What Influences the Timing of a Stratospheric Sudden Warming?

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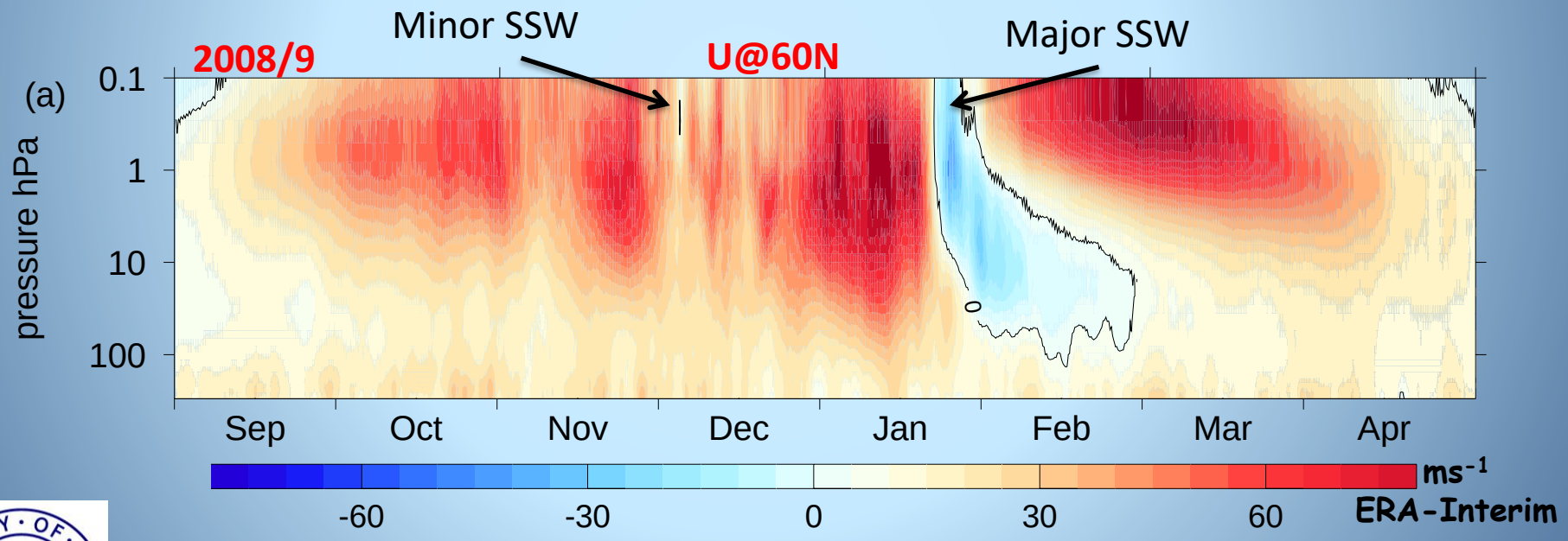

2008/9: a classic 'split' vortex SSW

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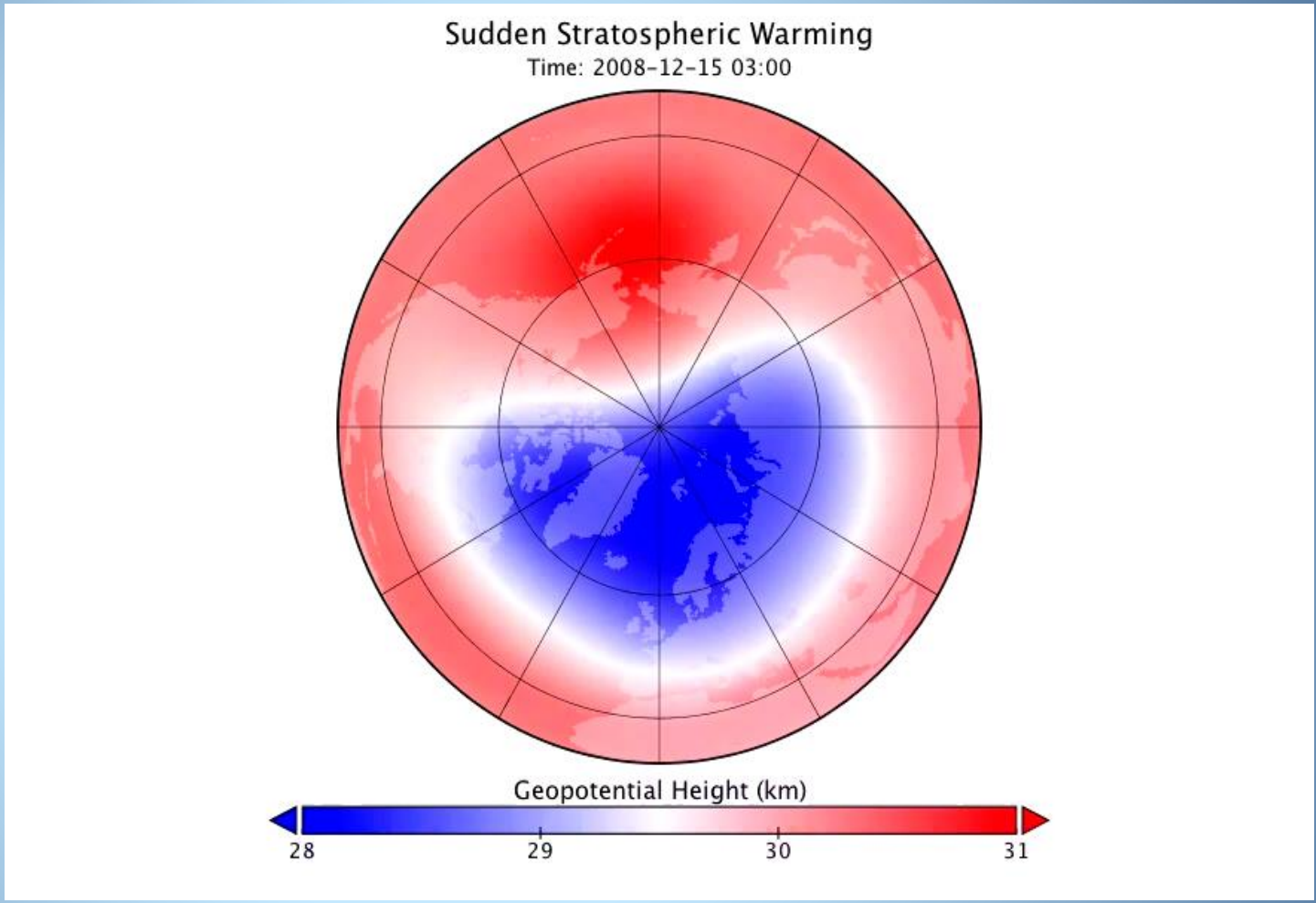
The Stratosphere: vortex variability



