Monthly, Seasonal (and a few comments on longer) prediction

David Anderson

Paco Doblas Reyes, Magdalena Balmaseda,
Frederic Vitart, Laura Ferranti, Franco Molteni, Tim Stockdale,
Kristian Mogensen, Alberto Troccoli.

Ice movie from Tom Agnew, Environment Canada.

Note the very unusual conditions around Svalbard as the ice melts away.
There were record warm winter temperature there. (P. Rhines).
Notice also the ice streaming out of the Arctic on both sides of Greenland and the Canadian Arctic Archipelago.

Overview

- Introductory remarks re extended range forecasting
- ECMWF activities, and multi-model
- Some results from monthly forecast system, specific cases, stratospheric warming, ice experiment
- NAO
- Prediction and predictability for high latitudes (and tropics)
- Snow cover and sea ice

- - If time permits
- Predictability in coupled and uncoupled mode
- Role of the Indian ocean in influencing the NAO
- Role of the Atlantic in influencing ENSO and vice versa

The basis for monthly and seasonal forecasting

- The forecast horizon for weather forecasting is a few days.
- Sometimes it is longer e.g. in blocking situations 5–10 days.
- Sometimes there might be predictability even longer as in the intraseasonal oscillation or Madden Julian Oscillation.
- But how can you predict 6 months (or maybe even further) ahead?

- The feature that gives longer potential predictability is the ocean (and maybe slow boundary changes associated with snow cover, sea ice, soil moisture...).

- The ocean has a large heat capacity and slow adjustment times relative to the atmosphere.
- If the ocean forces the atmosphere on these timescales, then there can be longer predictability.
- On the other hand if the atmosphere forces the ocean with little or no feedback, there might be little (atmospheric) predictability.

- Latif et al 2002, Timmermann 2005,
- Hasselmann 1976.

Noise (white)

$$\frac{dy}{dt} = \xi(t) - \lambda y$$

$$G(\omega) = \frac{\sigma^2}{(\lambda^2 + \omega^2)}$$

σ = std dev^{n} of noise

⇒ White noise forcing ⇒ red spectrum response

Hasselmann

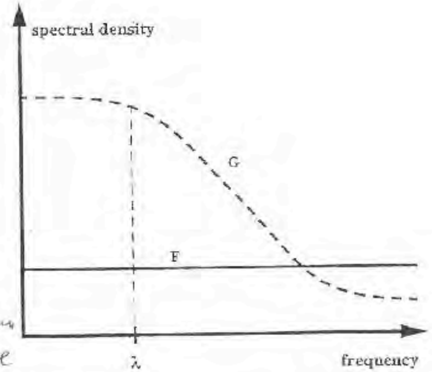


Fig. 9.5 Schematic input spectrum F and response spectrum G which result from the simplest version of the stochastic climate model (1). The atmospheric input spectrum is white, while the oceanic response spectrum is red down to a frequency which is determined by the damping λ.

158 Mojib Latif, Axel Timmermann, Anselm Grötzner, Christian Eckert, Reinhard Voss

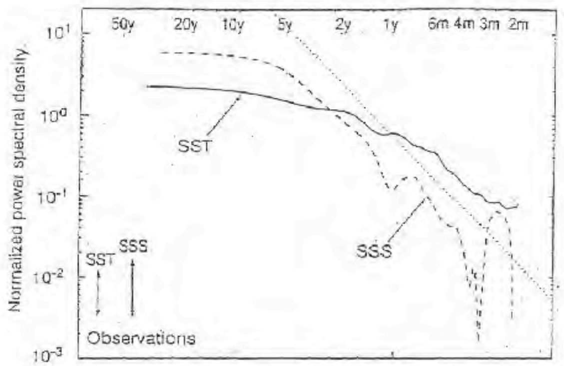


Fig. 9.6 Spectra of anomalous North Atlantic SST and SSS observed at ocean weather ship 'I' (60.8°N, 20.6°W). The dotted line shows the slope ω^{-2}. From Hall and Manabe (1997).

- The ocean response to white noise forcing is a red spectrum- the ocean integrates the noise to give low frequency variability. This is not a bad approximation in many parts of the extratropical world.
- Hasselmann 1976

$$\frac{d^2y}{dt^2} + \lambda\frac{dy}{dt} + \omega_0^2 y = \xi(t)$$

$$G(\omega) = \frac{\sigma^2}{(\omega^2-\omega_0^2)^2+\omega^2\lambda^2}$$

$$\omega_r^2 = \left(\omega_0^2 - \frac{\lambda^2}{2}\right)$$

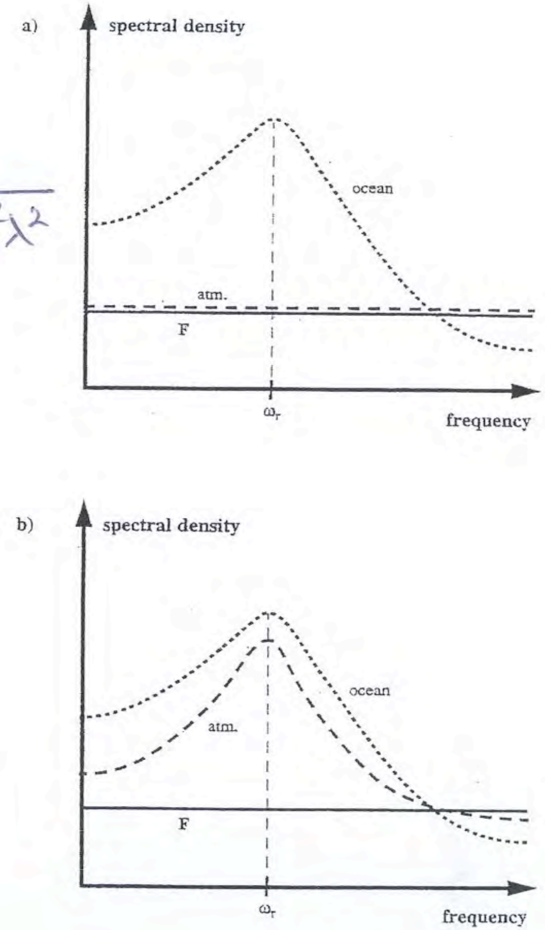


Fig. 9.7 Schematic atmospheric and oceanic spectra which result from the stochastic excitement of a) an 'ocean-only' mode and b) a 'coupled ocean-atmosphere' mode. In the former case, the atmospheric spectrum is white, while the oceanic spectrum shows a peak at the resonance frequency; in the latter case both the atmospheric and the oceanic spectra show a peak at the resonance frequency.

The ocean can have a resonance forced by noise.

Or there can be a coupled response.

From Latif et al MPI.

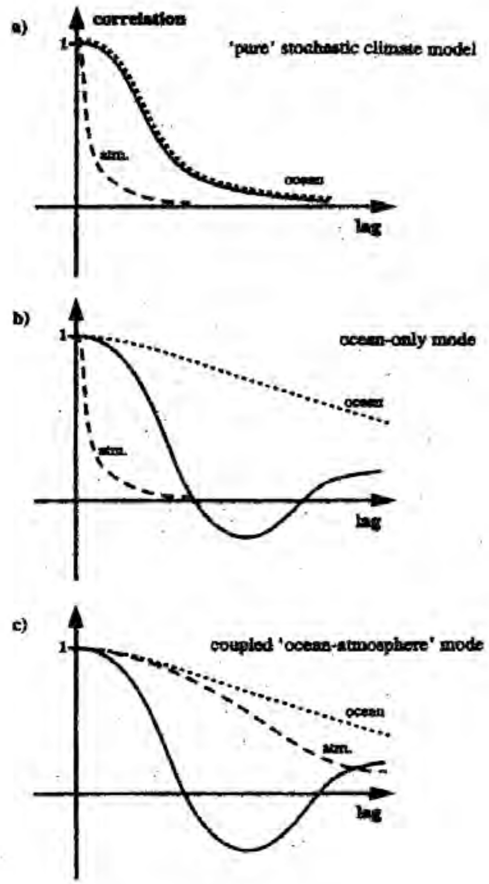
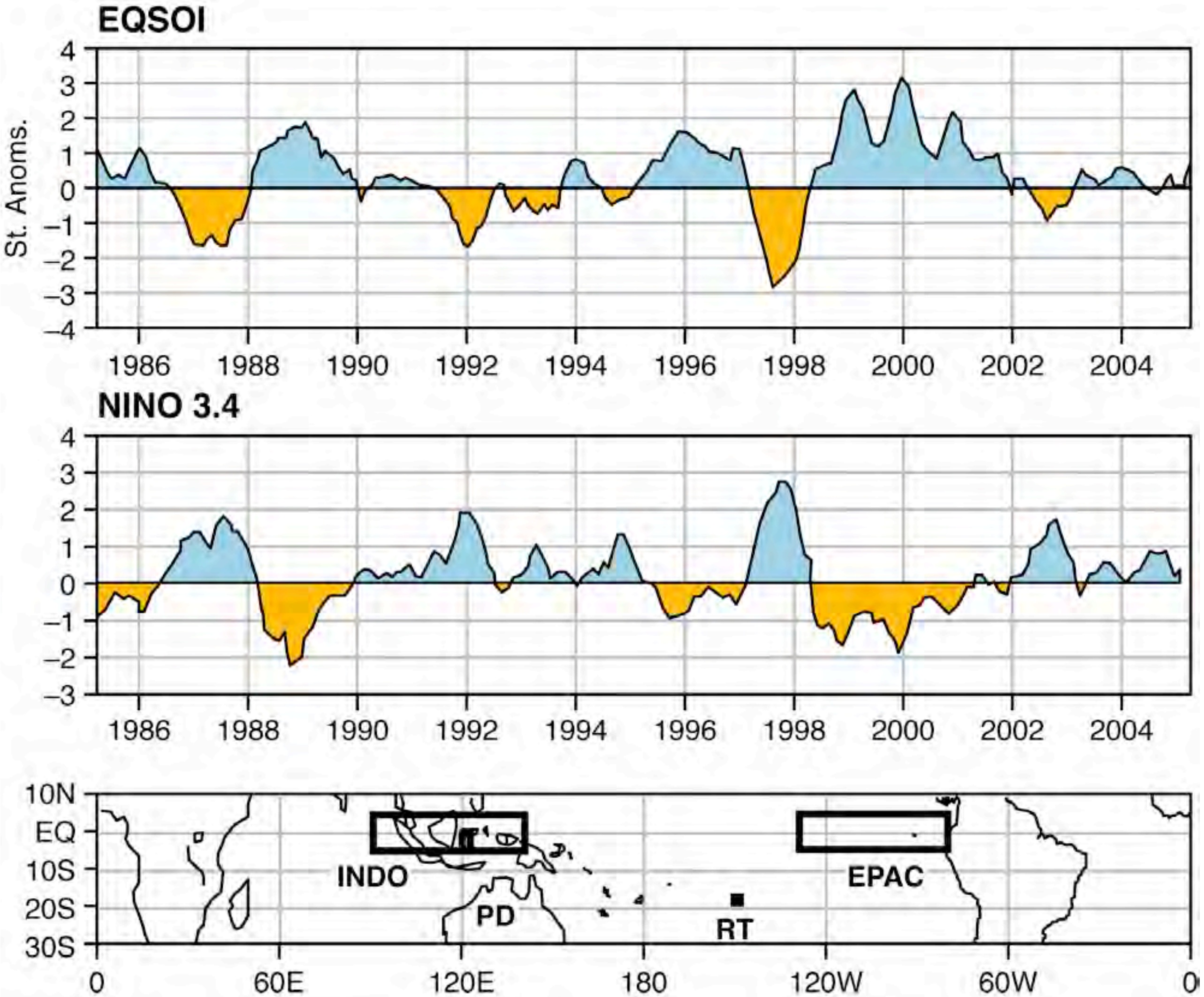


Fig. 9.17 Schematic atmospheric and oceanic skills expected from three scenarios. a) The 'pure' stochastic climate model, b) the stochastic excitement of an 'ocean-only', c) the stochastic excitement of a 'coupled ocean-atmosphere' mode. The persistence of a typical oceanic quantity (such as the anomalous SST) is given by the full lines. The typical oceanic skills are given by the dotted lines, while those of typical atmospheric quantitities are given by the dashed lines.

The predictability of the ocean might be much larger than the atmosphere depending on what is forcing what. The forcing might only influence part of the variance. The rest might be unpredictable.


EQSOI
St. Anoms.
NINO 3.4
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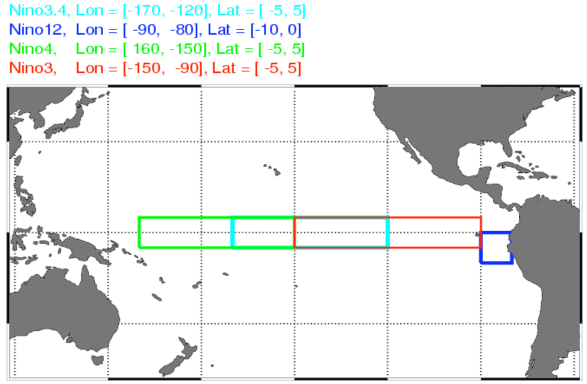
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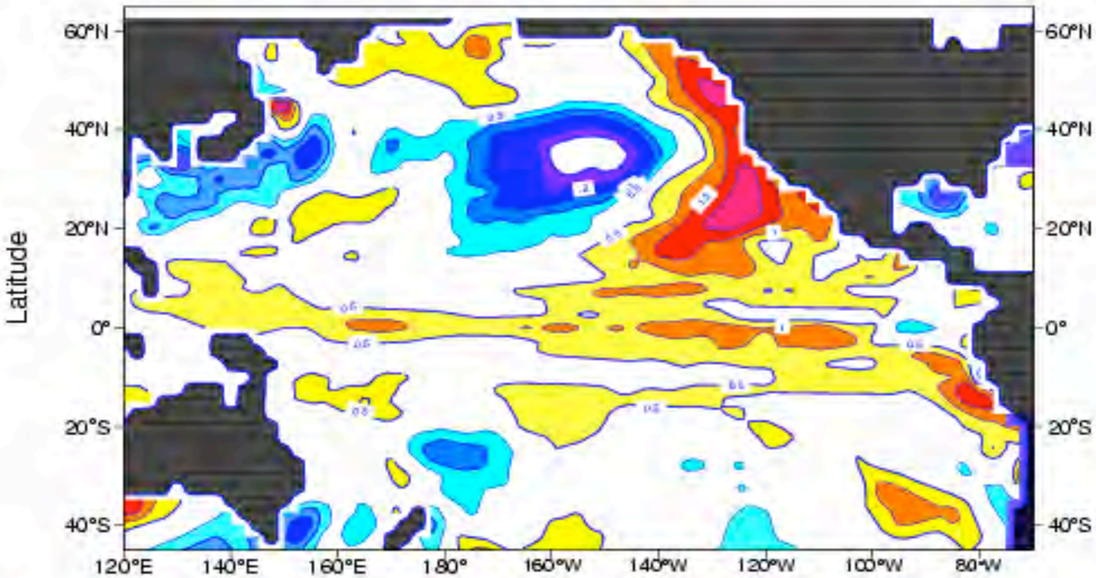
Nino12, Lon = [-90, -80], Lat = [-10, 0]
Nino4, Lon = [160, -150], Lat = [-5, 5]
Nino3, Lon = [-150, -90], Lat = [-5, 5]



Latitude
60°N
40°N
20°N
0°
20°S
40°S
120°E
140°E
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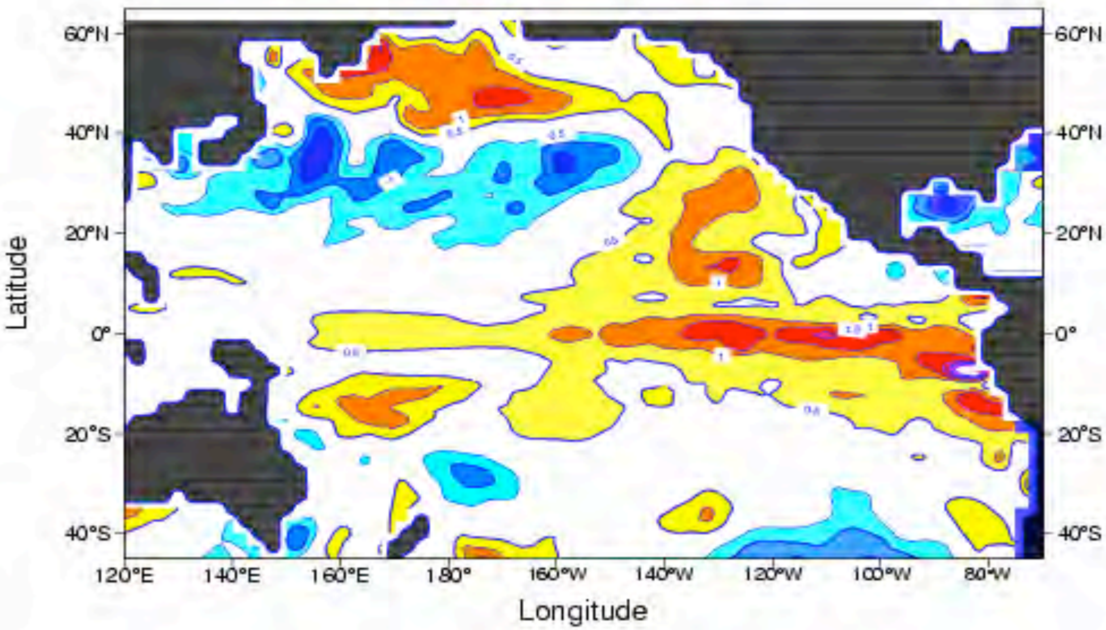
140°W
120°W
100°W
80°W



Latitude
Longitude
60°N
40°N
20°N
0°
20°S
40°S
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
80°W

