Stratosphere-Troposphere Interaction and Long Range Prediction

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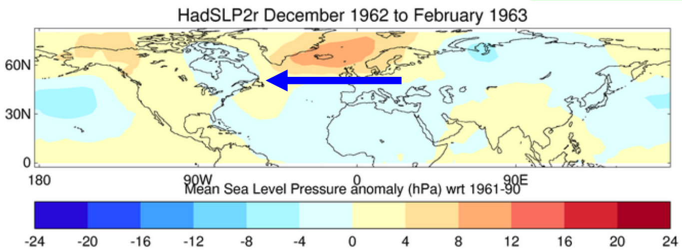
Outline

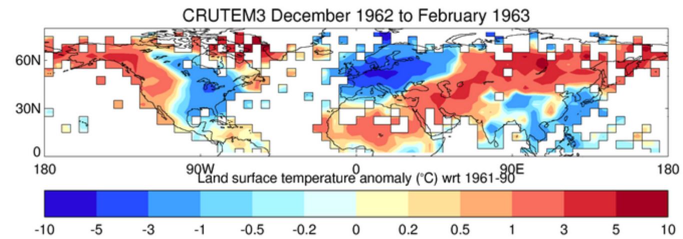
Stratosphere-Troposphere interaction:

- Monthly
- Seasonal
- Multiannual
- Longer term change

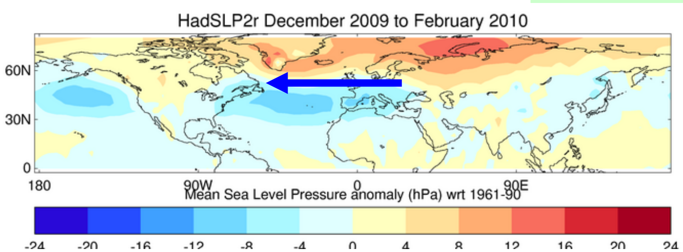
Year to year changes in Winter depend largely on which way the wind blows:

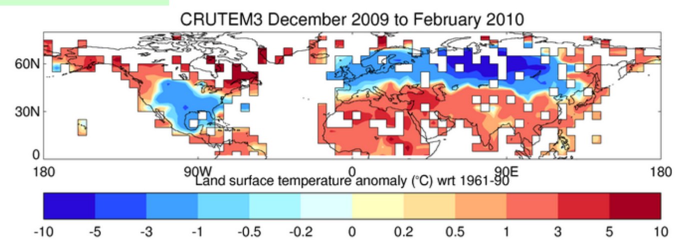
Winter 1962/63





Winter 2009/10



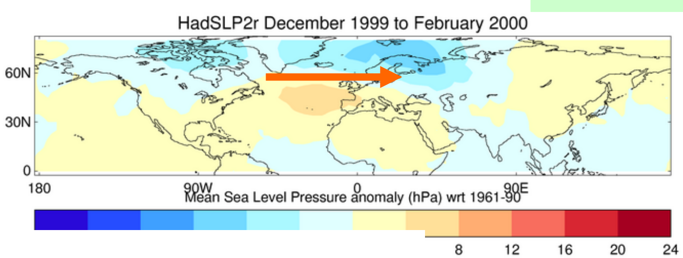


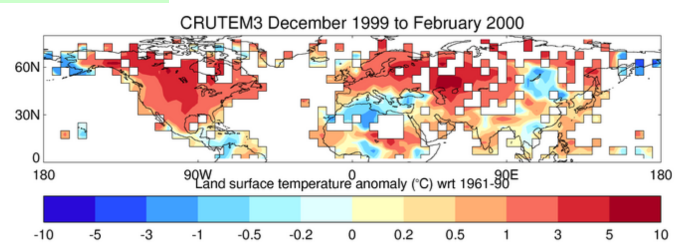
Weakened Pressure Gradient

Cold advection into Europe

Cold, calm and dry

Winter 1999/00





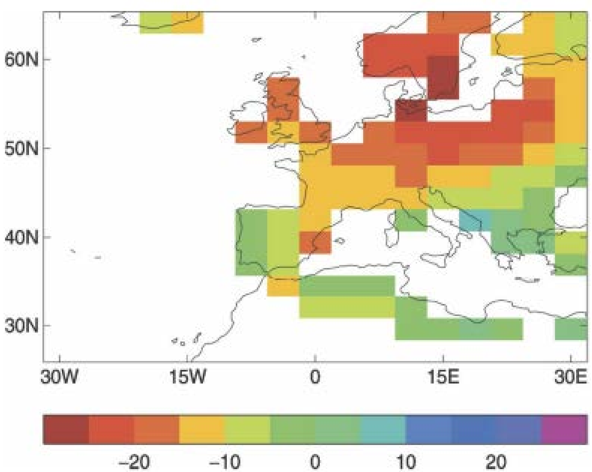
Strengthened Pressure Gradient

Warm Europe

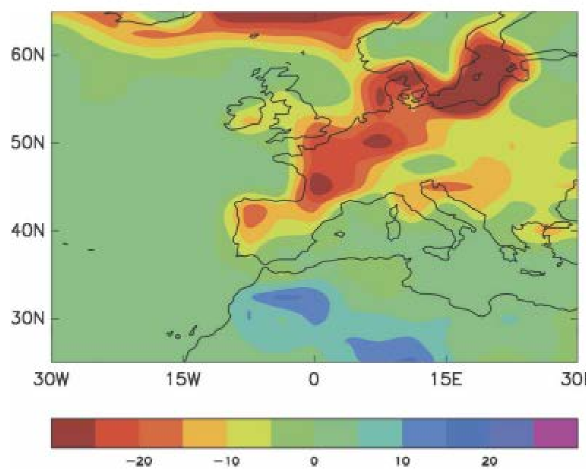
Mild, stormy and wet

Decade to decade changes depend largely on which way the wind blows (1960s to 1990s)

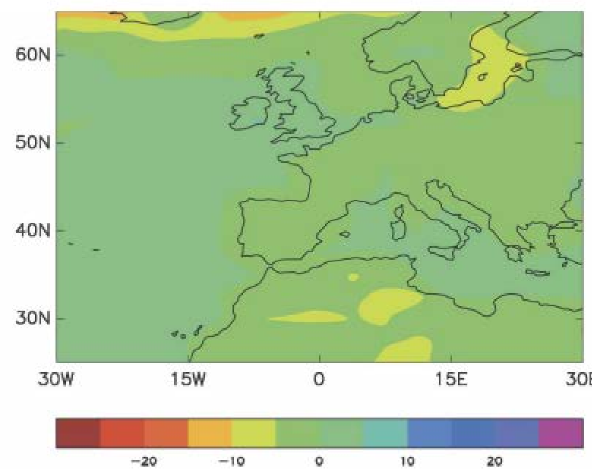
Observed Decrease in Frosts



Modelled Decrease in Frosts



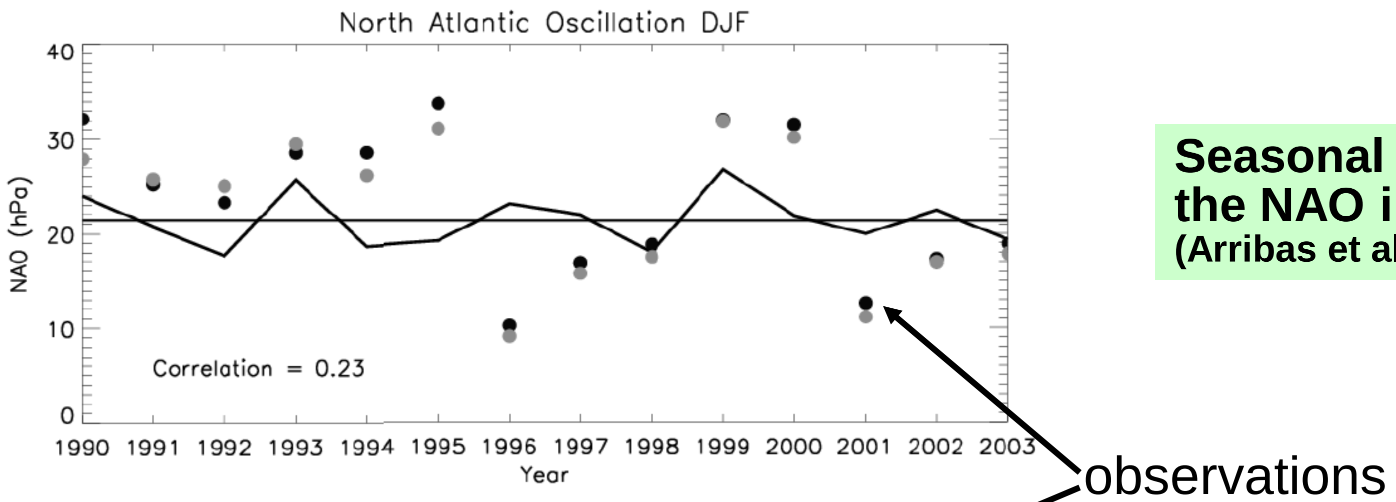
Without wind change



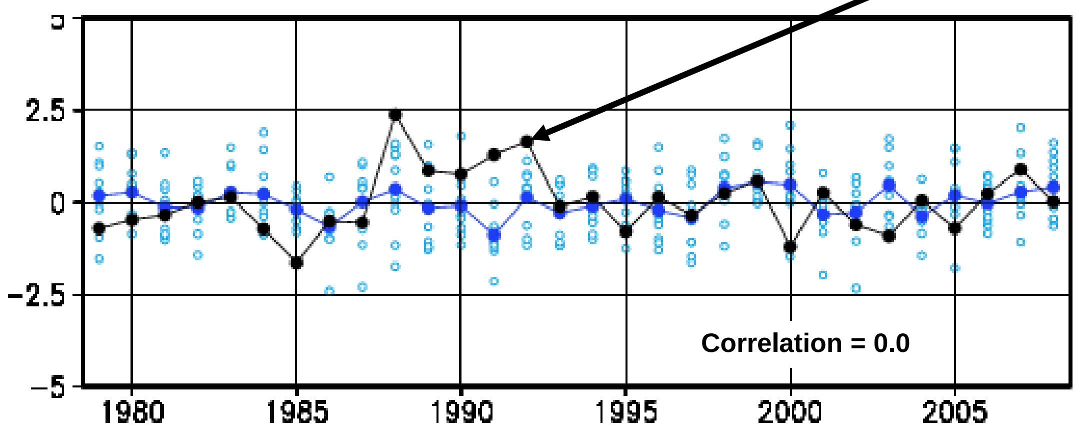
Scaife et al., *J.Clim.*, 2008

Nicely reproduced – but only if the winter mean winds are simulated

…and long range prediction skill of the NAO/AO is low:



Seasonal Predictions of the NAO in UKMO system
(Arribas et al., 2011, MWR)



Seasonal Predictions of the AO in JMA system
(Maeda, 2011, JMA)

