Reconstruction of atmospheric forcing data over the Arctic and the northern North Atlantic for the 20th century

Frank Kauker, Michael Karcher

Alfred Wegener Institute for Polar and Marine Research
and
O.A.Sys – Ocean Atmosphere Systems

Rüdiger Gerdes, Cornelia Köberle

Alfred Wegener Institute for Polar and Marine Research

AIM: *Reconstruction of atmospheric surface fields of the 20th century to force a coupled sea ice-ocean model of the Arctic Ocean and the North Atlantic*

Method: A statistical model is built with the help of the Redundancy Analysis (RA) *(Tyler, 1982).* RA identifies patterns by maximizing the variance of the target (Predictand) pattern.

PRO: Other methods like CCA (maximizes the correlation between the corresponding pattern coefficients) or SVD (maximizes the covariance) are symmetric, i.e. Predictor and Predictand are handled equally. RA maximizes the Predictand pattern variance respectless of the Predictor pattern variance.

CONTRA: ???

RA has been successfully applied to reconstruct atmospheric surface fields of the 20th century for a coupled sea ice-ocean model of the Baltic Sea *(Kauker and Meier, Meier and Kauker, JGR-Ocean, 2003).*

Used data sets:

Predictor:

- Monthly mean SLP of the northern hemispere from NCAR *(Trenberth and Paolino, 1980)*. 1899 to present on a 5x5 degree grid.
- Monthly mean SLP station data compiled by
  - IARC *(courtesy of I. Polyakov)*
  - SMHI *(courtesy H. Alexandersson)*
- Monthly mean SAT of the northern hemisphere from the AICSEX project *(compiled by G. Alekseev, courtesy O. Johannessen)*. 1860 to present on a 10x5 degree grid.
- Monthly mean SAT station data compiled by IARC *(courtesy of I. Polyakov)*.

Predictant (target data):

NCEP reanalysis fields interpolated onto the grid of the coupled sea ice-ocean model

Gappy data:

Stations (grid boxes) with less than 120 (months) data gaps in the period 1900 to 1997 are taken into account

Fitting period:

- 1958 to 1987 is used for the model building
- 1948 to 1957 and 1988 to 1997 are used for the validation

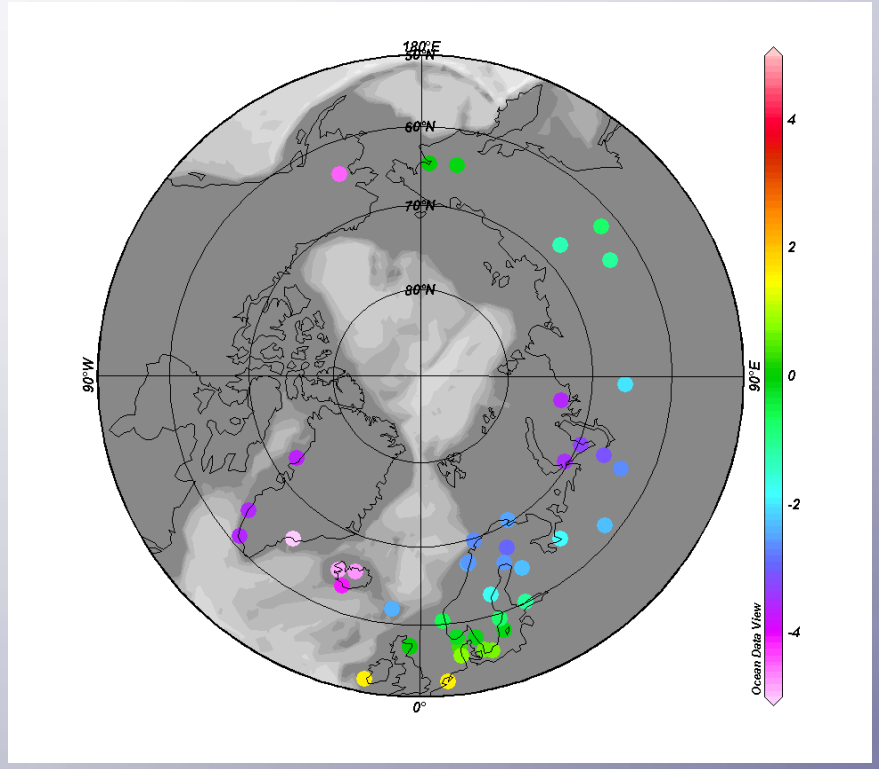
Comments for AOMIPers:

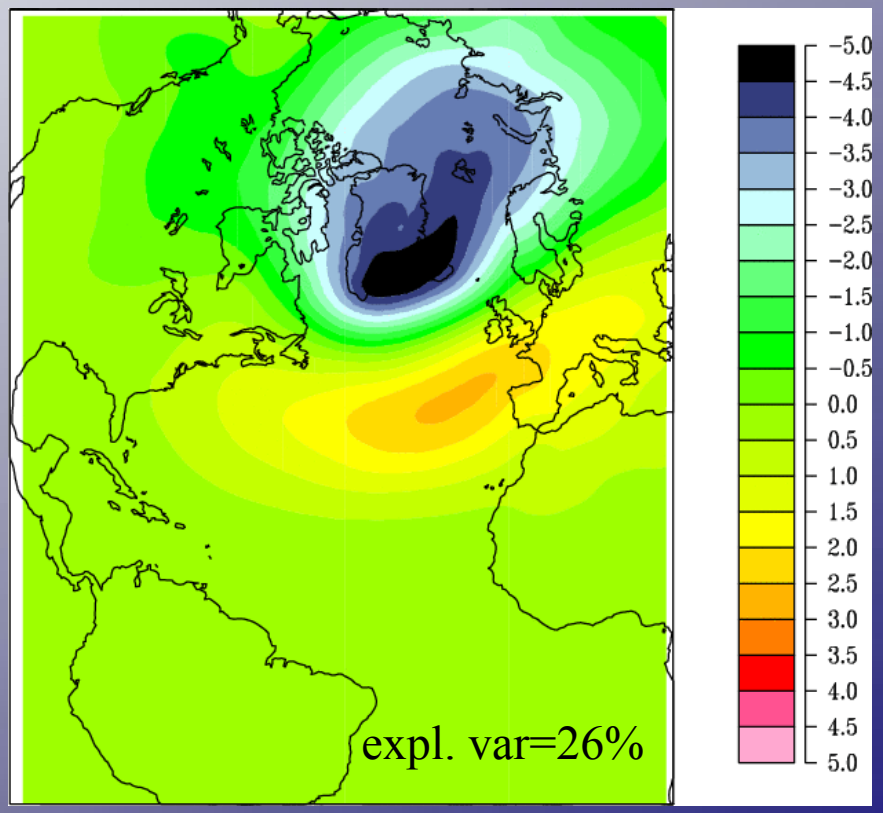
In the following the method is explained by depicting some of the redundancy modes for a specific reconstruction (see the blue box on the next slides). For the SLP reconstruction mode 1 (connected to NAO), mode 6 (connected to East Atlantic Jet pattern), and mode 8 (connected to the North Pacific (NP) pattern) are depicted to show that even a number of 48 station data are sufficient to distinguish between these patterns. However, note that we have only one long-term SLP station over North America. The reconstruction would surely improve if we could add some more stations for this area. Mode 1 and 2 of the SAT reconstruction are linked to NAO and NP. The time series (running-mean filtered) of the two modes of predictor and predictand show strong deviations from 1948 to about 1955. We address this to the questionable quality of the NCEP reanalysis during this (early) period. The predictor time series (black) of mode 2 shows negative values in the 1930s and 1940s. Combined with the Arctic-wide negative SAT anomaly shown in the corresponding redundancy pattern, this mode bears much of the warming of the Arctic atmosphere during 1930s and 1940s.

