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The effect of winter cooling on inter-annual changes of near-bottom water temperatures off Southwest Greenland - a forecast option for bottom water temperatures on half year time scales

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Abstract

Within the framework of ecosystem-based fishery management it might be useful to know in advance about the environmental conditions in which demersal marine resources live.

In this paper we analyse the variability of monthly sea surface temperatures (SSTs) off Southwest Greenland by using the "Wavelet Power Spectrum" analysis. We then present a method to forecast bottom water temperatures six months in advance. The paper uses linear correlations of SSTs with bottom water temperatures, derived from the oceanographic database of the Institut für Seefischerei, Hamburg. Mean January and April SSTs anomalies yield the best correlations (r^2=0.71) with autumn bottom water temperatures obtained from measurements off Southwest Greenland during 1987-2007.

Introduction

Ocean water temperature is a key parameter, impacting other physical, chemical and biological properties of the oceans. It also influences growth, distribution and survival of fish and other marine organisms (Rätz et al., 1999, Stein and Borovkov, 2004). Understanding of the thermal conditions of marine habitats is essential for effective management of fisheries and marine resources. Since the management of fish stocks is a long-term process, it would be desirable to pre-estimate ocean temperatures, e.g. on an intra-annual, annual or multi-annual time scale.

For the western North Pacific region, Schneider and Miller (2001) predict wintertime sea surface temperature (SST) anomalies in the confluence region of the Kuroshio–Oyashio Currents at lead times of up to 3 years. The predictions are based on the history of the wind stress over the North Pacific and oceanic Rossby wave dynamics. Stein and Lloret (2001) used statistical methods to describe and forecast monthly mean air and bottom water temperatures from 3 sites in the Northwest Atlantic region, up to one year in advance. The results show that the use of ARIMA models yields better forecasts for highly variable time series than simple models based upon averages of previous monthly averages alone.

Short-term prediction of ocean temperatures is one of the products which Real-Time Ocean Forecast Systems (RTOFS) are able to offer, e.g. for the Atlantic Ocean. RTOFS (Atlantic) is a basin-scale ocean forecast system based on the HYbrid Coordinate Ocean Model (HYCOM). The model is run once a day, completing at about 1400Z. Each run starts with a 24 hour assimiliation hindcast and produces ocean surface forecasts every hour and full volume forecasts every 24 hours from the 0000Z nowcast out to 120 hours. Incorporated in this RTOFS are different sub-regions of the Northwest Atlantic, e.g. the Labrador Sea. Although not designed for long-term forecast, the model results provide a comprehensive insight in the thermohaline and dynamic properties of the entire water column. This source of information might be used to learn about the internal structure of the Northwest Atlantic, especially to learn about interaction scales of boundary currents like the East Greenland Current and the West Greenland Current.

The signal transfer of winter cooling at the sea surface to the deep and near-bottom layers, is a product of convective mixing during winter. Convection can be forced by winter storms. Pickart et al. (2003), show that low-level atmospheric jets may even cause deep convection off Greenland.
In this paper we explore the potential of standard statistical methods including wavelet analysis and correlation analysis to amalgamate SST data - available from the internet, and bottom water temperatures - measured during more than 20 years in the waters around the southern seaboards of Greenland, to distil a forecast option for bottom water temperatures on half year time scales.

Data and Methods

Monthly sea surface temperature data (January, 1982 to December, 2007) for the region around Greenland were taken from the IGOSS (Integrated Global Ocean Services System) Data Base http://iridl.ldeo.columbia.edu. A software (GriDV.exe), provided by the Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, enables extraction of SST data, gridded 1 x 1 degree in latitude/longitude. The grid points for the extraction and averaging SST data are given in Table 3. Long-term monthly mean SST was calculated for the period 1982-2007.

Estimations of average near-bottom temperature of water in the same area in October - November 1987, 1989, 1991, 1993-2007 were taken from standard stations of German oceanographic surveys (oceanographic database of the Institut für Seefischerei, Hamburg).

