Stratosphere-Troposphere Coupling and Climate Prediction

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Outline

- Stratosphere-Troposphere interactions:

  monthly

  seasonal and interannual

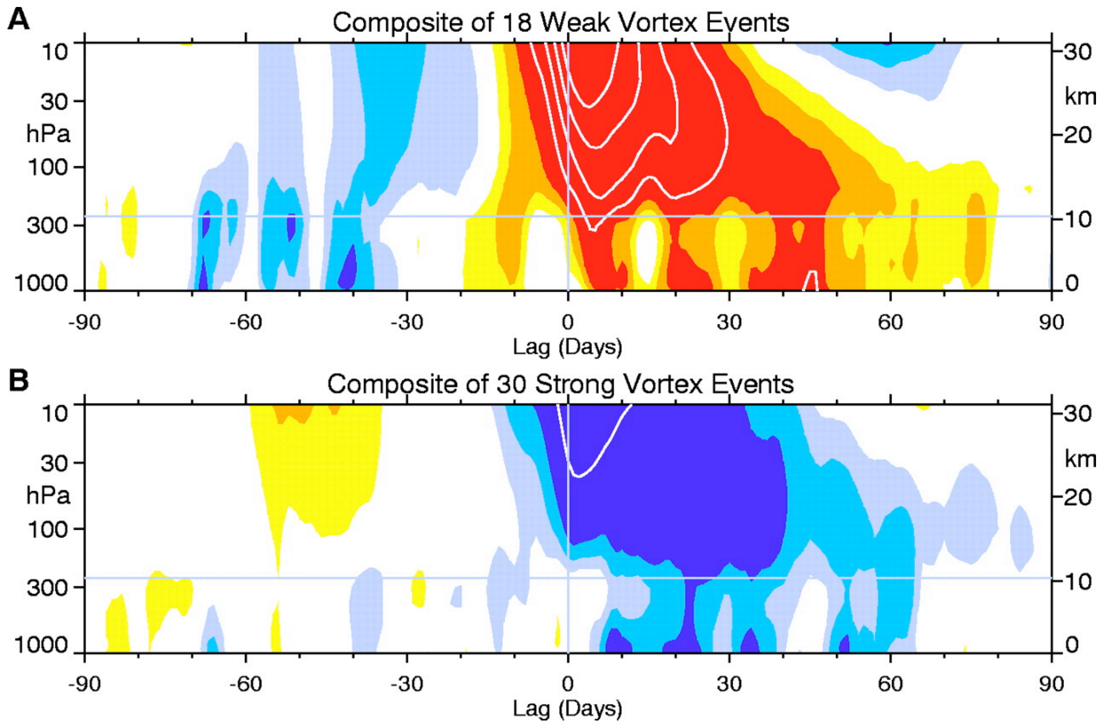
  longer

- Focus on predictability

Monthly Variability

- Early studies suggested an NAO/AO response to imposed stratospheric changes in GCMs
- Observations show downward propagation of wind anomalies from the upper stratosphere to the troposphere
- Some studies show additional predictability from the stratosphere on monthly to seasonal timescales

Downward propagating winds

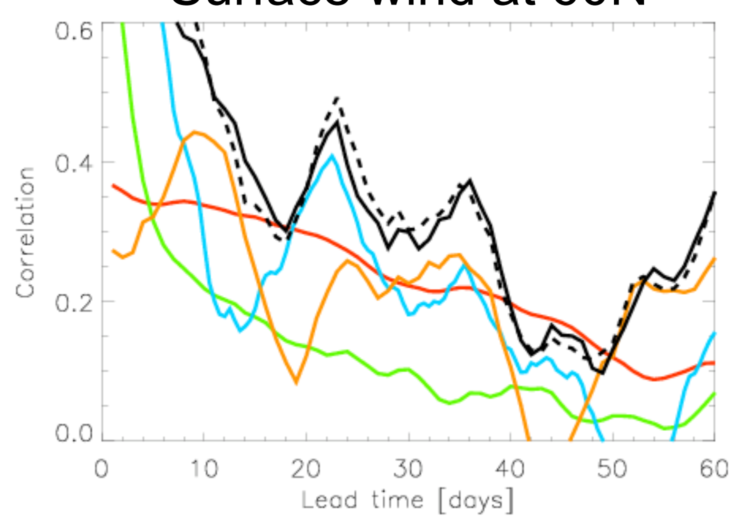


Baldwin and Dunkerton 2001

See also:

Kodera et al 1990, Boville 1984

Surface wind at 60N

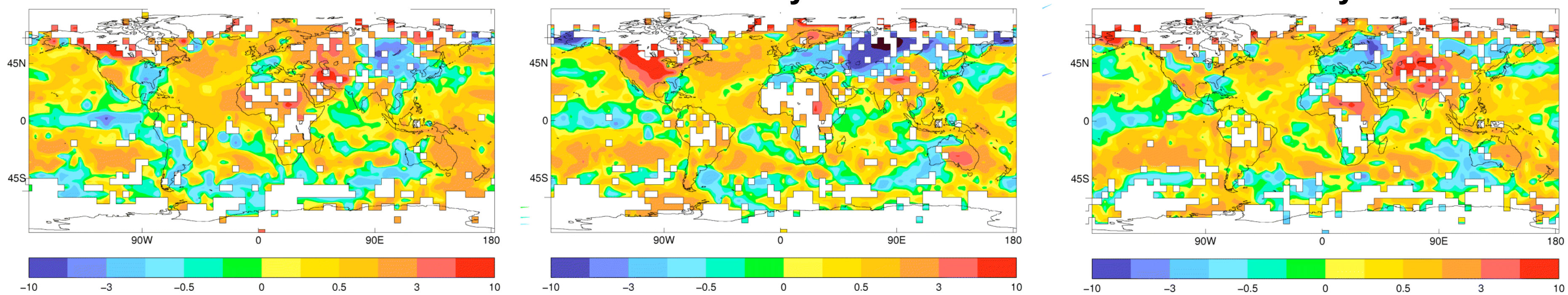


Dynamical forecast
Dynamical forecast + 70hPa stat fcast

Christiansen 2005

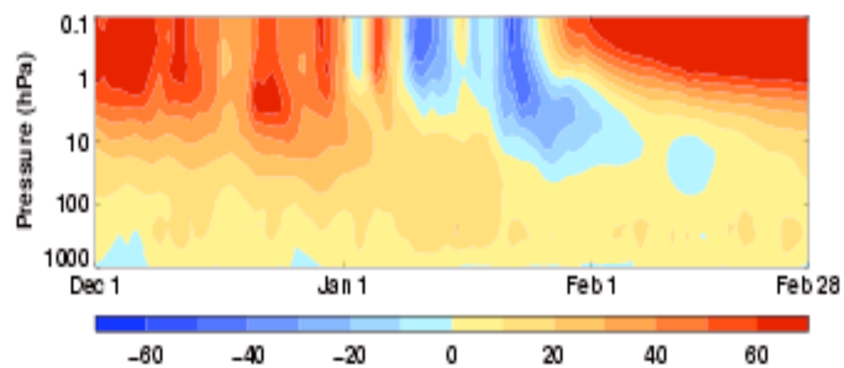
Cold Eurasian winter 2005/6

December 2005 **January 2006** **February 2006**



- **Colder than 1970-2000 over much of Europe**
- **2nd coldest in 10 years using area mean T**
- **Record snowfall in parts of central Europe**
- **Late winter colder than early winter**
- **Intense sudden stratospheric warming**

Zonal wind through the winter

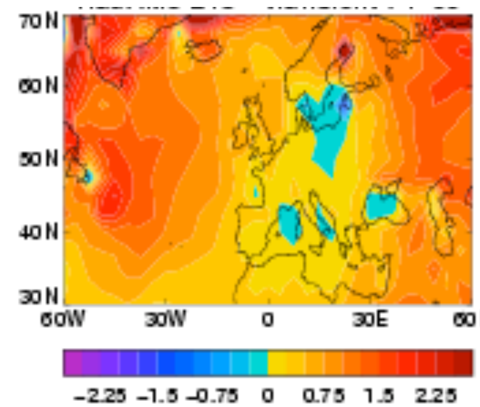


Winter 2005/6

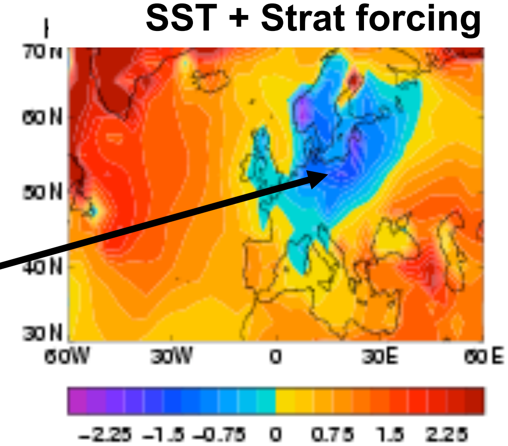
- **Atmospheric model**
  - **50/25 members**
  - **HadISST as a boundary condition**

