Climate modeling for Yamal territory using supercomputer atmospheric circulation model ECHAM5-wiso

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ABSTRACT

Dependences of monthly means of regional averages of model atmospheric parameters on initial and boundary condition remoteness in the past are the subject of the study. We used atmospheric general circulation model ECHAM5-wiso for simulation of monthly means of regional averages of climate parameters for Yamal region and different periods of pre-modeling. Time interval was varied from several months to 12 years. We present dependences of model monthly means of regional averages of surface temperature, 2 m air temperature and humidity for December of 2000 on duration of pre-modeling. Comparison of these results with reanalysis data showed that best coincidence with true parameters could be reached if duration of pre-modelling is approximately 10 years.

Climate is a statistical ensemble of states for system consisting of hydrosphere, lithosphere and atmosphere for the period of several decades. Climate modelling has sense in the frame of ergodicity hypothesis. It allows comparing modelled and observes temporal averages. Ergodicity of dynamic system appear when results of modelling forget initial condition on multi-decadal scales[1]. This study is a preliminary attempt to find period for pre-modelling to achieve best coincidence of modelled and observed climate parameters for target region of Yamal peninsula. We used atmospheric general circulation model ECHAM5-wiso[2] for modelling, and NCEP/NCAR reanalysis data[3] and direct observations from Labytnangi city as actual climate parameters.

Atmospheric general circulation model ECHAM5-wiso was used for all atmospheric simulation, it is isotopologues-enhanced model created on the base of ECHAM5[4]. It describes atmospheric dynamics using ECMWF[5] reanalysis data. Source code of this AGCM is written on Fortran 90, it provide an opportunity of enhancement with new modules due to modular structure and well documented code. In addition, our selection of ECHAM5-wiso was conditioned by its ability to use all possible parallelization methods (MPI, OpenMP, and vectorization). Executable code was assembled for two different architectures: massive parallel cluster[6] and PC with Intel Core i7 processor, which provides eight threads of computations. Input data includes initial and boundary conditions such as atmospheric parameters (vorticity, temperature, and humidity), surface parameters (orography, show depth, albedo, land and ocean shapes, and so on), ozone concentration, land and ocean surface temperature, ice coverage, leaf and grass coverages. Ocean temperature and ice coverage were taken from the Program for Climate Model Diagnosis and Intercomparison[7], while other data were taken from ECMWF ERA-40 reanalysis dataset.

We performed series of model runs with different periods of pre-modelling with 3.75º step along latitude and longitude and time step equal to 40 minutes. All simulated intervals ended by the end of December of 2000. Duration of modelling was from several months to 12 years. Supercomputer with installed ECHAM5-wiso spent 2.5 hours for 1-year simulation, so longest experiment required 30 hours. We used up to 32 CPU on supercomputer for modelling and found that increasing of CPU number greater than 32 does not accelerate the program any more. After simulations for all intervals of pre-modelling, we investigated mean temperature for December 2000 averaged over Yamal region (from 60° to 75°N and from 60° to 80°E) shown in Fig. 1 as rectangular. This region was selected for model experiments because of rapid industrial development recently from one side, and because of vulnerability of arctic ecosystems against human activity and climate change from the other side.

Figures 2 and 3 show dependences of mean air temperature and humidity at 2 m altitude averaged over Yamal region for December 2000 on pre-modelling duration. The data closed to real observation taken from NCEP/NCAR reanalysis are also shown on the same plots. NCEP/NCAR reanalysis data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/. We obtained that closest coincidence between model and reanalysis data is for 10-years duration of pre-modelling. This result is very preliminary, further

21st International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics,
edited by G. G. Matvienko, O. A. Romanovskii, Proc. of SPIE Vol. 9680, 96806B
 · doi: 10.1117/12.2205611

investigation is required. We plan to test longer periods of pre-modelling and averaging for longer period. In addition, it seems reasonable to use better spatial and temporal model resolution.