For the analysis of characteristic periods incorporated in the SST data, the corresponding de-trended time series was uploaded to the “Interactive Wavelet Plot” option, available at http://paos.colorado.edu/research/wavelets/ . Results of this analysis are displayed in Figs. 4 and 5.

A linear correlation was performed for the monthly SSTs and the bottom water temperatures. Three areas were analysed: SE Greenland, S Greenland and SW Greenland. The depth range of the grid positions covers 150 – 600m. Due to the temporal and spatial coverage of the bottom water data, the bottom water data set used comprises the years 1987-2007.

Results and Discussion

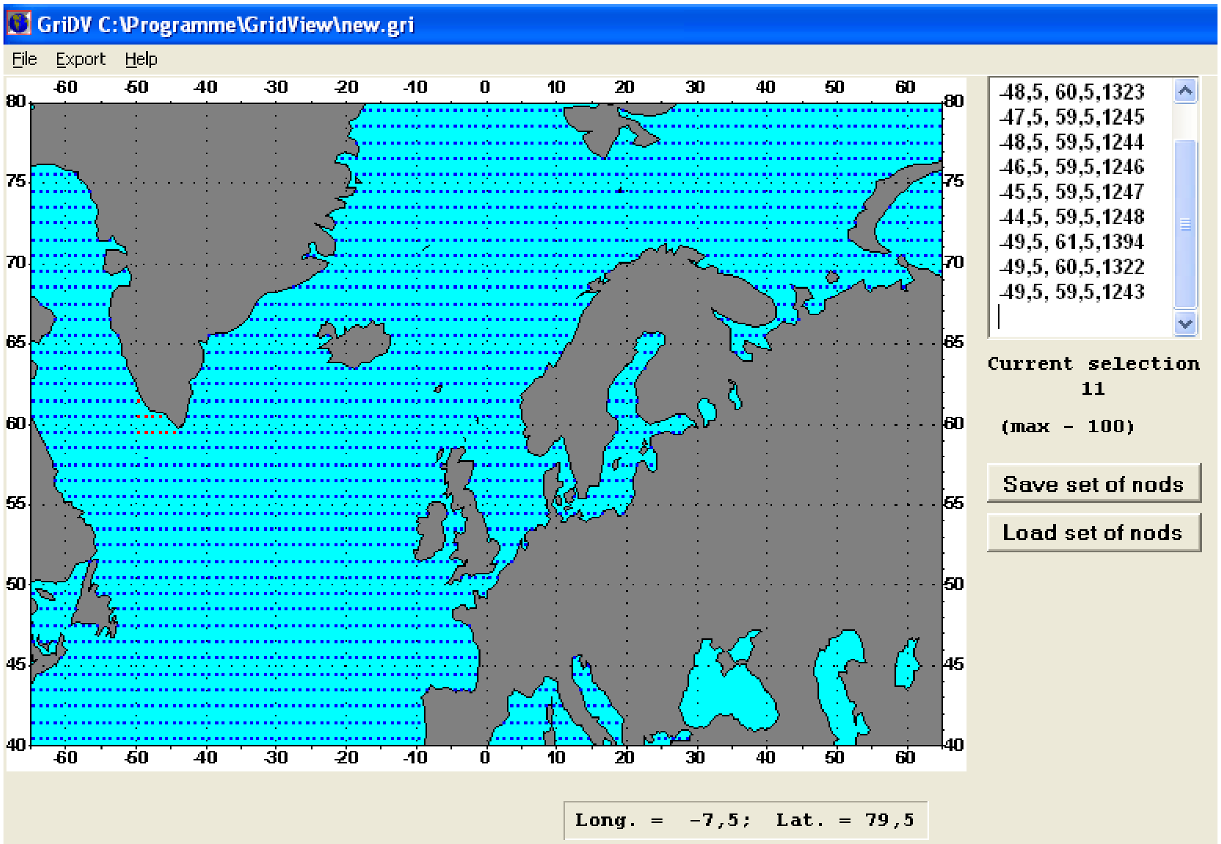

Fig. 1 Screen dump of GriDV.EXE; grid points selected off SW Greenland (red); grid point positions are given in the “Current selection” window