Monthly Prediction

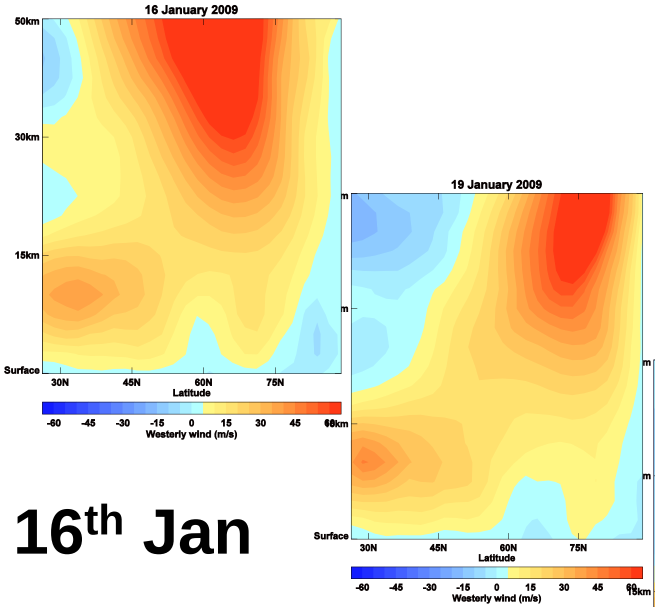
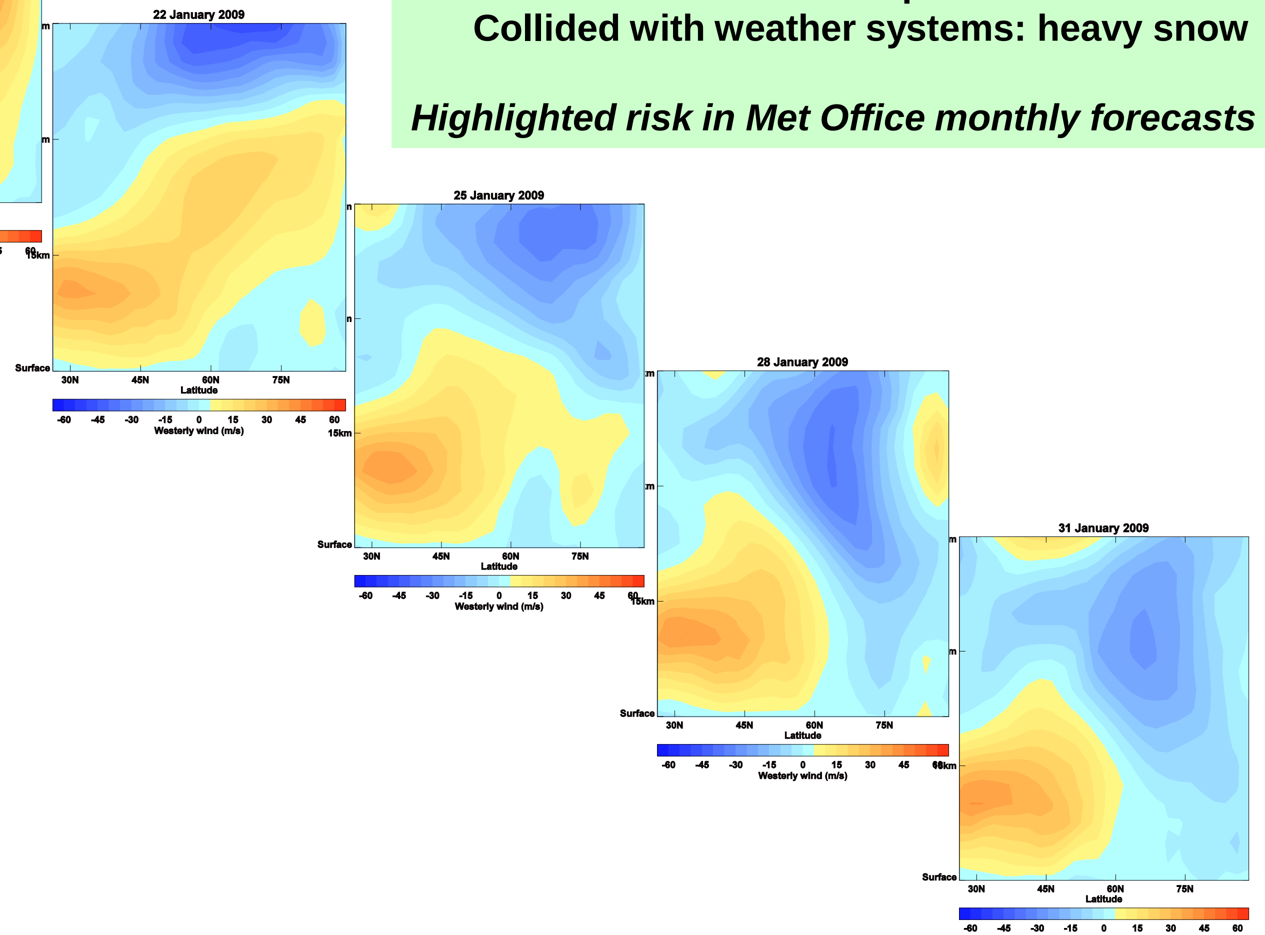
- Early studies suggested an atmospheric circulation response to imposed stratospheric changes in GCMs (e.g. Boville 1984)
- Observations show downward propagation of wind anomalies from the upper stratosphere to the troposphere (e.g. Kodera et al 1990)
- Some studies show additional predictability from the stratosphere on monthly to seasonal timescales (e.g. Christiansen 2005, Orsolini et al 2011)

February 2009

Easterly winds developed aloft
Descended with time to the surface
Advected cold air to Europe
Collided with weather systems: heavy snow

Highlighted risk in Met Office monthly forecasts

16th Jan

31st Jan

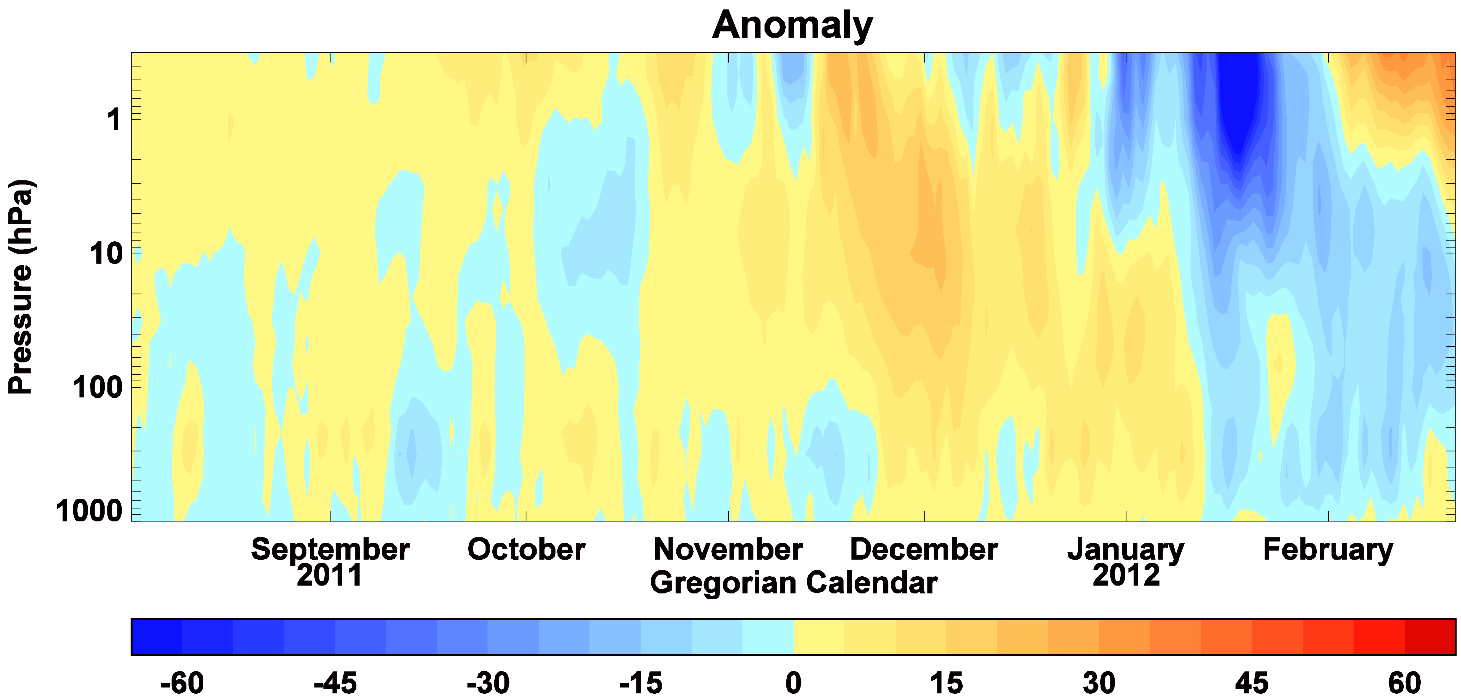
Example impact: Feb 2009 weather

London 5 Feb 2009

Widespread disruption to London transport services early Feb 2009

One of the main problems during the period of heavy snow in February was the dwindling supply of salt held by local authorities. We heard that local authorities had placed their usual orders for salt before the winter…..when local authorities ordered more stock, the suppliers "could not respond and deliver".
Commons Select Transport Committee Report on Feb 2009

February 2012

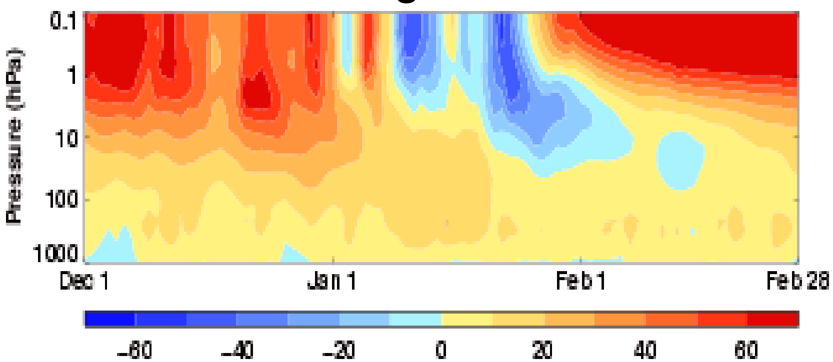


Descending easterly wind anomaly – initiated in early January

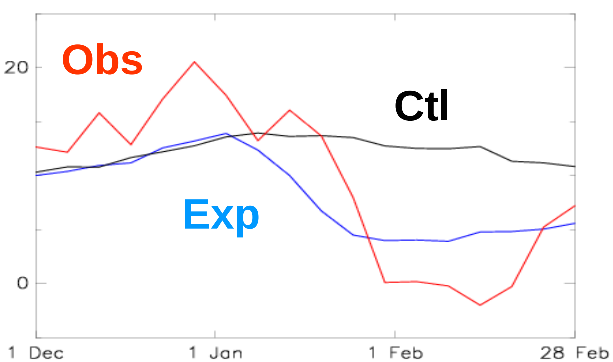
Met Office monthly forecasts issued from mid January highlighted increasing risk of cold conditions in February