- **Atmospheric model + stratospheric forcing:**
  - **25 members**
  - **HadISST as lower boundary condition**
  - **Perturbed stratosphere from 1st Jan**

SST only



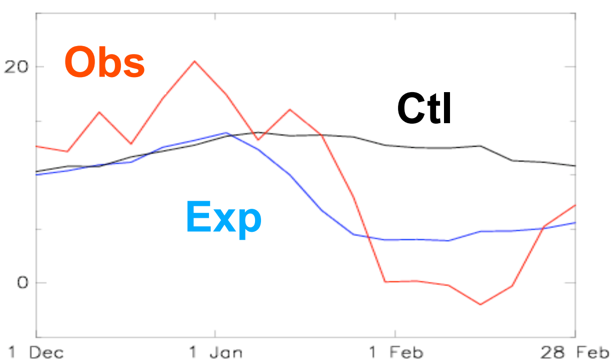
SST + Strat forcing



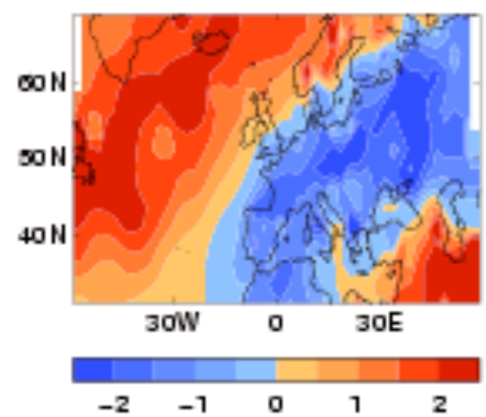
Cold European signal from *IMPOSED* stratospheric warming

Even clearer example in winter 2008/9

Zonal wind at 50hPa



Observations



Scaife and Knight, QJRMS, 2008

Cold Air Outbreaks across NH

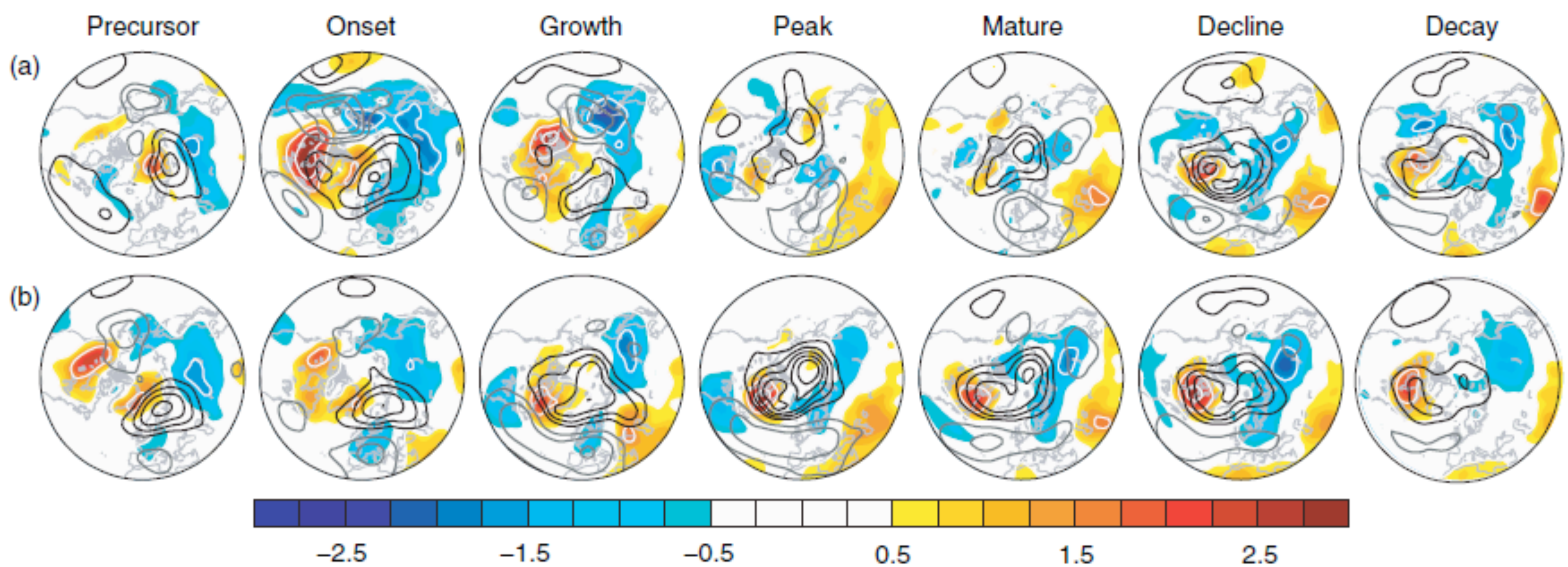


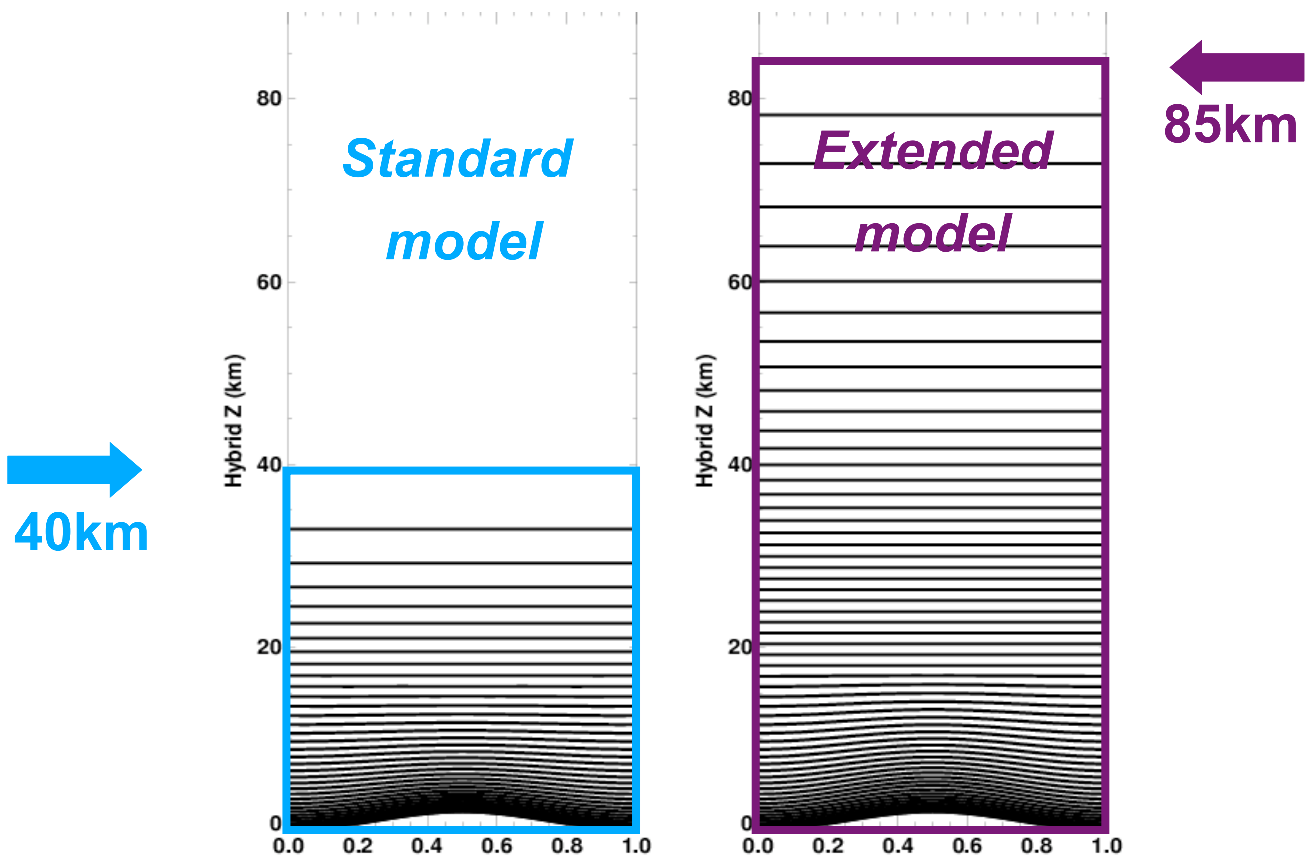
Figure 2. Composites of 850 hPa geopotential height anomalies (in m with solid contours, positive in black, negative in grey, contour interval 10 m, zero contour omitted) and 850 hPa temperature anomalies (in K with filled contours, with white contours along the values specified on the colour bar) relative to (a) SSW central dates and (b) WVDs, averaged over the specified time intervals. The region shown is the Northern Hemisphere north of 30°N, with Eurasia to the right and North America to the left.

