Air-Sea Interaction in Seasonal Forecasts:

Some outstanding issues

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ECMWF

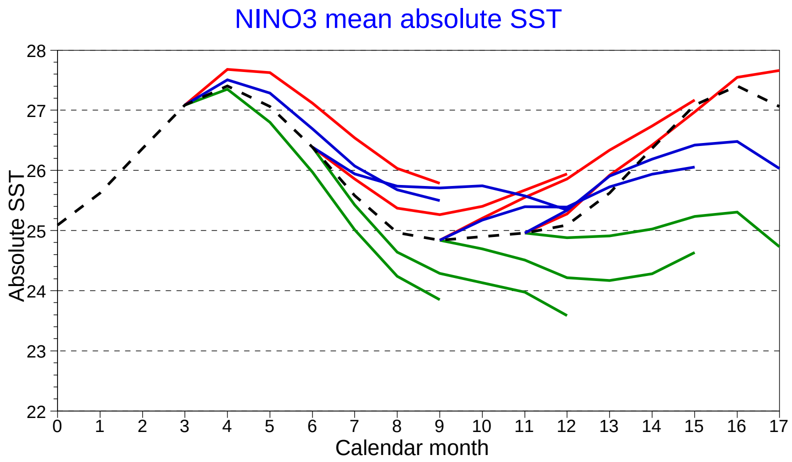
Outline

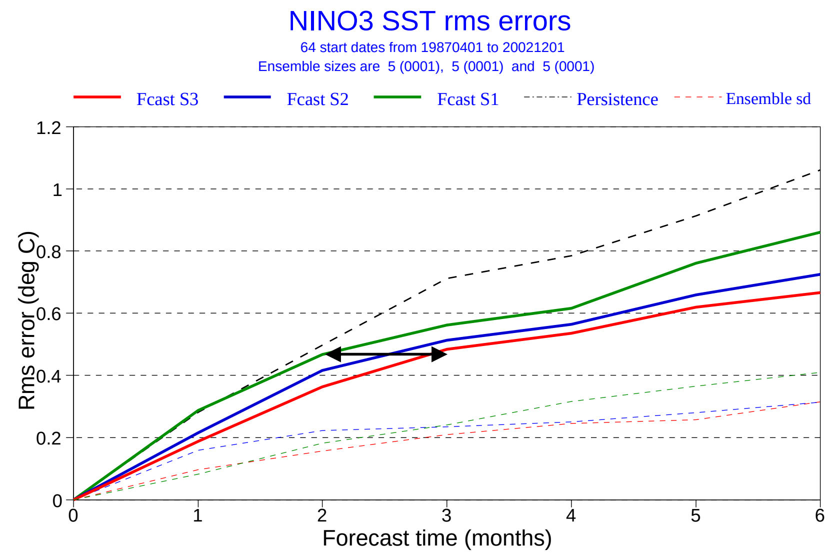
- **ECMWF Seasonal forecasting system**
- **Amplitude of ENSO variability**
  - **Intraseasonal variability**
  - **Heat flux response**
  - **Bias and Initialization**
- **May start forecasts over the North Atlantic Sector**
  - **Ocean Mixed Layer**
  - **Artic Ice**
  - **Gulf Stream**

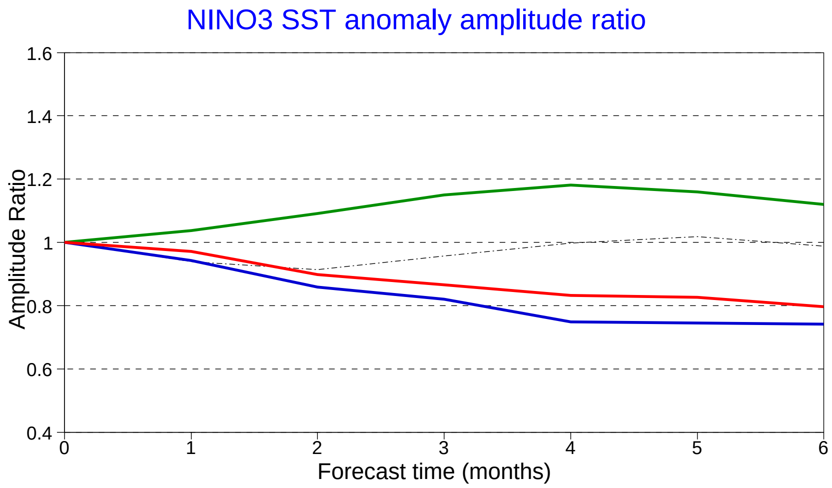
The seasonal forecast System-3 (since March 07)

- COUPLED MODEL (IFS + OASIS2 + HOPE)
  - Cycle of atmospheric model (Cy31R1). Resolution TL159 and 62 levels
  - Ocean: ~1 deg (0.3 at Eq.). 29 levels in the vertical (~10m upper ocean)
  - Time varying greenhouse gasses (but not aerosols)
  - No ice model: relaxation to climatological ice extent.
- SEPARATE INITIALIZATION of OCEAN AND ATMOSPHERE
  - Ocean Initialization:
    - Forcing fluxes from ERA40+operations
    - Assimilation of subsurface T & S, altimeter, SST
    - Bias correction algorithm
  - ERA-40 data used to initialize ocean and atmosphere in hindcasts
- BACK INTEGRATIONS and ENSEMBLE GENERATION
  - Extended range of back integrations: 11 members, 1981-2005.
  - Perturbations to the ocean i.c based on SST and wind perturbations
  - Use EPS Singular Vector perturbations in atmospheric initial conditions.
- Forecasts extended to 7 months (to 13 months 4x per year).

Evolution of the ECMWF SF



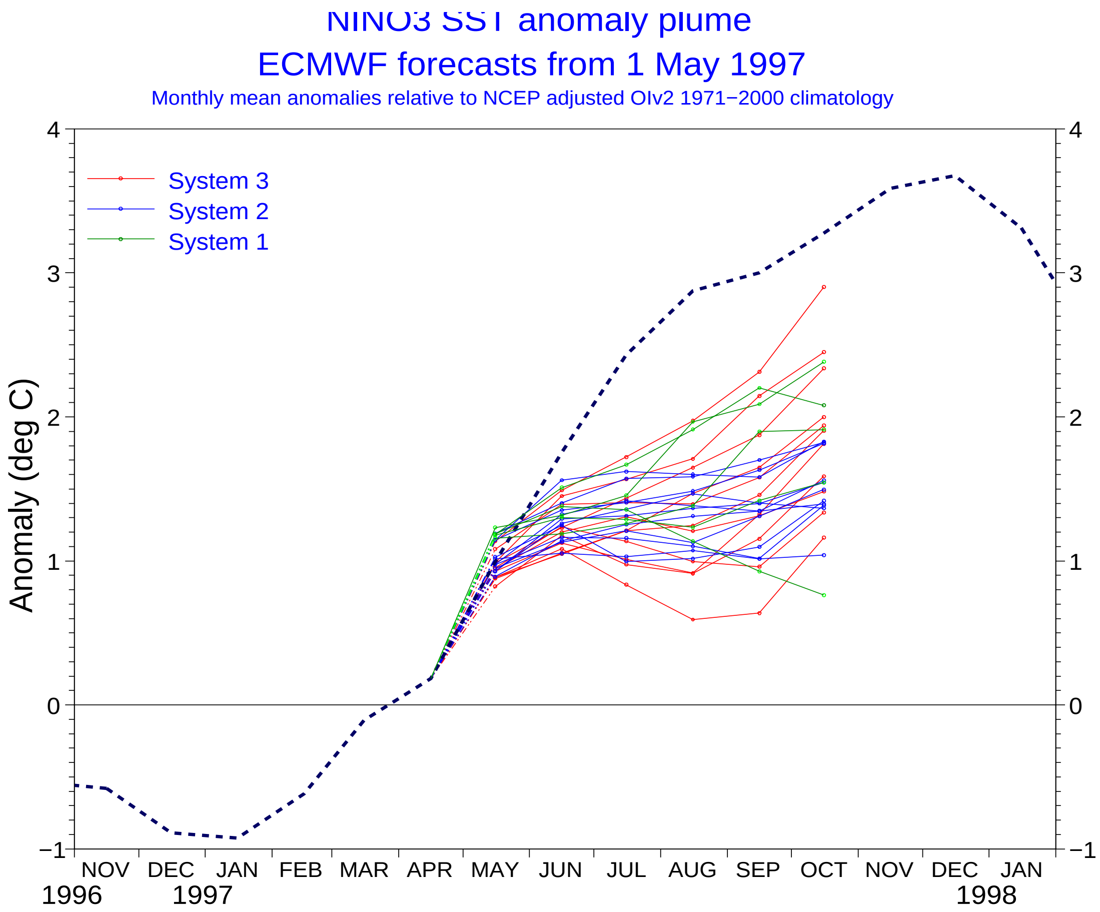




- •Steady progress: ~1 month/decade skill gain
- •Dramatic change in coupled behaviour between S1 & S2: bias and variability
- •Improvement in S3, but still
  - • Warm(est) bias in eastern Pacific
  - •Underestimation of interannual variability

S1 S2 S3

Common Feature:

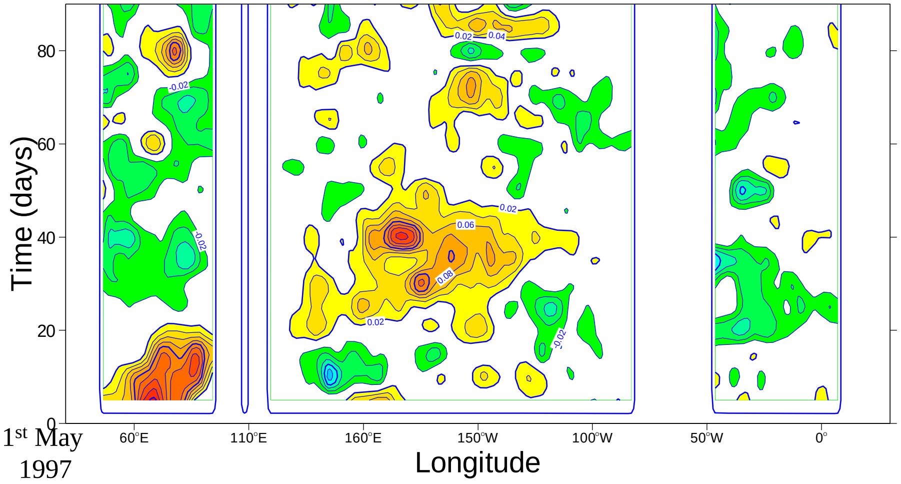


All the SF systems failed to predict the amplification of El Nino 1997 from spring starts (April/May 1997).

