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ICE EXTENT VARIATIONS DURING LAST CENTURIES

Observation and simulation of natural and anthropogenic effects

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Observations

Ice observations from the Nordic Seas have been evaluated for the individual seas from the database http://acsys.npolar.no/ahica/intro.htm. Previous to about 1850 most of the observations comprised only observation of the outer ice boarder in one or two of the three seas (Fig. 1). Interpolations were made for the remaining sea(s) based on inter-sea correlation analysis for the period 1890-2000 when the observation coverage was very good. Observations covering less than 50% of the outer ice edge were omitted. Uncertainties in the estimation of the remaining perimeter in question then became very limited, presumable corresponding to less than 10% of the total ice extent during winter and spring (with an increasing percentage for the summer months with a smaller ice cover).

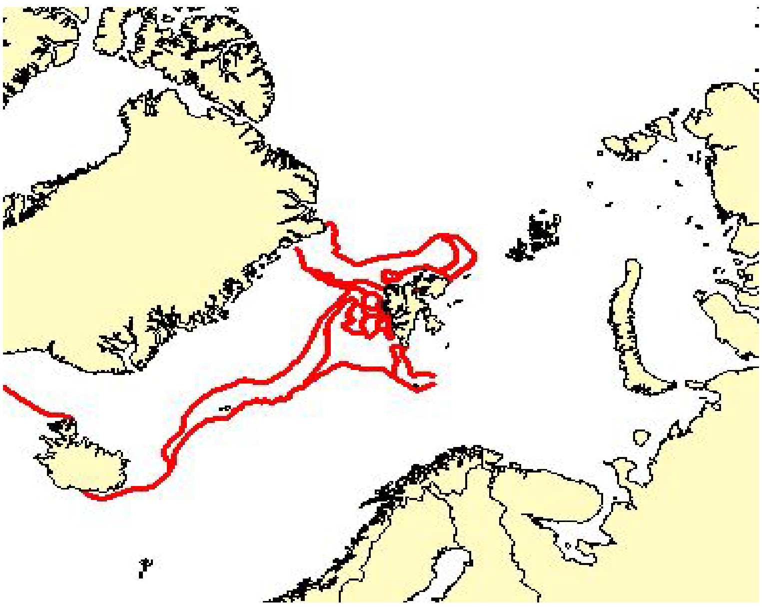


Fig. 1. Ice observations over a period of 14 days centred around 20 May 1806. Note the crossing of Fram Strait between Spitsbergen and Greenland at this very early time of the year. The next and last crossing of Fram Strait with sail ship occurred in 1812 probably in a flaw lead down-stream a frozen Arctic Ocean.

The variation of the ice extent is very similar in the three seas (Fig. 2) with a minimum extent around 1750 with slightly more ice than during the modern extreme around 2000, and a maximum in between, over the period 1800 to 1850.