Kolstad et al (2010)

Scandinavian blocking precedes warmings

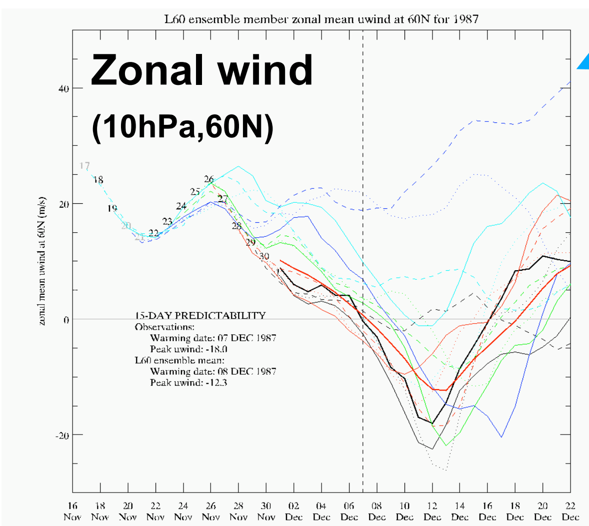
Negative Arctic Oscillation / North Atlantic Oscillation follows with cooling across the whole of northern Eurasia

Extended and Standard Models



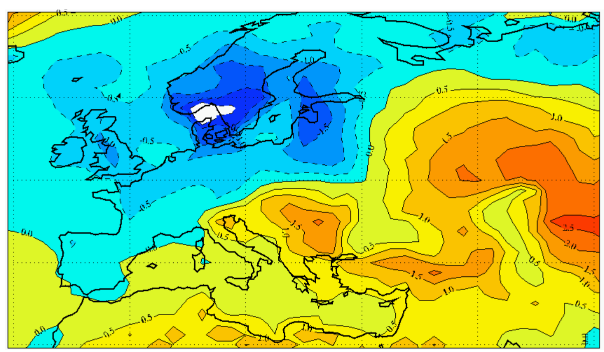
Predictability of stratospheric warmings

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

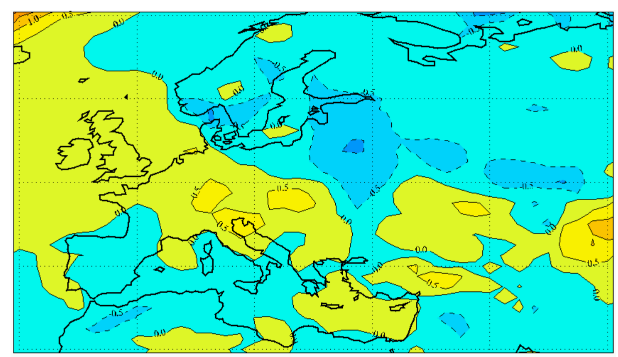


Improved seasonal prediction of European winter cold spells:

Extended



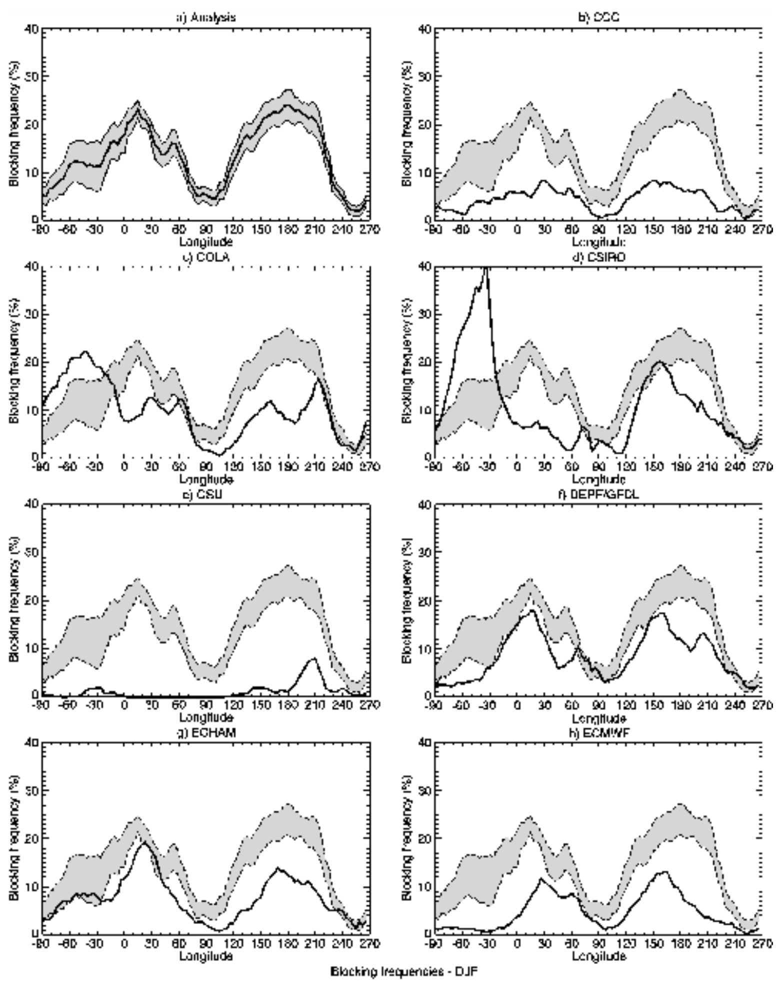
Standard

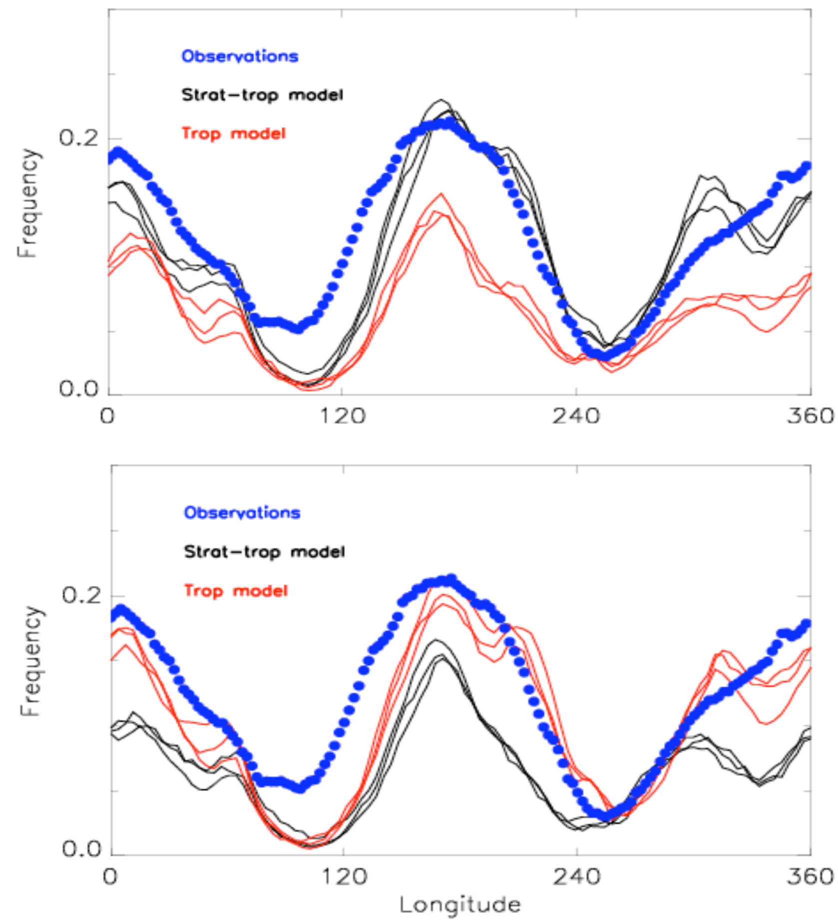


Marshall and Scaife, in press

Atmospheric blocking

Climate model blocking frequencies
(D’Andrea et al. 1997, Tibaldi and Molteni 1990)





Climate models underestimate blocking frequency after >5 days: this could be a major error in predictions

Strat - trop model reproduces maximum blocking frequency in both Pacific and Atlantic sectors