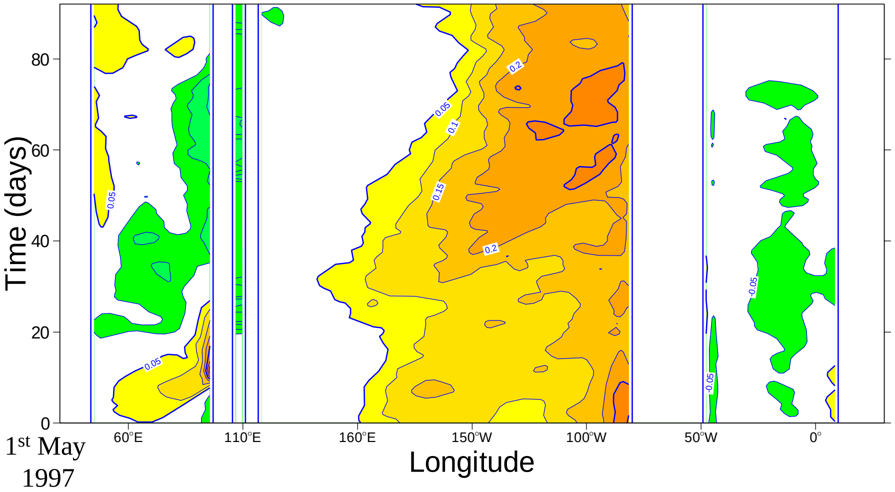
The reason: failure to generate a powerful WWB associated to an MJO event (already present in the initial conditions at the start of the integrations).

Analysis (hovmollers May-July 1997)

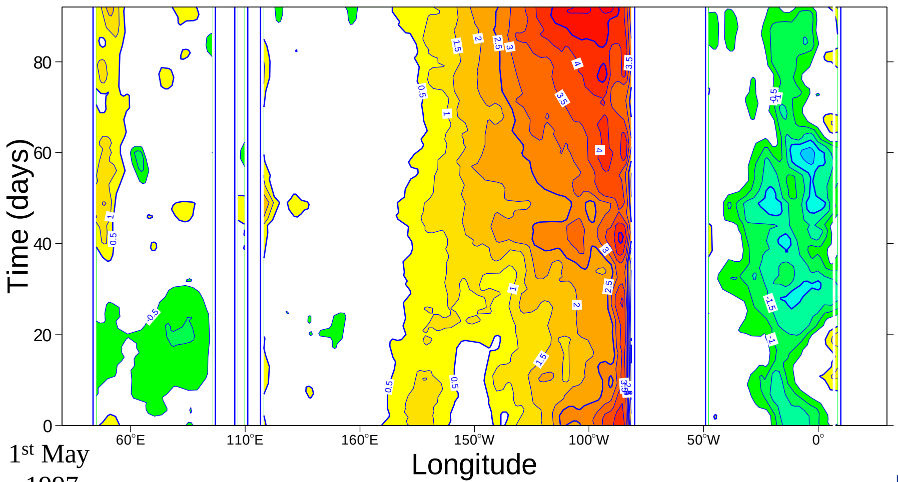
Taux anom (c.i. 0.02 N/m2)



Sea Level anom (c.i. 5cm)



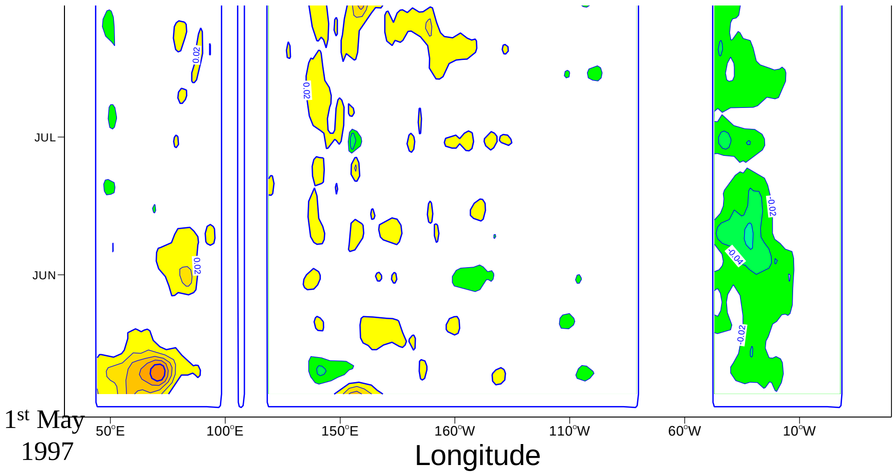
SST anom (c.i. 0.5 deg)



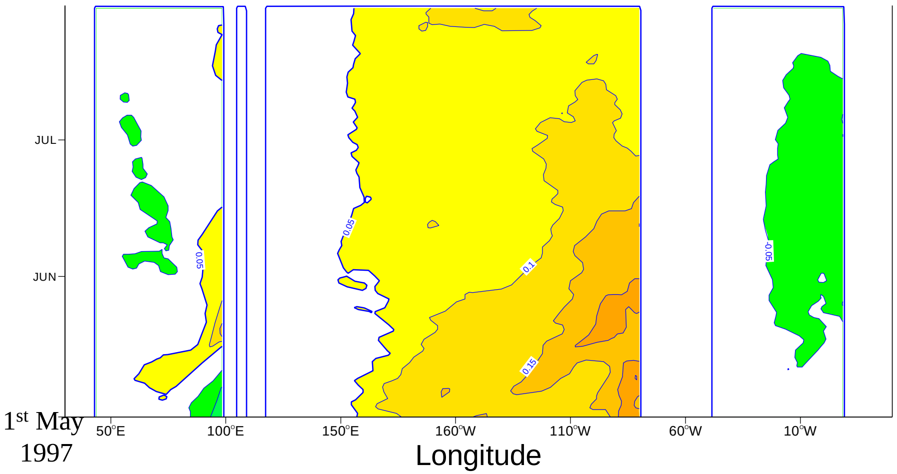
- •WWB in July associated to an MJO event (alrady present at initial time) reach peak values ~0.2N/m2 around dateline.
- •They trigger a downwelling Kelvin wave. Peak values of SL anomalies in the Eastern Pacific reach 25 cm by mid June..
- •SST anomalies reach maximum values of 4 deg in the Eastern Pacific by end of June-beg July

Coupled FC (hovmollers May-July 1997) (S3)

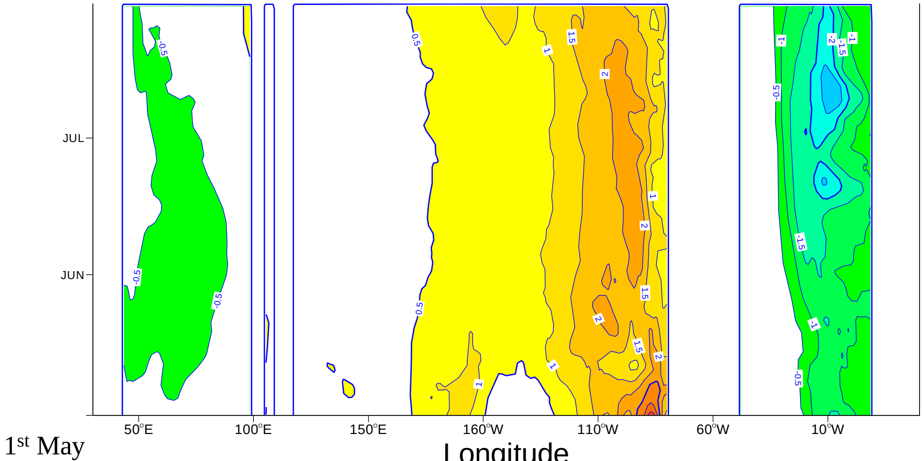
Taux anom (c.i. 0.02 N/m2)



Sea Level anom (c.i. 5cm)



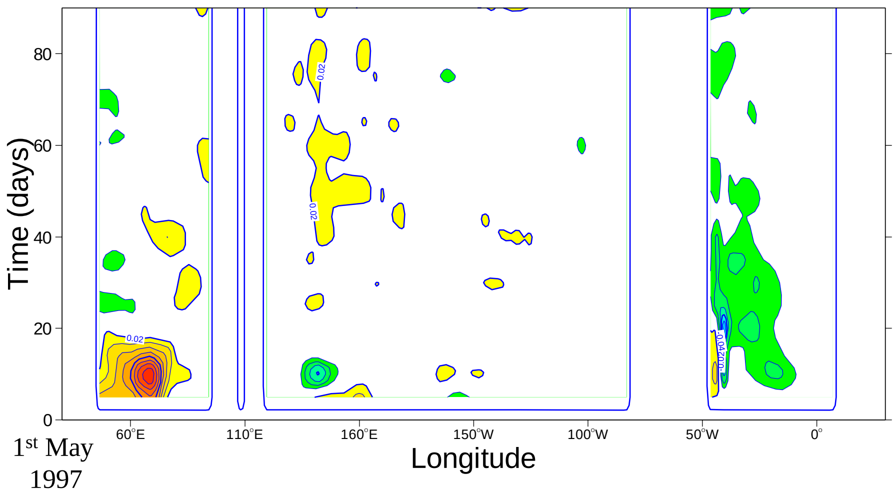
SST anom (c.i. 0.5 deg)



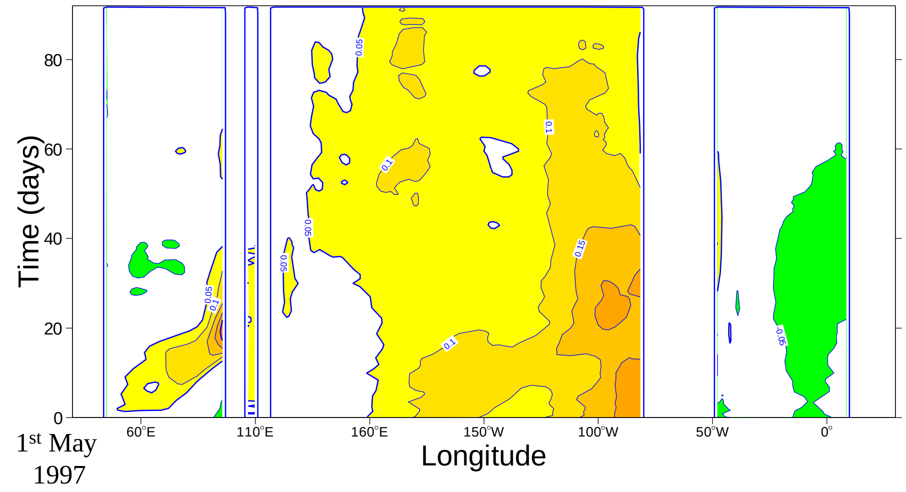
- In the Coupled forecasts the surface signature of the MJO dies after 20 days, there is not any propagation to the Pacific, and there is not any WWB.
- As a consequence, the SL and SST anomalies of the coupled forecasts are those associated with the ocean initial conditions.
- The El Nino fails to amplify. Peak SST values ~2 deg

