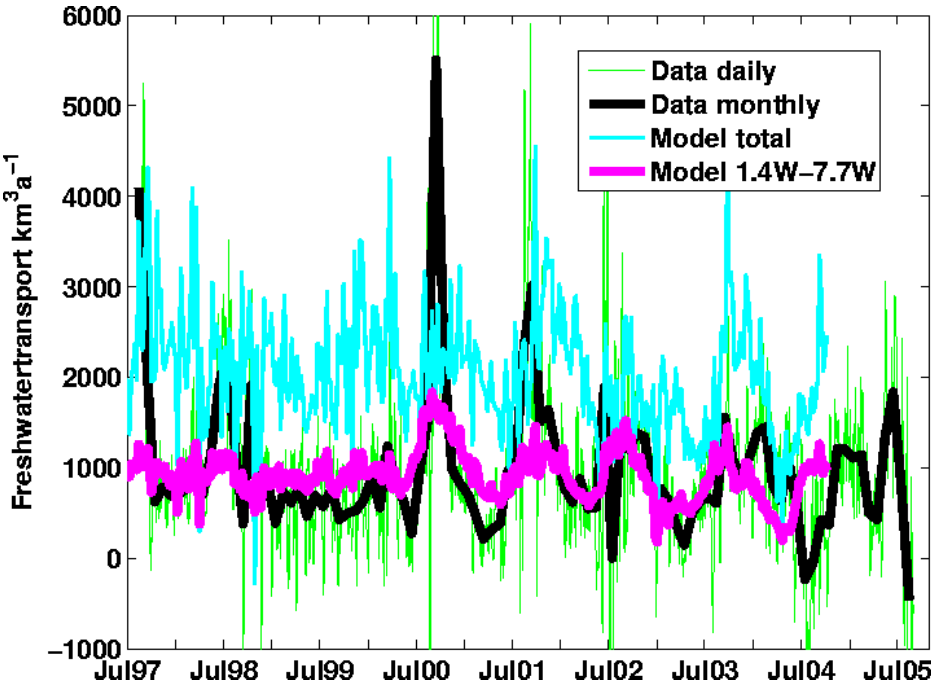


Fig. 4.9: Comparison of observed and modelled (NAOSIM) freshwater fluxes through Fram Strait.
Green line: Daily fw observations in the EGC.
Black line: Monthly average of the observed fw flux in the EGC.
Magenta line: Modelled fw flux in the EGC.
Cyan line: Modelled total fw flux, including the shelf region.

The model appears to reproduce the Fram Strait fresh water fluxes in the EGC very well (magenta and black lines). The average level around 1000 km^3/y is well reproduced, as is the timing of the seasonal signal. The model also appears to reproduce much of the interannual variability. The model indicates a total freshwater transport through Fram Strait of about 1500-2000 km^3/y on average (cyan line). This implies that a freshwater transport of 500-1000 km^3/y occurs outside the EGC in the model.

Figure 4.10 shows the average modelled freshwater flux for each grid cell across Fram Strait. The magenta circles indicate the position of moorings F11 to F14 across the EGC, which sums up to about 1000 km^3/y (magenta line in figure 4.8). The flux over the shelf west of the EGC sums up to about 700 km^3/y, which is consistent with or less than our estimates based on summertime CTD sections and geostrophy (Fig. 4.6). East of the EGC the model produces an average freshwater transport of about 450 km^3/y. This fraction of the transport is generally not observed in the summertime CTD sections, and is likely to be an overestimation by the model.

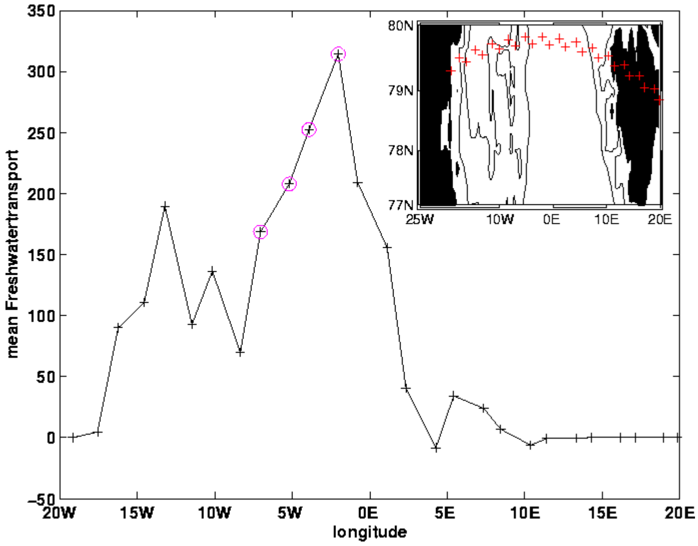


Fig. 4.9: Comparison of observed and modelled (NAOSIM) freshwater fluxes through Fram Strait. Green line: Daily fw observations in the EGC. Black line: Monthly average of the observed fw flux in the EGC. Magenta line: Modelled fw flux in the EGC. Cyan line: Modelled total fw flux, including the shelf region.

3. Socio-economic relevance and policy implication

Annual mean temperatures in North-west Europe are considerable higher than they should be for their latitude. This organization of the climate system is to a large extent maintained by the heat carried poleward from the tropics by the ocean. The net densification of water in the Arctic Mediterranean through salinification and cooling is a major component of this circulation. The strength of the oceanic heat transport, and hence the climate of NW Europe, is assumed to be sensible to the freshwater content and distribution within these seas. The flux of freshwater from the Arctic to the subarctic, and more specific through the Fram Strait to the Greenland and Labrador Seas, is thus thought to play a key role in the climate system governing our European everyday life.

The efforts undertaken in WP4 during the reporting period should be viewed in this context. From a climate research point of view, oceanographic data acquisition and data organization over only three years is difficult to directly relate to terms like “socio-economic relevance” and “policy implication”. Therefore the relevance and implications of the activities in the preceding year should be viewed in connection with the activities planned for the coming years under the EU funded Integrated Project DAMOCLES: The first time series of fresh water fluxes through Fram Strait from direct measurements have now been calculated. New estimates will be calculated in the coming years, building on the ASOF-N work. From the time series we may quantify the variability of the fluxes on various time scales, and understand how they interact with other components of the climate system. The ultimate goal is to assess the scale and extent of changes associated with ocean freshwater fluxes in this region, and their impact on the meridional overturning circulation. Since this directly addresses the efficiency with which the Arctic communicates with the Ocean’s thermohaline ‘conveyor’, it may prove to be a component vital for our understanding of the Earth’s changing climate system.

The monitoring array deployed and maintained under this WP form a vital component of the observing system necessary to obtain a long term consolidated data set of mass, heat and fresh water fluxes between the Arctic and the North Atlantic oceans. Although they are just a piece in the large puzzle, such long term data sets are essential for the development of believable predictive models that are required for developing a policy toward mitigation of socio-economic effects of climate change.

4. Discussion and conclusion

The tasks and deliverables of WP4 are on schedule, i.e., the deliverables have been met and the milestones have been reached. The major setback of this work package is the delay in calculating freshwater fluxes in the shape of sea ice. Shortly after the ASOF-N startup it was realized that new algorithms and processing steps could significantly reduce the errors in the ice thickness estimates. This reprocessing of the ice thickness data from the Upward Looking Sonars (ULS) have been time consuming, and it was soon realized that it would require more time than first expected. We therefore decided to keep full focus on the reanalysis, and not perform detailed flux calculations on data of non-optimal quality. However, the pre-ASOF-N data from the period 1990-2000 was shared with external collaborators. Using satellite derived velocity fields they calculated an average ice volume flux in the form of sea ice of 2218 km^3/y (Kwok, et al (2004), Fram Strait sea ice outflow, J. Geophys. Res., 109, C01009, doi:10.1029/2003JC001785). Until the ULS data reanalysis is finished, including data sampled during the ASOF-N years, this is the most recent figure on Fram Strait ice volume export. We expect the reanalysis to be finished during 2006.

Another setback is the loss of several full moorings. This obstacle has been overcome by using interpolation between the surviving moorings, and by spending internal NPI funding on purchases of new instrumentation replacing the lost equipment. This ensured the continuation of the time series.

The average annual liquid freshwater transport in the EGC over the 1997 to 2005 period is estimated to be approximately 1000 km^3/y (31.7 mSv), with an annual variability of about +/- 500 km^3/y (15.9 mSv). There is no trend in the freshwater transport over the 1997 to 2005 period. There is, however, a sinking trend in the volume transport. It appears that the average volume transport has decreased by about 1 Sv over the period. The cause of this decrease remains an open question, and is an obvious candidate for further research. The fact that the freshwater transport appears to be constant while the volume transport is sinking is another topic to be pursued. It is tempting to relate this to increased liquid freshwater content due to accelerated sea ice melting, but at this stage this remains speculative.

The CTD sections with geostrophic calculations indicate that significant amounts of freshwater transport occur over the shelf region. This is supported by numerical modelling results, which suggests that there is an average transport of roughly 700 km^3/y on the shelf west of the EGC. Our attempts to directly observe this flux have been severely hampered by the loss of two tube moorings and the failure to recover a third due to a positioning error. We will continue the efforts to directly observe the shelf flux during the DAMOCLES project.

The observations were compared with output from the NAOSIM model to assess its ability to calculate the liquid freshwater fluxes through Fram Strait. It was found that the model performs well, reproducing the average level, the seasonal cycle and much of the interannual variability. This is considered to be very promising for further use of the model to explore the causes of the freshwater export variability, not to mention the fate and effect of the freshwater exported to lower latitudes.

Summing the transport over the shelf as estimated from the model, the liquid transport in the EGC as observed by moorings, and the sea ice transport as estimated by Kwok et al (2004) for the 1990-1998 period, the total annual average freshwater transport through Fram Strait sums up to roughly 3900 km^3/y. How much is this? What is the scale of this figure compared to the meridional overturning and larger scale climatic impacts? To get an idea we put it into the context of the remarkable freshening of the Northern North Atlantic since 1965. It is estimated that an extra 19.000 km^3 of freshwater is responsible for the dilution between 1965 and 1995 (Curry and Mauritzen, 2005, Dilution of the northern North Atlantic Ocean in recent decades, SCIENCE 308 (5729): 1772-1774 Jun 17 2005). Of this roughly 4.000 km^3 remained in the Nordic Seas. More than half of the dilution happened during the Great Salinity

Anomaly (GSA) of the late 60ties; about 10.000 km^3 of extra freshwater was added during the GSA. This corresponds to 2.000 km^3/y, which is about half of the average annual freshwater amount exported through Fram Strait. Curry and Mauritzen furthermore estimated that to significantly weaken the northern limb of the MOC an extra 9.000 km^3 of freshwater input to the Nordic Seas would be required. For a full shutdown the number would be 18.000 km^3, although with the present mixing and dilution rates this would take two centuries of constant dilution.

We conclude this report on progress by addressing the deliverables and milestones for WP4:

- Deliverable 4.2: Preliminary data from moored array and repeated sections (due in month 37): OK
- Deliverable 4.3: Calibrated data, calculated fluxes, data reports (due in month 39): OK
- Deliverable 4.4: Time series of model and observations, analysis and interpretation of flux variability (due in month 39): OK
- Deliverable 4.5: Comparison of model and observation (due in month 39): OK

- Milestone (3) (due in month 39): This report, OK
- Milestone (5) (due in month 36): Annual water mass distribution, OK
- Milestone (7) (due in month 24): Annual flow pattern, OK
- Milestone (8) (due in month 39): Freshwater flux variability with variability in space and time, OK

WP 5 'DATA MANAGEMENT'

1. Objectives.

The main objectives on which the activities of WP5 'Data management' were focused during the reporting period are as follow:

1. To achieve a consistent, quality-controlled and publishable set of direct observations (from shipborne and autonomous measurements), derived quantities and principle model outputs.
2. To provide project data to the project scientists.
3. To monitor and report to the Steering Committee on data flow.
4. To achieve access for all project participants and scientific community to electronic information on the project and its aims, on the actual status of field and modelling work and on the data inventory.

The main way to approach these goals included the installation and maintaining of the ASOF-N homepage (Task 5.1), providing the reference material on data matters to ASOF-N participants (Task 5.2) and receive quality-checked data from participants, to catalogue and to distribute them (Task 5.3). Finally, CD-ROM with project data or metadata is under preparation.

2. Methodology and achievements related to WP5 including contributions from partners.

The ASOF-N website has been developed and is maintained by Alfred Wegener Institute and can be found under the link:

http://www.awi-bremerhaven.de/Research/IntCoop/Oce/ASOF/index.htm

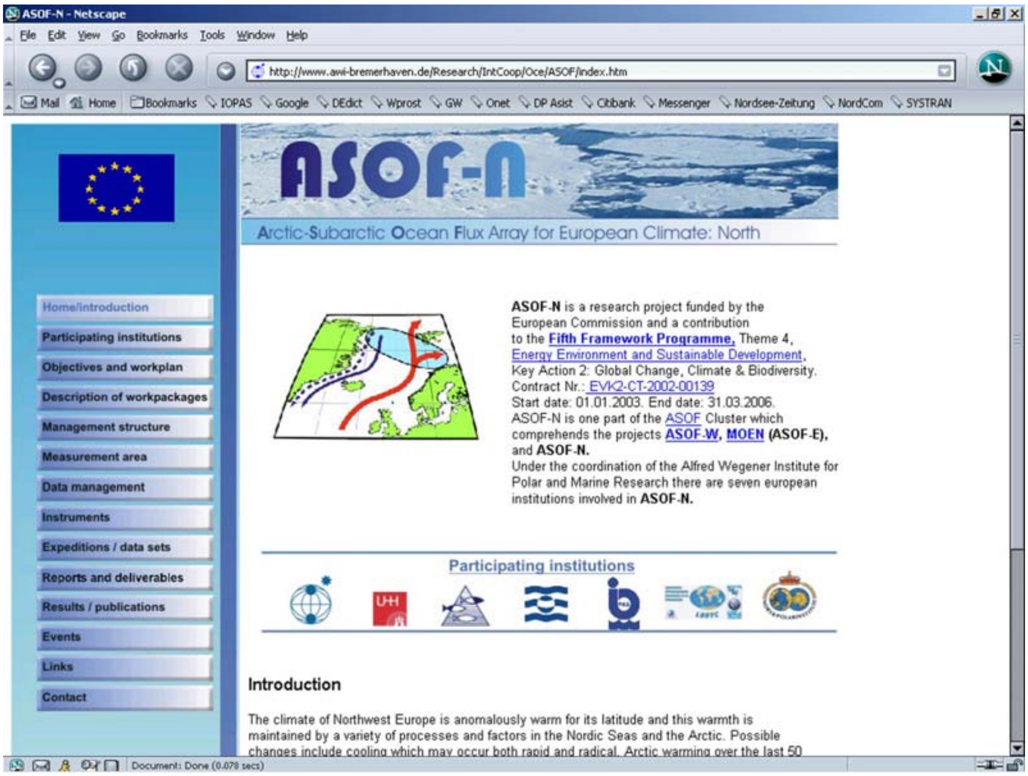


Fig. 5.1: The main page of the ASOF-N webpage as updated in 2005

The webpage includes a general description of the ASOF-N project, its plan and objectives, the detailed descriptions of project workpackages, the management structure and a map of the field investigations. Moreover separate webpages are dedicated to the data management, the description of cruises and instruments used during the performed measurements. Information about the important events related to ASOF-N is presented together with the working links. The reports from ASOF-N meetings and relevant project documents can be downloaded directly from the webpage. A set of useful links to the relevant EU projects and institutions is also included. A separate webpage is dedicated to the ASOF-N results, references and publications and those ASOF-N deliverables which are in a form of report were included also there. The Webpage will be maintained also after the end of the project until end of 2006 and actualized with all final results and produced documentation.

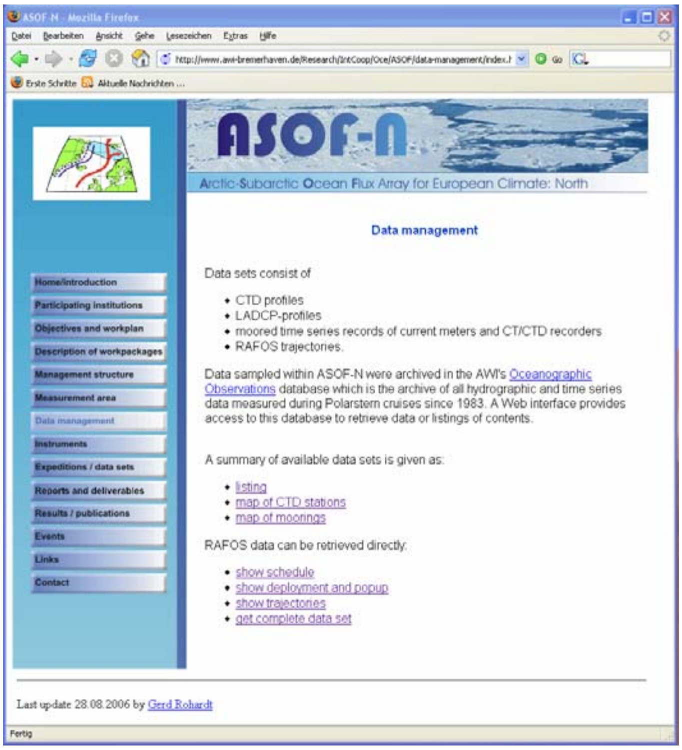


Fig. 5.2: ASOF-N webpage with references on the data management

Reference material on data management in the frame of ASOF-N is presented at the webpage (Fig. 5.2) and was also described in details during the ASOF-N seminar in December 2005 with a practical on-line presentation of the AWI database. Also some examples of the data access by using the tools being found on the AWI web site were also shown:

http://www.awi-bremerhaven.de/OZE/index.html

This demonstrates that the AWI database is suitable to perform the task of the data management using already existing hard and software to archive and provide the ASOF-N data sets. Some software extensions were necessary to implement additional instruments into the database. For example, the new data from LADCP measurements required some modifications in the data base structure. The database is also accessible through the ASOF-N website:

http://www.awi-bremerhaven.de/Research/IntCoop/Oce/ASOF/ data management/index.htm

The "database explorer" is a graphical user interface to retrieve information of existing data sets or download selected data. Software tools for the visualization can be downloaded from **http://www.pangaea.de/Software/**, e.g. ODV - the Ocean Data View - and tools to convert ASCII data files into dedicated data formats.

The list of hydrographic cruises providing data to the ASOF data base is presented in Tab.5.1.

Tab. 5.1: Hydrographic cruises during ASOF-N

Institution	Research vessel	Activities	Time period
2003			
AWI	Polarstern	CTD, ADCP, moorings	21.09.-13.10.03
IFM-HH	Lance	CTD, ADCP, moorings	29.09.-17.10.03
NPI	Lance	CTD, ADCP, moorings	07.09.-27.09.03
IOPAS	Oceania	CTD, ADCP, LADCP	08.06.-19.07.03
IMR	J. Hjort	CTD	16.01.-26.01.03
IMR	J. Hjort	CTD, moorings	08.03.-26.03.03
IMR	Sarsen	CTD, moorings, floats	06.04.-21.04.03
IMR	J. Hjort	CTD, moorings, floats	27.05.-16.06.03
IMR	G.O. Sars	moorings	01.09.-15.09.03
IMR	J. Hjort	CTD	03.10.-05.10.03
2004			
AWI	Polarstern	CTD, ADCP, moorings	16.07.-29.08.04
NPI	Lance	CTD, ADCP, moorings	31.08.-19.09.04
IFM-HH	Lance	CTD, ADCP, moorings	20.09.-12.10.04
IOPAS	Oceania	CTD, ADCP, LADCP	08.06-19.07.05
IMR	J. Hjort	CTD	17.01.-28.01.04
IMR	J. Hjort	CTD	05.03.-08.03.04
IMR	G.O. Sars	CTD	06.04.-12.04.04
IMR	Hakon Mosby	CTD	22.06.-24.06.04
IMR	J. Hjort	CTD, moorings	14.08.-15.08.04
IMR	J. Hjort	CTD	23.10.-24.10.04
2005			
AWI	Polarstern	CTD, ADCP, moorings	13.08-19.09.05
IOPAS	Oceania	CTD, ADCP, LADCP	08.06-18.07.05
NPI	Lance	CTD	18.05-04.06.05
NPI	Lance	CTD, ADCP, moorings	28.08-17.09.05
IFM-HH	Lance	CTD, ADCP, moorings	19.09-11.10.05
IMR	G.O. Sars	CTD	15.01-30.01.05
IMR	Johan Hjort	CTD	01.03-15.03.05
IMR	G.O.Sars	CTD	06.05-08.06.05
IMR	Johan Hjort	CTD	12.08.-14.08.05
IMR	Johan Hjort	CTD, moorings	13.09-18.09.05
IMR	Johan Hjort	CTD	11.10-08.11.05
2006			
IMR	Johan Hjort	CTD	15.01-30.01.06

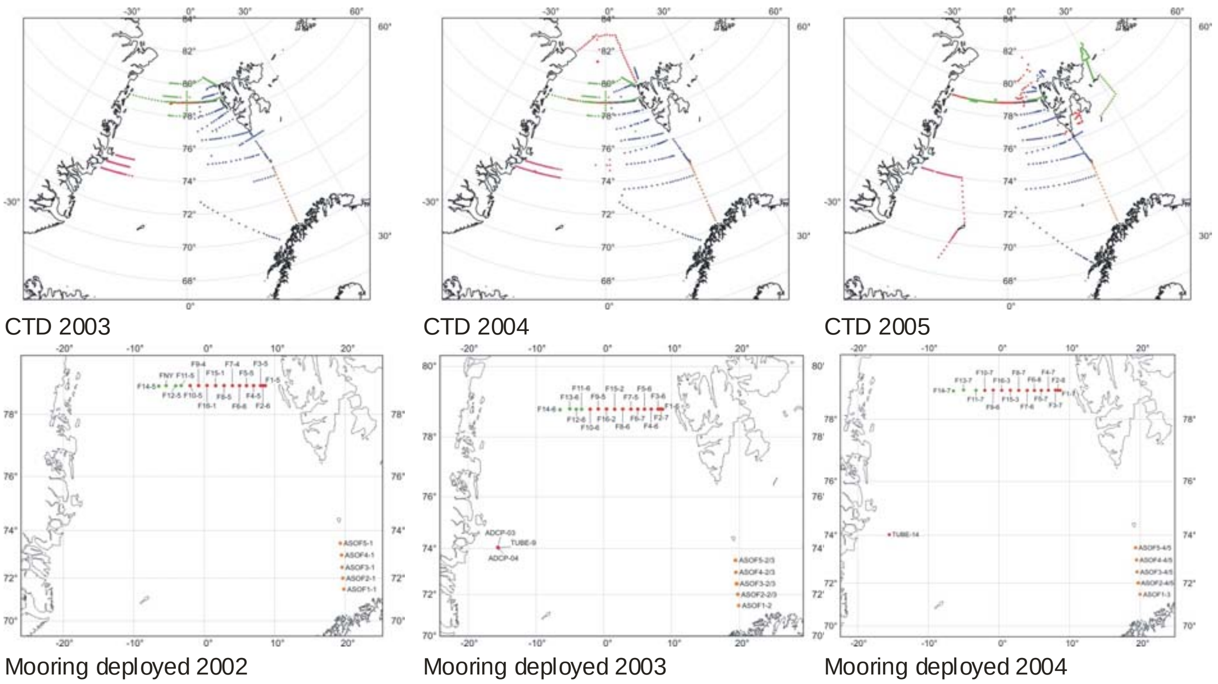


Fig. 5.3: Maps of CTD stations and moorings with data sets available from the project data base

Information about cruises and performed measurements is essential for the ASOF-N community. As soon as delivered by the project participants, this information is listed on the ASOF-N webpage with details on the region of the field work, the research vessel and the measuring equipment. Examples of the required instrument sheets or station listings can be found on the ASOF-N webpage for the Polarstern cruise ARK XIX/4 as well as empty forms to be filled by the project participants:
http://www.awi-bremerhaven.de/Research/IntCoop/Oce/ASOF/instruments/ index.htm.
Presently the ASOF-N cruise reports from 2003, 2004 and 2005 are available on the webpage.

During the ASOF-N meeting in December 2005 all participants were reminded about the requirement to deliver the current information about their field work, achieved results and prepared publications in order to keep the ASOF-N website updated.

Besides storing in the local database, the ASOF-N data are also transferred to the World Data Centre for Marine Environmental Sciences (**http://www.wdc-mare.org**).

For a demonstration the CTD profiles from Polarstern cruise ARK XIX/4 can be loaded from the WDC using the search string “ASOF-N”. This way provides an access to this first and later to all further data sets collected within the ASOF-N project.

3. Plan for the next period.

The main objectives for the third project year were achieved according to the schedule. A consistent, quality-controlled and publishable set of direct observations (from shipborne and autonomous measurements) is available from the project data base, other data set including derived quantities (e.g. fluxes, time variations) and principle model results will be available as metadata. The ASOF-N webpage will be maintained after the project end until end of 2006 to assure the oceanographic community the open access to project results and documentation. The ASOF-N data set from observations will be compiled on a CD-ROM which will be one of the ASOF-N final products.

WP 6 'INTEGRATION AND SYNTHESIS'

1. Objectives.

During third year of the project the work in WP6 was focused on the following tasks:

- analysis of the relationships between the property changes and processes, based on estimates of transport obtained by combination of hydrography, moored instruments and models and determining their strength and impact from both transport observations and model results,
- evaluation of the technical performance of innovative arrays, define minimum data set to describe measured variability and test results from reduced data sets from regional model outputs.

This will serve the following objectives:

- To determine water mass transformations in the Arctic Mediterranean that are the means by which the oceanic heat transported to the Arctic becomes available to the Arctic environment.
- To combine the measurements of property changes at choke points which give evidence of how and how strongly the ocean transports influence the Arctic and how this influence varies with time and atmospheric forcing.
- To evaluate the performance of deployed moorings.
- To design an array of minimum effort and assess the uncertainty.

2. Methodology and scientific achievements related to WP6 including contributions from partners including discussion and conclusions

- **Relationships between property changes and process - synthesis**

The work on the WP6 synthesis has during the last 15 month been concentrated on setting the results of the ASOF-N programme into a larger context. What insights do they give a bout the circulation in the Arctic Ocean? Do they contribute to our understanding of the global thermohaline circulation and the Arctic, and global, climate?

The backbones of ASOF-N are the current meter arrays. Especially Fram Strait but also the Barents Sea Opening are, at least when it comes to volume transports, the most important passages between the Arctic Ocean and the world ocean. How well must these transports balance to conserve volume in the Arctic Ocean? A net inflow to the Arctic Ocean of 0.5 Sv will rise the sea level in the central Arctic Ocean by 0.25 m, or 0.13 m if the same sea level rise takes place on the shelf seas. It is thus not likely that a net in or outflow of that magnitude can persist for periods longer than 2-3 weeks.