Example: SLP reconstruction

Predictor: monthly *SLP station data from IARC (courtesy I. Polykov) and SLP station data from SMHI (courtesy H. Alexandersson).*
Target data: monthly *SLP from the NCEP reanalysis interpolated onto the model grid.*

Redundancy **MODE 1**: *fitting period 1958 to 1987*

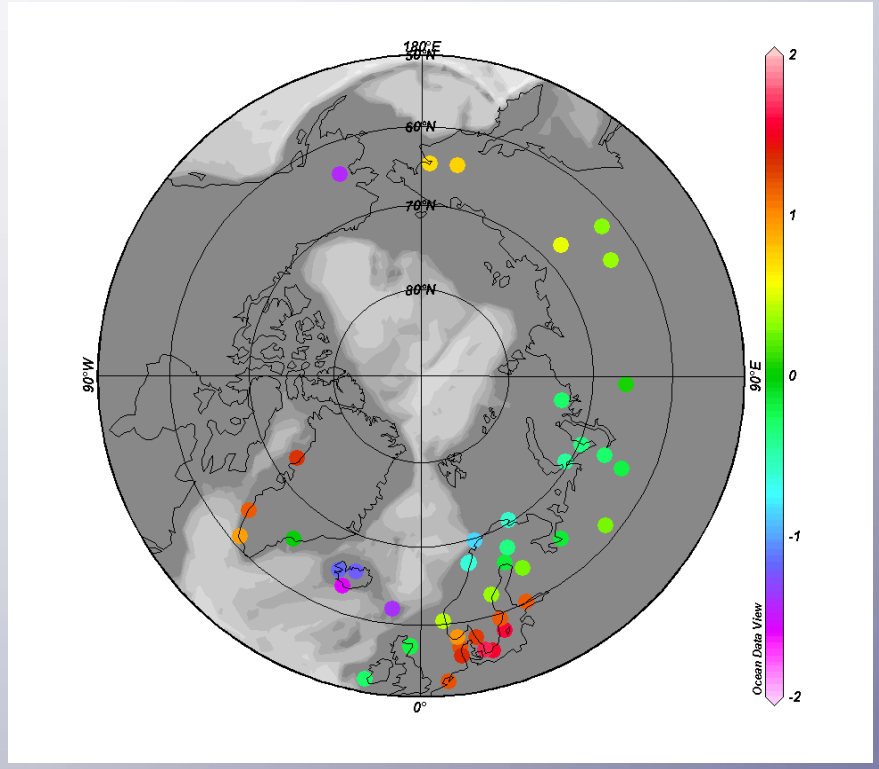


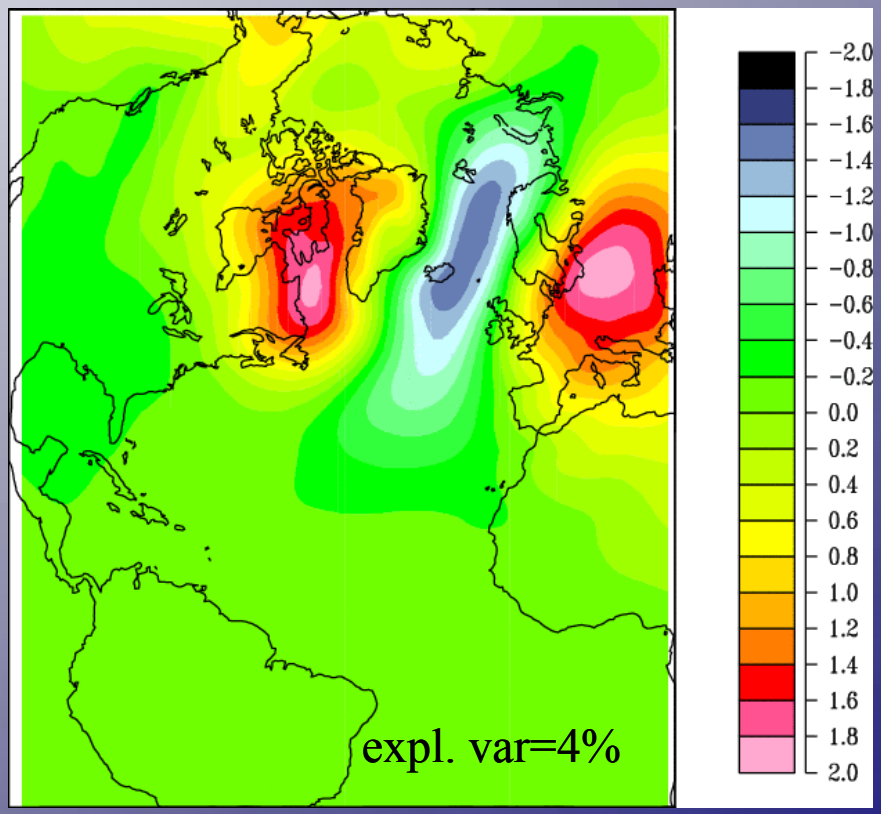


Example: SLP reconstruction

Predictor: monthly *SLP station data from IARC (courtesy I. Polykov) and SLP station data from SMHI (courtesy H. Alexandersson).*
Target data: monthly *SLP from the NCEP reanalysis interpolated onto the model grid.*