Coupled FC (hovmollers May-July 1997) (S2)

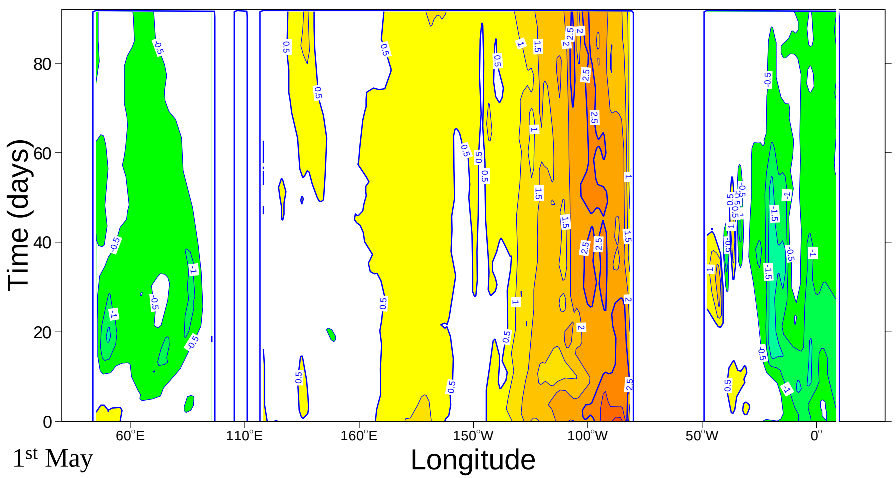
Taux anom (c.i. 0.02 N/m2)



Sea Level anom (c.i. 5cm)



SST anom (c.i. 0.5 deg)

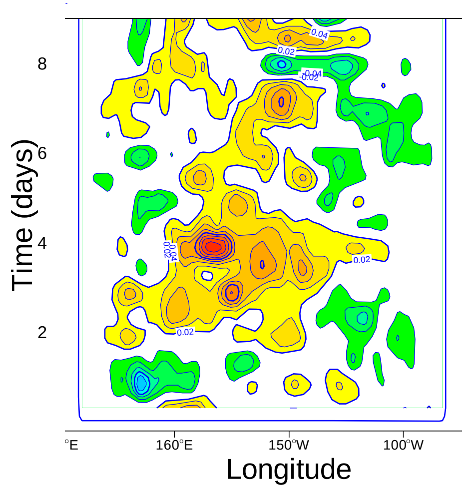


- Similar behaviour in S2.
- Vitart et al 2003 studied this case in detail using S2
  - Response to a prescribed WWB
  - Sensitivity to the parameterization of convection.

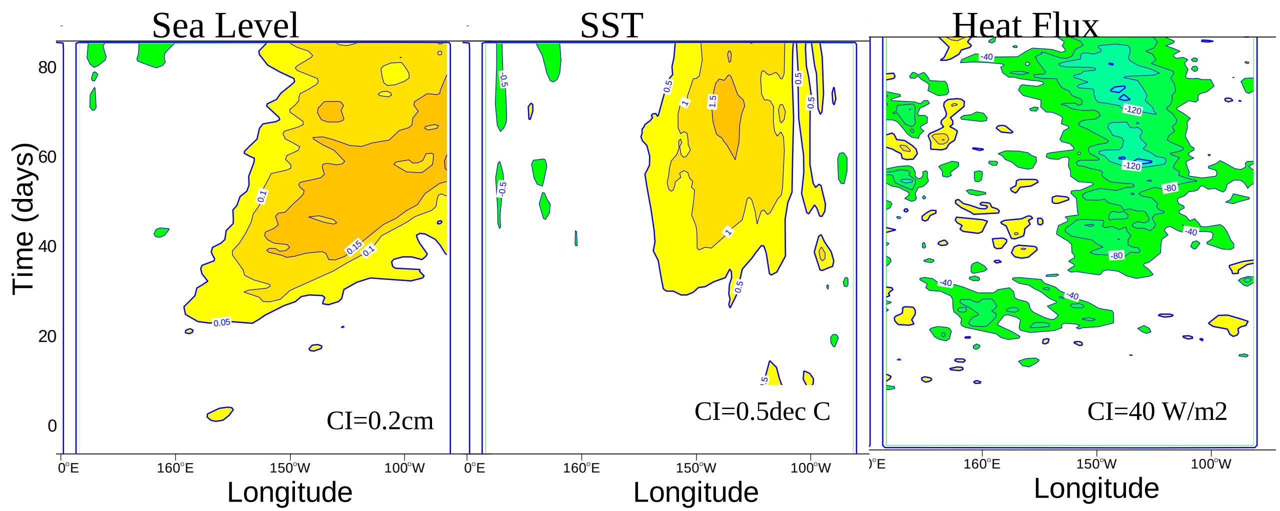
ECMWF

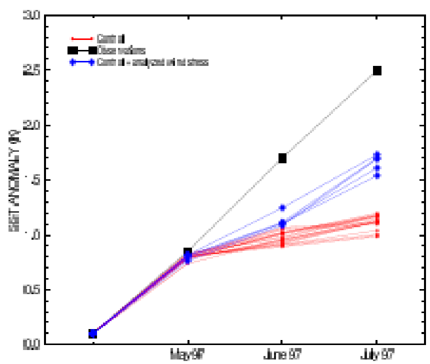
Coupled Response to a wind stress perturbation

Taux Perturbation



Atmospheric Response





The WWB does only explain 50% of the error in SST

The other 50% could be explained by a too strong atmospheric negative feedback (heat flux dumping)

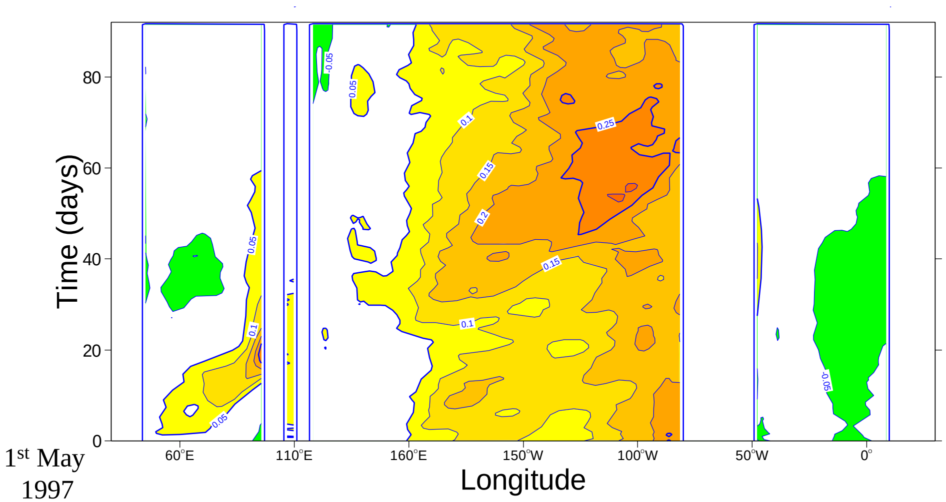
Is this consequence of the warm bias?

Results from Vitart et al 2003, based on S2

ECMWF

Coupled FC + WWB (hovmollers May-July 1997)

Sea Level anom (c.i. 5cm)

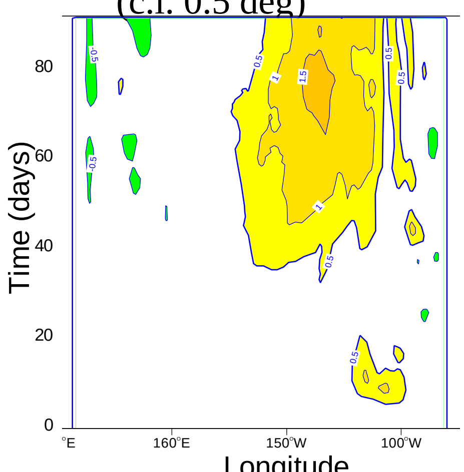


•Coupled + WWB has the right wind anomalies (prescribed) and correct SL anomalies=> **Correct dynamic response.**

•But the SST anomalies are still underestimated by about ~1 deg.

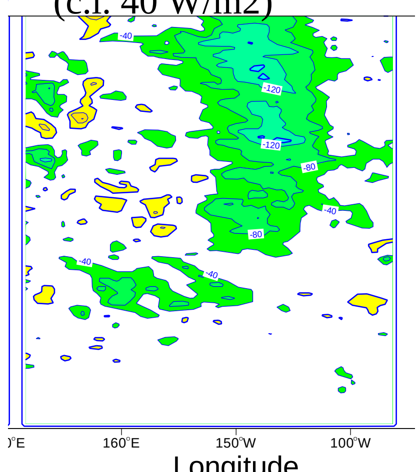
SST response

(c.i. 0.5 deg)



Heat flux response

(c.i. 40 W/m2)



•Possibility: **Too strong heat flux dumping in Eastren Pacific.**

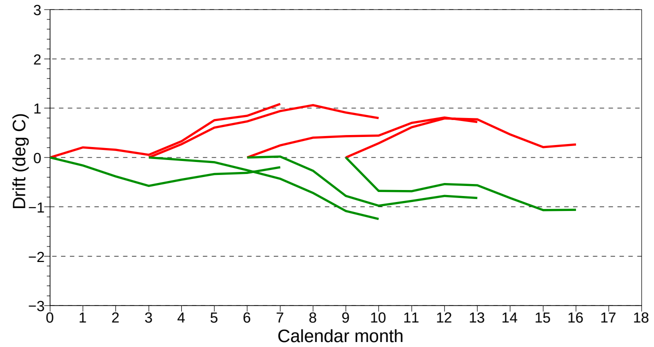
DQ/DT in S2~-80W/m2/degC

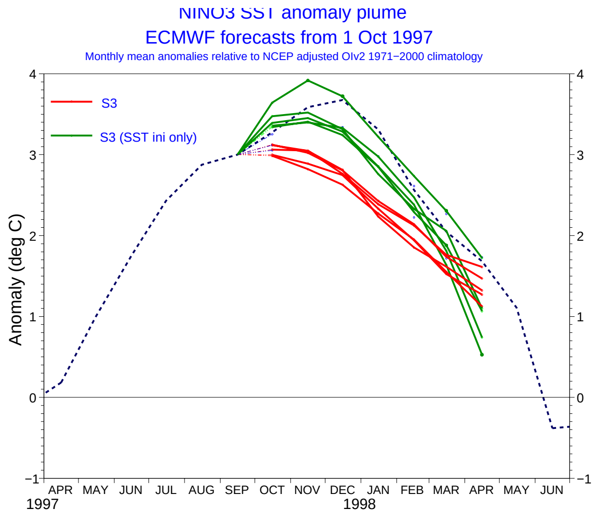
in ERA40 ~-30W/m2/degC

Why? Interaction with warm SST bias?