Winter 2005/6

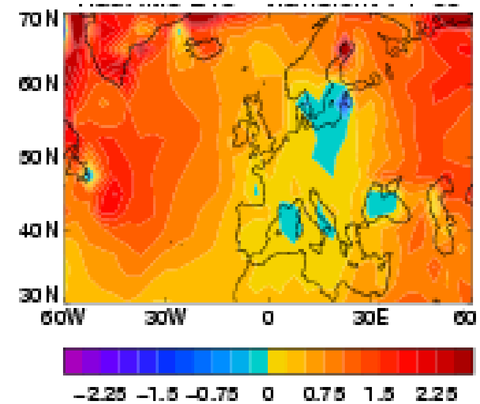
U wind through the winter



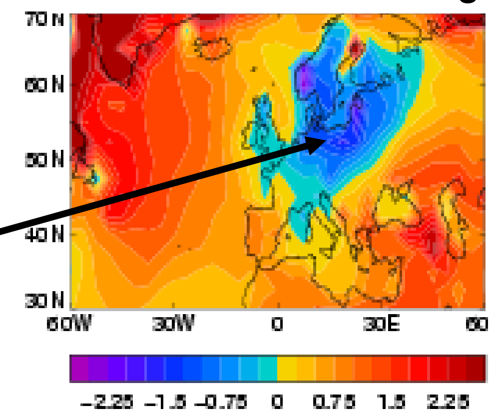
Zonal wind at 50hPa



SST only



SST + Strat forcing

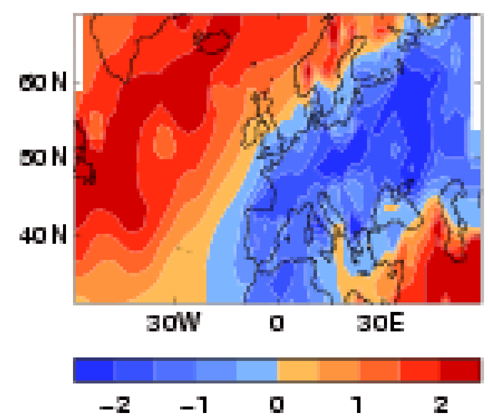


Cold European signal from *IMPOSED* stratospheric warming in Hadley Centre model

Implies stratospheric *influence*

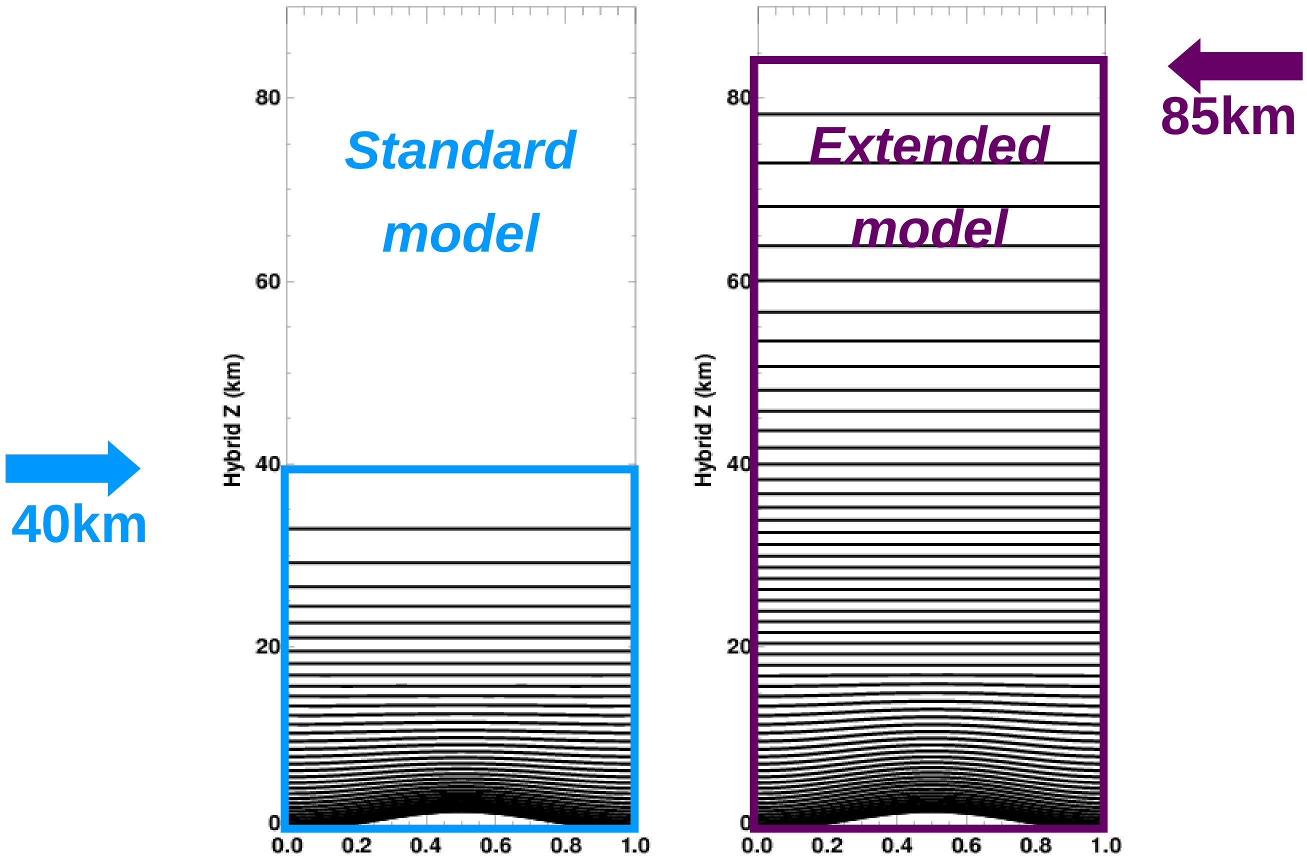
Other examples in winters 2008/9, 2009/10, 2011/12

Observations



Scaife and Knight, QJRMS, 2008

Extended and Standard Hadley Centre Models: HadGEM

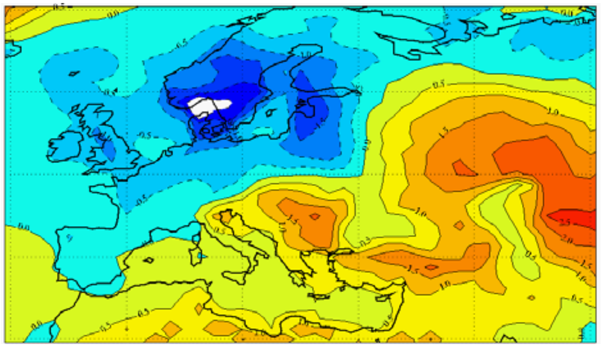


Predictability of stratospheric warmings

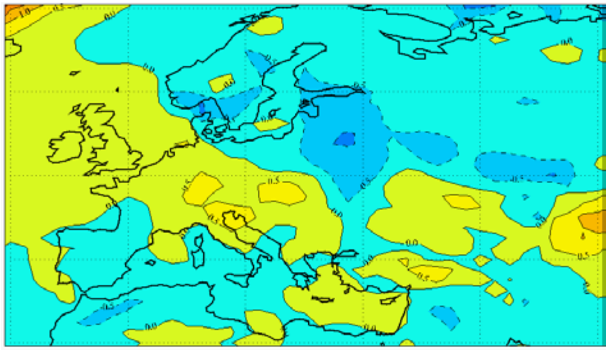
	24 Feb 1984 (Ext | Stand)	7 Dec 1987	15 Dec 1998	26 Feb 1999	Event Mean
Maximum lead time for capture (days)	13 | 5	15 | 10	12 | 12	9 | 6	**12 | 8**
Peak easterly magnitude (fraction of observed)	0.4 | 0.1	0.7 | 0.2	0.7 | 0.3	0.6 | 0.4	**0.6 | 0.3**

Improved intraseasonal prediction of European winter cold spells:

Extended



Standard



Marshall and Scaife, JGR, 2010

Seasonal Prediction

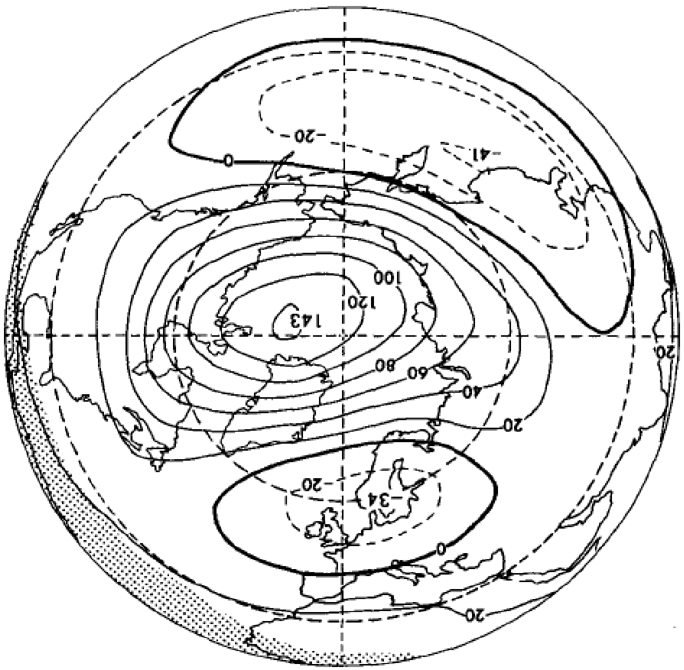
- **It is not only the ocean which has memory!**

(For example the QBO has a period of 2-3 yrs and is predictable for 1-2 cycles)

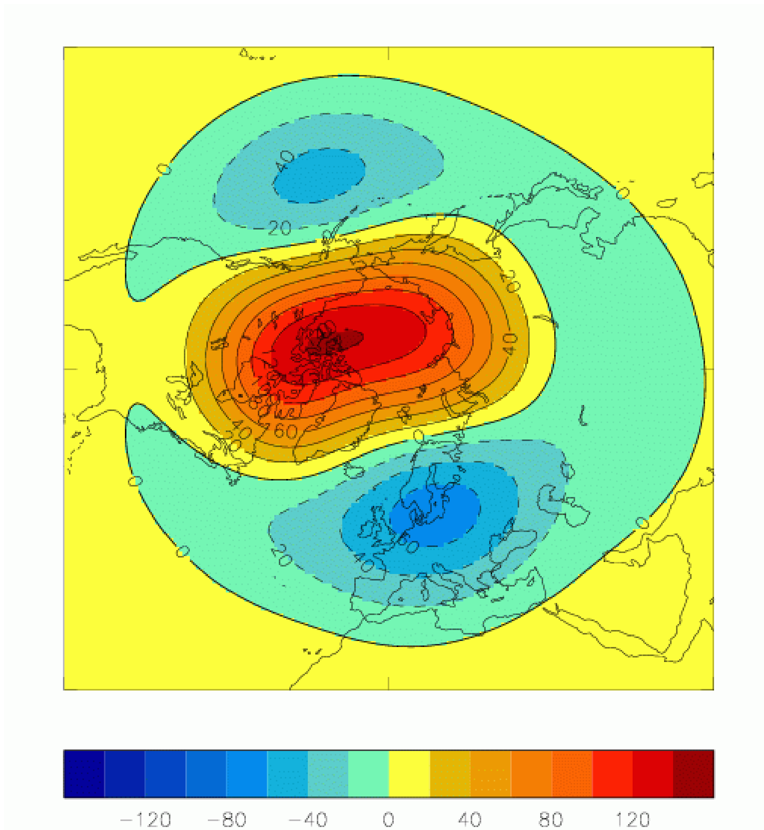
- **Two examples of the stratosphere playing a role….**

ENSO teleconnections

Observations (Hamilton, 1993)



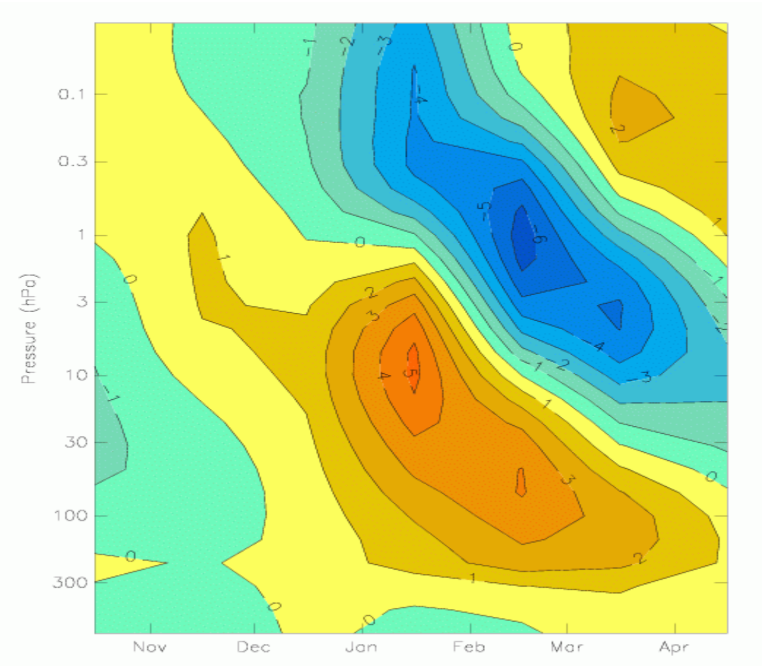
Model El Nino anomaly
(50hPa gph in HadGEM)



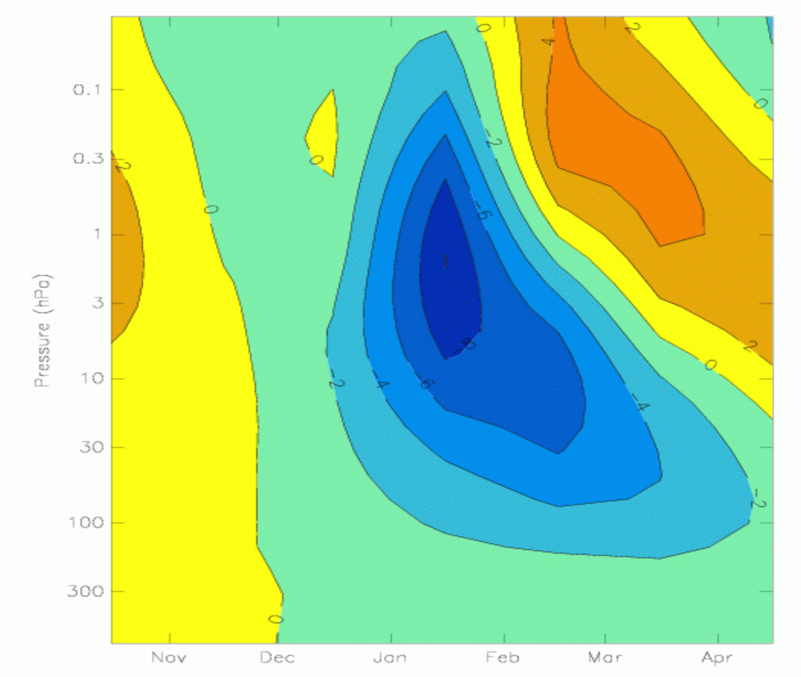
Stratospheric signal observed (Van Loon and Labitzke 1987, Hamilton, 1993, Scaife 1998, Manzini et al. 2006**)**
ENSO events produce a –ve NAO-like response (Moron and Gouirand 2003, Bronniman et al. 2004**)**
Clearly visible in 2/3 of observed El Nino events (Toniazzo and Scaife 2006**)**
Reproduced in numerical models (Cagnazzo and Manzini 2009, Ineson and Scaife 2009**)**