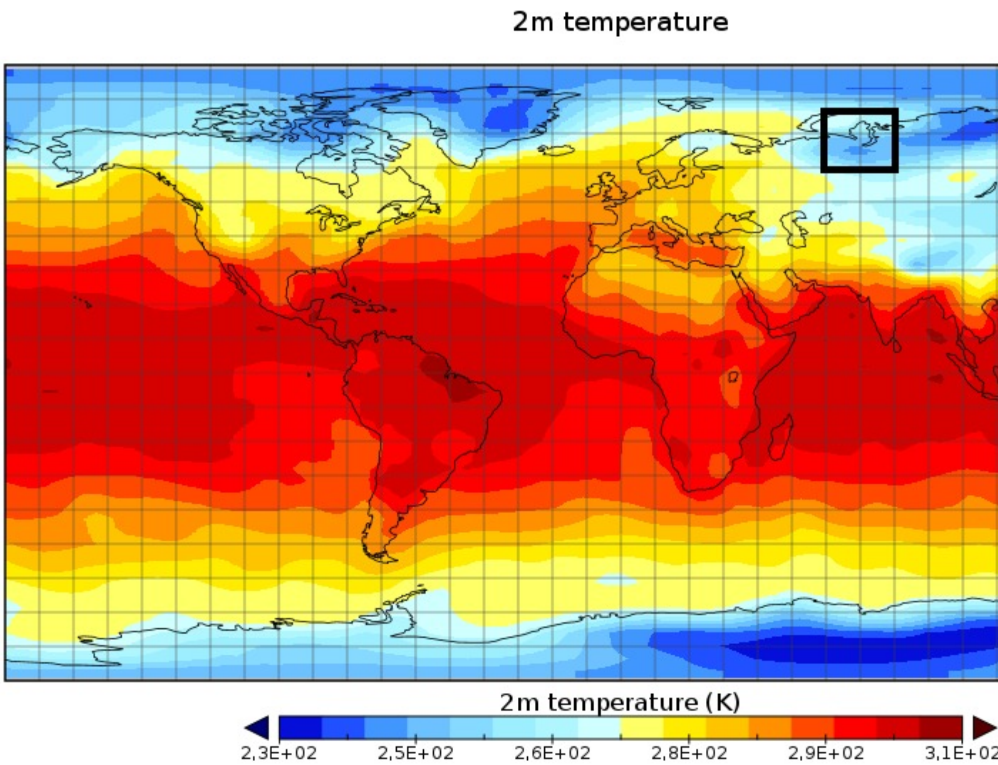

Fig. 1. Example output of ECHAM5-wiso for 2 m air temperature in December of 2000. Yamal region is shown as rectangular.