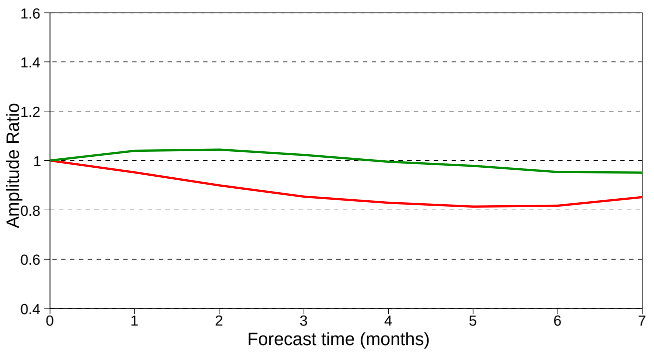
Drift, Amplitude of inter-annual variability and initialization (shock)

NINO3 SST Drift





Amplitude ratio (model/obs)



S3 (ocean data assim +analyzed wind +SST)

S3_INI (only SST)

- Shown are results using the same coupled model, different initialization.
- Warmer bias (drift) is associated with weaker interannual variability. The warmer bias can lead to stronger negative feedback (heat flux damping)
- Drift and Amplitude of interannual variability depend on initialization

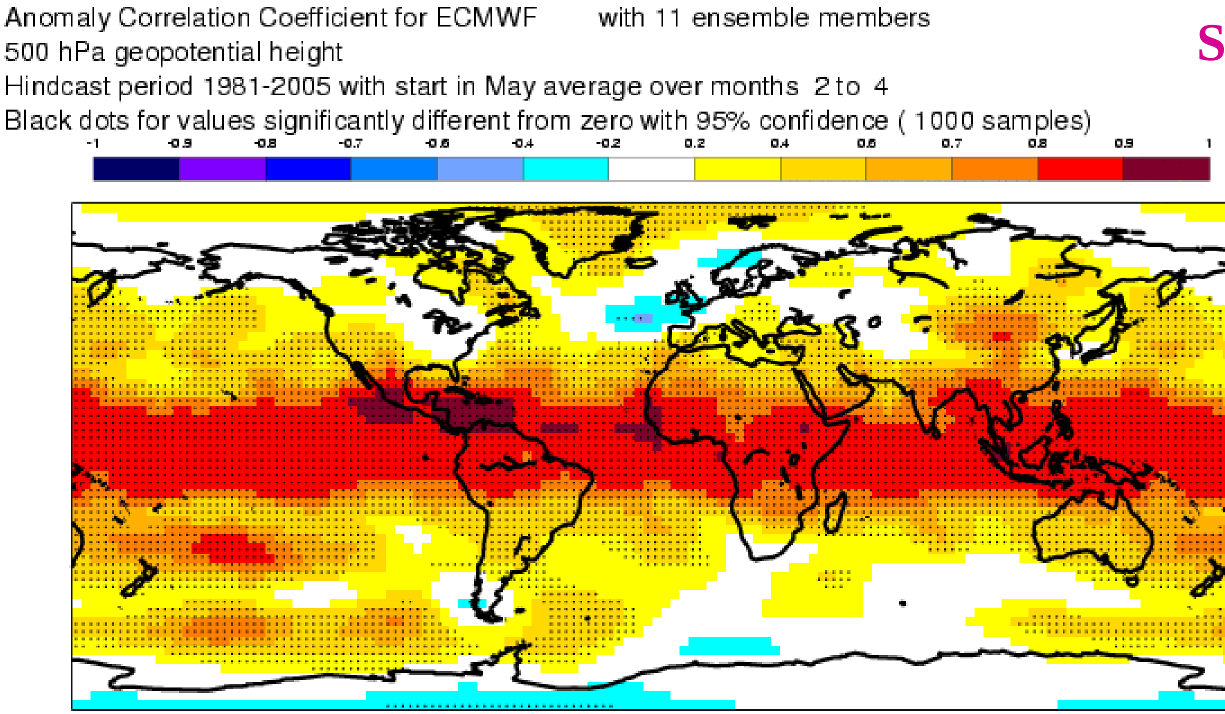
Summary (I)

- Possible reasons for the underestimation of the interannual variability in S3 are:
  - Under-representation of the Atmospheric Intraseasonal variability.
  - Strong heat flux damping as a consequence of interaction with warm bias
  - Not enough “upwelling feedbak” in the Eastern Pacific, due to too deep thermocline.
- The skill of seasonal forecasts is still limited by the deficient prediction of the atmospheric intra-seasonal variability at monthly time scales
  - MJO intensity and propagation, and its surface manifestation as WWB.
- Errors due to the interaction between the warm drift in SST and the inter-annual variability in the Eastern Pacific are not possible to correct by the a-posteriori bias removal.
- The warm SST is related with the initialization shock. More balanced initialization is needed.

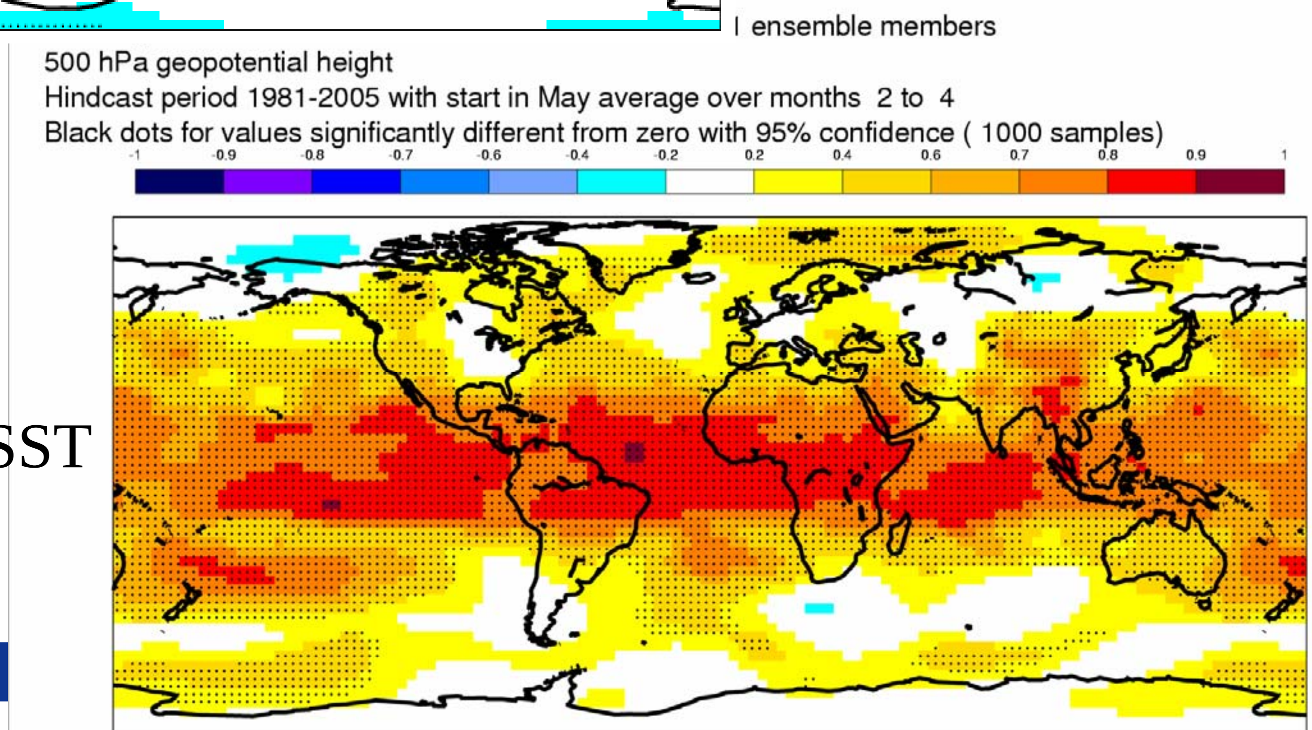
Seasonal forecasts of European Summers from spring

- Ocean Mixed layer depth
- Artic Sea-Ice
- Gulf Stream

Skill of JJA Z500 forecasts
(May Starts)



S3 (coupled model)