ENSO teleconnections

Model Temperature



Model Zonal wind



Descending El Nino signals

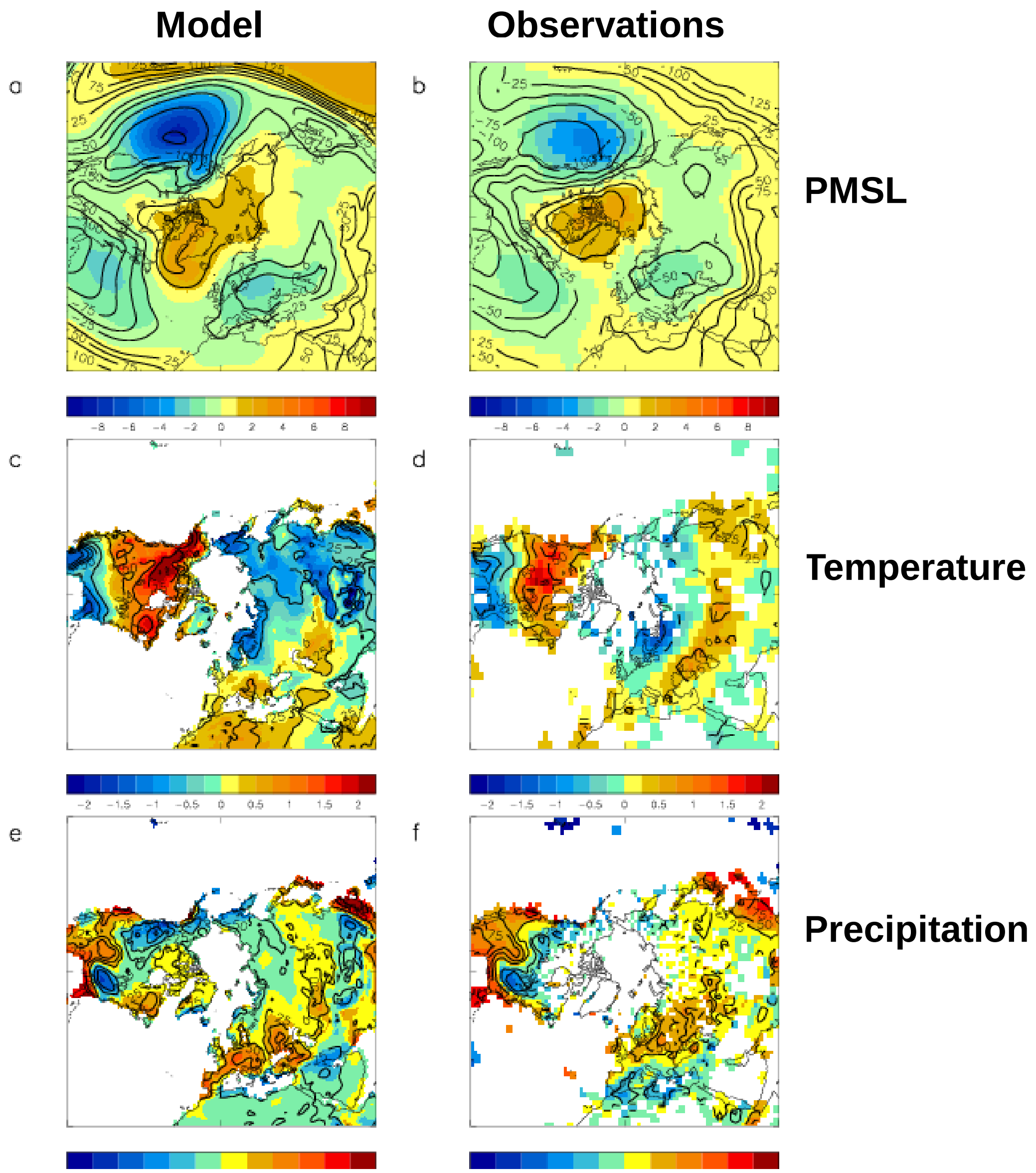
Slower at lower altitudes

Indicative of wave-mean flow interaction from a Rossby wave source in the troposphere

Ineson and Scaife, Nat. Geosci., 2009

ENSO teleconnections

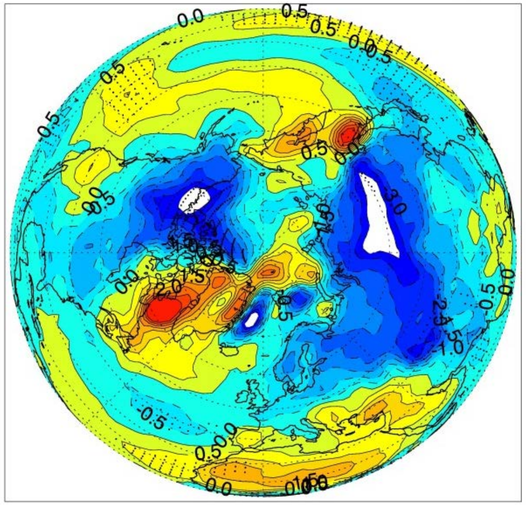
Big enough to strongly affect seasonal forecasts



Ineson and Scaife, Nat. Geosci., 2009

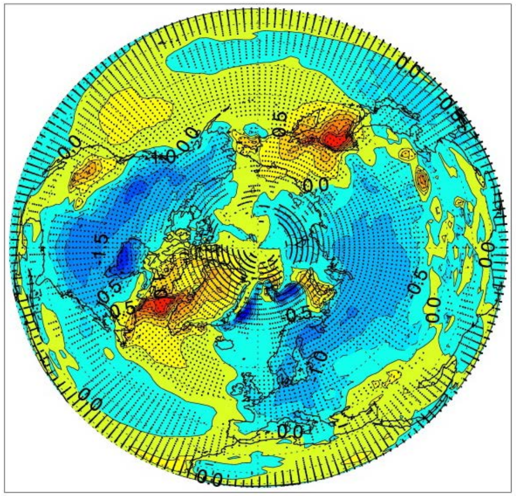
QBO teleconnections

OBS 2m Temperature



QBOE-QBOW

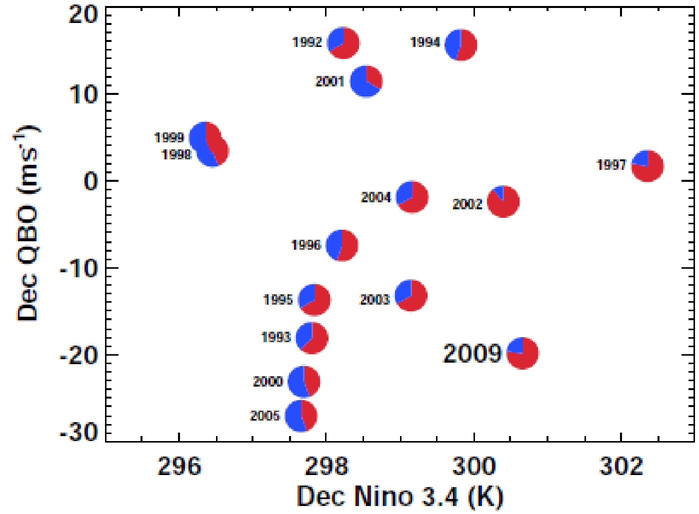
MODEL 2m Temperature



- **Highly predictable for 2-3 years at least**
- **Initialised in current models but decays after 2-3 months**
- **European (NAO like) signal: QBO -> extratropics -> surface**
- **Signal comparable to year-to-year variability and therefore important**

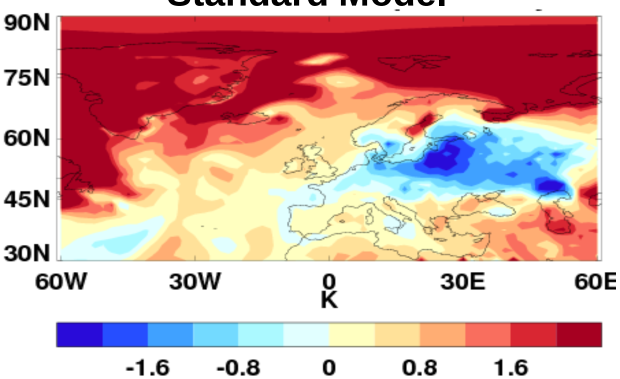
Marshall and Scaife, J. Geophys. Res., 2009.

Winter 2009/10: record low NAO
(El Nino and E QBO)

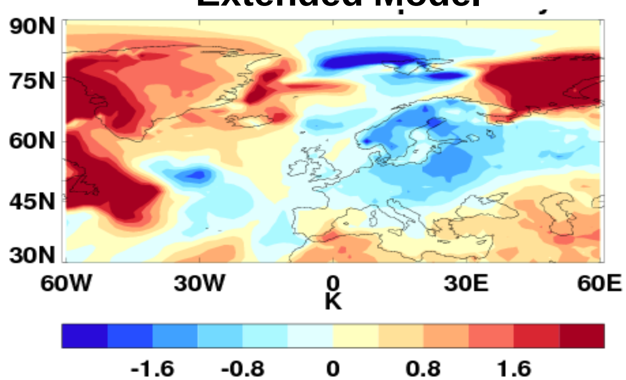


Reforecasts

Standard Model



Extended Model



Always significant internal variability but:

El Nino and E QBO in right phase for weak jet and -NAO

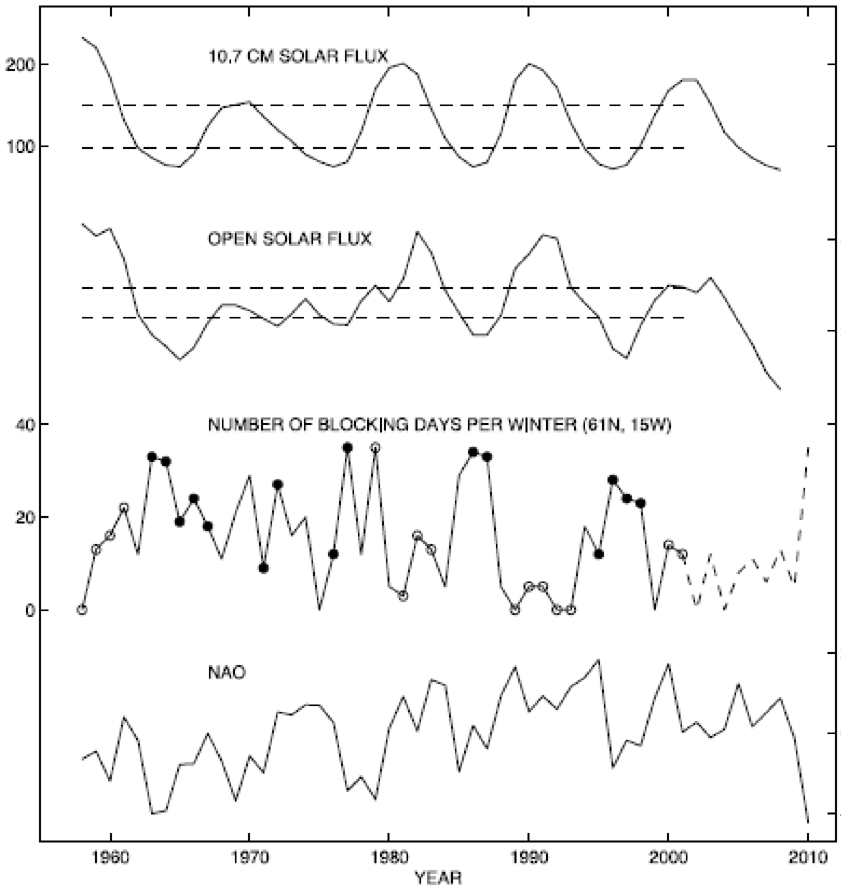
More predictability than currently realised…..