Of the four passages two sustain inflows, the Barents Sea and the Bering Strait, which together carry ~ 4 Sv to the Arctic Ocean. Fram Strait is the only passage that has a two-directional flow, but the net transport is generally believed to be southward, out of the Arctic Ocean. During a substantial period (> 1 year) the observations on the array indicated an inflow of 0.5 Sv. This means, if volume is conserved, that 3.5 Sv must exit through the Canadian Arctic Archipelago, the only pure outflow passage. The sill depths in the Canadian Arctic Archipelago are 150 m (Lancaster Sound) and 230 m (Nares Strait) and all the outflowing water has to be drawn from the upper, low salinity Polar water. Moreover, during the same time Fram Strait will also export about 1 Sv of low salinity Polar water to the Nordic Seas. The outflow from the upper layers is thus twice the normal outflow and since the residence time of the upper Polar water is about 10 years one year would reduced the upper layer by 10%. Alternatively the inflowing Atlantic water has to be sufficiently diluted by ice melt to pass through the Archipelago, which means that ice must be melted and mixed into the

Atlantic water at a rate of 0.1 Sv. This would reduce the ice thickness by 20% in one year. None of these scenarios appear likely and the most natural situation is that a net outflow is present in Fram Strait. This is also what is found during most of the time from the current meter array, giving a mean outflow of 0.6 Sv. As a comparison, the mean outflow from geostrophic computations was estimated to 2.5 Sv.

Many of the difficulties with assessing the exchanges through Fram Strait arise from the strong barotropic velocities, the eddies, baroclinic as well as barotropic, present in the strait and the large scale circulation between the West Spitsbergen Current and the East Greenland Current. One way to avoid these difficulties is to deploy a mooring array in the boundary current north of Svalbard. This was not attempted in ASOF-N. However, in spring 2002 IB Oden took 2 sections north of Fram Strait: One from Nordaustlandet through the Sofia Deep and across the Yermak Plateau into the Nansen Basin and the other from west of the Yermak Plateau along $81^{o}20'$N onto the Greenland shelf. The eastern section covered both inflow streams, the one close to Svalbard and the outer stream outside the Yermak Plateau. The deeper part of the outer stream was also observed circulating around the Sofia Deep and joining the inner stream at the slope. The inflow was found to be considerably smaller than in Fram Strait, around 3 Sv. On the western sections all velocities were towards the south and the total transports about 5 Sv. The Atlantic water characteristics indicated water returning from the interior of the Arctic Ocean and in the intermediate water range, in contrast to the eastern section, no SF_6 from the tracer release experiment in the Greenland Sea in 1996 was found, which indicated Arctic Ocean water masses. SF_6 was present on the eastern section showing that Arctic Intermediate water enters the Arctic Ocean in the boundary current (Marnela et al., submitted).

To examine the freshwater budget of the Arctic Ocean and of the Arctic Mediterranean Sea the freshwater fluxes were determined relative to a salinity of 35.2 (Dickson et al., submitted). This choice, the salinity of the inflowing Atlantic water to the Arctic Mediterranean, makes the volume transports and the freshwater transports move in the same directions at all levels, which simplifies the tracking of the freshwater. Furthermore, it also allows the freshwater, which is injected into the denser water masses and exported as overflow waters into the North Atlantic, to be taken into account. This freshwater export is considered to have the potential to weaken the thermohaline circulation.

To remove the dependence of freshwater transports and heat transports on reference salinity and temperature the system must be closed and the mass balance for the Arctic Ocean established. However, in view of the dominance of the Fram Strait exchanges as compared to the fluxes through the other passages experiments were conducted with the reference salinity and the reference temperature varying in time. Geostrophically computed transports for each available section were used. At each section the mean inflow salinity was chosen as reference salinity and the mean outflow temperature as reference temperature. The inflow then carries no freshwater and the outflow carries no heat. By also using the net outflow volume and the outflow temperature and the inflow salinity it is possible to separate, mentally, the freshwater flux into one part diluting the Fram Strait inflow and the other part as an added low salinity volume originating elsewhere. Possible sources for these two contributions can then be examined. In the same manner the heat transport into the Arctic Ocean can be seen partly as a cooling of the inflowing Fram Strait water column, partly as a heating of the net outflow volume to the mean outflow temperature, since most of the Polar water that is leaving the Arctic Ocean through Fram Strait and not originating from Fram Strait has been cooled, mostly to freezing temperature inside the Arctic Ocean. By examining in more detail these different heat sinks a somewhat clearer picture of the heat balance might evolve. Some results are presented in this final report Section 6.

Another feature of the circulation, and of the heat budget, is that pulses of warm Atlantic water can be followed entering the Arctic Mediterranean, passing through the Norwegian Sea. Some water moves into the Barents Sea, while the rest continues to Fram Strait, where it partly recirculates, partly enters the Arctic Ocean. Also in the Arctic Ocean these pulses can be followed in the boundary current along the continental slope. They bifurcate at the different ridges and enter the gyres of the different basins. The pulses thus become spread out and their residence time in the Arctic Ocean may range from one or a few years in the Nansen Basin to perhaps 20-30 years for the grand tour around the Canada Basin.

The third leg of the Beringia expedition, when IB Oden together with the USCGC Healy crossed the Arctic Ocean, passing through all the major basins, offered a unique opportunity to study the progress of the different warm water pulses that have entered the Arctic Ocean during the last 20 years. The first reported pulse (Quadfasel et al., 1991) had reached the southern Canada Basin beyond the Chukchi Cap. It had also entered the northern Canada Basin at the Chukchi Cap and was found to have circulated around the Makarov Basin and was now returning towards Siberia along the Lomonosov Ridge. On the other side of the Lomonosov Ridge and in the Amundsen Basin it had already disappeared, being advected towards Fram Strait. These findings have also been reported by others: Shimada et al. (2004), Smethie et al. (2000), Kikuchi et al. (2005). The Oden cruise also indicated that at least two more warm pulses were moving within the Eurasian Basin. The oldest one had already been observed at the NABOS array north of the Laptev Sea (Dmitrenko et al., 2005) and likely derived from the warm inflow observed at the VEINS/ASOF array in 1999 and 2000 (Schauer et al., 2004). The second pulse was observed just north of Nordaustlandet and probably originates from the warm inflow reported in 2004 (WP3).

The fact that the warm pulses can be identified and followed from the North Atlantic through the Nordic Seas and within the Arctic Ocean rises the question – will the warmer water increase the oceanic heat flux to the Arctic environment, e.g. lead to increased ice melt, or will they just temporarily increase the heat content in the Atlantic layer and then again be exported to the Nordic Seas and the North Atlantic? A question, which has to be answered to assess the importance of the variability of the ocean heat fluxes.

Geostrophical computations of the transports in Fram Strait have also been made for the existing sections up to 2005, the last ASOF section. These transports were used to estimate the heat and freshwater fluxes with a varying reference temperature and salinity and also to determine the variability of the transports and characteristics of the different water masses. The net transports were consistently southward (2.5 Sv) and somewhat larger than the mean net flow found from the current meter array. The geostrophic transports were smaller than those obtained by direct current measurements but not alarmingly so. The volume transports compared fairly well but the mean heat transport 25 TW was about 60% of that obtained from direct current measurements. The mean export of liquid freshwater (0.04 Sv) was similar to that found from the observations of the freshwater transports in WP4. The mean freshwater transport over the shelf obtained from the geostrophic calculations with velocity zero at the bottom on the few sections extending across the shelf was 0.025 Sv. If this is added to the freshwater transport estimated on the standard section, the export of liquid freshwater becomes 0.065 Sv, about 75% of the ice export. Results from these computations are shown in this report in Annex 1.

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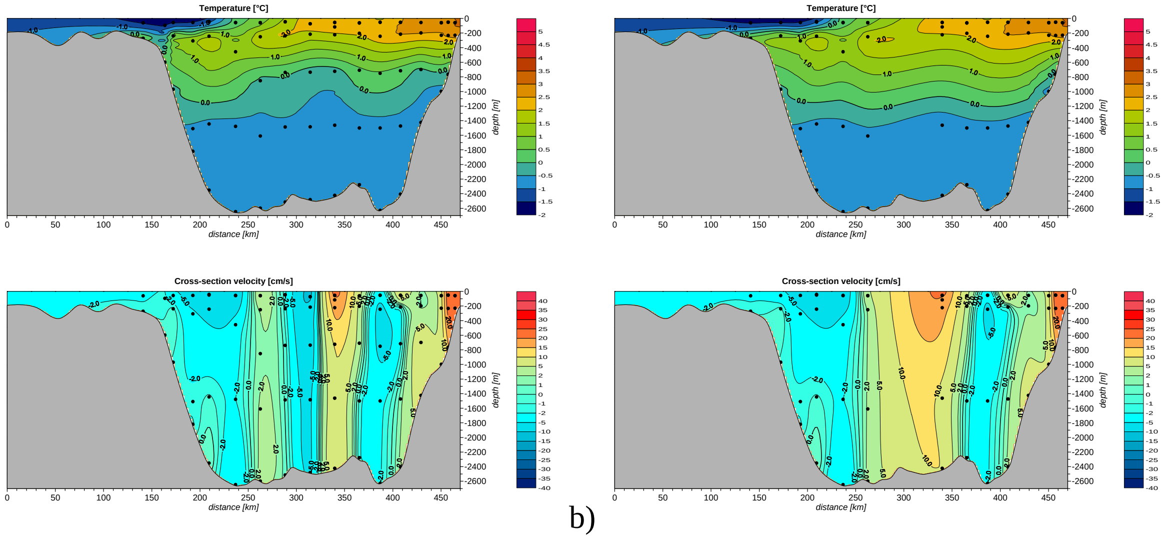
- **Evaluation of performance of deployed moorings and recommendations for a design of the optimised array**

The long term consolidated data sets necessary to determine the variability of the freshwater and heat fluxes between the Arctic Ocean and the North Atlantic require an innovative design of the cost effective and well calibrated measurement arrays. The northward flow of the Atlantic water carrying heat into the Arctic Ocean has to be monitored in two main gateways, the eastern Fram Strait and Barents Sea Opening. The southward freshwater flux which enters the Nordic Seas both as liquid water and sea ice needs to be measured across the western Fram Strait, including the wide shelf east of Greenland. The latter requires current measurements and salinity stratification in shallow depths as well as ice thickness and velocity. To monitor fluxes, not only the large cross-sections of the gateways have to be covered by measurements but also intensive variations on a wide range of scales, revealed by earlier observations have to be resolved. Thus a larger number of moorings and instruments is needed or integral methods, measuring the whole water column have to be used.

During ASOF-N observational arrays in Fram Strait and Barents Sea Opening were augmented and optimised in accordance with the observed time-space variability of measured parameters. Newly developed instruments were installed in the moorings, the observational arrays were redesigned for optimal combination of various properties, transport estimates were proposed based on empirical relations to selected instruments. To secure data collected under harsh environmental conditions the possibility of the near real-time data transfer via satellite link with pop-up buoys was tested. To complement the observing system of mooring arrays a grid of hydrographic stations was designed and repeated every summer to get the spatial variability of the Atlantic water pathways.

The Fram Strait mooring array was optimised to achieve better performance in measurements of temperature, salinity, currents and ice thickness - a prerequisite to derive heat and freshwater fluxes.



a) b)

Fig. 6.1: Temperature and cross-section current distribution in May 2003 obtained (a) for the ASOF set-up of instrumentation and (b) after subsampling data points to preASOF set-up. Monthly means of volume and heat transport are given for each case.

In the eastern and deep part of the strait additional instruments were added at the depth of ca 750 m to resolve the lower boundary of the Atlantic water layer. Two new moorings were placed in the deep part of the strait to resolve the recirculation patterns of the Atlantic water and thus to reduce the error in volume transport estimates. An example of improvement in resolved temperature and current fields is shown on figure 6.1. On the panel (a) distributions of temperature and cross-section current velocity is obtained from the optimised data set from ASOF deployment, on the panel (b) the full data set was subsampled to the preASOF distribution of instruments. Two most prominent features are: much better resolved lower boundary of the Atlantic water (represented by the depth of isotherm 0°C) and bi-directional flow structure in the deep area, which was not resolved by the preASOF array.

Tab. 6.1 Comparison of volume and heat transport calculated for the optimised ASOF deployment in 2002-2003 with new set-up of instruments (ASOF columns) and the same data set but subsampled only to the preASOF set-up (preASOF columns).

Year	**Month**	**Northward Volume Transport [Sv]**		**Southward Volume Transport [Sv]**		**Net Volume Transport [Sv]**		**Northward Heat Transport [TW]**		**Southward Heat Transport [TW]**		**Net Heat Transport [TW]**	
		pre ASOF	**ASOF**	**pre ASOF**	**ASOF**	**pre ASOF**	**ASOF**	**pre ASOF**	**ASOF**	**pre ASOF**	**ASOF**	**pre ASOF**	**ASOF**
2002	**9**	13.2	10.8	-8.6	-9.3	4.6	1.4	86.4	69.4	-16.0	-17.7	70.4	51.6
2002	**10**	12.4	9.1	-8.2	-11.9	4.2	-2.8	84.5	70.1	-24.6	-26.6	59.9	43.5
2002	**11**	8.2	12.2	-15.5	-12.8	-7.2	-0.6	74.0	79.7	-73.7	-40.1	0.3	39.6
2002	**12**	9.4	8.1	-6.3	-6.7	3.1	1.5	72.0	61.3	-16.3	-14.8	55.7	46.5
2003	**1**	7.8	8.5	-9.4	-10.5	-1.6	-2.1	60.8	55.3	-12.3	-5.9	48.6	49.5
2003	**2**	17.2	13.0	-9.7	-12.5	7.5	0.4	60.5	48.9	-16.1	-15.4	44.5	33.5
2003	**3**	15.8	14.9	-15.7	-17.5	0.1	-2.6	44.3	41.0	-20.2	-17.2	24.1	23.8
2003	**4**	21.5	14.9	-10.1	-12.4	11.4	2.6	64.6	46.1	-17.2	-13.1	47.4	33.0
2003	**5**	27.2	12.3	-7.6	-11.7	19.7	0.6	73.3	32.0	-11.4	-15.8	61.9	16.2
2003	**6**	18.6	9.5	-7.6	-7.9	11.0	1.6	73.7	38.1	-11.5	-9.7	62.3	28.4
2003	**7**	13.6	12.3	-10.0	-10.9	3.6	1.5	47.0	43.3	-13.9	-10.5	33.1	32.8
2003	**8**	29.6	15.3	-12.6	-12.7	17.0	2.6	128.4	75.2	-28.7	-23.6	99.7	51.6
Mean		**16.2**	**11.7**	**-10.1**	**-11.4**	**6.1**	**0.3**	**72.5**	**55.0**	**-21.8**	**-17.5**	**50.6**	**37.5**
STD		**6.9**	**2.6**	**2.9**	**2.8**	**7.4**	**1.9**	**24.2**	**15.8**	**17.5**	**9.1**	**24.6**	**11.5**

Comparison of volume and heat transports calculated as on figure 6.1 for the first ASOF deployment in 2002-2003 and for the data set subsampled to the preASOF set is given in table 6.1. A strong overestimation of the northward volume transport for the preASOF data set was due to not resolved flow structure in the deep part of Fram Strait and together with too thick Atlantic water layer resulted in significantly overestimated heat transport. Standard deviations of the monthly mean transports decreased strongly for the ASOF deployment as compared to the estimate for the preASOF period, in particular for the net volume transport from 7.4 Sv for the preASOF set-up to 1.9 Sv for the ASOF set-up. Also standard deviation of the net heat transport was lower by more than a half. This is an obvious proof that the optimized array was able to capture spatial variability of the flow and temperature to much better degree than the old version of the Fram Strait array. Both ASOF measurements at the moored array and model studies showed that in Fram Strait most of the heat transport variability can be captured by monitoring the eastern part of the strait, the West Spitsbergen Current domain (see results from WP3). However, to achieve reliable estimate of the volume transport variability, the recirculation in the deepest part of the strait has to be properly resolved. The EOF analysis of the current field revealed a strong coherence in vertical and dominating patterns of opposite, vertically uniform flows related to te bottom topography which can represent the pattern of barotropic circulation under varying atmospheric forcing.

In addition to the moorings, the integral measurements were performed with the use of bottom pressure recorders (BPR) and inverted echo sounders with pressure sensors (PIESs) to estimate the barotropic currents and heat content of the water column. The results from the bottom pressure recorders (BPR) and pressure inverted echo sounders (PIES) showed that they are able to capture the relevant range of the pressure variations and thus the resulting changes in the barotropic flow. Due to the highly barotropic character of the currents in Fram Strait, the bottom pressure recorders can be used to derive bottom pressure gradients between moorings and further to estimate barotropic currents. Variations of the vertical mean temperature, which are reflected in the sound velocity, result in variations of the acoustic two-way travel time. From the AOSF deployment of three PIES, the comparison of a vertical mean temperature measured at the neighboring mooring and a travel time measured by PIES revealed very high correlations for all three locations. Since changes in mean temperature are closely related to changes of the heat content, thus it is expected that changes in the heat transport can be captured by the inverted echo sounders. A description of first results from BPR and PIES measurements is given in the WP3 results presented in this section.

The performance of different current meters and TS sensors during the long-term deployments was evaluated and unreliable instruments were replaced to achieve the highest data recovery rate and the best data quality. The freshwater part of the mooring array in the western Fram Strait was equipped with near surface salinity sensors. Tube moorings in combination with Acoustic Doppler Current Profilers (ADCPs) were successfully deployed on the shelf, to great extent surviving the extensive ice cover and drifting icebergs.

The moorings in the Barents Sea Opening were combined with a high resolution hydrographic section repeated six times per year. Additionally this moored array was augmented with two bottom-mounted ADCPs in shallow parts. A new strategy was used for tracking the Atlantic water pathways based on combination of moorings, floats and hydrographic sections. The hydrographic sections included not only standard CTD casts but also currents profiles which were measured by the lowered ADCP and quasi-continuously by the vessel-mounted ADCP. The grid of stations was adjusted to optimise the coverage of spatial structures.

The detailed description of the performance of moored arrays and results of sensibility study to instrument reduction is given by Deliverables 6.3 and 6.5.

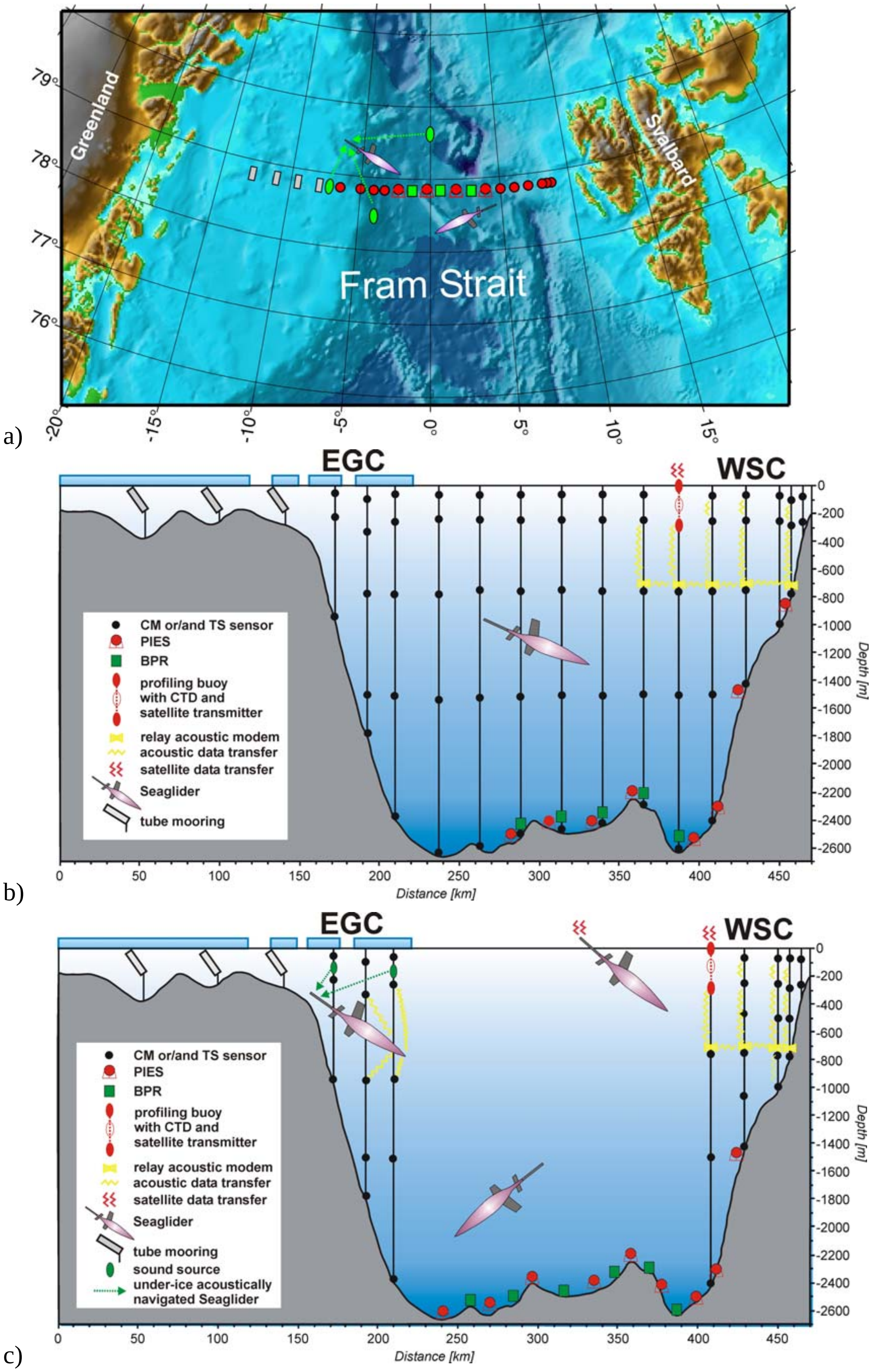


Fig. 6.2 The optimised observing system proposed in DAMOCLES on a basis of the ASOF-N recommendations. (a) A spatial scheme of moorings, bottom-mounted instrumentation and Seagliders, (b) a design of the array for the test phase in 2007-2008 with moorinngs in the central part of Fram Strait and (c) a design of the array for the operational work after the thest phase.

The recommendations for the optimised system were worked out from the results and experience achieved in the ASOF-N project and a design of the optimal observational arary was proposed. The observational array in Fram Strait for the DAMOCLES EU project was planned for the test phase and for the operational work (Fig. 6.2). For the test phase the set-up shown on figure 6.2b will be established. During this period the optimised ASOF array design will be kept and additionally the acoustic data transfer between moorings via relay modems will be tested. Data collected by different instruments will be transferred to the central mooring, equipped with the profiling top with CTD sensors and satellite transmitter and in the next step sent via Iridium link to the ground station in the near-real time. In addition the quasi-continuous CTD cross-sections through the Fram Strait will be performed by the Seaglider. With the help of Seagliders temperature and salinity distribution in the deep part of Fram Strait will be measured with a horizontal resolution significantly higher than with moorings (what was recommended by the ASOF experience) and with sufficient time resolution to resolve the seasonal cycle. Additionally the Seaglider will provide temperature and salinity profiles that extend to the ice-ocean interface over the full transect. However the Seagliders will not operate on the shelf where acoustic ranging is difficult. On the western shelf moorings will include sensors in tubes, designed to sample and survive near the interface. The gliders will be equipped with acoustic modems to serve for near real time data acquisition from the moorings. In the open water gliders will be controlled by Iridium communication while in the ice-covered part a triangle of RAFOS sounf sources will be used for navigation and data recovery. The intergral measurements of barotropic currents, mean temperature and heat content will be continued with a wide set of bottom mounted PIES and BPR. For the operational work after the tesing phase (Fig. 6.2c) the moorings in the central part of Fram Strait will be replaced by a set of bottom instruments, PIES and/or BPR, located in positions optimised for capturing the realistic variability of mean temperature and flow fields. More Seagliders will be introduced to serve as data messengers for instrumentation in the ice covered area as well as to provide vertical distributions of temperature and salinity with the high spatial resolution.

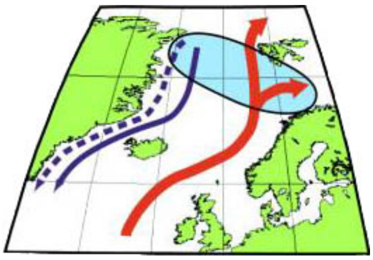
A design of such a technologically highly advanced observational system in the wide and deep passage with the complicated circulation and very tough atmospheric and ice conditions was feasible only due to the wide experience and detailed results gained during the ASOF-N project. Three years of the project have yielded a significant step forward to build the important component of the Arctic Optimised Observing System (AOOS).

ASOF-N

Arctic-Subarctic Ocean Flux Array for European Climate: North

Contract No:
EVK2-CT-2002-00139

FINAL REPORT



Section 4

Technological Implementation Plan

Energy,
Environment
and Sustainable Development

Fifth
Framework
Programm

4. Technological Implementation Plan

Description of project

EC PROGRAMME:	**EESD**
PROJECT TITLE:	Arctic-Subarctic Ocean flux array for european climate: North
ACRONYM:	ASOF-N
PROGRAMME TYPE:	5th FWP
CONTRACT NUMBER:	EVK2-CT-2002-00139
PROJECT WEB SITE (if any):	http://www.awi-bremerhaven.de/Research/IntCoop/Oce/ASOF/
START DATE:	01 Jan 2003
END DATE:	31 Mar 2006
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Commission Officer Name:	Dr. Georgios T. Amanatidis

Executive summary

Original research objectives

The climate of Northwest Europe is anomalously warm for its latitude and this warmth is maintained by a variety of processes and factors in the Nordic Seas and the Arctic. Possible changes include cooling which may occur both rapid and radical. Arctic warming over the last 50 years was three times stronger than the global increase of surface temperatures. ASOF-N, one part of the ASOF cluster, aims at understanding the controlling processes of climate change in the high latitude North Atlantic. To improve and validate models with a predictive power needed for the assessment of the socio-economic consequences of the potential changes which are already obvious in the Arctic, time series of oceanic parameters are required over time scales of decades. ASOF-N aims to advance the installation of a suitable cost effective component of a global ocean observation system in choke points of the oceanic circulation.

Expected deliverables

- D 1.1 Status report of existing data
- D 1.2 Status report of float deployment
- D 1.3 Calibrated float data, current fields
- D 1.4 Preliminary data from hydrographic surveys
- D 1.5 Calibrated data, T/S and ADCP current fields
- D 1.6 Merged modeled and observed fields of currents and water mass properties
- D 2.1 Status report of existing data
- D 2.2 Preliminary data from CM
- D 2.3 Preliminary data from repeat sections with CTD and ADCP
- D 2.4 Calibrated data, Analysis of time series and historical data
- D 2.5 Estimates of fluxes of volume, heat and salt
- D 2.6 Comparison of modelled and measured fluxes
- D 3.1 Status report of existing data
- D 3.2 Preliminary data from moored array and repeated sections (CM, DCM, ADCP, CTD)
- D 3.3 Calibrated data, calculated fluxes, data reports
- D 3.4 Time series of models and observations, analysis and interpretation of flux variability
- D 3.5 Comparison between model and observed statistics of the heat flux
- D 4.1 Status report of existing data
- D 4.2 Preliminary data from moored array and repeated sections (CM, ULS, DCM, ADCP, CTD)
- D 4.3 Calibrated data, calculated fluxes, data reports
- D 4.4 Time series of models and observations, analysis and interpretation of flux variability
- D 4.5 Comparison of model and observations
- D 5.1 ASOF-N-www-homepage installed
- D 5.2 Reference material on data matters provided
- D 5.3 Data-inventories, project data, historical data
- D 5.4 Project CD-ROM

Project's actual outcome

All deliverables listed above were submitted.
One outstanding achievement of ASOF-N was the estimation of the exchange of water masses between the Arctic and Atlantic Ocean. This has never been done before and is an important contribution towards understanding the impact of climate change on the Arctic ocean. In addition the optimisation of the observing system necessary to monitor oceanic fluxes in the Fram Strait and the western Barents Sea contributes to more accurate measurements and a better understanding of oceanic fluxes in this area. The optimised observing system is an outcome of ASOF-N that will be used in all follow-up projects.