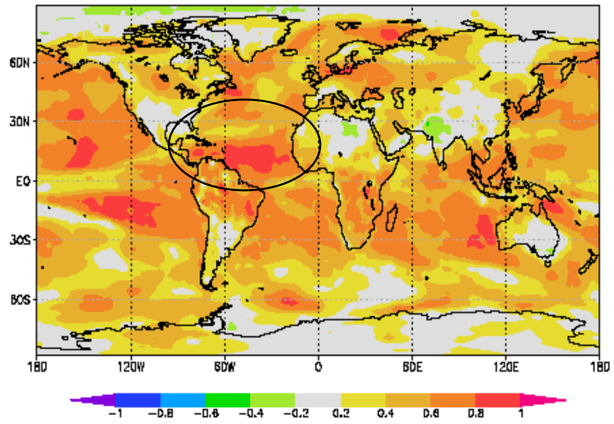
Forced by observed SST

Persistence and mixed layer depth

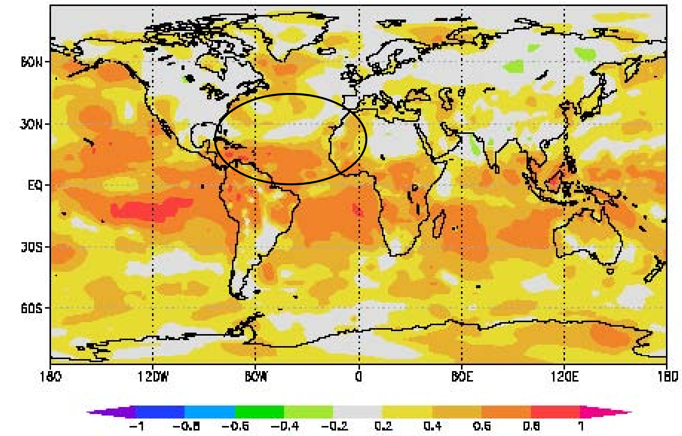
Persistence from April to JJA

From G.J. van Oldenborgh 2007

DEMETER

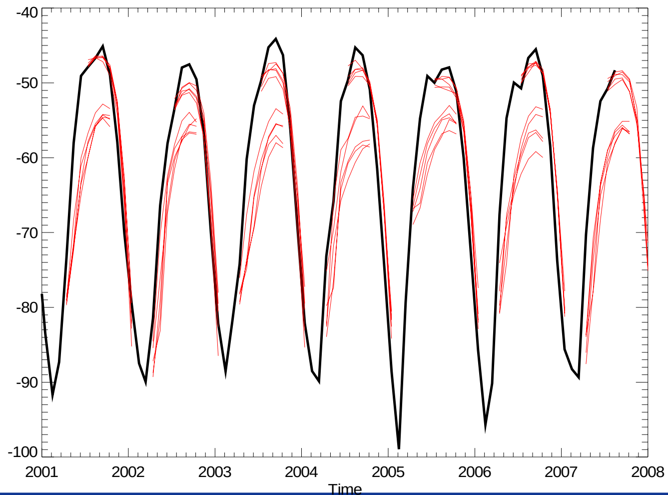


ERA-40



MLD in North Subtropical Atlantic

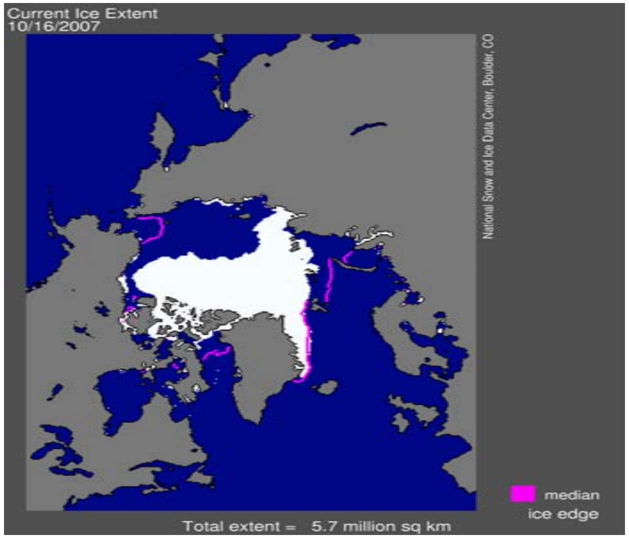
Apr and July starts

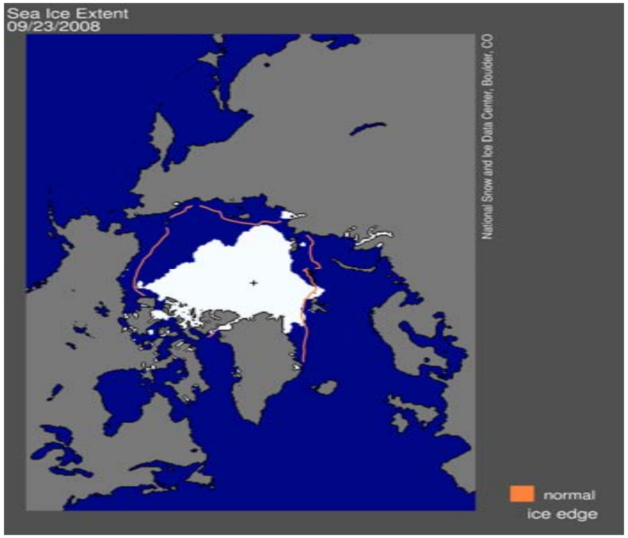


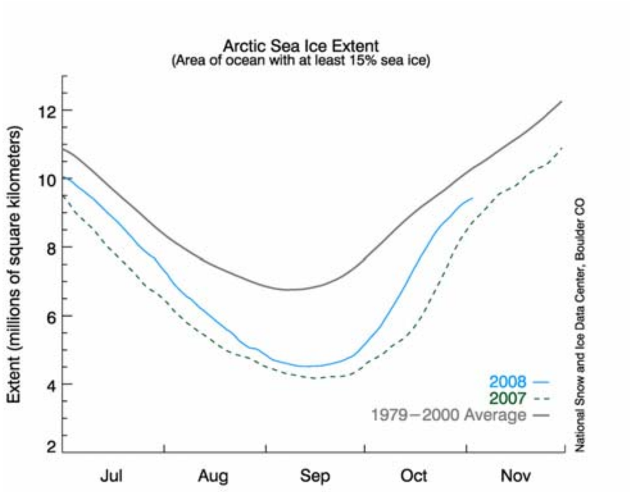
- Persistence (from spring to summer) in coupled models is too large in the North-Subtropical Atlantic

• The coupled model can not predict the rapid shallowing of the mixed layer from spring to summer.

Artic Sea-Ice







- The last 2 summers have seen unprecedented anomalies in the Artic ice extension
- The ECMWF SF system does not represent interannual variations of the sea-ice. Would the SF over Europe improve if artic sea-ice was predicted?

Images from the National Snow and Ice Data Center: http://www.nsidc.org/sotc/sea_ice.html

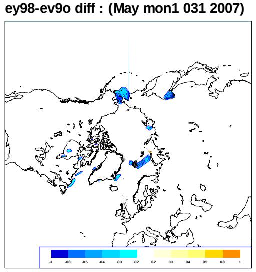
Sensitivity to the Artic Ice Anomaly

- **Exp A: Atmosphere forced by observed SST**
  With climatological and Observed ice extension. 2007 & 2008.

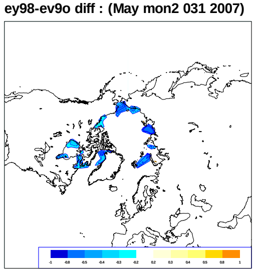
Differences in Ice Extension between Experiments
Obs ice – Clim ice

May to September 2007

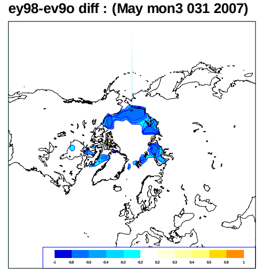
ey98-ev9o diff : (May mon1 031 2007)



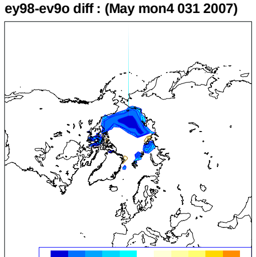
ey98-ev9o diff : (May mon2 031 2007)



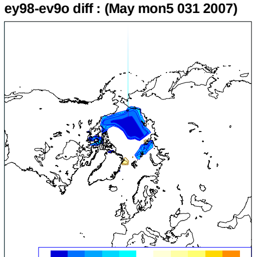
ey98-ev9o diff : (May mon3 031 2007)



ey98-ev9o diff : (May mon4 031 2007)

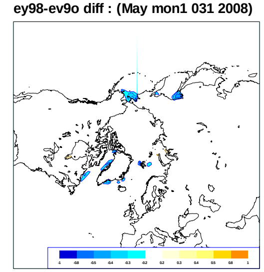


ey98-ev9o diff : (May mon5 031 2007)

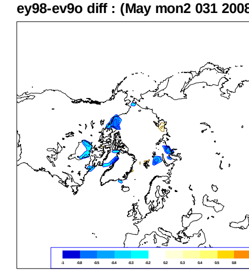


May to September 2008

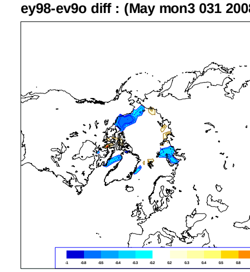
ey98-ev9o diff : (May mon1 031 2008)



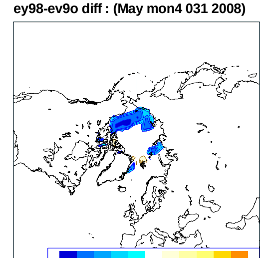
ey98-ev9o diff : (May mon2 031 2008)



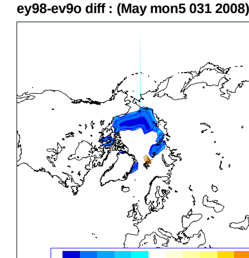
ey98-ev9o diff : (May mon3 031 2008)



ey98-ev9o diff : (May mon4 031 2008)



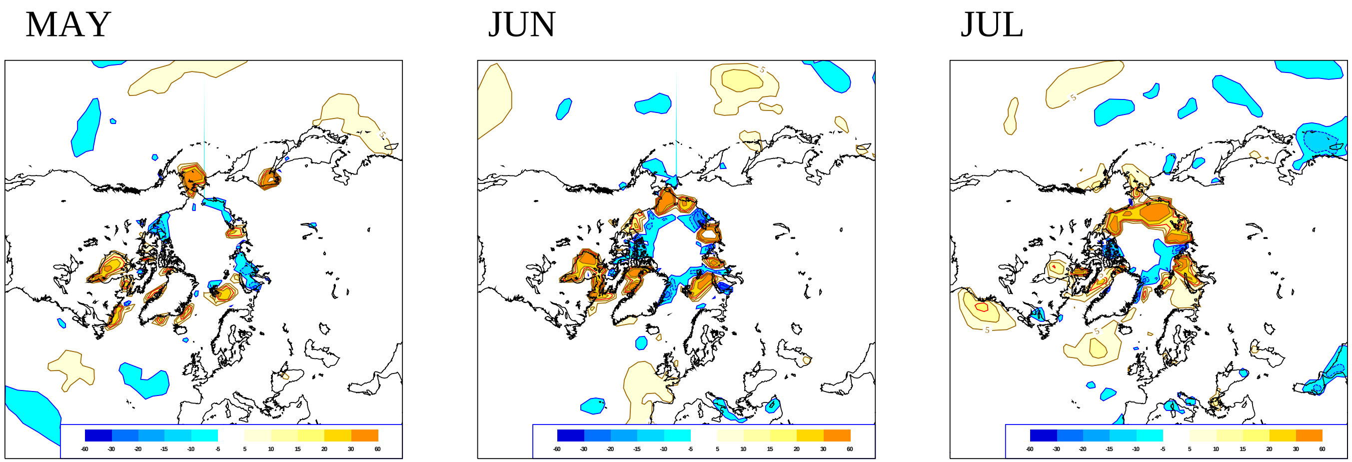
ey98-ev9o diff : (May mon5 031 2008)

