The early 20th century warming in the Arctic –
A possible mechanism

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Temperature anomalies

Johannessen et al. 2003
Zonal mean wintertime (November–April) SAT anomalies

SAT anomalies, °C

SAT 45–55N
SAT 60N–90N

1900 1920 1940 1960 1980 2000
Possible changes the distribution of important fish species in the future

Source: Reidar Toresen, IMR
Relation between temperature and herring stock

Source: Toresen & Østvedt (2000), *Fish and Fisheries*, 1, pp. 231-256
What could be a possible mechanism for the warming event?
Possible explanations for the early century warming

- **Solar forcing**

  - Solar irradiation data available for about 20 years only: long-term reconstructions are based on indirect data
  - Simulated temperature response to direct solar forcing does not match to the observed pattern of variability and its magnitude (e.g. Cubasch et al., 1997)
  - Cosmic radiation – cloud cover hypothesis has been refuted by recent analyses using longer and more comprehensive data sets (e.g. Sun and Bradley, 2002, JGR)
Possible explanations for the early century warming

**Volcanic forcing**

A series of major eruptions in the early part of the century: Santa Maria (1902), Ksudash (1907), Katmai (1912) then with no substantial eruptions until Mount Agung (1963).

- A cooling effect of a major eruption lasts for 1-3 years
- Neither geographical distribution nor the time evolution of the Arctic SAT correspond to the main volcanic events
- Pinatubo (1991) eruption was twice as powerful as Katmai
- Low latitude eruptions may produce even warming over land in high latitudes in wintertime
Possible explanations for the early century warming

- **Anthropogenic forcing (greenhouse gases, aerosols)**
  
  - The forcing during early decades of the 20th century was only about 20% of the present-day values
  - Increasing greenhouse forcing cannot explain 1940-1960 cooling
  - Neither geographical distribution nor the magnitude of the aerosol forcing correspond to the 1940-1960 cooling trend pattern
  - Global radiative forcing was positive (and even increasing) in the 1940-1960, when the global temperature decreased (Forcing data from Roeckner et al., 1999)
Possible explanations for the early century warming

- **Natural variability**
  
  - Decadal variability of the atmospheric (oceanic) circulation due to aggregation of stochastic events
  - Coupled ocean-atmosphere modes (e.g. Delworth and Mann, 2000; Ikeda, 2001; Mysak, 2001)
  - Fresh water balance – Arctic sea ice (Zakharov, 1997)
Delworth and Knutson, 2000

Monte-Carlo simulations with a coupled AO GCM: one out five simulations almost perfectly reproduced the observed global temperature variability.
Temp. Anomalies at the surface

Johannessen et al. 2003
Statistical analysis

Semenov and Bengtsson, 2003, JGR
Four leading EOFs of the wintertime (NDJFMA) SAT variability (40N-80N) for 1892-1998

EOF 1 (21%)  
EOF 2 (12%)  
EOF 3 (12%)  
EOF 4 (9%)

Correlation with atmosph. circulation indices

**PC1**
NAO (0.60), AO (0.77)

**PC2**
PNA (-0.48), SLP PC2 (-0.57)

**PC3**
Arctic SAT (0.79)

**PC4**
SCA (0.33)
EOF3 of the wintertime (NDJFMA) Arctic SAT

1935-1944 wintertime (NDJFMA) Arctic SAT 1935-1944 anomaly, in °C
Arctic SAT (60°N-80°N, NDJFMA) anomalies with subtracted variability (red) related to the EOF1, EOF3 and EOF1+3, and without subtraction (black). 5 years running means EOF1 and EOF3 explain 94% of the SAT variability north of 60°N

Semenov and Bengtsson (2003)
MPI Report 343
http://www.mpimet.mpg.de/
Ice area & temperature
5-yrs running mean

Johannessen et al. 2003
A link between Arctic SAT and sea ice area

Sea-ice extent anomalies derived from observations representing ~3/4 of the Arctic Ocean (Zakharov, 1997), compared with annual Arctic (60N-90N) SAT.

\[
\frac{dT}{dlce} = 1.44 \, ^{\circ}C/M \, km^2 \text{ (annual, Zakharov)}
\]

\[
\frac{dT}{dlce} = 0.98 \, ^{\circ}C/M \, km^2 \text{ (annual) or } 1.33 \, ^{\circ}C/M \, km^2 \text{ (winter) (Chapman&Walsh)}
\]
Empirical data analysis: summary

• The early century warming in the Arctic was most pronounced during winter and had a very distinguished spatial pattern with maximum warming over the Barents and Kara Seas.

• Variability associated with the early century warming pattern shows no link to the large-scale atmospheric circulation variability.

• There is a strong link between SAT and sea ice area variability in the Arctic. The Barents Sea is characterized by strong variability of the wintertime ice cover.