Experimental set-up

- **Met Office HadGAM;** N96 (2.5° lat x 3.75° long); 85 levels to ~85 km (0.01 hPa)
- **AMIP:** observed 2008/9 SSTs at lower boundary
- **Initialised Sept 2008** with observations
- Self-generated QBO (via an-orographic gravity wave scheme)
- **50 x ensembles**
- **Relaxation scheme applied to different parts of the atmosphere;** 6-hourly u,v,T; relax towards ERA-Interim reanalysis fields
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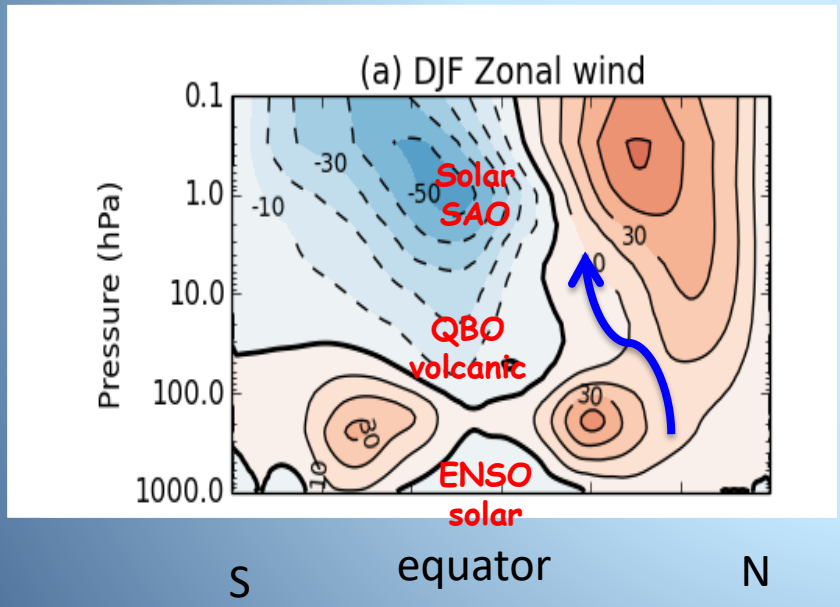
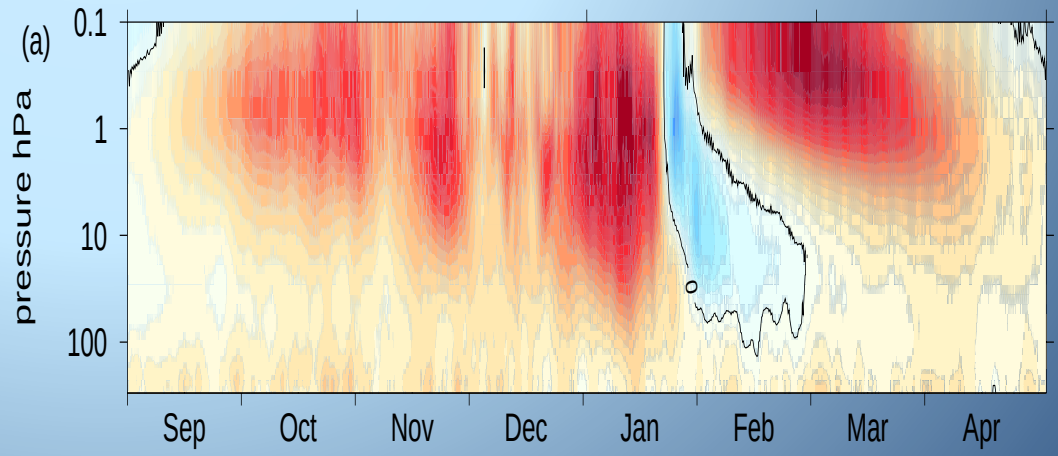
Main diagnostics: timing of the SSW and depth to which it penetrates – otherwise it's unlikely to influence the troposphere



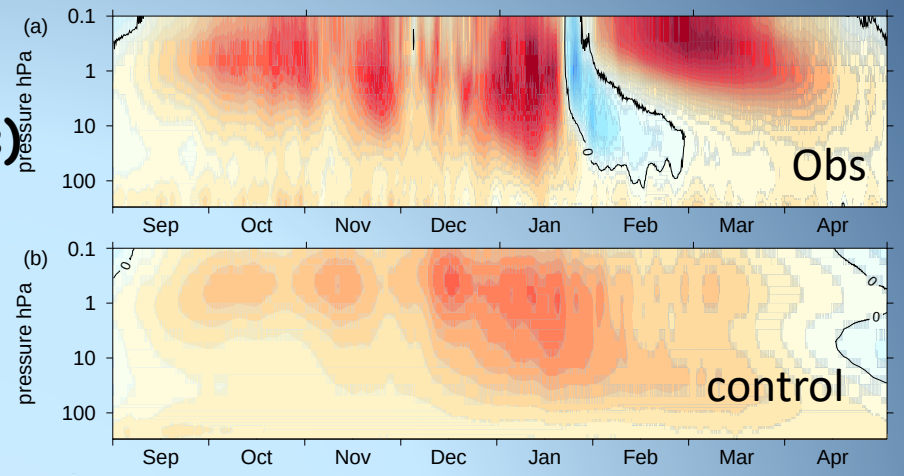
2 factors:
(a) Wave forcing from below
(b) Background flow through which the waves propagate