Redundancy **MODE 6**: *fitting period 1958 to 1987*

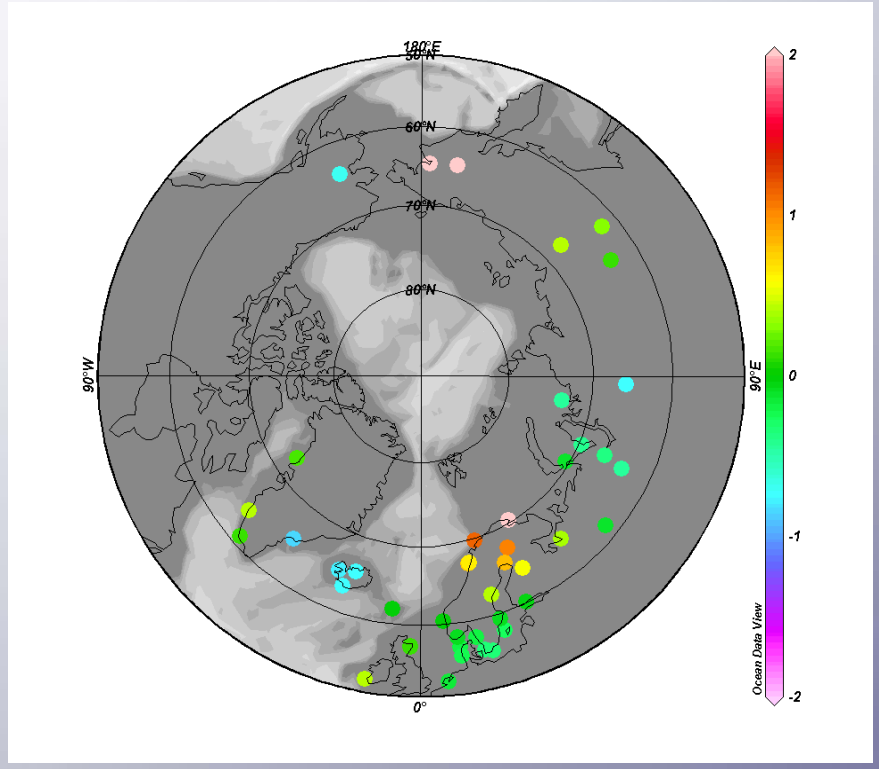


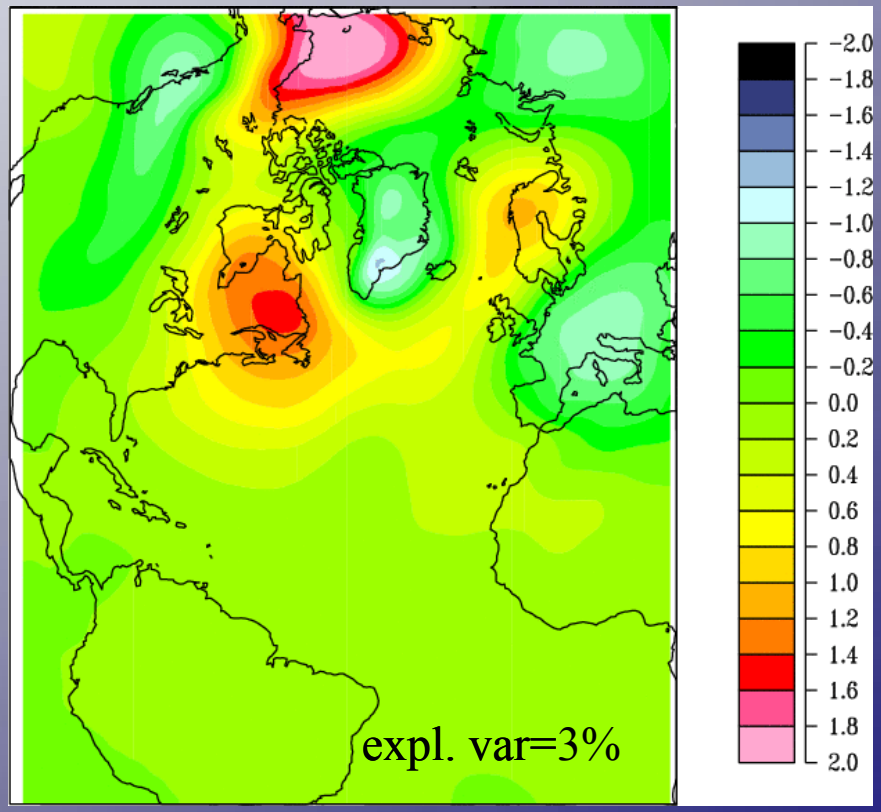


Example: SLP reconstruction

Predictor: monthly *SLP station data from IARC (courtesy I. Polykov) and SLP station data from SMHI (courtesy H. Alexandersson).*
Target data: monthly *SLP from the NCEP reanalysis interpolated onto the model grid.*

Redundancy **MODE 8**: *fitting period 1958 to 1987*

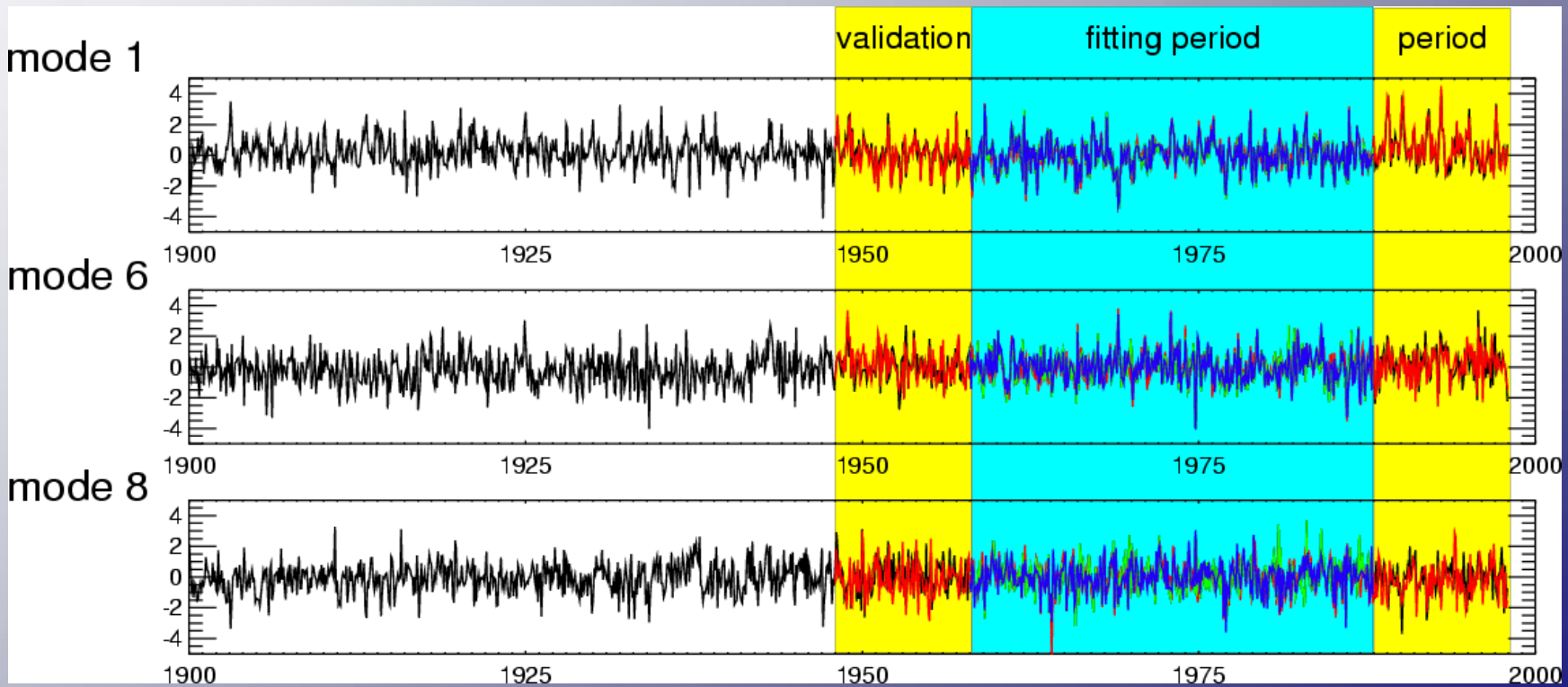




Example: SLP reconstruction

Predictor: monthly *SLP station data from IARC (courtesy I. Polykov) and SLP station data from SMHI (courtesy H. Alexandersson).*
Target data: monthly *SLP from the NCEP reanalysis interpolated onto the model grid.*

Redundancy time series:
fitting period 1958 to 1987 validation period 1948 to 1957 and 1988 to 1997



Example: SLP reconstruction

Predictor: monthly *SLP station data from IARC (courtesy I. Polykov) and SLP station data from SMHI (courtesy H. Alexandersson).*
Target data: monthly *SLP from the NCEP reanalysis interpolated onto the model grid.*