Real-time Seasonal Forecasting at ECMWF

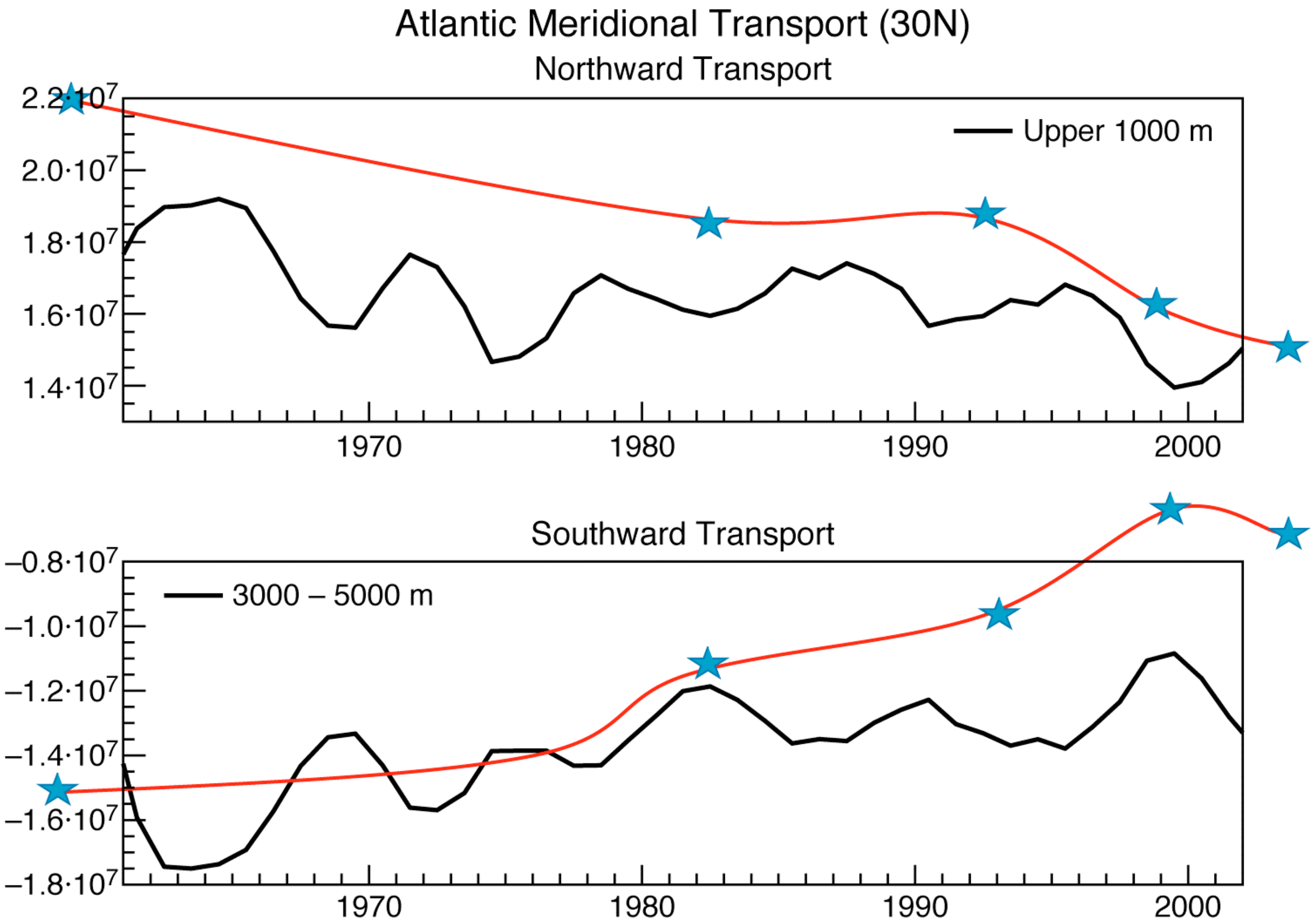
With a start date of the 1^{st} of each month, ECMWF carries out a 40-member ensemble of 6-monthly forecasts with its own coupled atmosphere-ocean model. To deal with model error and to assess the skill of these forecasts, it is necessary to run over a long period of past events. (Typically 15–25 years with a 5–11 member ensemble).

Forecasts are also made with the UK Met Office coupled model, following the same ensemble-generation strategy and with the Météo-France model using a different strategy.

From these 3 X 40-member ensembles, multi model forecasts can be made.

New ocean analysis and seasonal forecast system

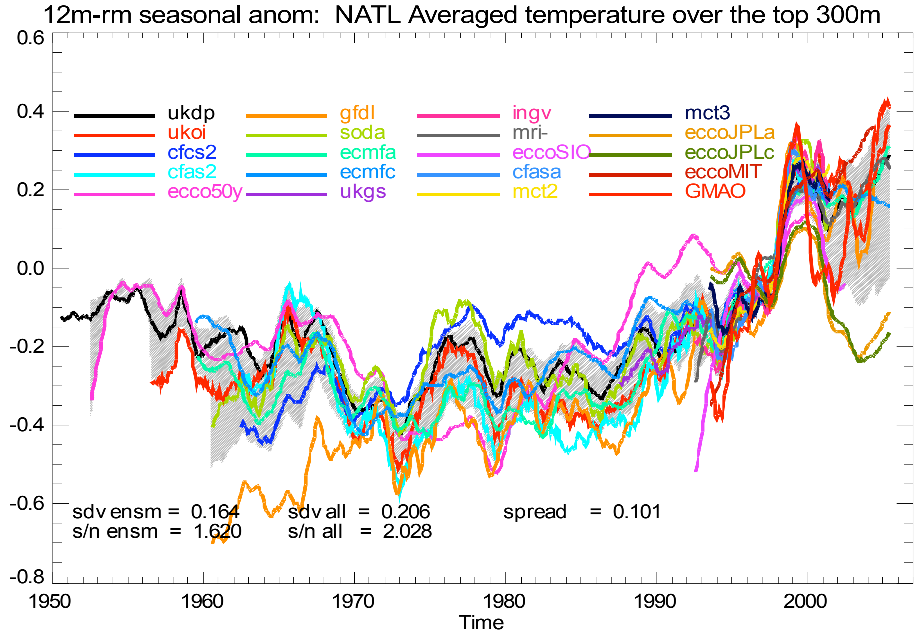
- ECMWF is about to introduce a new seasonal forecast system (S3). The current system is S2. DEMETER (an EU multi-model research project) used a slightly later version of S2, based on ERA40.
- There is also a new (ensemble) ocean analysis extending back to 1957. All available data are assimilated, XBTs, CTDs, ARGO, altimeter… This analysis can be used for climate studies as well as providing initial conditions for forecasts (hindcasts).

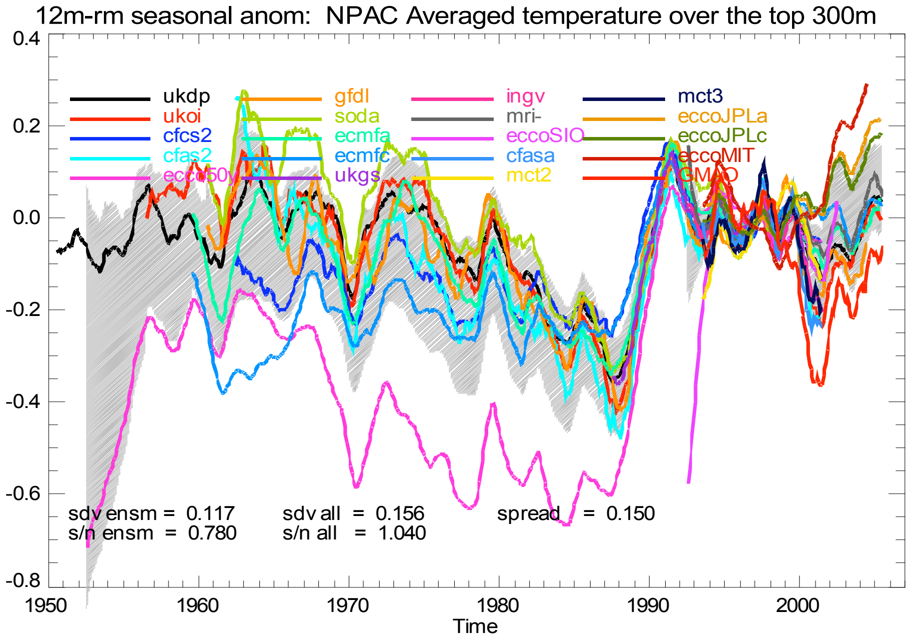


Magdalena Balmaseda

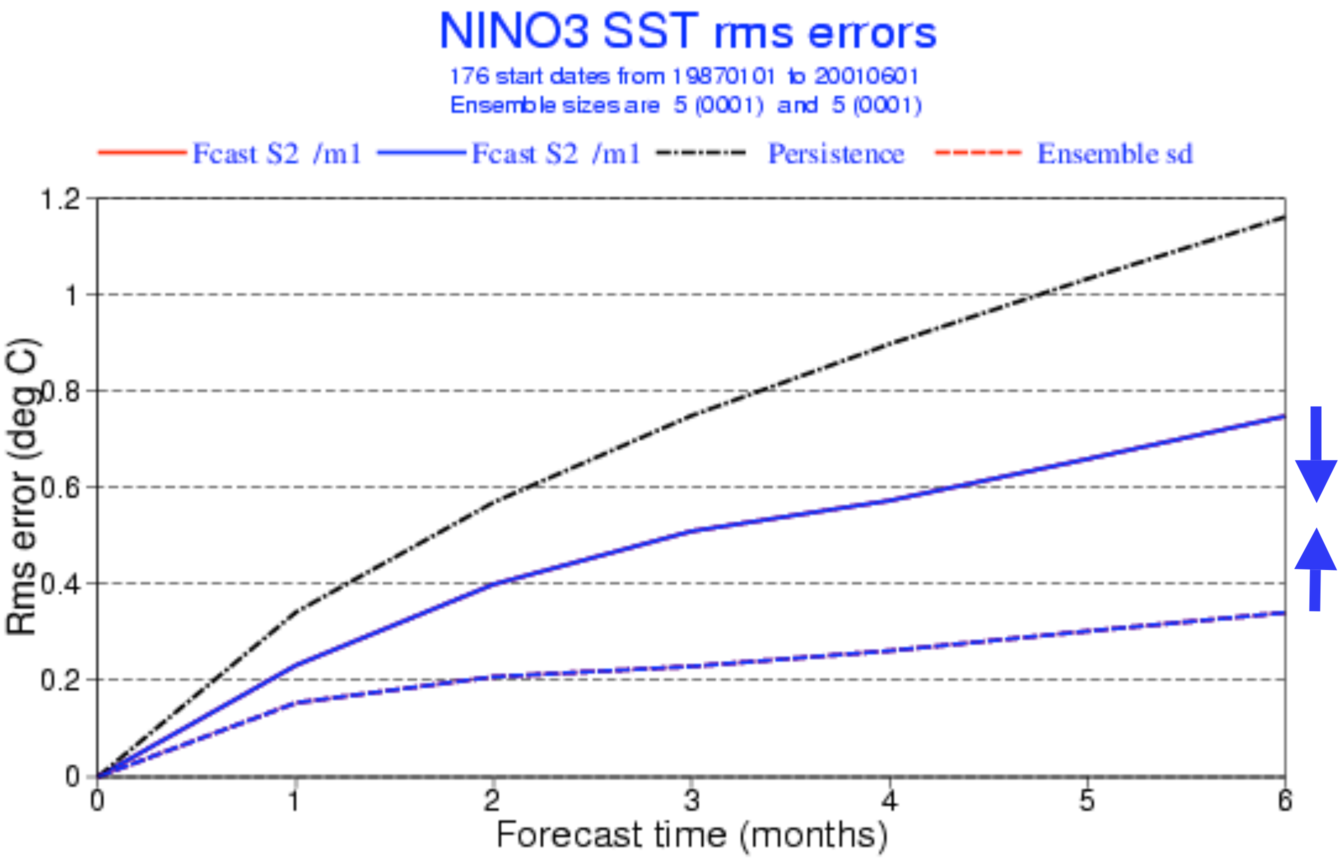
T300: Mid latitudes (northern)

- The North Atlantic is dominated by a warming trend, especially post 1997
- Large uncertainty after 2000.
- Phase/amplitude of decadal variability is poorly resolved.





- The North Pacific does not show a warming trend, but more of a rapid shift in the early 90s
- Large uncertainty after 2000
- Phase/amplitude of decadal signal is poorly resolved. Outliers.



Forecast System is not reliable:

RMS > Spread

A) Can we reduce the error? How much?

(Predictability limit)

B) Or can we only increase the spread?

A) Improve the ensemble generation: Need to sample model error

B) Improve calibration: A posteriori use of all available information

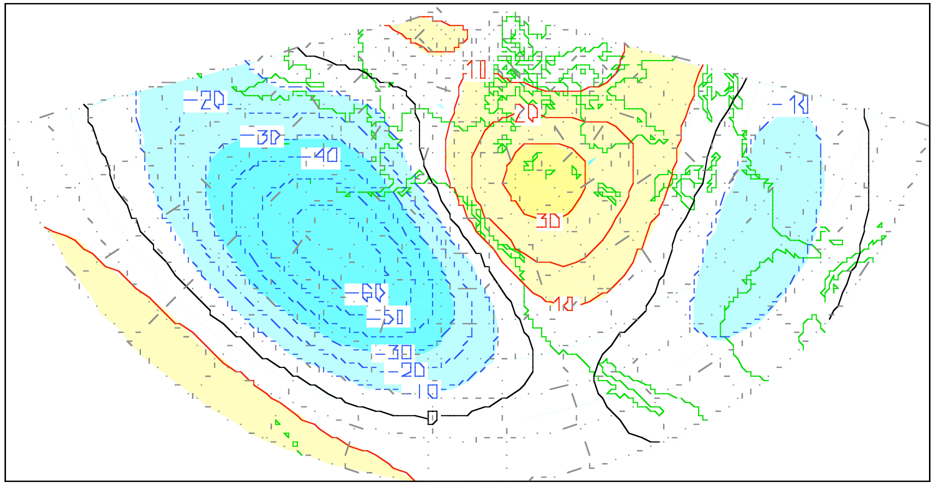
Monthly

- ECMWF runs a monthly forecast system. Currently this is run once per week, in coupled mode. The ocean initial conditions are based on S2 but with an accelerated analysis. (The analysis for S2 is 11 days behind real-time).

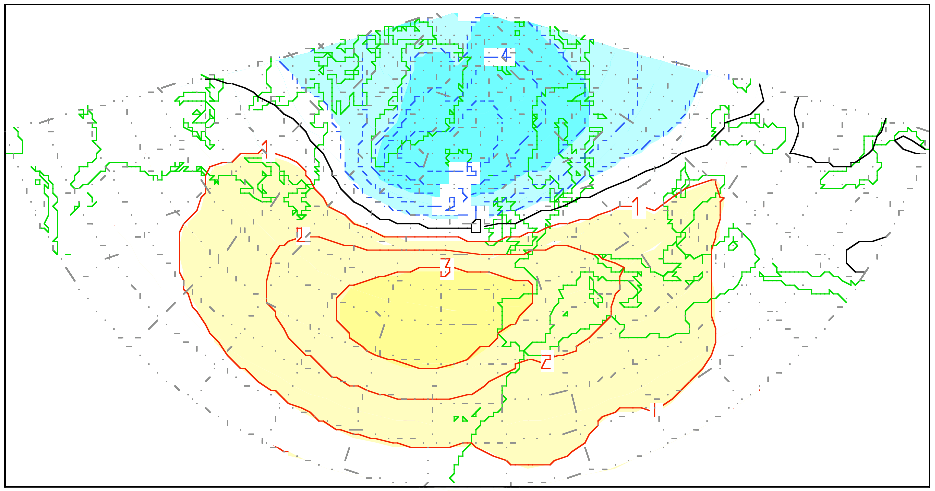
- For assessment and removal of model error, a series of hindcasts is also made, spanning 12 years.