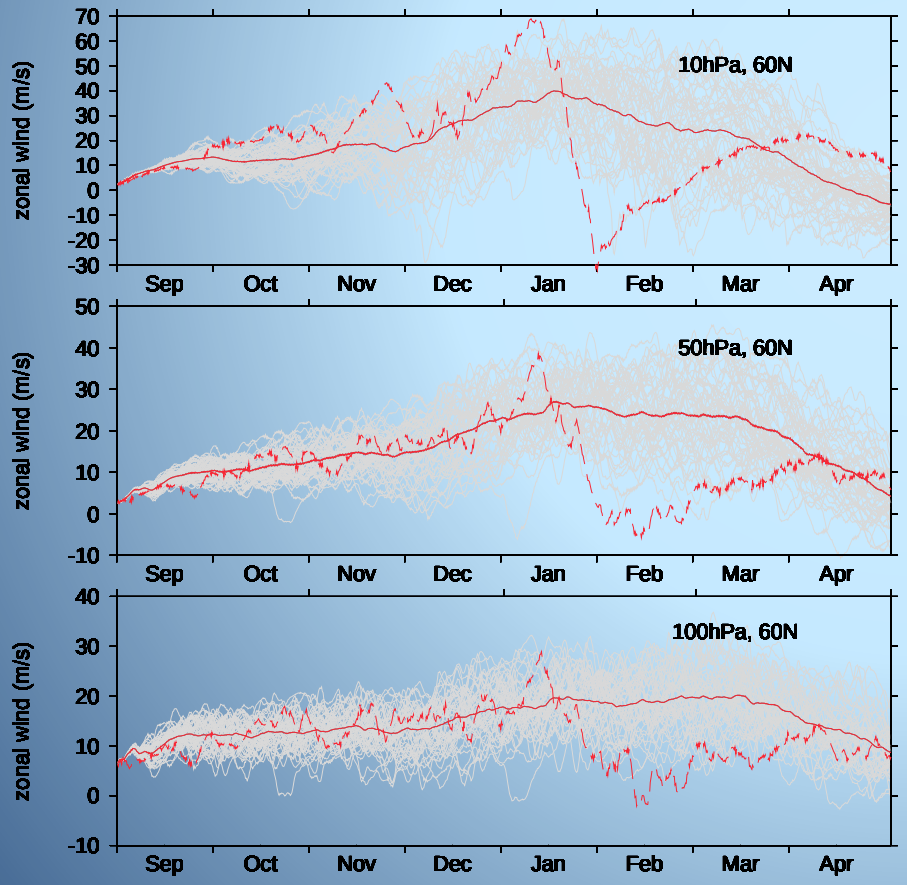
Control Run

- QBO in correct phase (initial conditions)
- SST forcing
- No relaxation

2008/9 Zonally-averaged zonal wind @ 60°N



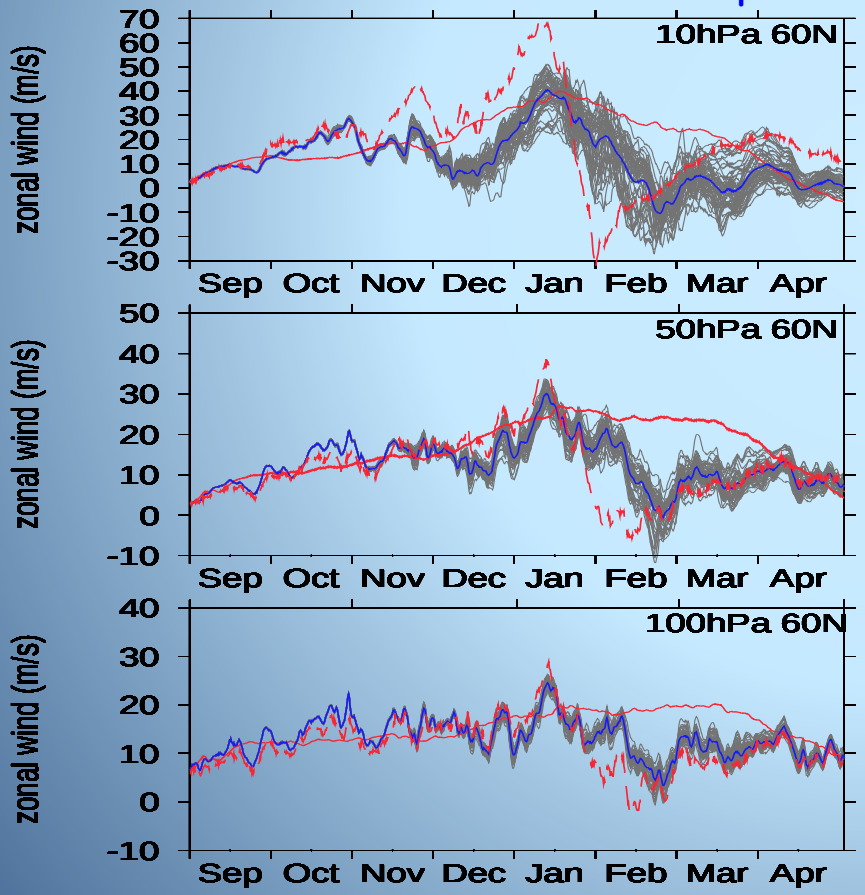
Red = control run ensemble-av
Dashed red = obs

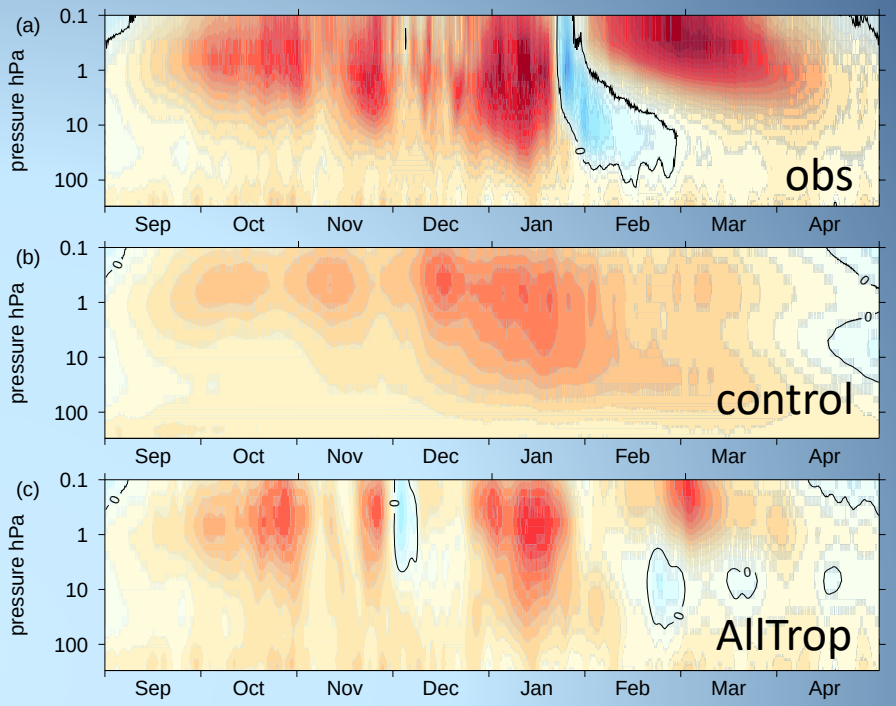


'AllTrop'

