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Arctic Sea Ice Thickness Remained Constant During the 1990s

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Abstract. The ice cover of the Arctic Ocean is considered to be a sensitive indicator of global climate change. Recent research, using submarine-based observations, suggests that the Arctic ice cover was thinner in the 1990s compared to an earlier period (1958-1979), and that it continued to decrease in thickness in the 1990s. Here I analyze subsurface ice thickness (draft) of Arctic sea ice from six submarine cruises from 1991 to 1997. This extensive data set shows that there was no trend towards a thinning ice cover during the 1990s. Data from the North Pole shows a slight increase in mean ice thickness, whereas the Beaufort Sea shows a small decrease, none of which are significant. Transects between the two areas from 76° N to 90° N also show near constant ice thicknesses, with a general spatial decrease from the Pole towards the Beaufort Sea. Combining the present results with those of an earlier study, I conclude that the mean ice thickness has remained on a near-constant level around the North Pole from 1986 to 1997.

1. Introduction

Coupled atmosphere-ocean models predict an increase in the global mean air temperature as a response to a gradual increase in atmospheric CO_2 with a strong amplification of the predicted warming at high latitudes [*Manabe and Stouffer,* 1993]. The ice cover of the Arctic Ocean, with its known sensitivity to atmospheric greenhouse forcing as shown in several model studies, may then serve as a precursor of global climate change.

Arctic sea ice has a complex structure, consisting of different kinds of ice and different thicknesses, ranging from very thin new ice to pressure ridges up to 50 m thick. Observations of ice thickness on a basin-wide scale have been obtained from submarine-based upward looking sonars that measure sea ice draft which is a measure of the subsurface ice thickness (the total thickness also includes the above-surface freeboard). *McLaren* [1989] presented draft data from two cruises (1958 and 1970) showing more severe ice conditions with thicker ice in 1958. *Wadhams* [1990] calculated a decrease of about 15 % of the total ice volume when analyzing draft data from two years (1976 and 1987) north of Greenland. *McLaren et al.* [1992] investigated six cruises from 1977 to 1990 and found a large interannual variability but little evidence of a thinning ice cover. Recently, *Rothrock et al.* [1999] analyzed the presently available Scientific Ice Expeditions (SCICEX) submarine cruises ('93, '96 and '97) and found that the mean ice thickness had decreased by 1.3 m when compared to similar data acquired during the 1958-1976 period. They further stated that the thinning has continued during the 1990s and estimated an overall mean decline of 0.1 m yr^{-1}. The latter conclusion, which has been cited widely, is carefully analyzed here using the most comprehensive data set presently available to the research community.

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2. Data Analysis and Results

Here the SCICEX data are re-examined together with three other submarine cruises from 1991, 1992 and 1994, all from April and May. The data is publicly available from the National Snow and Ice Data Center (NSIDC) and provide a good base to examine possible trends of the ice cover in the central Arctic. Statistical quantities derived from 50-km long sections are the mean draft d, and fractions of different ice classes defined in the same manner as in *Wadhams* [1992]; d >5 m, 2 m$\leq d \leq$5 m, 0.3 m$\leq d<$2 m, and d <0.3 m. Note that the latter fraction also includes open water. Figure 1 shows the spatial coverage of the data used in the present analysis. Transects, covering the central Arctic Basin, from 76° N to 90° N are used here. Furthermore, data is presented from two selected areas which have been particularly densely sampled, one centered around the North Pole (>87° N) and the other in the central part of the Beaufort Sea. Each area and year contain at least 500 km of draft data, ensuring high statistical significance to the mean values [*Wadhams*, 1997]. Other areas of the Arctic have been visited by submarines, but not by all six cruises, and generally there is not enough data in these areas to make a proper analysis. The North Pole area is particularly well suited for investigating possible trends in the ice sheet since the ice found here represents an integrated effect due to the advection of ice to this area from many sites in the Arctic. As the SCICEX cruises are from late autumn these drafts are increased with a typical seasonal ice growth (0.9 m) to be able to compare these with the other cruise data which are from April to May. The seasonal ice growth is taken from a coupled ice-ocean model that was run over a 40-year period for all observations to represent ice conditions around 1 May [*Zhang et al.,* 1998]. This method is imperfect as there are many complexities of ice growth not incorporated in the model, but it gives a representative average seasonal ice growth, and is the same method as used by *Rothrock et al.* [1999].