The NAO in the Seasonal forecasting system

PNA-z500

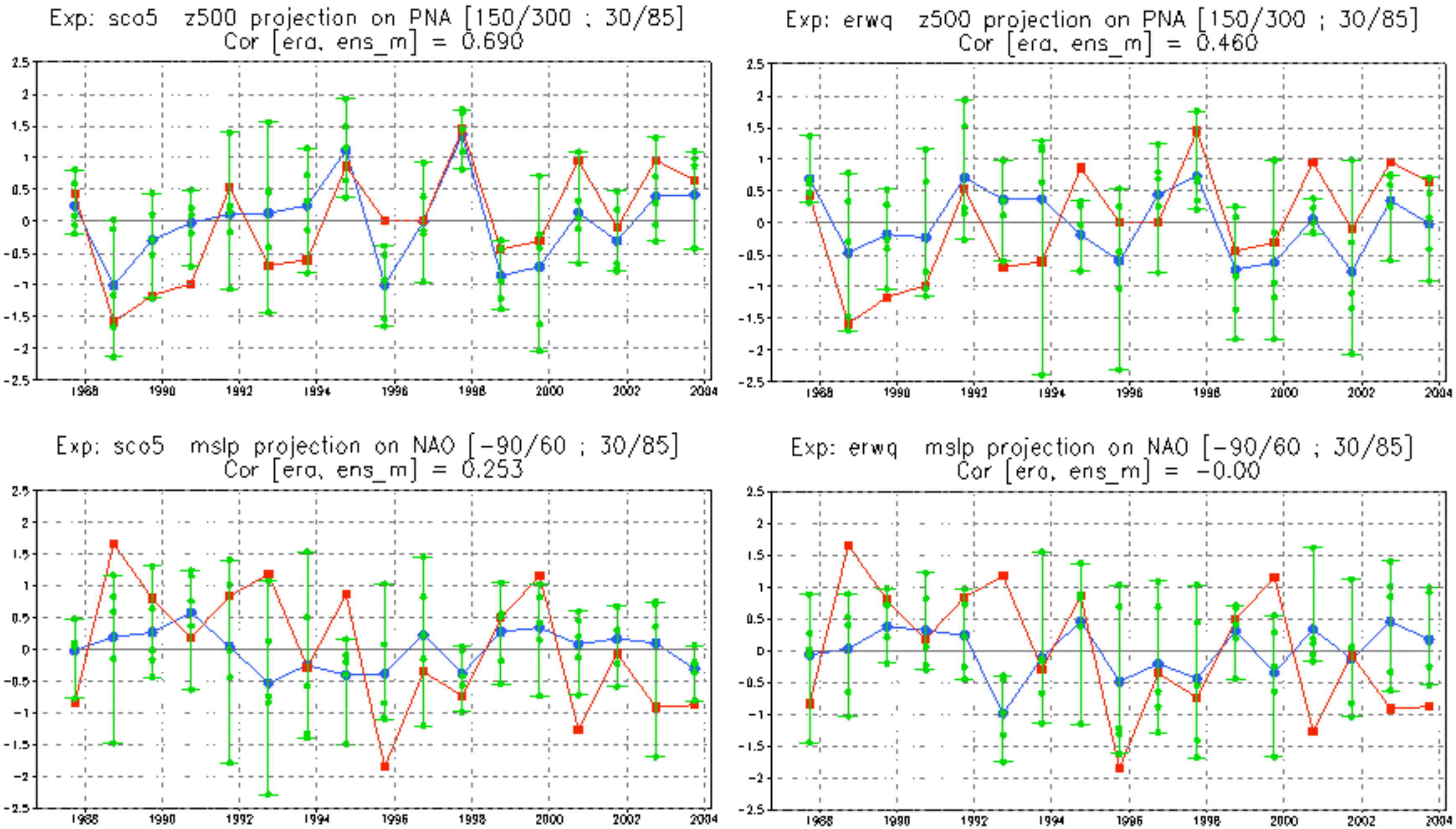


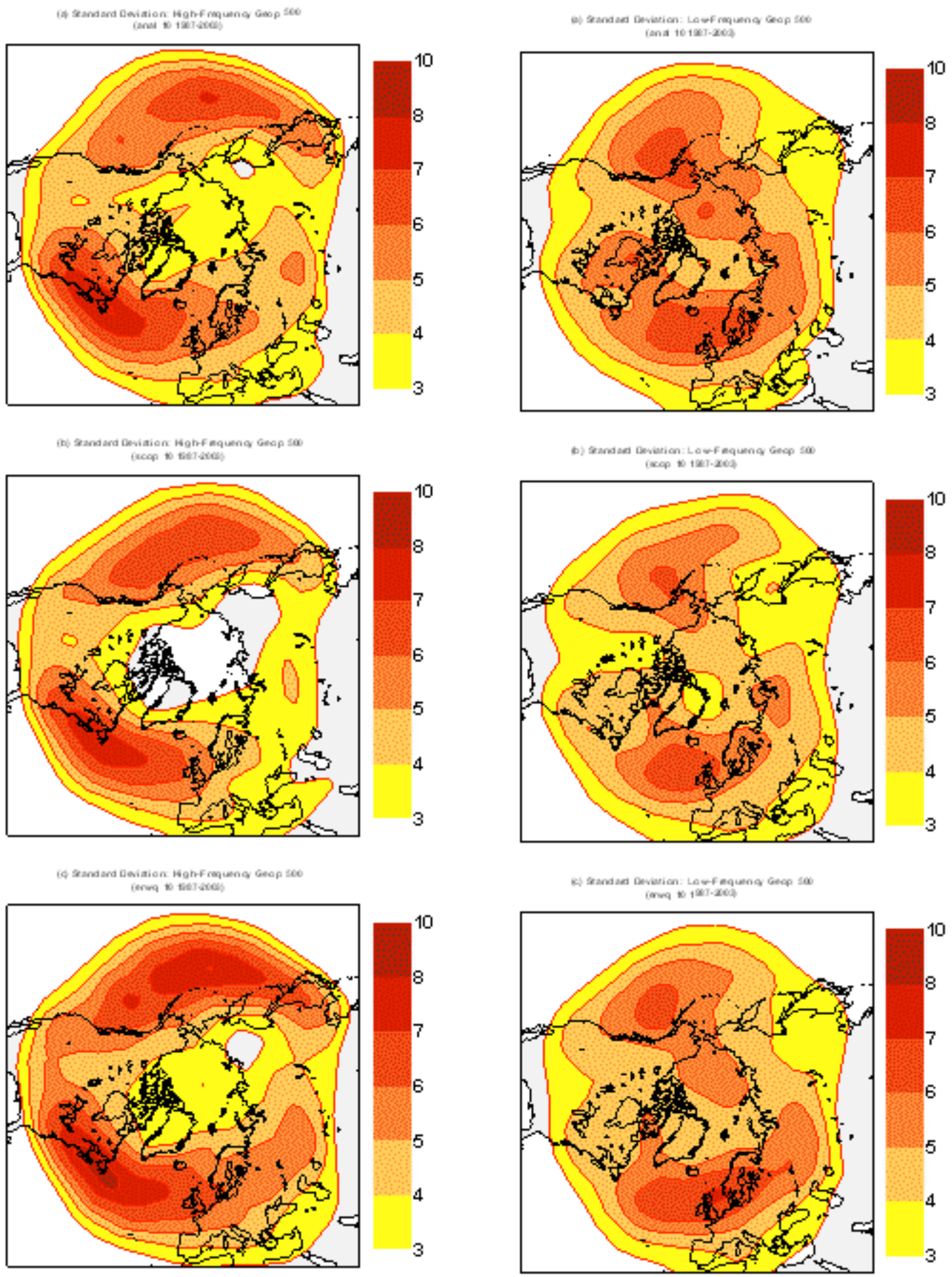
NAO-mslp



The model PNA and NAO patterns seem well represented. But can they be predicted?

It seems there is some skill in predicting the PNA but the skill is low for the NAO for both S2 (left) and S3 (right).
DJF. Red – ERA40, green – ensemble members, blue – ensemble mean

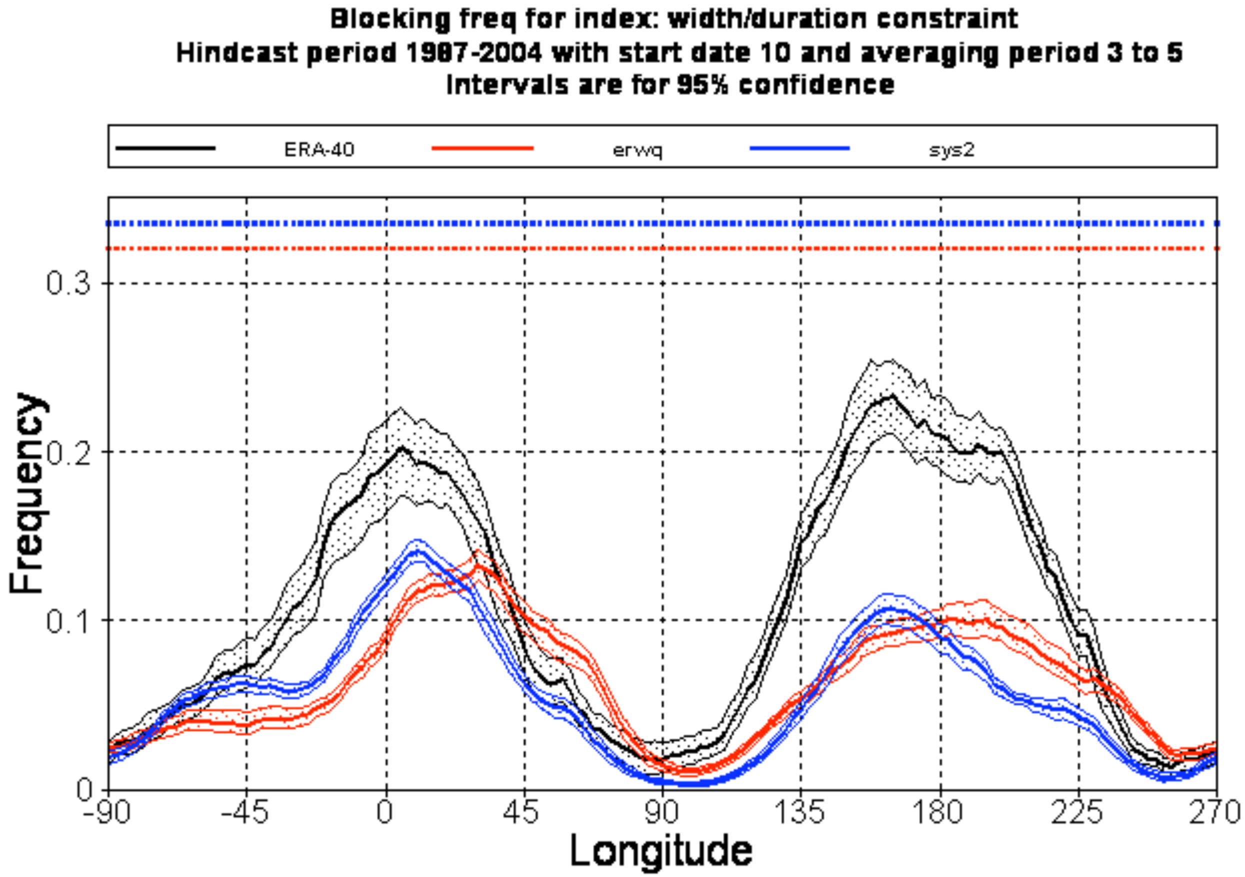




Variability in two frequency bands. Top ERA40, middle S2 and lower S3.

Left 2-8 day band, right 10-30 day band.

The variability seems good in both S2 and S3.



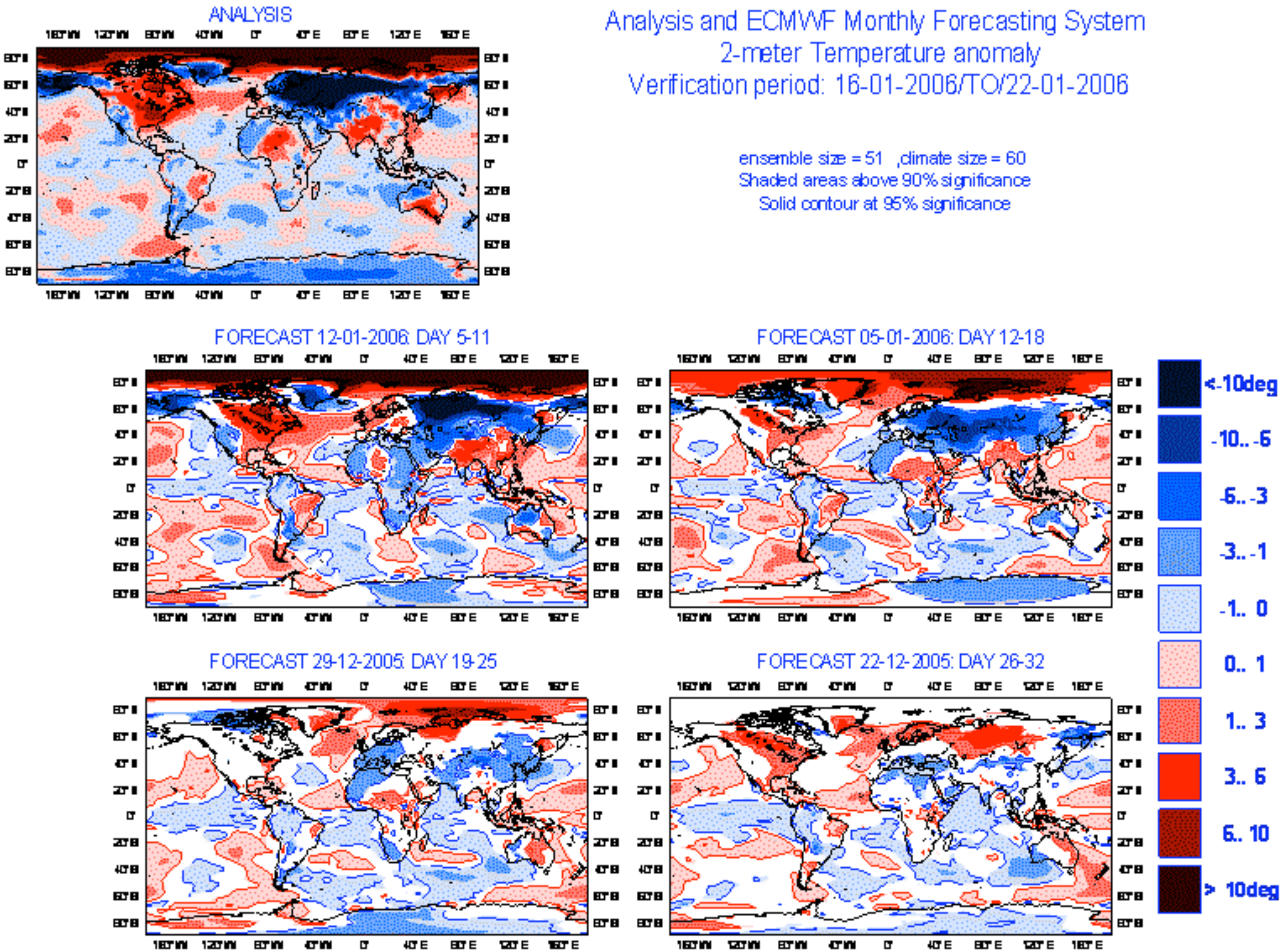
Blocking is not well handled in either S2 or S3, a common model problem

Monthly forecast system

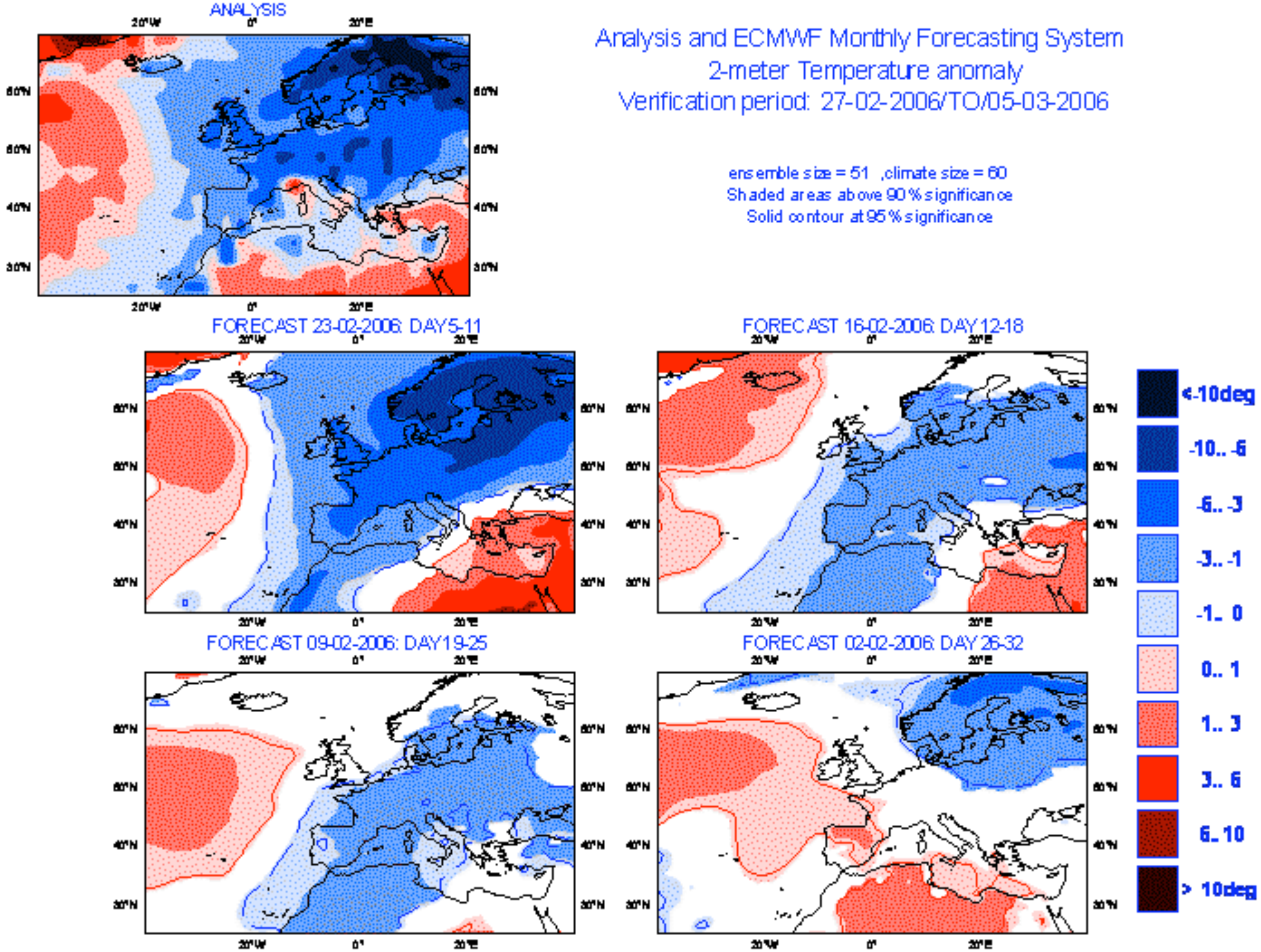
- 51 ensemble members in the real-time forecast.
- Back integrations for 12 years, 5 member ensemble.

Despite the poor prediction skill shown for the higher latitudes, there is a higher level of skill for the tropics and ENSO prediction.