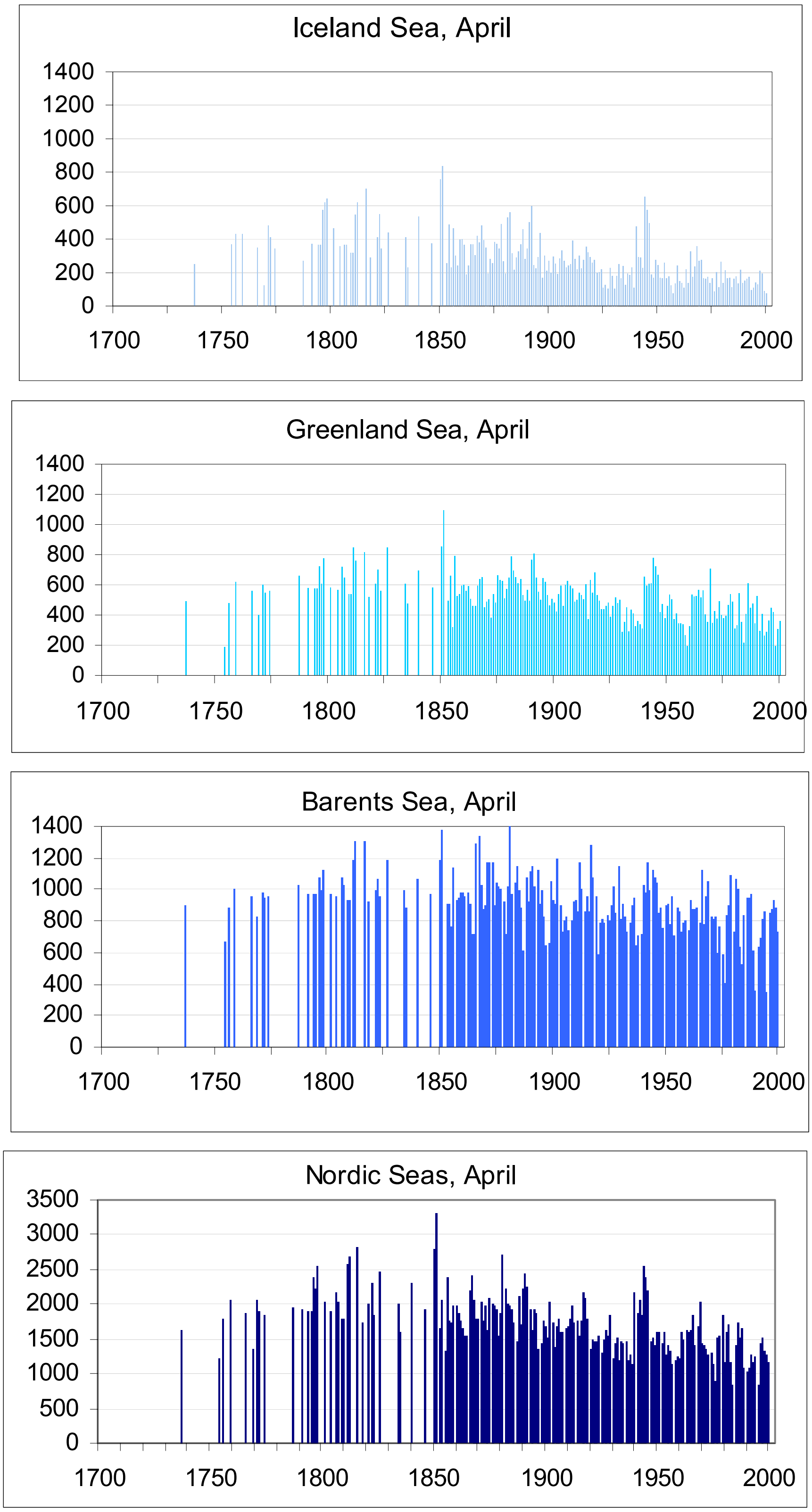


Fig. 2. Ice extent observations (10^3 km^2) in the Nordic Seas. Mainly based on logbook observations, and Icelandic coast observations by Ogilvie (1992).

The ice extent reduction since 1800 in the Nordic Seas is 50%, with a maximum reduction in the Barents Sea of 60% and a minimum reduction of 23% in the Iceland Sea. It is seen that the present reduction is a continuation of a processes that started about 200 years ago.

A corresponding variation in the ice extent is also observed in the Baltic (Fig. 3) revealing a *regionally* similar pattern in the ice extent evolution since 1750.