Figure 2 shows transects consisting of mean draft computed from 50-km sub-sections from the central part of the Beaufort Sea to the North Pole. The late winter cruises of 1992 and 1994 covered two identical transects over the central Arctic Basin (see Figure 1), and at the same time of the season (late April to beginning of May). The variability along transects between successive years has an overall span of 0.5 m throughout the transects. All data show a decline in ice thickness from the Pole towards the Beaufort Sea. There is little sign of any systematic change from year to year in the spatial distribution of ice thickness across the entire basin. Inserted in Figure 2 (top left corner) is the overall mean draft for each year, calculated from all transect data. This shows that the mean ice thickness across the Arctic Basin was almost constant in the period from 1991-1997. The mean draft for this 7-year period is 3.4 m.

Table 1 shows the mean drafts from the two densely sampled areas together with the different ice fractions. The values in brackets (for 1993, 1996, and 1997) show the mean draft prior to correcting for the average seasonal ice growth as described above. Drafts from the North Pole show little variability throughout the six years (~0.4 m), with an overall mean draft of 3.7 m. Examining the data there is no trend towards a thinner ice cover. In fact, a linear regression gives a slight increasing trend for the whole period, although not significant. The late winter observations (1991, 1992, and 1994) show remarkably constant levels in the mean fractions of the different ice types. The fraction of d <0.3 m (including open water) is between 0.5 and 2 % in the late winter observations compared to 3-9 % in the late summer observations (as a result of summer ice melt).

The variability in the Beaufort Sea is larger than for the North Pole area (~0.8 m) with lower drafts in the 1996 and 1997 observations (see Table 1). The overall mean draft is 2.6 m, some 30 % less than the North Pole mean. Among the late winter observations, 1992 stands out with a higher fraction of open water (6 %) compared to the 1991 and 1994 fractions (1 %). The most striking feature is the absence of thicker ice classes in the 1996 and 1997 observations as also noted by the drifting ice camp SHEBA [*McPhee et al.,* 1998].

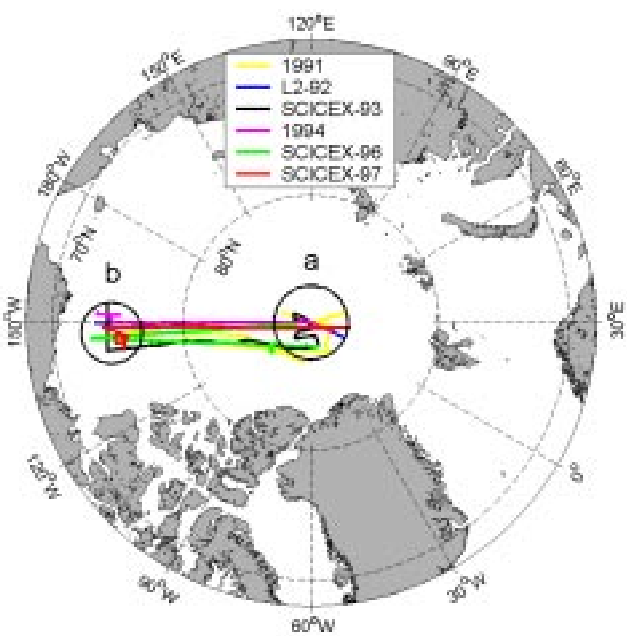

Figure 1. Cruise tracks of the 1991, L2-92, SCICEX'93, 1994, SCICEX'96, and SCICEX'97 submarine cruises used in the analysis (see legend for color codes). Also shown are the North Pole and Beaufort Sea areas (circles marked with a and b respectively) from which data are also compared.