Broad dissemination and use intentions for the expected outputs

The scientific achievements made during ASOF-N are disseminated in peer reviewed scientific publications. A total of 22 papers have been published in high ranking scientific journals and a further 10 are estimated to be published within the next three years. Additionally, results were presented and discussed with fellow scientists at various conferences. Final results of the ASOF-N project will be presented to a broad audience at the European Geosciences Union General Assembly 2006 in Vienna. The ASOF-N data will be also accessible on request via AWI's Internet database: www.awi-bremerhaven.de/OZE

ASOF-N is integrated in the ASOF cluster with ASOF-EC(E) and ASOF-EC (W) which measured exchanges of water further south. The results from ASOF-N will be merged with results from these projects and will be also incorporated into the Arctic-Subarctic Ocean study (ASOF international). The outcome of these projects will be presented in a joint publication.

This book is planned to comprise 31 chapters and will cover: i) the Subarctic seas as source of Arctic change, ii) the freshwater flux from the Northern seas as a moderator of the Atlantic Meridional Overturning Circulation, iii) the dense water overflows of the Northern seas as drivers of the Atlantic Meridional Overturning Circulation and iv) the receiving volume of the Labrador Sea as well as a concluding chapter. Integrated results of the projects as well as details about the book will be discussed at the ASOF conference in June 2006 in Faroe Islands.

Furthermore consortium members of all three EU projects will join the activities and integrate the results within IP DAMOCLES to increase the understanding of oceanic fluxes in the Arctic and Northern Seas and expand the results to studying interactions of oceanic fluxes with ice and air. ASOF-N results will be also used within various activities for the International Polar Year (IPY) and several nationally funded projects.

The ASOF-N consortium was also very active in disseminating the results to politicians and stake holders. Results from ASOF-N and the EU-funded preceding projects VEINS and MAIA gave background information to the scientific report from the Arctic Climate Impact Assessment (ACIA) published in 2005. ACIA is an international project of the Arctic Council and the International Arctic Science Committee (IASC), to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. The Arctic Council is a high level intergovernmental forum of the following member states: Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States of America. The ASOF-N results are included into reports to ICES (the International Council for the Exploration of the Sea), which gives advice to the member countries and helps them manage the North Atlantic Ocean and adjacent seas. The results are included in reports presented at different ICES working groups like Working Group on Oceanic Hydrography (WGOH) and Arctic Fishery Working Group (AFWG), and during the last two years were also included in overall ICES assessment reports. In addition stake holders were informed about ASOF-N results e.g. by distributing a leaflet during an aquaculture exhibition in Norway. The dissemination activity was lead by the Institute of Marine Research in Bergen, Norway. Meetings with politicians were held by ASOF-N members from the IMR, NPI and IOPAN to assure the dissemination of results. Strategies for future research were developed in the frame of ICARP II (International Conference on Arctic Research Planning II) and AOSB (Arctic Ocean Sciences Board). In the frame of the Arctic Science Summit Week held in Potsdam early 2006, journalists were briefed about challenges and results of Arctic research.

TV documentaries shot during one of the ASOF-N cruises and a radio interview disseminated the ASOF-N project to the general public. In addition ASOF-N members had open institute or open ship days and gave lectures to pupils and students.

Overview of all your main project results

No.	Self-descriptive title of the result	Category A, B or C*	Partner(s) owning the result(s) (referring in particular to specific patents, copyrights, etc.) & involved in their further use
1	Heat Flux through Fram Strait calculated from high-resolution year-round measurements and from hindcasts with the NAOSIM model	A	Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung Institute of Oceanology PAS
2	Freshwater Flux through Fram Strait during 2003-2005 as measured during ASOF-N	A	Norwegian Polar Institute Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung
3	Heat Flux in the Western Barents Slope measured from 2003-2005 during ASOF-N	A	Institute of Marine Research
4	Inflow of Atlantic water into the Nordic Seas measured during ASOF-N from 2003 to 2005	A	LOCEAN (Laboratoire d'Oceanographie et du Climat) Institute of Oceanology PAS
5	Dissemination of results from oceanographic measurements in the Ocean between northern Norway, Spitsbergen and Greenland to decision takers	A	Institute of Marine Research
6	Data and data management of CTD profiles and mooring	A	Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung Norwegian Polar Institute Institute of Marine Research Institute of Oceanology PAS LOCEAN (Laboratoire d'Oceanographie et du Climat)
7	Exchanges of volume, heat and freshwater between the Atlantic and the Arctic Ocean	A	Finnish Institute of Marine Research Institute of Oceanology, Polish Academy of Sciences Norwegian Polar Institute Institute of Marine Research LOCEAN (LABORATOIRE D'OCEANOGRAPHIE ET DU CLIMAT) Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung
8	The optimised observing system for monitoring oceanic fluxes in Fram Strait and western Barents Sea	A	Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung Finnish Institute of Marine Research LOCEAN (Laboratoire d'Oceanographie et du Climat) Institute of Marine Research Norwegian Polar Institute Institute of Oceanology PAS
9	Data of Lagrangian floats deployed in the Norwegian Sea during the years 2002-2005	A	LOCEAN (LABORATOIRE D'OCEANOGRAPHIE ET DU CLIMAT)

*A: results usable outside the consortium /B: results usable within the consortium /C: non usable results

Quantified Data on the dissemination and use of the project results

Items about the dissemination and use of the project results (consolidated numbers)	Currently achieved quantity	Estimated future* quantity
Product innovations	1	1
Process innovations	1	1
New services (commercial)	0	1
New services (public)	1	1
New methods	2	2
Scientific breakthrought	22	10
Technical standards to which this project has contributed	0	0
EU regulations/directives to which this project has contributed	0	0
International regulations to which this project has contributed	3	3
PhDs generated by the project	0	1
Grantees/trainees including transnational exchange of personnel	3	5

* "Future" means expectations within the next 3 years following the end of the project

Comment on European Interest

Community added value and contribution to EU policies

European dimension of the problem

ASOF-N contributed to understanding the processes that control the transports of warm and salty waters toward the Arctic Ocean and of cold, fresh water and sea ice to the Nordic Seas. This understanding is a prerequisite to predict possible effects of “global warming” on the climate in Northern Europe and to mitigate these effect. The EC decided to foster a European GOOS (Global Ocean Observing System) component, the necessity of which was agreed in the UN FCCC. A measurement array was developed during ASOF-N that is able to monitor cost effectively oceanic fluxes at sufficient resolution. It will permit to establish this well calibrated array as an Arctic component of the European contribution to GOOS. The region covered by the ASOF-N includes very productive fishing grounds, where environmental changes have direct effects on commercial fish stocks, and where a sustainable fishery is of central importance. The region is also of interest as a depository of fossil fuels.

Contribution to developing S&T co-operation at international level. European added value

ASOF-N was integrated in a project cluster of ASOF(EC)W and E and an international component with partners from the US and Canada. The close cooperation between the projects, (project meetings were usually attended by a representative of the cluster) eased the identification of appropriate partners for further studies and contributed to the development of expertise in this research area. The collaboration during joint ASOF-N cruises improved the transfer of methods and know-how. The valuable data sets created during ASOF-N add to the time series generated by previous projects in the region. These data series are the key to understanding the longer time scale variability of the fluxes and their implications. Such effort can only be carried out at the community level and will be continued with IP DAMOCLES which started in 12/2005. The international scientific cooperation will be intensified during the International Polar Year (IPY), an interdisciplinary study of the polar system.

Contribution to policy design or implementation

Results from ASOF-N provided background information to the scientific report from ACIA published in 2005. (details about ACIA, ICES see dissemination and use intentions) and are included into reports to ICES working groups (WGOH, AFWG) and the overall ICES assessment reports. ASOF-N also contributed, by developing an optimised observing system, to the establishment of an European GOOS component, the necessity of which was agreed in the UN Framework Convention on Climate Change (FCCC)and further stressed in the Gleneagles Plan of Action 2005. ASOF-N results are also expected to be communicated to the IPCC (Intergovernmental Panel on Climate Change) through Prof. Lemke (AWI senior scientist and lead author of IPCC 4th Assessment Report). The importance of the IPCC was stressed in the Gleneagles Plan of Action and the analysis of research being undertaken to complete the 4th Assessment report was welcomed in order to manage the impact of climate change.

Contribution to Community social objectives

Improving the quality of life in the Community:

The ASOF-N region includes some of the world's most productive fishing grounds, where climate changes have direct effects on the growth, distribution and food consumption of commercial fish stocks, and where a sustainable fishery is of central importance for the socio-economic conditions of European nations. ASOF-N contributes to the development of a system to monitor environmental change, which could be used to develop a predictive capability to anticipate changes in fish stocks. ASOF-N took a first step towards understanding the regional effects of global change. Reliable predictions of climate change will help implementing adaptation and mitigation measures and ensure employment in sectors likely to be effected (e.g. fisheries, aquaculture, agriculture, oil drilling and transport). The quest to understand our environment is part of our culture and ASOF-N advanced the understanding of the poorly understood Arctic environment.

Provision of appropriate incentives for monitoring and creating jobs in the Community (including use and development of skills):

During ASOF-N all involved scientists continued to improve their expertise and skills, thereby improving chances for future employment. One key aspect in skill development was the involvement of the SME Optimare. The skills acquired during ASOF will improve the competitiveness of this company.

Supporting sustainable development, preserving and/or enhancing the environment (including use/conservation of resources):

ASOF-N contributed to developing predictive capabilities which will reliably anticipate changes in fish stocks. Such a system together with understanding the ocean fluxes are needed for a sustainable use of the productive fishing grounds in these regions. Such an understanding is also necessary to evaluate options and risks of oil drilling and transport activities. In order to conserve such a unique environment as the Arctic a sound understanding of the processes and driving forces of water transport, ice formation and their reaction to climate change is necessary.

Development of an Arctic Ocean Observing System: A measurement array was developed during ASOF-N that is able to monitor cost effectively oceanic fluxes at sufficient resolution. It will permit to establish this well calibrated array as an Arctic component of the European contribution to GOOS.

Expected project impact (to be filled in by the project coordinator)

EU Policy Goals	I SCALE OF EXPECTED IMPACT OVER THE NEXT 10 YEARS -1 0 1 2 3	II other Not applicable to project	 Project Impact too difficult to estimate
1. Improved sustainable economic development and growth, competitiveness	0	√	
2. Improved employment	1		
3. Improved quality of life and health and safety	1		
4. Improved education	1		
5. Improved preservation and enhancement of the environment	0		
6. Improved scientific and technological quality	3		
7. Regulatory and legislative environment	1		
8. Other	3		

1. Economic development and growth, competitiveness	Scale of Expected Impacts over the next 10 years (2) By Project End -1 0 1 2 3	 After Project End -1 0 1 2 3
a) Increased Turnover for project participants - national markets		
b) Increased Turnover for project participants - international markets		
c) Increased Productivity for project participants		
d) Reduced costs for project participants		
e) Improved output quality/high technology content		

2. Employment	Scale of Expected Impacts over the next 10 years (2) By Project End -1 0 1 2 3	 After Project End -1 0 1 2 3
a) Safeguarding of jobs	1	1
b) Net employment growth in projects participants staff	1	2
c) Net employment growth in customer and supply chains	1	1
d) Net employment growth in the European economy at large	0	0

3. Quality of Life and health and safety	Scale of Expected Impacts over the next 10 years (2) By Project End -1 0 1 2 3	 After Project End -1 0 1 2 3
a) Improved health care	0	0
b) Improved food, nutrition	1	1
c) Improved safety (incl. consumers and workers safety)	0	0
d) Improved quality of life for the elderly and disabled	0	0
e) Improved life expectancy	0	0
f) Improved working conditions	0	0
g) Improved child care	0	0
h) Improved mobility of persons	0	0

4. Improved education	**Scale of Expected Impacts over the next 10 years (2)**	
	By Project End -1 0 1 2 3	**After Project End -1 0 1 2 3**
a) Improved learning processes including lifelong learning	1	1
b) Development of new university curricula	0	0
5. Preservation and enhancement of the environment	**Scale of Expected Impacts over the next 10 years (2)**	
	By Project End -1 0 1 2 3	**After Project End -1 0 1 2 3**
a) Improved prevention of emissions	0	0
b) Improved treatment of emissions	0	0
c) Improved preservation of natural resources and cultural heritage	1	1
d) Reduced energy consumption	0	0
6. S&T quality	**Scale of Expected Impacts over the next 10 years (2)**	
	By Project End -1 0 1 2 3	**After Project End -1 0 1 2 3**
a) Production of new knowledge	3	3
b) Safeguarding or development of expertise in a research area	3	3
c) Acceleration of RTD, transfer or uptake	1	1
d) Enhance skills of RTD staff	3	2
e) Transfer expertise/know-how/technology	3	2
f) Improved access to knowledge-based networks	2	2
g) Identifying appropriate partners and expertise	2	2
h) Develop international S&T co-operation	3	3
i) Increased gender equality	1	1
7. Regulatory and legislative environment	**Scale of Expected Impacts over the next 10 years (2)**	
	By Project End -1 0 1 2 3	**After Project End -1 0 1 2 3**
a) Contribution to EU policy formulation	1	2
Contribution to EU policy implementation	0	0
8. Other (please specify)	**Scale of Expected Impacts over the next 10 years (2)**	
	By Project End -1 0 1 2 3	**After Project End -1 0 1 2 3**
	3	3

Description of Results

No.	Title:
1	**Heat Flux through Fram Strait calculated from high-resolution year-round measurements and from hindcasts with the NAOSIM model**

CONTACT PERSON FOR THIS RESULT

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Specific Result URL	http://www.awi-bremerhaven.de/Research/IntCoop/Oce/ASOF/

SUMMARY

Fram Strait is the only deep connection between the Arctic Ocean and Nordic Seas and represents the major gateway for the flux of warm water from mid latitudes to the Arctic Ocean. The oceanic heat imported from the North Atlantic has the potential to affect the ice cover in the Eurasian Arctic and to be released to the Arctic atmosphere. Thus, it is an important component for understanding Arctic climate, which is strongly linked with European climate, necessitating long-term measurements and simulations in a regional model. Since 1997 a continuous time series of volume and heat flux through Fram Strait was derived from measurements with moored instruments. The moorings cover the cross section over the entire deep part of Fram Strait. Temperature and velocity are monitored, allowing to integrate heat fluxes and to distinguish between northward, southward and net fluxes. ASOF-N allowed continuing the time series, which is now sufficiently long to determine the variability of the oceanic fluxes through Fram Strait on interannual time scales - and also to approach the declared objective of the ASOF cluster to capture variability on decadal time scales. The yearly averaged northward heat flow through Fram Strait increased dramatically, from about 38 to 60 Terrawatt (TW), during 1997-2000. In the following years the heat flow decreased slightly although summer temperatures of the inflow measured during ship surveys showed record high values in 2004 and 2005. While moorings record year round data and provide high temporal resolution, they still have a limited spatial resolution. Therefore, since 2001 they are complemented by ADCP (Acoustic Doppler Current Profiler) recordings during ship cruises that deliver high spatial resolution temperature and velocity data sets (typically two or three per year in the summer season). Yearly hydrographic measurements with high spatial resolution were also used to derive the flow field and heat flux with a third independent method.

Key innovative features:

1) The combination of these three observational methods, which to the best of our knowledge has never been published before, is one innovation made during the ASOF-N project in obtaining an as accurate estimate as possible of the heat transport.

2) The complicated topographic structure of Fram Strait leads to a splitting of the warm West Spitsbergen Current into various branches transporting water northward and eastward or recirculating immediately in Fram Strait. The size and strength of the different branches largely determine the input of oceanic heat to the inner Arctic Ocean and have to be distinguished. Therefore one key progress made during ASOF-N was recognizing the strong impact of areas of high recirculation on calculated heat and volume flow. By deploying additional moorings in the central part of Fram Strait the error of calculated heat and volume flow was considerably reduced.

3) A realistic model representation of these different branches was made possible by another innovation, the improved spatial resolution in the North Atlantic-Arctic Ocean-Sea Ice Model (NAOSIM) of AWI. The NAOSIM models use meteorological data and simulate their influence on sea ice, currents, temperature and salinity in the ocean north of approximately 50°N. The improved model has a horizontal resolution of approximately 9km and a vertical resolution of down to 10 m in upper ocean layers (with 50 depths layers in total). The modelling was done for the period from 1990 (using initial conditions in 1990 based on the coarser resolution version of the model) to 2005 using NCEP (National Centers for Environmental Predictions) reanalysis data for the integration. This model version resulted in a number of improvements, for instance the far better reproduction of the recirculation of Atlantic waters in Fram Strait. The averaged northward volume transport increased to around 10 Sverdrup (Sv) between 1995 and 2003. This fits observations much better than the around 3Sv of the previous model. The good agreement between the model and the observationally based estimates in Fram Strait makes it possible to use the model to relate changes in Fram Strait to large scale oceanic developments.

Potential users:

- The scientific community working in climate research (because the oceanic heat flux through Fram Strait is an important part in the North Atlantic and Arctic heat balance)
- Scientists working in Arctic Ocean research (influence of ocean temperature on sea ice, atmosphere, chemical & biological processes)
- Off-shore technology and shipping in the Arctic (since the oceanic heat is expected to affect the Arctic ice cover)
- Commercial fishery (because of the temperature effect on the distribution of marine organisms)
- Advisory panels for national and international policies

SUBJECT DESCRIPTORS CODES

172 EARTH OBSERVATION TECHNOLOGY AND INFORMATION EXTRACTION
174 EARTH SCIENCES FOR CLIMATE RESEARCH
272 GLOBAL CHANGE: CLIMATE CHANGE
369 MARINE: OCEANOGRAPHY (PHYSICAL AND OPERATIONAL)
400 MODELLING/MODELLING TOOLS, 3-D MODELLING

DOCUMENTATION AND INFORMATION ON THE RESULT

Documentation type	Details (Title, ref. number, general description, language)	Status: PU=Public CO=Confidential
Scientific article (peer reviewed)	Fahrbach, E., J. Meincke, S. Østerhus, G. Rohardt, U. Schauer, V. Tverberg, and J. Verduin (2001), Direct measurements of volume transports through Fram Strait, Polar Research, 20(2), 217-224.	Public
Scientific article	Gerdes, R., M. Karcher, F. Kauker, and U. Schauer (2003), Causes	Public

(peer reviewed)	and development of repeated Arctic Ocean warming events, Geophysical Research Letters, Vol.30, 1980.(No.19), DOI: 10.1029/2003GL018080.	
Scientific article (peer reviewed)	Polyakov, I.V., A. Beszczynska, E.C. Carmack, I.A. Dmitrenko, E. Fahrbach, I.E. Frolov, R. Gerdes, E. Hansen, J. Holfort, V.V. Ivanov, M.A. Johnson, M. Karcher, F. Kauker, J. Morison, K.A. Orvik, U. Schauer, H.L. Simmons, Ø. Skagseth, V.T. Sokolov, M. Steele, L.A. Timokhov, D. Walsh, and J.E. Walsh (2005), One more step toward a warmer Arctic, Geophysical Research Letters, in press.	Public
Scientific article (peer reviewed)	Rudels, B., Jones, E.P., Schauer, U., Eriksson, P. (2004) Atlantic sources of the Arctic Ocean surface and halocline waters Polar Research 232 (2) 181-208	Public
Scientific article (peer reviewed)	Waldemar Walczowski, Jan Piechura, Robert Robert Osiński, Piotr Wieczorek (2005), The West Spitsbergen Current volume and heat transport from synoptic observations in summer, Deep Sea Research I, 52 (2005) 1374-1391	Public
Scientific article (peer reviewed)	Schauer, U., Fahrbach, E., Osterhus, S., Rohardt, G. (2004) Arctic warming through the Fram Strait - oceanic heat transport from three years of measurements. Journal of Geophysical Research 109	Public
Scientific article (peer reviewed)	Karcher, M. J., Gerdes, R., Kauker, F., Koeberle, C.(2003). Arctic warming - Evolution and Spreading of the 1990s warm event in the Nordic Seas and the Arctic Ocean, Journal of Geophysical Research, Vol. 108(C2), 3034, 10.1029/2001JC001265	Public

INTELLECTUAL PROPERTY RIGHTS

Type of IPR	**KNOWLEDGE: Tick a box and give the corresponding details(reference numbers, etc) if appropriate**					**Pre-existing know-how Tick a box and give the corresponding details(reference numbers, etc) if appropriate**	
	Current				Foreseen	Tick	Details
	Tick	NoP[1)]	NoI[2)]	Details	Tick		
Patent applied for							
Patent granted							
Patent search carried out							
Registered design							
Trademark applications							
Copyrights							
Secret know-how							
Other - please specify:						√	NAOSIM Hierarchy of Ocean Sea Ice Models was provided by AWI

1) Number of **P**riority (national) applications/patents
2) Number of **I**nternationally extended applications/patents

MARKET APPLICATION SECTORS

Market application sectors
80 Education
73 Research and development
61.1 Sea and coastal water transport

CURRENT STAGE OF DEVELOPMENT

Scientific and/or Technical knowledge (Basic research)

Other:

QUANTIFIED DATA ABOUT THE RESULT

Items (about the results)	Actual current quantity	Estimated (or future) quantity
Time to application / market *(in months from the end of the research project)*	0	0
Number of (public or private) entities potentially involved in the implementation of the result:	2	46
of which: number of SMEs:	0	8
of which: number of entities in third countries (outside EU):	0	11
Targeted user audience: of reachable people	250	500
& publications (referenced publications only)	5	7
publications addressing general public (e.g. CD-ROMs, WEB sites)	2	4
publications addressing decision takers / public authorities / etc.	0	3
Visibility for the general public	YES	

FURTHER COLLABORATION, DISSEMINATION AND USE OF THE RESULT

COLLABORATIONS SOUGHT

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement		**INFO**	Information exchange/training	√
JV	Establish a joint enterprise or partnership		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

The result will be merged with the data from the ASOF-EC(E) and ASOF-EC(W) cluster components and contribute directly to the the circum-Arctic International Arctic/Subarctic Ocean Flux Array (http://asof.npolar.no/about.html)

Based on the results of ASOF-N, time series of heat flow through Fram Strait will be continued within the EU-funded IP "DAMOCLES" (Developing Arctic Modelling and Observing Capabilities for Long-term Environment Studies). The aim is to obtain longer time series to be able to tackle decadal variability of the fluxes and to improve and develop new instrumental technology based on experiences during ASOF-N to monitor the input of mass and heat to the Arctic Ocean.

The flux time series will be used in order to integrate the expected high resolution SPACE (Synoptic Pan-Arctic study of Climate and Environment) planned during the International Polar Year 2007/08 (IPY).

In a Polish/US cooperation the velocity measurements from lowered ADCPs will be combined with modelling activities in the SBI (Shelf-Basin Interaction) project.

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

In the course of the three follow up projects and one proposal, there might be the demand for scientist or Ph.D. students fitting the requirements of the programme.

No.	Title:
2	**Freshwater Flux through Fram Strait during 2003-2005 as measured during ASOF-N**

CONTACT PERSON FOR THIS RESULT

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URL	
Specific Result URL	

SUMMARY

Background and result description: Fram Strait is the main source of freshwater for the Greenland and Iceland Seas. Along with Davis Strait it is also the main provider of freshwater for the Labrador Sea and North Atlantic. This freshwater export from the Arctic to subarctic seas have the potential to influence the northbound current systems by modifying the stratification of the receiving basins. This would alter the oceanic heat transport, which again would influence the climate of North Western Europe. The export of fresh water occurs in liquid (polar water) and solid (sea ice) phase. With the advent of ASOF-N we were able to continue and extend existing time series (solid phase freshwater flux since 1990 and liquid freshwater flux since 1997), and hence determine the seasonal and interannual variability of freshwater fluxes through Fram Strait. The annual cycle of the liquid freshwater transport in the East Greenland Current (EGC) has a minimum in spring (~600 km3/yr) and a maximum in late summer (~2000 km3/yr). The mean of the transport time series is 900 km3/yr. The anomalies with respect to the mean seasonal cycle have a magnitude of typically 500 km3/yr. There is no general trend in the freshwater transport over the period 1997 to 2005. From the first ASOF-N winter time CTD section and the first mooring on the shelf it is clear that additional moorings are needed, as there is a potential for considerable freshwater transport across the wide shelf. During the May 2005 cruise low salinity water was found also east of the EGC, meaning that an additional freshwater transport could occur east of the existing mooring array. The comparison between fresh water observations at 79 N, 74 N and 63 N so far shows no significant signal propagation of water mass characteristics along the EGC path, in contrast to what is observed along the Atlantic Water path in the east.
Key innovations: Time series have been maintained using more basic observational arrays since 1997 but ASOF-N allowed using a full scale version of the observational array facilitating.

Key innovations:

1) With the advent of ASOF-N we were able to tailor make the observational setup to study fresh water transport, as far as the physical conditions allow. This includes near surface salinity sensors and tube moorings with ADCPs (Acoustic Doppler Current Profiler).

2) The wide shelf at this latitude was an open issue as due to extensive ice cover and icebergs drifting through the region, access is difficult and moorings are not likely to survive. Few observations have therefore been made in this area. Introducing tube moorings has provided our first direct measurements of salinity on the shelf at 79 N.

3) The moorings provide year round point measurements in the vertical and horizontal. Annual cruises during summer provide high resolution hydrography which aids in the interpretation of the point measurements. However, for the observation of freshwater fluxes we also need high resolution spatial information on the seasonal cycle of the stratification. An extensive ice cover with heavy multiyear ice has prevented access to the region during winter. In 2005 a coastguard ice breaker was used to penetrate into the pack, serving as a base for helicopter CTD transects with portable equipment. This allowed ASOF-N to do the first high resolution wintertime hydrographic transect.

4) For some years freshwater observations have been performed also at the 74 and 63 North latitudes. With ASOF-N we were able to do the first comparisons of freshwater observed at these different latitudes. The aim of this ongoing work is to draw conclusions on the fate and pathways of freshwater exiting the Arctic at 79 N.

5) Model results from the high resolution version of AWI's NAOSIM have been used to fill spatial and temporal gaps in the observations and to link the freshwater fluxes in the East Greenland Current with the large scale oceanic circulation as well as with the meteorological forcing fields. The large liquid fresh water export event of the mid-1990s could thus be linked to changes in the Arctic Ocean freshwater distribution during previous years. These redistributions were forced by the strong positive NAO wind forcing during the early 1990s. Current status: The time series are now approaching a length which will enable us to quantify variability on decadal time scales, a stated objective of the ASOF cluster.

Potential users:

Climate scientists, since the freshwater output from the Arctic is thought to influence the net densification at high latitudes, and hence the current systems governing the oceanic heat transport to northern regions.

Oceanographers working in the Labrador and Nordic Seas, since the freshwater output will modify the stratification and hence the processes occurring here.

Advisory panels for national and international policies, particularly when the link between Arctic freshwater output and the climate system is better established.