Example: Extreme cold over Russia



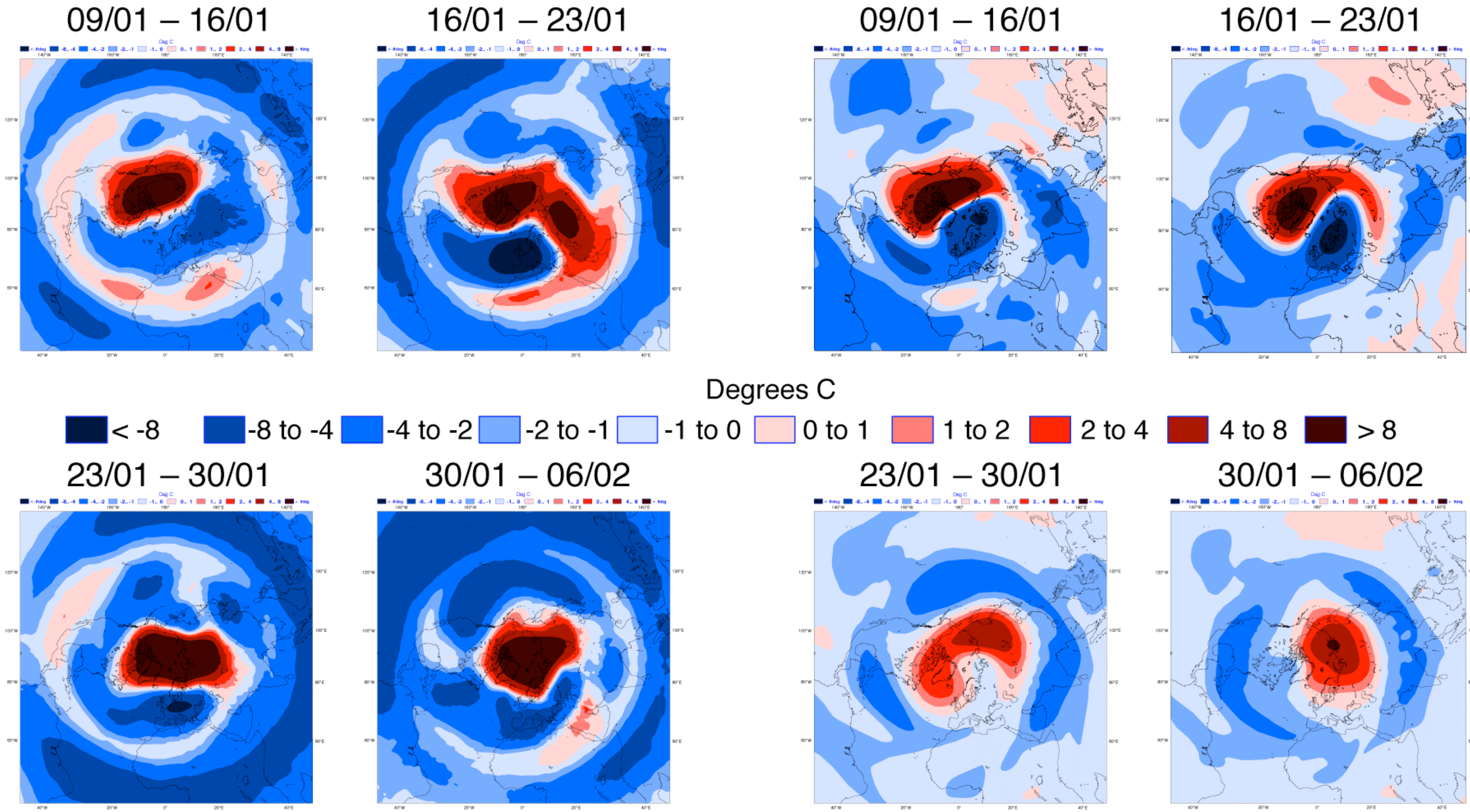
Cold over Europe



StratosphereT50 anomaly

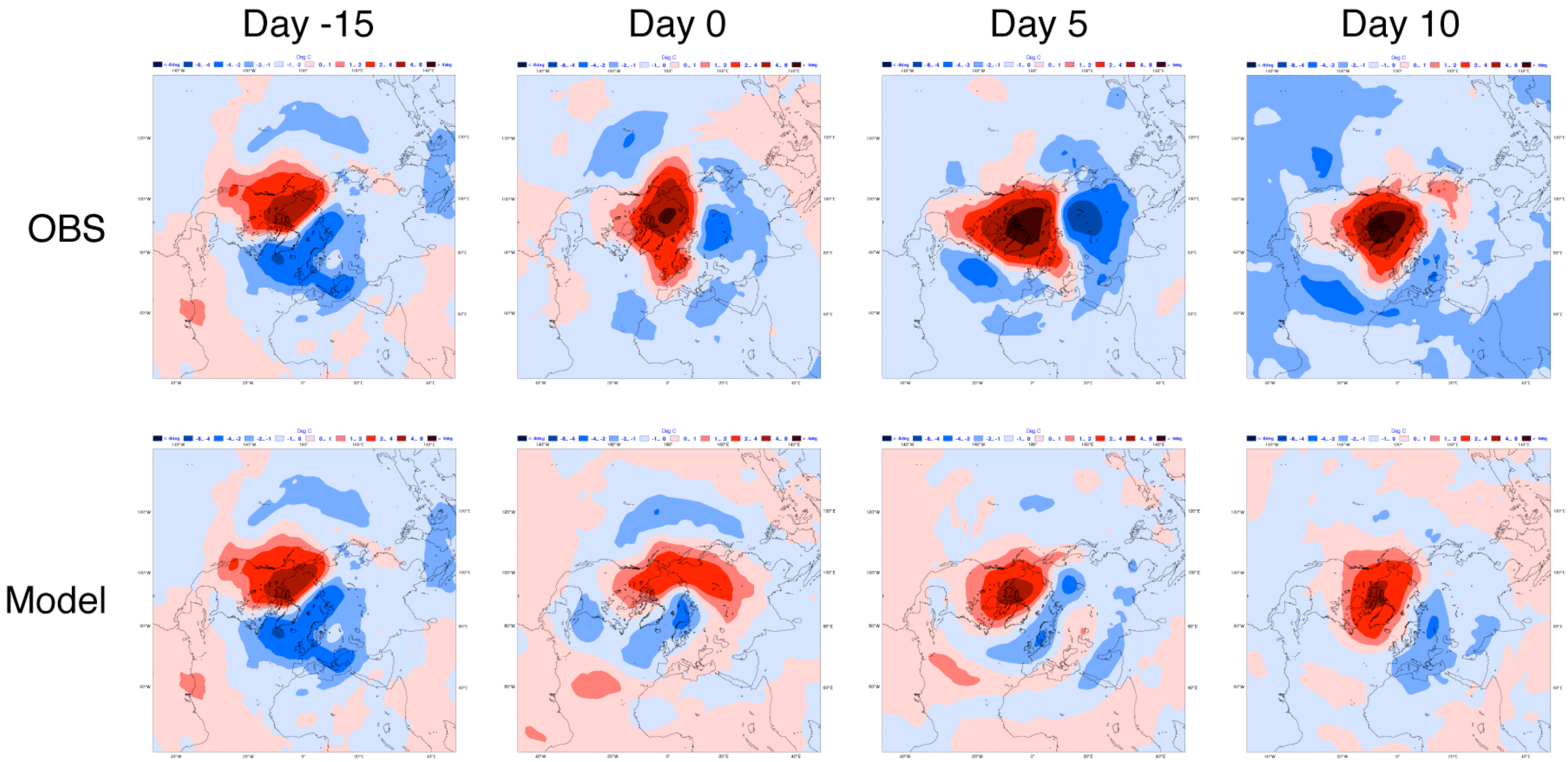
ANALYSIS

Ensemble mean forecast starting on 5 January 2006



Stratosphere T50

Composites: Weak vortex cases



Sea Ice

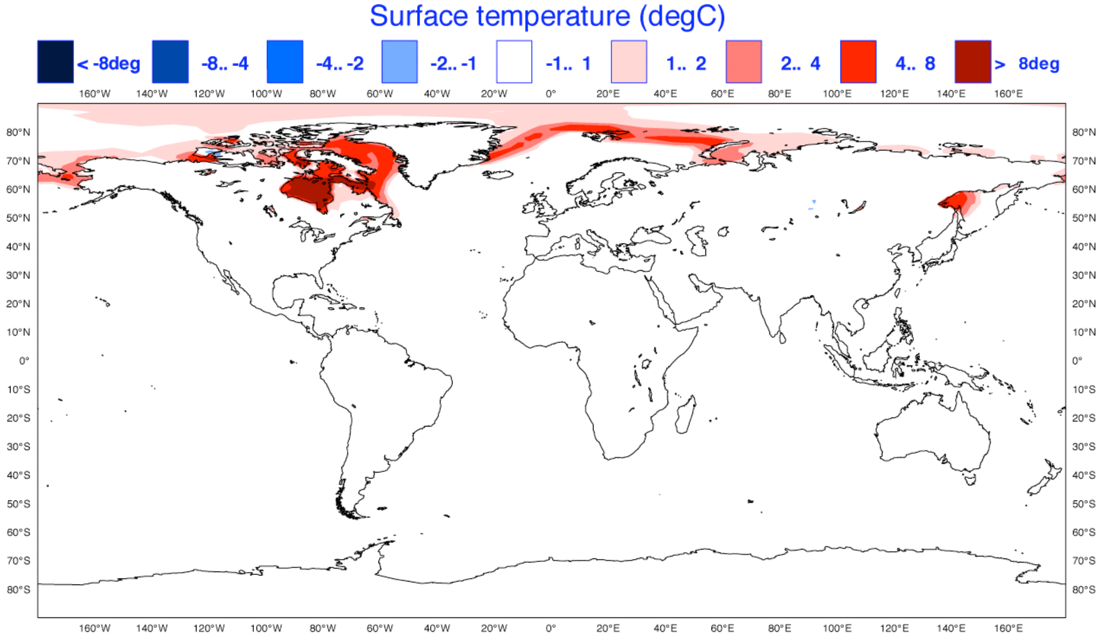
- Sea ice is handled differently in S2 and S3.
- In S2, there is sea-ice if $SST<-1.73 +C$ where C is a tolerance. In S2 it has the value 0.05.
- The tolerance C might be too small as it can give rise to marked changes in the sea-ice cover in both summer and winter. In summer too much Arctic ice can disappear, but the effect on the atmosphere seems small. In winter, it can create problems in the Hudson Bay area and in the sea of Okotsk (north of Japan). We will return to this later.

Sea ice

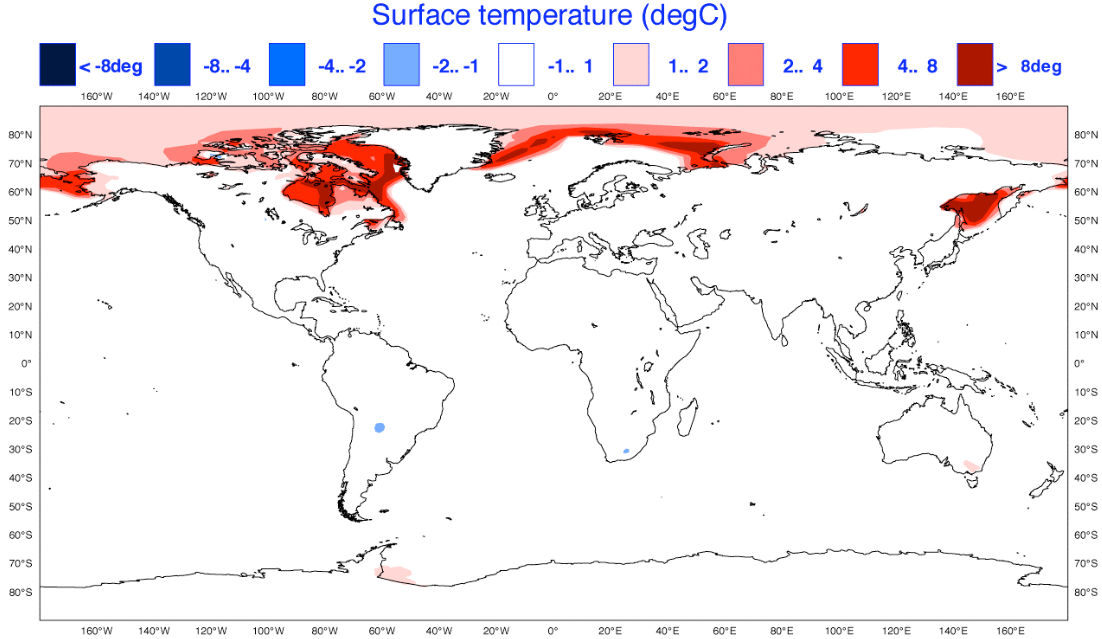
- The sea ice in S3 is persisted for the first 10 days of a forecast. Over the next 20 days the ice edge is linearly reduced to climatology. Fractional ice cover is used but the fields passed to the atmosphere are either 0 or 1. If fractional ice cover is greater than 0.55, it is rounded up to 1, otherwise it is reduced to 0.
- Under ice, the ocean T is relaxed to climatology.
- **This treatment has been used in the monthly system for some time.**

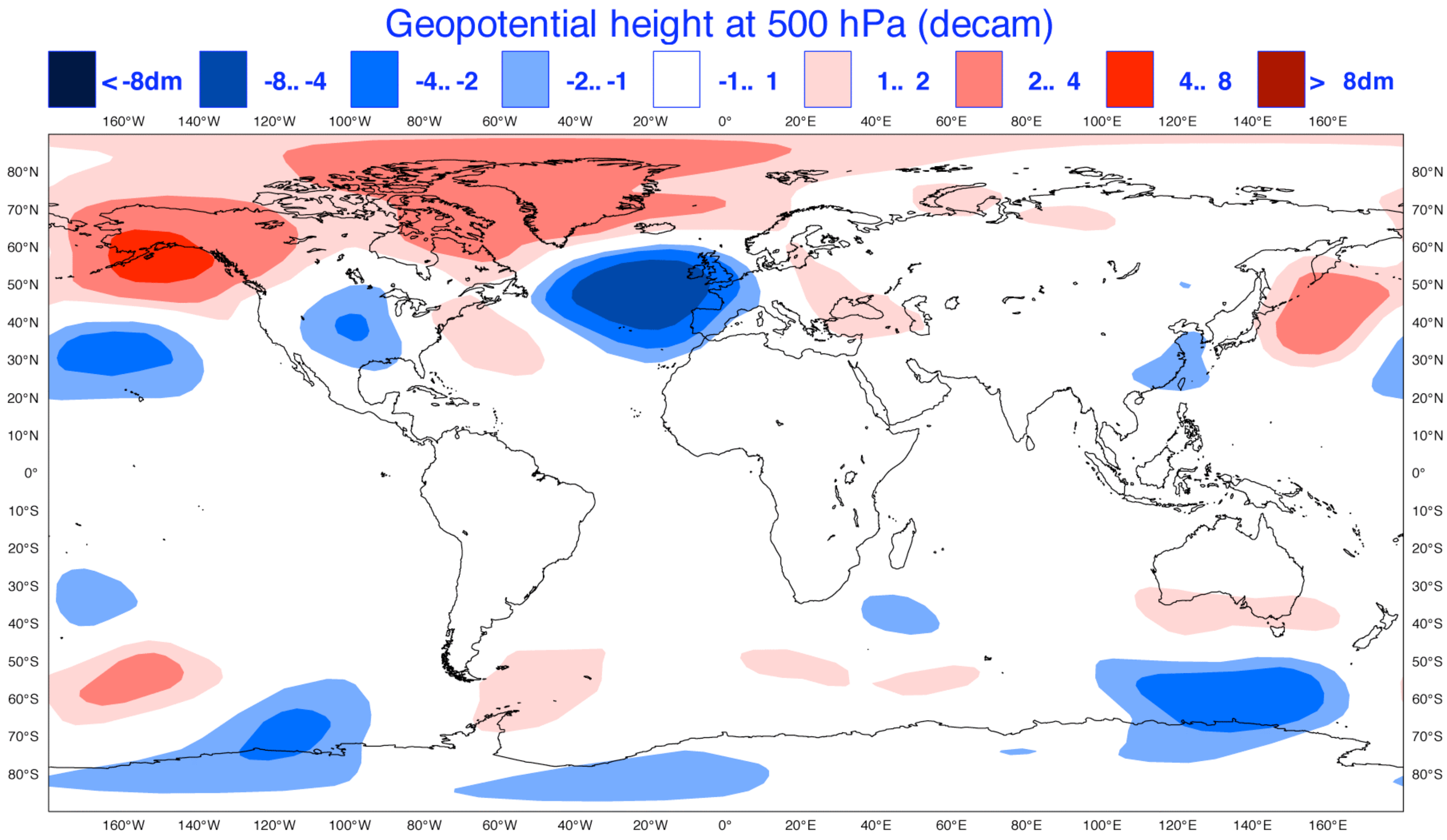
An inadvertent sea-ice experiment

- 1) With the ice problem in the Hudson Bay and Sea of Okotsk
- 2) With it fixed
- Two sets of experiments have been run over a 13 year period from 1 January.
- Difference plots of the two 65 member ensemble means are plotted for Z500.



Surface T after 1 (upper) and 4 (lower) weeks.




Geopotential height at 500 hPa (decam)
< -8dm
-8.. -4
-4.. -2
-2.. -1
-1.. 1
1.. 2
2.. 4
4.. 8
> 8dm

Week 4

Snow cover

- Cohen J. and D Entekhabi 1999: Eurasian snow cover variability and NH climate predictability. GRL, 26,345-8.
- Cohen J. and D Entekhabi 2001:The influence of snow cover on northern hemisphere climate variability. Atmosphere-ocean 39, 35-53
- Gong G., D Entekhabi and J Cohen 2002: A large ensemble model study of the wintertime AO-NAO and the role of interannual snow perturbations, J Clim, 15, 3488-99.
- Kumar A and F Yang 2003: Comparative influence of snow and SST variability on extratropical climate in northern winter. J Clim, 16, 2248-2261.