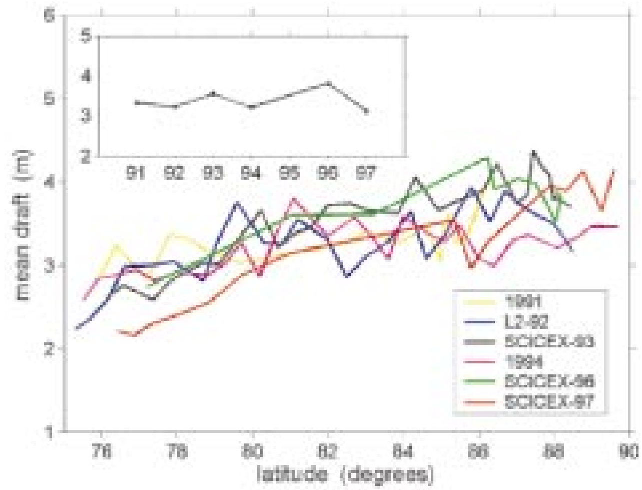

Figure 2. Late-winter mean ice draft along transects computed from 50-km-long sub-sections over the central Arctic Basin from the Beaufort Sea to the North Pole. The inserted figure (top left corner) shows the late-winter yearly mean drafts (in m) based on all transects.

The ice fraction of d >5 m is nearly absent and the fraction of drafts in the 2 m≤ d ≤5 m interval is reduced by over 40 % compared to the 1993 observations in this area. For the 7-year period as a whole, no significant trend in mean draft can be found.

3. Discussion and Conclusions

Draft data from the North Pole, the Beaufort Sea, and transects between the two areas over a 7-year period from 1991 to 1997 show no evidence of a thinning ice cover. The Beaufort Sea area shows larger variability, being closer to the marginal ice zone and sensitive to circulation type and the location of the Beaufort high. Using a more extensive data set (6 years compared to 3), the negative trend in ice thickness found by *Rothrock et al.* [1999] during the 1990s is not supported by the present investigation. Combining the mean drafts derived by *McLaren et al.* [1992] from 1986 to 1990 with those from the present study, I conclude that the thickness of the sea ice cover has remained on a near-constant level at the North Pole during the 12-year period from 1986 to 1997. This result is also supported by *Wadhams and Davis* [2000] who concluded that a substantial part of the thinning between 1976 and 1996 probably took place during the first of those two decades.

The Arctic ice cover varies greatly on seasonal, interannual and longer time scales, both regarding extent and thickness [e.g., *Parkinson et al.*, 1999; *Haas and Eicken*, 2000]. This makes the analysis of draft data complicated, especially when comparing different years and areas. Undergoing work to digitize and analyze historical submarine data together with continued monitoring during the next decades should be encouraged as current draft data only cover a few discrete years. Annual data with similar spatial coverage, over a climate-relevant time period (50 years or more), is needed in order to understand the natural variability of the ice cover, and to detect possible climate trends of the Arctic sea ice.

Table 1. Late-winter mean drafts together with fractions of different ice types. Numbers in brackets show the mean draft prior to correcting for the average seasonal ice growth (see text for details).

Year	Mean draft (m)	$d > 5$ m (%)	2 m$\leq d \leq$5 m (%)	0.3 m$\leq d <$2 m (%)	$d <$0.3 m (%)
			North Pole		
1991	3.73	18.4	69.8	11.0	0.8
1992	3.45	18.4	55.6	24.7	1.3
1993	3.56 (2.66)	8.9	50.5	37.5	3.1
1994	3.51	18.1	63.5	16.8	1.6
1996	3.67 (2.77)	9.6	65.7	15.6	9.1
1997	3.84 (2.94)	11.4	66.4	13.7	8.5
			Beaufort Sea		
1991	2.89	14.1	37.5	47.4	1.0
1992	2.58	10.3	39.5	44.1	6.1
1993	2.79 (1.89)	5.6	33.0	45.2	16.2
1994	2.80	10.9	45.7	42.4	1.0
1996	2.09 (1.19)	2.1	19.7	56.0	22.2
1997	2.16 (1.26)	1.3	18.0	62.2	18.5

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