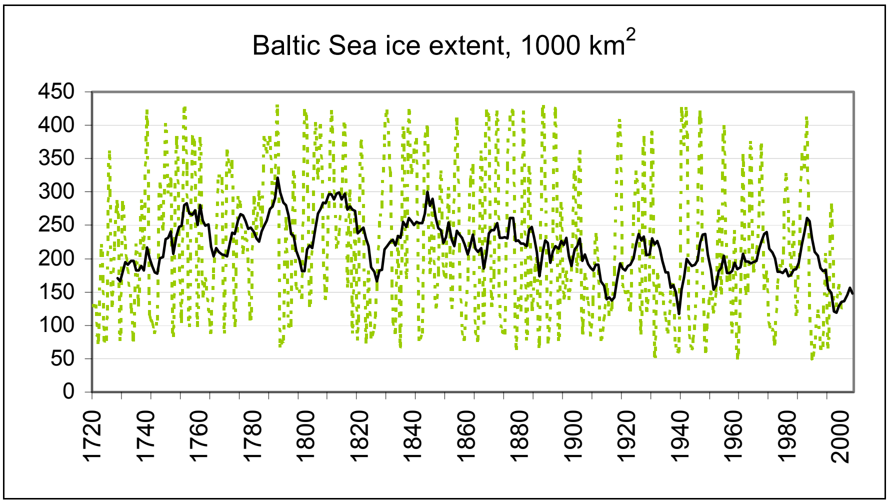


Fig. 3. Green line: Annual maximum ice extent. Dark line: 10 yr running mean. ©Finnish Institute of Marine Research. (After Seina, A.,E. Palosuo "The classification of the maximum annual extent of ice cover in the Baltic Sea 1720-1995, Meri Report No 27, 1996", and Seina, A.,H. Gronvall, S. Kalliosaari, and J. Vainio "Ice seasons 1996-2000in Finnish sea areas, Meri Report No. 43, 2001").

The above ice extent variations with a secondary minimum around 1720-1750, a maximum between 1800 and 1850, and the subsequent ice extent reduction correspond (negatively) with variations in the solar irradiance, e.g. Lean et al. (1995), and with the proxy temperature series by Bradley and Jones (1993), Overpeck et al. (1997), and Vaganov et al. (2000) [Fig. 4], and the solar cycle length (SCL) closely related to radiation Friis Christensen and Lassen (1991) [Fig. 5]. The close correspondence between the SCL and the Arctic temperature north of 62 N suggests that *most* of the temperature variability over the recent 150 years is caused by variations in the radiation.

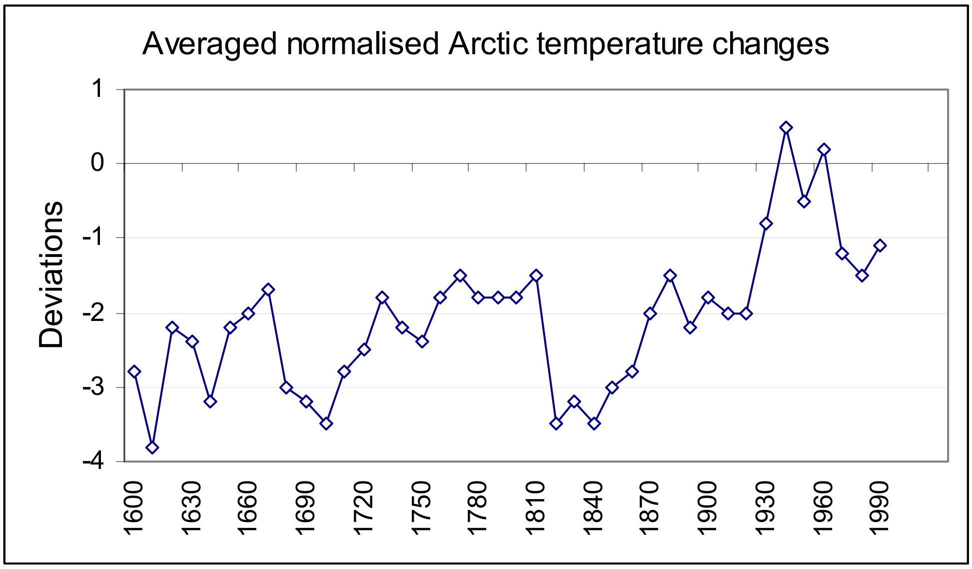


Fig. 4. The mean normalized temperature changes for the Arctic region obtained mainly from tree ring studies by Overpeck et al. (1997), and Vaganov et al. (2000). Figure redrawn after averaging data given in Fig. 2 in Vaganov et al. (2000).