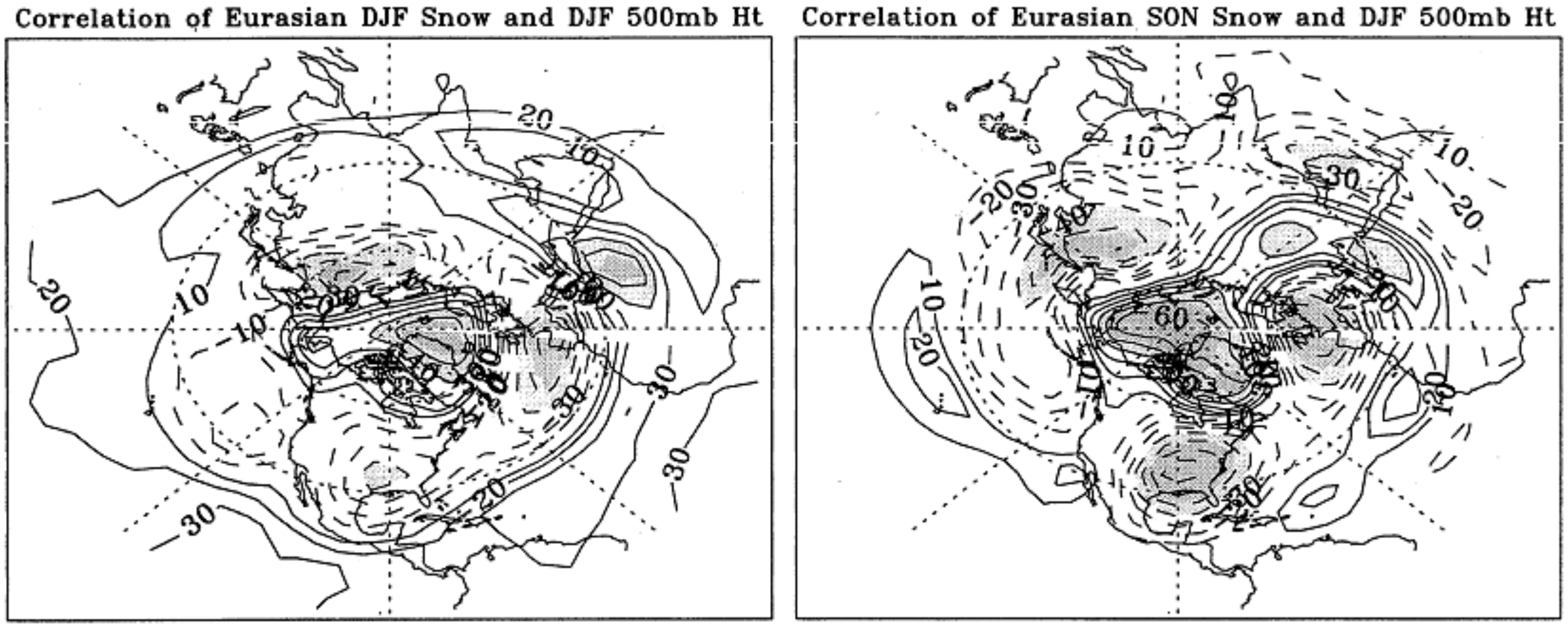


Figure 2. a) Percent correlation between observed Eurasian DJF snow cover and observed NH DJF 500 mb heights. b) Percent correlation between observed Eurasian SON snow cover and observed NH DJF 500 mb heights. Light shading indicates correlation values with 95% statistical significance and dark shading indicates correlation values with 99% statistical significance.

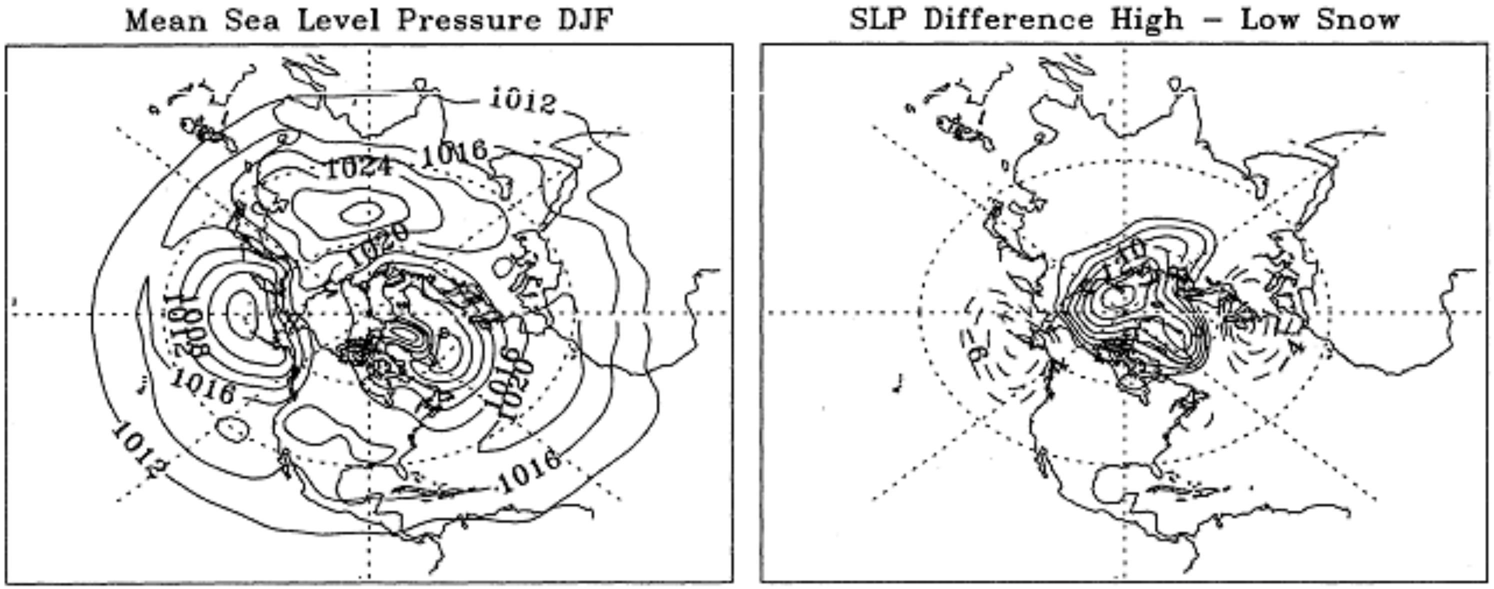


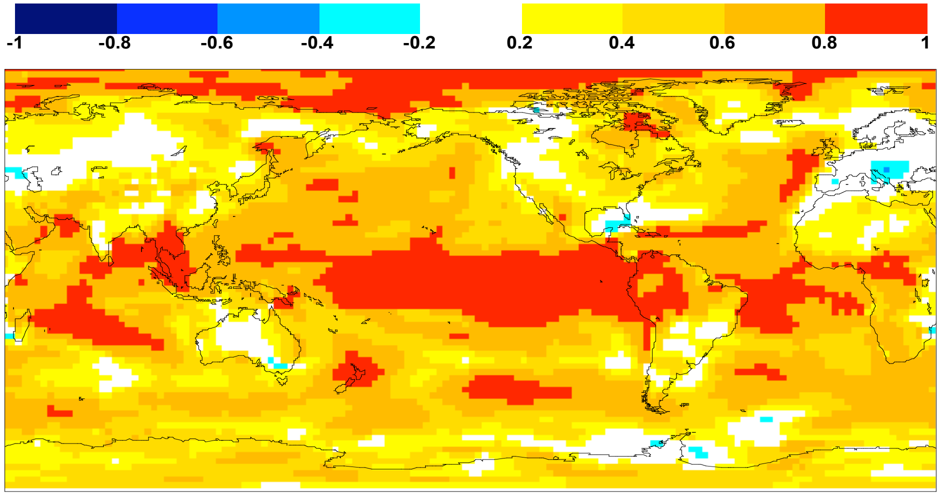
Figure 3. a) Mean sea level pressure for DJF. b) Sea level pressure difference between winters where preceding mean SON Eurasian snow cover were in highest 10% and winters preceding mean SON Eurasian snow cover were in lowest 10%. Figure closely resembles first EOF of DJF SLP (please refer to Fig. 3 in *Hurell* [1995] and Fig. 1 in *Thompson and Wallace* [1998]). Clearly evident is the expansion of the Siberian high north and west.

- Gong et al use ECHAM3 with climatological SST and ice. In 1 expt snow cover is prescribed, in another it can evolve. 20 ensemble members run for 6 months.
- Results suggest that anomalous values of winter NAO may be preceded by anomalous autumn snow conditions in Siberia, but

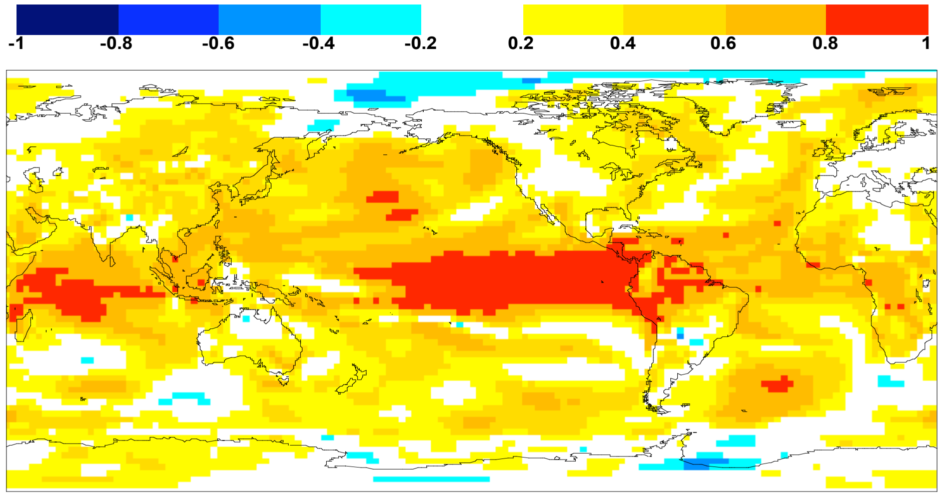
- Do not find NAO to be directly correlated with Autumn snow cover, contradicting Cohen et al 1999. i.e. snow is not the main contributor to NAO variability, but model snow variability is only 1/3 that observed.

What predictability do we have in the multi-model system for winter? We will look at forecasts initiated 1 Nov, for 20 years, 9-member ensembles, with 3 models, at higher resolution than used in previous studies.

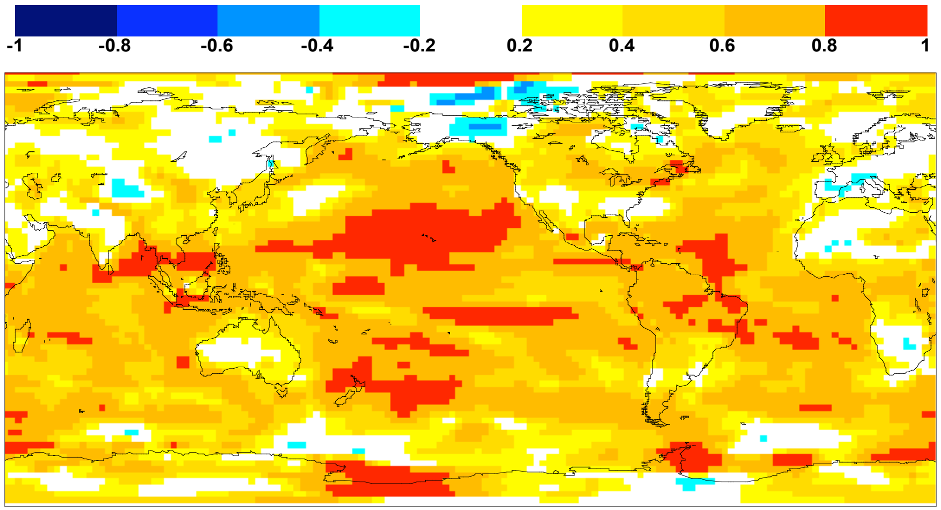
Near-surface temperature
Perfect-model Anomaly Correlation Coefficient for Emm02 with 27 ensemble members
Forecast period 1980-2001 with start in November and averaging period 2 to 4



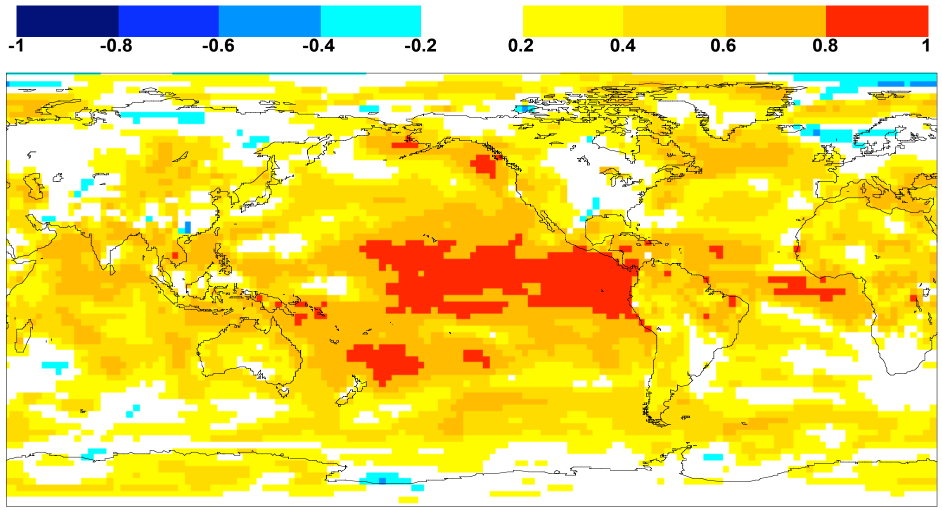
Near-surface temperature
Anomaly Correlation Coefficient for Emm02 with 27 ensemble members
Forecast period 1980-2001 with start in November and averaging period 2 to 4



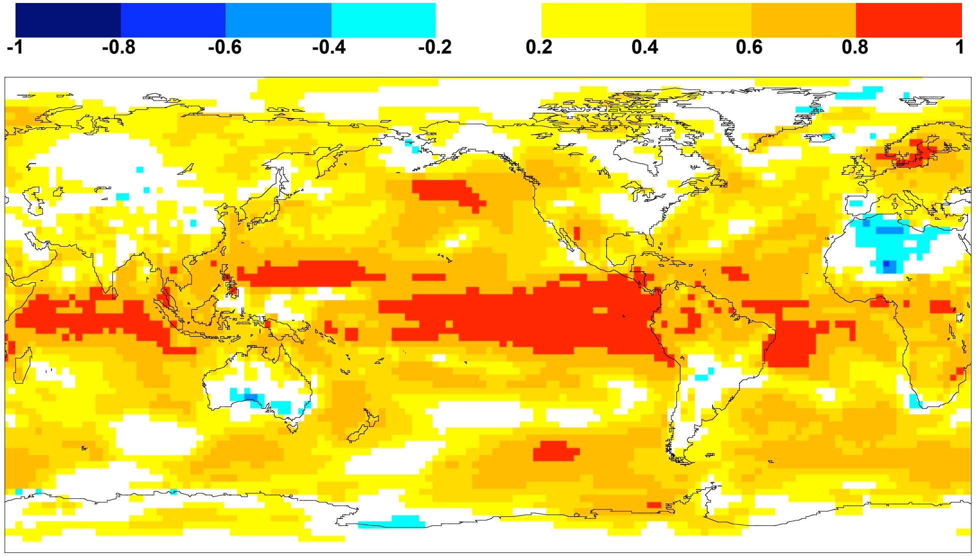
Near-surface temperature
Perfect-model Anomaly Correlation Coefficient for Emm02 with 27 ensemble members
Forecast period 1980-2001 with start in May and averaging period 2 to 4



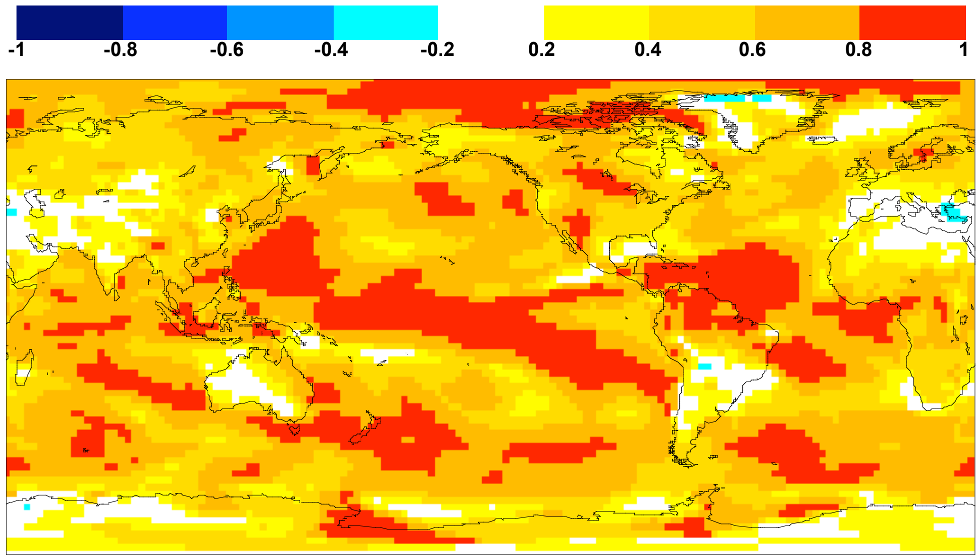
Near-surface temperature
Anomaly Correlation Coefficient for Emm02 with 27 ensemble members
Forecast period 1980-2001 with start in May and averaging period 2 to 4



Near-surface temperature
Anomaly Correlation Coefficient for Emm02 with 27 ensemble members
Forecast period 1980-2001 with start in February and averaging period 2 to 4