SUBJECT DESCRIPTORS CODES

46 ARCTIC ENVIRONMENT

174 EARTH SCIENCES FOR CLIMATE RESEARCH

269 GEOPHYSICS, PHYSICAL OCEANOGRAPHY, METEOROLOGY, GEOCHEMISTRY, TECTONICS

272 GLOBAL CHANGE: CLIMATE CHANGE

369 MARINE: OCEANOGRAPHY (PHYSICAL AND OPERATIONAL)

DOCUMENTATION AND INFORMATION ON THE RESULT

Documentation type	Details (Title, ref. number, general description, language)	Status: PU=Public CO=Confidential
Scientific article (peer reviewed)	Holfort, Jürgen; Hansen, Edmond Timeseries of Polar Water properties in Fram Strait (2005) Geophys. Res. Lett., Vol. 32, No. 19, L19601	Public
Scientific article (peer reviewed)	Polyakov, Igor V.; Beszczynska, Agnieszka; Carmack, Eddy C.; Dmitrenko, Igor A.; Fahrbach, Eberhard; Frolov, Ivan E.; Gerdes, Rüdiger; Hansen, Edmond; Holfort, Jürgen; Ivanov, Vladimir V.; Johnson, Mark A.; Karcher, Michael; Kauker, Frank; Morison, James; Orvik, Kjell A.; Schauer, Ursula; Simmons, Harper L.; Skagseth, Øystein; Sokolov, Vladimir T.; Steele, Michael; Timokhov, Leonid A.; Walsh, David; Walsh, John E. One more step toward a warmer Arctic Geophys. Res. Lett. (2005) Vol. 32, No. 17, L17605 10.1029/2005GL023740	Public
Book chapter in preparation	Hansen et al Fresh water fluxes east of Greenland	Confidential

INTELLECTUAL PROPERTY RIGHTS

<u>Type of IPR</u>	<u>KNOWLEDGE:</u> Tick a box and give the corresponding details (reference numbers, etc) if appropriate					<u>Pre-existing know-how</u> Tick a box and give the corresponding details (reference numbers, etc) if appropriate	
	Current				Foreseen	Tick	Details
	Tick	NoP[1)]	NoI[2)]	Details	Tick		
Patent applied for							
Patent granted							
Patent search carried out							
Registered design							
Trademark applications							
Copyrights							
Secret know-how							
Other - please specify:							

1) Number of Priority (national) applications/patents
2) Number of Internationally extended applications/patents

MARKET APPLICATION SECTORS

80 Education

73 Research and development

CURRENT STAGE OF DEVELOPMENT

Scientific and/or Technical knowledge (Basic research)

Other:

QUANTIFIED DATA ABOUT THE RESULT

Items (about the results)	Actual current quantity	Estimated (or future) quantity
Time to application / market *(in months from the end of the research project)*	0	0

Number of (public or private) entities potentially involved in the implementation of the result:	2	53
of which: number of SMEs:	0	8
of which: number of entities in third countries (outside EU):	1	18
Targeted user audience: of reachable people	150	500
& publications (referenced publications only)	1	5
publications addressing general public (e.g. CD-ROMs, WEB sites)	4	2
publications addressing decision takers / public authorities / etc.	5	5
Visibility for the general public	YES	

FURTHER COLLABORATION, DISSEMINATION AND USE OF THE RESULT

COLLABORATIONS SOUGHT

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement		**INFO**	Information exchange/training	√
JV	Establish a joint enterprise or partnership		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

The observations will continue, partially funded under the EU funded Integrated Project DAMOCLES. The subtask dealing with the effect of the Arctic output of freshwater will directly build on the results achieved during ASOF-N. The result will be merged with the data from the ASOF-EC(E) and ASOF-EC(W) cluster components and contribute directly to the the circum-Arctic International Arctic/Subarctic Ocean Flux Array (http://asof.npolar.no/about.html)

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

Oceanographer and sea ice physicists can contribute within new projects. Field work expertise as well as experiences with EU funded projects are of advantage.

No.	Title:
3	**Heat Flux in the Western Barents Slope measured from 2003-2005 during ASOF-N**

CONTACT PERSON FOR THIS RESULT

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URL	
Specific Result URL	

SUMMARY

The Barents Sea influences the Arctic Ocean both by providing a pathway for Atlantic Water (AW), but also as a shallow shelf sea producing dense water through cooling and brine release. The Barents Sea provides intermediate water down to 1200 m depth in the Arctic Ocean, and, together with the Kara Sea, is the only source area for shelf waters ventilating the Nansen Basin below the halocline. Thus, knowledge of the variability of the Atlantic inflow to the Barents Sea is important for the understanding of the climatic state of the Arctic Ocean, and for evaluations of climate change. ASOF-N continued a time series started in 1997 of volume and heat flux through the Western Barents Slope (WBS) using moored instruments. These cover the cross section where the Atlantic inflow takes place -with the exception of heavily fished waters. Temperature and velocity are monitored, allowing to integrate heat fluxes and to distinguish between eastward, westward and net fluxes. The time series is now sufficiently long to determine the variability of the oceanic fluxes through the WBS on interannual time scales - and to approach the declared objective of the ASOF cluster to capture variability on decadal time scales. The long-term mean heat flux is 40 Terrawatt (TW) into the Barents Sea. Considering the interannual variability there was a relatively high heat flux into the Barents Sea in the winter of 2002/2003. Thereafter there was a pronounced decrease and 2003/2004 had the lowest heat flux observed during winter. In addition to the moorings, hydrographic measurements with high spatial resolution were used to derive flow field and heat flux six times a year.

Key innovative features and findings:

1) The combination of these two observational methods is one innovation made during the ASOF-N in obtaining an estimate of heat transport as accurate as possible.

2) The splitting of the flow of AW across the WBS was observed to take place in one wide branch but also to be split into several narrower branches, depending on the wind field. Between the branches there might be a weaker inflow or a return flow. At times the flow across the section is dominated by outflow (westward flow) and AW is flowing into the Barents Sea only in the southernmost part of the section.

3) There is no correlation between the fluxes and the temperature of the inflowing water. In fact, in certain periods temperature increases while the volume flux decreases. This shows that the WBS temperature is independent of the volume flux. The reason is that while the temperature of the inflowing water depends on the temperatures upstream in the Norwegian Sea, the volume flux depends mainly on the local wind field. This shows the importance of measuring both volume transport and temperature, since they not always are varying in the same manner. The short-time variations in the heat flux closely resembles the short-time variations in the volume flux, while the temperature variations influence the longer term variations in the heat flux.

4) A realistic model representation of the Barents Sea region was made possible by another innovation, the coupling of a dynamic-thermodynamic sea ice model to a three-dimensional ocean general circulation model for the purpose of conducting climate dynamical downscaling experiments for the Barents Sea region. The Regional Ocean Model System (ROMS, http://marine.rutgers.edu/po/index.php?model=roms) was chosen as most appropriate since its model architecture is suitable for shelf seas as the Barents Sea. The improvement of the ROMS model is the sea-ice model extension, which performs well also on the high resolution grid used and is absolutely necessary for realistic Barents Sea simulations. The model will be used to conduct a hindcast for the period 1990-2005 including 3D fields of velocity and hydrography as well as water level and sea ice thickness and concentration. The horizontal grid resolution is ~10km. The vertical is resolved by 32 terrain

following levels. Previous model validation with results from a similar model implementation (i.e. using slightly different and less accurate forcing) against observations show that seasonal and interannual variability in the ocean are tracked successfully. Furthermore the model results are used to examine details in space not covered by observations (incl. estimates of the throughflow of AW in the Barents Sea to the Arctic Ocean).

Potential users:

Scientists in climate research - the oceanic heat flux through the Barents Sea is an important part in the North Atlantic and Arctic heat balance.

Scientists in Arctic Ocean research – influence of ocean temperature on sea ice, atmosphere, chemical & biological processes.

Off-shore technology and shipping in the Barents Sea and the Arctic - oceanic heat is expected to affect the Arctic ice cover.

Commercial fishery - the temperature effect on the distribution of marine organisms.

Advisory panels for national and international policies.

SUBJECT DESCRIPTORS CODES

46 ARCTIC ENVIRONMENT

174 EARTH SCIENCES FOR CLIMATE RESEARCH

269 GEOPHYSICS, PHYSICAL OCEANOGRAPHY, METEOROLOGY, GEOCHEMISTRY, TECTONICS

271 GLOBAL CHANGE: BIOGEOCHEMICAL AND HYDROLOGICAL CYCLES

400 MODELLING/MODELLING TOOLS, 3-D MODELLING

DOCUMENTATION AND INFORMATION ON THE RESULT

Documentation type	Details (Title, ref. number, general description, language)	Status: PU=Public CO=Confidential
Scientific article (peer reviewed)	Ingvaldsen, Randi B. Width of the North Cape Current and location of the Polar Front in the western Barents Sea Geophys. Res. Lett., Vol. 32, No. 16, L16603 10.1029/2005GL023440	Public
Scientific article (peer reviewed)	Ingvaldsen R., Asplin L., Loeng H. 2004 The seasonal cycle in the Atlantic transport to the Barents Sea during the years 1997-2001 Continental Shelf Research 24 (2004) 1015–1032	Public
Scientific article (peer reviewed)	Ingvaldsen R., Asplin L., Loeng H. 2004 Velocity field of the western entrance to the Barents Sea. Journal of Geophysical Research vol. 109, C03021	Public
Scientific article (peer reviewed)	Budgell, W. 2005 Numerical simulation of ice-ocean variability in the Barents Sea region Ocean Dynamics, vol. 55, no. 3, pp. 370-387	Public
Report	The Deliverable D 2.6 describes the process of analysing the archive of model results. The analysis includes validation against the available observations of currents and hydrography at the WBS. Furthermore the model results are used to examine details in space not covered by the available observations (including estimates of the throughflow of AW in the Barents Sea to the Arctic Ocean).	Confidential

INTELLECTUAL PROPERTY RIGHTS

Type of IPR	KNOWLEDGE: Tick a box and give the corresponding details (reference numbers, etc) if appropriate					Pre-existing know-how Tick a box and give the corresponding details (reference numbers, etc) if appropriate	
	Current				Foreseen	Tick	Details
	Tick	NoP[1)]	NoI[2)]	Details	Tick		
Patent applied for							
Patent granted							
Patent search carried out							
Registered design							
Trademark applications							
Copyrights							
Secret know-how							
Other - please specify:							

1) Number of Priority (national) applications/patents
2) Number of Internationally extended applications/patents

MARKET APPLICATION SECTORS

80 Education

73 Research and development

61.1 Sea and coastal water transport

CURRENT STAGE OF DEVELOPMENT

Scientific and/or Technical knowledge (Basic research)

Other:

QUANTIFIED DATA ABOUT THE RESULT

Items (about the results)	Actual current quantity	Estimated (or future) quantity
Time to application / market *(in months from the end of the research project)*	0	0
Number of (public or private) entities potentially involved in the implementation of the result:	1	61
of which: number of SMEs:	0	8
of which: number of entities in third countries (outside EU):	1	15
Targeted user audience: of reachable people	500	800
& publications (referenced publications only)	4	8
publications addressing general public (e.g. CD-ROMs, WEB sites)	10	10
publications addressing decision takers / public authorities / etc.	4	4
Visibility for the general public	YES	

FURTHER COLLABORATION, DISSEMINATION AND USE OF THE RESULT

COLLABORATIONS SOUGHT

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	

MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement		**INFO**	Information exchange/training	√
JV	Establish a joint enterprise or partnership		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

The result will be merged with the data from the ASOF-EC(E) and ASOF-EC(W) cluster components and contribute directly to the the circum-Arctic International Arctic/Subarctic Ocean Flux Array (http://asof.npolar.no/about.html)

The studies on the Heat flux western Barents Slope are of interest to a wide scientific community, especially to:

- Climate scientists, since the freshwater output from the Arctic is thought to influence the net densification at high latitudes, and hence the current systems governing the oceanic heat transport to northern regions.
- Oceanographers working in the Labrador and Nordic Seas, since the freshwater output will modify the stratification and hence the processes occurring here
- Advisory panels for national and international policies, particularly when the link between Arctic freshwater output and the climate system is better established.

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

Within the new projects physical oceanographers and modellers will be involved. A partner that has experience in Air-Sea-Ice interactions will be of special use to the projects.

No.	Title:
4	**Inflow of Atlantic water into the Nordic Seas measured during ASOF-N from 2003 to 2005**

CONTACT PERSON FOR THIS RESULT

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URL	
Specific Result URL	

SUMMARY

The Atlantic water masses circulating across the Nordic Seas towards the Arctic Ocean, are of prime importance for the climate of the northern hemisphere. An excessive freshening of the Nordic Seas might be a prelude to a slow down of warm and salty Atlantic water masses advected from subtropical regions towards the Arctic Ocean. This reduced input of Atlantic water masses and their transformation in denser Arctic intermediate waters might eventually

lead to a shut down of the general thermohaline circulation and overturning in the northern North Atlantic. At the moment the observations taken at various strategic spots in the Nordic Seas and the Arctic Ocean, tend to indicate a temperature increase of Atlantic warm and salty waters all along the continental margin north of Eurasia intruding in large sectors of the central basin of the Arctic Ocean.

ASOF-N allowed studying Atlantic water pathways across the northern Norwegian Sea (Lofoten and Boreas basins) as well as the time and space variability of heat, salt and total transports associated with the Norwegian Atlantic current. The equipment and combined effort of three institutions (LOCEAN-formerly known as LODYC, Paris, France, IMR, Bergen, Norway and IOPAN, Sopot, Poland) was used to install the following main instruments (a) neutrally buoyant floats tracked acoustically underwater, (b) current meters installed on moorings and (c) CTD and LADCP operated from research vessels during field campaigns organised in 2003, 2004 and 2005.

The main objectives consisted in:

(1) studying the Norwegian Atlantic current and eventually confirm the nature of the general circulation of Atlantic water masses in the Lofoten and Boreas basins,

(2) measuring the variability in temperature and salinity of the Atlantic water masses circulating across the northern Norwegian sea,

(3) observing the main pathways of Atlantic water masses entering either in the Barents Sea or heading north towards Fram Strait,

(4) estimating the heat losses to the atmosphere versus the heat transferred to deep Arctic intermediate waters and the freshening via internal mixing of the Atlantic water masses in the Lofoten Boreas basins and the Greenland Sea.

The key scientific results:

(1) The real nature and structure of the so-called Norwegian Atlantic current which looks more like a broad and highly turbulent current extending 100 kms offshore from the shelf break of the Lofoten basin, rather than a narrow jet current constrained to the continental slope west of Norway, as often described in the literature.

(2)The two stream nature of the West Spitsbergen Current

(3) The intense and prominent mesoscale eddy variability characterizing the Norwegian Atlantic current, and the West Spitsbergen Current.

(4) A pronounced seasonal and interannual variability of temperature and salinity fields showing episodic freshening and cooling events.

(5) A remarkable interannual variability of the main transport of Atlantic water masses across the Lofoten basin.

(6) A long-term variability of temperature and salinity fields corresponding to an increase in temperature and salinity of the Atlantic water masses of more than 0.5°C and 0.1 psu over the past 25 years.

(7) The pulsating nature of the Atlantic Water transport within the West Spitsbergen Current.

(8) The close relation of the Atlantic Water volume transport with the local forcing in short-term variability.

The strategy used for better documenting the Atlantic water masses pathways in the northern Norwegian Sea was based on a combination of Eulerian techniques (moorings) and Lagrangian techniques (floats) as well as observations taken from research vessels (CTD, LADCP). This strategy provided an unprecedented level of information concerning the nature, structure, time and space variability of the Norwegian Atlantic current, the main carrier of Atlantic water masses to the Arctic Ocean.

Potential users:

Besides scientists interested in the role of the ocean circulation on climates, our result show important avenues to explore together with biologists concerned with the impacts of the physical environment on biomass accumulation, plankton distribution, over-wintering of fish larvae and all other major aspects characterizing one of the most productive ecosystems on Earth.

SUBJECT DESCRIPTORS CODES

46 ARCTIC ENVIRONMENT

272 GLOBAL CHANGE: CLIMATE CHANGE

369 MARINE: OCEANOGRAPHY (PHYSICAL AND OPERATIONAL)

DOCUMENTATION AND INFORMATION ON THE RESULT

Documentation type	Details (Title, ref. number, general description, language)	Status: PU=Public CO=Confidential
Scientific article (peer reviewed)	Polyakov, Igor V.; Beszczynska, Agnieszka; Carmack, Eddy C.; Dmitrenko, Igor A.; Fahrbach, Eberhard; Frolov, Ivan E.; Gerdes, Rüdiger; Hansen, Edmond; Holfort, Jürgen; Ivanov, Vladimir V.; Johnson, Mark A.; Karcher, Michael; Kauker, Frank; Morison, James; Orvik, Kjell A.; Schauer, Ursula; Simmons, Harper L.; Skagseth, Øystein; Sokolov, Vladimir T.; Steele, Michael; Timokhov, Leonid A.; Walsh, David; Walsh, John E. One more step toward a warmer Arctic Geophys. Res. Lett. (2005) Vol. 32, No. 17, L17605 10.1029/2005GL023740	Public
Scientific article (peer reviewed)	Orvik, K. A., and Ø. Skagseth (2005), Heat flux variations in the eastern Norwegian Atlantic Current toward the Arctic from moored instruments, 1995–2005, Geophys. Res. Lett., 32, L14610, doi:10.1029/2005GL023487.	Public

INTELLECTUAL PROPERTY RIGHTS

Type of IPR	KNOWLEDGE: Tick a box and give the corresponding details (reference numbers, etc) if appropriate					Pre-existing know-how Tick a box and give the corresponding details (reference numbers, etc) if appropriate	
	Current				Foreseen	Tick	Details
	Tick	NoP[1)]	NoI[2)]	Details	Tick		
Patent applied for							
Patent granted							
Patent search carried out							
Registered design							
Trademark applications							
Copyrights							
Secret know-how							
Other - please specify:							

1) Number of Priority (national) applications/patents

2) Number of Internationally extended applications/patents

MARKET APPLICATION SECTORS

73 Research and development

CURRENT STAGE OF DEVELOPMENT

Scientific and/or Technical knowledge (Basic research)

Other:

QUANTIFIED DATA ABOUT THE RESULT

Items (about the results)	Actual current quantity	Estimated (or future) quantity
Time to application / market *(in months from the end of the research project)*	0	0
Number of (public or private) entities potentially involved in the implementation of the result:	2	50
of which: number of SMEs:	0	8
of which: number of entities in third countries (outside EU):	0	18
Targeted user audience: of reachable people	150	300
& publications (referenced publications only)	1	3
publications addressing general public (e.g. CD-ROMs, WEB sites)	1	10
publications addressing decision takers / public authorities / etc.	0	2
Visibility for the general public	YES	

FURTHER COLLABORATION, DISSEMINATION AND USE OF THE RESULT

COLLABORATIONS SOUGHT

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement		**INFO**	Information exchange/training	
JV	Establish a joint enterprise or partnership		**CONS**	Available for consultancy	
Other	(please specify)				
Details:					

POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

The result will be merged with the data from the ASOF-EC(E) and ASOF-EC(W) cluster components and contribute directly to the the circum-Arctic International Arctic/Subarctic Ocean Flux Array (http://asof.npolar.no/about.html).

The combination of Eulerian (moorings) and Lagrangian (floats) techniques proved to be adequate and should be pursued in the future. Special emphasis should be taken on separating various scales of variability from general trends in the change of Atlantic water pathways. Furthermore emphasis should be given to the various mechanisms responsible for the variability observed on the shelves, the continental slope and the abyssal plain. New techniques such as sea gliders are very promising for dealing with these issues and in particular for studying internal mixing due to high frequency forcing such as tidal currents which are prominent all along the continental slope. Temperature and salinity fields should be retrieved in full coherency with currents and transports of water masses.

There are numbers of well structured programs such as PAN-AME (An EoI for IPY dealing with a Pan Arctic Cluster for Climate forcing of the Arctic Marine Ecosystem) the future EU Integrated Project DAMOCLES standing for Developing Arctic Modelling and Observing

Capabilities for Long-term Environmental Studies. ESSAS (EcoSystem Studies of SubArctic Seas) within GLOBEC (the International Geosphere-Biosphere Programme(IGBP) core project responsible for understanding how Global Change will affect the abundance, diversity and productivity of marine populations) which would strongly profit from developing active cooperation with ASOF-like programs.

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

No.	Title:
5	**Dissemination of results from oceanographic measurements in the Ocean between northern Norway, Spitsbergen and Greenland to decision takers**

CONTACT PERSON FOR THIS RESULT

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URL	
Specific Result URL	

SUMMARY

The region covered by the ASOF-N includes some of the most productive fishing grounds of the world, where environmental changes have direct effects on the growth, recruitment, distribution, migration and food consumption of commercial fish stocks, and where a sustainable fishery is of central importance for the social and economic conditions of nations. The need is for a reliable system of environmental change monitoring to use in developing a predictive capability, which will reliably anticipate changes in fish-stocks. The Barents Sea for example is a high latitude ecosystem that is heavily depending on the inflow of Atlantic water from the south. Recent current measurements show a great variability of heat flux to the Barents Sea, which has consequences for the marine ecosystem. The heat flux has impact on species composition, distribution and migration of commercially important fish species. In addition the heat flux also determines the possibility of a Northern Sea route and the exploitation of natural resources (fossil fuel). It is therefore important to continue scientific activities to monitor this flow in order to investigate how it is related to climate variability and change. At the same time it is of prime importance to disseminate the scientific results and their implications to politicians and stake holders like fisheries organisations and the general public.

Current status:

ASOF-N data were compared with models and used for the preparation of information of ASOF-N results in a layman language. ASOF-N is an excellent example where observations and model results support each other in a very positive way: observations are used to validate model results and on the other hand, models are important tools for explaining variability in the observations. The results of ASOF-N therefore support the requirements for data derived both from mathematical models and observational data. In addition information on ASOF-N results were supplemented by results from related projects (ECOBE; ProClim and NESSAS)

with financial support from the Research Council of Norway. These results were presented in layman language to fisheries organisation as talks, newspaper articles and in form of a leaflet that was distributed during an Aquaculture exhibition through IMR, Norway. Scientific results on the effect of the changing climate on the marine ecosystem was also presented to the Norwegian Ministry of Fisheries during an oral presentation.
In addition results on climate variability and its link to ecosystem development have been conveyed to the general public especially students and high school teachers during lectures given at universities and schools.

Results from ASOF-N and the EU-funded preceding projects VEINS and MAIA also gave background information to the scientific report from the Arctic Climate Impact Assessment (ACIA) published in 2005. ACIA is an international project of the Arctic Council and the International Arctic Science Committee (IASC), to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. The Arctic Council is a high level intergovernmental forum of the following member states: Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States of America.

The ASOF-N results are included into reports to ICES (the International Council for the Exploration of the Sea), which gives advice to the member countries and helps them manage the North Atlantic Ocean and adjacent seas. The results are included in a few reports presented at different ICES working groups like Working Group on Oceanic Hydrography (WGOH) and Arctic Fishery Working Group (AFWG), and during the last two years also included in ICES assessment reports.

Benefits:

The communication of scientific results based on measurements in the Arctic as well as on predictive models to decision takers is a central requirement for anticipating and mitigating the regional effects of global warming.

SUBJECT DESCRIPTORS CODES

46 ARCTIC ENVIRONMENT
272 GLOBAL CHANGE: CLIMATE CHANGE
366 MARINE ECOSYSTEMS
369 MARINE: OCEANOGRAPHY (PHYSICAL AND OPERATIONAL)
400 MODELLING/MODELLING TOOLS, 3-D MODELLING

DOCUMENTATION AND INFORMATION ON THE RESULT

Documentation type	Details (Title, ref. number, general description, language)	Status: PU=Public CO=Confidential
Report	ACIA report Impacts of a Warming Arctic - Arctic Climate Impact Assessment available at http://amap.no/acia/ or at Cambridge University Press ISBN-10: 0521617782	Public
Newsletter	Asplin, L., R. Ingvaldsen, H. Loeng and R. Sætre, 2005: General aspects of the southern Barents Sea circulation, Globec International Newsletter, Vol.11, no.1, p15	Public
Scientific article (peer reviewed)	Ottersen, G., Loeng, H., Ådlandsvik, B. and Ingvaldsen, R. 2003. Temperature variability in the northeast Atlantic. Ices Mar. sci. Symp.219 86-94	Public
Scientific article	Loeng, H. and Sætre, R. 2001. Features of the Barents Sea circulation. Fisken og Havet, 2001 (1): 1-40	Public
Scientific article (peer reviewed)	Tengberg, A., Andersen, T., Guillen, J., Hovdenes, J., Ingvaldsen, R. Józa, J. Loeng, H., Minken, H., Palanques, A., Pejrop, M. and	Public

	Sakkula, J. 2001. Use of current meters in aquatic research and engineering. Sea Technology, 42.2, 10-18.	

INTELLECTUAL PROPERTY RIGHTS

Type of IPR	KNOWLEDGE: Tick a box and give the corresponding details (reference numbers, etc) if appropriate					Pre-existing know-how Tick a box and give the corresponding details (reference numbers, etc) if appropriate	
	Current				Foreseen	Tick	Details
	Tick	NoP[1)]	NoI[2)]	Details	Tick		
Patent applied for							
Patent granted							
Patent search carried out							
Registered design							
Trademark applications							
Copyrights							
Secret know-how							
Other - please specify:							

1) Number of Priority (national) applications/patents
2) Number of Internationally extended applications/patents

MARKET APPLICATION SECTORS

80 Education

05 Fishing, operation of fish hatcheries and fish farms; service…

73 Research and development

61 Water transport

CURRENT STAGE OF DEVELOPMENT

Other:

Dissemination activities

QUANTIFIED DATA ABOUT THE RESULT

Items (about the results)	Actual current quantity	Estimated (or future) quantity
Time to application / market *(in months from the end of the research project)*	0	0
Number of (public or private) entities potentially involved in the implementation of the result:	1	45
of which: number of SMEs:	0	8
of which: number of entities in third countries (outside EU):	1	11
Targeted user audience: of reachable people	750	1500
& publications (referenced publications only)	0	0
publications addressing general public (e.g. CD-ROMs, WEB sites)	5	6
publications addressing decision takers / public authorities / etc.	6	6
Visibility for the general public	YES	

FURTHER COLLABORATION, DISSEMINATION AND USE OF THE RESULT

COLLABORATIONS SOUGHT

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement		**INFO**	Information exchange/training	√
JV	Establish a joint enterprise or partnership		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

The current measurements started out in the EU-funded VEINS project in 1997 and continued under MAIA and finally under ASOF-N. In the future, the measurements will be a part of DAMOCLES and probably the International Polar Year (IPY). The array of moorings between Norway and Bear Island with support from EU, has recently been expanded with financial support from the Research Council of Norway and includes measurements in the inflowing Norwegian Coastal Current and the outflowing Arctic water south of Bear Island.

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

The following partners could contribute to the advice of managers:

economists to assess the impact of climate change on the economy,

physical oceanographers to continue the mooring and CTD time series,

modellers to contribute to observationally supported model improvements.

No.	Title:
6	**Data and data management of CTD profiles and mooring**

CONTACT PERSON FOR THIS RESULT

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URL	
Specific Result URL	

SUMMARY

Result description CTD Data: CTD (Conductivity, Temperature, Depth) profiles were measured during 10 cruises in 2003 and during 10 cruises in 2004, 11 cruises in 2005 and 0ne cruise in 2006 by AWI, IFMH, IMR, IOPAS, and NPI across Fram Strait, in the East Greenland Current between 74° and 79° N and in the eastern part of the Greenland Sea. Detailed information on the CTD stations can be found at the ASOF-N website. The CTD dataset contains 2514 profiles which can be retrieved via www.awi-bremerhaven.de/OZE. A summary of CTD datasets are presented in Tables provided in the documentation.