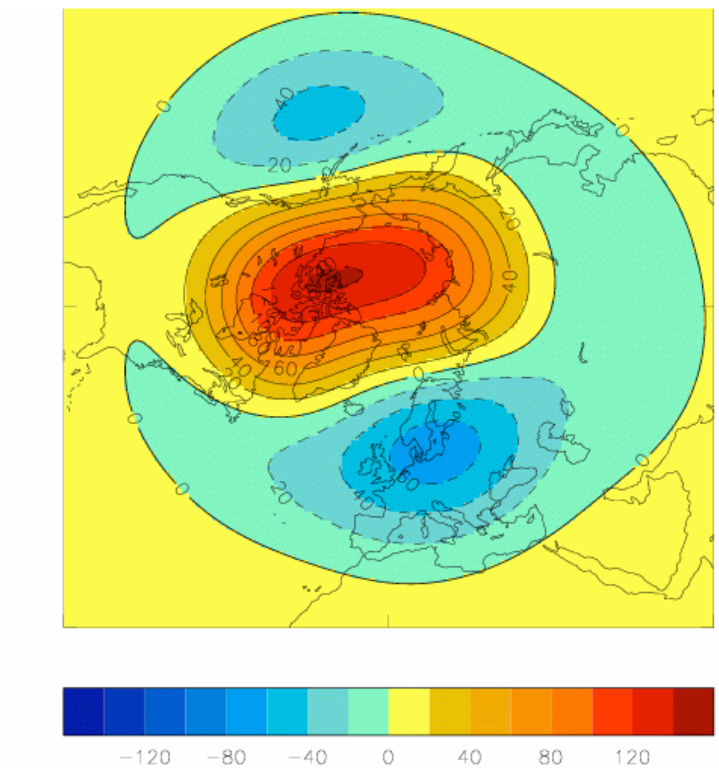
Is this true in general?

Seasonal to Interannual Variability

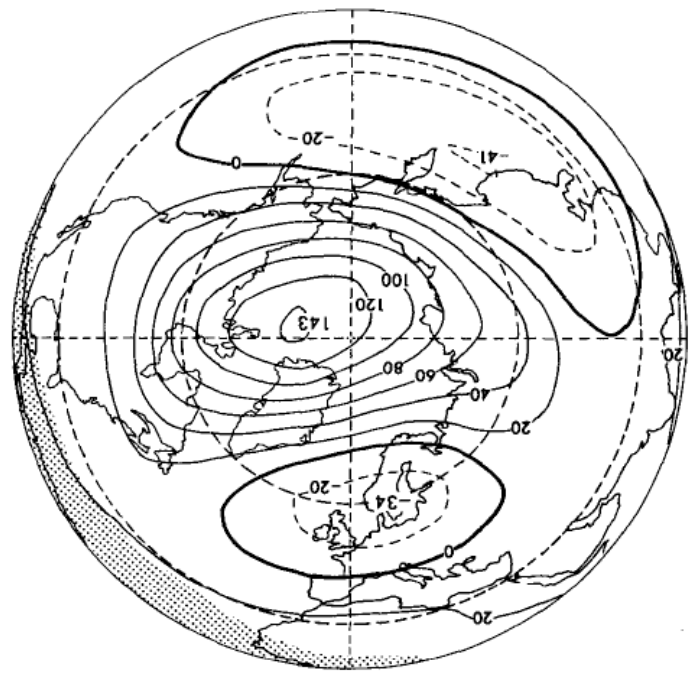
- It is not only the ocean which contains a long memory - stratospheric processes have a long memory too! The QBO has a period of 2-3 yrs and is predictable for 1-2 cycles.
- Key mechanisms of interannual to decadal variability can also involve stratospheric processes.
- Two recent examples…..

ENSO teleconnections

Model El Nino anomaly
(50hPa geopotential height)



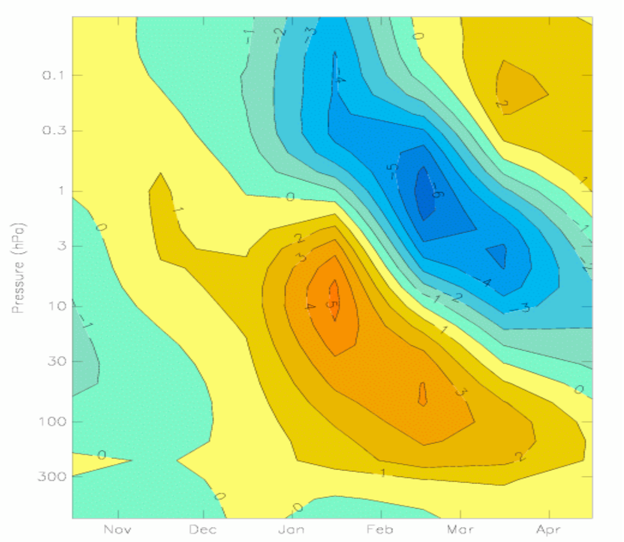
Observations (Hamilton, 1993)



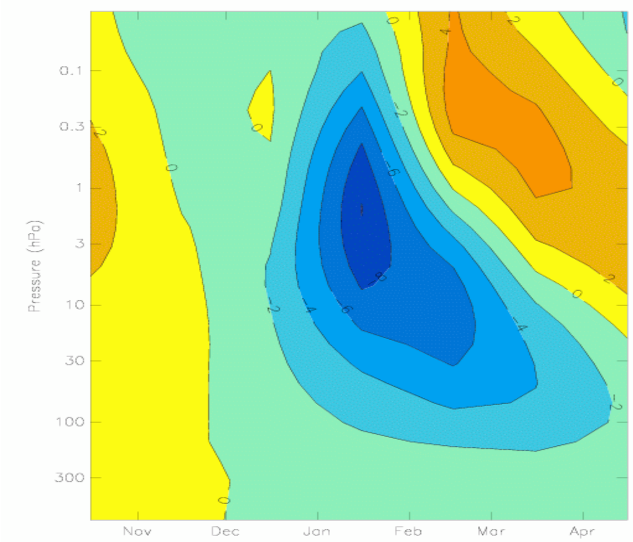
Stratospheric component appears in models (Van Loon and Labitzke 1987, Hamilton, 1993, Manzini et al. 2006)
ENSO events produce a –ve NAO-like response (e.g. Moron and Gouirand 2003, Bronniman et al. 2004)
Clearly visible in 2/3 of observed El Nino events (Toniazzo and Scaife 2006)
Reproduced in numerical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