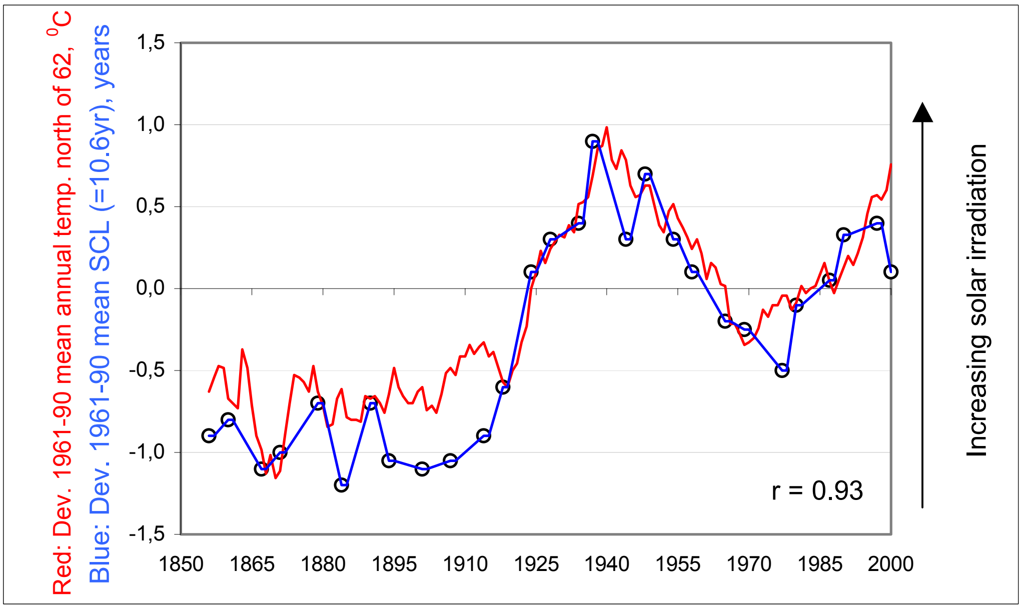


Fig. 5. Red line: deviation from the 1961-1990 mean temperature north of 62 N from Polyakov et al. (2001). The temperatures before 1880 are not representative for a circumpolar mean. Blue line: deviation from the 1961-1990 mean solar cycle length (10.6 years) smoothed according to the scheme, L121, in http://web.dmi.dk. The correlation between the two lines is 0.93. Note the temporal correspondence in maximum and minimum with Arctic proxy temperature deviations in Fig. 4.

The importance of natural forcing for the climate change becomes even more pronounced when comparing the radiation with the ice extent over the recent 250 years (Fig. 6).