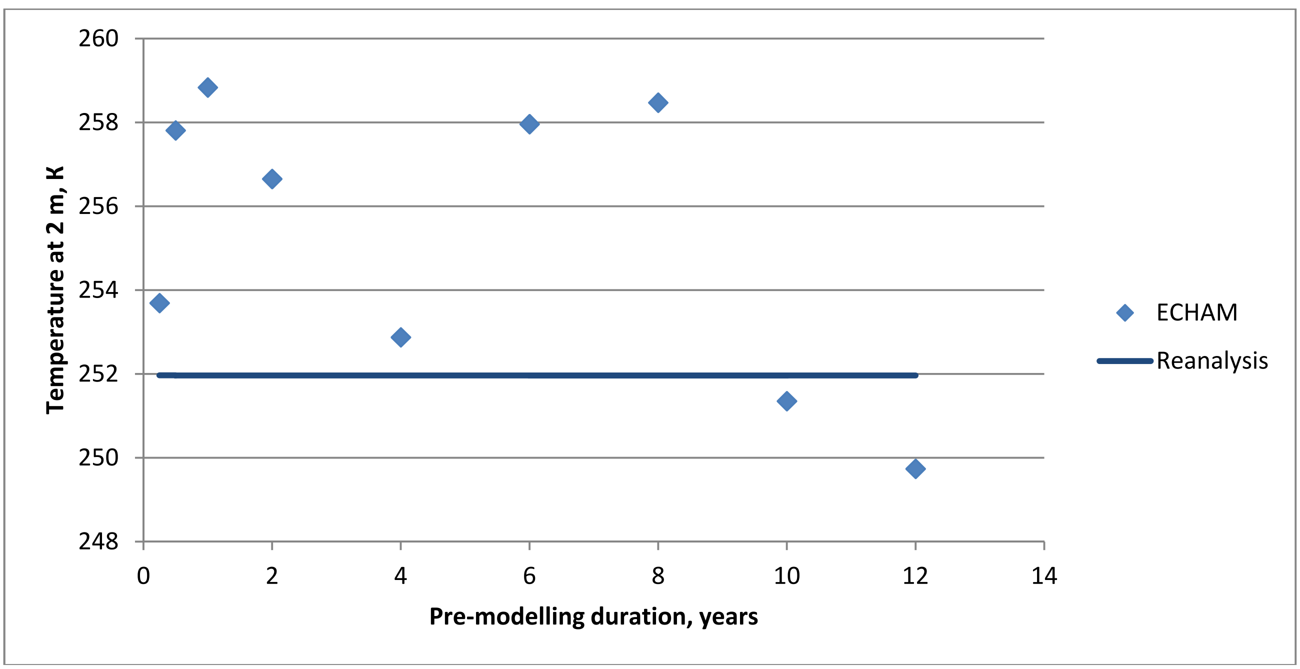

Fig. 2. Monthly mean 2 m air temperature in December of 2000 averaged over target region vs period of pre-modelling.

Next series of model experiments provided simulations for comparison with directly measured data at observation station of Climate and Environmental Physics Laboratory (CEPL) at Labytnangi (polar circle, 66.659°N, 66.409°E). We compare daily means for whole 2014 year with pre-modelling period since the beginning of 1991. All CEPL observation sites equipped with PICARRO L2130-i laser analyzers measuring isotopic composition (δHDO and $\delta H_2{}^{18}O$) of atmospheric water vapor approximately at 8 m above the surface, and with automated weather stations (currently Vaisala WXT520) measuring meteorological parameters (temperature, humidity, wind speed and direction). Water isotopologues (HDO and $H_2{}^{18}O$) provide integrated tracers of the atmospheric water cycle because of fractionation of stable water isotopologues in all processes of evaporation, condensation both to liquid and to ice, and re-evaporation of liquid precipitation within the atmosphere. In addition, these isotopologues have spectral features, which allow determination using various method of infrared spectroscopy, including remote sensing techniques. Usually, concentration ratios of isotopologues are expressed in terms of delta-values. We represent formula for δHDO,

$$\delta HDO = \left(\frac{(HDO/H2O)_{sample}}{(HDO/H2O)_{SMOW}} - 1\right) * 1000‰, \quad (1)$$

where molecule notation means absolute concentration and SMOW means Standard Mean Ocean Water. Value of $\delta H_2{}^{18}O$ is determined by the same way.