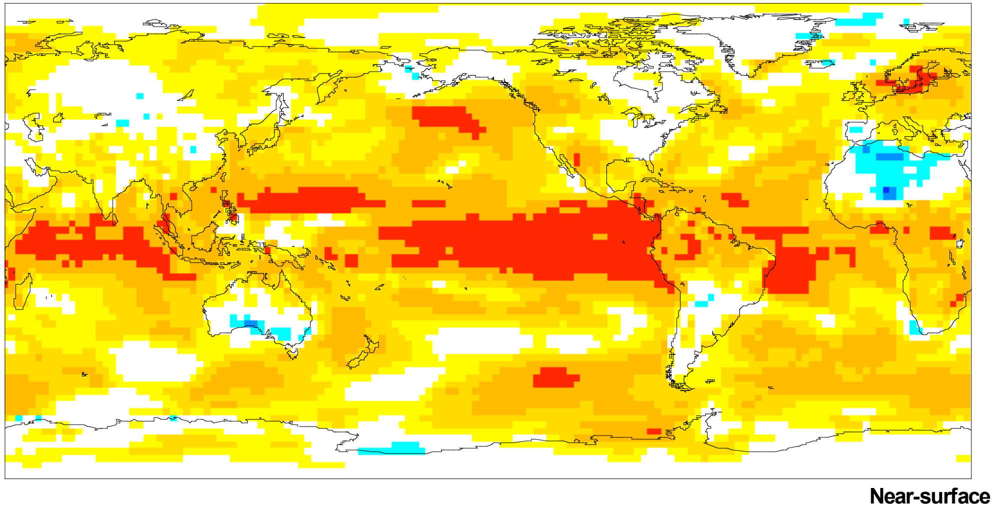


Near-surface temperature
Perfect-model Anomaly Correlation Coefficient for Emm02 with 27 ensemble members
Forecast period 1980-2001 with start in February and averaging period 2 to 4



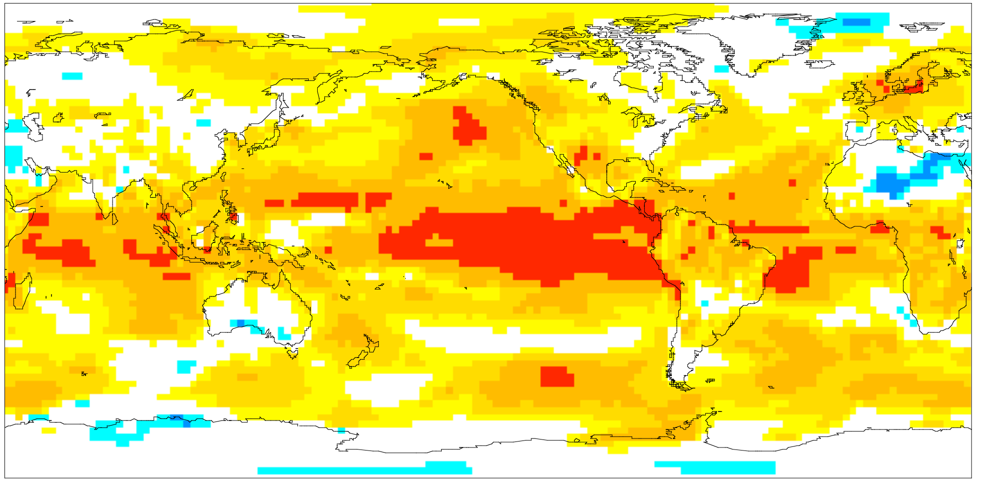
Near-surface temperature
Anomaly Correlation Coefficient for Emm02 with 27 ensemble members
Forecast period 1980-2001 with start in February and averaging period 2 to 4

-1 -0.8 -0.6 -0.4 -0.2 0.2 0.4 0.6 0.8 1

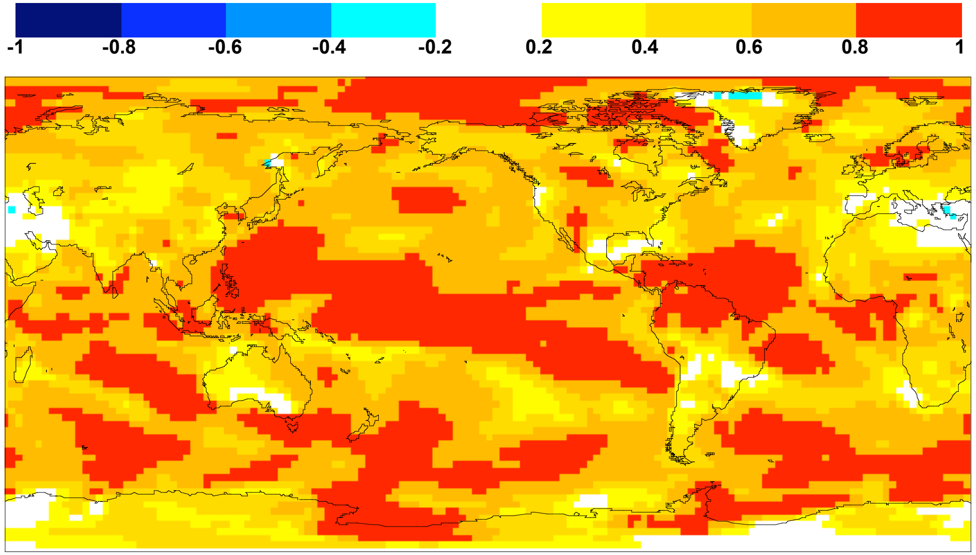


Near-surface temperature
Anomaly Correlation Coefficient for CdmOecmfEscwfS000M001 with 9 ensemble members
Forecast period 1980-2001 with start in February and averaging period 2 to 4

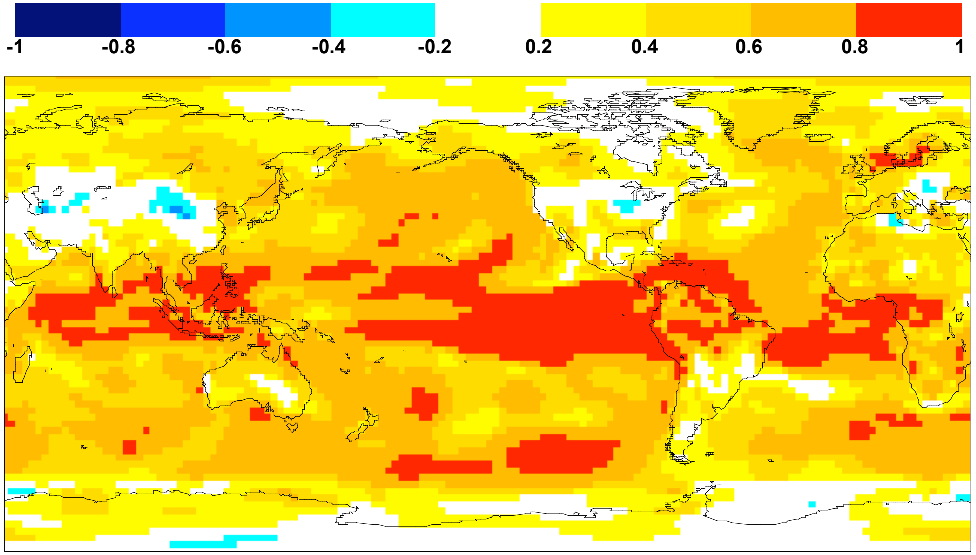
-1 -0.8 -0.6 -0.4 -0.2 0.2 0.4 0.6 0.8 1



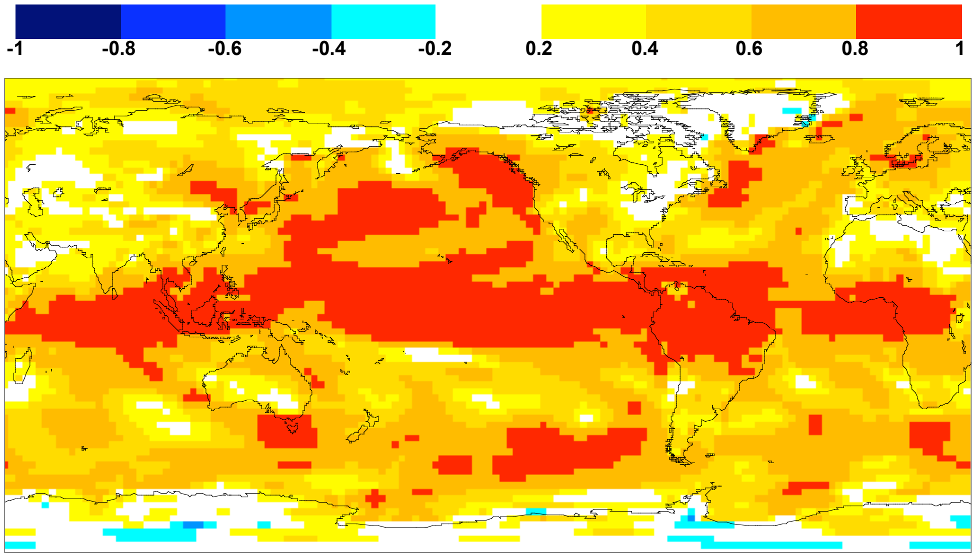
Near-surface temperature
Perfect-model Anomaly Correlation Coefficient for CdmOlfpwEcnrmS000M001 with 9 ensemble members
Forecast period 1980-2001 with start in February and averaging period 2 to 4



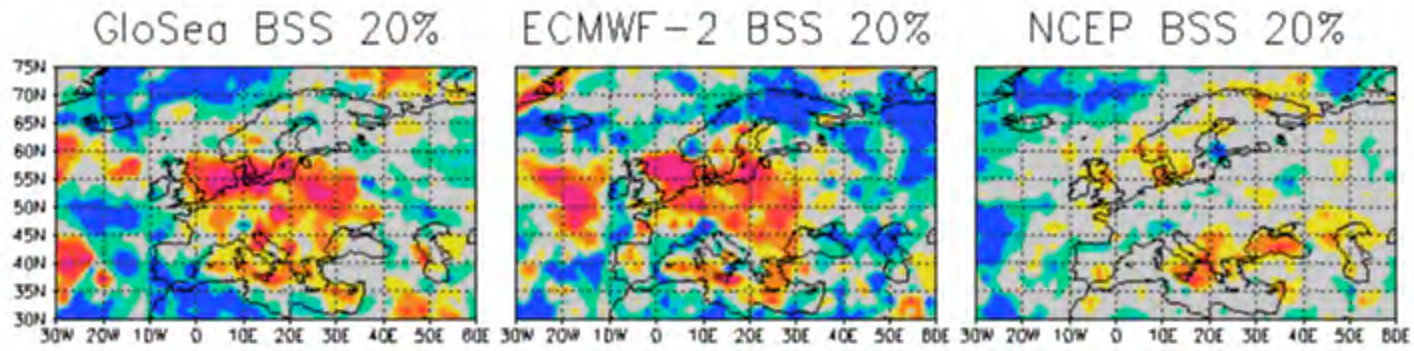
Near-surface temperature
Perfect-model Anomaly Correlation Coefficient for CdmOecmfEscwfS000M001 with 9 ensemble members
Forecast period 1980-2001 with start in February and averaging period 2 to 4



Near-surface temperature
Perfect-model Anomaly Correlation Coefficient for CdmOegrrEukmoS000M001 with 9 ensemble members
Forecast period 1980-2001 with start in February and averaging period 2 to 4



- Mxolisis Shongwe, C Ferro, A Coelho and Geert Jan van Oldenburgh: Predictability of cold springs in Europe.
- They have compared ECMWF (S2), UKMO and NCEP forecasts of T2m in lowest quintile. They find considerable skill using ROC and Briar skill scores for UKMO, ECMWF but less for NCEP. They link this to snow cover during melt season. NCEP predicts too short a snow season, probably because the snow depth in the initial conditions is too thin.
- Very cold temperatures in spring follow high SWE at the beginning of February. SWE=surface water equivalent

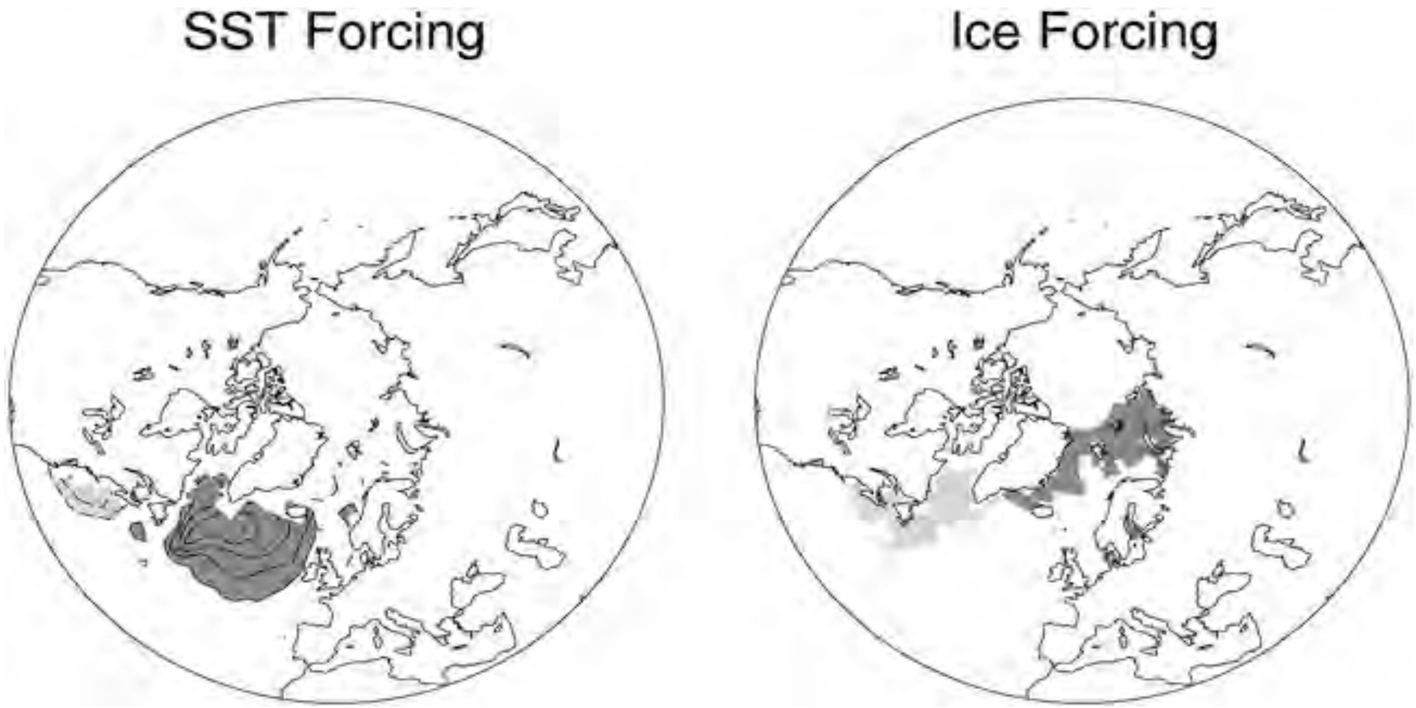

GloSea BSS 20%
ECMWF-2 BSS 20%
NCEP BSS 20%
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
30W 20W 10W 0 10E 20E 30E 40E 50E 60E

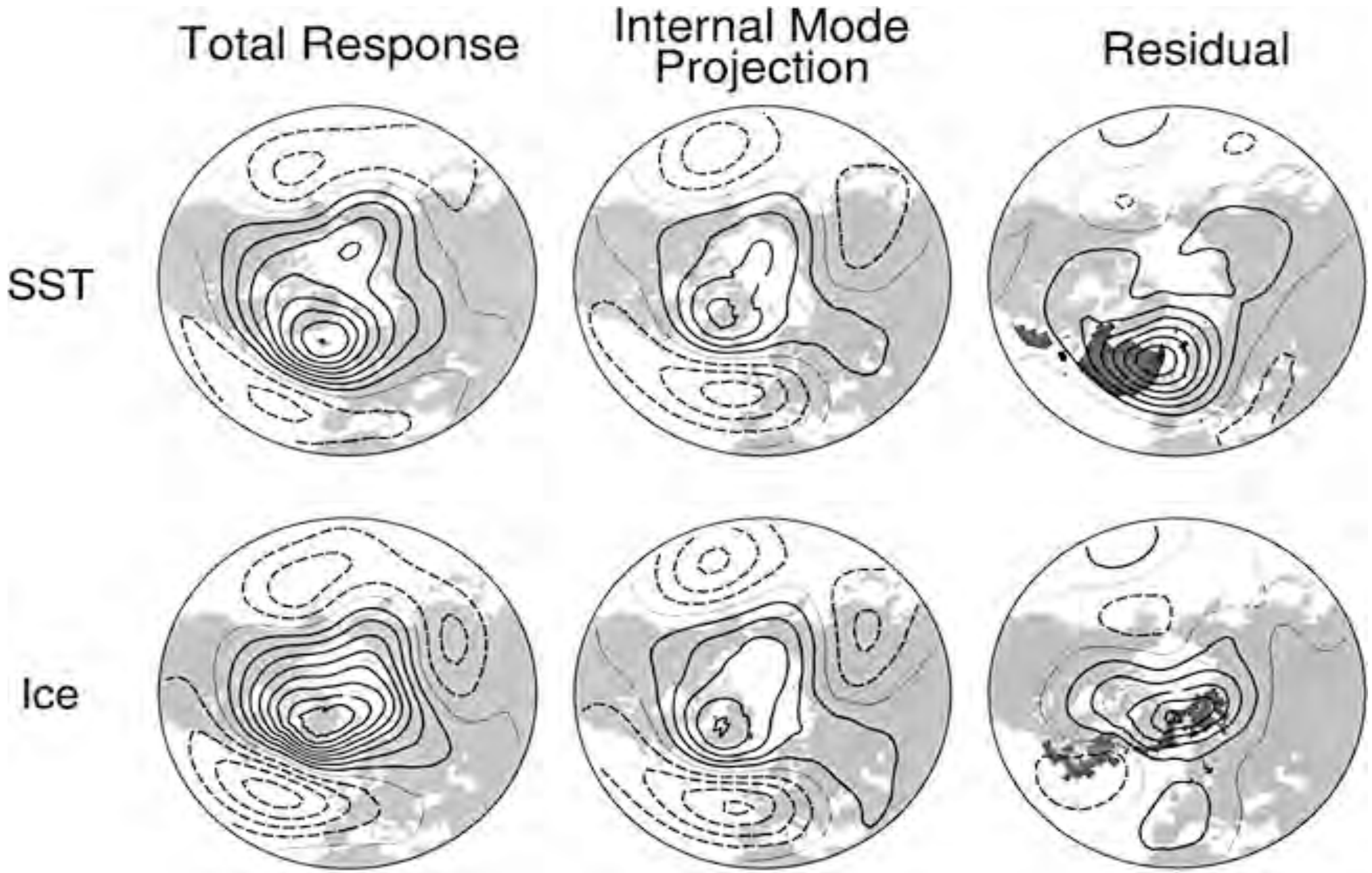
The influence of sea ice

- The effects of North Atlantic SST and sea-ice on the winter circulation Deser et al 2004, J Clim.