Instruments:

All institutions used a Sea Bird SBE911plus CTD profiler with a single CT-Sensor package (double CT-Sensor for AWI profilers). The CT sensors were frequently calibrated at Seabird Electronics. In addition salinity samples were taken to correct for sensor drift. The final data have been processed using Seabirds post-processing software which includes all necessary operations. The raw data have a vertical resolution of 0.04 dbar but still including noise e.g. due to ship motion. To reduce this noise, data were averaged to a vertical resolution of 1dbar. The number of data cycles averaged in each 1dbar record was stored together with the individual data points. ASOF-N continued a CTD time series started in 1997, which is now sufficiently long to determine the variability on interannual time scales - and also to approach the declared objective of the ASOF cluster to capture variability on decadal time scales.

Result description

Mooring Data:

Moorings were deployed and recovered during 15 cruises from 2003 to 2005 by AWI, IFMH, IMR, and NPI across Fram Strait and in the East Greenland Current at 74° N. A detailed map with mooring location is provided in the documentation. The current dataset contains 900 time series which can be retrieved via www.awi-bremerhaven.de/OZE. A summary of mooring records are presented in the documentation.

Instruments:

Most instruments being used in the mooring were current meters. Reliable current measurements were maintained by frequent services (usually before and after deployment). The common current meter type is a rotor current meter from Aanderaa Instruments. In addition to current speed and direction these instruments also measure temperature. CT recorders from Seabird (SBE16, SBE37) were used to measure precise temperature and salinity based on calibrations before deployment and after recovery. The sample rate depends on the different instrument types (and their power consumption and memory size) and ranges between 10 minutes and 2 hours. Data processing was done by the institution that provided the instrument. The standard procedures included converting binary data to engineering units, apply magnetic deviation correction, removing of spikes (small gaps were filled by interpolation and long gaps were filled with a dummy data value, e.g. NaN) and correcting for sensor drifts for example by applying post calibration.

Potential users:

Scientists working in Arctic Ocean research

Archiving and providing the data:

As important as collecting new data about the temporal variability of oceanographic parameters, is the availability of collected data. The ASOF-N partner send their processed and calibrated CTD and/or mooring datasets to the AWI where they are stored together with information about additional dataset available for this region. The data are transferred into a uniform format and archived in AWI's database with general cruise and instrument information. ASOF-N partners have password protected direct access via the internet or can order complete datasets on CD.

This process has the following key advantages:

Project partners can access all collected data from all over the world via the internet without delay. This is of great importance especially in the oceanographic community where scientists are often on cruises and answering requests for data are therefore delayed. Data are provided centrally in a uniform data format. The time consuming process of converting data is performed centrally using a fixed routine. The user accesses a uniform data format and can compare profiles directly without tedious and time consuming conversion of data formats. The data format supports importing of data using Matlab if desired by the user and can be visualised using the software ODV (Ocean Data View). ODV can be retrieved from http://odv.awi-bremerhaven.de. In contrast to archives, this working data base can be easily edited after the upload. This easy modification of the database allows for a fast correction if comparisons of data sets reveal faulty data points. Furthermore it enables the subsequent expansion of the data base. CTD data are processed fast and can made available immediately and data sets that need more time to process e.g. oxygen profiles can be easily added at a later stage without affecting the accessibility of CTD data.

SUBJECT DESCRIPTORS CODES

46 ARCTIC ENVIRONMENT

150 DATABASES, DATABASE MANAGEMENT, DATA MINING

172 EARTH OBSERVATION TECHNOLOGY AND INFORMATION EXTRACTION

174 EARTH SCIENCES FOR CLIMATE RESEARCH

269 GEOPHYSICS, PHYSICAL OCEANOGRAPHY, METEOROLOGY, GEOCHEMISTRY, TECTONICS

DOCUMENTATION AND INFORMATION ON THE RESULT

Documentation type	Details (Title, ref. number, general description, language)	Status: PU=Public CO=Confidential
Map of CTD stations and Moorings	The files show the location of moorings and CTD cruises. Additional information include number of profiles and time series, information on research vessels and cruise dates.	Public
Webpage	Detailed information on CTD stations and moorings can be found at: www.awi-bremerhaven.de/Research/IntCoop/Oce/ASOF/data-management/Map-CTD-Moor.htm. The CTD and mooring datasets can be retrieved via www.awi-bremerhaven.de/OZE.	Public
Data CD ROM	The complete ASOF-N dataset is available on CD ROM	Confidential

INTELLECTUAL PROPERTY RIGHTS

Type of IPR	KNOWLEDGE: Tick a box and give the corresponding details (reference numbers, etc) if appropriate					Pre-existing know-how Tick a box and give the corresponding details (reference numbers, etc) if appropriate	
	Current				Foreseen	Tick	Details
	Tick	NoP[1)]	NoI[2)]	Details	Tick		
Patent applied for							
Patent granted							
Patent search carried out							
Registered design							
Trademark applications							
Copyrights							
Secret know-how							

Other - please specify:						

1) Number of Priority (national) applications/patents
2) Number of Internationally extended applications/patents

MARKET APPLICATION SECTORS

73 Research and development

CURRENT STAGE OF DEVELOPMENT

Scientific and/or Technical knowledge (Basic research)

Other:

QUANTIFIED DATA ABOUT THE RESULT

Items (about the results)	Actual current quantity	Estimated (or future) quantity
Time to application / market *(in months from the end of the research project)*	0	0
Number of (public or private) entities potentially involved in the implementation of the result:	5	45
of which: number of SMEs:	0	8
of which: number of entities in third countries (outside EU):	2	11
Targeted user audience: of reachable people	50	500
& publications (referenced publications only)	0	0
publications addressing general public (e.g. CD-ROMs, WEB sites)	2	1
publications addressing decision takers / public authorities / etc.	0	0
Visibility for the general public	YES	

FURTHER COLLABORATION, DISSEMINATION AND USE OF THE RESULT

COLLABORATIONS SOUGHT

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement		**INFO**	Information exchange/training	√
JV	Establish a joint enterprise or partnership		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

The result will be merged with the data from the ASOF-EC(E) and ASOF-EC(W) cluster components and contribute directly to the the circum-Arctic International Arctic/Subarctic Ocean Flux Array (http://asof.npolar.no/about.html)

The data will be of interest for scientists working in Arctic ocean research. The strategy used during ASOF-N to improve the availability of collected data, is of interest for all scientist collecting large amount of data with different instruments or project partners. The data collected during ASOF-N were accessible for project partners via internet from all over the world in a uniform data format without delay. The working data base used during ASOF-N can be easily edited and expanded.

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

No.	Title:
7	**Exchanges of volume, heat and freshwater between the Atlantic and the Arctic Ocean**

CONTACT PERSON FOR THIS RESULT

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E-mail	bert.rudels@fimr.fi
URL	
Specific Result URL	

SUMMARY

Motivation:

One key question in Arctic climate research is, whether the sensible heat carried by the oceanic inflow can influence the formation of sea ice and whether e.g. a large increase in oceanic heat input could considerably diminish the ice cover. The inflow of water and heat from the Atlantic Ocean to the Arctic Ocean was studied during the ASOF-N programme. The Atlantic water (AW) reaches the Arctic Ocean through two passages, the deep (2600m) Fram Strait and across the broad shelf of the Barents Sea, where it enters through the Bear Island Channel and passes through the Barents Sea into the Kara Sea and most of the AW continues into the Arctic Ocean via the St. Anna Trough. The programme also attempted to quantify the outflow of sea ice and low salinity surface water (the export of liquid freshwater) from the Arctic Ocean to the Nordic Sea through Fram Strait and, since Fram Strait is the only deep passage connecting the Arctic Ocean to the world ocean, to estimate the exchanges of intermediate and deep waters between the Arctic Ocean and the Nordic Seas. The AW was followed on its way through the Norwegian Sea from the Greenland – Scotland Ridge to the two inflow passages and the strength of the transport and the changes in water mass characteristics were studied.

Background information:

The AW loses a considerable amount of heat in the open area north of Svalbard, the Whalers' Bay, to the atmosphere and to the melting of ice. As the AW then passes eastward along the continental slope, it is covered by a less saline surface layer comprising AW diluted by ice melt, and its still large heat content is isolated from the sea ice and the atmosphere. The transformations of the Barents Sea inflow are much larger. Denser water masses are created that enter the deeper layers of the Arctic Ocean, as well as less dense waters that eventually enter the central Arctic Ocean and supply the low salinity surface water, the polar mixed layer, of the Arctic Ocean. The strongest transformation affecting the AW after it has entered the Arctic Ocean occurs north of the Kara Sea, where it meets and mixes with the colder, less saline Barents Sea branch entering the Arctic Ocean via the St. Anna Trough. The mixing between the two branches leads to a cooling of the AW in the Fram Strait branch. The heat still remains in the Atlantic layer, but it is now distributed over a larger volume. The largest changes in AW characteristics occur, when it penetrates from one basin into another basin and mixes with the water column present there. Another process changing the water mass properties in the deep Arctic Ocean basins is the injection of cold, dense water, formed by ice formation and brine rejection on the shelves, which sinks down the slope as dense, entraining boundary plumes. Some plumes enter and cool the Atlantic layer, some sink deeper, entrain AW and bring it into the deep, warming the deeper layers.

Key findings:

Time series from the ASOF-N moorings in Fram Strait showed that several pulses of warmer AW combined with a stronger inflow, passed through the strait, adding heat to the interior of the Arctic Ocean. The net flow through Fram Strait is generally southward, ranging between 1 and 2 Sv. However, over long periods, extending over more than a year a monthly mean net transport into the Arctic Ocean was measured. The strength of this transport was close to 1 Sv. The AW supplies the main inflow of volume, salt and heat to the Arctic Ocean. The inflow through Fram Strait is, according to the recent ASOF-N results, an order of the magnitude larger than the inflow of Pacific water through Bering Strait, 10Sv as compared to 1Sv from the Pacific. In addition the inflow over the Barents Sea contributes about 1.5 Sv of AW. However, not all 10 Sv entering through Fram Strait are AW but also include intermediate and deep waters and a large part may be involved in a recirculation in, or just north of, the strait. The circulation loops (described in more detail in "potential offered for further dissemination and use") in the different basins have different residence times, and the heat that enters the Arctic Ocean as a warmer, and perhaps stronger, pulse becomes spread out spatially and temporally. Its return to Fram Strait extends over a period from perhaps less than 1 year for the re-circulation in (or just north of) the strait to 20–30 years for the farthest loops passing through the remote Canada Basin. This redistribution of the heat added to the Atlantic layer in the Arctic Ocean makes it difficult to determine how much of the oceanic sensible heat is lost to ice melt and released to the atmosphere, and how much is stored in the layer to eventually return to Fram Strait and the Nordic Seas.

Potential users:

Oceanographers working in the Arctic.

Scientists studying climate and climate change.

Fisheries, shipping, oil drilling companies (open water is a condition, which benefits these activities)

SUBJECT DESCRIPTORS CODES

46 ARCTIC ENVIRONMENT

272 GLOBAL CHANGE: CLIMATE CHANGE

369 MARINE: OCEANOGRAPHY (PHYSICAL AND OPERATIONAL)

400 MODELLING/MODELLING TOOLS, 3-D MODELLING

DOCUMENTATION AND INFORMATION ON THE RESULT

Documentation type	Details (Title, ref. number, general description, language)	Status: PU=Public CO=Confidential
Report	The Deliverable D 6.2 identifies active processes and estimates of their strength and time (forcing) dependence	Confidential
Scientific article (submitted for peer review)	Rudels, B., Anderson, L.G., Eriksson, P., Fahrbach, E., Jakobsson, M., Jones, E.P., Melling, H., Prinsenberg, S., Schauer, U. and Yao, Y. 2006: ACSYS chapter 4: Observations in the Ocean. In "Arctic Climate Change – The ACSYS Decade and Beyond" P. Lemke, T. Fichefet, C. Dick (Eds), (Submitted Feb. 2005)	Confidential
Book chapter	Rudels, B. 2001: Ocean Current: Arctic Basin Circulation. In "Encyclopedia of Ocean Sciences" Eds J. Steele, S. Thorpe and	Public

	K. Turekian. Academic Press, 177-187.	
Scientific article (peer reviewed)	Rudels, B., Björk, G., Nilsson, J., Winsor, P., Lake, I. and Nohr, C. 2005: The interaction between waters from the Arctic Ocean and the Nordic Seas north of Fram Strait and along the East Greenland Current: results from the Arctic Ocean-02 Oden expedition. Journal of Marine Systems 55, 1-30.	Public
Scientific article (peer reviewed)	Rudels, B., Jones, E.P., Schauer, U. and Eriksson, P. 2004: Atlantic Sources of the Arctic Ocean surface and halocline waters. Polar Research, 23, 181-208.	Public

INTELLECTUAL PROPERTY RIGHTS INTELLECTUAL PROPERTY RIGHTS

Type of IPR	KNOWLEDGE: Tick a box and give the corresponding details (reference numbers, etc) if appropriate					Pre-existing know-how Tick a box and give the corresponding details (reference numbers, etc) if appropriate	
	Current				Foreseen	Tick	Details
	Tick	NoP[1)]	NoI[2)]	Details	Tick		
Patent applied for							
Patent granted							
Patent search carried out							
Registered design							
Trademark applications							
Copyrights							
Secret know-how							
Other - please specify:							

1) Number of Priority (national) applications/patents
2) Number of Internationally extended applications/patents

MARKET APPLICATION SECTORS

80 Education

73 Research and development

CURRENT STAGE OF DEVELOPMENT

Scientific and/or Technical knowledge (Basic research)

Other:

QUANTIFIED DATA ABOUT THE RESULT

Items (about the results)	Actual current quantity	Estimated (or future) quantity
Time to application / market *(in months from the end of the research project)*	0	0
Number of (public or private) entities potentially involved in the implementation of the result:	6	45
of which: number of SMEs:	0	8
of which: number of entities in third countries (outside EU):	2	11

Targeted user audience: of reachable people	50	500
& publications (referenced publications only)	3	5
publications addressing general public (e.g. CD-ROMs, WEB sites)	1	1
publications addressing decision takers / public authorities / etc.	0	0
Visibility for the general public	YES	

FURTHER COLLABORATION, DISSEMINATION AND USE OF THE RESULT

COLLABORATIONS SOUGHT

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement		**INFO**	Information exchange/training	
JV	Establish a joint enterprise or partnership		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

The result will be merged with the data from the ASOF-EC(E) and ASOF-EC(W) cluster components and contribute directly to the the circum-Arctic International Arctic/Subarctic Ocean Flux Array (http://asof.npolar.no/about.html)

IP DAMOCLES will continue the investigations.

An interesting feature for further investigation are the recirculation patterns: The AW entering the Arctic Ocean returns towards Fram Strait in several loops confined to the different sub-basins of the Arctic Ocean to be re-exported to the Nordic Seas and eventually to the North Atlantic. The separation into several loops with different residence times and different mixing histories begins already in Fram Strait. This first recirculation loop is arguably the largest one and the one returning most heat to the Nordic Seas. A recirculation towards Fram Strait takes place in the northern Nansen basin, the water returning along the Gakkel Ridge. This return flow mainly comprises Fram Strait branch water. The Barents Sea branch water becomes gradually more prominent at the continental slope and in the basins and ridges farther from Fram Strait; in the Amundsen Basin, along the Lomonosov Ridge, in the Makarov Basin, along the Mendeleyev Ridge, at the Chukchi Cap, and in the loops in the Canada basin.

Another issue to be investigated in the future is how much the heat loss to ice and atmosphere in the Arctic Ocean depends upon the temperature of the entering Atlantic water and upon the strength of the inflow and how much is determined by the mixing processes driven by the local atmospheric conditions, atmospheric circulation, wind strength and cooling in the Arctic Ocean. It is conceivable that a larger inflow of heat is mainly manifested in a warmer Atlantic layer. Since the Atlantic waters in the different loops can, at least rudimentary, be distinguished by their salinities and by other tracers, it should be possible to estimate the storage in the different loops and determine the heat loss variations. This will require long time series of the hydrography in the strait and also in the interior of the basins. It is an important question though, since it addresses the vulnerability of the ice cover to changes of oceanic heat transports.

Another intriguing question arises from the fact that Fram Strait is the only passage that sustains transports in both directions and that the observations indicate periods longer than a year with a net inflow to the Arctic Ocean through Fram Strait. Part of the outflow from the Arctic Ocean is low salinity surface water and ice, part is intermediate and deep waters. Since

Fram Strait is also the only deep passage, it is the one passage, which allows Arctic Ocean intermediate and deep waters to exit. A net inflow through Fram Strait, together with the inflow of Atlantic water over the Barents Sea and the inflow of Pacific water through Bering Strait, then requires a balancing export of low salinity surface water, which must occur through the shallow Canadian Arctic Archipelago. The upper waters in the Arctic Ocean have a residence time of the order of 10 years with the present outflow rate of 2 – 3 Sv, divided about equal between Fram Strait and the Canadian Arctic Archipelago. A net inflow in Fram Strait implies that the outflow of upper water will at least double and most of this increased outflow must take place through the Canadian Arctic Archipelago. This would in a few years lead to a thinning of the upper layers, because the exported low salinity water can only be replaced by mixing and diluting Atlantic water with freshwater, and there is not enough freshwater supplied to the Arctic Ocean to accomplish this. The Atlantic water will be brought closer to the sea surface and could start to influence the ice formation and the thickness of the ice cover. These transport results must therefore be examined and tested in a Pan-Arctic context, where all passages are considered and where volume and salt balances are used as constraints on the obtained results. Such study will require long-term observations in order to obtain consistent results.

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

No.	Title:
8	**The optimised observing system for monitoring oceanic fluxes in Fram Strait and western Barents Sea**

CONTACT PERSON FOR THIS RESULT

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URL	
Specific Result URL	

SUMMARY

The long term consolidated data sets necessary to determine the variability of the freshwater and heat fluxes between the Arctic Ocean and the North Atlantic require an innovative design of the cost effective and well calibrated measurement arrays. The northward flow of the Atlantic water carrying heat into the Arctic Ocean has to be monitored in two main gateways, the eastern Fram Strait and Barents Sea Opening. The southward freshwater flux which enters the Nordic Seas both as liquid water and sea ice needs to be measured across the western Fram Strait, including the wide shelf east of Greenland. The latter requires current measurements and salinity stratification in shallow depths as well as ice thickness and velocity. To monitor fluxes not only the large cross-sections of the gateways have to be covered by measurements but also intensive variations on a wide range of scales, revealed by earlier observations have to be resolved. Thus a larger number of moorings and instruments is

needed or integral methods, measuring the whole water column have to be used. During ASOF-N observational arrays in Fram Strait and Barents Sea Opening were augmented and optimised in accordance with the observed time-space variability of measured parameters. Newly developed instruments were installed in the moorings, the observational arrays were redesigned for optimal combination of various properties, transport estimates were proposed based on empirical relations to especially selected instruments. To secure data collected under harsh environmental conditions the possibilities of the near real-time data transfer via satellite link with pop-up buoys was tested. To complement the observing system of mooring arrays a grid of hydrographic stations was designed and repeated every summer to get the spatial variability of the Atlantic water pathways.

Key innovations:

The Fram Strait mooring array was optimized to achieve better performance in measurements of temperature, salinity, currents and ice thickness – a prerequisite to derive heat and freshwater fluxes. In the eastern and deep part of the strait additional instruments were added at the depth of ca 700 m to resolve the lower boundary of the Atlantic water layer. Two new moorings placed in the deep part of the strait to resolve the recirculation patterns of the Atlantic water and thus to reduce the error in volume transport estimates. In addition to the moorings, integral measurements were performed with the use of bottom pressure recorders (BPRs) and inverted echo sounders with pressure sensors (PIESs) to estimate the barotropic currents and heat content of the water column. The performance of different current meters and TS sensors during the long-term deployments was evaluated and unreliable instruments were replaced to achieve the highest data recovery rate and the best data quality. The freshwater part of the mooring array in the western Fram Strait was equipped with near surface salinity sensors. Tube moorings in combination with Acoustic Doppler Current Profilers (ADCPs) were successfully deployed on the shelf, surviving the extensive ice cover and drifting icebergs. The moorings in the Barents Sea Opening were combined with a high resolution hydrographic section repeated 6times per year. Additionally this moored array was augmented with two bottom-mounted ADCPs in shallow parts. A new strategy was used for tracking the Atlantic water pathways based on combination of moorings, floats and hydrographic sections. The hydrographic sections included not only standard CTD casts but also currents profiles which were measured by the lowered ADCP and quasi-continuously by the vessel-mounted ADCP. The grid of stations was adjusted to optimise the coverage of spatial structures.

Potential users:

Scientists needing information on the physical conditions in the Arctic ocean. Companies working on development of the novel oceanographic instrumentation. Environmental Protection Agencies and fishery management (recommendation for sustainable observing systems). Climate or ocean observing programmes such as GOOS/GCOS could be interested in recommendations for the Arctic Ocean Observing System regarding methods of measurements, instrumentation, efficiency of the observing system, data transfer, etc.

Expected benefits:

Improvement of the existing observing system to assess Arctic change including additional observed properties, better coverage of the key areas, higher data recovery rate. Improved estimates of the oceanic fluxes due to more reliable and accurate time series, measured in representative locations with higher resolution. This allows for a better model validation and improvements in the potential of the models to predict environmental conditions. The experience gained in the design of a sustainable and cost effective observational system under harsh Arctic conditions.

SUBJECT DESCRIPTORS CODES

46 ARCTIC ENVIRONMENT
172 EARTH OBSERVATION TECHNOLOGY AND INFORMATION EXTRACTION
174 EARTH SCIENCES FOR CLIMATE RESEARCH
269 GEOPHYSICS, PHYSICAL OCEANOGRAPHY, METEOROLOGY, GEOCHEMISTRY, TECTONICS
369 MARINE: OCEANOGRAPHY (PHYSICAL AND OPERATIONAL)

DOCUMENTATION AND INFORMATION ON THE RESULT

Documentation type	Details (Title, ref. number, general description, language)	Status: PU=Public CO=Confidential
Newsletter	Fahrbach E., U.Schauer, G. Rohardt, 2003. How to measure oceanic fluxes from the North Atlantic through Fram Strait. ASOF Newsletter, no. 1, 3-7.	Public
Scientific article (peer reviewed)	Schauer U., E. Fahrbach, S. Osterhus, G. Rohard, 2004. Arctic warming through the Fram Strait: Oceanic heat transport from 3 years of measurements, JGR, vol. 109, C06026, doi:10.1029/2003JC001823,	Public
Scientific article (peer reviewed)	Holfort J, E. Hansen, 2005. Time series of Polar water properties in Fram Strait, GRL, vol. 32, L19601, doi:10.1029/2005GL022957.	Public
Scientific article (peer reviewed)	Walczowski W., J. Piechura, R. Osinski, P. Wieczorek, 2005. The West Spitsbergen Current volume and heat transport from synoptic observations in summer, DSR I, vol. 52, 1374□1391.	Public

INTELLECTUAL PROPERTY RIGHTS

Type of IPR	KNOWLEDGE: Tick a box and give the corresponding details (reference numbers, etc) if appropriate					Pre-existing know-how Tick a box and give the corresponding details (reference numbers, etc) if appropriate	
	Current				Foreseen	Tick	Details
	Tick	NoP[1)]	NoI[2)]	Details	Tick		
Patent applied for							
Patent granted							
Patent search carried out							
Registered design							
Trademark applications							
Copyrights							
Secret know-how							
Other - please specify:							

1) Number of Priority (national) applications/patents
2) Number of Internationally extended applications/patents

MARKET APPLICATION SECTORS

73 Research and development

CURRENT STAGE OF DEVELOPMENT

Scientific and/or Technical knowledge (Basic research)

Other:

QUANTIFIED DATA ABOUT THE RESULT

Items (about the results)	Actual current quantity	Estimated (or future) quantity
Time to application / market *(in months from the end of the research project)*	0	0
Number of (public or private) entities potentially involved in the implementation of the result:	6	45
of which: number of SMEs:	0	8
of which: number of entities in third countries (outside EU):	2	11
Targeted user audience: of reachable people	150	750
& publications (referenced publications only)	3	3
publications addressing general public (e.g. CD-ROMs, WEB sites)	1	0
publications addressing decision takers / public authorities / etc.	0	0
Visibility for the general public	YES	

FURTHER COLLABORATION, DISSEMINATION AND USE OF THE RESULT

COLLABORATIONS SOUGHT

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement		**INFO**	Information exchange/training	√
JV	Establish a joint enterprise or partnership		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

An augmented and optimised system (described in more detail in the TIP summary) which includes two gateway arrays of moorings and the hydrographic grid repeated on the annual basis is in operation at the moment and will be continued in the frame of the EU DAMOCLES integrated project. On the basis of knowledge achieved during ASOF-N the further optimisation of the observing system will take place, employing new techniques which became available during the project. The ASOF-N results showed that while the optimised mooring array in the eastern Fram Strait covers efficiently the main core of Atlantic water flow, the complex and variable recirculation in the deep part requires measurements with a high spatial resolution. Instead of increasing the number of moorings, it is planned to complement the deep part of the existing array by measurements with Seagliders, autonomous profiling devices capable to survey the repeated sections and to transfer data via satellite. A combination of this novel technique with the integral measurements tested in ASOF-N (BPRs, PIESs) should allow to decrease the number of moored instruments and to make the observing system more cost effective. For the near real-time data transfer the experience with pop-up buoys suggests that other solutions like a moored yo-yo data transmitter are more reliable and feasible for the Fram Strait array. The freshwater part of the moored array will be also continued with an effort put into the improvement of the tube moorings resistance under heavy ice conditions. The grid of hydrographic measurements will be repeated to trace the propagation of anomalies between the moored arrays and to establish a secondary observing system, allowing to cover gaps in the observations by moorings.

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

In the future the following partners could contribute to further optimisation of the observing system: Scientists e.g. oceanographers studying the physical conditions in the Arctic ocean. Engineering companies to develop novel oceanographic instrumentation.

No.	Title:
9	**Data of Lagrangian floats deployed in the Norwegian Sea during the years 2002-2005**

CONTACT PERSON FOR THIS RESULT

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Specific Result URL	

SUMMARY

Neutrally buoyant floats are devices that drift with the currents and thereby track the water pathways. During ASOF-N standard RAFOS floats were used. They were equipped with acoustic receivers tuned to the same frequency as the SOFAR sound sources installed on 13 moorings. The floats' acoustic receivers are detecting the time of arrivals (TOA) of signals transmitted regularly by the SOFAR sources. With these TOAs the position of the floats is tracked underwater acoustically. Thirty-eight floats were ballasted to drift at depths of about 300 m and an additional four floats were ballasted to drift at 1000m. The floats were deployed west of the Lofoten Islands, across the Norwegian Atlantic Current and close to the continental slope. After drifting for approximately 6 months, the floats were released to pop up at the surface, where they transmitted via satellite the data recorded during the previous 6 months. During this transmission the floats also recorded in situ temperature and pressure. Of the 38 floats ballasted for 300m, 25 transmitted data. While in general the data transmission rate was very good (of 24 floats deployed between spring 2003 and 2004 only 3 were lost) all ten floats deployed in November 2004 were lost. The best explanation to account for this strange loss is that they got transported northward by a current surge and got stuck under the ice cover. This would then indicate that in winter 2004 none of floats got transported into the Barents Sea, where they would have been safe but all ten floats got transported into Fram Strait.