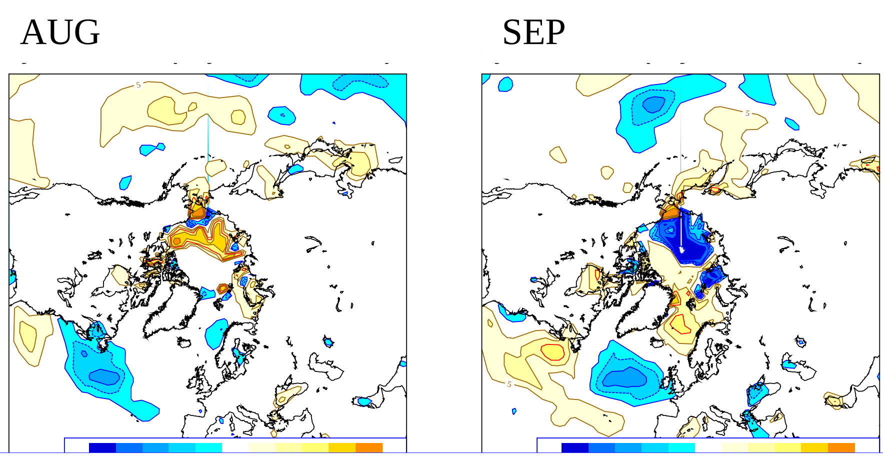


Resulting Heat Flux Forcing

Total Heat Flux

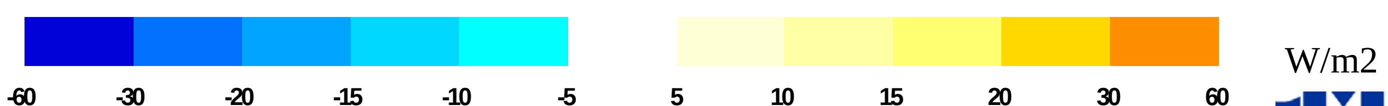
May-to-September 2007





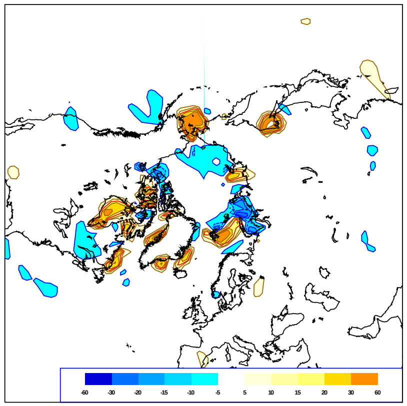
Mainly more solar heat flux going into the ocean (July-August)

In September there is a change: the dominant term is latent heat released by the ocean into the atmosphere.

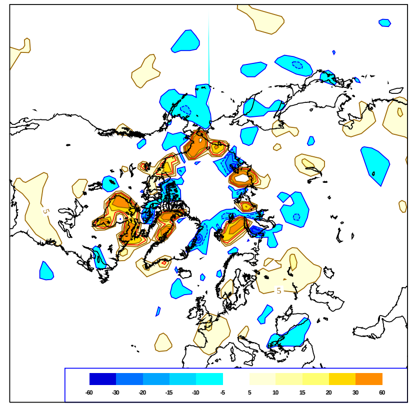


Solar Heat Flux (May-September 2007)

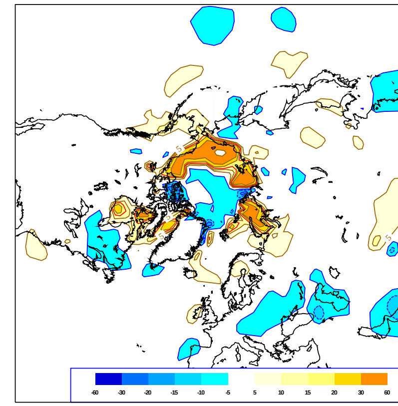
ey98-ev9o diff : (May mon1 solar 2007)



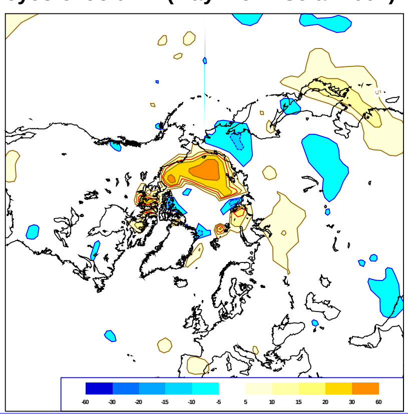
ey98-ev9o diff : (May mon2 solar 2007)



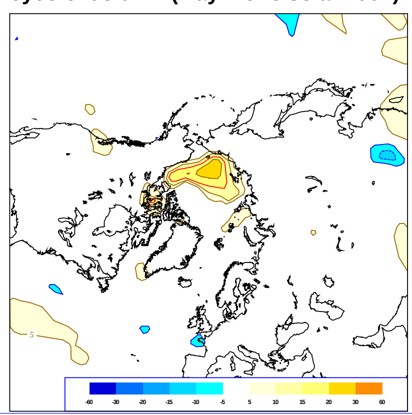
ey98-ev9o diff : (May mon3 solar 2007)

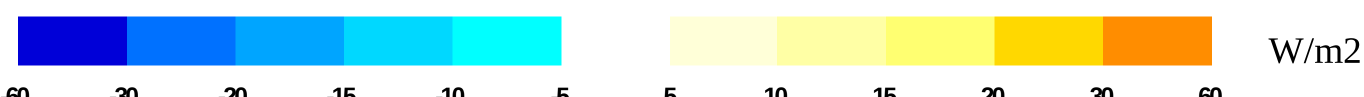


ey98-ev9o diff : (May mon4 solar 2007)



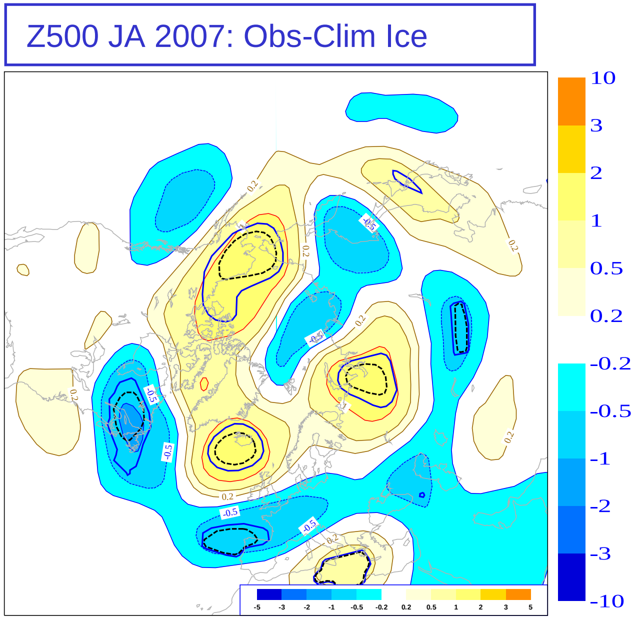
ey98-ev9o diff : (May mon5 solar 2007)





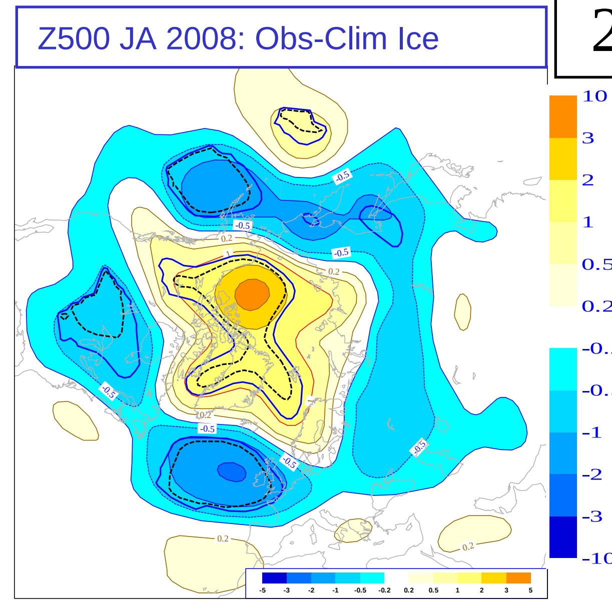
Impact on Z500

2007



Atmos model

(uncoupled)



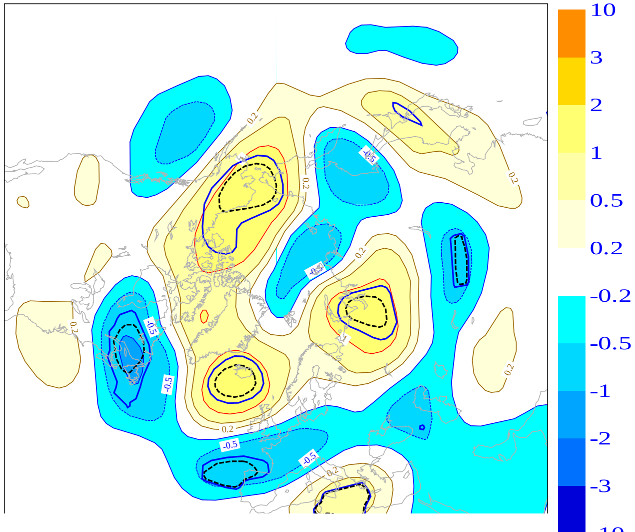
2008

- Similar response in both years
- Low over Western Europe and NorthEast of USA is significant in both cases. So it is the Artic high
- Peak values of the ensemble mean ~2-3Dm

Comparison with observed anomalies

2007

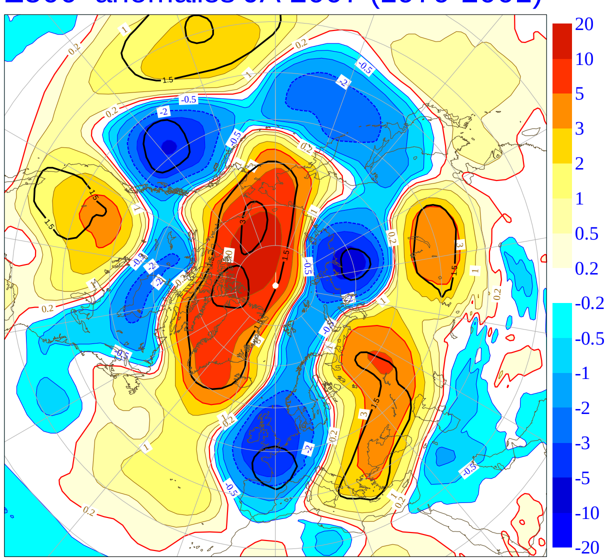
Z500 JA 2007: Obs-Clim Ice



Atmos model

(uncoupled)