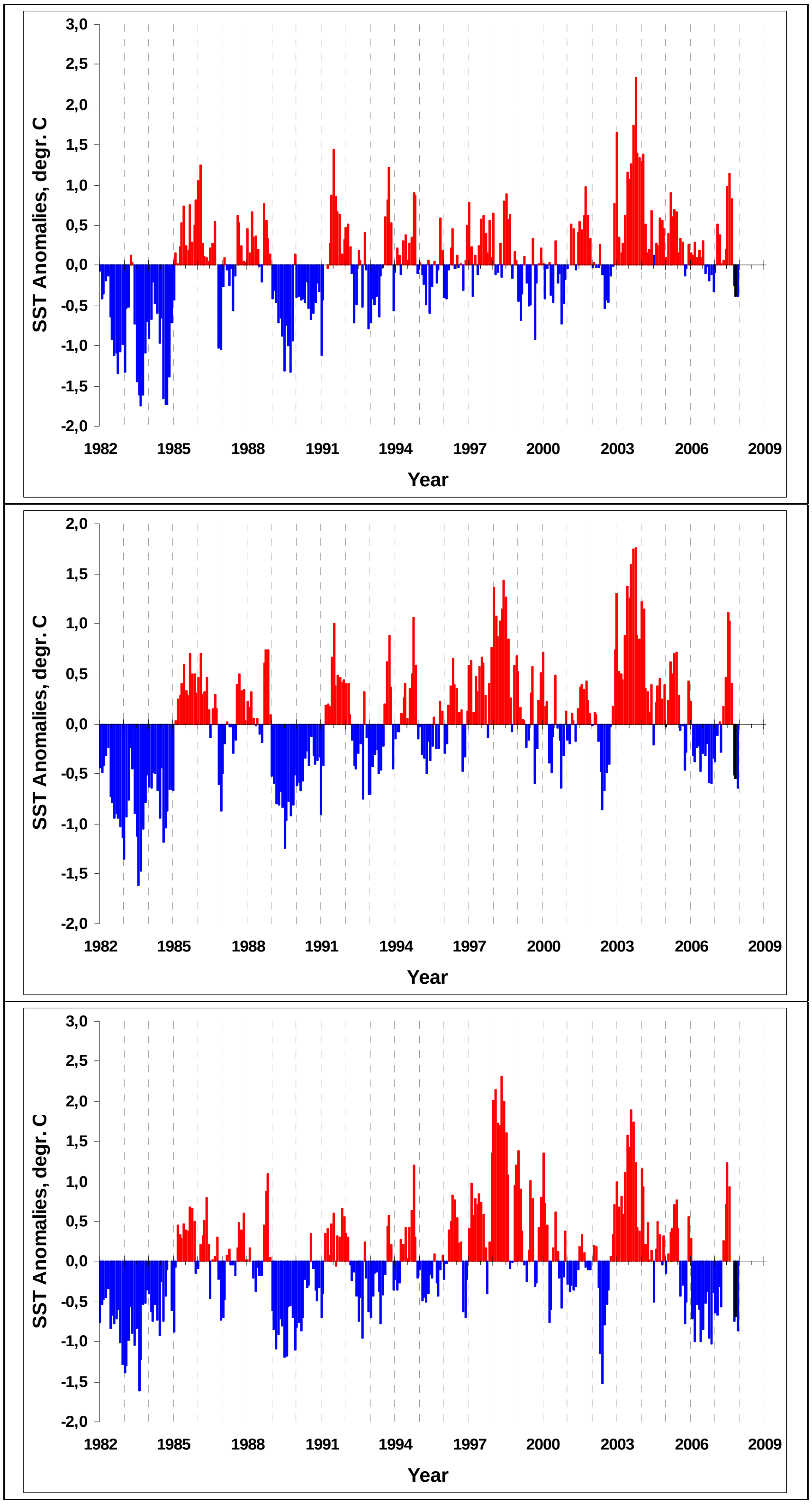

Fig. 2 Sea surface temperature anomalies, JAN 1982 – DEC 2007; SW Greenland (top panel), S Greenland (middle panel), SE Greenland (bottom panel)

A screen dump of the program GriDV.EXE is given in Fig. 1. Eleven positions are marked (red) and displayed in the “Current selection” window. The panels in Fig. 2 display the SST anomalies off the southern shores of Greenland. The cold early-1980s and early-1990s clearly emerge from all figures. Warming during the late-1990s is most expressed at South and Southeast Greenland (panel b, c). Peak warming during 2003 can be observed in all panels. Cooling