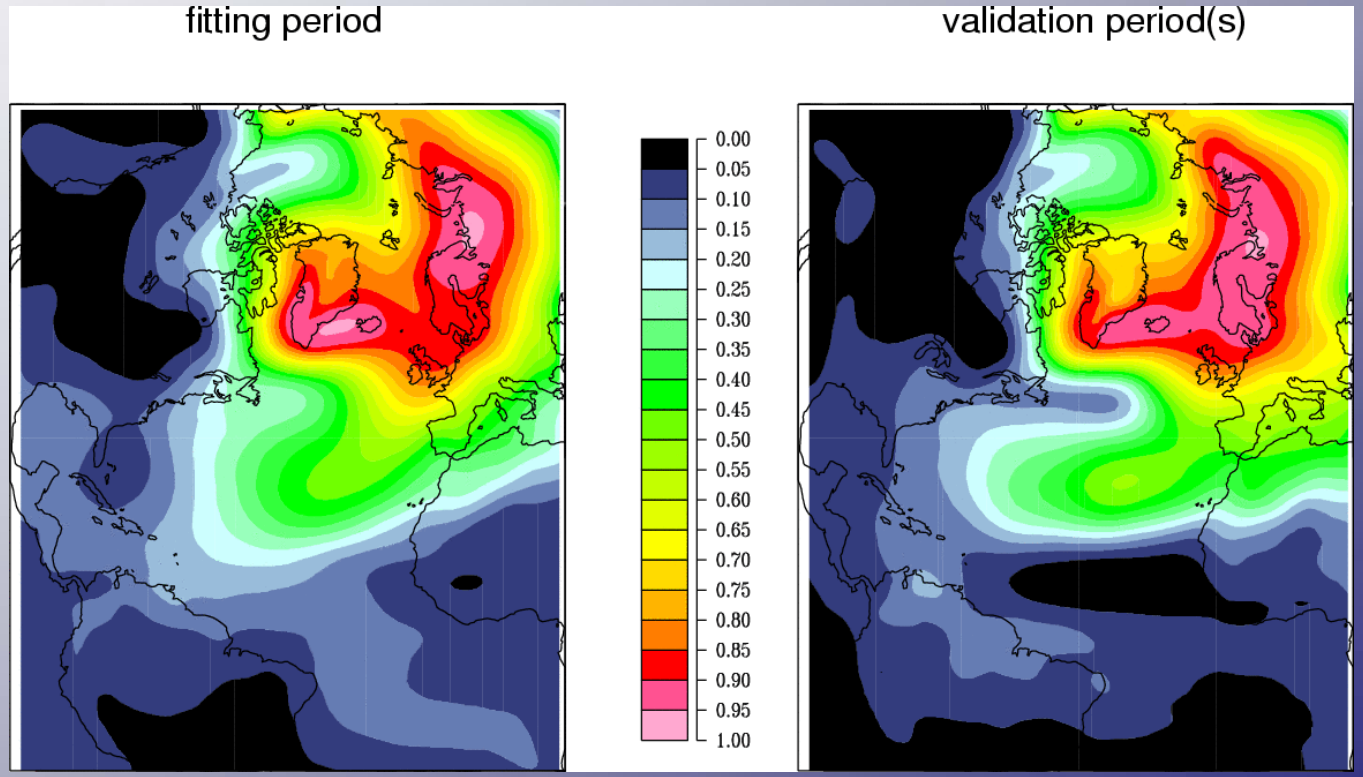
Redundancy time series:
fitting period 1958 to 1987 validation period 1948 to 1957 and 1988 to 1997

	Correlation Fitting period	***Correlation Validation period***	***Explained Variance predictand***
Mode 1	0.98	0.95	26 %
Mode 2	0.98	0.96	14 %
Mode 3	0.90	0.84	11 %
Mode 4	0.87	0.86	9 %
Mode 5	0.91	0.85	6 %
Mode 6	0.87	0.77	4 %
Mode 7	0.72	0.59	3 %
Mode 8	0.57	0.50	3 %

Example: SLP reconstruction

Predictor: monthly *SLP station data from IARC (courtesy I. Polykov) and SLP station data from SMHI (courtesy H. Alexandersson).*
Target data: monthly *SLP from the NCEP reanalysis interpolated onto the model grid.*

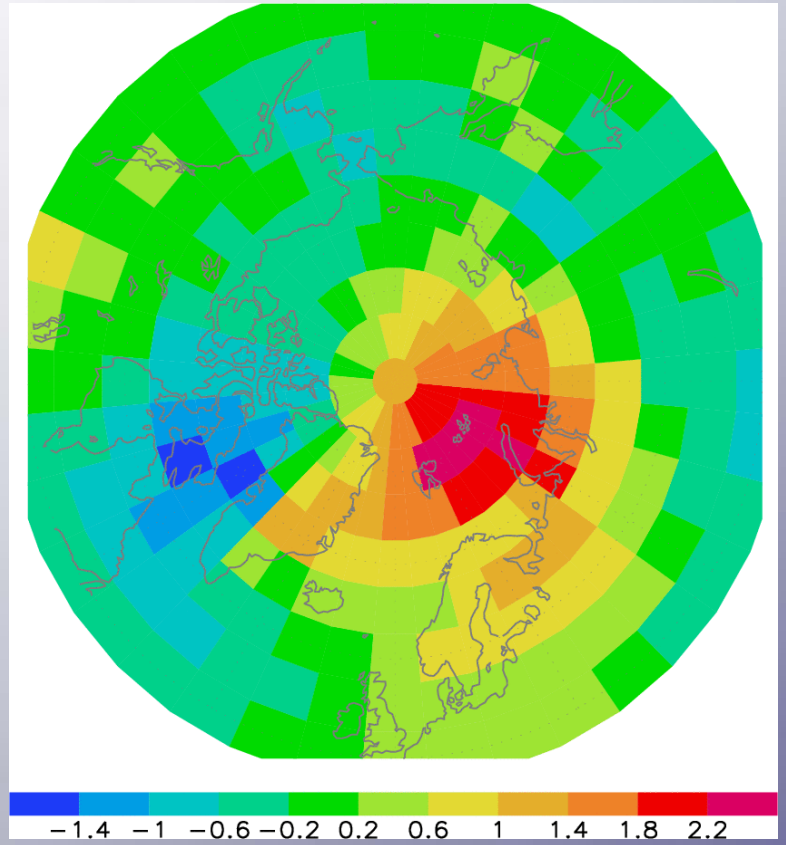
Locally explained variances:
fitting period 1958 to 1987, validation period 1948 to 1957 and 1988 to 1997