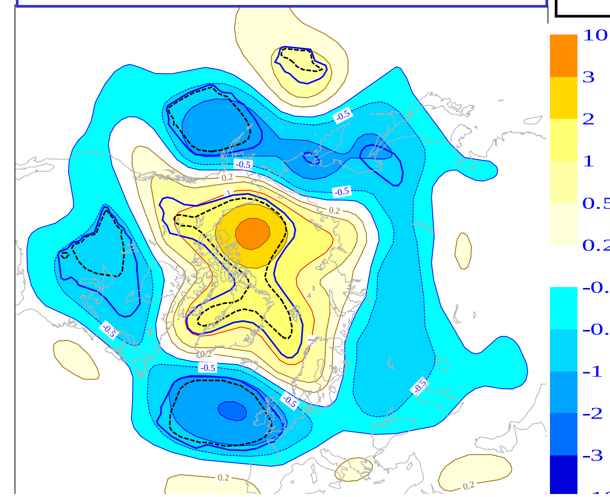
Z500 anomalies JA 2007 (1979-2001)



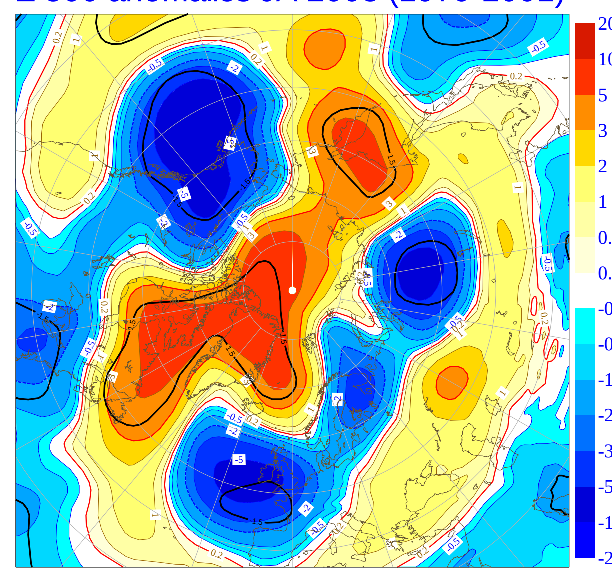
Observed Anomalies

2008

Z500 JA 2008: Obs-Clim Ice



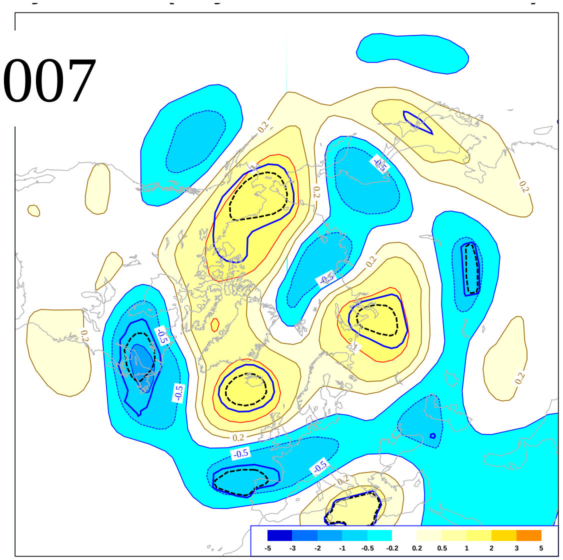
Z 500 anomalies JA 2008 (1979-2001)



But the response is very different in coupled mode. Why?

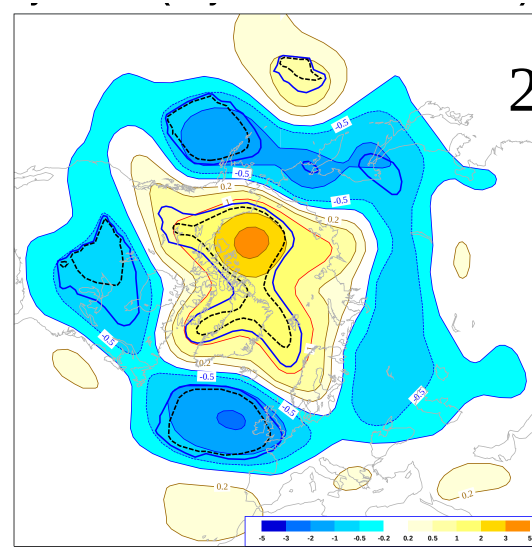
Z sensitivity: Obs-Clim JA 2007

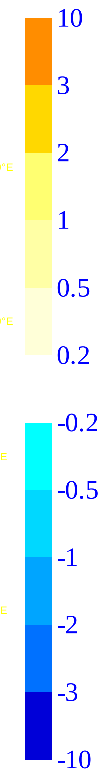
2007



Z sensitivity: Obs-Clim JA 2008

2008

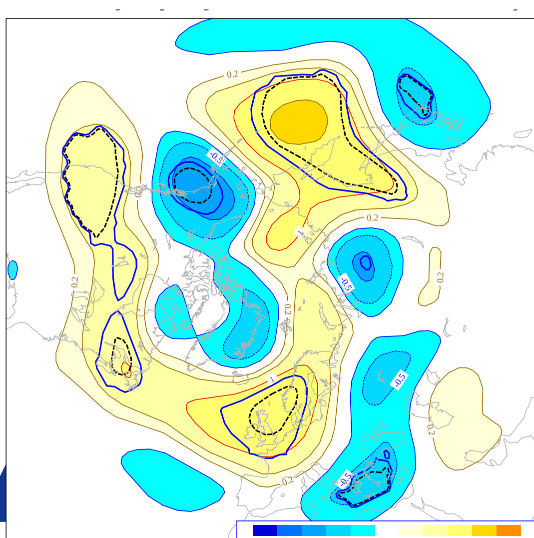




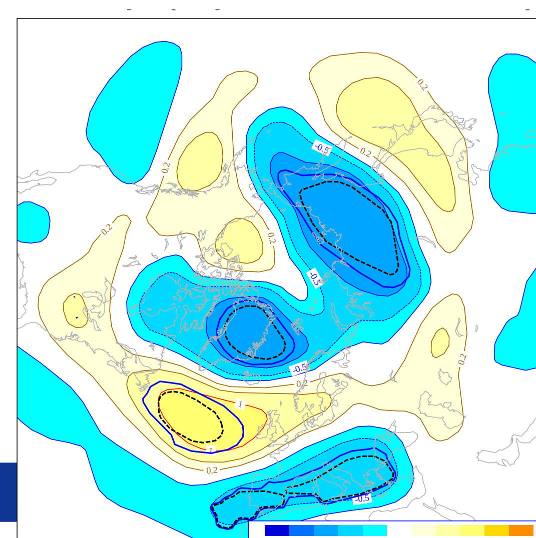
Atmos model

(uncoupled)