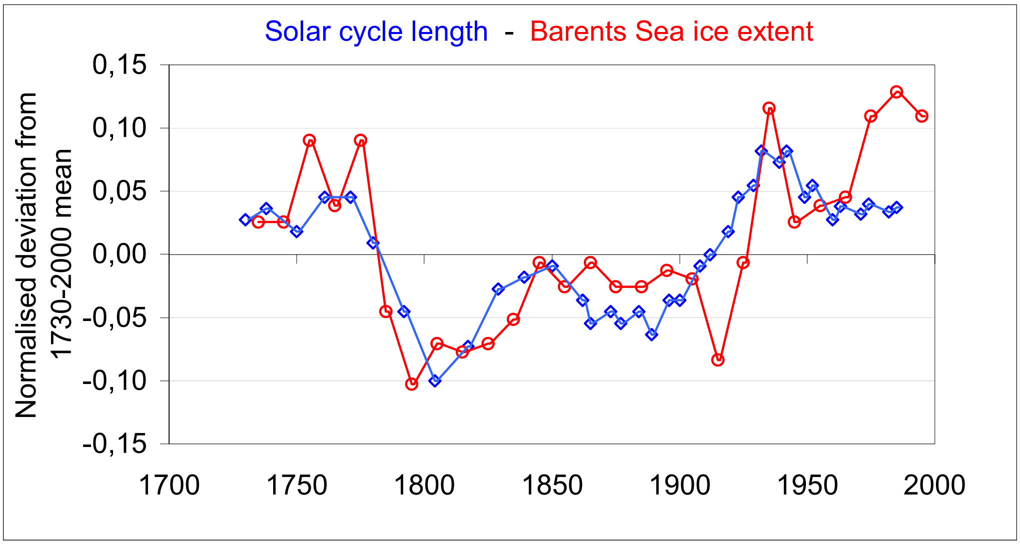


Fig. 6. Left scale and blue curve: Normalised deviation from the 1750-2000 mean of the August ice extent in the Barents Sea. Left scale and red curve: Normalised deviation from the 1750-2000 mean solar cycle length after Friis-Christensen and Lassen (1991), Lassen and Friis-Christensen (1995), and Thejll and Lassen (2000) denoted as (L12221) and given in http://web.dmi.dk. The correlation between the two curves is 0.77. Note the temporal correspondence between max/min Arctic temperatures in Fig. 5 and min/max Barents Sea summer ice extent in Fig. 6.

Anthropogenic forcing

After about 1960 there seems to be a clear, temporally increasing divergence between the two curves indicating that other than natural effects becomes dominant. This divergence occurs in spite of the fact that the ocean and atmospheric surface temperatures in the Norwegian Sea show a downward trend since 1955 (Fig. 7) and that the solar cycle length, or radiation, as well as Arctic temperatures are lower today than around 1940 (Fig. 5 and Fig. 6). In accordance with these observations the tree ring width from the circumpolar Arctic surveys has also decreased markedly since then (Fig. 4) indicating reduced growing intensity. As the ice continues to retreat regardless of these environmental cooling trends, indicates that greenhouse gases have over the recent few decades become dominant regarding environmental changes. We presumably here see an effect of increased downward long-wave radiation from a warmer atmosphere causing reduced freezing during the Polar Night and a subsequent increasing retreat the following summer.

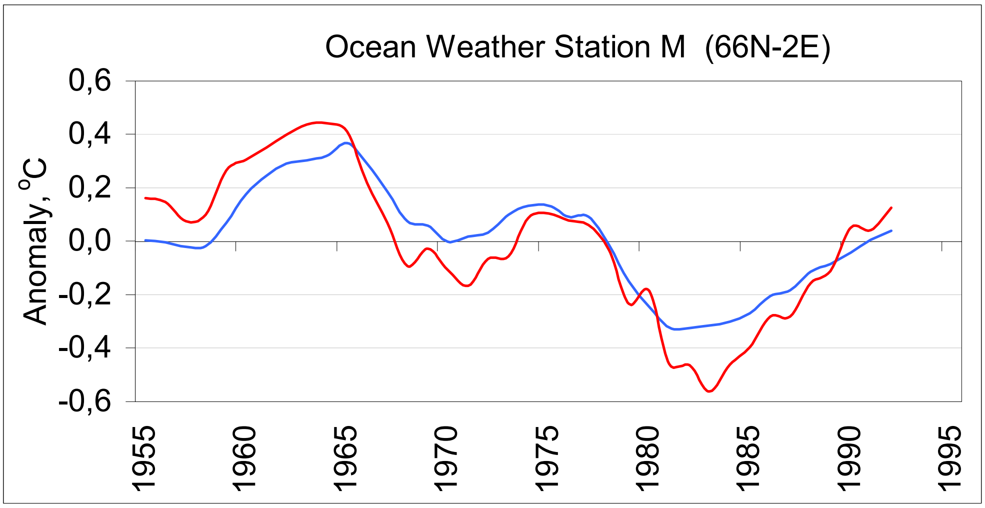
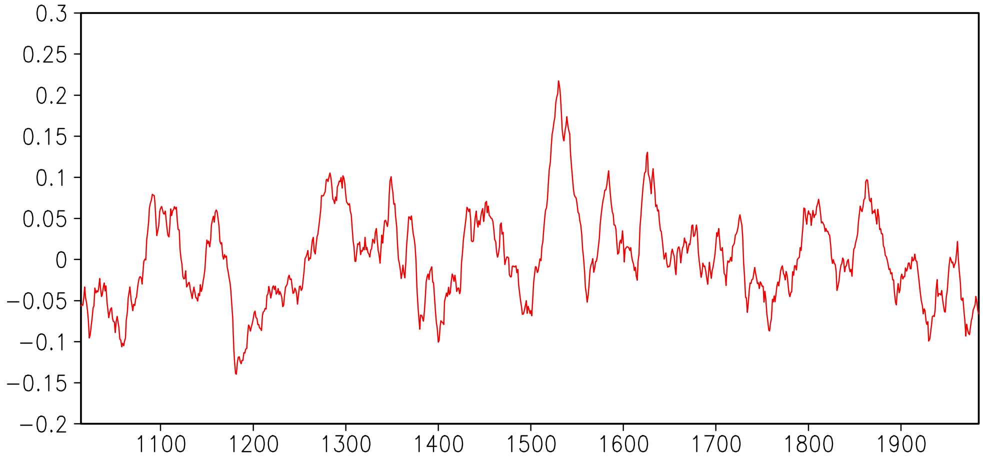