Fereday et al, ERL, submitted

Multiannual Prediction

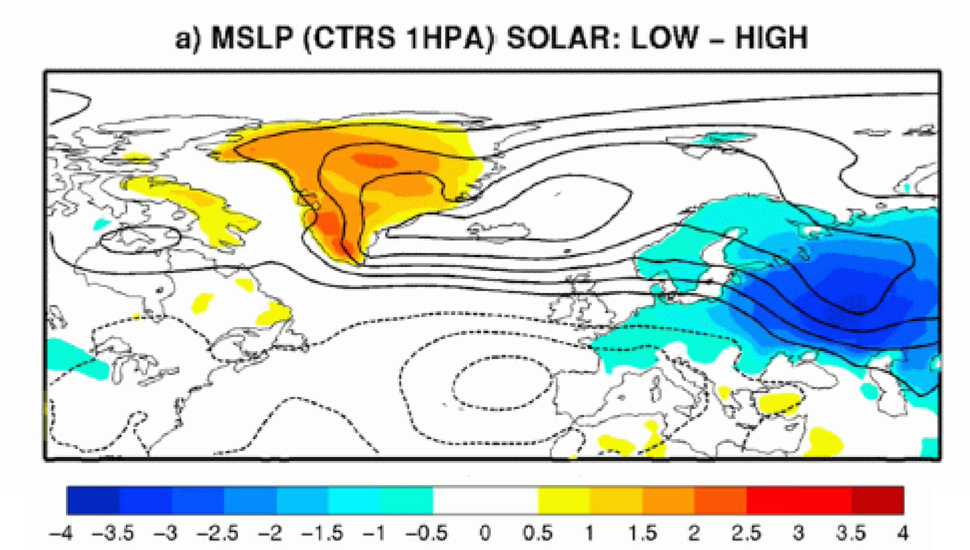
- **Single example: SOLAR VARIABILITY**

Observed solar effects on Europe in winter



Composite difference between low and high solar activity

NAO-like pattern and cold anomalies over Europe



2m temperature

Woollings et al., 2010, GRL,

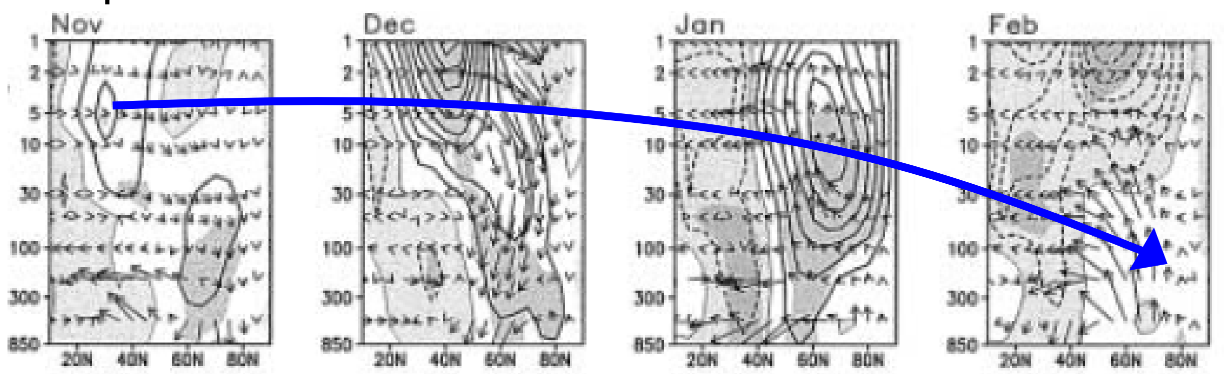
Lockwood et al., 2010, ERL

Observed solar variability

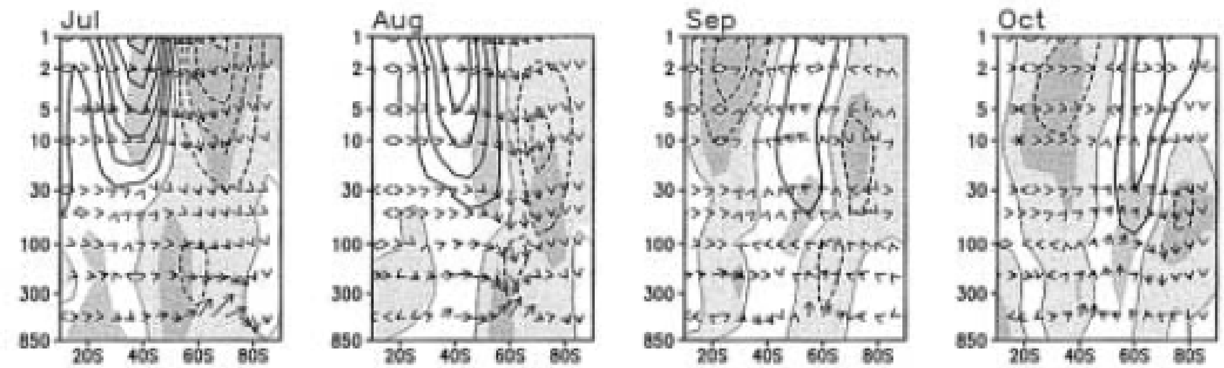
Solar maximum minus solar minimum from the 11 year cycle

Descending wind anomalies, Winter only, strongest in NH

N. Hemisphere winter

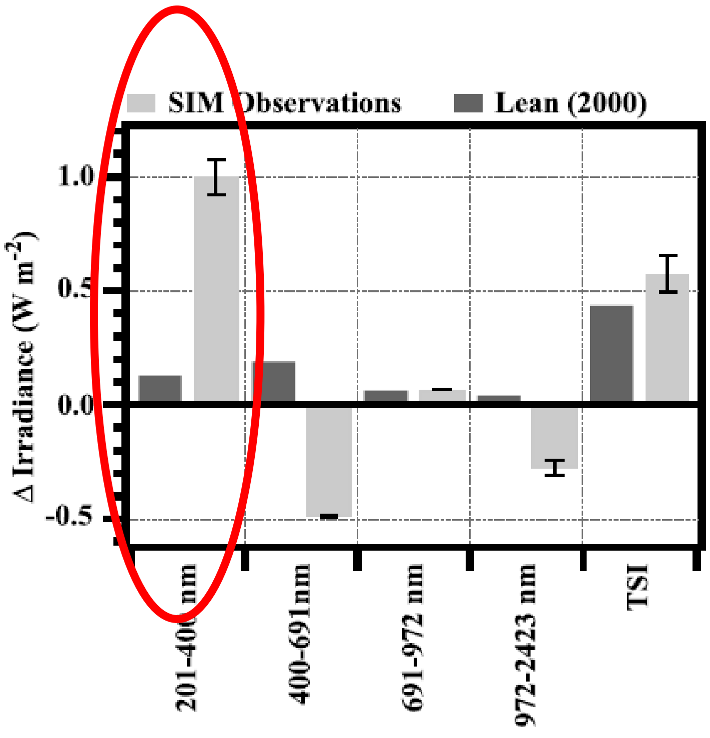


S. Hemisphere winter



Kuroda and Kodera, 2002, JMSJ

New satellite UV data: the SIM instrument on board SORCE

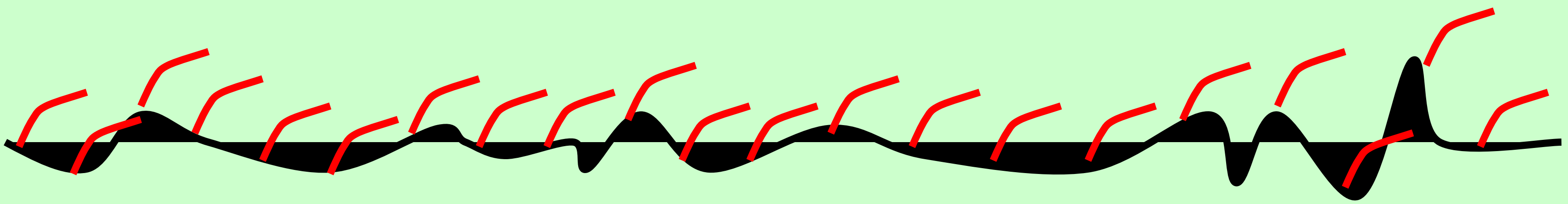


SIM observations indicate a decline in ultraviolet from 2004-2007 that is a factor of 4 to 6 times larger than the NRL model of solar variability

Harder et al., 2009, GRL

Experiment: solar min-max

- **HadGEM3, Hadley Centre ocean-atmosphere climate model**
    - **Well resolved middle atmosphere**
    - **Internally generated QBO** **(Scaife et al., GRL, 2000)**
- **Solar minimum (80 yrs): control run**
- **Solar maximum (20 x 4 yrs) with +1.2Wm^{-2} in 200-320nm** **c.f. Harder et al 2009**



- **Climatological ozone***

* Is neglecting ozone changes a reasonable thing to do? YES if SIM data are correct:

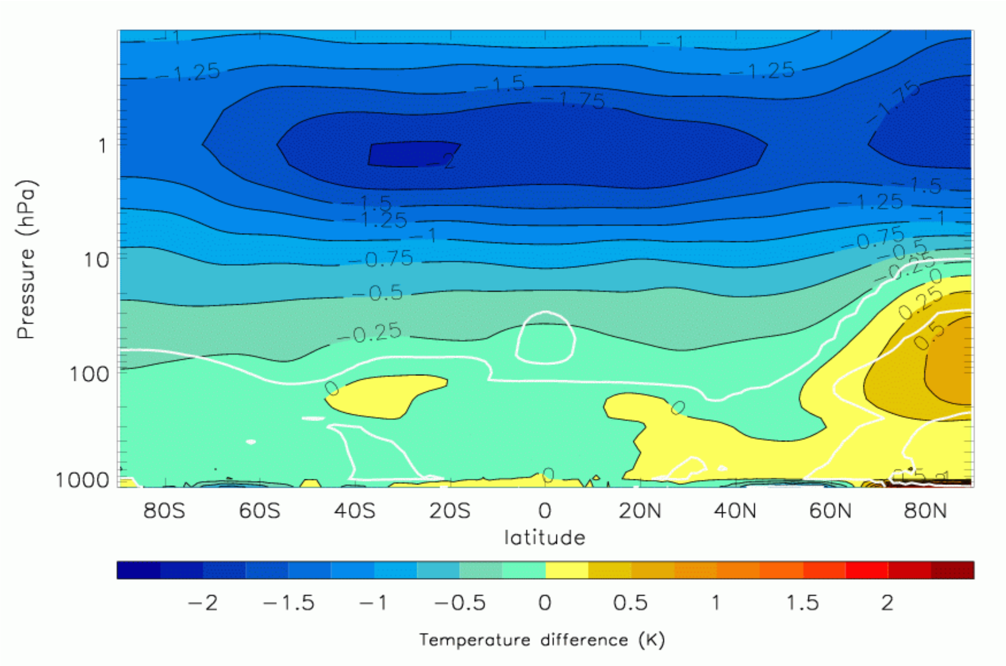
Heating Rate ~ { O_3 + ΔO_3 } . { UV + ΔUV } **$\Delta O_3/O_3 \sim \Delta UV/UV|_{Lean} \sim 0.2\Delta UV/UV|_{Harder}$**

Cooling of the equatorial stratopause at solar minimum

Weaker meridional temperature gradient

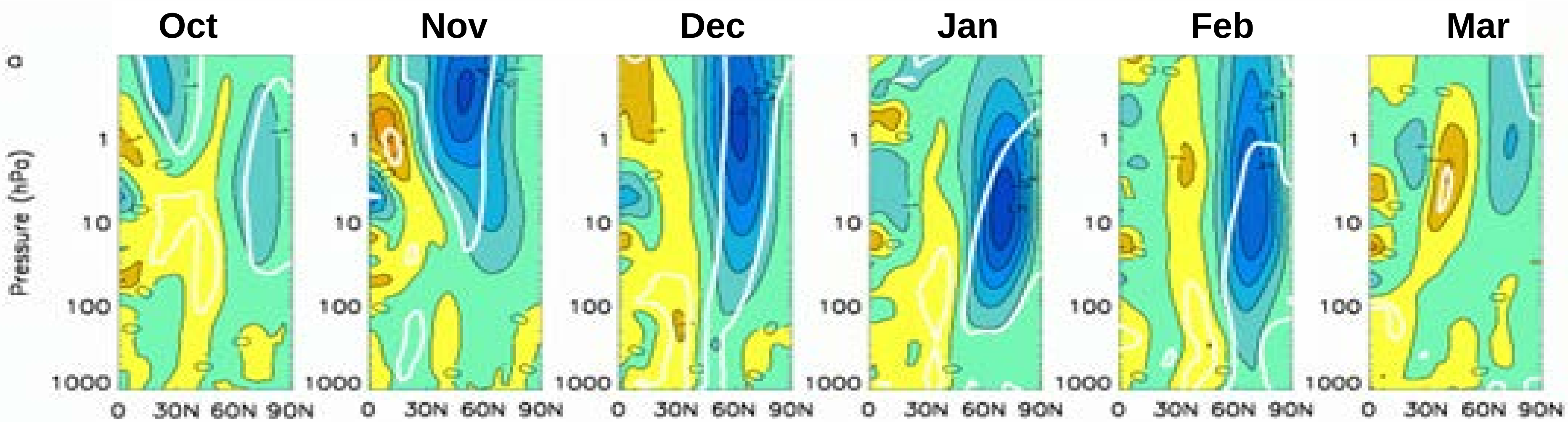
Weakened westerly flow

Annual zonal mean temperature



Ineson et al., Nat. Geosci., 2011

Poleward and downward propagation of wind anomaly – winter *only*

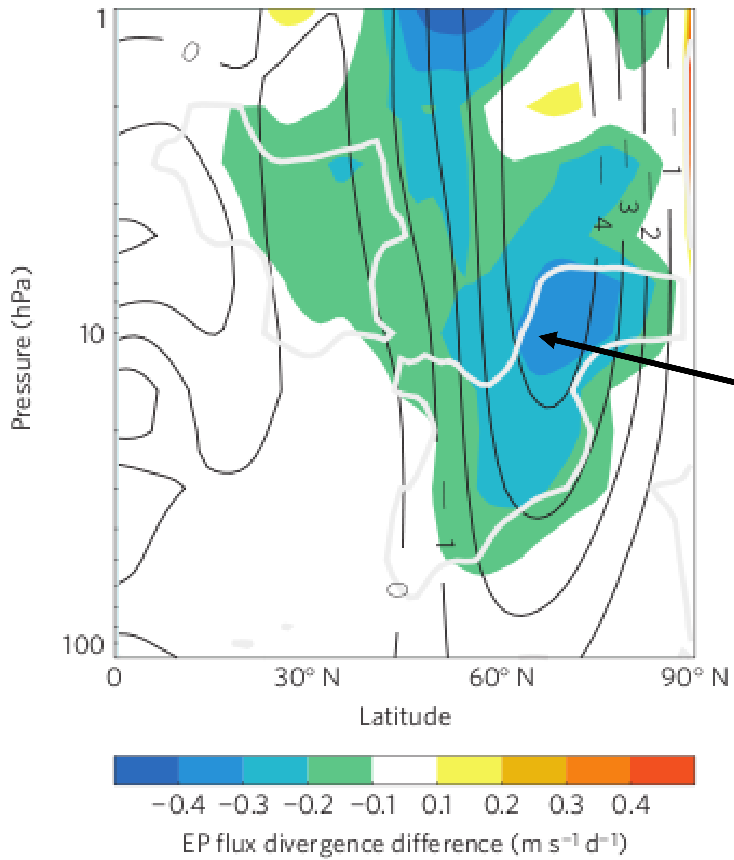


Similar to wave mean flow interactions seen in other contexts

Ineson et al., Nat. Geosci., 2011.