Z sensitivity: Obs-Clim JA 2008



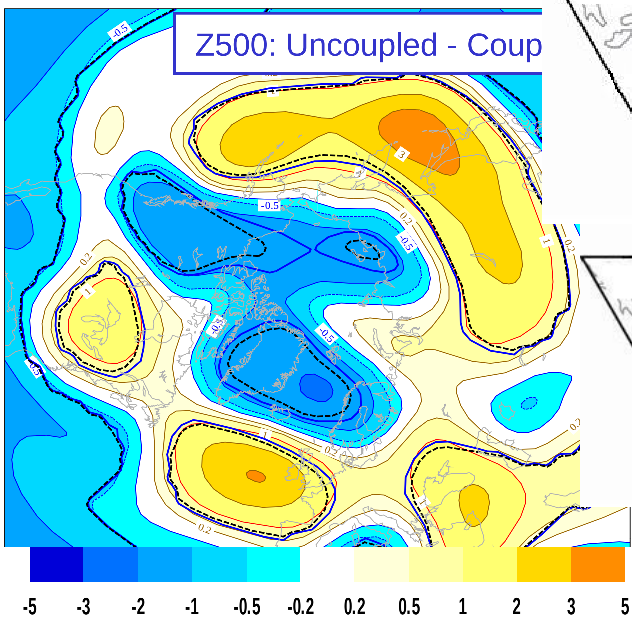
Z sensitivity: Obs-Clim JA 2008

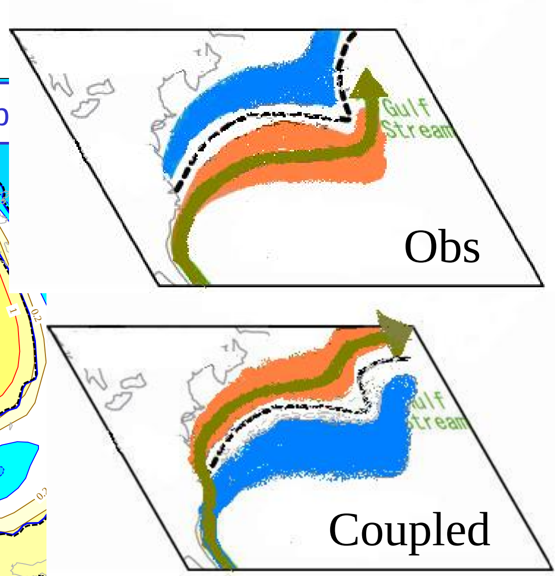


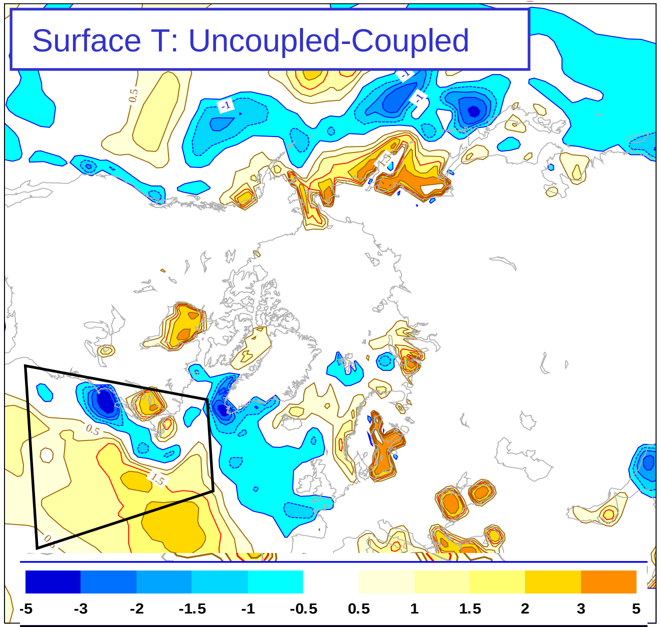
Coupled

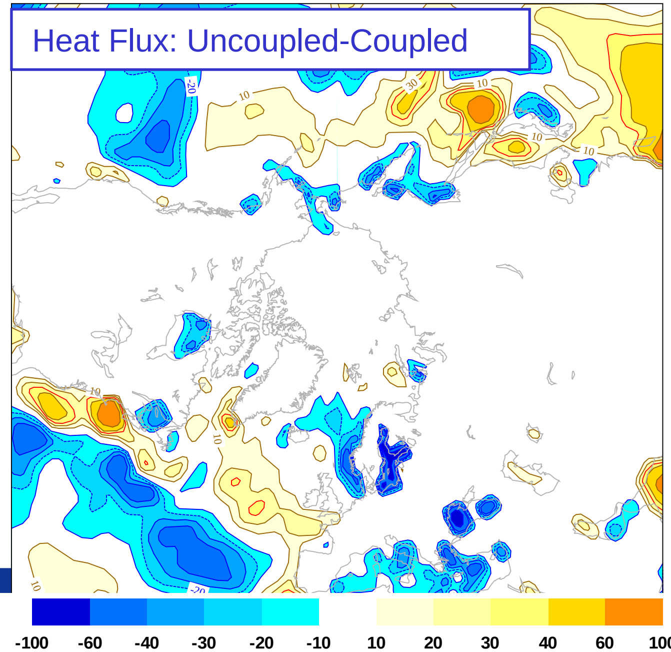
model

Differences in circulation and surface forcing
Uncoupled - Coupled



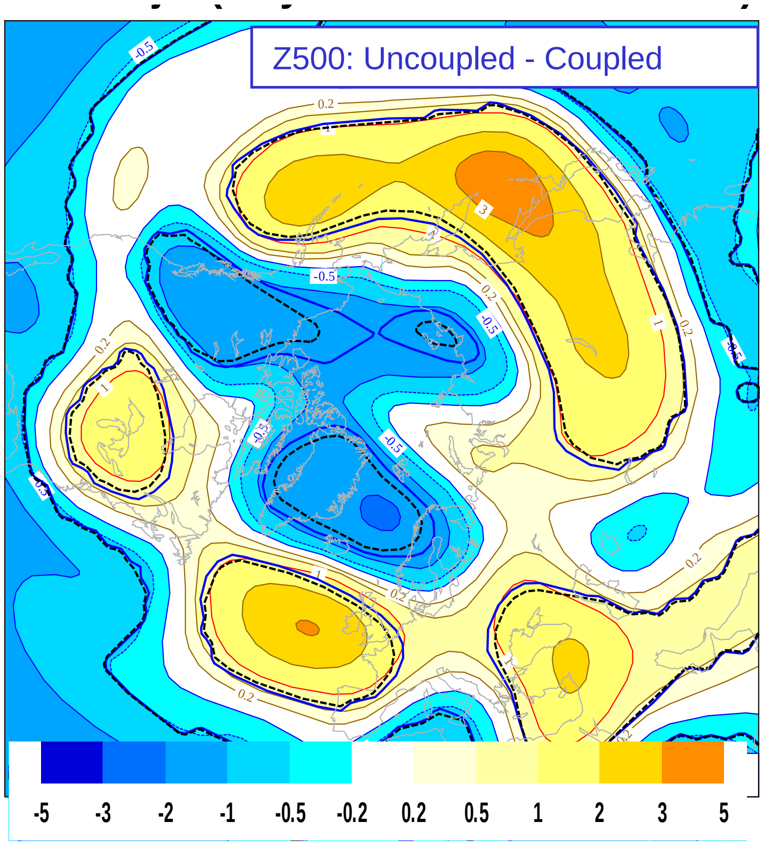


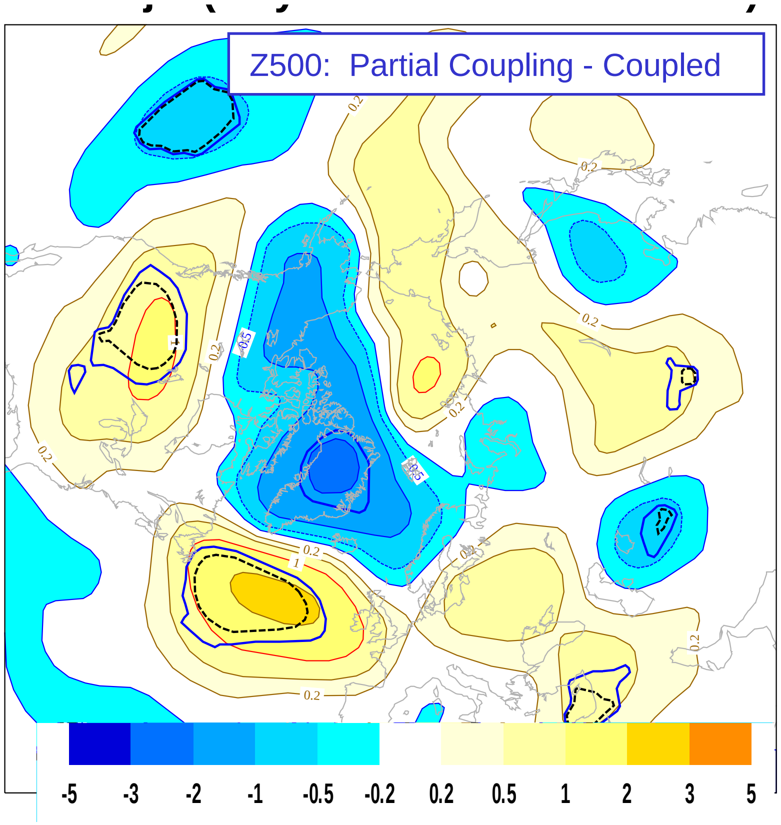




- Large Surface Temperature differences in the Western Boundary Currents, consistent with the wrong separation off the coast in the coupled model
- Large associated heat flux (latent 60-100W/m2)

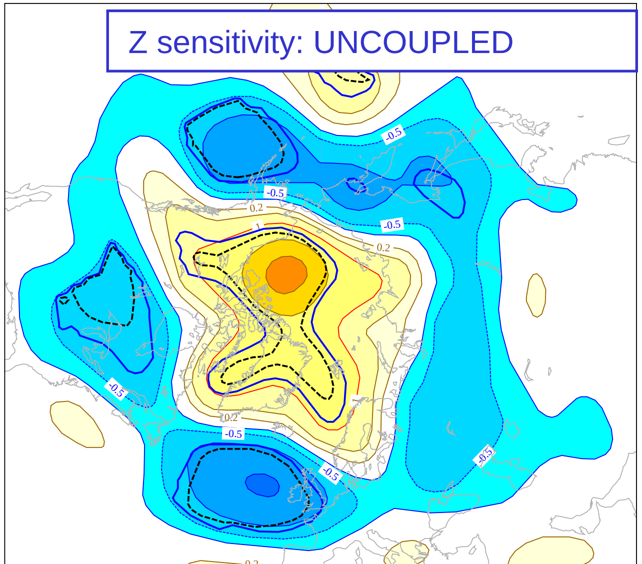
Impact of Gulf Stream area in the Atmosphere
1) Impact on mean circulation

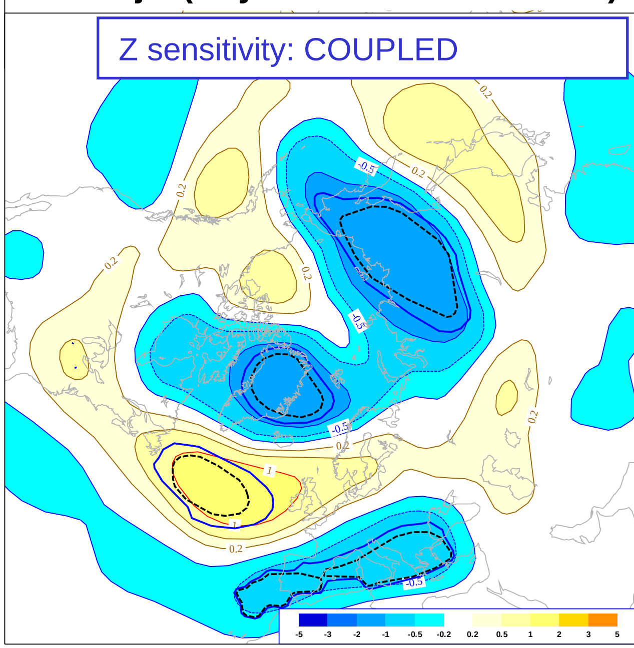


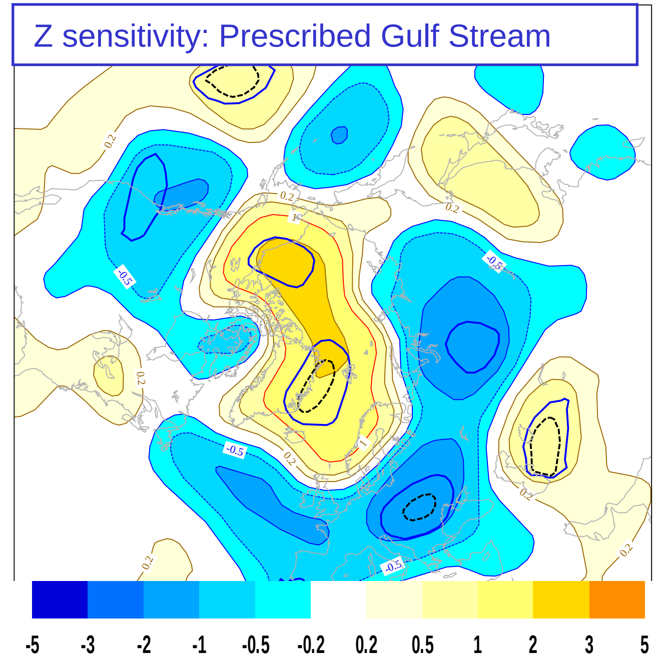


Gulf Stream could explain a large part of the mean error over North Atlantic Sector

Impact of Gulf Stream area in the Atmosphere
2) Impact on the response to the Artic Ice anomaly







Correcting the Gulf Stream changes the response of the atmosphere to the given ice anomaly

Summary (II):

- The failure of the ocean mixed layer to produce the rapid summer shallowing may be responsible for part of the seasonal forecast error over Europe.
- Experiments suggest that the observed Artic ice anomaly over the last 2 years had a significant impact on the atmospheric circulation over the North Atlantic sector.
- The incorrect representation of the Gulf Stream in the coupled model is partly responsible for the erroneous atmospheric circulation over the North Atlantic sector in the coupled model.
- The response of the atmosphere to the ice anomaly depends on the mean state. The representation of the Gulf Stream also affects the response of the atmosphere to an anomalous surface forcing.

Implications

- Seasonal forecasts will benefit from better treatment of the ocean mixed layer.
- The importance of Western Boundary Currents on the correct representation of the atmospheric circulation at seasonal time scales needs attention. **This can have implications for the horizontal resolution of the ocean model**.
- Need for a more balance initialization of the coupled model to avoid initialization shock.
- The "linear" approach of a-posteriori bias correction is limited. Need to tackle mean errors in coupled models.
- The ocean model configuration needed for improvement of seasonal forecasts may not be that different from that of monthly forecasts