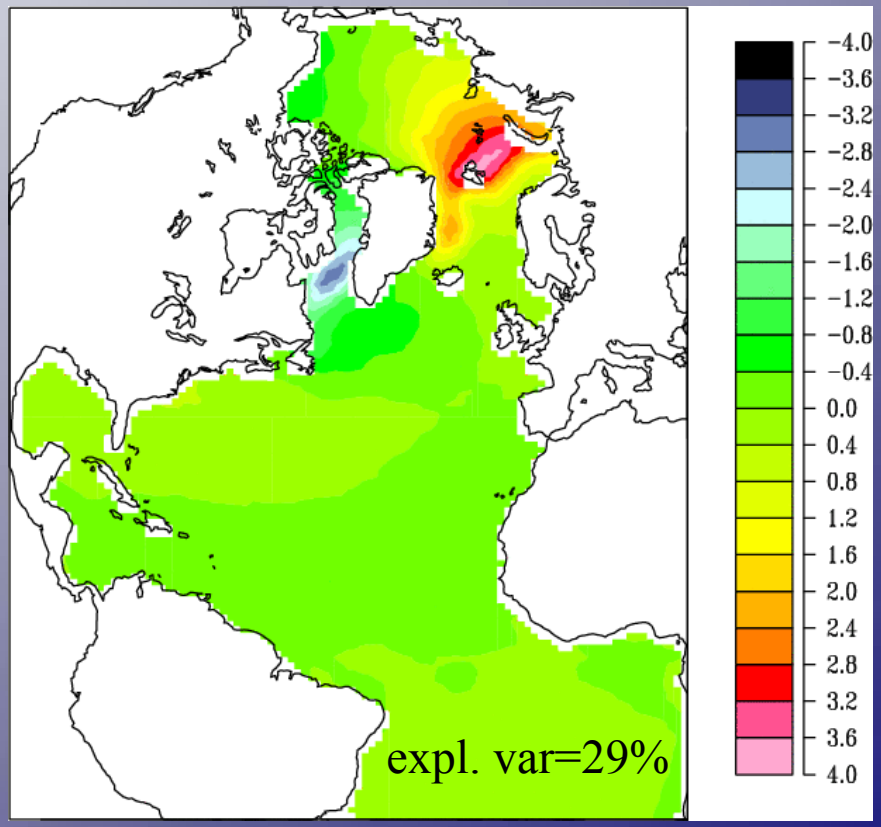


Example: SAT reconstruction

Predictor: monthly SAT gridded data (10x5 degree) from the AICSEX project *(compiled by G. Alekseev, courtesy O. Johannessen).*
Target data: monthly SAT *from the NCEP reanalysis interpolated onto the model grid.*

Redundancy **MODE 1**: *fitting period 1958 to 1987*

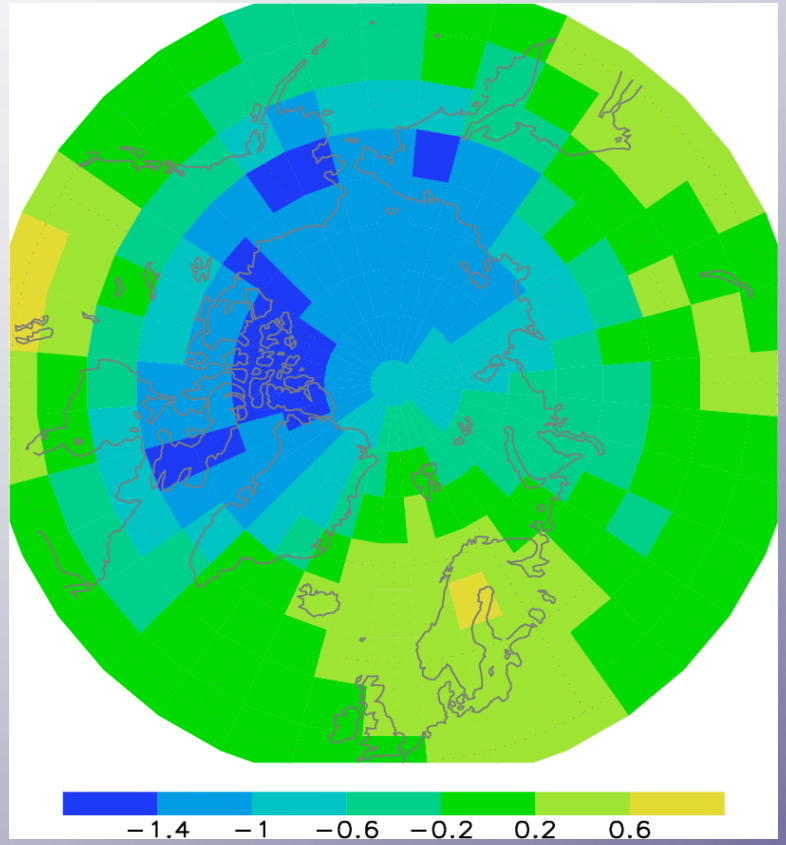


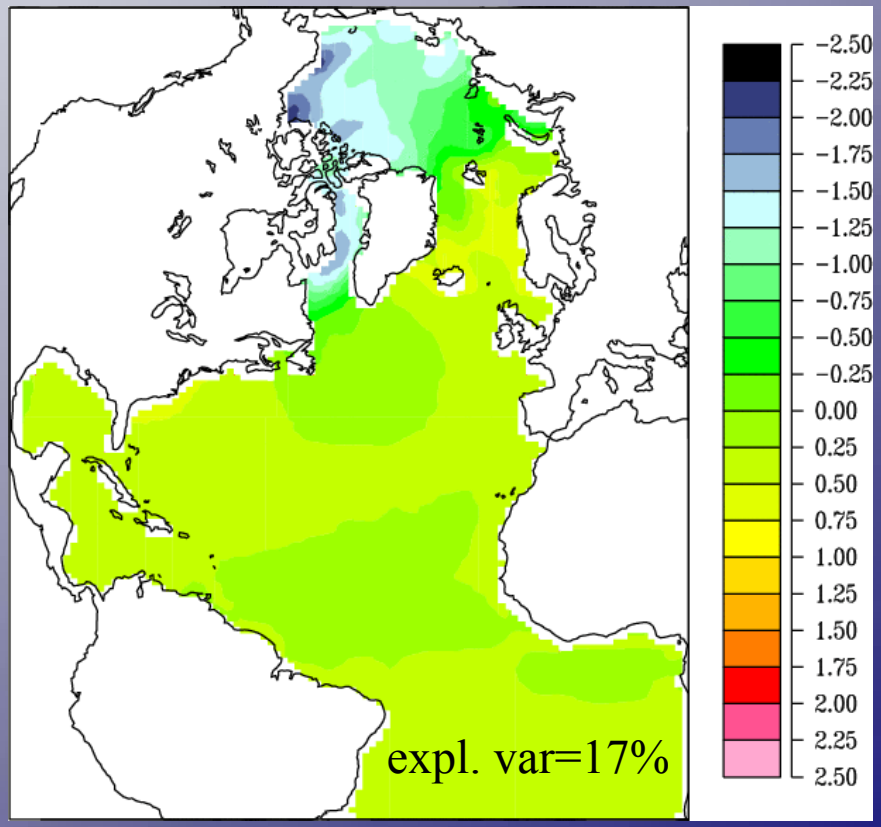


Example: SAT reconstruction

Predictor: monthly SAT gridded data (10x5 degree) from the AICSEX project *(compiled by G. Alekseev, courtesy O. Johannessen).*
Target data: monthly SAT *from the NCEP reanalysis interpolated onto the model grid.*