- QBO in correct phase (initial conditions)
- SST forcing
- Relaxation up to tropopause; all lats

Red = control run ensemble-av
Dashed red = obs
Blue = AllTrop ens-av





'Correct' tropospheric wave forcing from below does not guarantee a correct SSW

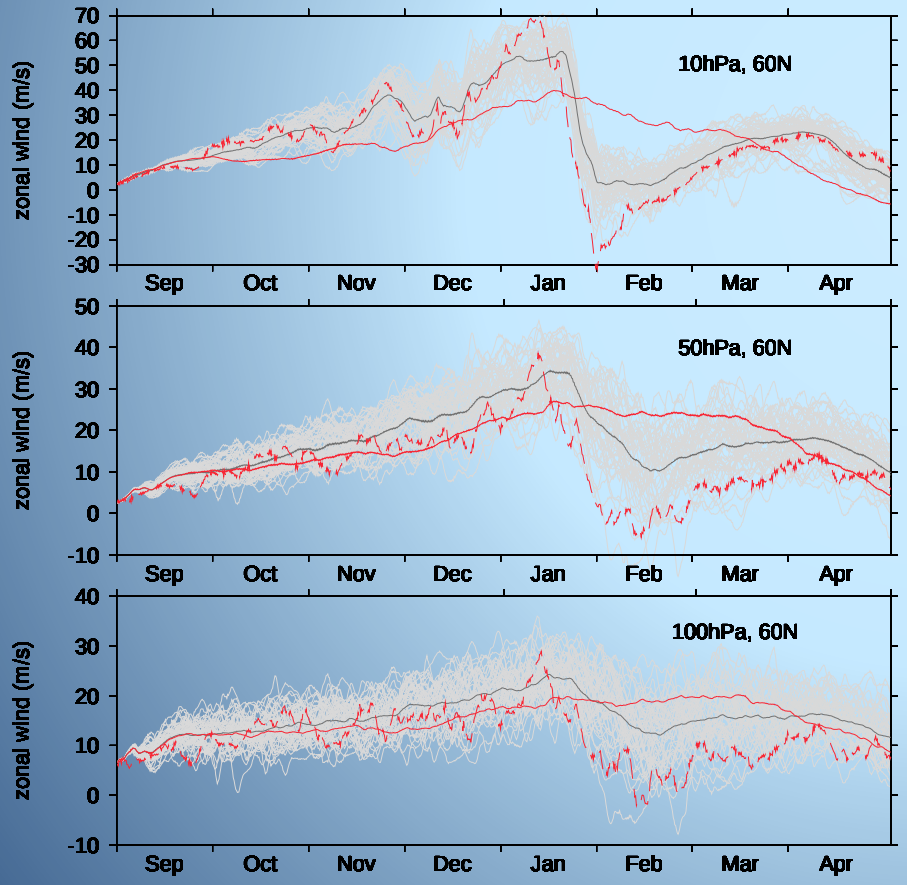
Background flow in the stratosphere is also important

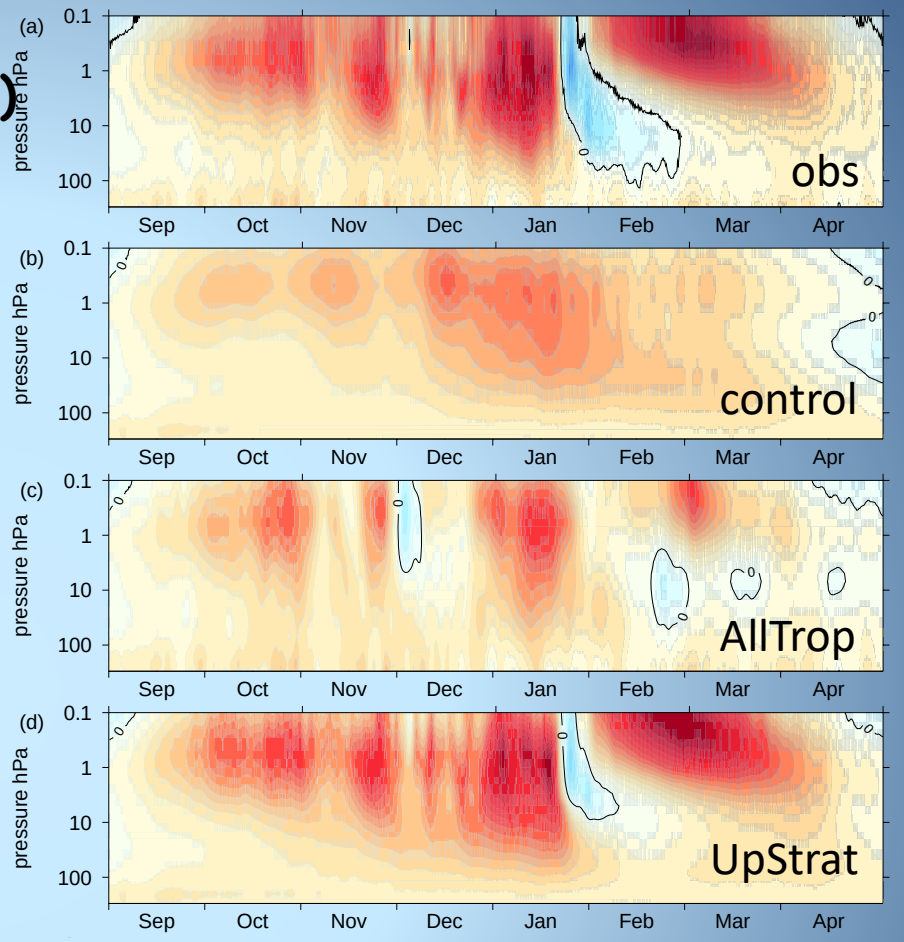
The stratosphere is not simply a 'slave' to the troposphere