Mechanism: descent through the stratosphere

zonal mean zonal wind (contours) and EP flux divergence (cols)



$$\frac{\partial u}{\partial t} - 2\Omega \sin\phi\, \overline{v}^{*} = \boldsymbol{F}$$

After Andrews and McIntyre 1978

increase in planetary wave driving **F**

⇒ deceleration just *below* easterly wind anomaly

⇒ *descent* of the anomaly

Ineson et al., Nat. Geosci., 2011.

Mechanism: Impact on the troposphere

Decreased vertical wind shear

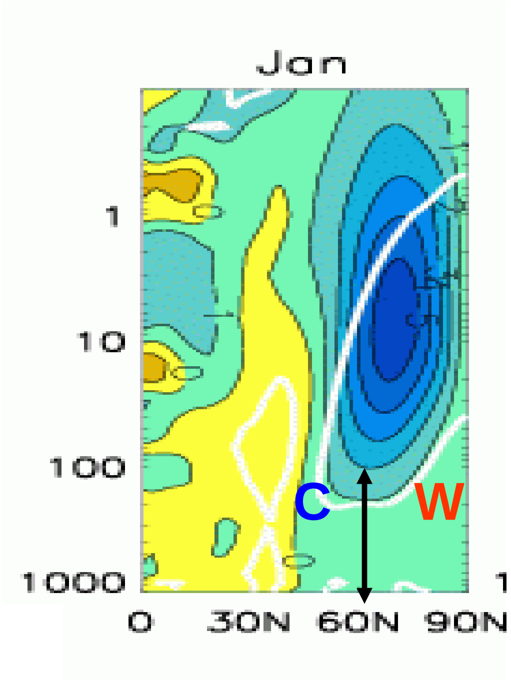
⇒ Reduced baroclinic eddy growth:

$$\text{Growth Rate} = \sigma = \frac{0.3U_z f}{NH}$$

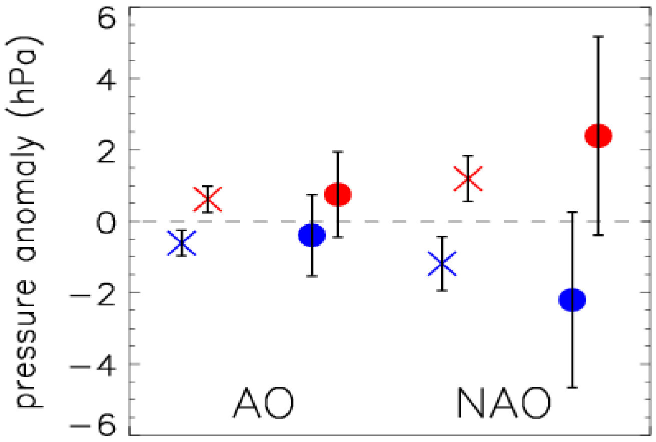
***Expect* negative NAO/AO**

Occurs across all our examples

e.g. Scaife et al., Clim. Dyn., 2011

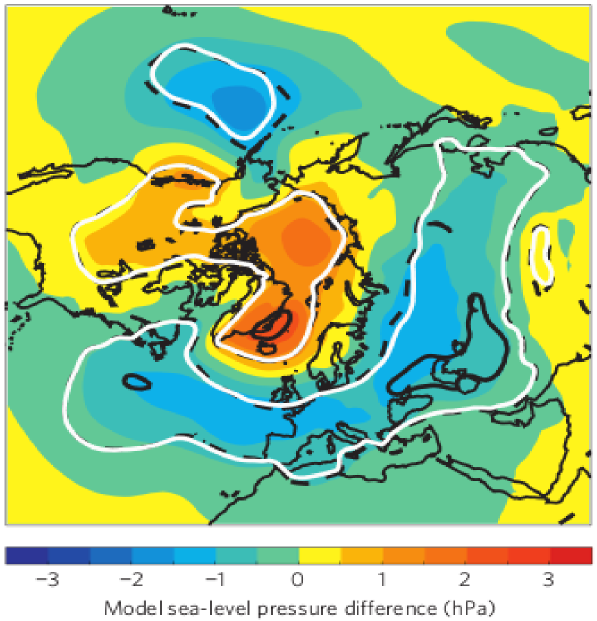


Arctic Oscillation / North Atlantic Oscillation response

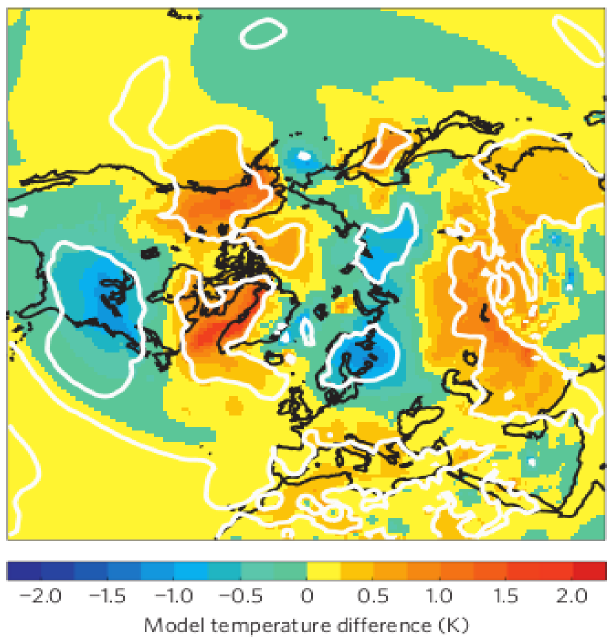


Winter surface climate response (solar min – solar max)

Sea level pressure



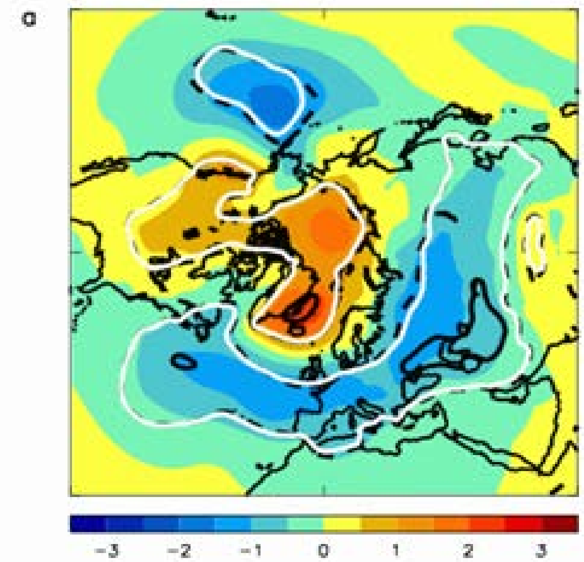
Surface temperature



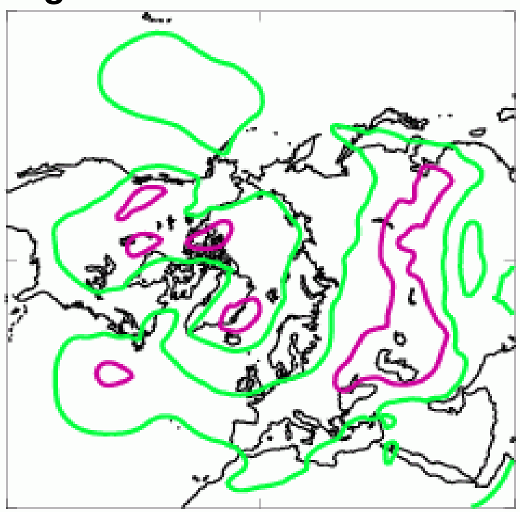
Ineson et al., Nat. Geosci., 2011.

Large enough to be useful?

Sea Level Pressure Signal



Signal to noise ratio

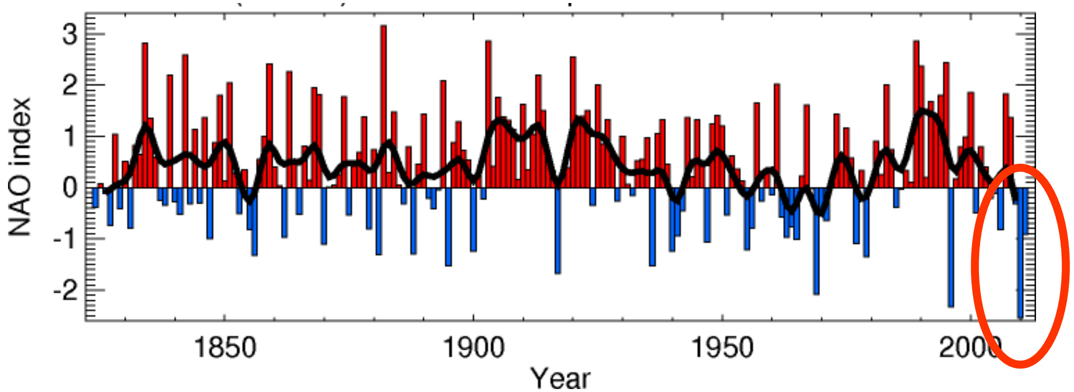


Potentially very important for seasonal to decadal forecasting

purple (green) contour indicates 50 (25)% of interannual standard deviation

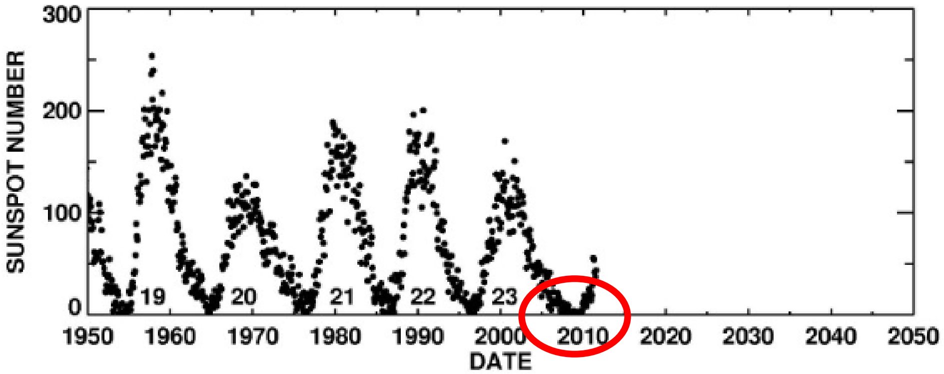
Winter 2009/10: three factors conspiring?