Innovations:

During ASOF-N the balance depth was increased to 300m as previous experience from the MAIA project showed that this is the depth were the core of Atlantic water is found. The 5 float deployments made during ASOF-N means that for the first time variability between the years can be traced. During the predecessor project MAIA only 1 deployment of 5 floats took place. The measurements with floats made during ASOF-N showed that the Atlantic current is not restricted to a swift boundary current (like a jet) but more like a broad current dominated by mesoscale eddies.

Potential users:

Oceanographer, especially scientists interested in Arctic ocean research.
Scientists investigating ocean circulation.
Scientist studying the interactions of water circulation and climate.

SUBJECT DESCRIPTORS CODES

46 ARCTIC ENVIRONMENT
172 EARTH OBSERVATION TECHNOLOGY AND INFORMATION EXTRACTION
272 GLOBAL CHANGE: CLIMATE CHANGE
366 MARINE ECOSYSTEMS
367 MARINE SCIENCES/MARITIME STUDIES

DOCUMENTATION AND INFORMATION ON THE RESULT

Documentation type	Details (Title, ref. number, general description, language)	Status: PU=Public CO=Confidential
Report on float deployment	The report contains geographical locations (longitude and latitude) for each floats deployment and release. It also shows the position of the SOFAR moorings and selected float trajectories.	Confidential

INTELLECTUAL PROPERTY RIGHTS

Type of IPR	KNOWLEDGE: Tick a box and give the corresponding details (reference numbers, etc) if appropriate					Pre-existing know-how Tick a box and give the corresponding details (reference numbers, etc) if appropriate	
	Current				Foreseen	Tick	Details
	Tick	NoP[1)]	NoI[2)]	Details	Tick		
Patent applied for							
Patent granted							
Patent search carried out							
Registered design							
Trademark applications							
Copyrights							
Secret know-how							
Other - please specify:							

1) Number of Priority (national) applications/patents
2) Number of Internationally extended applications/patents

MARKET APPLICATION SECTORS

73 Research and development

CURRENT STAGE OF DEVELOPMENT

Scientific and/or Technical knowledge (Basic research)

Other:

QUANTIFIED DATA ABOUT THE RESULT

Items (about the results)	Actual current quantity	Estimated (or future) quantity
Time to application / market *(in months from the end of the research project)*	0	0
Number of (public or private) entities potentially involved in the implementation of the result:	1	45
of which: number of SMEs:	0	8
of which: number of entities in third countries (outside EU):	0	11
Targeted user audience: of reachable people	150	300
& publications (referenced publications only)	0	3
publications addressing general public (e.g. CD-ROMs, WEB sites)	0	5
publications addressing decision takers / public authorities / etc.	0	2
Visibility for the general public	YES	

FURTHER COLLABORATION, DISSEMINATION AND USE OF THE RESULT

COLLABORATIONS SOUGHT

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement		**INFO**	Information exchange/training	√
JV	Establish a joint enterprise or partnership		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

The result will be merged with the data from the ASOF-EC(E) and ASOF-EC(W) cluster components and contribute directly to the the circum-Arctic International Arctic/Subarctic Ocean Flux Array (http://asof.npolar.no/about.html)

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

Exploitation plans

CONFIDENTIAL

Description of the use and the dissemination of result(s), partner per partner

Contract number:	EVK2-CT-2002-00139
Result number:	32062
Partner's name:	Eberhard Fahrbach

CONTACT PERSON(S):

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TITLE AND BRIEF DESCRIPTION OF MAIN RESULT(S)

HEAT FLUX THROUGH FRAM STRAIT CALCULATED FROM HIGH-RESOLUTION YEAR-ROUND MEASUREMENTS AND HINDCASTS WITH THE NAOSIM MODEL

A continuous time series of volume and heat flux through Fram Strait was derived from measurements with moored instruments. The moorings cover the cross section over the entire deep part of Fram Strait. Temperature and velocity are monitored, allowing to integrate heat fluxes and to distinguish between northward, southward and net fluxes. ASOF-N allowed continuing the time series, which is now sufficiently long to determine the variability of the oceanic fluxes through Fram Strait on interannual time scales - and also to approach the declared objective of the ASOF cluster to capture variability on decadal time scales.

TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Activity:	Proposal: CLIVAR
Timescale(month):	3
Brief description:	A proposal in the framework of the international program CLIVAR (CLImate VARiability and Predictability) has been submitted to the BMBF. The project plans to monitor and model the circulation of fresh water in the Arctic and its release to the North Atlantic. In addition it is planed to submit a proposal to use ASOF-N data to advance understanding of the coupling between circulation and physical properties of Atlantic Water and zooplankton distribution in the Arctic Ocean.
Activity:	International Polar Year: SPACE

Timescale(month):	9
Brief description:	The flux time series will be used in order to integrate the expected high resolution synoptic Pan-Arctic study of Climate and Environment (SPACE) planned during the International Polar Year 2007/08 (IPY).
Activity:	Follow up project: IP DAMOCLES
Timescale(month):	0
Brief description:	Based on the results of ASOF-N, time series of heat flow through Fram Strait will be continued within the EU-funded IP "DAMOCLES" (Developing Arctic Modelling and Observing Capabilities for Long-term Environment Studies). The aim is to obtain longer time series to be able to tackle decadal variability of the fluxes and to improve and develop new instrumental technology based on experiences during ASOF-N to monitor the input of mass and heat to the Arctic Ocean.
Activity:	International Project: AOMIP
Timescale(month):	1
Brief description:	Optimisation of the NAOSIM model will continue within the Arctic Ocean Model Intercomparison Project (AOMIP). The project is an official activity of the Arctic Climate System Study / Climate and Cryosphere Numerical Experimentation Group (ACSYS/CliC NEG).

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement/Franchising		**INFO**	Information exchange	√
JV	Joint venture		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

QUANTIFIED DATA

Items	Currently achieved quantity	Estimated future quantity
Economic impacts (in EURO)	0	0
number of licenses issued (within EU)	0	0
numberof licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
number of entrepreneurial actions (start-up company, joint ventures...)	0	0
number of direct jobs created[c]	0	0
number of direct jobs safeguarded[c]	1	1
number of direct jobs lost	0	0

Description of the use and the dissemination of result(s), partner per partner

Contract number:	EVK2-CT-2002-00139
Result number:	34678
Partner's name:	Eberhard Fahrbach

CONTACT PERSON(S):

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TITLE AND BRIEF DESCRIPTION OF MAIN RESULT(S)

DATA AND DATA MANAGEMENT OF CTD PROFILES AND MOORING

CTD Data
CTD (Conductivity, Temperature, and Depth) profiles were measured during cruises in 2003 - 2005 across Fram Strait, in the East Greenland Current between 74° and 79° N and in the eastern part of the Greenland Sea. For detailed information on the CTD stations see www.awi-bremerhaven.de/Research/IntCoop/Oce/ASOF/data-m anagement/Map-CTD-Moor.htm. The current CTD dataset can be retrieved via www.awi-bremerhaven.de/OZE.

Mooring Data
Moorings were deployed across Fram Strait and in the East Greenland Current at 74° N. A detailed map with mooring location is presented in the web. The current dataset can be retrieved via www.awi-bremerhaven.de/OZE.

TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Activity:	Improvements of database
Timescale(month):	4
Brief description:	In addition to the information about cruise details and data an additional service is planned for the summer 2006. In addition to the data set already provided, the data will be plotted and shown as profiles directly on the internet.
Activity:	IP DAMOCLES
Timescale(month):	0
Brief description:	During IP DAMOCLES mooring and CTD measurements will continue.

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement/Franchising		**INFO**	Information exchange	√
JV	Joint venture		**CONS**	Available for consultancy	√
Other	(please specify)				

Details:

QUANTIFIED DATA

Items	Currently achieved quantity	Estimated future quantity
Economic impacts (in EURO)	0	0
number of licenses issued (within EU)	0	0
numberof licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
number of entrepreneurial actions (start-up company, joint ventures...)	0	0
number of direct jobs created[c]	0	0
number of direct jobs safeguarded[c]	4	4
number of direct jobs lost	0	0

Description of the use and the dissemination of result(s), partner per partner

Contract number:	EVK2-CT-2002-00139
Result number:	35048
Partner's name:	Eberhard Fahrbach

CONTACT PERSON(S):

Name	Eberhard Fahrbach
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E-mail	efahrbach@awi-bremerhaven.de

TITLE AND BRIEF DESCRIPTION OF MAIN RESULT(S)

THE OPTIMISED OBSERVING SYSTEM FOR MONITORING OCEANIC FLUXES IN FRAM STRAIT AND WESTERN BARENTS SEA

During ASOF-N observational arrays in Fram Strait and Barents Sea Opening were augmented and optimised in accordance with the observed time-space variability of measured parameters. Newly developed instruments were installed in the moorings, the observational arrays were redesigned for optimal combination of various properties, transport estimates were proposed based on empirical relations to especially selected instruments. To secure data collected under harsh environmental conditions the possibilities of the near real-time data transfer via satellite link with pop-up buoys was tested. To complement the observing system of mooring arrays a grid of hydrographic stations was designed and repeated every summer to get the spatial variability of the Atlantic water pathways.

TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Activity:	IP DAMOCLES
Timescale(month):	0
Brief description:	An augmented and optimised system (described in more detail in the TIP summary) which includes two gateway arrays of moorings and the hydrographic grid repeated on the annual basis is in operation at the moment and will be continued in the frame of the EU DAMOCLES integrated project. On the basis of knowledge achieved during ASOF-N the further optimisation of the observing system will take place, employing new techniques which became available during the project.

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement/Franchising		**INFO**	Information exchange	√
JV	Joint venture		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

QUANTIFIED DATA

Items	**Currently achieved quantity**	**Estimated future quantity**
Economic impacts (in EURO)	0	0
number of licenses issued (within EU)	0	0
numberof licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
number of entrepreneurial actions (start-up company, joint ventures...)	0	0
number of direct jobs created[c]	1	1
number of direct jobs safeguarded[c]	0	1
number of direct jobs lost	0	0

Description of the use and the dissemination of result(s), partner per partner

Contract number:	EVK2-CT-2002-00139
Result number:	33135
Partner's name:	Eberhard Fahrbach

CONTACT PERSON(S):

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E-mail	efahrbach@awi-bremerhaven.de

TITLE AND BRIEF DESCRIPTION OF MAIN RESULT(S)

FRESHWATER FLUX THROUGH FRAM STRAIT DURING 2003-2005 AS MEASURED DURING ASOF-N

Freshwater export from the Arctic to subarctic seas have the potential to influence the northbound current systems by modifying the stratification of the receiving basins. This would alter the oceanic heat transport, which again would influence the climate of North Western Europe. The export of fresh water occurs in liquid (polar water) and solid (sea ice) phase. With the advent of ASOF-N we were able to continue and extend existing time series (solid phase freshwater flux since 1990 and liquid freshwater flux since 1997), and hence determine the seasonal and interannual variability of freshwater fluxes through Fram Strait.

TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Activity:	International Project: AOMIP
Timescale(month):	1
Brief description:	Optimisation of the NAOSIM model will continue within the Arctic Ocean Model Intercomparison Project (AOMIP). The project is an official activity of the Arctic Climate System Study / Climate and Cryosphere Numerical Experimentation Group (ACSYS/CliC NEG).
Activity:	IP DAMOCLES
Timescale(month):	0
Brief description:	During IP DAMOCLES the high resolution version of AWI's model NAOSIM will be used to support the observations and data interpretation.

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

R&D	Further research or development	√	**FIN**	Financial support
LIC	Licence agreement		**VC**	Venture capital/spin-off funding

MAN	Manufacturing agreement	**PPP**	Private-public partnership
MKT	Marketing agreement/Franchising	**INFO**	Information exchange
JV	Joint venture	**CONS**	Available for consultancy
Other	(please specify)		

Details:

QUANTIFIED DATA

Items	Currently achieved quantity	Estimated future quantity
Economic impacts (in EURO)	0	0
number of licenses issued (within EU)	0	0
numberof licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
number of entrepreneurial actions (start-up company, joint ventures...)	0	0
number of direct jobs created[c]	0	0
number of direct jobs safeguarded[c]	0	0
number of direct jobs lost	0	0

Description of the use and the dissemination of result(s), partner per partner

Contract number:	EVK2-CT-2002-00139
Result number:	34692
Partner's name:	Eberhard Fahrbach

CONTACT PERSON(S):

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Fax	+49(471)4831-1797
E-mail	efahrbach@awi-bremerhaven.de

TITLE AND BRIEF DESCRIPTION OF MAIN RESULT(S)

EXCHANGES OF VOLUME, HEAT AND FRESHWATER BETWEEN THE ATLANTIC AND ARCTIC OCEAN

The inflow of water and heat from the Atlantic Ocean to the Arctic Ocean was studied during the ASOF-N programme. The Atlantic water (AW) reaches the Arctic Ocean through two passages, the deep (2600m) Fram Strait and across the broad shelf of the Barents Sea, where it enters through the Bear Island Channel and passes through the Barents Sea into the Kara Sea and most of the AW continues into the Arctic Ocean via the St. Anna Trough. The programme also attempted to quantify the outflow of sea ice and low salinity surface water (the export of liquid freshwater) from the Arctic Ocean to the Nordic Sea through Fram Strait and, since Fram Strait is the only deep passage connecting the Arctic Ocean to the world ocean, to estimate the exchanges of intermediate and deep waters between the Arctic Ocean and the Nordic Seas. The AW was followed on its way through the Norwegian Sea from the Greenland – Scotland Ridge to the two inflow passages and the strength of the transport and the changes in water mass characteristics were studied.

TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Activity:	IP DAMOCLES
Timescale(month):	0
Brief description:	During DAMOCLES an extensive, multifaceted observation programme (ice, atmosphere, ocean) will be launched and the measurements will be coupled with intense modelling activity.

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

R&D	Further research or development	√	**FIN**	Financial support	
LIC	Licence agreement		**VC**	Venture capital/spin-off funding	
MAN	Manufacturing agreement		**PPP**	Private-public partnership	
MKT	Marketing agreement/Franchising		**INFO**	Information exchange	
JV	Joint venture		**CONS**	Available for consultancy	√
Other	(please specify)				
Details:					

QUANTIFIED DATA

Items	Currently achieved quantity	Estimated future quantity
Economic impacts (in EURO)	0	0
number of licenses issued (within EU)	0	0
numberof licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
number of entrepreneurial actions (start-up company, joint ventures...)	0	0
number of direct jobs created[c]	0	0
number of direct jobs safeguarded[c]	0	0
number of direct jobs lost	0	0

Overview of Exploitations Plans

RESULT TITLE / OWNER	COMMENT
Heat Flux through Fram Strait calculated from high-resolution year-round measurements and from hindcasts with the NAOSIM model / Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung	Exploitation plan included in eTIP
Data and data management of CTD profiles and mooring / Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung	Exploitation plan included in eTIP
The optimised observing system for monitoring oceanic fluxes in Fram Strait and western Barents Sea / Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung	Exploitation plan included in eTIP
Freshwater Flux through Fram Strait during 2003-2005 as measured during ASOF-N / Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung	Exploitation plan included in eTIP
Exchanges of volume, heat and freshwater between the Atlantic and the Arctic Ocean / Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung	Exploitation plan included in eTIP

I am the Co-ordinator of the above project, and confirm on behalf of the contracted Partners the information contained in this Technological Implementation Plan, and I authorise its public dissemination.

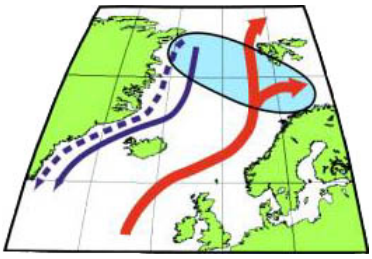
Signature:	Name:
Date:	**Organisation:**

ASOF-N

Arctic-Subarctic Ocean Flux Array for European Climate: North

Contract No:
EVK2-CT-2002-00139

FINAL REPORT



Section 5

Executive Summary
of the Overall Project

Energy,
Environment
and Sustainable Development

Fifth
Framework
Programm

5. Executive publishable summary of the overall project

Contract n°:	EVK2-CT-2002-00139	Reporting period:	1.01.2003 - 31.3.2006
Title:	Arctic-Subarctic Ocean Flux Array for European Climate: North (ASOF-N)		

Objectives:

The main ASOF-N objective is to establish the components of the global observing system in choke points of the Nordic Seas to determine the fluxes between the Arctic Ocean and the North Atlantic and to understand and predict how they respond to climatic forcing. To achieve this goal long time series are needed. For this purpose the main tasks were to perform the field measurements with a special focus on setting up of the long term measuring arrays of moored instruments and floats:

- WP 1 'Atlantic water pathways' - measurements of the track lines of Atlantic water flow by floats and mapping horizontal distributions of the Atlantic water properties;
- WP 2 'Fluxes across the western Barents Sea' - measurements by the mooring array in the Barents Sea opening and carrying out the hydrographic sections;
- WP 3 'Heat flux through Fram Strait' - currents and temperature measurements by the mooring array in the eastern and central Fram Strait and the high resolution vertical section of temperature and salinity across the strait;
- WP 4 'Freshwater flux through Fram Strait' - currents and temperature measurements by the mooring array in the western Fram Strait and the high resolution vertical sections of temperature and salinity across and along the strait.

The following set of tasks included analysis of data sets, obtained during field measurements in WP1, WP2, WP3 and WP4 in the first year of the project The objective of WP5 'Data Management' was to provide access to the project data and the actual status of field and modelling work and to organize the data flow to the project data centre from all partners. The WP6 'Integration and Synthesis' aimed to develop the adequate water mass classification for Fram Strait including also a description of time evolution of the water mass properties and regional correlations between the observed variables.

Scientific achievements:

The field work carried out during the third year of ASOF-N provided repeated hydrographic surveys including vertical sections of temperature and salinity in the observation area (Barents Sea, Greenland Sea, Fram Strait). The ASOF-N mooring arrays maintained during the project provided time series of fluxes in the Barents Sea opening and across Fram Strait. The analysis of the data obtained during ASOF-N in combination with data measured before ASOF-N permitted to describe the longer term variability of the oceanic conditions in the ASOF-N area. On this basis time variability of the water mass properties, heat and volume fluxes were estimated for the three-year long period and beyond. In combination with historical data a nearly decadal time series of fluxes resulted. The variability of volume, heat and freshwater fluxes was analyzed on different time scales from daily to interannual and nearly decadal ones. The contributions of local and remote forcing to the temporal and spatial changes of flow and temperature fields were estimated, giving the insight into the relationship between variability of forcing and of fluxes. High resolution numerical models for the western Barents Sea (NPI) and the Greenland Sea, Fram Strait and Arctic Ocean (AWI) were implemented and runs covering the ASOF-N period were completed. A refined water mass classification for Fram Strait was derived and the possibility was explored to compute the time evolution of heat and salt fluxes through Fram Strait, using variable reference salinities and temperatures. The adjustments of the measuring arrays based on the assessment of the observational system performance during the deployments resulted in a data return of about 90% during the final phase of the project.

Socio-economic relevance and policy implications:

Variability of the ocean circulation and the water mass distribution in the Nordic Seas lead to changes in the volume, heat and freshwater fluxes between the Arctic Ocean and North Atlantic. Changes in these fluxes can have a strong influence on the role of the ocean in the climate system which includes the potential of abrupt climate changes. The climate variability in particular in the northern North Atlantic has a strong impact on the living conditions in Northwest Europe. This includes energy consumption, sea traffic and marine living resources. Therefore a reliable prediction system is of high value to maintain the present living conditions. Prediction requires understanding and modelling of the relevant processes and monitoring key parameters to validate and constrain the models. Since variability of the relevant time scales can be only studied on the base of the long-term time series, ASOF-N aimed to pave the way towards an observing system consisting of a cost-effective array of instruments in the key areas for the exchanges between the North Atlantic and Arctic Ocean. The results of ASOF-N will help to design such a system, to give advice for its implementation and consequently contribute to maintain the quality of life in Northwest Europe.

Results from ASOF-N gave background information to the scientific report from the **Arctic Climate Impact Assessment** (ACIA) published in 2005 which is a project of the Arctic Council and the International Arctic Science Committee (IASC) a high level intergovernmental forum. The ASOF-N results are included into reports to **ICES** (the International Council for the Exploration of the Sea), which gives advice to the member countries and helps them manage the North Atlantic Ocean and adjacent seas. ASOF results are a contribution to the formation of the EU-Integrated Project **DAMOCLES** standing for Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies.

ASOF results underline the need of an sustained observing system in the Arctic and Subarctic regions in the framework of the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS) which can be maintained beyond the time of individual research projects.

Conclusions:

The evaluation of the available historical data together with the results of the ASOF-N field measurements and modelling results revealed a significant warming of the Atlantic Water propagating through the ASOF-N region and an increased heat flux into the Arctic Ocean. The data indicate that variations of the fluxes between the North Atlantic and the Arctic Ocean occur on a wide range of time scales and are interlinked between the main passages. The volume and heat fluxes are also controlled by local and remote atmospheric forcing. Both in the Barents Sea Opening and Fram Strait variability of temperature is independent of the variations in the volume flux. The former is dominated by advective processes and depends mostly on the upstream conditions while the latter is related to the local atmospheric forcing. Observed variations in the Atlantic Water pathways (namely intensification/ weakening of the branches of the Norwegian-Atlantic Current) result in the redistribution of the Atlantic Water in Fram Strait and strongly influence the heat transport into the Arctic Ocean. All these changes occur over long time scales and only quasi-continuous measurements over a decade and more give a chance to identify the nature of these

fluctuations. Lacking spatial resolution is a problem in spite that the major parts of the transports occur in relatively narrow boundary currents. Technical problems with the present day equipment require redundancy. New technology available to replace conventional instruments on an operational basis is under development and a design of optimized observational array has been worked out on the basis of the ASOF-N experience.

Keywords:

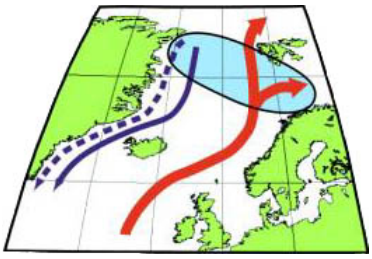
Fram Strait, Barents Sea, heat flux, freshwater flux, Atlantic water inflow, Arctic Ocean-North Atlantic exchange, moorings, floats, CTD sections

ASOF-N

Arctic-Subarctic Ocean Flux Array for European Climate: North

Contract No:
EVK2-CT-2002-00139

FINAL REPORT



Section 6

Detailed Report
of the Overall Project

Energy,
Environment
and Sustainable Development

Fifth
Framework
Programm

6. Detailed report of the overall project

6.1. Background

The spread of warmth to high latitudes in the Atlantic sector is due to a complex ocean-atmosphere interaction, which includes the vast amount of heat (about 1015 W) carried northward by the ocean's Thermohaline Circulation (THC). The THC consists of deep convection induced by surface cooling at high latitudes, sinking to depth, and upwelling of deep waters at lower latitudes, with horizontal shallow and deep currents connecting these vertical flows. The deep convection and sinking in the North Atlantic (in the Labrador and Greenland Seas) have no counterpart in the North Pacific Ocean, where northward heat transport is consequently much weaker. However, the Atlantic THC has not always been like today's. Palaeoclimate records prove that massive and abrupt climate change has occurred in the Northern Hemisphere, especially during and just after the last Ice Age (Dansgaard et al., 1993; see also Broecker 1997, 2000; Marotzke, 2000), with THC change as the most plausible driver. Similar change might occur in the future. Model results suggest that the human-induced increase in the atmospheric concentration of CO_2 and other greenhouse gases will lead to a dramatic reduction in THC strength in the Atlantic (e.g., Manabe and Stouffer, 1993; Rahmstorf and Ganopolski, 1999; Wood et al., 1999), and both palaeo-climate records and models suggest that the changes in the strength of the THC may occur rapidly, in a few decades. The large scale and abrupt nature of these changes will make adaptation to, and mitigation of, their impacts exceedingly difficult in the regions affected, and our ability to assess the probability of these changes is poor. While most climate models indicate that there will be weakening of the THC, there is considerable spread between their projections. In addition, large scale climate predictions do not show a cooling in the relevant areas of the northern hemisphere.

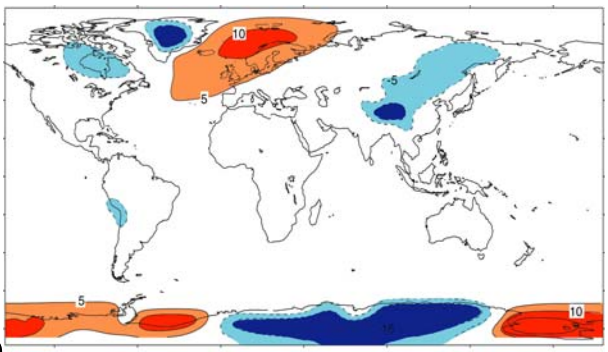
The mechanisms believed to control the strength of the THC include: the poleward flux of warm and salty Atlantic surface water; the freshwater flux out of the Arctic; the speed and density of the deep overflows crossing the Greenland-Scotland Ridge; open-ocean convection; mixing near the ocean margins, including the sea surface; ice-ocean and atmosphere-ocean interactions; freshwater input from the atmosphere and rivers. These processes and transports are poorly observed and understood. Before the ASOF period there had been no measurements of the freshwater flux between the Arctic Ocean and Atlantic by either of its two main pathways; we had had VEINS measurements of the heat and salt flux to the Arctic Ocean but not yet of its variability on any scale; we had had a growing knowledge of the long-term variability of the hydrography of the dense overflows which "drive" the THC but only embryonic ideas as to their causes, etc. Understandably then, these key mechanisms and processes were too crudely represented in the present generation of climate models.

Observations suggest that significant changes occurred in the Arctic during the last decades. They affect the marine and terrestrial systems with a noticeable impact on human life. At present it is not clear, if these changes are part of natural variability or related to human action. The high latitude oceans form a sensitive and important component of the global climate system which implies a strong Arctic response to global change and a strong global response to Arctic change. The climate of the European sector is especially vulnerable. Annual-mean temperatures in Northwest Europe and Scandinavia are considerably higher than they should be for their latitude (Fig. 6.1) because a vast amount of heat is carried northward by the large scale circulation in the ocean which is maintained by cooling-induced deep convection and sinking at high latitudes, upwelling at lower latitudes, and the horizontal ocean currents which connect the two. In the North Atlantic the warm water flows through the Nordic Seas and finally reaches the Arctic Ocean through the Barents Sea and Fram Strait where it significantly affects the conditions which determine the properties of polar water and sea ice flowing from the Arctic to the south.

The North Atlantic Oscillation (NAO), the dominant recurrent pattern of atmospheric forcing in the wintertime North Atlantic, has amplified over the past few decades to its most extreme positive state since records began in 1865. However, it relaxed again during the period of ASOF-N. Temperature increase in the Arctic is three times higher than globally observed during the last 50 year (Fig. 6.1). The Arctic sea ice is shrinking, the September trend from 1979 to 2005 shows a decline of more than 8 percent by decade (as given by a joint press release between the National Snow and Ice Data Center, CIRES at the University of Colorado, Boulder; NASA; and the University of Washington, 28 September 2005). This suggests that model-derived future scenarios contain realistic features which include that climatic conditions in the Arctic are tending towards an extreme situation and will influence not only the Arctic but will have significant effects on the north-western Europe. Rapid and radical climate changes are a not-unlikely scenarios.