Redundancy **MODE 2**: *fitting period 1958 to 1987*





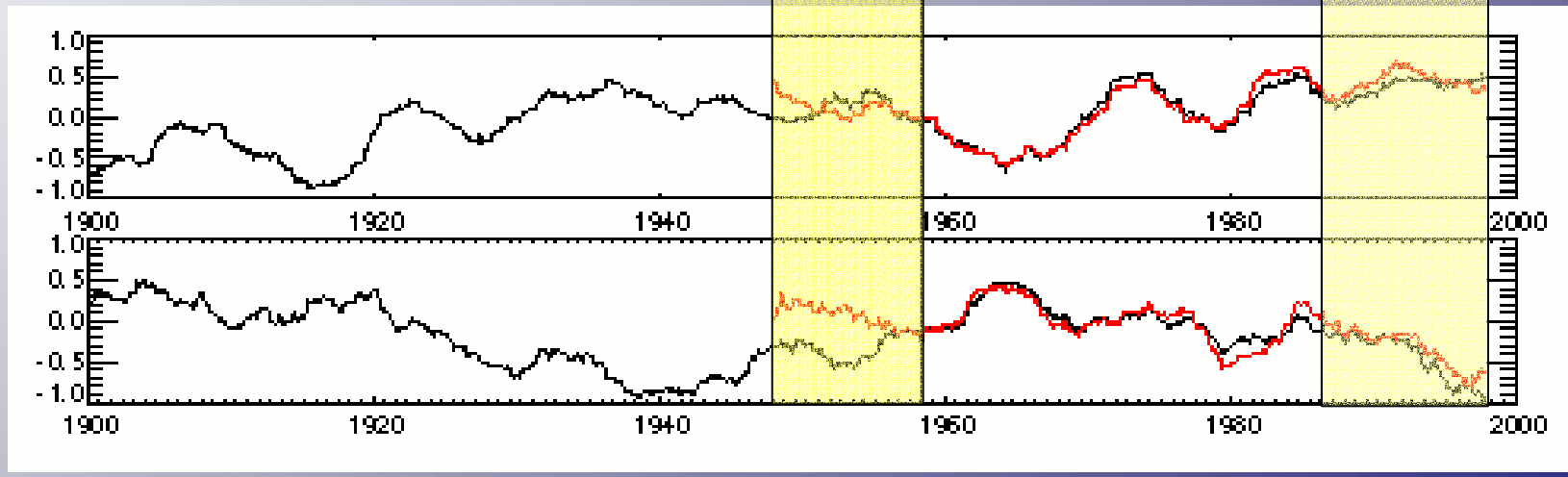
Example: SAT reconstruction

Predictor: monthly SAT gridded data (10x5 degree) from the AICSEX project *(compiled by G. Alekseev, courtesy O. Johannessen).*
Target data: monthly SAT *from the NCEP reanalysis interpolated onto the model grid.*

Redundancy time series:
fitting period 1958 to 1987 validation period 1948 to 1957 and 1988 to 1997
time series filtered with 5 years running mean

Mode 1

Mode 2



Example: SAT reconstruction

Predictor: monthly SAT gridded data (10x5 degree) from the AICSEX project *(compiled by G. Alekseev, courtesy O. Johannessen).*
Target data: monthly SAT *from the NCEP reanalysis interpolated onto the model grid.*

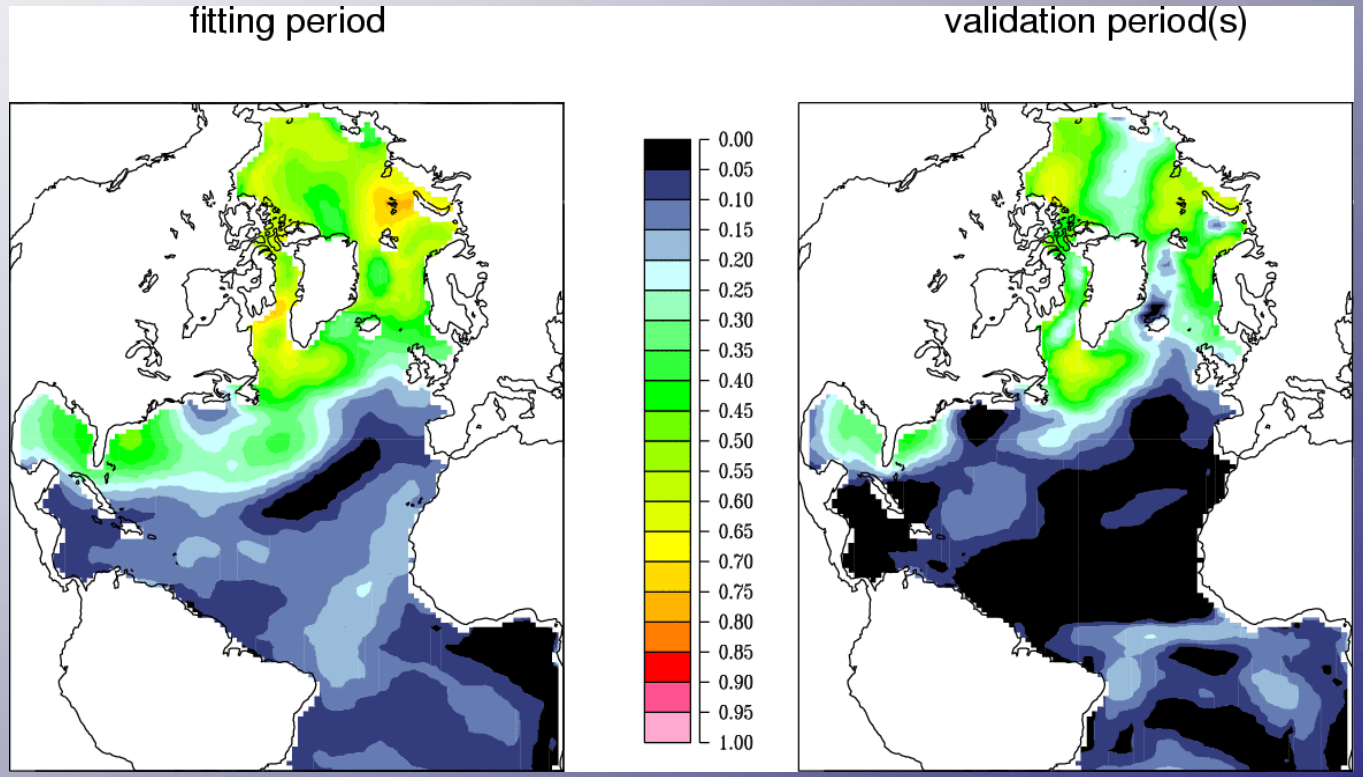
Redundancy time series:
fitting period 1958 to 1987 validation period 1948 to 1957 and 1988 to 1997

	Correlation Fitting period	***Correlation Validation period***	***Explained Variance predictand***
Mode 1	0.94	0.84	29 %
Mode 2	0.89	0.78	17 %
Mode 3	0.89	0.74	10 %
Mode 4	0.88	0.76	8 %
Mode 5	0.78	0.58	5 %
Mode 6	0.78	0.49	4 %
Mode 7	0.73	0.60	3 %
Mode 8	0.69	0.45	4 %
Mode 9	0.60	0.34	3 %
Mode 10	0.60	0.47	2 %
Mode 11 to 17	< 0.5	< 0.4	< 2 %

Example: SAT reconstruction

Predictor: monthly SAT gridded data (10x5 degree) from the AICSEX project *(compiled by Aleekseev, courtesy O. Johannessen).*
Target data: monthly SAT *from the NCEP reanalysis interpolated onto the model grid.*

Locally explained variances:
fitting period 1958 to 1987, validation period 1948 to 1957 and 1988 to 1997



Building the reconstruction:

$$rec = \sum cor * pc\_predictor * pattern\_predictand$$

The coupled sea ice -ocean model:

- Ocean: Based on the MOM-2 code, z-coordinate, 1x1 degree resolution, Arctic Ocean
  and North Atlantic north of 20S, 19 uneven spaced layers, tracer adv.: FTC, momentum adv.: centered-differences
- Sea ice: Hibler type model, viscous-plastic rheology, same grid as ocean model

Comments for AOMIPers:

Here the Arctic ice volume for three integrations with different reconstructions is shown. The blue corresponds to the previously presented recon. Green is AWI 1degree AOMIP run.