• The sea ice cover variability (basically in the Barents Sea) is suggested to be a reason for the early century warming.
Atmospheric model simulations: experimental setup

- atmospheric general circulation model **ECHAM4**
- 19 vertical levels
- spatial resolution of approximately 2.8 deg in lat/lon
- an ensemble of four simulations using the **GISST2.2** SST/SIC analysis for 1903-1994 (Rayner et al., 1996) as boundary conditions was carried out
- observed changes in the greenhouse gases concentrations were included
- the experiments started from slightly different initial atmospheric states but had all identical boundary conditions
Atmospheric model simulations: sea ice data

**Annual mean Arctic sea ice area**

GISST2.2: wintertime SIC difference (in%) between the 1954-1983 and 1910-1939 averages
Atmospheric model simulations: temperature changes

Wintertime Arctic SAT anomalies simulated by 4 ensemble experiments with ECHAM4 model

Wintertime SAT difference between 1910-39 and 1954-83 means

\[
\text{cor (Ice,SAT)} = -0.59 \text{ (wintertime 1951-1994)}
\]
\[
\frac{dT}{d\text{Ice}} = 0.67 \text{ °C/M km}^2 \text{ (wintertime)}
\]
\[
\frac{\Delta T}{\Delta \text{Ice}} = 1.13 \text{ °C/M km}^2
\]
Atmospheric model simulations: circulation changes

SIC

Heat flux, \( \text{W/m}^2 \)

SLP, \( \text{mb} \)

10m wind
Atmospheric model simulations: circulation changes
Atmospheric model simulations: summary

- Simulated Arctic temperature showed a strong dependence on the prescribed sea ice changes with 1.13 °C SAT increase corresponding to 1Mkm² sea ice area decrease (wintertime). This is similar to the observed value (1.33).
- A pattern of the SAT change is very similar to the observed pattern with major changes in the Barents Sea.
- A reduced sea ice cover in the Barents Sea causes a cyclonic atmospheric circulation in the Barents Sea region associated with enhanced westerly winds between Norway and Spitsbergen.
Coupled model simulation: Arctic sea ice – temperature link

**Wintertime Arctic SAT and sea ice area**

- **Correlation between wintertime Arctic sea ice area and SATs**

- **Correlation**
  \[ \text{cor (Ice,SAT)} = -0.62 \text{ (wintertime)} \]

- **dT/dIce**
  \[ \frac{dT}{d\text{Ice}} = 1.70 \text{ °C/M km}^2 \text{ (wintertime)} \]
Coupled model simulation: Barents Sea inflow

Annual mean Arctic sea ice area anomalies and oceanic volume flux (upper 125 m) through Spitzbergen-Norway meridional (about 20E) cross-section

\[ r = -0.77 \]
Coupled model simulation: Barents Sea inflow

Annual mean oceanic volume flux and DJF SLP difference Spitzbergen-northern Norway

\[ r = 0.42 \]
Coupled model simulation: summary

- Simulated Arctic temperature showed a strong link to the sea ice changes with 1.70 °C SAT increase corresponding to 1Mkm² sea ice area decrease (wintertime). This is similar to the observed value (1.33).

- A pattern of the SAT change is very similar to the observed pattern with major changes in the Barents Sea, where the highest variability of the ice cover occurs.

- Variability of the sea ice cover in the Barents Sea are caused by changes of the oceanic inflow through the western opening of the sea.

- The inflow variability is linked to the strength of westerlies north of Norway.
DJF SLP difference between Spitsbergen and the northernmost Norwegian coast (mb) and annual mean Arctic SAT anomalies (°C, 5-year running means)
Feedback mechanism scheme

Cyclonic circulation

Westerly winds

Barents inflow

Barents Sea

Correlation between Arctic wintertime SAT anomalies and DJF SLP (1920-1970)
Conclusions

- A reduced sea ice cover (mainly in the Barents Sea) is the main cause of the warming
- The ice retreat was caused by enhanced wind driven oceanic inflow into the Barents Sea
- The increased inflow can be explained by intensified westerly winds between Spitsbergen and the Norwegian coast in 1920s-1940s
- A positive feedback is proposed sustaining the enhanced westerly winds by a cyclonic atmospheric circulation in the Barents Sea region created by a strong surface heat flux over the ice-free areas
Recent numerical experiments: sea-ice and temperature
Experiments with the atmospheric GCM ECHAM5 (T31L19)

20th century climate simulations:

1) ensemble runs with HadISST1 SST/sea ice concentration data (1950-1998)

Sensitivity experiments:

1) experiments with constant sea ice / SST
2) climatological experiments with regionally reducing sea ice cover (e.g. in the Barents Sea)
3) “ice free Arctic” experiment
ECHAM5/HadISST1 ensemble runs:
Arctic wintertime SAT anomalies, °C
(black – observed, Jones)

ECHAM5/HadISST1 ensemble runs:
SLP difference Azores-Iceland, mb
ECHAM5: Arctic wintertime SAT anomalies, °C
ECHAM5 “ice free Arctic” experiment:
Wintertime SAT difference ice free – AMIP ice
END