Such large, fast climate change would make adaptation and mitigation exceedingly difficult for the affected countries without believable predictive models as a base of assessment and advice. At present no measurements over sufficient time periods with appropriate spatial coverage and accuracy are available to validate climate models which are under development and in which key mechanisms and processes are still only crudely represented. If those data sets will not be provided, conclusions will keep their speculative nature and realistic advice e.g. for use of the Northern sea route or exploitation of natural resources in ice covered areas will not be possible. If an optimal observation system will be developed, cost effective diagnosis of the Arctic and the Northwest European natural conditions will be possible and societal management including natural resources can occur on the basis of predictions with properly validated models.

a)



b)

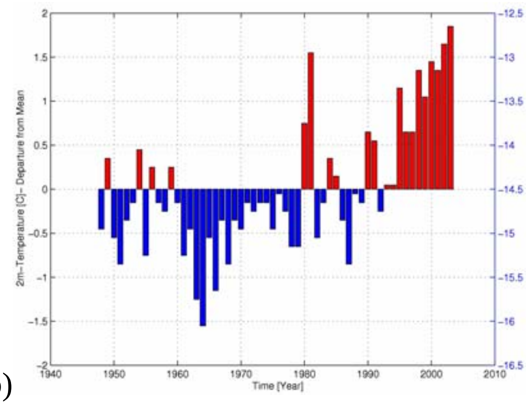


Fig. 6.1a: Annual mean surface temperature anomalies, from NCAR data, relative to zonal averages (Rahmstorf and Ganopolski, Clim. Change, 1999). There is a 5-10°C warm anomaly over NW Europe and the Nordic Seas.

Fig. 6.2b: The observed changes of Arctic surface air temperature during the last 50 years between 70° to 90°N from NCEP. The trend of 1.6°C per 50 years than three times stronger than the global one over last 50 years.

Thus the specific rationale for the ASOF-N study was based on the following main points:

- The Framework 5 Programme was taking place at a special time for the climate of Europe. The North Atlantic Oscillation, our dominant recurrent pattern of atmospheric forcing in the wintertime North Atlantic, has amplified over the past few decades to its most extreme positive state since 1865. And there is a strong expectation that atmospheric carbon dioxide levels will continue to rise in a spectacular fashion over the next century, even assuming compliance with Rio and Kyoto agreements on limiting emissions.
- Temperature increase in the Arctic is three times higher than globally observed during the last 50 years (Fig. 6.2). This suggests that model-derived future scenarios contain realistic

features that suggest that climatic conditions in the Arctic are tending towards an extreme situation which will influence not only the Arctic but will have significant effects on the north-western Europe.

- Thus rapid and radical climate changes in our sector are a likely scenario; this expectation is reinforced by the fact that most climate models predict that anthropogenic greenhouse gas forcing will act to maintain or amplify NAO-positive conditions in our sector.
- Such large, fast climate change would make adaptation and mitigation exceedingly difficult for the affected countries, and we have only a few decades in which to develop an understanding of the climatic forcing, the ocean’s response and the socio-economic impact of both. Though peak CO_2 is not expected before 2100, we will need believable predictive models well before that point is reached.
- We have strong evidence that changes in the Arctic are related to oceanic fluxes from mid latitudes which enter the Arctic Ocean along different pathways either through the Barents Sea or through Fram Strait. Models suggest that the two pathways are interlinked and observations indicate that fluctuations might occur in an inverse mode. Since the transfer of heat and freshwater is affected by the different ocean-atmosphere interaction over the shallow Barents Sea or the deep passage of Fram Strait, the spreading into the different pathways affects the climatic conditions in the Arctic.
- ASOF-N therefore intended to focus on the key area between northern Norway and Greenland (Barents Sea opening and Fram Strait) where the warm and saline water from the North Atlantic reaches the Arctic Ocean from the south and sea ice as well as fresh and cold Polar Water enter the Nordic Seas from the north. The Atlantic water inflow affects the stratification in the Arctic Ocean and the outflow from the Arctic Ocean is either transferred south by the East Greenland Current or enters and affects the water mass modification in the Nordic Seas. These are the locations where we have already developed our best data set on the nature and the variability of the fluxes and assure the establishment of an observational system which allows to contribute with a regional component to the overall measurements of Arctic/subarctic fluxes.
- At present our coupled climate models suggest that oceanic exchanges between high- and mid latitudes determine the rate of the overturning circulation in the North Atlantic and we have direct observational evidence that changes in the high latitude ocean are able to drive change in the deep and abyssal layers of the North Atlantic.

6.2. Scientific/technological and socio-economical objectives

Whereas models predict a stronger temperature increase due to greenhouse gas forcing in the high northern latitudes, there is concern that “global warming” will be accompanied by regional cooling across Northwest Europe and Scandinavia due to weakening of this THC loop. This weakening is likely to take effect through processes occurring in the Arctic since the freshwater fluxes from the high Arctic control the deep dense overflows of water which drive the THC. For this reason, the ASOF projects (ASOF-East, ASOF-West, ASOF-North) have been designed to meet the following overall objective:

To establish the appropriate components of the global observing system in the choke points of the Nordic Seas necessary to obtain the long term consolidated data set required to determine the variability of dense water, freshwater, and heat fluxes between the Arctic Ocean and the North Atlantic, to understand and predict how the fluxes respond to climatic forcing, and to provide the tools needed to asses the risks of abrupt changes

In this part of the project cluster, ASOF-N, we focused on the northern part of the area which is a choke point for the above indicated processes. Each of the three ASOF projects provided independent results, but they will gain their full value only by the combination of all three.

Three components of ASOF (North, East and West) intended to provide the most direct measurements to derive those fluxes using moored arrays in the four passages which bound the Nordic Seas through which the controlling fluxes occur. It was the objective to build an observation system on existing data to provide the basis of estimates of the variability of the fluxes on decadal time scales.

ASOF-N was focused on the northern boundaries where warm and salty waters enter the Arctic Ocean and cold and fresh water as well as sea ice are advected from the Arctic Ocean into the Nordic Seas. The measurements aimed to understand the processes which control the transports by a combination of field work and modelling and served to establish a well calibrated array which should be a European contribution to a global observing system. Novel instrumentation and methods were implemented for the purpose.

The workplan agreed upon by the ASOF-N consortium was aimed at:

- **Measuring time-series of ocean fluxes between the Arctic and the Atlantic which have greatest bearing on the overturning rate of the thermohaline "conveyor"** specifically the heat flux into the Arctic Ocean from the Nordic Seas and the freshwater flux passing south from the Arctic Ocean along the coast of Greenland. Despite its apparent importance in a range of climate models, the latter flux had never been measured, largely because of the difficulty of obtaining repeated profiles of the freshwater distribution to the base of the east Greenland ice-pack over long periods of time. A prototype system was used to accomplish this task for the first time.
- **Proposing a design for an optimised array to make the longer-term decadal measurements needed to understand and monitor ocean-atmosphere interaction on climate time-scales in the North Atlantic**, as exemplified by the NAO. Such design requires adequate knowledge of time-space variability for the selected location and parameters. This project has made a start with arrays and methods for measuring the heat flux into and the freshwater outflows from the Arctic.

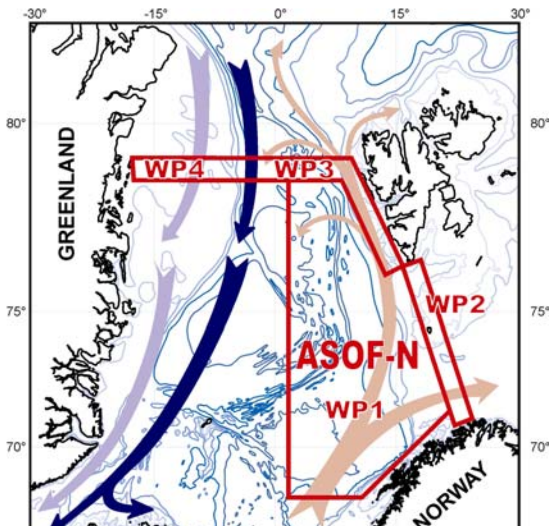


Fig. 6.3: The measurements areas in ASOF-N according to workpackages.
The system of main currents is shown in the background.

The principal measurement areas are shown in figure 6.3. To reach our aim, the workplan consisted of six groups of activities (observations, modelling, instrument-development, system design, data management and synthesis) grouped into six workpackages, which structured the project into manageable units:

WP1: Atlantic water pathways

The water mass properties in the Arctic are significantly influenced by the heat and salt supplied by the northward flow of warm Atlantic Water. Its high salinity counteracts the input of freshwater from the continents and the relative fresh seawater entering through Bering Strait. Consequently it affects the stability and the water mass modification in the Arctic Ocean. It reaches the Arctic Ocean either through the Barents Sea opening or through Fram Strait. Deployment of acoustically ranged floats in relatively shallow depth and hydrographic surveys together with a regional model were used to monitor and understand the spreading of the Atlantic Water into the different pathways.

WP 2: Fluxes across the western Barents Slope

Part of the northward flow of warm Atlantic Water reaches the Arctic Ocean through Barents Sea. Deployment of moorings and hydrographic surveys together with a regional model provided the basis to monitor and understand the flow of Atlantic Water into the Barents Sea.

WP 3: Heat Flux through Fram Strait

Part of the northward flow of warm Atlantic Water reaches the Arctic Ocean through Fram Strait. Since Fram Strait is the only deep passage to the Arctic Ocean, it plays a significant role in the exchange between the Nordic Seas and the Arctic Ocean. Deployment of moorings and hydrographic surveys together with a regional model were employed to monitor and understand the flow of Atlantic Water into the Arctic Ocean. In particular the recirculation within Fram Strait which affects the net heat transport significantly was a subject of more detailed studies.

WP 4: Freshwater Fluxes through Fram Strait

Sea ice and Polar Water of low salinity provide the freshwater flux from the Arctic. Deployment of moorings and hydrographic surveys together with a basin scale model allowed to monitor and understand the flow of Polar Water and sea ice from the Arctic Ocean into the Nordic Seas. The techniques to measure the ice-bound freshwater were developed to obtain time-series measurements of the salinity profile from underneath the ice to the bottom.

WP 5: Data Management

The project established a system which is able to provide data for climate observation as timely as possible to a user community. Therefore transfer of data sets from ships and moorings into the network of ASOF-N users was developed through a central data bank. The final data will be available to the public through the project data base, WDCD, ICES data centre and on CD-ROM.

WP 6: Integration and Synthesis

The members of the consortium have long-standing experience in high-latitude fieldwork, modelling, data management and data interpretation. Due to this experience the data synthesis was carried out not only within the specific frame of the project but also within the wider context of arctic-subarctic exchanges. The synthesis comprises:

- Reviewing the observations from this and earlier projects with respect to the relationship of fluxes through the individual passages, upstream oceanic and sea ice conditions, and atmospheric forcing.
- Establishing the reliability of models to reproduce the observed variability of fluxes.
- Using model experiments and observations to generate an improved overall understanding of the exchanges between Arctic Ocean and Nordic Seas.

- Designing an optimised monitoring array for long-term measurements of heat and freshwater to become a contribution to an ocean observing system.

6.3. Applied methodology, scientific achievements and main deliverables

Key results achieved during the ASOF-N period:

- **WP1 result: Inflow of Atlantic water into the Nordic Seas measured during ASOF-N from 2003 to 2005**

The Atlantic water masses circulating across the Nordic Seas towards the Arctic Ocean, are of prime importance for the climate of the northern hemisphere. An excessive freshening of the Nordic Seas might be a prelude to a slow down of warm and salty Atlantic water masses advected from subtropical regions towards the Arctic Ocean. This reduced input of Atlantic water masses and their transformation in denser Arctic intermediate waters might eventually lead to a shut down of the general thermohaline circulation and overturning in the northern North Atlantic. At the moment the observations taken at various strategic spots in the Nordic Seas and the Arctic Ocean, tend to indicate a temperature increase of Atlantic warm and salty waters all along the continental margin north of Eurasia intruding in large sectors of the central basin of the Arctic Ocean.

ASOF-N allowed studying Atlantic water pathways across the northern Norwegian Sea (Lofoten and Boreas basins) as well as the time and space variability of heat, salt and total transports associated with the Norwegian Atlantic current. The equipment and combined effort of three institutions (LOCEAN-formerly known as LODYC, Paris, France, IMR, Bergen, Norway and IOPAN, Sopot, Poland) was used to install the following main instruments (a) neutrally buoyant floats tracked acoustically underwater, (b) current meters installed on moorings and (c) CTD and LADCP operated from research vessels during field campaigns organised in 2003, 2004 and 2005.

The main objectives consisted of:
- studying the Norwegian Atlantic current and eventually confirm the nature of the general circulation of Atlantic water masses in the Lofoten and Boreas basins,
- measuring the variability in temperature and salinity of the Atlantic water masses circulating across the northern Norwegian Sea,
- observing the main pathways of Atlantic water masses entering either in the Barents Sea or heading north towards Fram Strait,
- estimating the heat losses to the atmosphere versus the heat transferred to deep Arctic intermediate waters and the freshening via internal mixing of the Atlantic water masses in the Lofoten Boreas basins and the Greenland Sea.

Main findings:

- The real nature and structure of the so-called Norwegian Atlantic current which looks more like a broad and highly turbulent current extending 100 km offshore from the shelf break of the Lofoten basin, rather than a narrow jet current constrained to the continental slope west of Norway, as often described in the literature.
- The two stream nature of the West Spitsbergen Current.
- The intense and prominent mesoscale eddy variability characterizing the Norwegian Atlantic Current, and the West Spitsbergen Current.
- A pronounced seasonal and interannual variability of temperature and salinity fields showing episodic freshening and cooling events.

- A remarkable interannual variability of the main transport of Atlantic water masses across the Lofoten basin.
- A long-term variability of temperature and salinity fields corresponding to an increase in temperature and salinity of the Atlantic water masses of more than 0.5°C and 0.1 in salinity over the past 25 years.
- The pulsating nature of the Atlantic Water transport within the West Spitsbergen Current.
- The close relation of the Atlantic Water volume transport with the local forcing in short-term variability.

The strategy used for better documenting the Atlantic water masses pathways in the northern Norwegian Sea was based on a combination of Eulerian techniques (moorings) and Lagrangian techniques (floats) as well as observations taken from research vessels (CTD, LADCP). This strategy provided an unprecedented level of information concerning the nature, structure, time and space variability of the Norwegian Atlantic current, the main carrier of Atlantic water masses to the Arctic Ocean.

- **WP1 result: Data of Lagrangian floats deployed in the Norwegian Sea during 2002-2005**

Neutrally buoyant floats are devices that drift with the currents and thereby track the water pathways. During ASOF-N standard RAFOS floats were used. They were equipped with acoustic receivers tuned to the same frequency as the SOFAR sound sources installed on 13 moorings. The floats' acoustic receivers are detecting the time of arrivals (TOA) of signals transmitted regularly by the SOFAR sources. With these TOAs the position of the floats is tracked underwater acoustically. Thirty-eight floats were ballasted to drift at depths of about 300 m and an additional four floats were ballasted to drift at 1000 m. The floats were deployed west of the Lofoten Islands, across the Norwegian Atlantic Current and close to the continental slope. After drifting for approximately 6 months, the floats were released to pop up at the surface, where they transmitted via satellite the data recorded during the previous 6 months. During this transmission the floats also recorded in situ temperature and pressure. Of the 38 floats ballasted for 300 m, 25 transmitted data. While in general the data transmission rate was very good (of 24 floats deployed between spring 2003 and 2004 only 3 were lost) all ten floats deployed in November 2004 were lost. The best explanation to account for this strange loss is that they got transported northward by a current surge and got stuck under the ice cover. This would then indicate that in winter 2004 none of floats got transported into the Barents Sea, where they would have been safe but all ten floats got transported into Fram Strait.

- **WP2 result: Heat Flux in the Western Barents Slope measured from 2003-2005 during ASOF-N**

The Barents Sea influences the Arctic Ocean both by providing a pathway for Atlantic Water (AW), but also as a shallow shelf sea producing dense water through cooling and brine release. The Barents Sea provides intermediate water down to 1200 m depth in the Arctic Ocean, and, together with the Kara Sea, is the only source area for shelf waters ventilating the Nansen Basin below the halocline. Thus, knowledge of the variability of the Atlantic inflow to the Barents Sea is important for the understanding of the climatic state of the Arctic Ocean, and for evaluations of climate change. ASOF-N continued a time series started in 1997 of volume and heat flux through the Western Barents Slope (WBS) using moored instruments. These cover the cross section where the Atlantic inflow takes place -with the exception of heavily fished waters. Temperature and velocity are monitored, allowing to integrate heat fluxes and to distinguish between eastward, westward and net fluxes. The time series is now sufficiently long to determine the variability of the oceanic fluxes through the WBS on interannual time scales - and to approach the declared objective of the ASOF cluster to capture variability on decadal time scales. The long-term mean heat flux is 40 Terrawatt (TW) into the Barents Sea. Considering the interannual variability there was a relatively high heat flux into the Barents Sea in the winter of 2002/2003. Thereafter there was a pronounced decrease and 2003/2004 had the lowest heat flux observed during winter. In addition to the moorings, hydrographic measurements with high spatial resolution were used to derive flow field and heat flux six times a year.

Main findings:

- The combination of these two observational methods is one innovation made during the ASOF-N in obtaining an estimate of heat transport as accurate as possible.
- The splitting of the flow of AW across the WBS was observed to take place in one wide branch but also to be split into several narrower branches, depending on the wind field. Between the branches there might be a weaker inflow or a return flow. At times the flow across the section is dominated by outflow (westward flow) and AW is flowing into the Barents Sea only in the southernmost part of the section.
- There is no correlation between the fluxes and the temperature of the inflowing water. In fact, in certain periods temperature increases while the volume flux decreases. This shows that the WBS temperature is independent of the volume flux. The reason is that while the temperature of the inflowing water depends on the temperatures upstream in the Norwegian Sea, the volume flux depends mainly on the local wind field. This shows the importance of measuring both volume transport and temperature, since they not always are varying in the same manner. The short-time variations in the heat flux closely resemble the short-time variations in the volume flux, while the temperature variations influence the longer term variations in the heat flux.
- A realistic model representation of the Barents Sea region was made possible by another innovation, the coupling of a dynamic-thermodynamic sea ice model to a three-dimensional ocean general circulation model for the purpose of conducting climate dynamical downscaling experiments for the Barents Sea region. The Regional Ocean Model System (ROMS, http://marine.rutgers.edu/po/index.php?model=roms) was chosen as most appropriate since its model architecture is suitable for shelf seas as the Barents Sea. The improvement of the ROMS model is the sea-ice model extension, which performs well also on the high resolution grid used and is absolutely necessary for realistic Barents Sea simulations. The model will be used to conduct a hindcast for the period 1990-2005 including 3D fields of velocity and hydrography as well as water level and sea ice thickness and concentration. The horizontal grid resolution is ~10 km. The vertical is resolved by 32 terrain following levels. Previous model validation with results from a similar model implementation (i.e. using slightly different and less accurate forcing) against observations show that seasonal and interannual variability in the ocean are tracked successfully. Furthermore the model results are used to examine details in space not covered by observations (incl. estimates of the throughflow of AW in the Barents Sea to the Arctic Ocean).

- **WP3 result: Heat Flux through Fram Strait calculated from high-resolution year-round measurements and from hindcasts with the NAOSIM model**

Fram Strait is the only deep connection between the Arctic Ocean and Nordic Seas and represents the major gateway for the flux of warm water from mid latitudes to the Arctic Ocean. The oceanic heat imported from the North Atlantic has the potential to affect the ice cover in the Eurasian Arctic and to be released to the Arctic atmosphere. Thus, it is an important component for understanding Arctic climate, which is strongly linked with European climate, necessitating long-term measurements and simulations in a regional model. Since 1997 a continuous time series of volume and heat flux through Fram Strait was derived from measurements with moored instruments. The moorings cover the cross section over the entire deep part of Fram Strait. Temperature and velocity are monitored, allowing to integrate heat fluxes and to distinguish between northward, southward and net fluxes. ASOF-N allowed continuing the time series, which is now sufficiently long to determine the variability of the oceanic fluxes through Fram Strait on interannual time scales - and also to approach the declared objective of the ASOF cluster to capture variability on decadal time scales. The yearly averaged northward heat flow through Fram Strait increased dramatically, from about 38 to 60 TW, during 1997-2000. In the following years the heat flow decreased slightly although summer temperatures of the inflow measured during ship surveys showed record high values in 2004 and 2005. While moorings record year round data and provide high temporal resolution, they still have a limited spatial resolution. Therefore, since 2001 they are complemented by ADCP (Acoustic Doppler Current Profiler) recordings during ship cruises that deliver high spatial resolution temperature and velocity data sets (typically two or three per year in the summer season). Yearly hydrographic measurements with high spatial resolution were also used to derive the flow field and heat flux with a third independent method.

Main findings:

- The combination of the three observational methods, which to the best of our knowledge has never been published before, is one innovation made during the ASOF-N project in obtaining an as accurate estimate as possible of the heat transport.
- The complicated topographic structure of Fram Strait leads to a splitting of the warm West Spitsbergen Current into various branches transporting water northward and eastward or recirculating immediately in Fram Strait. The size and strength of the different branches largely determine the input of oceanic heat to the inner Arctic Ocean and have to be distinguished. Therefore one key progress made during ASOF-N was recognizing the strong impact of areas of high recirculation on calculated heat and volume flow. By deploying additional moorings in the central part of Fram Strait the error of calculated heat and volume flow was considerably reduced.
- A realistic model representation of these different branches was made possible by another innovation, the improved spatial resolution in the North Atlantic-Arctic Ocean-Sea Ice Model (NAOSIM) of AWI. The NAOSIM models use meteorological data and simulate their influence on sea ice, currents, temperature and salinity in the ocean north of approximately 50°N. The improved model has a horizontal resolution of approximately 9 km and a vertical resolution of down to 10 m in upper ocean layers (with 50 depths layers in total). The modelling was done for the period from 1990 (using initial conditions in 1990 based on the coarser resolution version of the model) to 2005 using NCEP (National Centers for Environmental Predictions) reanalysis data for the integration. This model version resulted in a number of improvements, for instance the far better reproduction of the recirculation of Atlantic waters in Fram Strait. The averaged northward volume transport increased to around 10 Sv between 1995 and 2003. This fits observations much better than the around 3 Sv of the previous model. The good agreement between the model and the observationally based estimates in Fram Strait makes it possible to use the model to relate changes in Fram Strait to large scale oceanic developments.

- **WP4 result: Freshwater Flux through Fram Strait during 2003-2005 as measured during ASOF-N**

Fram Strait is the main source of freshwater for the Greenland and Iceland Seas. Along with Davis Strait it is also the main provider of freshwater for the Labrador Sea and North Atlantic. This freshwater export from the Arctic to subarctic seas has the potential to influence the northbound current systems by modifying the stratification of the receiving basins. This would alter the oceanic heat transport, which again would influence the climate of North Western Europe. The export of fresh water occurs in liquid (polar water) and solid (sea ice) phase. With the advent of ASOF-N we were able to continue and extend existing time series (solid phase freshwater flux since 1990 and liquid freshwater flux since 1997), and hence determine the seasonal and interannual variability of freshwater fluxes through Fram Strait. The annual cycle of the liquid freshwater transport in the East Greenland Current (EGC) has a minimum in spring (~600 km^3/yr) and a maximum in late summer (~2000 km^3/yr). The mean of the transport time series is 900 km^3/yr. The anomalies with respect to the mean seasonal cycle have a magnitude of typically 500 km^3/yr. There is no general trend in the freshwater transport over the period 1997 to 2005. From the first ASOF-N winter time CTD section and the first mooring on the shelf it is clear that additional moorings are needed, as there is a potential for considerable freshwater transport across the wide shelf. During the May 2005 cruise low salinity water was found also east of the EGC, meaning that an additional freshwater transport could occur east of the existing mooring array. The comparison between fresh water observations at 79°N, 74°N and 63°N so far shows no significant signal propagation of water mass characteristics along the EGC path, in contrast to what is observed along the Atlantic Water path in the east.

Main findings:

Time series have been maintained using more basic observational arrays since 1997 but ASOF-N allowed using a full scale version of the observational array facilitating key innovations to be made:

- With the advent of ASOF-N we were able to tailor make the observational setup to study fresh water transport, as far as the physical conditions allow. This includes near surface salinity sensors and tube moorings with ADCPs (Acoustic Doppler Current Profiler).
- The wide shelf at this latitude was an open issue as due to extensive ice cover and icebergs drifting through the region, access is difficult and moorings are not likely to survive. Few observations have therefore been made in this area. Introducing tube moorings has provided our first direct measurements of salinity on the shelf at 79°N.
- The moorings provide year round point measurements in the vertical and horizontal. Annual cruises during summer provide high resolution hydrography which aids in the interpretation of the point measurements. However, for the observation of freshwater fluxes we also need high resolution spatial information on the seasonal cycle of the stratification. An extensive ice cover with heavy multiyear ice has prevented access to the region during winter. In 2005 a coastguard ice breaker was used to penetrate into the pack, serving as a base for helicopter CTD transects with portable equipment. This allowed ASOF-N to do the first high resolution wintertime hydrographic transect.
- For some years freshwater observations have been performed also at the 74° and 63°N latitudes. With ASOF-N we were able to do the first comparisons of freshwater observed at these different latitudes. The aim of this ongoing work is to draw conclusions on the fate and pathways of freshwater exiting the Arctic at 79°N.
- Model results from the high resolution version of AWI's NAOSIM have been used to fill spatial and temporal gaps in the observations and to link the freshwater fluxes in the East

Greenland Current with the large scale oceanic circulation as well as with the meteorological forcing fields. The large liquid fresh water export event of the mid-1990s could thus be linked to changes in the Arctic Ocean freshwater distribution during previous years. These redistributions were forced by the strong positive NAO wind forcing during the early 1990s.

- **WP5 result: Data and data management of CTD profiles and mooring measurements**

CTD data:
CTD (Conductivity, Temperature, Depth) profiles were measured during 10 cruises in 2003 during 10 cruises in 2004, 11 cruises in 2005 and 1 cruise ion 2006 by AWI, IFMH, IMR, IOPAS, and NPI across Fram Strait, in the East Greenland Current between 74° and 79° N and in the eastern part of the Greenland Sea. Detailed information on the CTD stations can be found at the ASOF-N website. The current CTD dataset contains 2514 profiles which can be retrieved via www.awi-bremerhaven.de/OZE. A summary of CTD datasets are presented in Tables provided in the documentation.

Instruments (CTD):
All institutions used a Sea Bird SBE911plus CTD profiler with a single CT-Sensor package (double CT-Sensor for AWI profilers). The CT sensors were frequently calibrated at Seabird Electronics. In addition salinity samples were taken to correct for sensor drift. The final data have been processed using Seabirds post-processing software which includes all necessary operations. The raw data have a vertical resolution of 0.04 dbar but still including noise e.g. due to ship motion. To reduce this noise, data were averaged to a vertical resolution of 1dbar. The number of data cycles averaged in each 1dbar record was stored together with the individual data points. ASOF-N continued a CTD time series started in 1997, which is now sufficiently long to determine the variability on interannual time scales - and also to approach the declared objective of the ASOF cluster to capture variability on decadal time scales.