'UpStrat'

- QBO in correct phase (initial conditions)
- SST forcing
- Relaxation in stratosphere above 5 hPa level; all lats

Red = control run ensemble-av
Dashed red = obs
Black = UpStrat ens-av



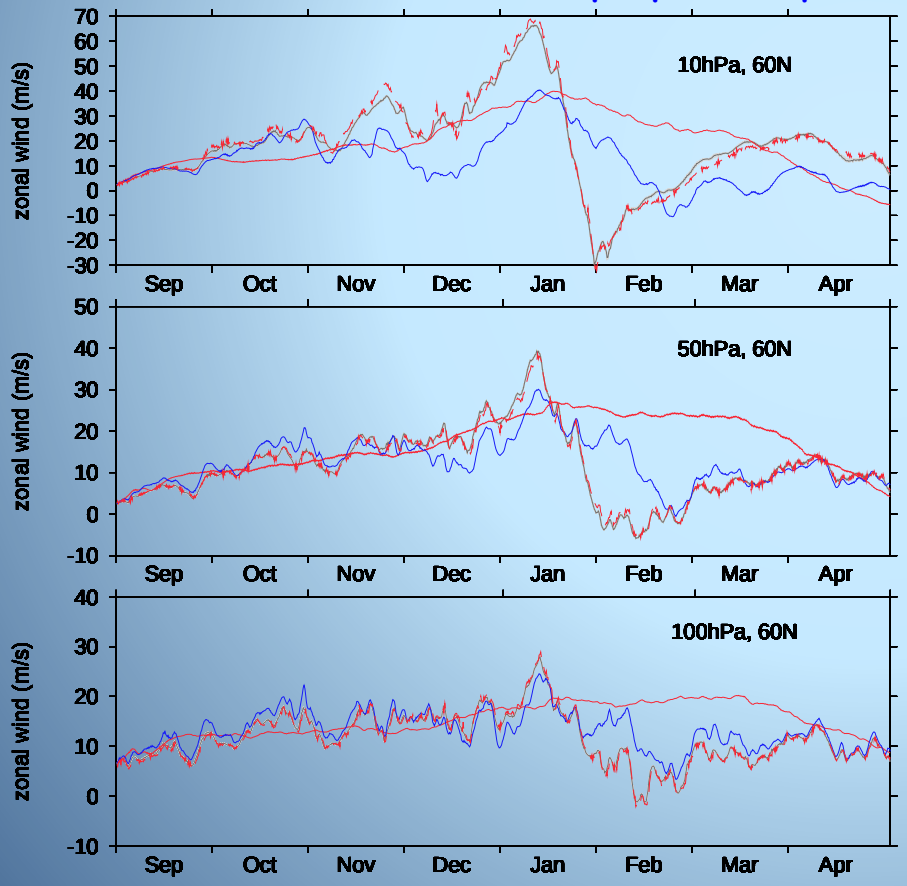


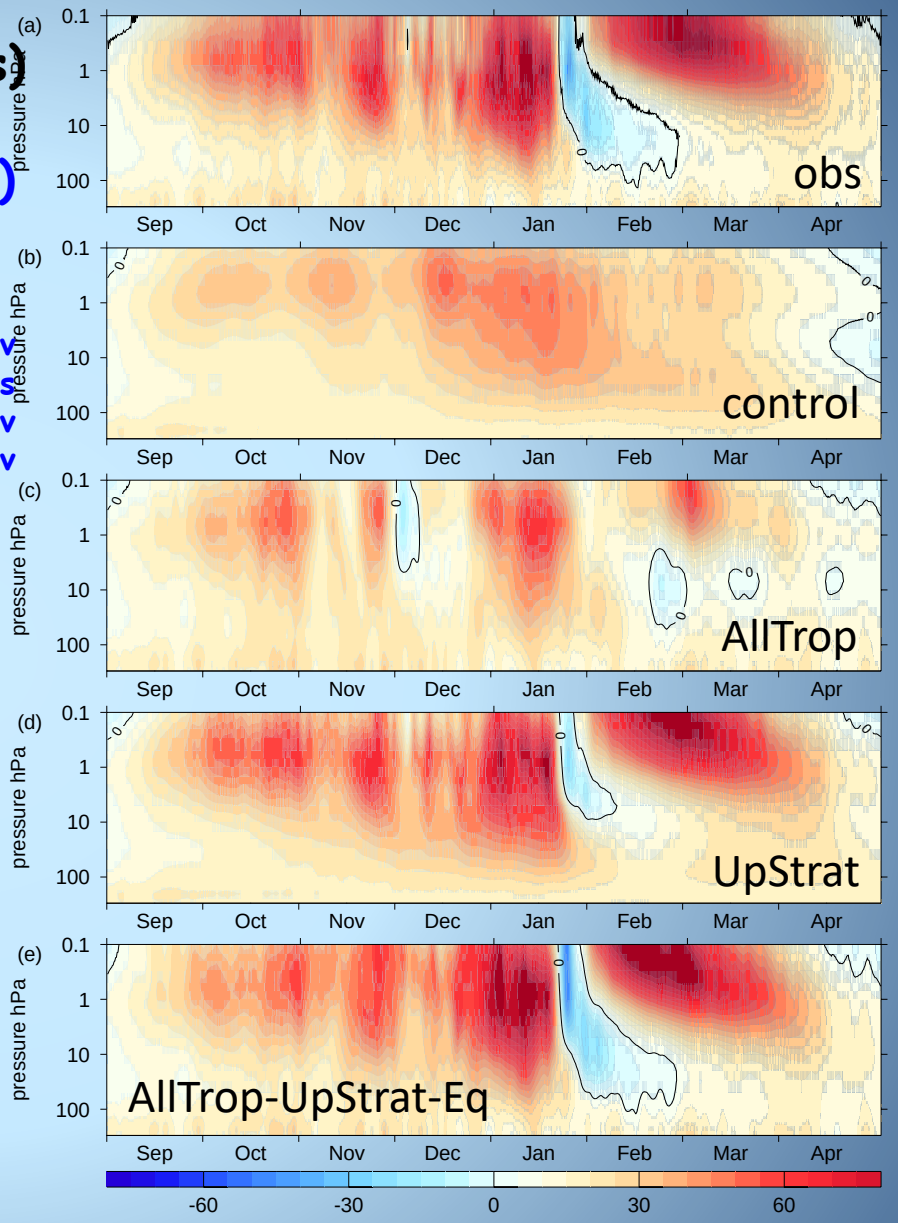
Correct' stratospheric flow gives good timing of SSW but not deep enough