- CCM3
- 9 experiments:
- SST-5
- SST-2.5
- SST+2.5
- SST+5
- ICE2
- ICE1
- ICELAB (as ICE2 but only Labrador sea altered)
- ICEGRN (as ICE2 but only Greenland sea altered)
- Control
- All experiments are for 60 years

The relative importance of Sea ice and SST on winter circulation. Deser et al. J Clim 2004.





Contour interval 10m, Z500

- Response is shown in previous slide for SST-5 and ICE2:
- Mostly AO, some local response.
- The response is very similar between these two experiments in pattern and amplitude
- Response to the SST+5 is much weaker than SST-5
- SST-2.5 is half that of SST-5 (i.e. linear)
- Internal mode response is equivalent barotropic increasing with height.
- Removal of ice in Greenland sea is more important than increase in ice in Labrador sea

- Peak changes in heat flux are ~-300 W/m^2 over the Labrador sea and +150 W/m^2 over Greenland sea in ICE2. (These are considerably larger than in SST-5 but over smaller area.)
- Heating in confined to lower troposphere. Why does it not penetrate as high as that associated with the warm SST anomaly in SST-5?
- A large SST difference (17 K) between ice and ocean can only penetrate to ~700 mb, but an SST of 4 K in Atlantic can penetrate to ~350 mb, because the stratification is different.

- ?? Given that the anomalous heating in the Greenland sea does not penetrate as deeply as SST anomaly over NA, why is the AO response so similar? Sensitive area?

- The previous slide used rather large sea-ice coverage changes and SST anomalies. More realistic changes were tested by **Alexander et al. 2004: The atmospheric response to realistic Arctic sea ice anomalies in an AGCM during winter. J Clim, 17, 890–905.**
- Changes in sea-ice largely RESULT from changes in atmospheric circulation. Strengthening of the NAO linked to increased ice in Labrador sea and decreased ice in Greenland Iceland Norwegian (GIN) sea. Deser et al. 2000 suggest ice forces atmosphere.
- Honda et al 1999 found a large response to changing ice cover in sea of Okhotsk (locally and downstream over Alaska and N America). Differences looked like observed composite based on ice differences in Sea of Okhotsk.

- Looked at winters of 82/3 – extensive ice cover and 95/6 – reduced ice cover.
- Integrations start 1 Oct and run to April. 50 ensemble members.
- Response has local and large-scale features. The latter is larger at upper levels and resembles NAO. Anomalies are ~15 m at 500 mb, but little is significant at 95%. Changes at surface are ~2 mb.
- Based on 95/6 case, changing concentration had a bigger effect than changing extent.

- Rinke et al. 2006 JGR, 111, D 16103. Influence of sea ice on the atmosphere: a study with an Arctic atmospheric regional climate model.
- 15 year integrations 79–93. Sea ice cover :
- 0 if SST>-1, 1 if SST<-1.8. For intermediary SSTs , fractional ice cover.
- Domain is poleward of 65 N, resolution 0.5 deg.
- Two different specifications of ice cover – one based on ERA15 and the other based on a coupled ice-ocean model forced with ERA15/OPS (25 years, but covering ERA15 period).

Figure 8 from Rinke et al. JGR 2006

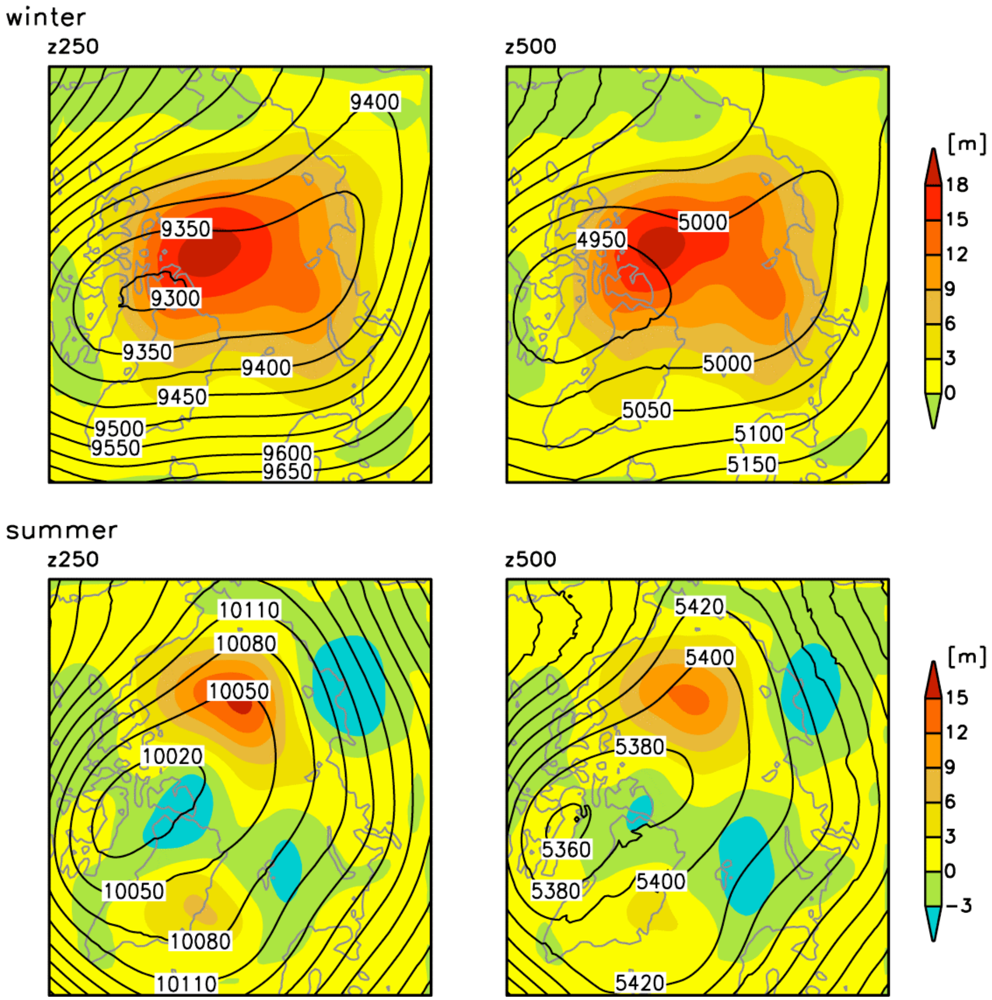
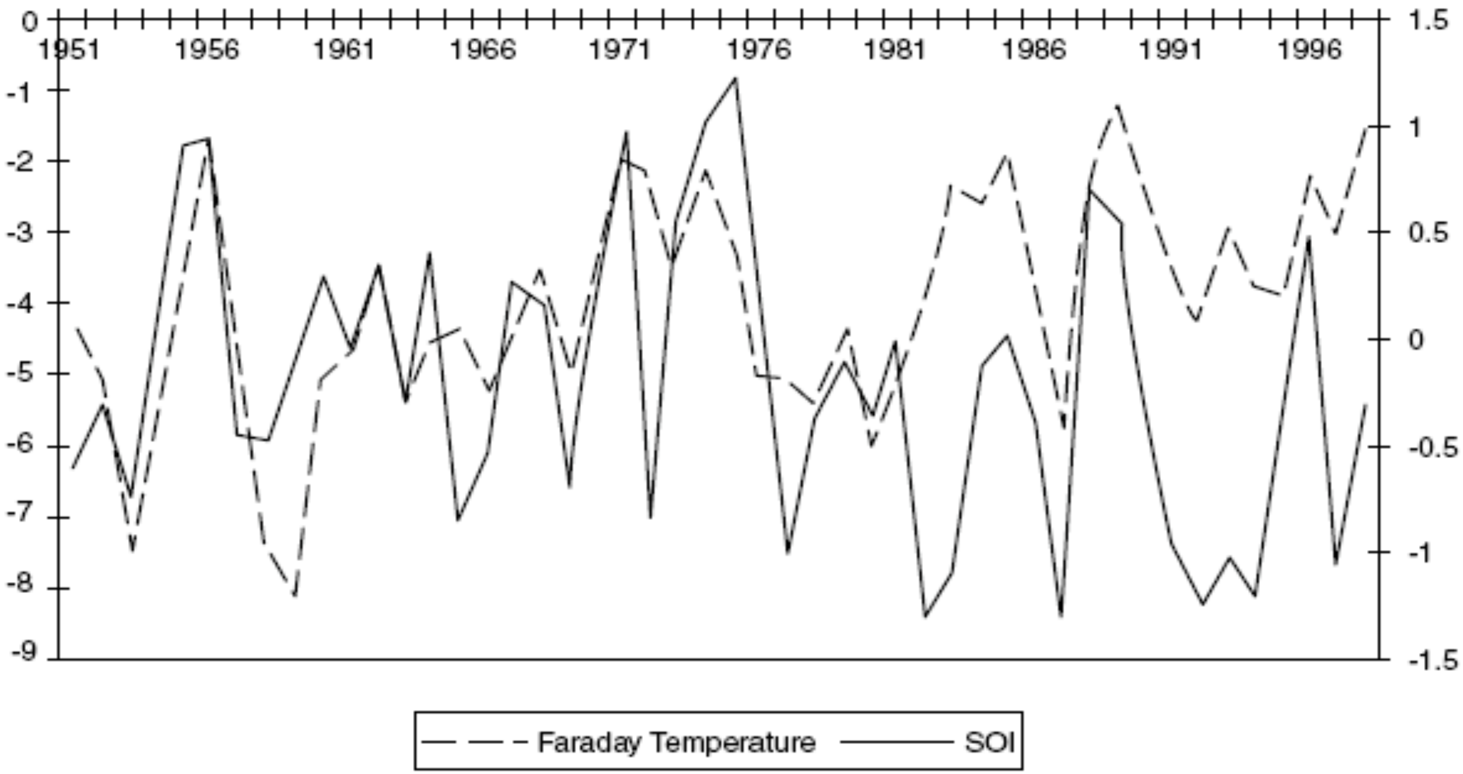


Figure 8. Differences “HIRHA M.nps minus HIRHAM.era” (color shading) and HIRHAM.era (isolines) of geopotential heights at 250 hPa and 500 hPa for DJF and JJA 1979–1993.

- Sea ice variability largest in winter in Atlantic, a see-saw pattern with centres of action in the Labrador and GIN seas.
- Linked to NAO (+ve NAO goes with more ice in Labrador sea and less in GIN sea)
- Kvamsto, Skeie, Stephenson 2004: Impact of Labrador sea-ice extent on NAO. I J Clim.
- They used ARPEGE with ice determined by -1.9 C. Considered winter cases, differing between max and min sea ice. Differences look like NAO-AO ~10 m at Z500.

Antarctic Variability

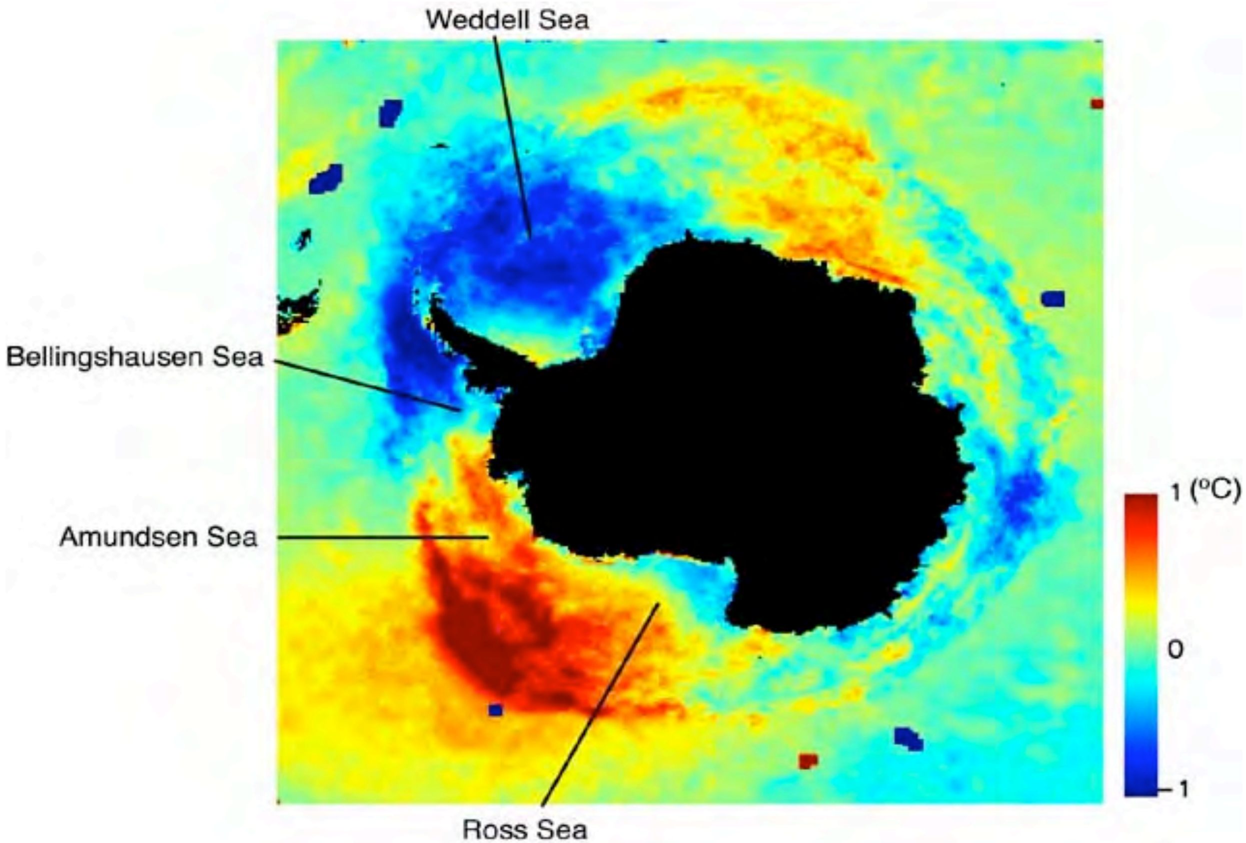
Turner 2004


0
-1
-2
-3
-4
-5
-6
-7
-8
-9
1951
1956
1961
1966
1971
1976
1981
1986
1991
1996
1.5
1
0.5
0
-0.5
-1
-1.5
Faraday Temperature
SOI

This surface temperature map shows the average pattern of warming and cooling of the southern ocean around Antarctica associated with El Niño episodes. Warming is represented by red and cooling by blue. The intensity of the warming is strongest in the Amundsen and Ross Seas, located in the pacific sector of the southern ocean. In contrast, the cooling is strongest in the Bellingshausen and Weddell Seas in the Atlantic Sector. Record decreases in the ice coverage between 1982-1999 in the Amundsen and the Ross Seas are associated with this warming. Similarly, increases in the ice coverage in the Weddell Sea can be seen during the same period.

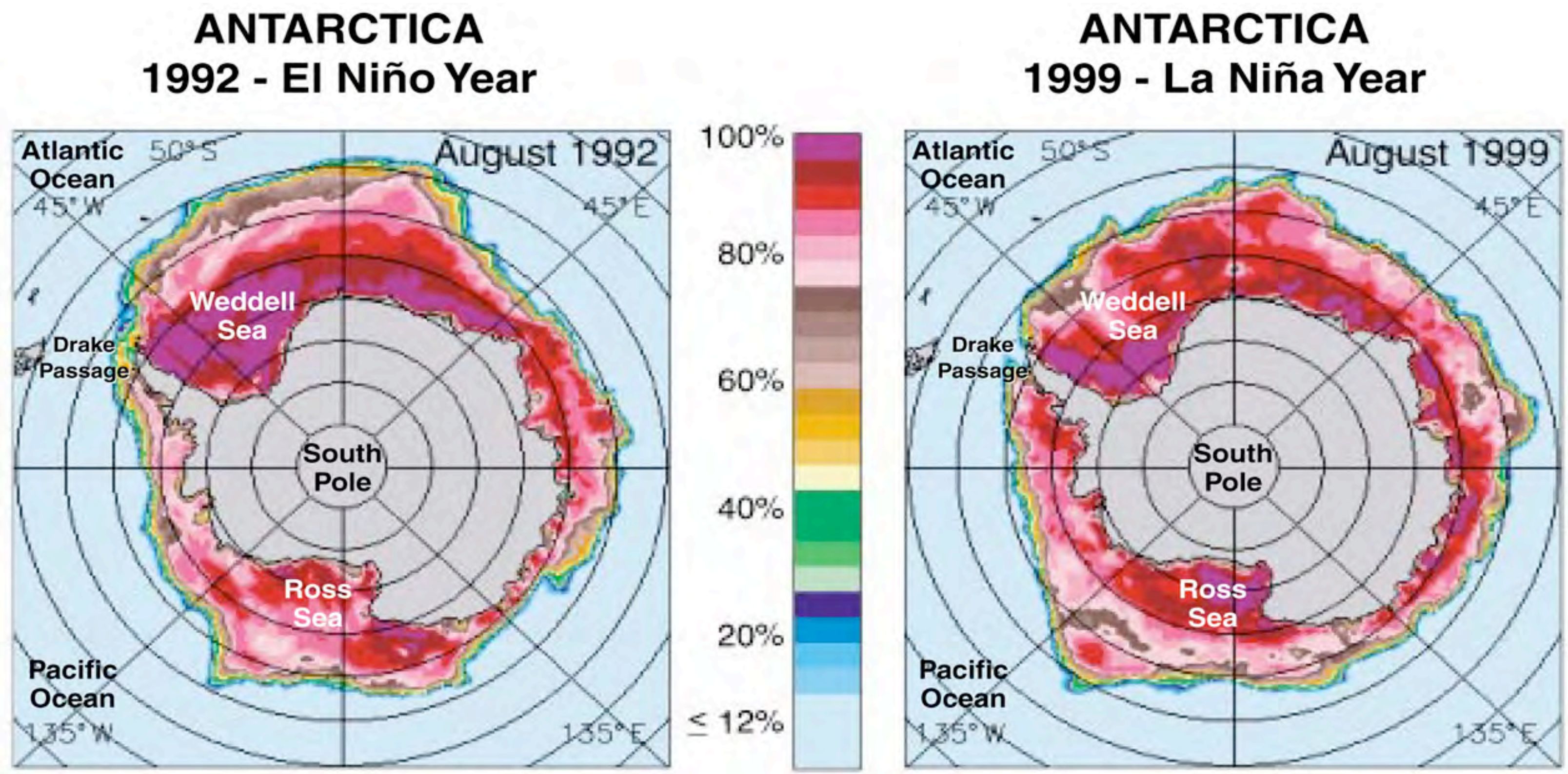
The behaviour of the southern ocean climate and ice cover is strongly linked to the tropical El Niño phenomenon. The far-reaching connections between tropical and polar climate is clearly demonstrated here.