during 2006 is most expressed at SE Greenland (panel c). During most of 2007, SST anomalies are positive, except for the data October-December, 2007 which indicate cooling in all sub-regions (all panels in Fig. 2).

SST Variability off SW Greenland

The variability of mean monthly SST anomalies in SW Greenland waters is characterized by an increasing trend which contributes about 19 % to the variability of the time series (Fig. 3).

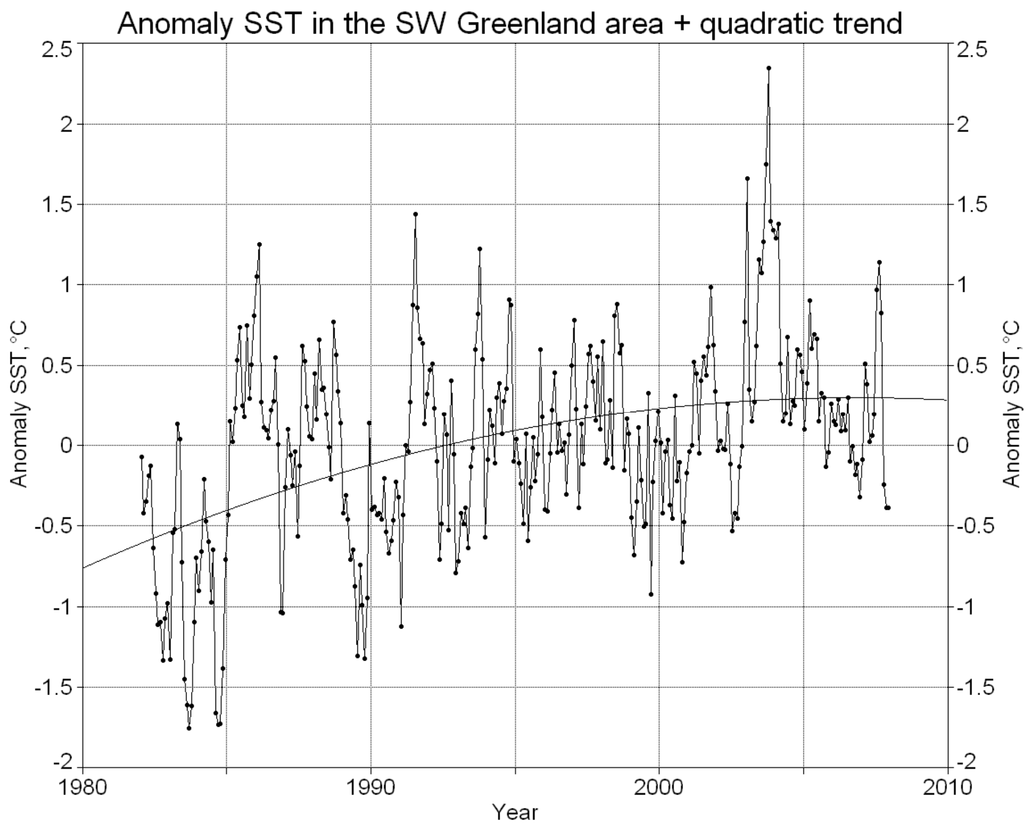

Fig. 3 Sea surface temperature anomalies, JAN 1982 – DEC 2007, SW Greenland; a quadratic trend has been applied, explaining about 19% of the total variation