AllTrop-UpStrat-Eq

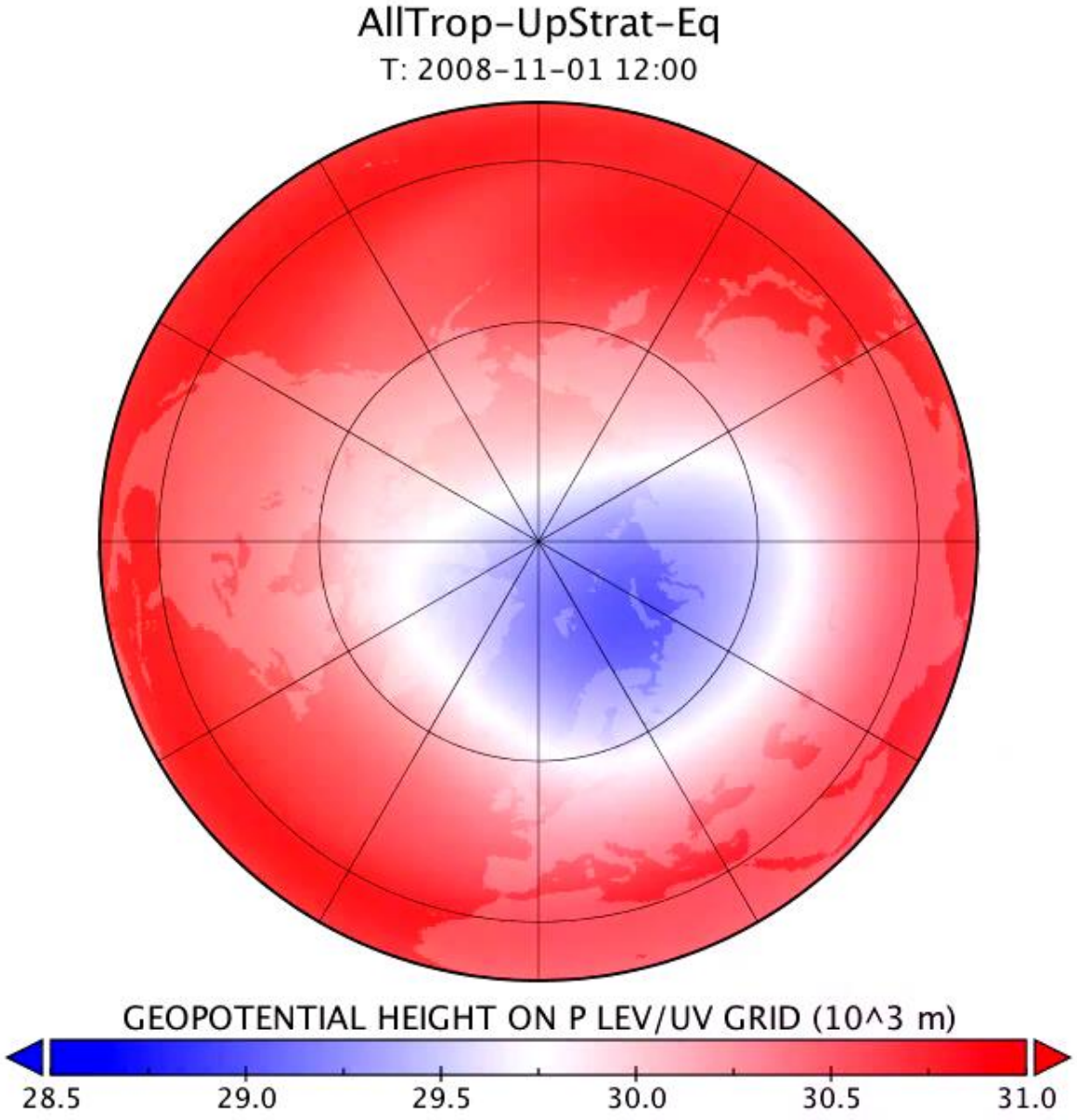
- QBO in correct phase (initial conditions)
- SST forcing
- Relaxation to tropopause (as in AllTrop) plus in stratosphere above 5 hPa level; 0-30°N only

Red = control run ensemble-av
Dashed red = obs
Blue = AllTrop ens-av
Black =AllTrop-UpStrat-Eq ens-av