Downward progression

Temperature



Zonal wind

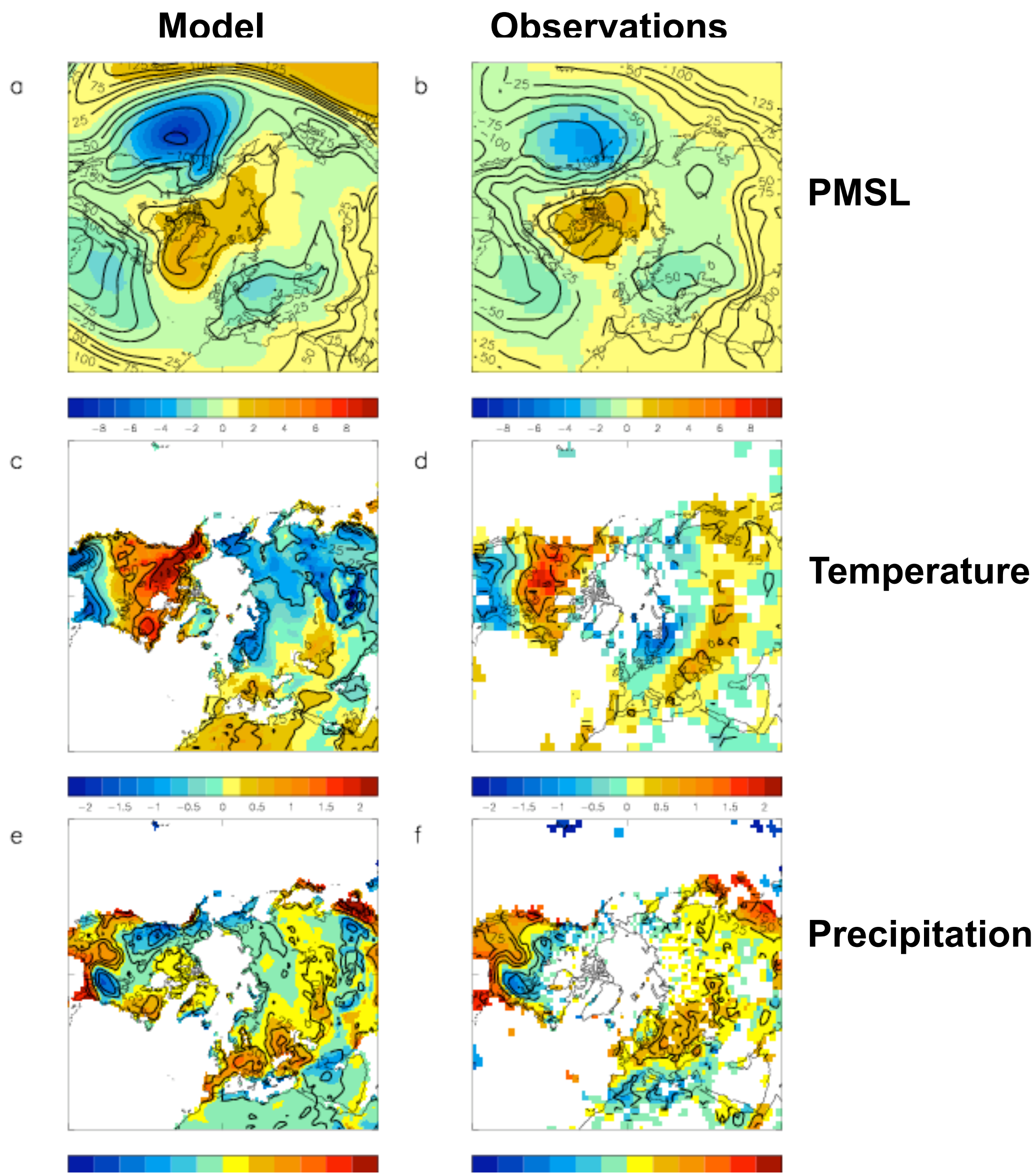


Descending signals

Slower at lower altitudes

Indicative of wave-mean flow interaction from a steady wave source

Surface Climate Impact



Big enough to affect seasonal forecasts

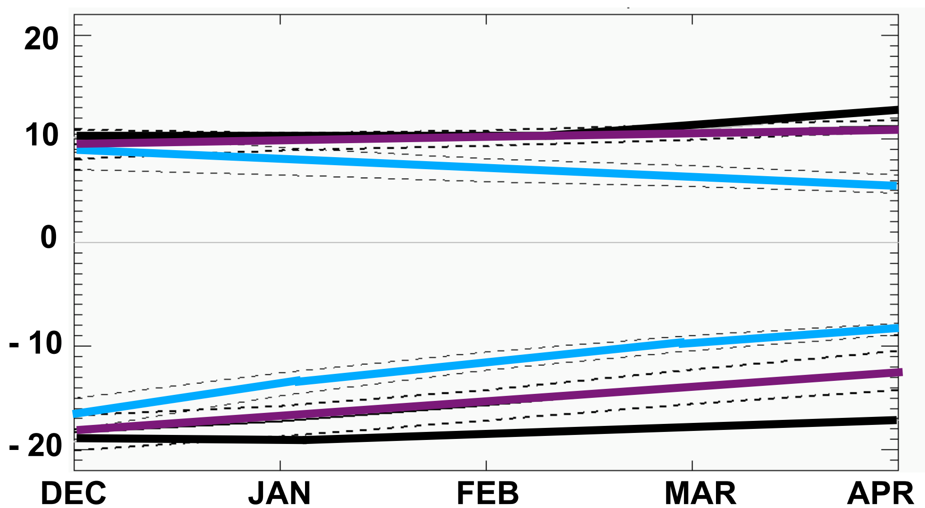
Ineson and Scaife, Nat. Geoscience, 2009

Quasi-Biennial Oscillation in models

QBOW: 1963/64, 1982/83, 1992/93 and 1998/99

QBOE: 1962/63, 1974/75, 1983/84, 1989/90, 1991/92, 1995/96 and 1997/98

QBO anomaly, 30hPa



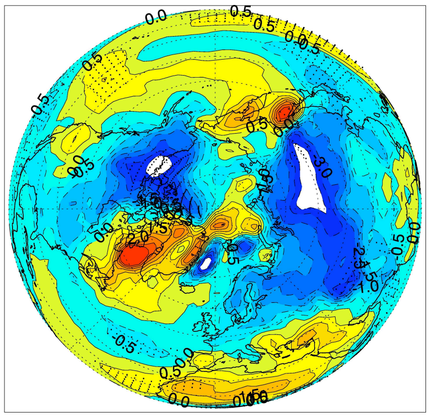
Standard model drifts to weak easterlies **(c.f. Boer and Hamilton 2008)**

Extended model simulates realistic QBO

=> Interannual predictability of extratropics in winter

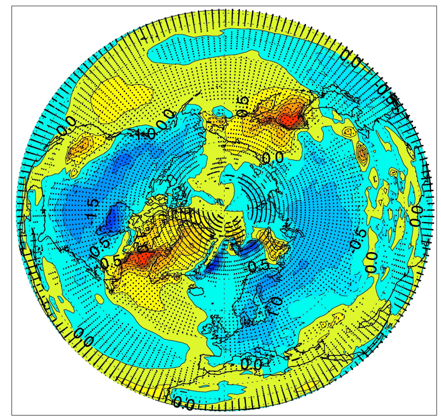
Quasi-Biennial Oscillation

OBS



QBOE-QBOW

MODEL



- **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.

Decadal Changes

- Antarctic climate and ozone depletion/recovery
- Decadal changes in the NAO
- Greenhouse gas forcing

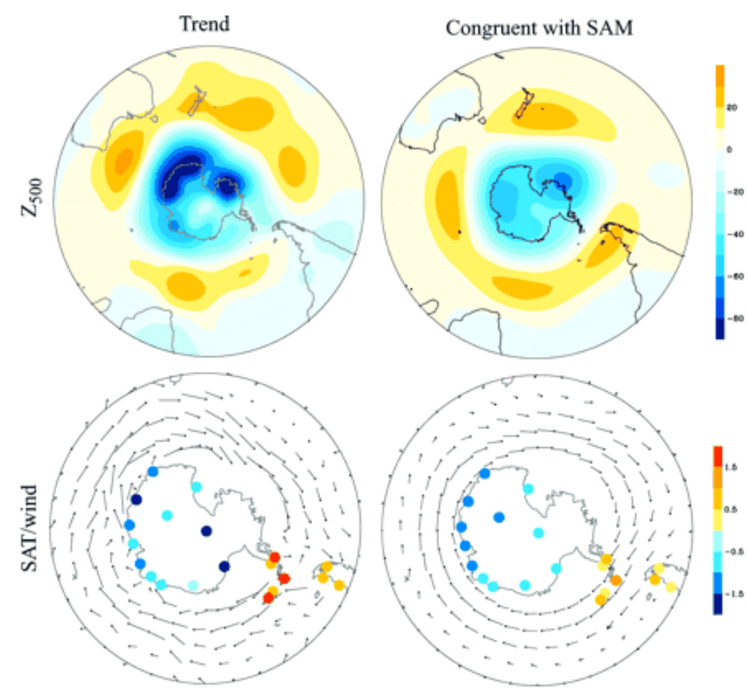
Decadal climate: Antarctica

Ozone depletion led to increased Antarctic winds from the stratosphere to the surface.

Observations and models agree on the impact: cooling over pole surrounded by warming

Ozone recovery expected by ~2060 so this signal will reverse

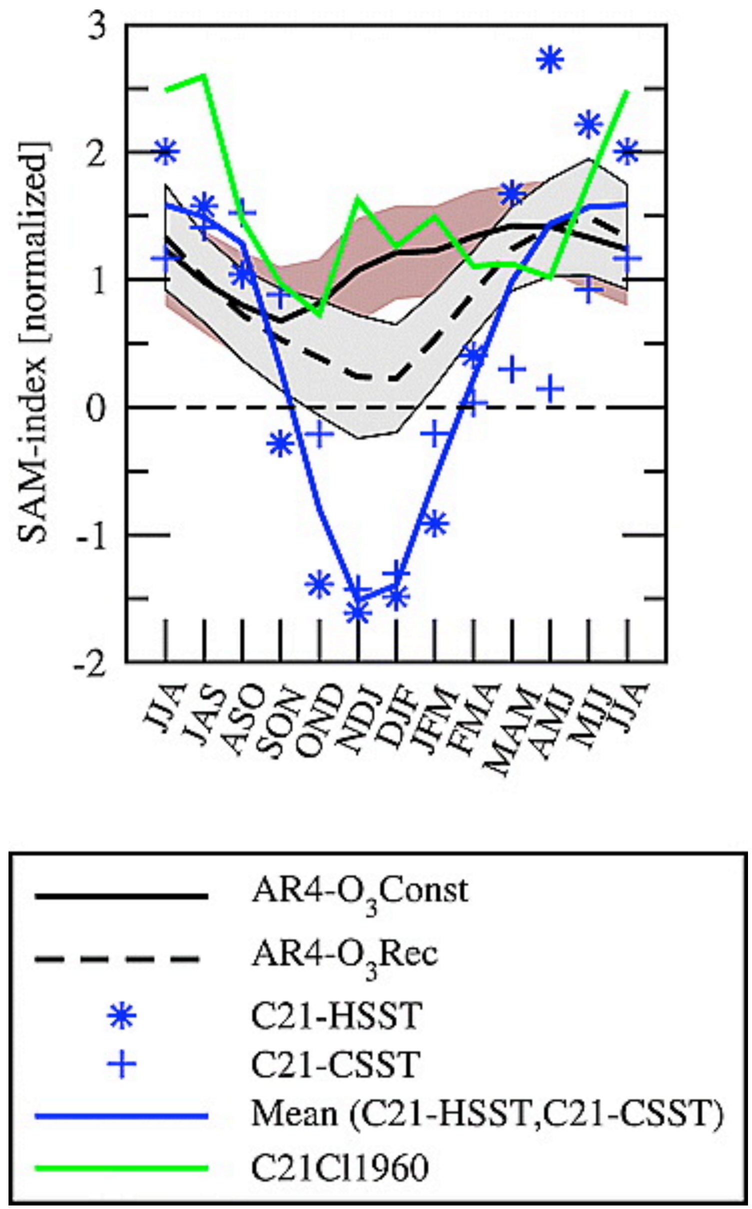
Potential for decadal prediction skill?