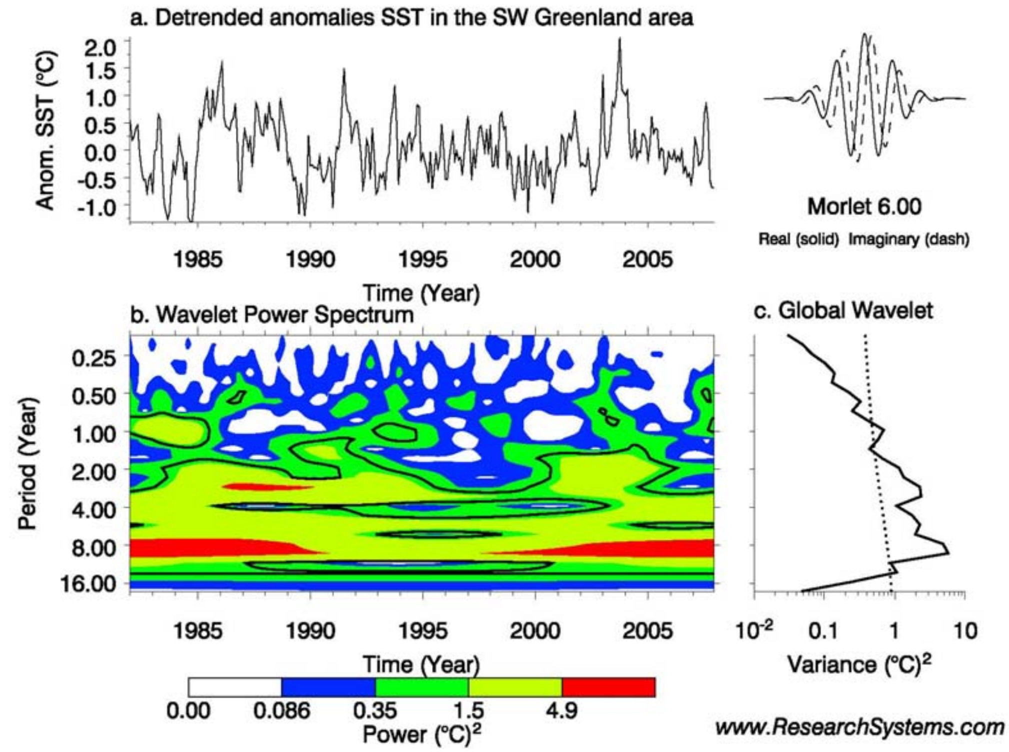

Fig. 4: (a) Detrended monthly anomalies SST off SW Greenland. (b) The wavelet power spectrum. The contour levels are chosen so that 75%, 50%, 25%, and 5% of the wavelet power is above each level, respectively. Black contour is the 5% significance level, using a white-noise background spectrum. (c) The global wavelet power spectrum (black line). The dashed line is the significance for the global wavelet spectrum, assuming the same significance level and background spectrum as in (b).

The "Wavelet Power Spectrum" analysis reveals characteristic periods around 8 yr which dominated during the 1980s, and during the 2000s (red band in Fig. 4). During most of the 1990s, this 8 yr periodicity is absent.