The surface temperature field shown here is derived from infrared data from the AVHRR (A Very High Resolution Radiometer) sensor on a NOAA satellite.



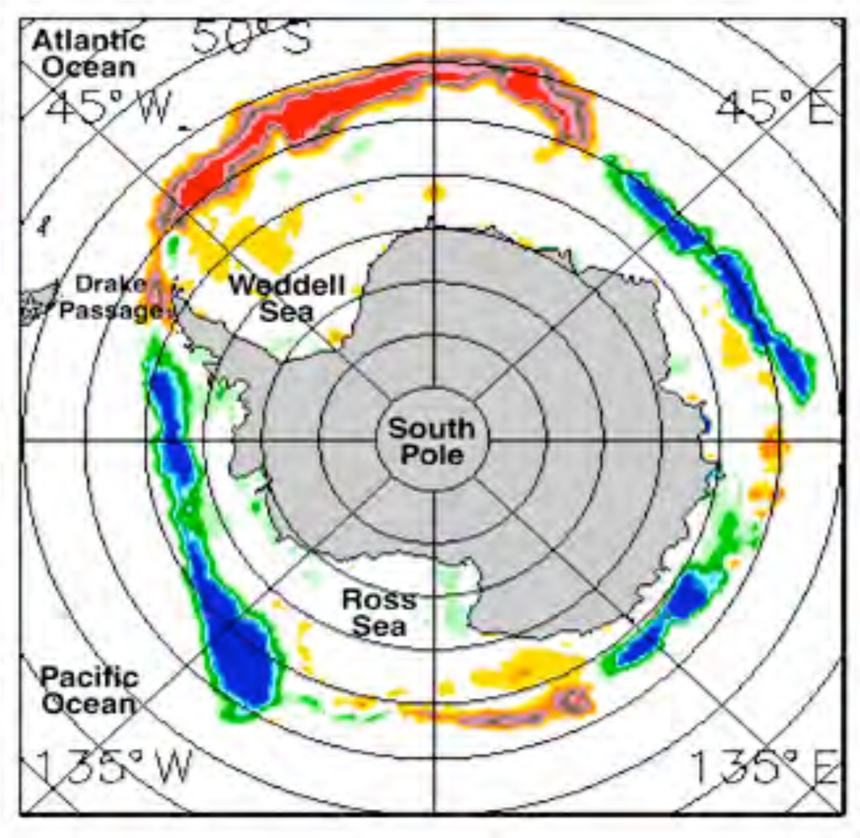
During the El Nino year of 1992, the Pacific Ocean from the Drake Passage to the Ross Sea (about 70 W to 180 W) had less sea ice than in a normal year. Meanwhile, the sea ice in the Weddell Sea (20 E to 60 W) extended further north.
In contrast, sea ice in the Pacific Ocean had a larger northward extension in 1999, a La Nina year, particularly east of the Ross Sea. Meanwhile, sea ice in the Weddell Sea had a less than normal northern extent. Credit: Claire Parkinson and Nick DiGirolamo, NASA Goddard Space Flight Center.

COLOR KEY: The light blue areas indicate open ocean water. All other areas show the presence of sea ice.



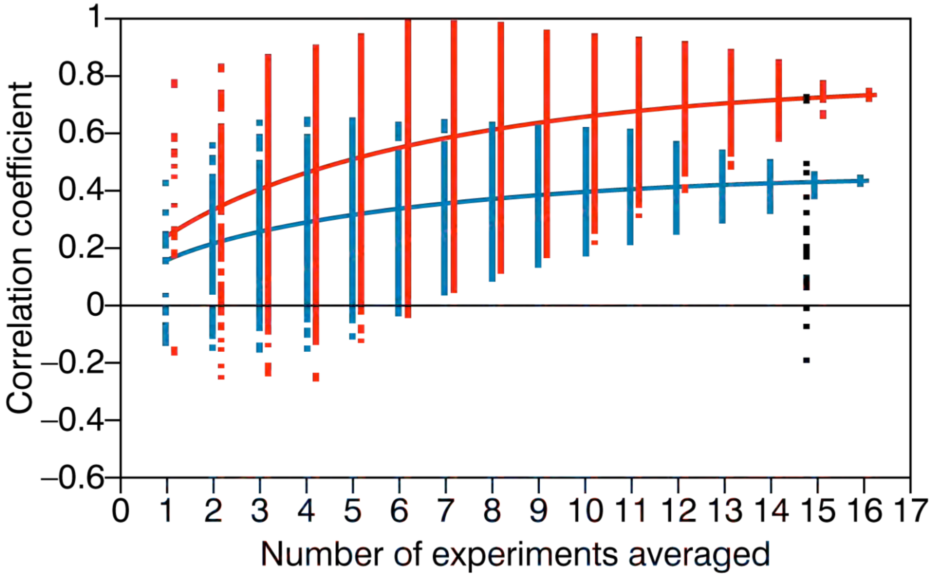
Locations of increased sea ice during El Niño and La Niña years

This map shows the difference in sea ice cover between 1992 and 1999 around Antarctica. The red color indicates areas where there was a higher concentration of sea ice in 1992 than in 1999, as a result of a 1992 El Niño event. The blue colour indicates places where ice concentrations were higher in 1999 than 1992, as a result of a 1999 La Niña event. Credit: Claire Parkinson and Nick DiGirolamo, NASA Goddard Space Flight Center.



Mehta et al. GRL 2000, 121-124.
Oceanic influence on NAO and associated NH climate variations.
See also Rodwell et al. Nature 1999.

- Mehta et al. GRL 2000, 121-124. Oceanic influence on NAO and associated NH climate variations. See also Rodwell et al. Nature 1999. 16 member ensemble for 45 years using observed SSTs and sea ice. Coarse resolution.
- Ensemble mean NAO correlates quite well with observed NAO. (~0.8), but correlation of observed NAO with individual ensemble NAO ranged from nearly zero to nearly 1. Groups of ensembles were then averaged to reduce the random component and correlated with the observed NAO.
- Correlation increases with ensemble size.
- Perfect model correlations are also shown for the 15 member mean and the 1 perfect realisation.
- The correlation ranges from -0.2 to 0.7, with an average of 0.21 (much smaller than with the observed NAO).



Black dots represent 1 ensemble member v the mean of the others i.e. perfect model.

Mehta et al. GRL 2000, 121-124. Oceanic influence on NAO and associated NH climate variations. See also Rodwell et al. Nature 1999.

- 16 member ensemble for 45 years using observed SSTs and sea ice. Coarse resolution.
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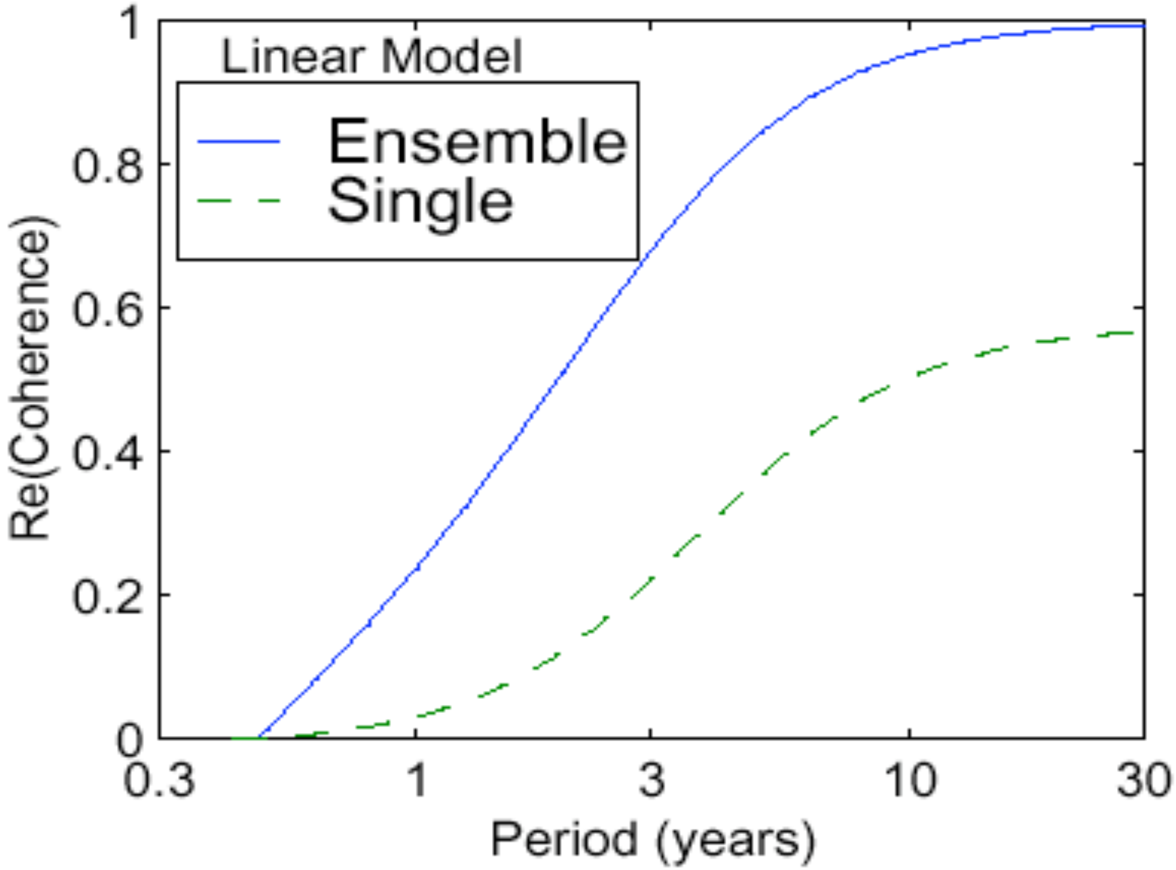
$$\frac{\partial T_a}{\partial t} = \quad aT_a + bT_o + N(t); \tag{1}$$

$$\square \, \frac{\partial T_o}{\partial t} = \quad cT_a \quad dT_o \;: \tag{2}$$

Four nondimensional parameters enter the right hand side;

- N is noise. Run the coupled system with a given noise sequence. Store the ocean response To. Run the atmosphere with the time history of To. Do that many times with different N. Compare Ta from the coupled run with the ensemble mean of forced runs all using the same To but different N.
- You can reproduce the ‘true’ phase of Ta if the ensemble is large enough and the time sequence long enough, but the ensemble mean amplitude is small (~40% of the true signal).

- In the coupled run the flux drives the ocean but in the forced runs the flux seems to act to damp the ocean.
- Even with perfect initial conditions, the predictability horizon is ~6 months, based on an infinite ensemble.

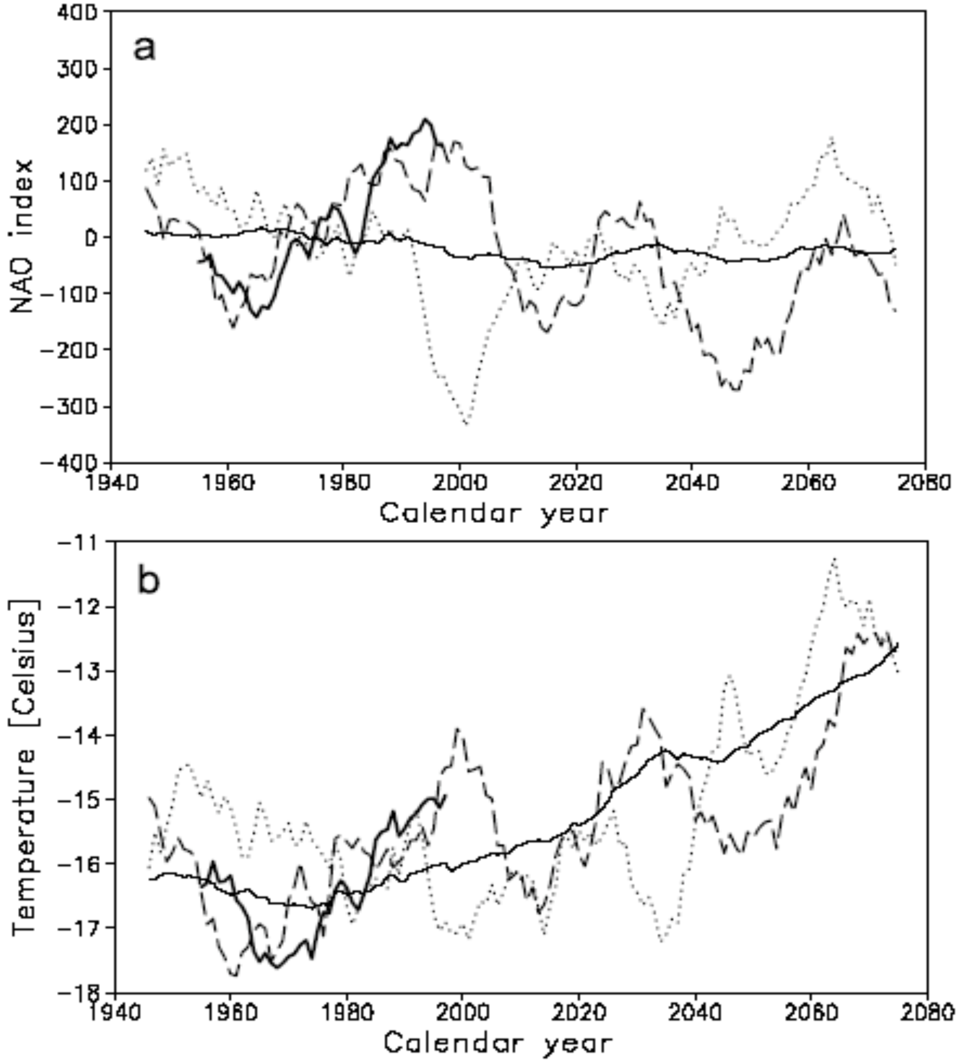

Linear Model
Ensemble
Single
Re(Coherence)
0
0.2
0.4
0.6
0.8
1
0.3
1
3
10
30
Period (years)

NAO (circum global wave pattern?) back to the tropics

- Hoerling et al. Science 2001. AGCM experiments with various prescribed forcings of SST and sea ice, GOGA means Global ocean SSTs used, TOGA means just tropical ocean SSTs used

- NAO trend is linked to warming of tropical oceans.
- GOGA ensemble mean explains the observed NAO signal very well but only ~40% of the amplitude, over last 50 years.
- TOGA does just as well (based on 500hPa).
- Precipitation is increased in western tropical Pacific and Indian ocean.
- Tropical Atlantic SSTs do little
- What causes tropical warming? Could it be GHG?

- Selten et al. GRL 2004.Coupled integrations over 140 years from 1940. Ensemble size 50?.
- Ensemble mean shows no NAO trend. Some ensemble members do. So, observed trend in NAO is not due to GHG or solar. Random climate variations are enough.
- But there is a trend in Eurasian winter temperature, though some members show cooling.
- Long NAO trends of 30 years are quite common, but it is rare for values to be above recent averages. (200)
- They confirm that decade long trends in NAO are linked to precip in Indian ocean.
- Link to CWP. (Circumglobal wave pattern)



Upper: NAO index observed (solid), and 2 ensemble members dotted and dashed. Lower: Eurasian temperatures. From Selten et al GRL 2004.

Ensemble average NAO shows no trend (thin solid), but one ensemble member follows observed trend while the other has opposite trend.

For Eurasian T2m, there is a trend later on but in the early part of the record the trend can be up or down.

SOI	Southern Oscillation Index
EQOI	Equatorial version

Northern Oscillation

NAO	North Atlantic Oscillation
AO	Arctic Oscillation
NPI	North Pacific Index

Antarctic Dipole

Antarctic Circumpolar Wave.

PDO	Pacific Decadal Oscillation.
PNA	Pacific North America pattern
MJO	Intraseasonal Oscillation.

- There seems to be a growth industry in running coupled model with suppressed SSTs somewhere.
- Dong et al. GRL 2006: Modulation of ENSO by Atlantic SSTs.
- Observations suggest a link between high northern latitude warm SST and cold mid latitude southern SSTs (Atlantic Multidecadal Oscillation) and ENSO. AMO leads to a deeper thermocline in the Pacific and reduced ENSO variability.

- Semenov and Latif Impact of`tropical Pacific variability on north Atlantic thermohaline circulation.
- If fix tropical pacific SSTs i.e. suppress ENSO variability, MOC (meridional overturning circulation) in the ocean is reduced by 1 Sverdrup. Precipitation is increased in tropical Atlantic, and salinity reduced which ultimately reduces the MOC.
- Dong and Sutton J. Clim. 2006: Enhancement of El Nino Southern Oscillation variability by a weakened Atlantic thermohaline circulation in a coupled GCM.
- Weaken MOC by adding fresh water at high latitudes. ITCZ shifts south, atmospheric bridge leads to westerly wind anomaly over West Pacific → eastward displacement of warm pool → more precipitation and more ENSO activity.

- Dommenget et al. Impacts of tropical Indian ocean on ENSO.
- Suppress variability in Indian ocean SST (and Atlantic) → increased ENSO period but reduced variance.
- So, you can't do much without the tropics.