Change per 30 yrs, Thompson and Solomon (2002)

Antarctic Change

- Ozone depletion is primary reason for Antarctic circulation change and recent cooling (CO_2 adds to this)
- Ozone recovery will reverse this and add an Antarctic warming component in future
- Extended models can give a bigger signal in surface climate than IPCC models
- Son et al. 2008 suggest this is true of climate models in general



Perlwitz et al 2008

Decadal Climate: N Atlantic

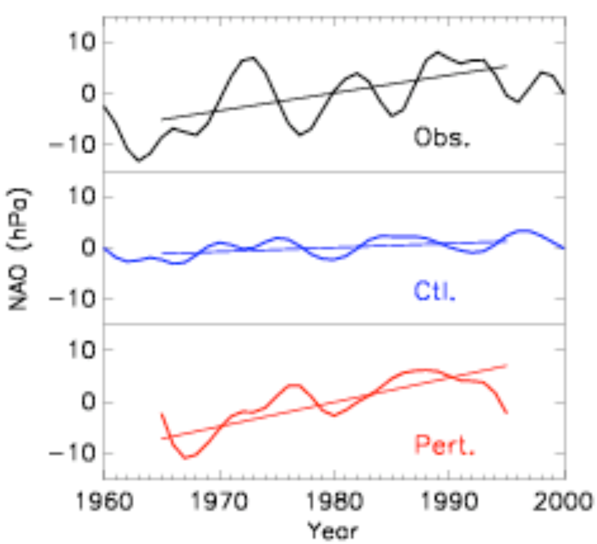
Met Office
Hadley Centre

Impose a body force in the modelled stratosphere

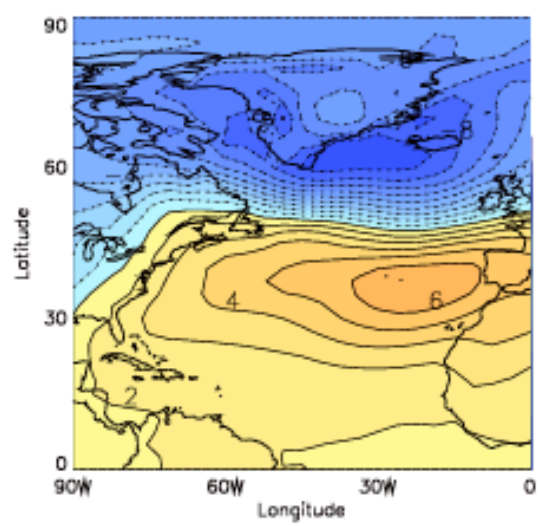
=> Increase in stratospheric wind from 1960s to 1990s

=> Increase in NAO similar to observed value

Change in NAO index

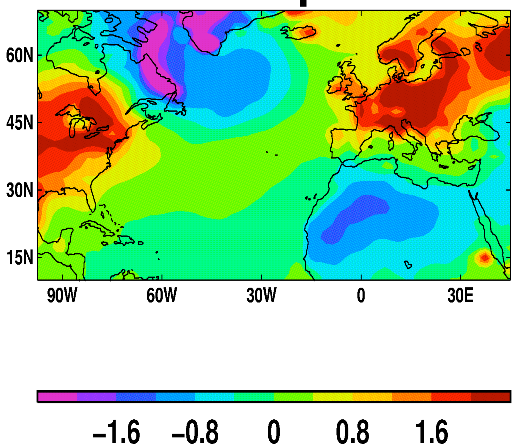


Change in surface pressure

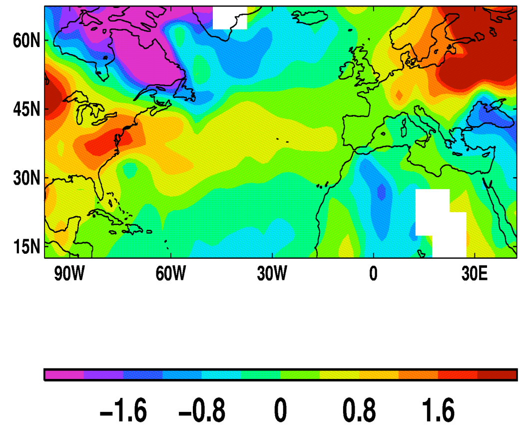


Decadal Climate: N Atlantic

Model Temperature



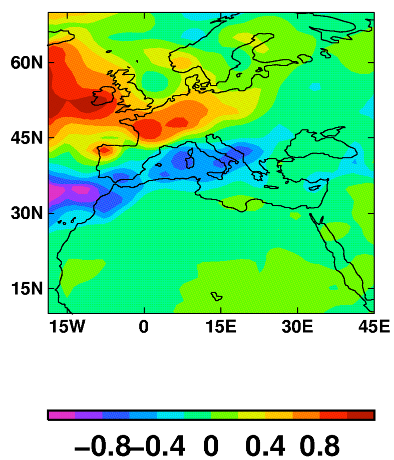
Observed Temperature



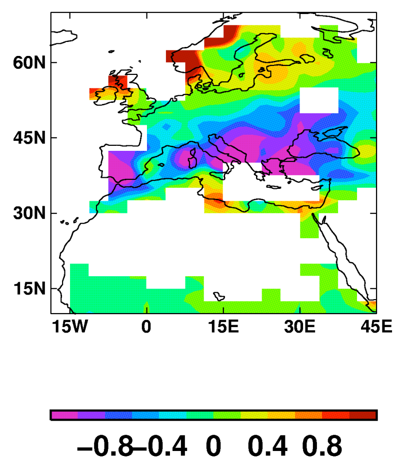
<u>European T trends 1960s-1990s</u>

HadAM3 ctl	**0.15K/decade**
HadAM3 expt	**0.59K/decade**
Observations	**0.53K/decade**