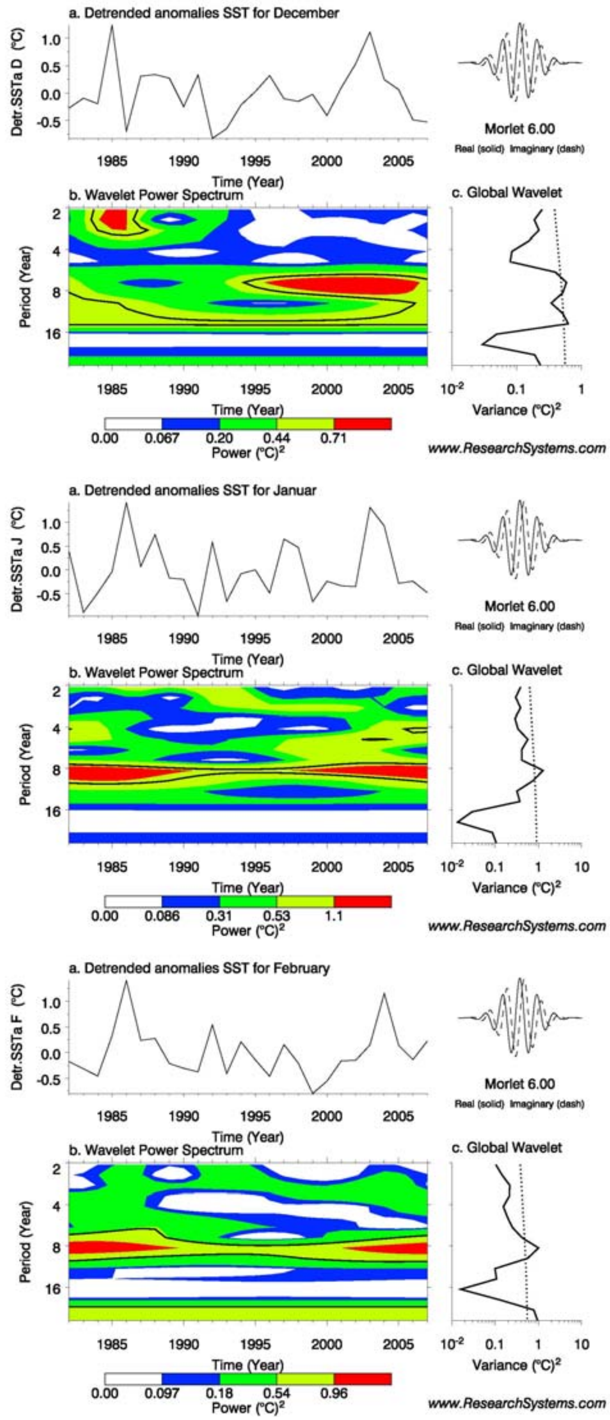

Fig. 5: (a) Detrended SST anomalies for December (top panel), January (middle panel) and February (bottom panel). (b) The wavelet power spectrum. The contour levels are chosen so that 75%, 50%, 25%, and 5% of the wavelet power is above each level, respectively. Black contour is the 10% significance level, using a white-noise background spectrum. (c) The global wavelet power spectrum (black line). The dashed line is the significance for the global wavelet spectrum, assuming the same significance level and background spectrum as in (b).

A similar structure of variability can be seen in the wavelet power spectra for the monthly time series December, January and February (Fig. 5). At the end of winter and in the beginning of spring, the power spectra of SST lose the dominant component with the period of about 8 yr, and as a whole resemble a spectrum of white noise.

Inertia of thermal changes in the SW Greenland SSTs can be derived from the correlations between monthly averages (Table 1).

Table 1 Coefficients (r) of linear correlation between monthly average SSTs
(bold values are statistically significant at $p<0.01$)

	Dec	Jan	Feb	Mar
Dec				
Jan	**0,784**			
Feb	**0,587**	**0,751**		
Mar	0,390	0,466	**0,653**	
Apr	0,317	0,379	0,354	**0,661**

The data in Table 1 indicate that the winter months December to February, are most coherent as concerns statistically significant ($p<0.01$) correlations between the next months. Coherence in the periodicity signal of about 8 yr as mentioned above, gives the additional contribution of high correlation between SSTs during the winter season (December - February).