Mooring Data:
Moorings were deployed and recovered during 15 cruises from 2003 to 2005 by AWI, IFMH, IMR, and NPI across Fram Strait and in the East Greenland Current at 74° N. A detailed map with mooring location is provided in the documentation. The current dataset contains 890 time series which can be retrieved via www.awi-bremerhaven.de/OZE. A summary of mooring records are presented in the documentation.

Instruments (moorings):
Most instruments being used in the mooring were current meters. Reliable current measurements were maintained by frequent services (usually before and after deployment). The common current meter type is a rotor current meter from Aanderaa Instruments. In addition to current speed and direction these instruments also measure temperature. CT recorders from Seabird (SBE16, SBE37) were used to measure precise temperature and salinity based on calibrations before deployment and after recovery. The sample rate depends on the different instrument types (and their power consumption and memory size) and ranges between 10 minutes and 2 hours. Data processing was done by the institution that provided the instrument. The standard procedures included converting binary data to engineering units, apply magnetic deviation correction, removing of spikes (small gaps were filled by interpolation and long gaps were filled with a dummy data value, e.g. NaN) and correcting for sensor drifts for example by applying post calibration.

Archiving and providing the data:
As important as collecting new data about the temporal variability of oceanographic parameters, is the availability of collected data. The ASOF-N partner send their processed and

calibrated CTD and/or mooring datasets to the AWI where they are stored together with information about additional dataset available for this region. The data are transferred into a uniform format and archived in AWI's database with general cruise and instrument information. ASOF-N partners have password protected direct access via the internet or can order complete datasets on CD.

Main advantages:

- Project partners can access all collected data from all over the world via the internet without delay. This is of great importance especially in the oceanographic community where scientists are often on cruises and answering requests for data are therefore delayed.
- Data are provided centrally in a uniform data format. The time consuming process of converting data is performed centrally using a fixed routine. The user accesses a uniform data format and can compare profiles directly without tedious and time consuming conversion of data formats.
- The data format supports importing of data using Matlab if desired by the user and can be visualised using the software ODV (Ocean Data View). ODV can be retrieved from http://odv.awi-bremerhaven.de.
- In contrast to archives, this working data base can be easily edited after the upload. This easy modification of the database allows for a fast correction if comparisons of data sets reveal faulty data points. Furthermore it enables the subsequent expansion of the data base.
- CTD data are processed fast and can made available immediately and data sets that need more time to process e.g. oxygen profiles can be easily added at a later stage without affecting the accessibility of CTD data.

- **WP6 result: Synthesis of exchanges of volume, heat and freshwater between the Atlantic and the Arctic Ocean**

One key question in Arctic climate research is, whether the sensible heat carried by the oceanic inflow can influence the formation of sea ice and whether e.g. a large increase in oceanic heat input could considerably diminish the ice cover. The inflow of water and heat from the Atlantic Ocean to the Arctic Ocean was studied during the ASOF-N programme. The Atlantic water (AW) reaches the Arctic Ocean through two passages, the deep (2600 m) Fram Strait and across the broad shelf of the Barents Sea, where it enters through the Bear Island Channel and passes through the Barents Sea into the Kara Sea and most of the AW continues into the Arctic Ocean via the St. Anna Trough. The programme also attempted to quantify the outflow of sea ice and low salinity surface water (the export of liquid freshwater) from the Arctic Ocean to the Nordic Sea through Fram Strait and, since Fram Strait is the only deep passage connecting the Arctic Ocean to the world ocean, to estimate the exchanges of intermediate and deep waters between the Arctic Ocean and the Nordic Seas. The AW was followed on its way through the Norwegian Sea from the Greenland – Scotland Ridge to the two inflow passages and the strength of the transport and the changes in water mass characteristics were studied.

The AW loses a considerable amount of heat in the open area north of Svalbard, the Whalers' Bay, to the atmosphere and to the melting of ice. As the AW then passes eastward along the continental slope, it is covered by a less saline surface layer comprising AW diluted by ice melt, and its still large heat content is isolated from the sea ice and the atmosphere. The transformations of the Barents Sea inflow are much larger. Denser water masses are created that enter the deeper layers of the Arctic Ocean, as well as less dense waters that eventually enter the central Arctic Ocean and supply the low salinity surface water, the polar mixed layer, of the Arctic Ocean. The strongest transformation affecting the AW after it has entered the Arctic Ocean occurs north of the Kara Sea, where it meets and mixes with the colder, less saline Barents Sea branch entering the Arctic Ocean via the St. Anna Trough. The mixing between the two branches leads to a cooling of the AW in the Fram Strait branch. The heat still remains in the Atlantic layer, but it is now distributed over a larger volume. The largest changes in AW characteristics occur, when it penetrates from one basin into another basin and mixes with the water column present there. Another process changing the water mass properties in the deep Arctic Ocean basins is the injection of cold, dense water, formed by ice formation and brine rejection on the shelves, which sinks down the slope as dense, entraining boundary plumes. Some plumes enter and cool the Atlantic layer, some sink deeper, entrain AW and bring it into the deep, warming the deeper layers.

Key findings:

Time series from the ASOF-N moorings in Fram Strait showed that several pulses of warmer AW combined with a stronger inflow, passed through the strait, adding heat to the interior of the Arctic Ocean. The net flow through Fram Strait is generally southward, ranging between 1 and 2 Sv. However, over long periods, extending over more than a year a monthly mean net transport into the Arctic Ocean was measured. The strength of this transport was close to 1 Sv. The AW supplies the main inflow of volume, salt and heat to the Arctic Ocean. The inflow through Fram Strait is, according to the recent ASOF-N results, an order of the magnitude larger than the inflow of Pacific water through Bering Strait, 10 Sv as compared to 1 Sv from the Pacific. In addition the inflow over the Barents Sea contributes about 1.5 Sv of AW. However, not all 10 Sv entering through Fram Strait are AW but also include intermediate and deep waters and a large part may be involved in a recirculation in, or just north of, the strait. The circulation loops in the different basins have different residence times, and the heat that enters the Arctic Ocean as a warmer, and perhaps stronger, pulse becomes spread out spatially and temporally. Its return to Fram Strait extends over a period from perhaps less than 1 year for the re-circulation in (or just north of) the strait to 20–30 years for the farthest loops passing through the remote Canada Basin. This redistribution of the heat added to the Atlantic layer in the Arctic Ocean makes it difficult to determine how much of the oceanic sensible heat is lost to ice melt and released to the atmosphere, and how much is stored in the layer to eventually return to Fram Strait and the Nordic Seas.

Interesting features for further investigation are the recirculation patterns. The AW entering the Arctic Ocean returns towards Fram Strait in several loops confined to the different sub-basins of the Arctic Ocean to be re-exported to the Nordic Seas and eventually to the North Atlantic. The separation into several loops with different residence times and different mixing histories begins already in Fram Strait. This first recirculation loop is arguably the largest one and the one returning most heat to the Nordic Seas. A recirculation towards Fram Strait takes place in the northern Nansen basin, the water returning along the Gakkel Ridge. This return flow mainly comprises Fram Strait branch water. The Barents Sea branch water becomes gradually more prominent at the continental slope and in the basins and ridges farther from Fram Strait; in the Amundsen Basin, along the Lomonosov Ridge, in the Makarov Basin, along the Mendeleyev Ridge, at the Chukchi Cap, and in the loops in the Canada Basin.

Another issue to be investigated in the future is how much the heat loss to ice and atmosphere in the Arctic Ocean depends upon the temperature of the entering Atlantic water and upon the strength of the inflow and how much is determined by the mixing processes driven by the local atmospheric conditions, atmospheric circulation, wind strength and cooling in the Arctic Ocean. It is conceivable that a larger inflow of heat is mainly manifested in a warmer Atlantic layer. Since the Atlantic waters in the different loops can, at least rudimentary, be distinguished by their salinities and by other tracers, it should be possible to estimate the storage in the different loops and determine the heat loss variations. This will require long time series of the hydrography in the strait and also in the interior of the basins. It is an important question though, since it addresses the vulnerability of the ice cover to changes of oceanic heat transports.

Another intriguing question arises from the fact that Fram Strait is the only passage that sustains transports in both directions and that the observations indicate periods longer than a year with a net inflow to the Arctic Ocean through Fram Strait. Part of the outflow from the Arctic Ocean is low salinity surface water and ice, part is intermediate and deep waters. Since Fram Strait is also the only deep passage, it is the one passage, which allows Arctic Ocean intermediate and deep waters to exit. A net inflow through Fram Strait, together with the inflow of Atlantic water over the Barents Sea and the inflow of Pacific water through Bering Strait, then requires a balancing export of low salinity surface water, which must occur through the shallow Canadian Arctic Archipelago. The upper waters in the Arctic Ocean have a residence time of the order of 10 years with the present outflow rate of 2 – 3 Sv, divided about equal between Fram Strait and the Canadian Arctic Archipelago. A net inflow in Fram Strait implies that the outflow of upper water will at least double and most of this increased outflow must take place through the Canadian Arctic Archipelago. This would in a few years lead to a thinning of the upper layers, because the exported low salinity water can only be replaced by mixing and diluting Atlantic water with freshwater, and there is not enough freshwater supplied to the Arctic Ocean to accomplish this. The Atlantic water will be brought closer to the sea surface and could start to influence the ice formation and the thickness of the ice cover. These transport results must therefore be examined and tested in a Pan-Arctic context, where all passages are considered and where volume and salt balances are used as constraints on the obtained results. Such study will require long-term observations in order to obtain consistent results.

The detailed report on ASOF-N synthesis can be found in the Annex 1.

- **WP6 result: The optimised observing system for monitoring oceanic fluxes in Fram Strait and western Barents Sea**

The long term consolidated data sets necessary to determine the variability of the freshwater and heat fluxes between the Arctic Ocean and the North Atlantic require an innovative design of the cost effective and well calibrated measurement arrays. The northward flow of the Atlantic water carrying heat into the Arctic Ocean has to be monitored in two main gateways, the eastern Fram Strait and Barents Sea Opening. The southward freshwater flux which enters the Nordic Seas both as liquid water and sea ice needs to be measured across the western Fram Strait, including the wide shelf east of Greenland. The latter requires current measurements and salinity stratification in shallow depths as well as ice thickness and velocity. To monitor fluxes not only the large cross-sections of the gateways have to be covered by measurements but also intensive variations on a wide range of scales, revealed by earlier observations have to be resolved. Thus a larger number of moorings and instruments is needed or integral methods, measuring the whole water column have to be used. During ASOF-N observational arrays in Fram Strait and Barents Sea Opening were augmented and optimised in accordance with the observed time-space variability of measured parameters. Newly developed instruments were installed in the moorings, the observational arrays were redesigned for optimal combination of various properties, transport estimates were proposed based on empirical relations to especially selected instruments. To secure data collected under harsh environmental conditions the possibilities of the near real-time data transfer via satellite link with pop-up buoys was tested. To complement the observing system of mooring arrays a grid of hydrographic stations was designed and repeated every summer to get the spatial variability of the Atlantic water pathways.

Key achievements:

- The Fram Strait mooring array was optimized to achieve better performance in measurements of temperature, salinity, currents and ice thickness – a prerequisite to derive heat and freshwater fluxes. In the eastern and deep part of the strait additional instruments were added at the depth of ca 700 m to resolve the lower boundary of the Atlantic water layer. Two new moorings placed in the deep part of the strait to resolve the recirculation patterns of the Atlantic water and thus to reduce the error in volume transport estimates. In addition to the moorings, integral measurements were performed with the use of bottom pressure recorders (BPR) and inverted echo sounders with pressure sensors (PIESs) to estimate the barotropic currents and heat content of the water column. The performance of different current meters and TS sensors during the long-term deployments was evaluated and unreliable instruments were replaced to achieve the highest data recovery rate and the best data quality. The freshwater part of the mooring array in the western Fram Strait was equipped with near surface salinity sensors. Tube moorings in combination with Acoustic Doppler Current Profilers (ADCPs) were successfully deployed on the shelf, surviving the extensive ice cover and drifting icebergs.
- The moorings in the Barents Sea Opening were combined with a high resolution hydrographic section repeated 6times per year. Additionally this moored array was augmented with two bottom-mounted ADCPs in shallow parts. A new strategy was used for tracking the Atlantic water pathways based on combination of moorings, floats and hydrographic sections. The hydrographic sections included not only standard CTD casts but also currents profiles which were measured by the lowered ADCP and quasi-continuously by the vessel-mounted ADCP. The grid of stations was adjusted to optimise the coverage of spatial structures.

6.4 Conclusions, socio-economic relevance, strategic aspects and policy implications

The evaluation of the available historical data together with the results of the ASOF-N field measurements revealed a significant warming of the Atlantic Water propagating through the ASOF-N region and an increased heat flux into the Arctic Ocean. The field measurements and the model results suggest that variations of the fluxes between the North Atlantic and the Arctic Ocean occur on a wide range of time scales and are interlinked between the main passages. The volume and heat fluxes are also controlled by local and remote atmospheric forcing. Both in the Barents Sea Opening and Fram Strait variability of temperature is independent of the variations in the volume flux. The former is dominated by advective processes and depends mostly on the upstream conditions while the latter is related to the local atmospheric forcing. Observed variations in the Atlantic Water pathways (namely intensification/weakening of the branches of the Norwegian-Atlantic Current) result in the redistribution of the Atlantic Water in Fram Strait and strongly influence the heat flux into the Arctic Ocean. All these changes occur over long time scales and only quasi-continuous measurements over a decade and more give a chance to identify the nature of these fluctuations. Lacking spatial resolution is a problem in spite that the major parts of the transports occur in relatively narrow boundary currents. Technical problems with the present day equipment require redundancy. New technology available to replace conventional instruments on an operational basis is under development and a design of optimized observational array has been worked out on the basis of the ASOF-N experience.

Variability of the ocean circulation and the water mass distribution in the Nordic Seas lead to changes in the volume, heat and freshwater fluxes between the Arctic Ocean and North Atlantic. Changes in these fluxes can have a strong influence on the role of the ocean in the climate system which includes the potential of abrupt climate changes. The climate variability in particular in the northern North Atlantic has a strong impact on the living conditions in Northwest Europe. This includes energy consumption, sea traffic and marine living resources. Therefore a reliable prediction system is of high value to maintain the present living conditions. Prediction requires understanding and modelling of the relevant processes and monitoring key parameters to validate and constrain the models. Since variability of the relevant time scales can be only studied on the base of the long-term time series, ASOF-N aimed to pave the way towards an observing system consisting of a cost-effective array of instruments in the key areas for the exchanges between the North Atlantic and Arctic Ocean. The results of ASOF-N will help to design such a system, to give advice for its implementation and consequently contribute to maintain the quality of life in Northwest Europe.

Results from ASOF-N and the EU-funded preceding projects VEINS and MAIA also gave background information to the scientific report from the **Arctic Climate Impact Assessment** (ACIA) published in 2005. ACIA is an international project of the Arctic Council and the International Arctic Science Committee (IASC), to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. The Arctic Council is a high level intergovernmental forum of the following member states: Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States of America.

The ASOF-N results are included into reports to ICES (the International Council for the Exploration of the Sea), which gives advice to the member countries and helps them manage the North Atlantic Ocean and adjacent seas. The results are included in a few reports presented at different **ICES working groups** like Working Group on Oceanic Hydrography (WGOH) and Arctic Fishery Working Group (AFWG), and during the last two years also included in **ICES assessment reports** and **ICES Annual Ocean Climate Status Summaries** (IAOCSS).

6.5 Dissemination and exploitation of results

The region covered by the ASOF-N includes some of the most productive fishing grounds of the world, where environmental changes have direct effects on the growth, recruitment, distribution, migration and food consumption of commercial fish stocks, and where a sustainable fishery is of central importance for the social and economic conditions of nations. The need is for a reliable system of environmental change monitoring to use in developing a predictive capability, which will reliably anticipate changes in fish-stocks. The Barents Sea for example is a high latitude ecosystem that is heavily depending on the inflow of Atlantic water from the south. Recent current measurements show a great variability of heat flux to the Barents Sea, which has consequences for the marine ecosystem. The heat flux has impact on species composition, distribution and migration of commercially important fish species. In addition the heat flux also determines **the possibility of a Northern Sea route and the exploitation of natural resources (fossil fuel)**. It is therefore important to continue scientific activities to monitor this flow in order to investigate how it is related to climate variability and change. At the same time it is of prime importance to disseminate the scientific results and their implications to politicians and stake holders like fisheries organisations and the general public.

The ASOF-N results will be merged with the data from the ASOF-EC(E) and ASOF-EC(W) cluster components and contribute directly to the **circum-Arctic International Arctic/Subarctic Ocean Flux Array** (http://asof.npolar.no/about.html).

There are numbers of well structured programs such as **PAN-AME** (An EoI for IPY dealing with a Pan Arctic Cluster for Climate forcing of the Arctic Marine Ecosystem), the EU-Integrated Project **DAMOCLES** standing for Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies, **ESSAS** (EcoSystem Studies of SubArctic Seas) within the GLOBEC (the International Geosphere-Biosphere Programme(IGBP) core project responsible for understanding how Global Change will affect the abundance, diversity and productivity of marine populations), **IPY-SPACE** (Synoptic Pan-Arctic study of Climate and Environment), **AOMIP** (Arctic Ocean Model Intercomparison Project) which can strongly profit from active cooperation with ASOF-like programs and make a wide use of ASOF-N results.

ASOF-N data were compared with models and used for the preparation of information of ASOF-N results in a layman language. ASOF-N is an excellent example where observations and model results support each other in a very positive way: observations are used to validate model results and on the other hand, models are important tools for explaining variability in the observations. The results of ASOF-N therefore support the requirements for data derived both from mathematical models and observational data. In addition information on ASOF-N results were supplemented by results from related projects (ECOBE; ProClim and NESSAS) with financial support from the Research Council of Norway. These results were presented in layman language to **fisheries organisation** as talks, newspaper articles and in form of a leaflet that was distributed during an **Aquaculture exhibition** through IMR, Norway. Scientific results on the effect of the changing climate on the marine ecosystem was also presented to the **Norwegian Ministry of Fisheries** during an oral presentation.

In addition results on climate variability and its link to ecosystem development have been conveyed to the general public especially **students and high school teachers** during lectures given at universities and schools.

ASOF- N results were displayed in numerous conferences, seminars and workshops as well as in publications and reports. By these efforts they are brought to the awareness of a broad scientific public. The ultimate product of the ASOF synthesis will be a book which is in progress and will reach a broad readership. During the project the distribution of the ASF-N leaflet at appropriate events and the links in the website helped to draw attention to ASOF-N and later to disseminate the results.

6.6 Main literature produced:

Authors	Date	Title	Journal	Reference
Ottersen G., Loeng H., Ådlandsvik B., Ingvaldsen R.	2003	Temperature variability in the northeast Atlantic.	Ices Mar. Sci. Symp.	219, 86-94
Fahrbach E., G. Rohardt, U. Schauer, J. Meincke, S. Osterhus, J. Verduin	2003	Direct measurements of heat and mass transport through Fram Strait	Ices Mar. Sci. Symp.	219: 378-381
Osinski R., Wieczorek P., Beszczynska-Möller A., Goszczko I.	2003	ADCP referenced geostrophic velocity and transport in the West Spitsbergen Current.	Oceanologia	45(3), 425-435
Schauer U., Fahrbach E ., Østerhus S., Rohardt G.	2004	Arctic warming through the Fram Strait - oceanic heat transport from three years of measurements.	Journal of Geophysical Research	109, C06026, doi:10.1029/ 2003JC001823
Gascard J.C., Raisbeck G., Sequeira S., Yiou F., Mork K. A.	2004	The Norwegian Atlantic Current in the Lofoten basin inferred from hydrological and tracer data (^{129}I) and its interaction with the Norwegian Coastal Current.	Geophysical Research Letters	31, L01308, doi:10.1029/ 2003GL018303
Ingvaldsen R., Asplin L., Loeng H.	2004	The seasonal cycle in the Atlantic transport to the barents Sea during the years 1997-2001	Continental Shelf Research	24, 1015–1032
Ingvaldsen R., Asplin L., Loeng H.	2004	Velocity field of the western entrance to the Barents Sea.	Journal of Geophysical Research	109, C03021, doi:10.1029/ 2003JC001811
Schlichtholz, P. and I. Goszczko	2004	Was the Atlantic Water temperature in the West Spitsbergen Current predictable in the 1990s?	Geophysical Research Letters	32, L04610, doi:10.1029/ 2004GL021724
Walczowski, W., Piechura, J., Osinski R.	2005	The West Spitsbergen Current volume and heat transport from synoptic observations in summer	Deep-Sea Research Part I: Oceanographic Research Papers	52 (8), 1374-1391, doi: 10.1016/ j.dsr.2005.03.009
Maslowski W., Marble D., Walczowski W., Schauer U., Clement J. Semtner A.J.	2004	On climatological mass, heat, and salt transports through the Barents Sea and Fram Strait from a pan-Arctic coupled ice-ocean model simulation	Journal of Geophysical Research	109, C03032, doi:10.1029/ 2001JC001039
Rudels B., Björk G., Nilsson J., Winsor P., Lake I., Nohr C.	2004	The interaction between waters from the Arctic Ocean and the Nordic Seas north of Fram Strait and along the East Greenland Current: results from the Arctic Ocean-02 Oden expedition	Journal of Marine Systems	55(1-2), 1-30

Rudels, B., Jones, E.P., Schauer, U., Eriksson, P.	2004	Atlantic sources of the Arctic Ocean surface and halocline waters	Polar Research	23(2), 181-208
Losch M., Sidorenko D., Beszczynska-Möller A.	2004	FEMSECT: an Inverse Section Model Based on the Finite Element Method.	Journal of Geophysical Research	110, C12023, doi:10.1029/ 2005JC002910.
Ingvaldsen, R., Loeng, H., Ottersen, G., and Ådlandsvik, B	2004	The Barents Sea climate during the 1990's	Ices Mar. Sci. Symp.	219: 160-168
Olsson, K.A., Jeansson, E., Tanhua, T., Gascard, J.-C.	2005	The East Greenland Current studied with CFCs and released sulphur hexafluoride	Journal of Marine Systems	55 (1-2), 77-95
Holfort, J., Meincke, J.	2005	Time series of freshwater-transport on the East Greenland Shelf at 74°N	Meteorologische Zeitschrift	14 (6), 703-710, doi: 10.1127/0941-2948/2005/0079
Holfort, J., Hansen, E.	2005	Timeseries of Polar Water properties in Fram Strait	Geophysical Research Letters	32 (19), 1-4, doi: 10.1029/ 2005GL022957
Polyakov, I.V., Beszczynska, A., Carmack, E.C., Dmitrenko, I.A., Fahrbach, E., Frolov, I.E., Gerdes, R., Hansen, E., Holfort, J., Ivanov, V.V., Johnson, M.A., Karcher, M., Kauker, F., Morison, J., Orvik, K.A., Schauer, U., Simmons, H.L., Skagseth, O., Sokolov, V.T., Steele, M., Timokhov, L.A.,	2005	One more step toward a warmer Arctic	Geophysical Research Letters	32(17), 1-4, doi: 10.1029/ 2005GL023740
Clement, J.L., Maslowski, W., Cooper, L.W., Grebmeier, J.M., Walczowski, W.	2005	Ocean circulation and exchanges through the northern Bering Sea - 1979-2001 Model results	Deep-Sea Research Part II: Topical Studies in Oceanography	52 (24-26), 3509-3540
Rudels, B., Björk, G., Nilsson, J., Winsor, P., Lake, I. And Nohr, C.	2005	The interaction between waters from the Arctic Ocean and the Nordic Seas north of Fram Strait and along the East Greenland Current: results from the Arctic Ocean – 02 Oden expedition	Journal of Marine Systems	55, 1-30, doi:10.1016/ 2004.06.008
Schlichtholz P.	2005	Climatological baroclinic forcing of the barotropic flow in the East Greenland Current in Fram Strait	Journal of Geophysical Research	110, C08013, doi:10.1029/ 2004JC002701.
Walczowski W., J. Piechura	2006	New evidence of warming propagating toward the Arctic Ocean	Geophysical Research Letters	33, L12601, doi:10.1029/ 2006GL025872.

Schlichtholz P., Goszczko I.	2006	Interannual variability of the Atlantic water layer in the West Spitsbergen Current at 76.5N in summer 1991–2003	Deep-Sea Research Part I: Oceanographic Research Papers	53, 608–626

Manuscripts in preparation:			
Carmack, E., Barber, D., Christensen, J., Macdonald, R., Rudels, B. and Sakshaug, E.	Climate Variability and Physical Forcing of the Food Webs and the Carbon Budget on Panarctic shelves	Progress in Oceanography	submitted
Jeansson, E., Jutterström, S., Rudels, B., Anderson, L.G., Olsson, K.A., Jones, E.P., Smethie Jr., W.H. and Swift, J.H.	Sources to the East Greenland Current and its contribution to the Denmark Strait overflow	Progress in Oceanography	submitted
Marnela, M., Rudels, B, Olsson, K.A., Anderson, L.G., Jeansson, E., Torres, D.J., Messias, M.-J., Swift, J.H. and Watson, A.J.	Transports of Nordic Seas water masses and excess SF_6 through Fram Strait to the Arctic Ocean	Progress in Oceanography	submitted
Nilsson, J., Björk, G., Rudels, B., Winsor, P., Torres, D.J.	Late winter conditions and freshwater transport in the East Greenland Current: result from an icebreaker-based survey.		submitted
Rudels, B., Anderson, L.G., Eriksson, P., Fahrbach, E., Jakobsson, M., Jones, E.P., Melling, H., Prinsenberg, S., Schauer, U. and Yao, T.	Observations in the Ocean.	Chapter 4 in "ARCTIC Climate Change – The ACSYS Decade and Beyond", Editors: P. Lemke, T. Fichefet, C. Dick	submitted
Wassmann, P., Reigstad, M., Haug, T., Rudels, B., Carroll, M.L., Hop, H., Gabrielsen, G.W., Falk-Petersen, S., Denisenko, S.G., Arashkevich, E., Slagstad, D. and Pavlova, O.	Food webs and carbon flux in the Barents Sea.	Progress in Oceanography	submitted
Fieg K. et al.	High resolution model results in Fram Strait	Peer revied literature	in preparation
Beszczynska-Möller A., U. Schauer, E. Fachrbach, G. Rohardt	Variablity of flow and fluxes through Fram Srait	Peer revied literature	in preparation
Loeng H., B. Aadlandsvik, T. Furevik, J.-C. Gascard, R. Ingvaldsen, K.-A. Orvik, Ø. Skagseth	Flux of heat, salt and mass to the Arctic Ocean via Norway Coast and Barents Sea	ASOF Book 2007 (peer revied book chapter)	in preparation

Fahrbach E., U. Schauer, A. Beszczynska-Möller, E. Hansen, J. Piechura, W. Walczowski	Flux of heat, salt and mass to the Arctic Ocean via Fram Strait.	ASOF Book 2007 (peer revied book chapter)	in preparation
Holfort J., E. Hansen, S. Østerhus, S. Dye, S. Jonsson, J. Meincke, J. Mortensen, M. Meredith	Freshwater fluxes east of Greenland	ASOF Book 2007 (peer revied book chapter)	in preparation
Rudels B.	Constraints on calculating the balances of heat, mass and salt for the Arctic Mediterranean	ASOF Book 2007 (peer revied book chapter)	in preparation
Gerdes R., Karcher M., Koeberle C..	Long term variability of the freshwater export from the Arctic Ocean as seen in model results	ASOF Book 2007 (peer revied book chapter)	in preparation