Model Precipitation

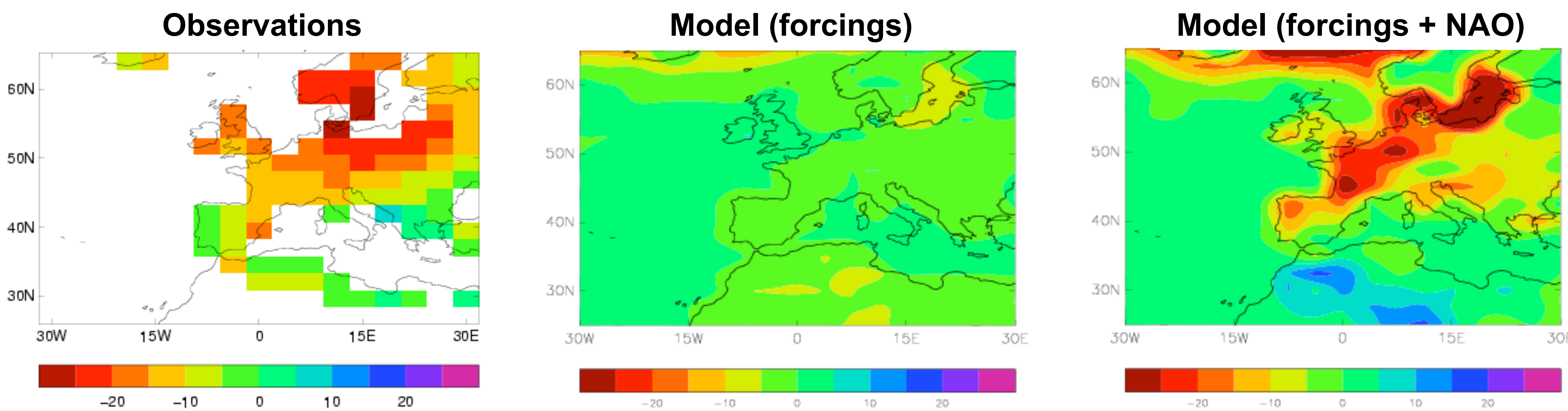


Observed Precipitation



Scaife et al. GRL, 2005

Decadal changes in daily extremes

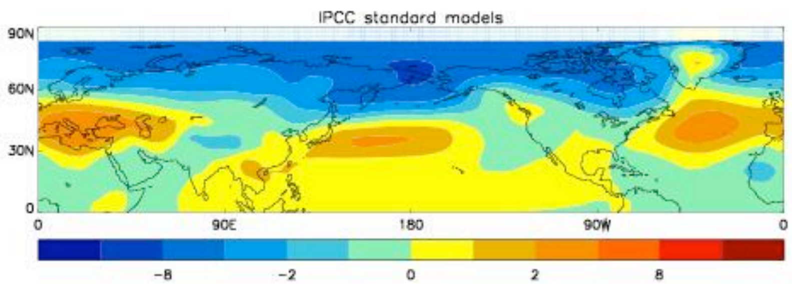


Stratosphere influences extremes as well as mean climate

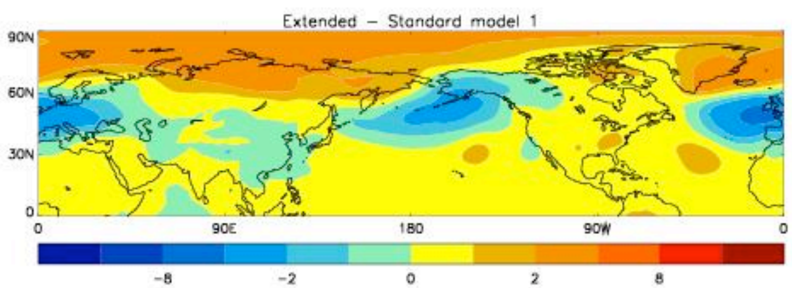
Stratospheric influence is larger than modelled changes with all anthropogenic forcings

Scaife et al., J.Clim., 2008

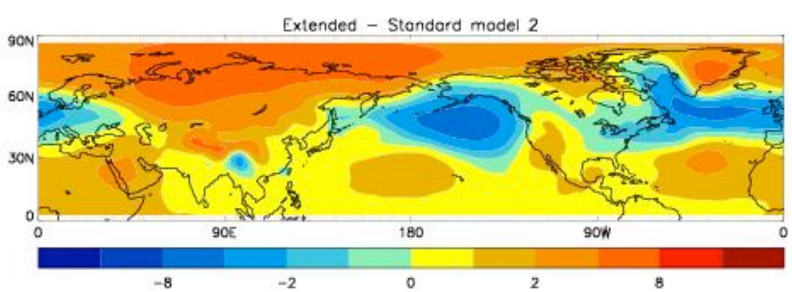
Climate Change ($4xCO_2$)



IPCC AR4 Models



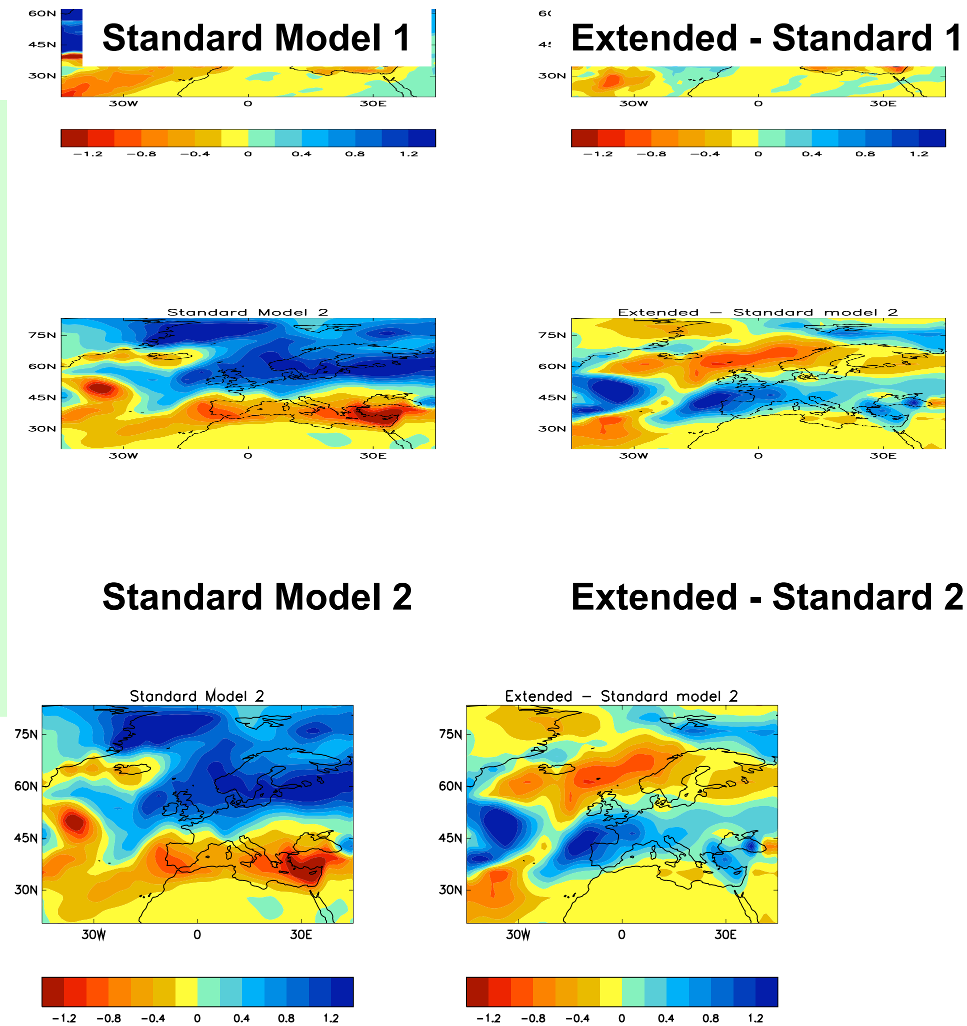
Extended – Standard 1



Extended – Standard 2

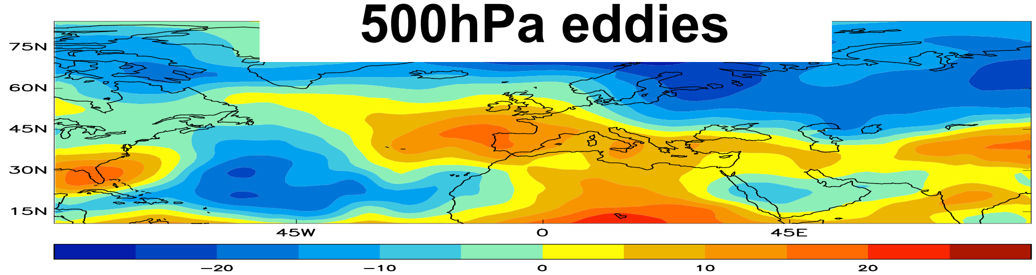
Future Models: Resolution

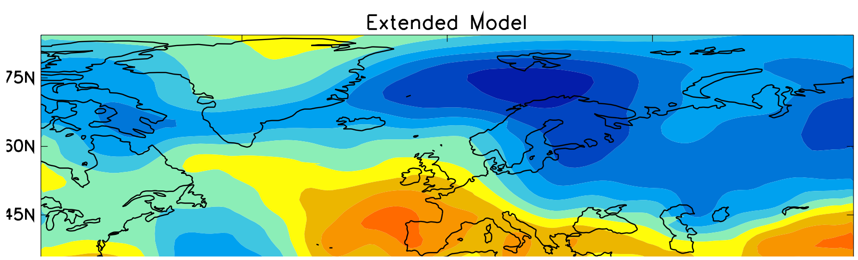
- Standard (IPCC) models wetter in winter
- Vertical resolution makes a robust difference
- Error is similar size to original signal
- Decadal UK climate prediction needs extended models