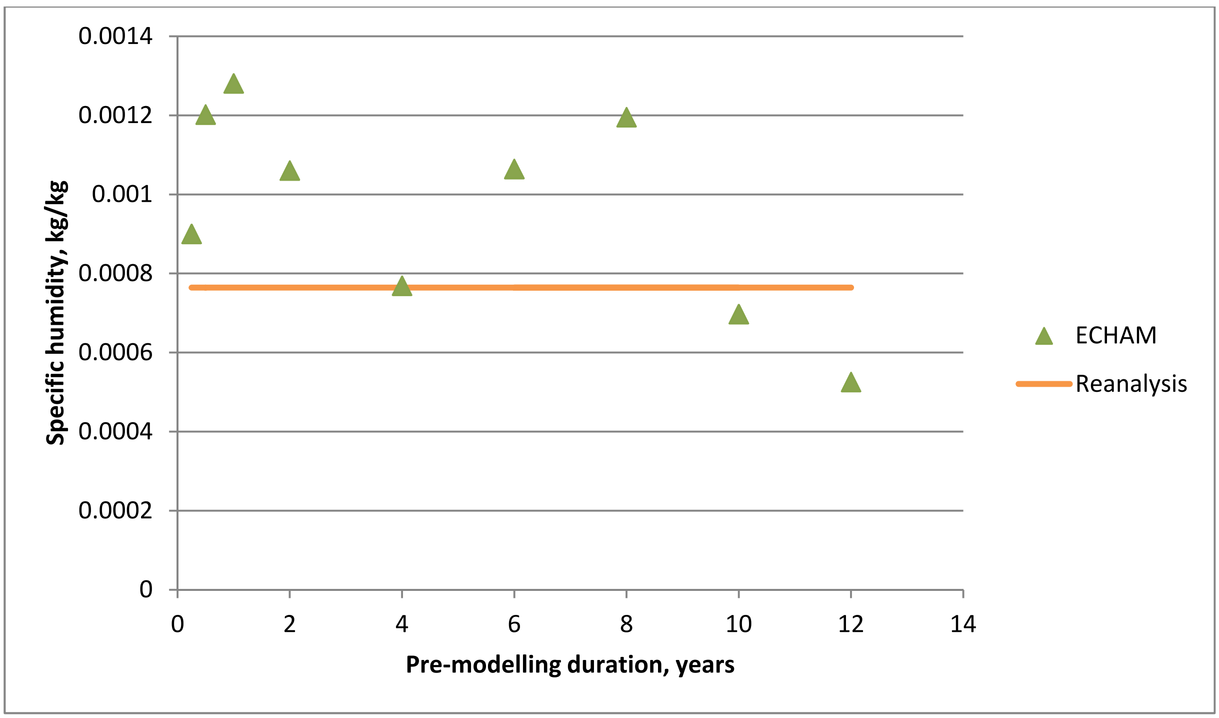

Fig. 3. Monthly mean 2 m specific humidity in December of 2000 averaged over target region vs period of pre-modelling.

Fig.4 shows comparison of daily mean temperature at 2 m as modelled by ECHAM5-wiso and represented in NCEP/NCAR reanalysis. Largest discrepancies are observed in winter period. All specific humidity data (model, reanalysis, and direct measurements) are shown in Fig. 5. One can note that direct measurements are higher than model and reanalysis data. Possible explanation is that model, reanalysis, and measured data are obtained for different altitude scales. Lowest model layer is approximately 100 m; lowest layer in reanalysis has thickness of approximately 600 m, while direct measurements were taken at altitude of approximately 10 m. Comparison of data discovered another problem in Labytnangi connected with serious discrepancies for some measurements in winter season. These data are intentionally left Fig. 5. Observation site in Labytnangi located near natural gas boiler-house, which distorts our measurements in those moments when wind direction is from boiler-house to observation station mast. Almost all winter data are shifted because the plot contains only daily means, and because of boundary layer turbulence and variation of wind direction within the day, averaging (summation) without filtering includes many members corresponding to high water vapor levels because of boiler-house vicinity. We plan to filter such measurements in future using wind direction data measured by our automated weather station. Measurements are performed with high repetition rate (once per 1-3 seconds), so it will be enough data for obtaining correct daily means.