Record low NAO

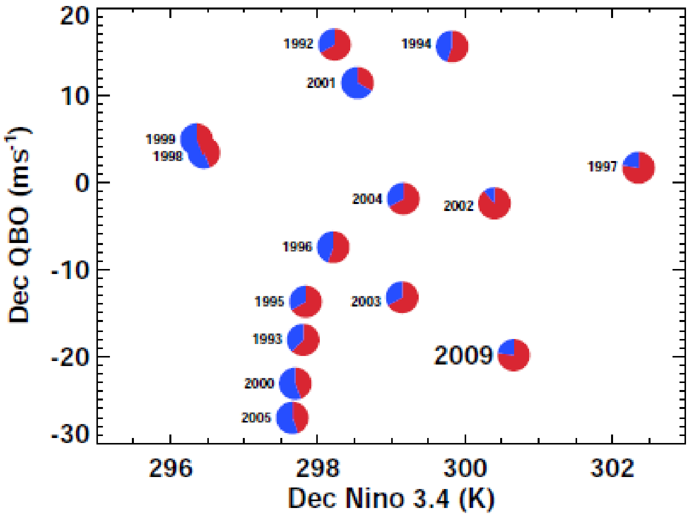


Barcelona, Spain, March 2010

Solar Minimum



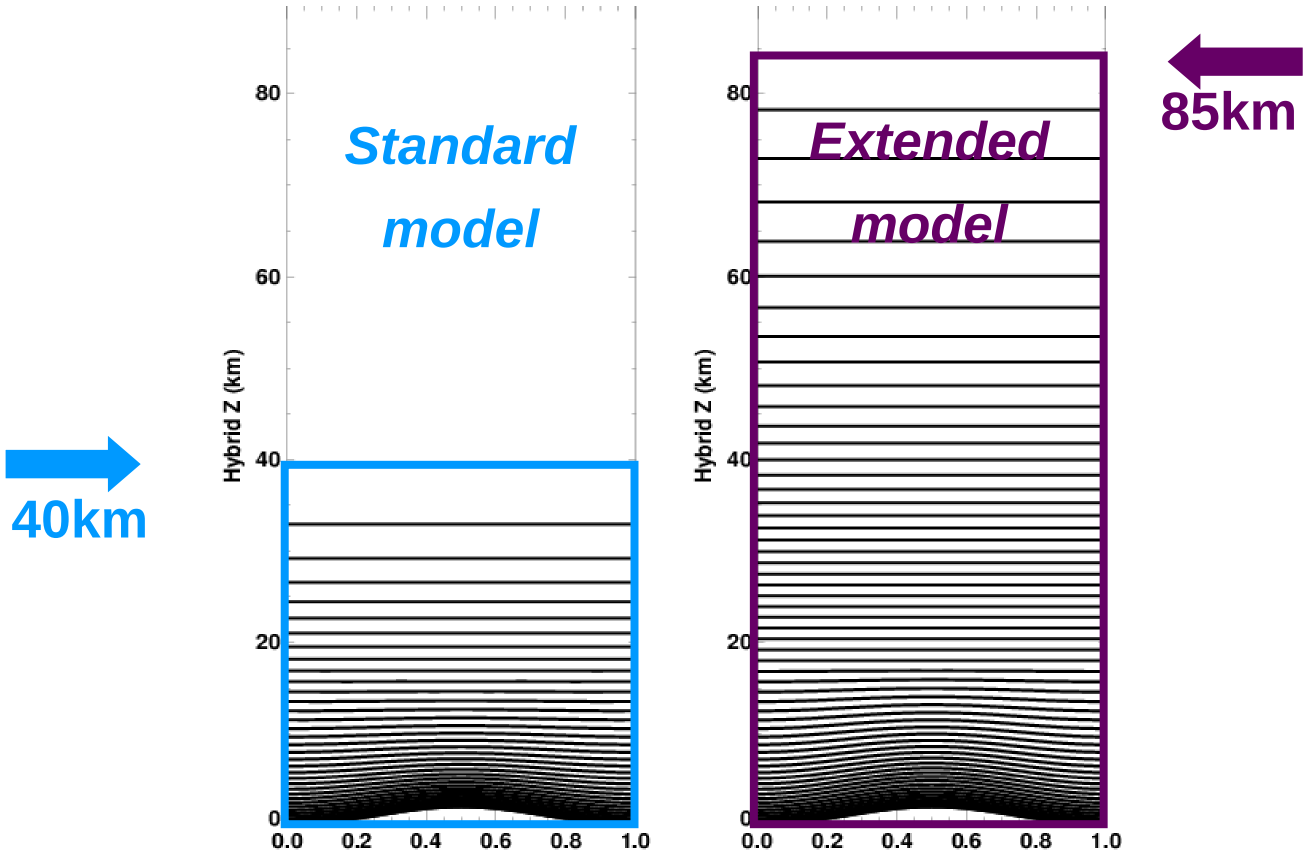
El Nino & QBO



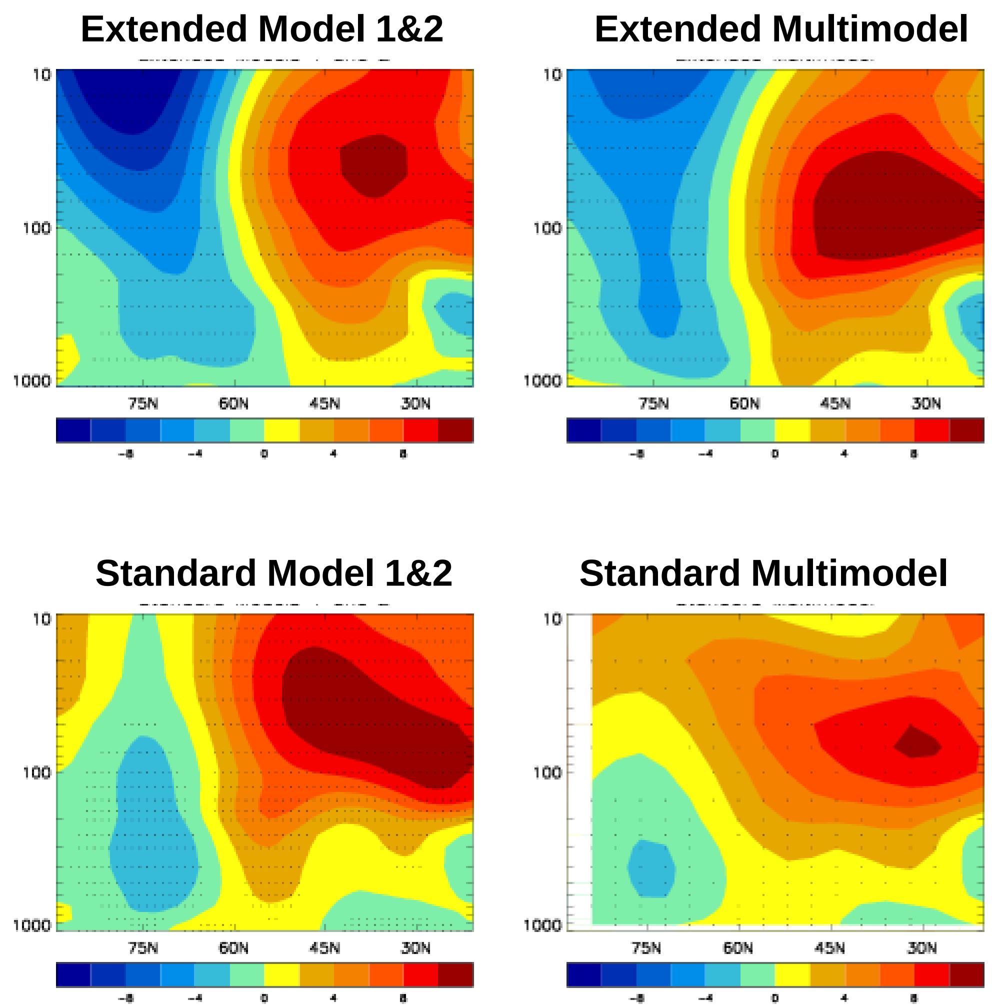
Long Term Change

- $4xCO_2$ studies with HadGEM, EGMAM and low vertical resolution versions
- Complemented by multimodel simulations

Extended and Standard Models



Climate Change in Atlantic Winds

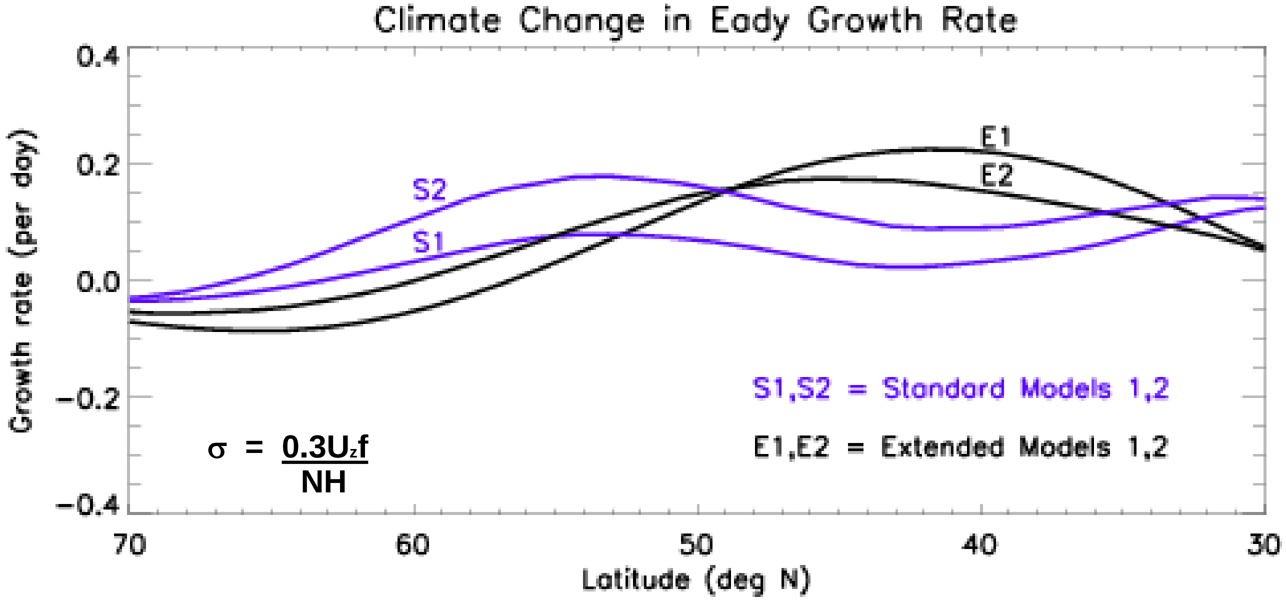


Increase in meridional winds and the Brewer-Dobson circulation => Dipole in zonal wind

Extends into troposphere

Scaife et al, Clim. Dyn., 2012

Eady (linear) Baroclinic Eddy Growth Rate



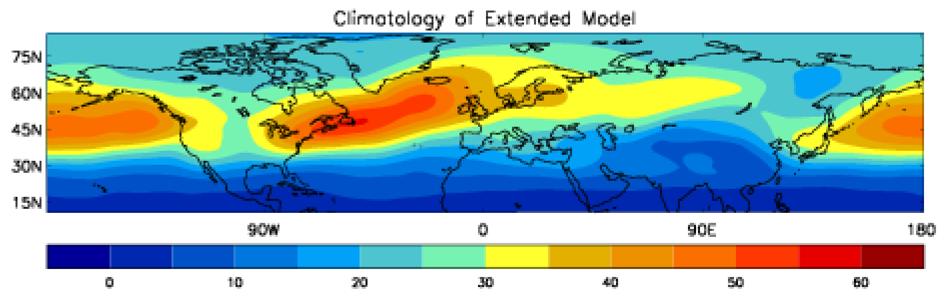
Increased growth rate at high latitudes in standard models from increased vertical shear

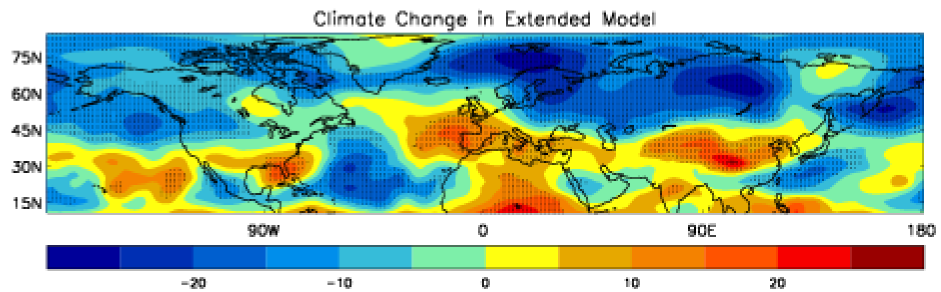
At mid latitudes in extended models

Scaife et al, Clim. Dyn., 2012

Storm Track Changes

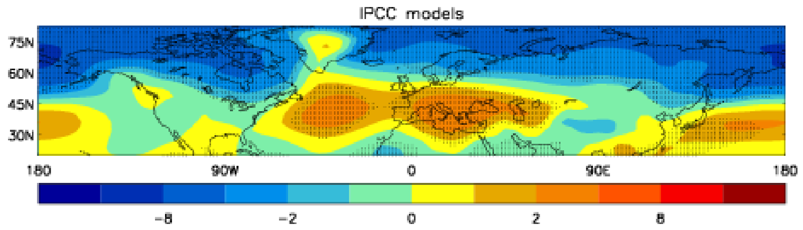
Fractional change in 500hPa eddy activity



