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Arctic sea ice, climate change and related climate feedback mechanisms

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Sea ice in the Arctic plays a central role in the context of climate change: both in its role when influencing the surface energy balance and the freshwater transport, and acting as an indicator for climate changes (see e.g. IPCC 2001). It is well established that the ice extent in the Arctic is currently significantly decreasing. While there is evidence that the ice thickness is also decreasing (e.g. Haas 2004; Yu et al. 2004), the record is not as comprehensive as that for ice extent.
At an ACIA workshop on climate feedback mechanisms (Gerland & Njåstad 2004), held in Tromsø/Norway in 2003, a working group collated key sea ice parameters for climate change and feedbacks, including information on how they are changing, corresponding confidence levels related to measured or modeled changes, and what the group would recommend for future work (Perovich & Wadhams 2004; Tab. 1). Among parameters listed were ice extent, ice thickness distribution and mean ice thickness (Haas et al. 2004; Hansen et al. in press; Perovich et al. 2003), ice types, albedo (Eicken et al. 2004; Perovich et al. 2002; Perovich & Grenfell 2004), length of ice-free period, melt pond fraction, snow depth and snow properties. As one example, the surface albedo and optical properties of sea ice (Hamre et al. in press) are crucial for the ice-albedo-feedback mechanism, being a key to summer melting. Among other relevant parameters were leads and polynyas, surface energy balance (Ivanov et al. 2003) and ice motion. Process studies on sea ice properties and their changes with specialised *in situ* observations provide data (along with remote sensing information) for large scale atmosphere-ice-ocean modelling (Haapala 2004; Karcher & Harms 2004; Kauker et al. 2003; Magnusdottir et al. 2004a,b). In return, the models enable the identification of key areas, e.g. sensitive regions in respect to climate feedbacks, and they give the possibility for the calculation of future scenarios.
Our recent research and monitoring activities with *in situ* and remote sensing studies aim at addressing and understanding the processes that are responsible for observed changes include observations and measurements undertaken at Svalbard, Fram Strait and Greenland Sea, the Barents and Kara seas, Alaska, the Beaufort Sea, and the central Arctic Ocean. Detailed long-term process studies are performed at Barrow (Alaska) and Ny-Ålesund (Svalbard), and on mooring profiles (Fram Strait, Hansen et al. in press), and are supplemented by studies on drifting ice stations (SHEBA, Perovich et al. 2003).
Here, physical parameters and related feedback processes are considered. The effects for the environment including habitats, biota etc. are not discussed. However, recent work indicates that biota itself can also be an active component in feedback processes (Leck et al. 2004).

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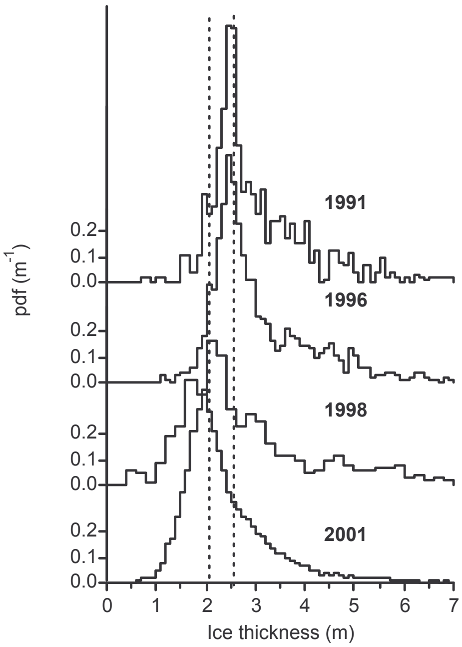

Fig. 1 (*left*): Ice thickness distributions (pdfs: probability density functions) of ice floes in the Transpolar Drift in 1991, 1996, 1998 and 2001. Dashed lines at 2 and 2.5 m are shown as a reference. From Haas et al. (2004). The modal ice thickness was reduced by 20% within 1991 and 2001.

Table 1 (*below*): Key sea ice parameters for climate change and feedbacks. Also listed are changes in the parameters, whether the changes were detected by observation or theory, our confidence in the results, future work recommendations, and comments. Abbreviations: MY=multi-year sea ice, FY= first-year sea ice, ULS= upward looking sonar, AUV= autonomous underwater vehicle, RS=remote sensing, cal-val=calibration-validation, RGPS=RADARSAT geophysical processor system.

Parameter	Change	Obs./ Theory	Confidence	Recommendations	Comment
Ice extent & ice concentration	Decreasing	O	High	Continue time series, improve spatial resolution	Automatic camera monitoring from ships
Thickness distribution	Shifting			ULS-time series, submarine surveys, ship obs.	Key climate parameter
Ice type	Shifting	O	High	Continue time series, improve spatial resolution	Automatic camera monitoring from ships
Mean thickness	Decreasing	O	High	Increase satellite cal-val	Since 1950's
Ridges	Decreasing	O	Medium	Submarine (or AUV) & aircraft campaigns	
Rafting	Increasing	T	Low	Process studies, thickness surveys, models	Difficult to determine what is rafted
Thin ice	Unknown		Low	Process studies	Important for ice prod., inferred from RGPS
Leads and polynyas	Unknown		Low	Process studies	Important for ice prod.
Energy balance	Increasing	O	Medium		
Ice mass balance	Decreasing	O	Medium	Field campaigns, autonomous buoys, Particular ice types	Demand of separation dynamics/ thermo-dynamics impact
Albedo	Decreasing	T	Low	Process studies (FY and special surfaces), RS input	Key to summer melt; important for climate models
Length of ice free period	Increasing	O	Medium	Satellite analysis	Important for mass bal., biology, shipping
Melt pond fraction	Increasing	T	Low	Field campaigns	Major impact on albedo
Ice motion	Different regimes	O	High (large scale), low (small scale)	High time resolution (hourly), coastal radars	Atmosphere driven, influences thickness distribution
Snow depth and properties	Unknown		Low	Satellite snow depth maps, field campaigns	Superimposed & snow ice formation; important for albedo

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