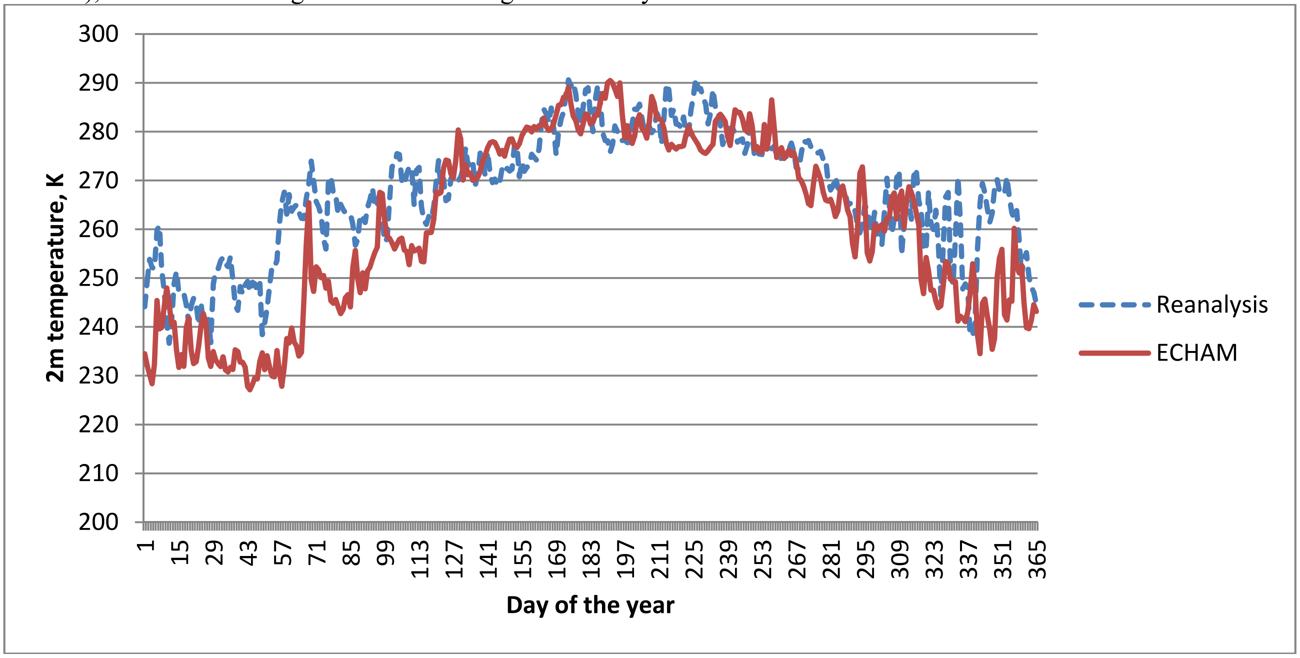

Fig. 4 Daily mean temperature at surface in Labytnangi in 2014 as modelled by ECHAM5-wiso compared to NCEP/NCAR reanalysis.