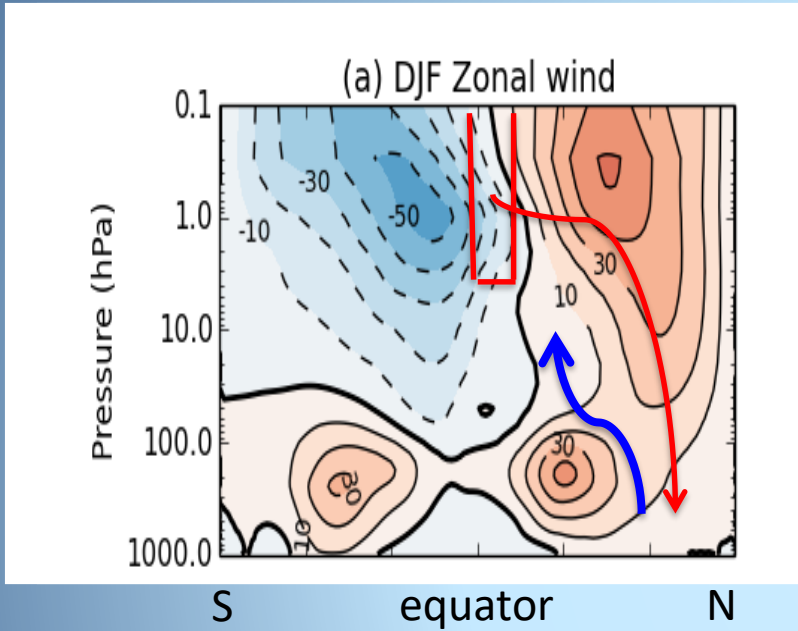


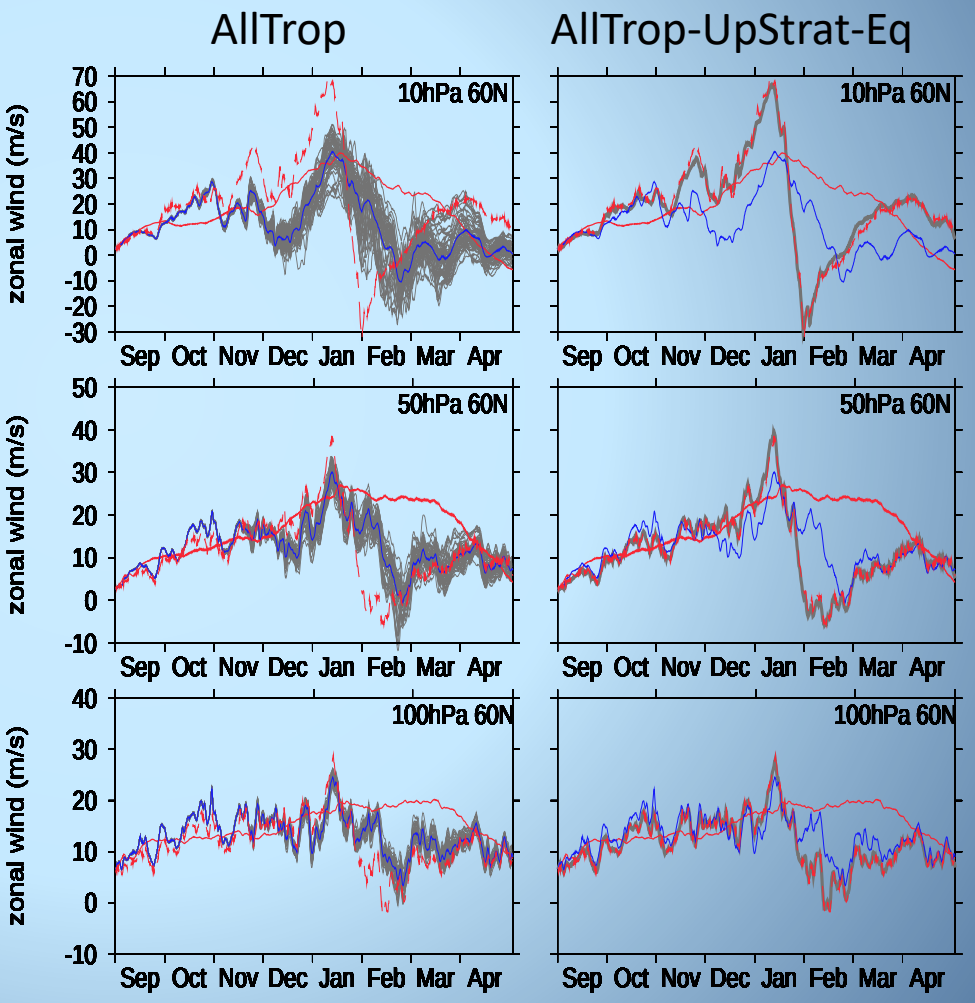


Remarkably good simulation with v. little ensemble spread


AllTrop-UpStrat-Eq
T: 2008-11-01 12:00
GEOPOTENTIAL HEIGHT ON P LEV/UV GRID (10^3 m)
28.5
29.0
29.5
30.0
30.5
31.0