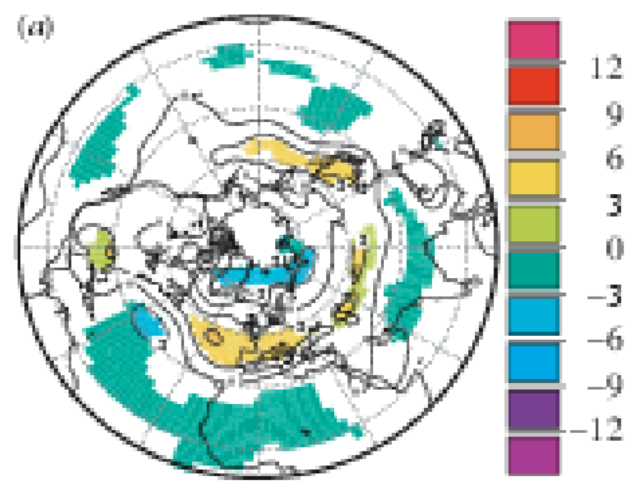
Storm Track Changes

Fractional change in 500hPa eddies





Storm track changes (c.f. Huebener et al. 2007)



Mechanism

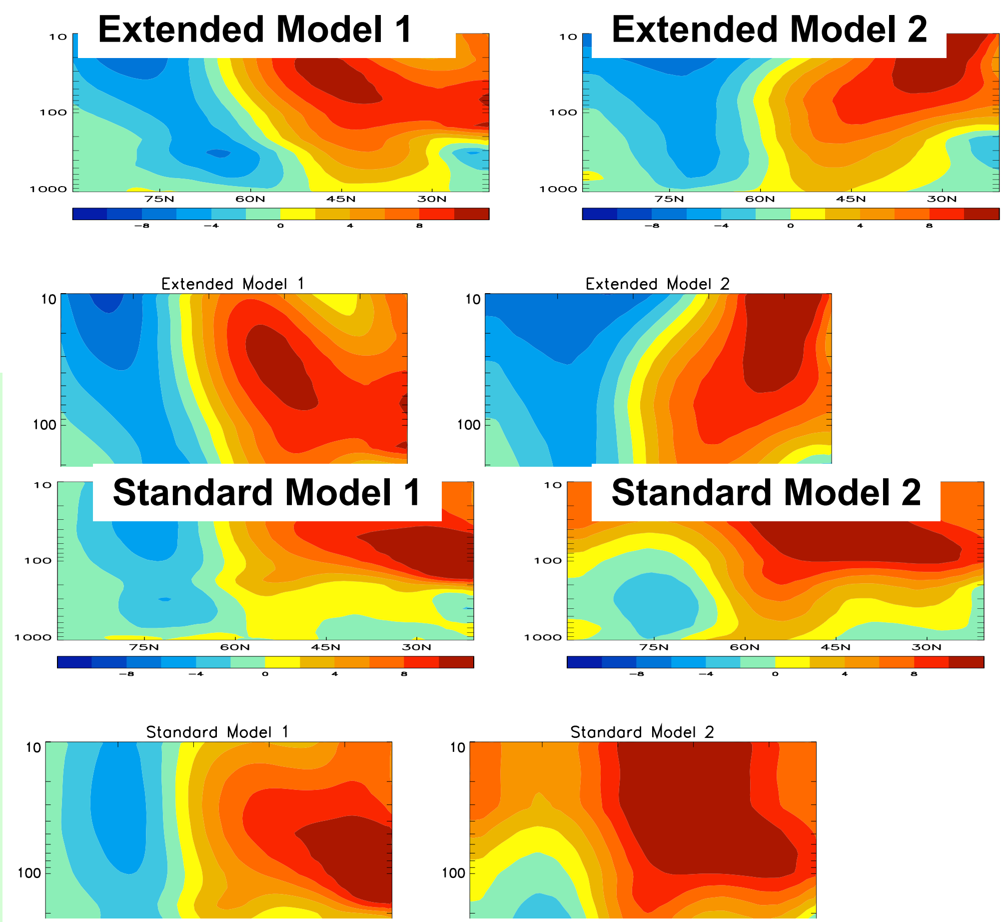
- Increase in meridional winds and the Brewer-Dobson circulation (c.f. interannual)

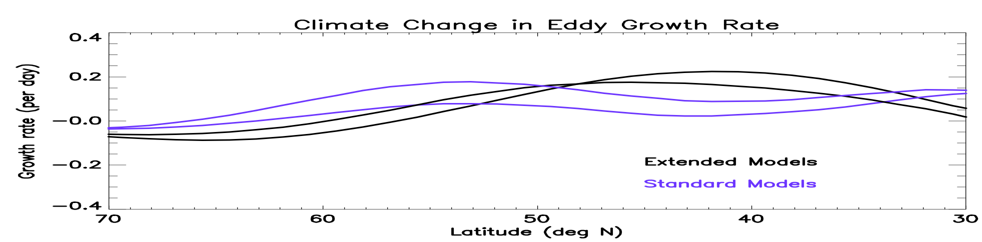
=> Dipole in zonal wind

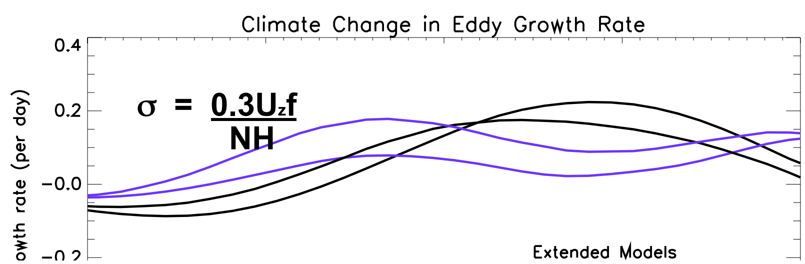
- Extends into troposphere

- Increased eddy growth in mid-latitudes

- No "poleward shift" of Atlantic storm track (IPCC AR4 reports)







SUMMARY

- Stratospheric dynamics are important for monthly to decadal surface variability:
  - Sudden Warmings -> persistent anomalies 30-60d, blocking
  - ENSO -> extratropics -> stratosphere -> NAO
  - Volcanoes -> stratosphere -> extratropics -> NAO
  - QBO -> extratropics -> NAO
  - Decadal climate variability -> NAO, SAM
- Stratospheric dynamics are important for regional climate change
- Necessary to include these effects to maximise prediction skill in the extratropics and accurately predict regional climate change

CLIVAR-WGSIP CHFP

Hi Top Hindcasts

- Parallel to WGSIP-CHFP
- Extended models
- Same initial ocean data - just initialising extra atmosphere

- **Integrations**
  - 4 month lead times (1st November and 1st May start dates)
  - 2 seasons (DJF and JJA)
  - Case study years: 1989 onwards
  - At least 6 members for each hindcast season

Participants so far:

Institute	Model	Resolution	Model top	Reference	Contact
Met Office HC	HadGEM	N96L85 N96L38	85km 40km	Martin et al 2006, J. Clim., 19, 1217-1301	Adam.scaife@metoffice.gov.uk
Meteo France	Arpege 4.4 + OPA	L91 L31	0.01hPa 10hPa	Gueremy et al, 2005, Tellus, 57A, p308-319	Michel.deque@meteo.fr jean.philippe.piedelievre@meteo.fr
CCCMA	CCCMA	?	?	?	George.Boer@ec.gc.ca
NCEP	CFS v1	L64 ?	?	Saha et al, J.Clim., vol.19, no.15, p3483-3517	Hualu.Pan@noaa.gov Judith.perlwitz@noaa.gov.uk
CPTEC	CPTEC	?	?	?	pnobre@cptec.inpe.br

On longer timescales CMIP5 will contain high-top models……

Institute	Model	Atm Res'n	Scenario	Contact
Hadley / NCAS	HadGEM2	192x145xL60 top=85km	RCP4.5 to 2100	neal.butchart@metoffice.gov.uk
MPI	ECHAM6/MPIOM	~360x180xL95 top=0.01hPa	RCP4.5,2.6,8.5	marco.giorgetta@zmaw.de
GFDL	CM2	?	?	john.austin@noaa.gov
NCAR	CCSM: WACCM + POP2	95x144xL66 top=6×10^{-6}hPa~135km	RCP4.5 to 2050	rgarcia@ucar.edu marsh@ucar.edu
CMCC	ECHAM5+OPA	T63xL95 top=0.01hPa	RCP4.5 to 2030	manzini@bo.ingv.it Chiara.cagnazzo@cmcc.it
GISS	GISS-E	90x144xL40 top=0.1hPa	All 4 RCPs	dshindell@giss.nasa.gov
DMI	EC_Earth	T159xL91 top=0.01hPa	RCP4.5 to 2100	shuting@dmi.dk boc@dmi.dk
IPSL	IPSL-CM5	96x95xL35 top=65km	RCP4.5	Francois.lott@lmd.jussieu.fr