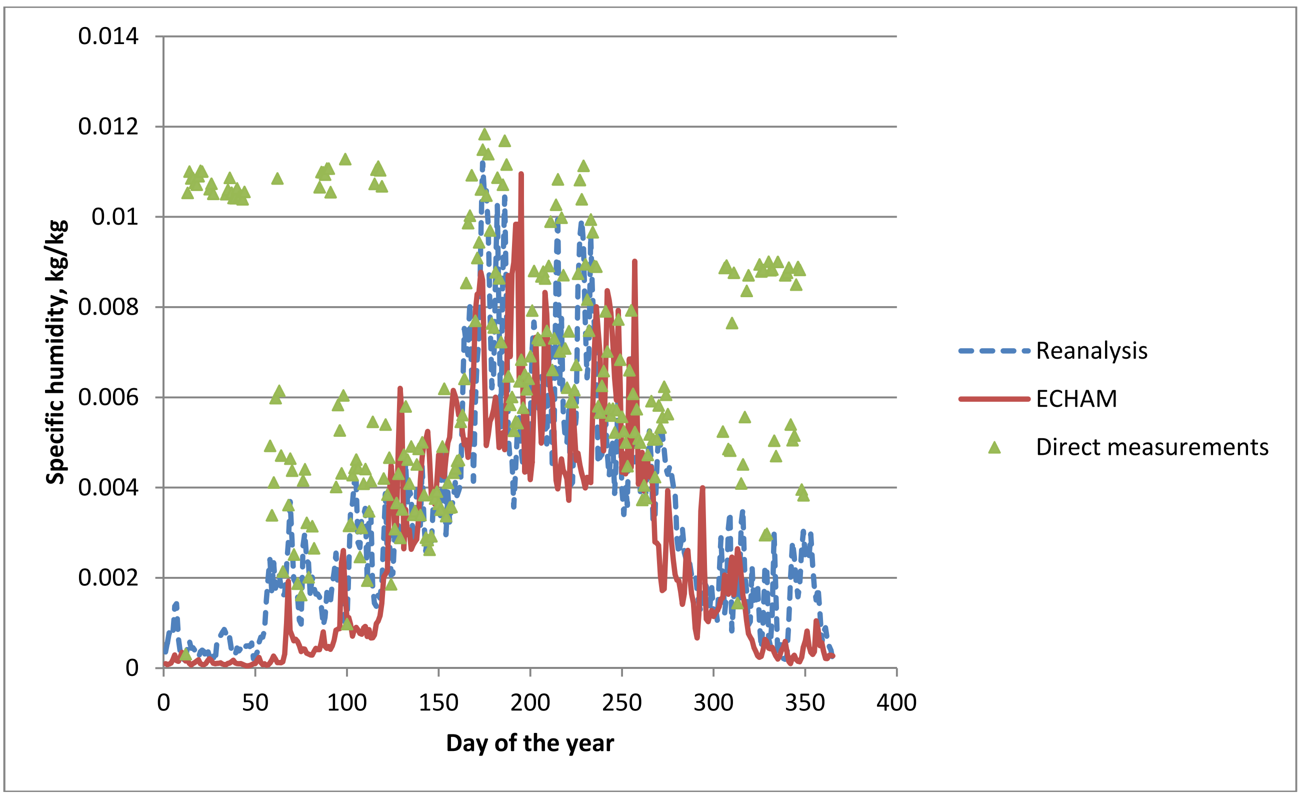

Fig. 5. Specific humidity in Labytnangi as obtained from the model, reanalysis, and direct measurements for 2014.

Figures 6 and 7 demonstrate good summer agreement of model and measured data on daily means of atmospheric water vapor isotopologues values $\delta H_2^{18}O$ and δHDO in Labytnangi during 2013-2014. Isotopic composition is also distorted in winter season by the vicinity of boiler-house.

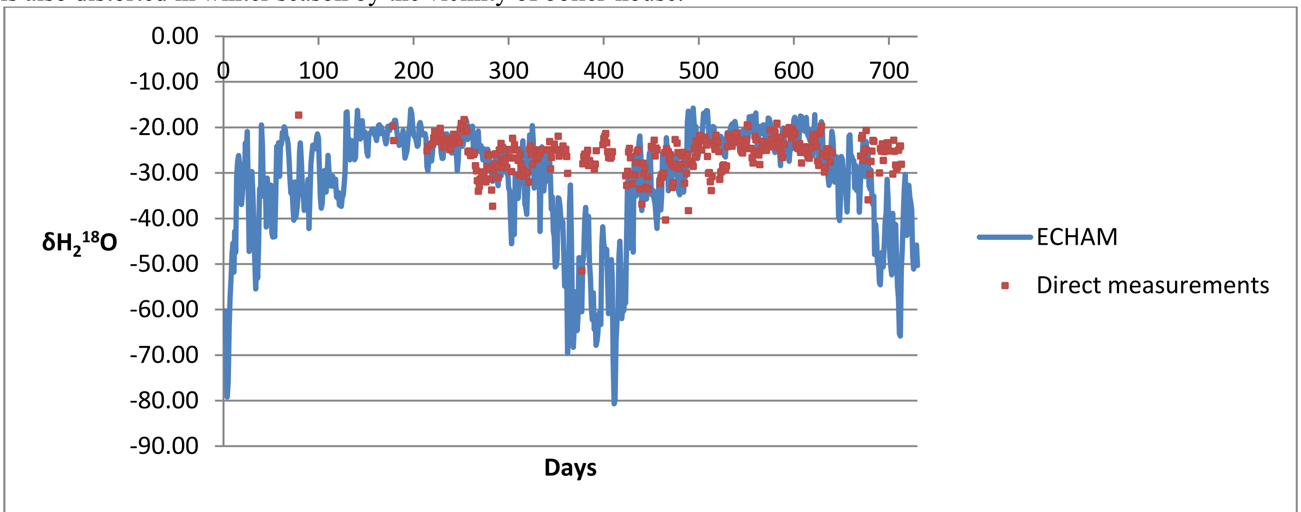

Fig. 6. Model and measured values of $\delta H_2^{18}O$ in Labytnangi for 2013-2014 years.