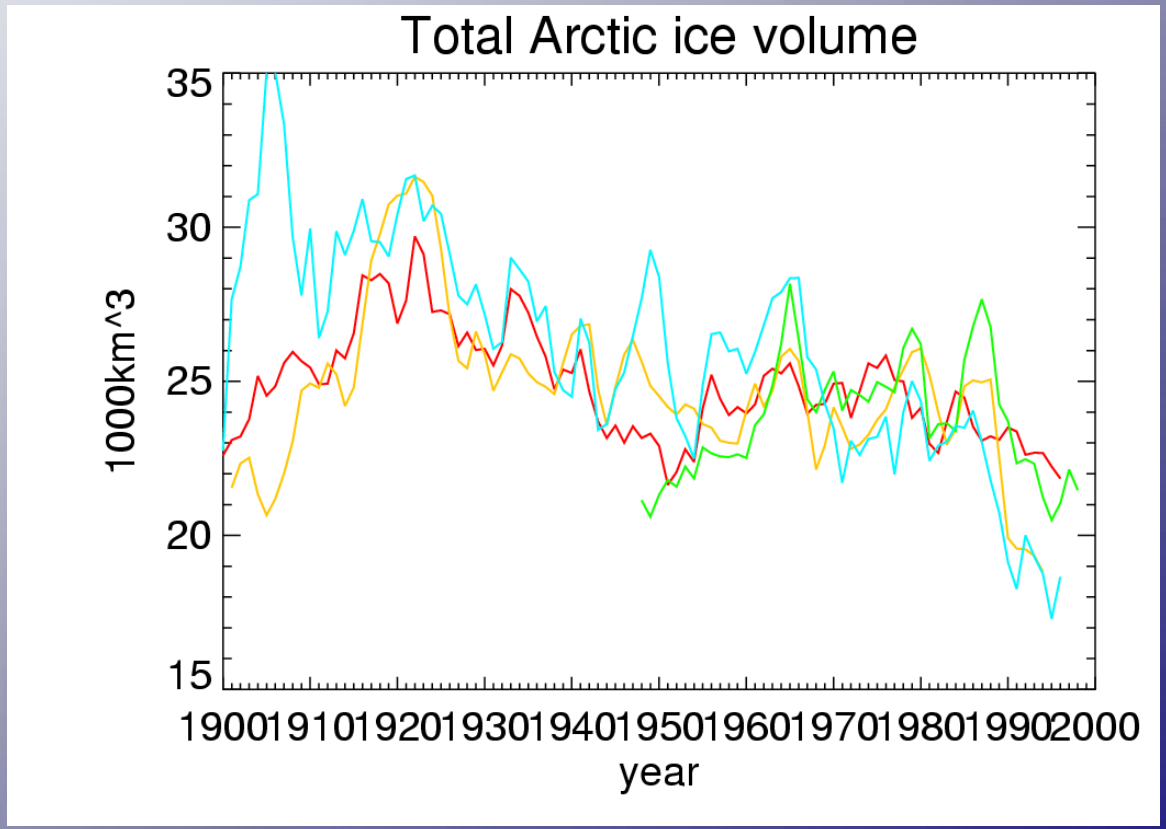
Experiments:

Predictor:MSLPG
Predictand: wind stress, SAT, cloud, precip, scalar wind, humidity
Time scales: rm 36 month

Predictor: IARC slp+sat,
Predictand: SLP, SAT
Others: climatology (AOMIP)
Time scales: monthly

Predictor: IARC_SMHI
Predictand: SLP
Predictor: Alekseev
Predictand: SAT
Others: climatology (AOMIP)
Times scales: monthly

Control run: NCEP forced, AOMIP protocol



Comments for AOMIPers:

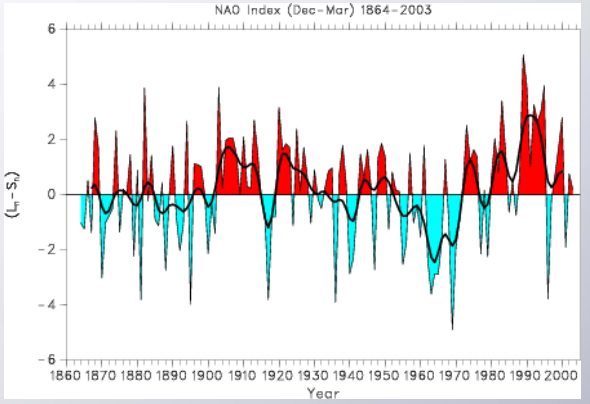
The next three slides try to understand the modeled total arctic ice volume variability. It is shown that a large portion of the variance of the SLP and SAT in the Arctic can be explained by two climate indices, the NAO and NP. A linear regression model suggest a positive dependence on the NP and a negative (weaker) dependence on the NAO. This stat. model can explain part of the very high Arctic ice volume in the 1910s and 1920s but fails to describe the strong reduction in the 1990s. The non-linear MARS model on the other hand is able to describe both aspects of the sea ice volume.

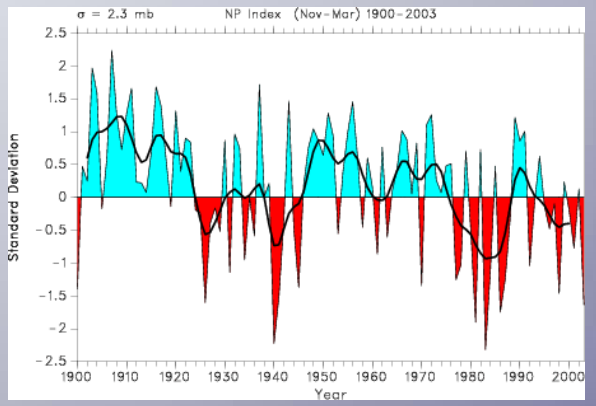
The last slide shows a comparison with historical sea ice area data on the Arctic shelves.

NAO (Hurrel's home page)

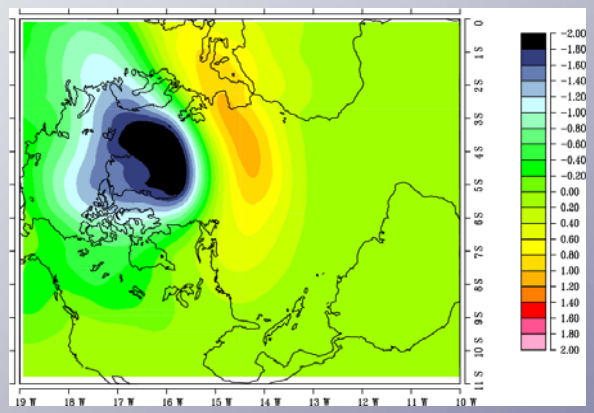
NP (Hurrel's home page)

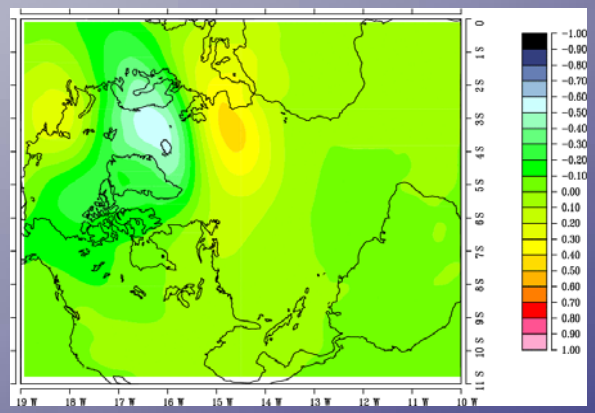
NP: area-weighted SLP
(30-50N,160E-140W)
Trenberth and Hurrel (1999)