Fig. 7. Seven years running mean of temperature anomalies relative to the 1949-1998 mean as measured at the Ocean Weather Station M in the Norwegian Sea. Blue line: Anomalies of the temperature at 50 m depth (After Gammelsrød et al. 1992 plus updates). Red line: Anomalies of the surface air temperature (After Førland et al. 2002 and http://projects.dnmi.no/~narp).

The ocean temperature measured since 1949 at the Ocean Weather Station M in the Norwegian Sea show decadal variations with amplitude of about 1° C. (Gammelsrød et al. 1992). A comparison between temperature anomalies at Station M and the April ice extent anomalies in the Barents Sea indicates that a rice/fall in the ice extent of about 325x10^3 km^2 correspond to a fall/rise in the ocean temperature of 1° C. (Vinje 2001). The April ice extent reduction from 1800-1850 to 1950-2000 is 240x10^3 km^2 suggesting an increase in the ocean temperature of about 0.7° C over the recent 150-200 years. This increase is similar to the one obtained from the below model.

Simulations
The model, ECBIL-CLIO, used in the simulations below is a three-dimensional coupled atmosphere-ocean-sea ice model. The atmospheric component is ECBILT2, a T21, 3-level quasi-geostrophic model, with simple parameterisations for the diabatic heating due to radiative fluxes, the release of latent heat, and the exchange of sensible heat with the surface. The CLIO model comprises a primitive equation, free surface ocean general circulation model coupled to a thermodynamic-dynamic sea ice model. A five-member simulation experiment has been performed with ECBILT-CLIO, forced by the main natural (i.e. solar and volcanic) and anthropogenic forcing (increase in greenhouse gases and in sulphate aerosols) over the period 1000-2000 AD (Goosse and Renssen 2003).