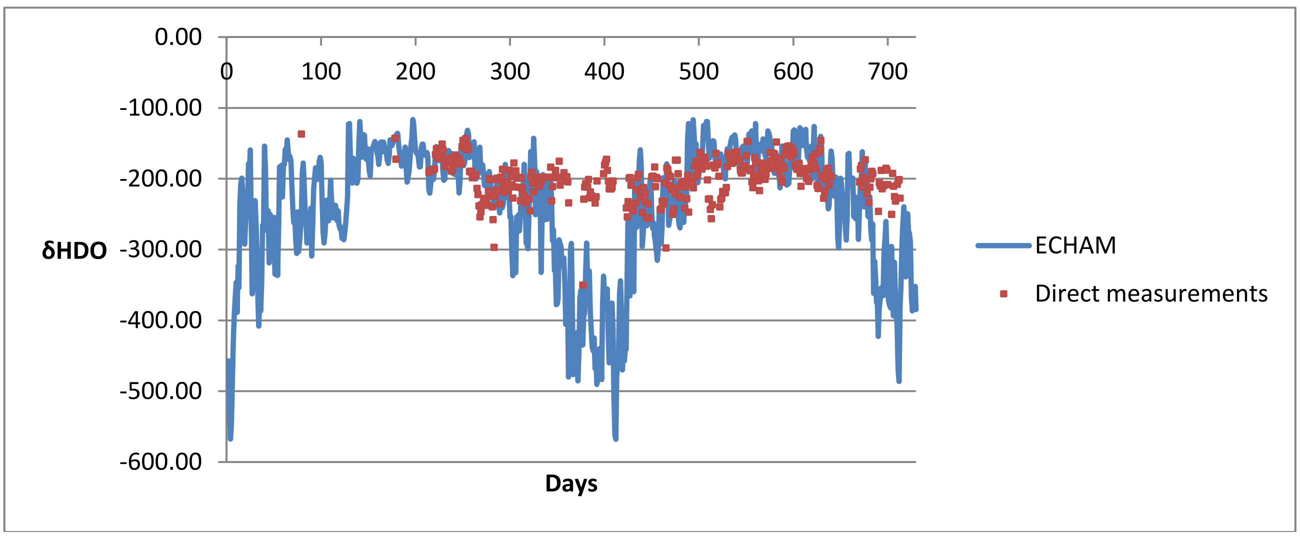

Fig. 7. Model and measured values of δHDO in Labytnangi for 2013-2014.

Climate and Environmental Physics Laboratory mastered climate simulation with supercomputer isotopic atmospheric general circulation model ECHAM5-wiso and started studying climate parameters of arctic regions of Russian Federation. First preliminary results demonstrate satisfied agreement of model, reanalysis, and measured parameters. We discovered winter distortion of measurements due to vicinity of boiler-house to observation station in Labytnangi and plan to filter measurements by determining and selecting admissible directions of wind in the period when boiling-house works.

Acknowledgments: Authors thank administration of Institution of Mathematics and Mechanics for providing us with access to supercomputer.

The research was partly supported by the grant RFBR 15-01-05984 and by the financial support from Ministry of Education and Science of RF, project #2189.

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5 The European Center for Medium-Range Weather Forecasts (ECMWF) – ERA-40 dataset: http://apps.ecmwf.int/datasets/data/era40-daily/, last access: 1 March 2015.

6 Institute of Mathematics and Mechanics UrB RAS – Computers: http://www.imm.uran.ru/Computers/, last access: 1 March 2015.

7 Program for Climate Model Diagnosis and Intercomparison : http://www-pcmdi.llnl.gov/projects/pcmdi/index.php, last access: 1 March 2015.