Estimates of relationships between winter-spring SSTs and autumn water temperatures in the bottom-near layer

Statistical characteristics of linear correlations between winter-spring SSTs and autumn near-bottom temperature of water are given in Table 2:

Table 2 Linear correlations between winter-spring SSTs and autumn near-bottom temperature

Month	Dec	Jan	Feb	Mar	Apr
r	**0.706**	**0.694**	0.352	0.455	**0.782**
Degrees of freedom	15	16	16	16	16
p=0.01	0.633	0.615	0.615	0.615	0.615

The data given in Table 2 yield a statistically significant signal of winter cooling in changes of near-bottom water temperature off SW Greenland during autumn. However, for February and March this effect is only shown as a non-significant tendency.

Probably, the presence of sea ice cover in the considered area during these months, and the use of sea-ice to SST conversion algorithm bring additional errors which mask the process of seasonal cooling of waters in the considered months. At the retreat of sea ice during approaching spring time, these errors and their masking influence seem to be reduced, or do disappear. Due to this, and due to the intrinsic inertia of the thermal processes, the April SSTs again show statistically significant relationship with inter-annual changes of near-bottom water temperature during autumn.

Regression models for forecasting autumn near-bottom temperature

The statistical analysis presented above, gives an opportunity to use winter-spring SSTs for forecasting near-bottom water temperatures along the shelf edge off southwest Greenland in the subsequent autumn period. Besides regression models which use monthly average SSTs for December, January and April, characterized by close correlations with near-bottom water temperature, it is possible to calculate models with linear combinations of these series.

One example is given below, a regression model of autumn bottom water temperature and average SST anomalies in previous January and April (Fig. 6, 7). Other combinations of monthly SST anomalies appeared to be less effective, or, in the case of increasing the components of combination, resulted in loss of its statistical correctness because of involving correlated series.

The results, a correlation which explains 71 % of the variation of the mean bottom water temperature off Southwest Greenland, gave convincing evidence that our assumed link of mean January and April SSTs anomalies/autumn bottom water temperatures might represent an existing coupling mechanism in Southwest Greenland waters.