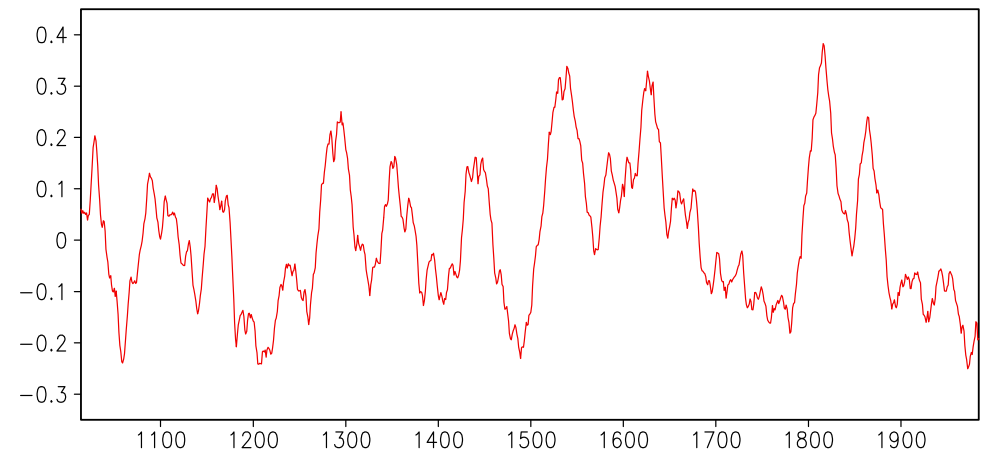


Figure 6. Anomaly of ice cover in the Barents Sea (in 10^6 km^2) averaged over 5 simulations that differ only in their initial conditions in spring (top) and summer (bottom).

Comparison
The observed variation during the recent 250 years corresponds qualitatively with the chosen simulations represented in Fig. 6.: The minimum around 1750 is

slightly less than the modern minimum around 2000, and the maximum expansion over the period 1800-1850 is well pronounced. The August maximum expansion is clearly larger than the April maximum revealing a more rapid reduction in the summer ice extent then in the winter ice extent over the recent 200 years. Both observations and simulations show also that the reduction of sea ice is a process that started about 200 years ago, contemporary with the onset of a long-term increase in the irradiation. This is more clearly seen in the anomaly curve for the Northern Hemisphere (Fig. 7).

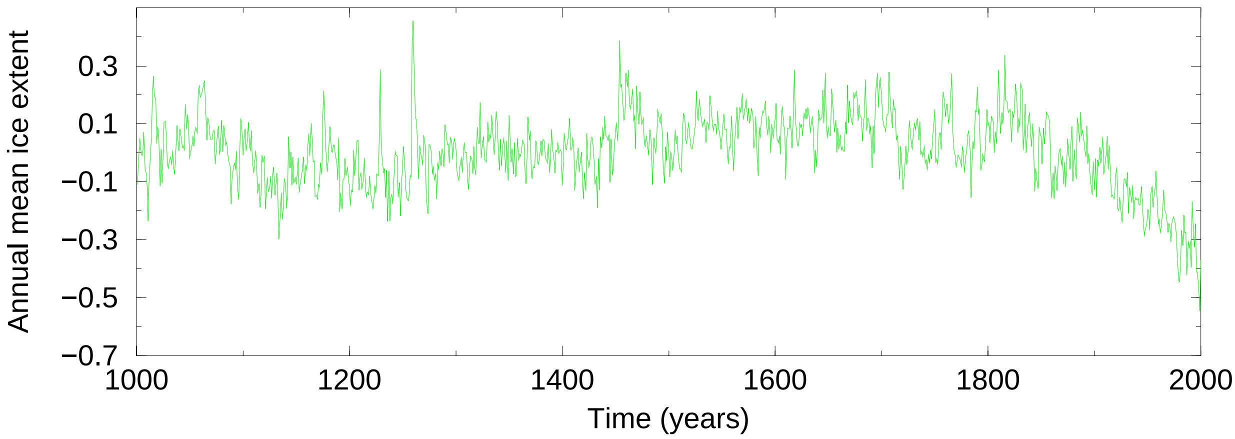


Figure 7. Anomaly of annual mean ice extent in the Northern Hemisphere averaged over 5 simulations that differ only in their initial conditions (in 10^6 km^2).

The temperature increase in the Norwegian Sea since the Little Ice Age, which from ice extent observations, was estimated to be about 0.7° C is similar to the figure obtained from the simulations over the same period. When anthropogenic effects are omitted from the ECBIL-CLIO model, the simulated values start diverging markedly from simulations including anthropogenic effects from about 1960 (Goosse and Renssen 2003), at the same time when the ice extent observations indicated an onset of non-natural effects.

Quantitatively the model seems to underestimate the variations. Change in the April ice extent from 1800-1850 to 1950-2000 was above estimated to be $310x10^3$ km^2 while the model suggests only $70x10^3$ km^2.

Conclusion

Both observations and simulations indicate that natural forcing is dominating the climate change from 1750 to mid 20th century, and that anthropogenic forcing becomes increasingly dominant thereafter.

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