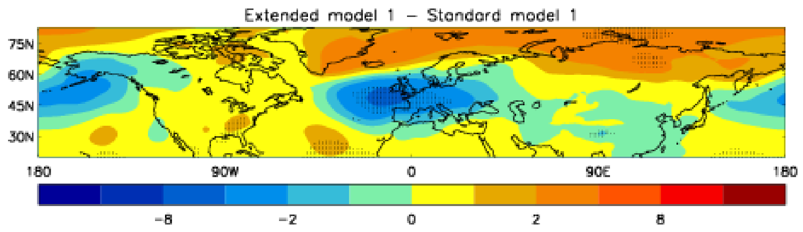


Scaife et al, Clim. Dyn., 2012

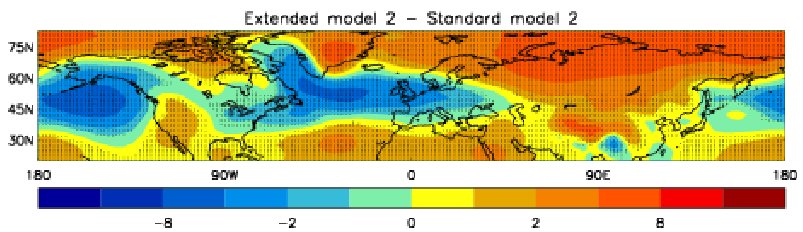
Sea Level Pressure Change



IPCC AR4 Models



Extended – Standard HadGEM



Extended – Standard EGMAM

Scaife et al, Clim. Dyn., 2012

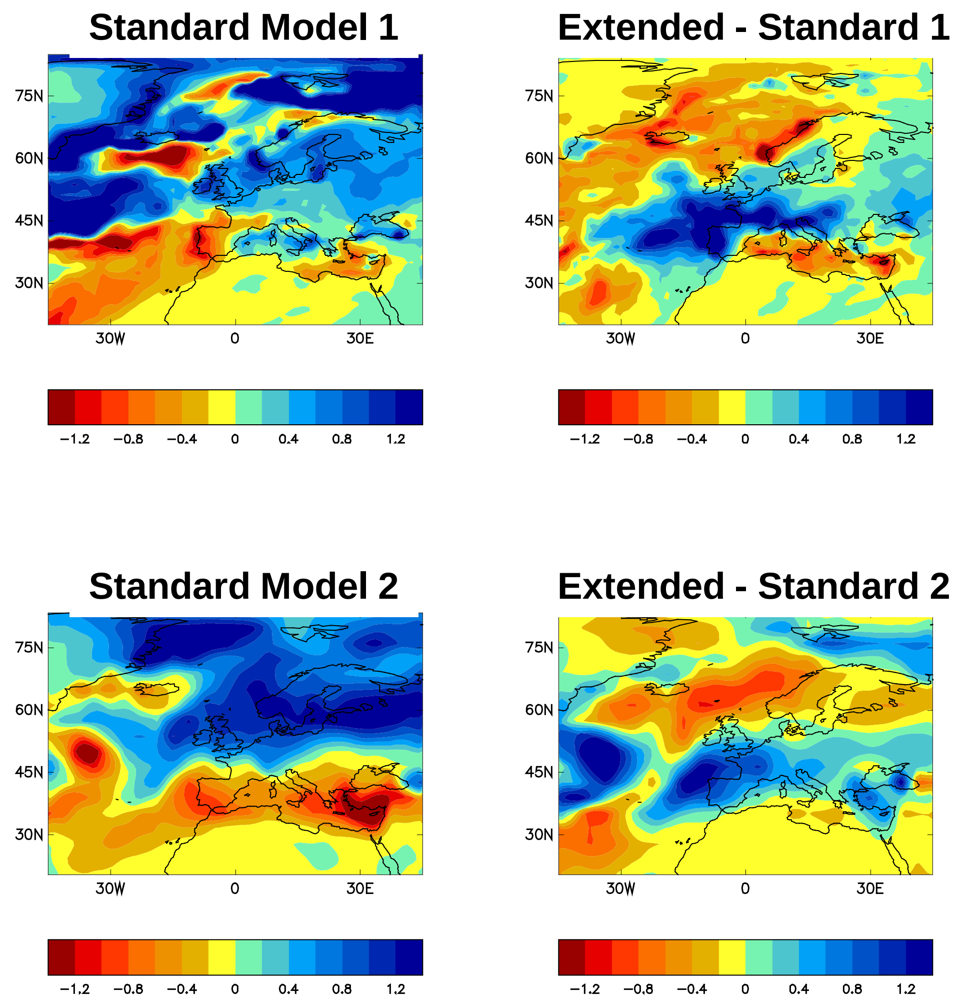
Rainfall Impacts

Standard (IPCC) models wetter in winter

Makes a robust difference

Error is similar size to original signal

European climate prediction needs extended models



Scaife et al, Clim. Dyn., 2012

Extreme Rainfall

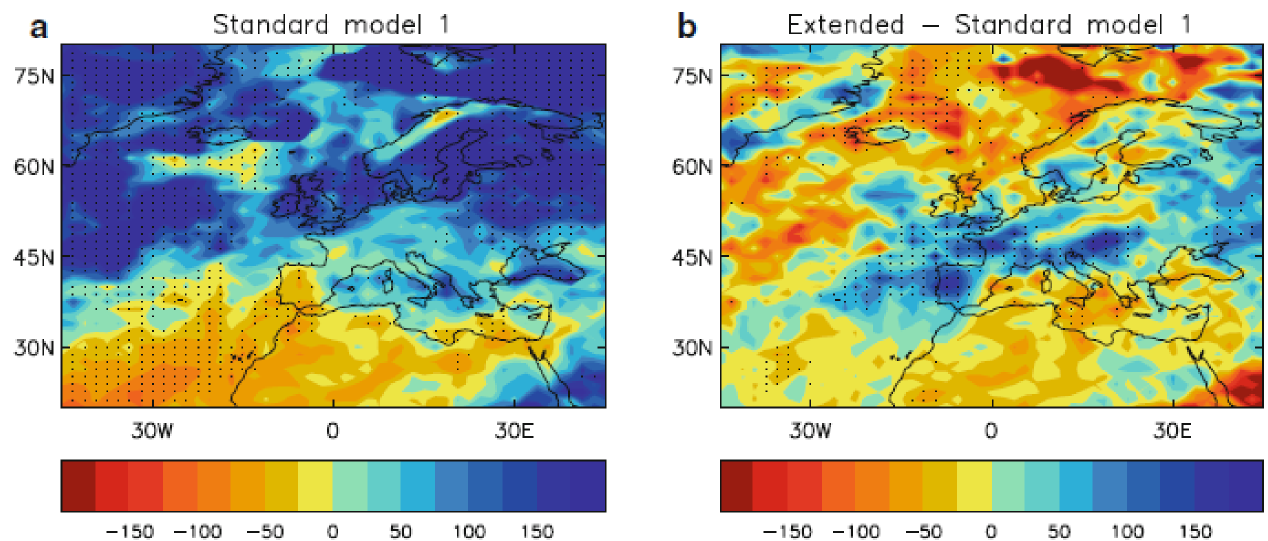


Fig. 7 Percentage change in the frequency of extreme rainfall in extended model 1 (daily data for model 2 were not available for this calculation. The very marked similarity between mean rainfall changes and rainfall extremes is easily seen by comparison with Fig. 6 for model 1). Extremes here are defined as 98th percentile daily totals at each model grid point. Climate change in standard model 1 (a) and the difference between extended and standard model 1 (b). Hatching shows where the change in mean rainfall is statistically significant at the 95% level according to a *t* test and has the same sign as the change in extreme rainfall frequency

Large increase in frequency of extreme rainfall in western and central Europe

Extra increase as big as, and in some regions outweighs, the original signal e.g. Spain

Scaife et al, Clim. Dyn., 2012

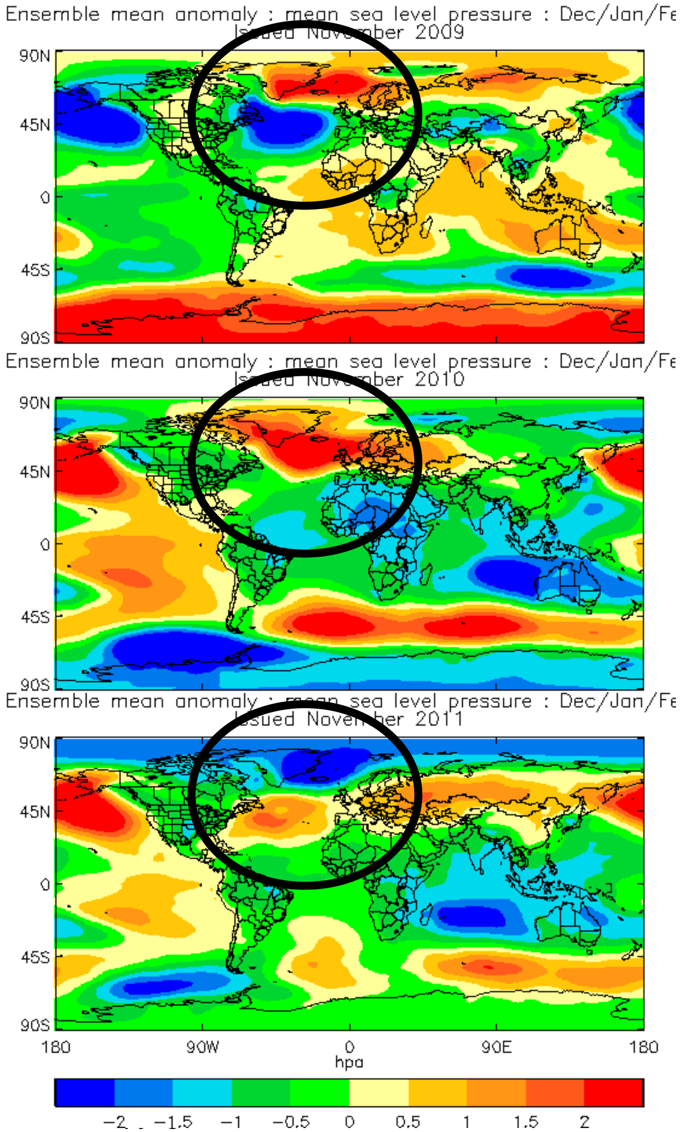
SUMMARY

- **Stratosphere-troposphere interaction is important for surface climate and can provide *conditional* skill on seasonal timescales:**
  - **SUDDEN WARMINGS => monthly NAO/AO**
  - **ENSO & QBO => extratropics => stratosphere => winter NAO/AO**
  - **SOLAR VARIABILITY => extratropics => winter NAO/AO**
  - **CLIMATE CHANGE => NAO/AO like effects**
- **Well resolved stratosphere included in the Met Office seasonal forecast system from 2010**
- **We will introduce GloSea5 with increased *horizontal* resolution this Autumn**
- ***Finally, recent real time forecasts….***

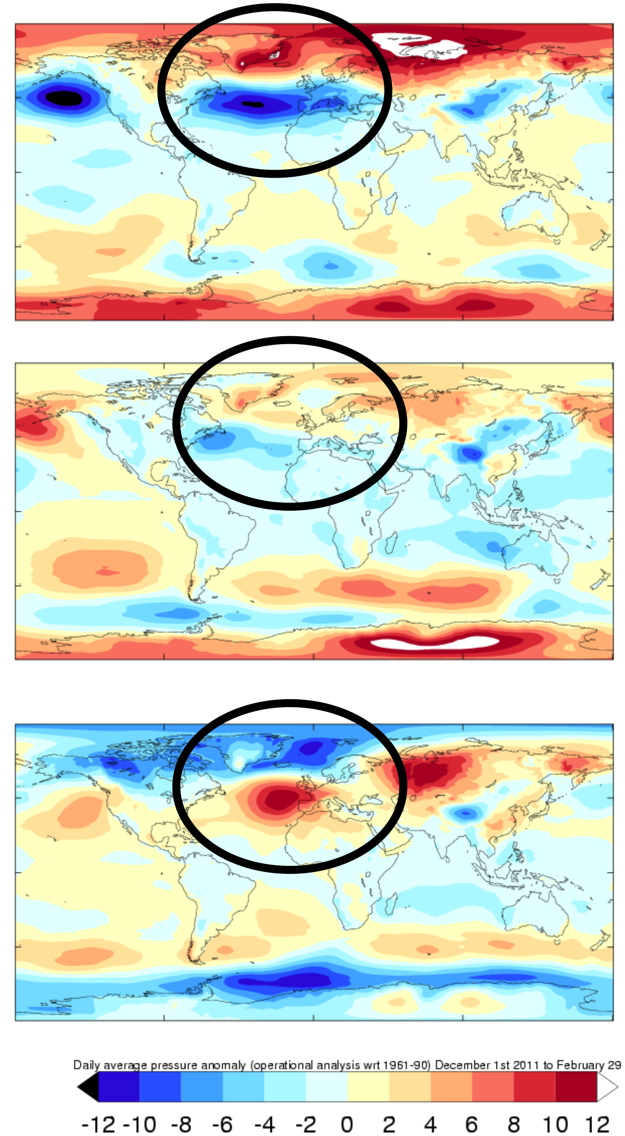
Recent *real time* forecasts from the Met Office

(http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/long-range/forecasts)

Winter Forecast



Observations



2009/10

2010/11

2011/12