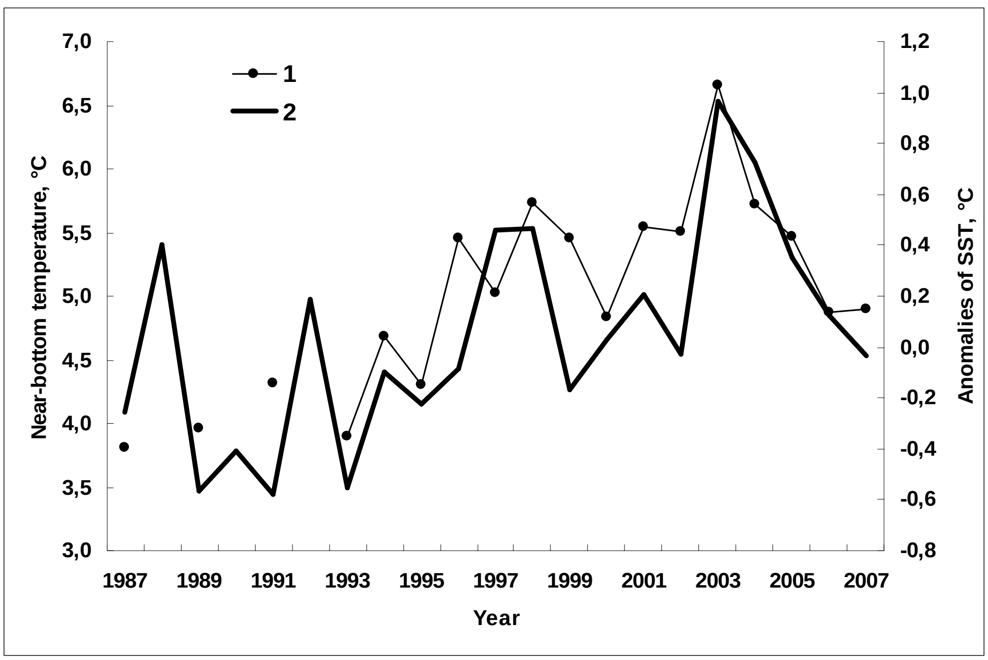

Fig. 6 Sea surface temperature anomalies, JAN + APR 1987 – 2007, SW Greenland (2), and near-bottom water temperature in autumn (1)

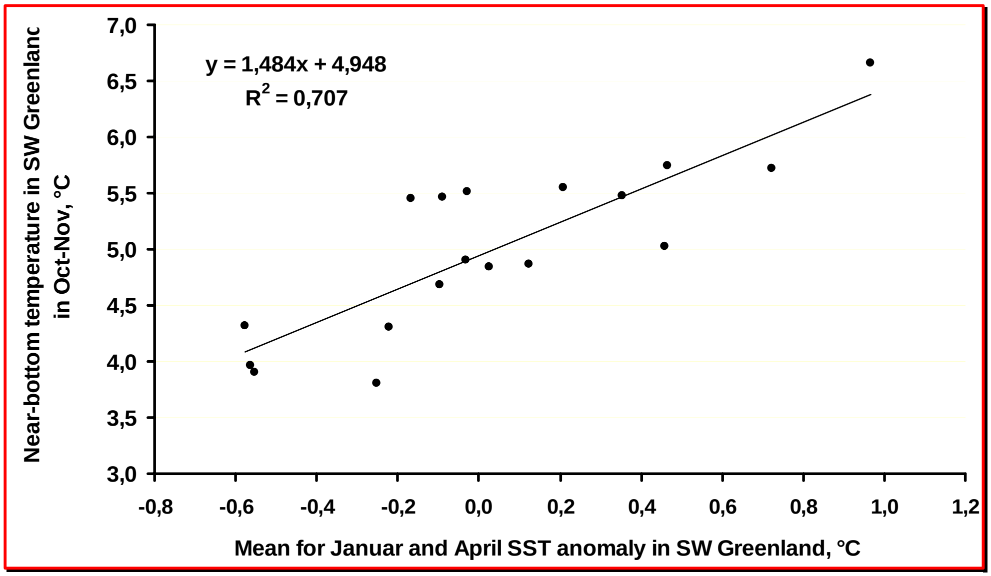

Fig. 7 Linear regression of sea surface temperature anomalies, JAN + APR 1987 – 2007, SW Greenland, and near-bottom water temperature in autumn

Table 3 Grid points for extraction of SST anomalies off Greenland

SW_Greenland	S_Greenland	SE_Greenland
-44.5, 59.5	-44.5, 59.5	-40.5, 63.5
-45.5, 59.5	-45.5, 59.5	-39.5, 63.5
-47.5, 60,5	-47.5, 60.5	-41.5, 62.5
-48.5, 60.5	-48.5, 60.5	-40.5, 62.5
-50.5, 61.5	-50.5, 61.5	-41.5, 61.5
-51.5, 62.5	-51.5, 62.5	-42.5, 60.5
-52.5, 63.5	-52.5, 63.5	-43.5, 59.5
-53.5, 64.5	-53.5, 64.5	-39.5, 64.5
-54.5, 64.5	-54.5, 64.5	-38.5, 64.5
	-43.5, 59.5	-37.5, 64.5
	-42.5, 60.5	
	-41.5, 61.5	
	-41.5, 62.5	
	-40.5, 62.5	
	-40.5, 63.5	
	-39.5, 63.5	
	-39.5, 64.5	
	-38.5, 64.5	
	-37.5, 64.5	

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