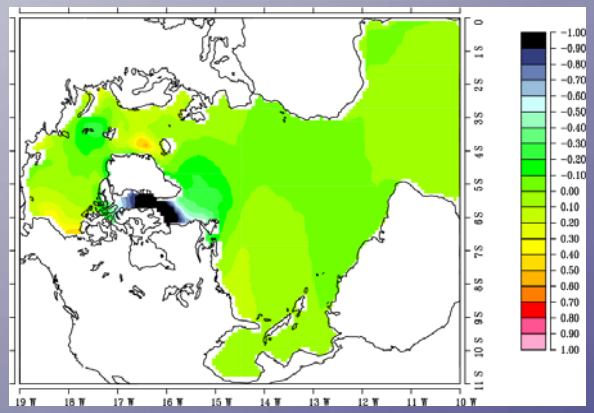


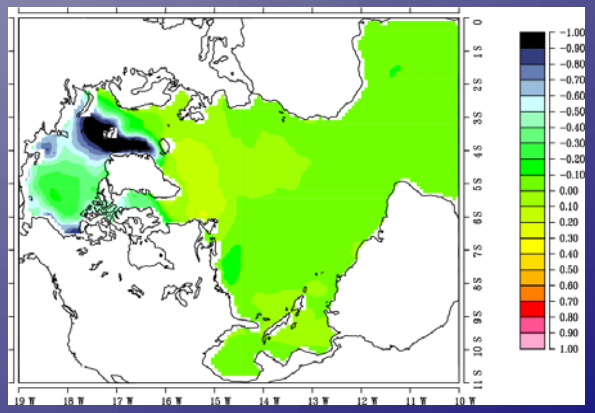
Reconstructed SLP
(IARC_SHMI)
Nov-Mar rm 5years
regressed upon NAO
and NP





Reconstructed SAT
(Alekseev)
Nov-Mar rm 5years
regressed upon NAO
and NP



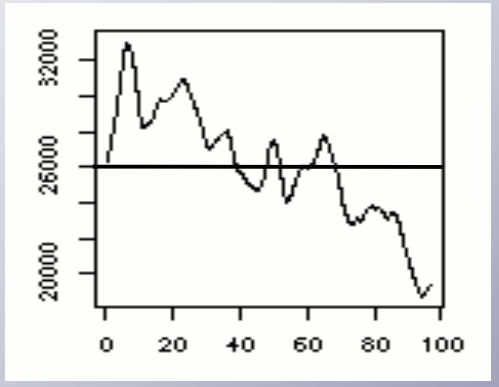


IARC_SMHI/Alekseev reconstruction

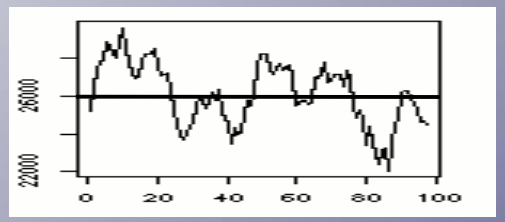
Lin. Regression Model between annual mean (Nov-Oct) 20th century Arctic ice volume and the NAO and NP (both Nov-Mar, 5 years running-mean filtered)

$$ice\_vol = -459{,}1 * NAO + 2932 * NP$$

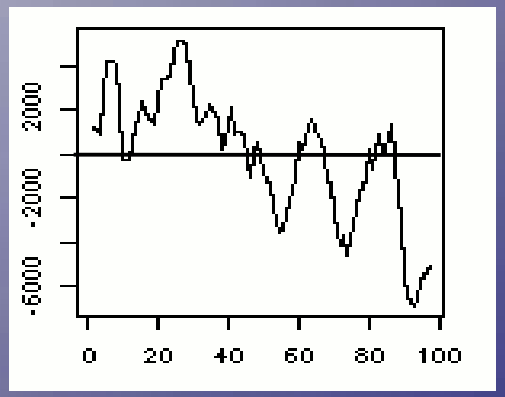
simulated



lin. model

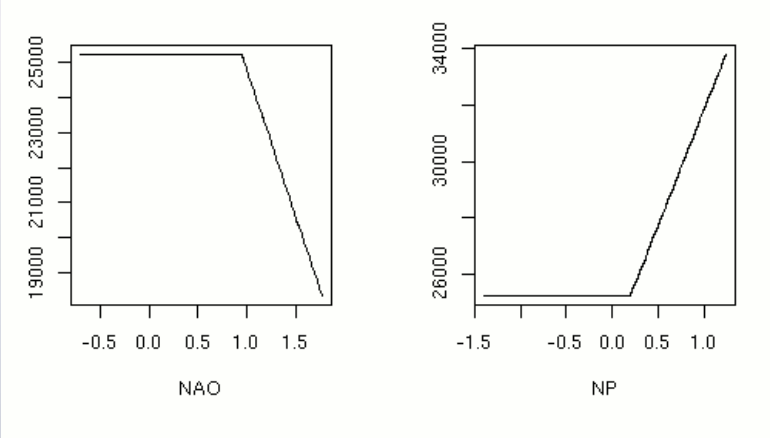


residual



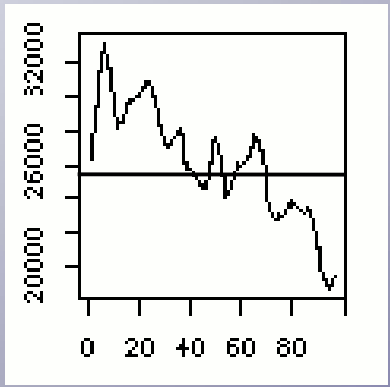
IARC_SMHI/Alekseev reconstruction

Multivariate Adaptive Regression Splines (MARS, *Friedmann, 1991*)
Multivariate non-linear, non-parametric statistical modelling method.
(applied with great success in econometrics and risk analysis)

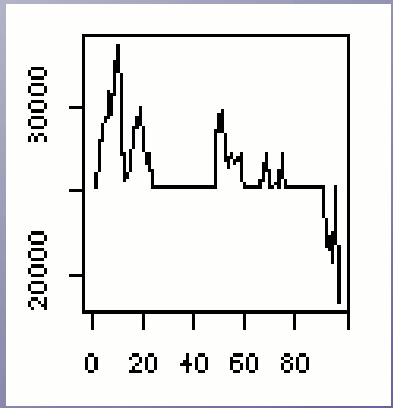


The figs on the left shows the non-linear dependence on the NAO and NP as predicted by the stat. model.

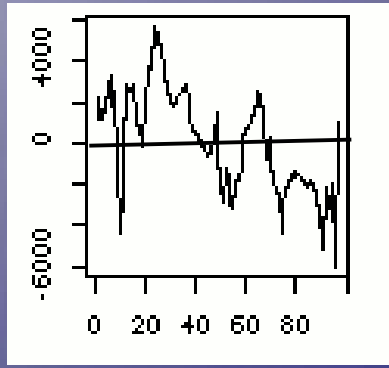
simulated



MARS model



residual



Comparison of the Reconstruction IARC_SMHI/Alekseev with historical data

historical data: *ice area in August in the Kara, Laptev, East Sibirian and Chukchi Seas compiled by I. Polyakov (2003) for 1900 to 2002*

Simulation

Historical data