Teleconnection from equatorial upper stratosphere …. to polar lower stratosphere

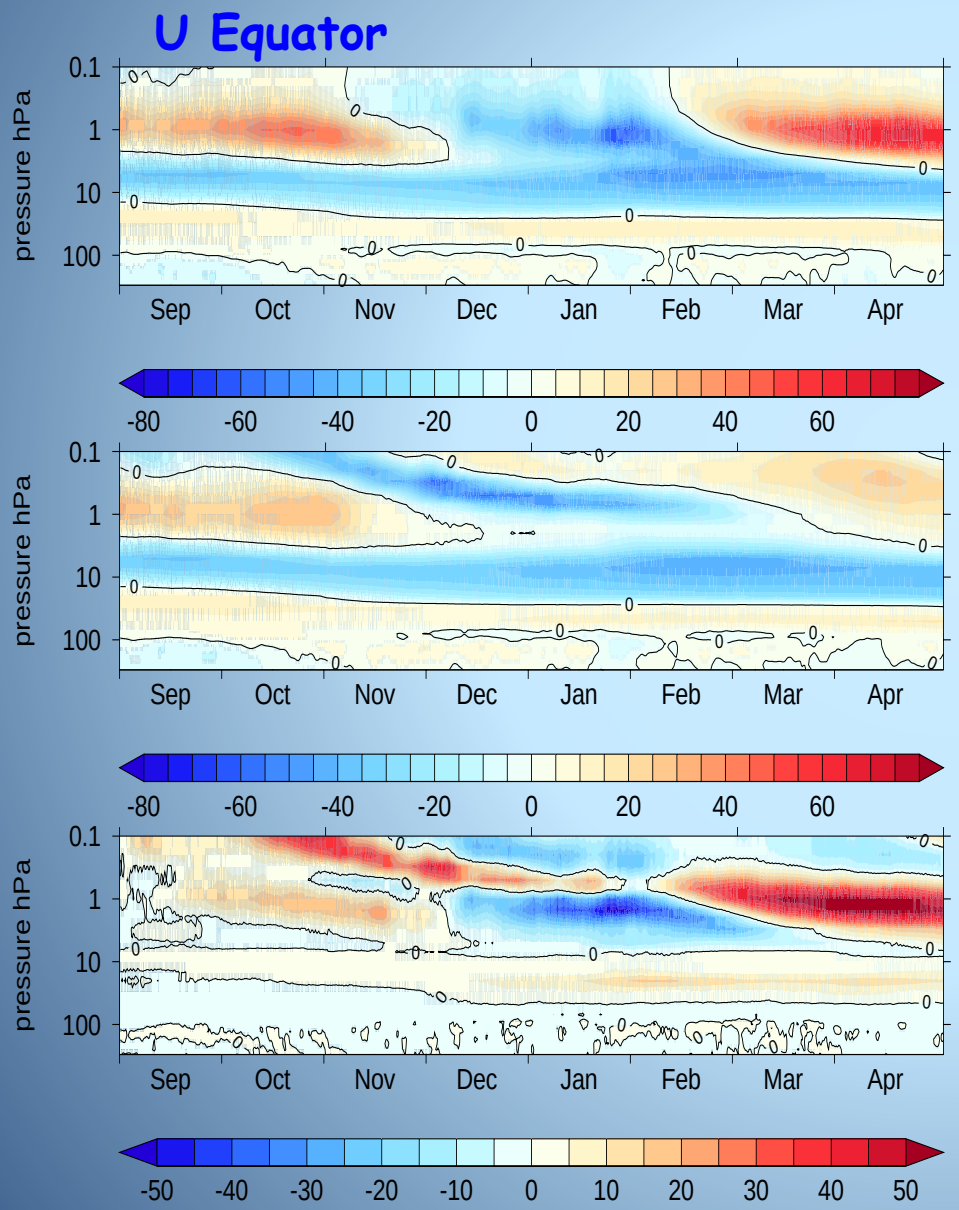




- Remarkably good simulation with v. little ensemble spread
- Only difference between AllTrop and AllTrop-UpperStrat-Eq is the relaxation in the equatorial upper stratosphere (0-30°N; above 5 hPa)
- Relaxing 0-10°N instead of 0-30°N gives a good SSW prediction too,
- This region is dominated by the semi-annual oscillation (SAO)

Mechanism? The Semi Annual Oscillation

Equatorial time-series of zonally-averaged zonal winds (ms^{-1})



AllTrop-UpStrat-Eq ('ERA-I')

AllTrop ('model')

AllTrop-UpStrat-Eq minus AllTrop ('ERA-I' minus 'model')

Model has an early winter easterly bias above ~1 hPa

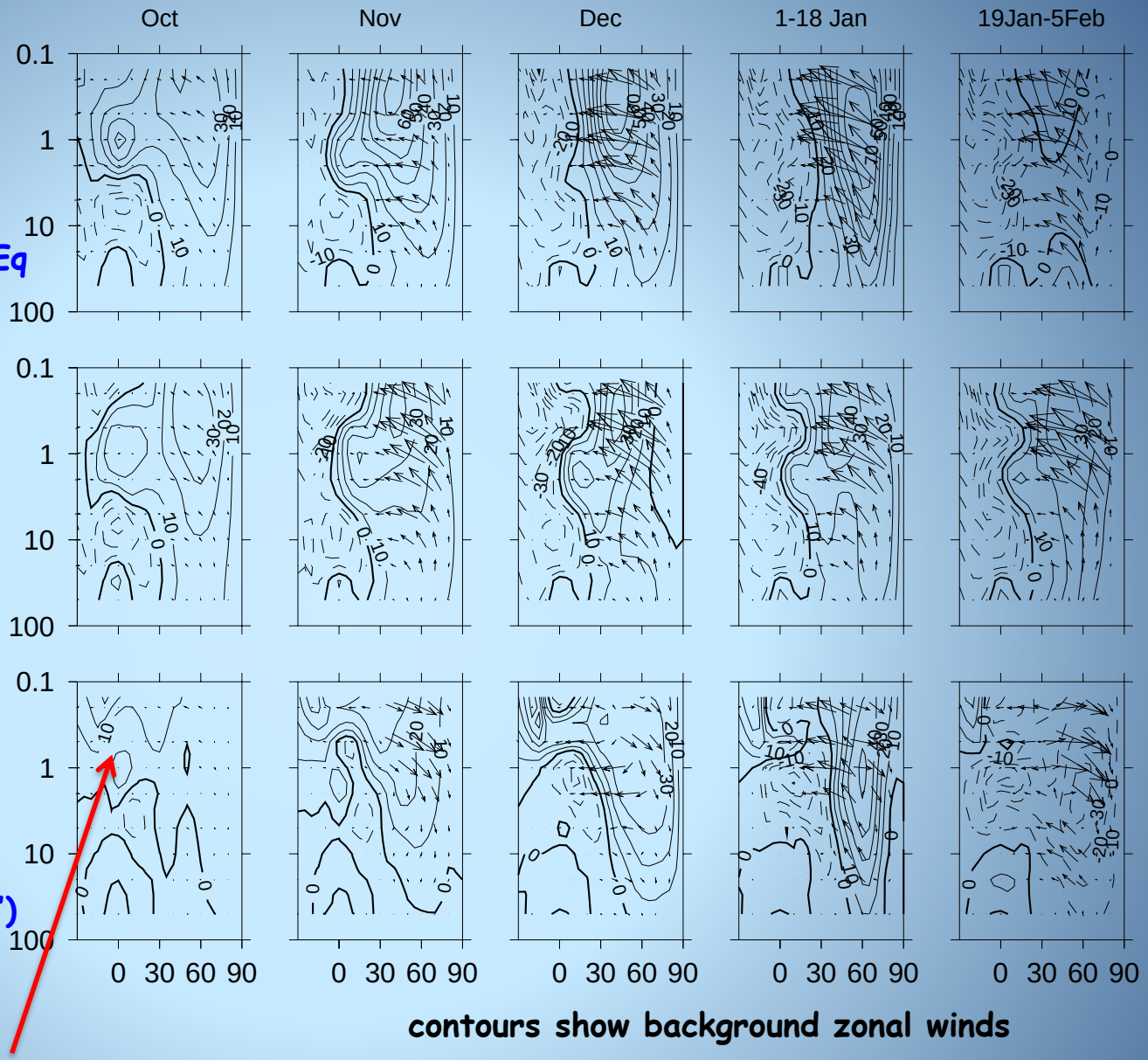
Mechanism?

E-P Flux Diagnostics

AllTrop-UpStrat-Eq ('ERA-I')

AllTrop ('model')

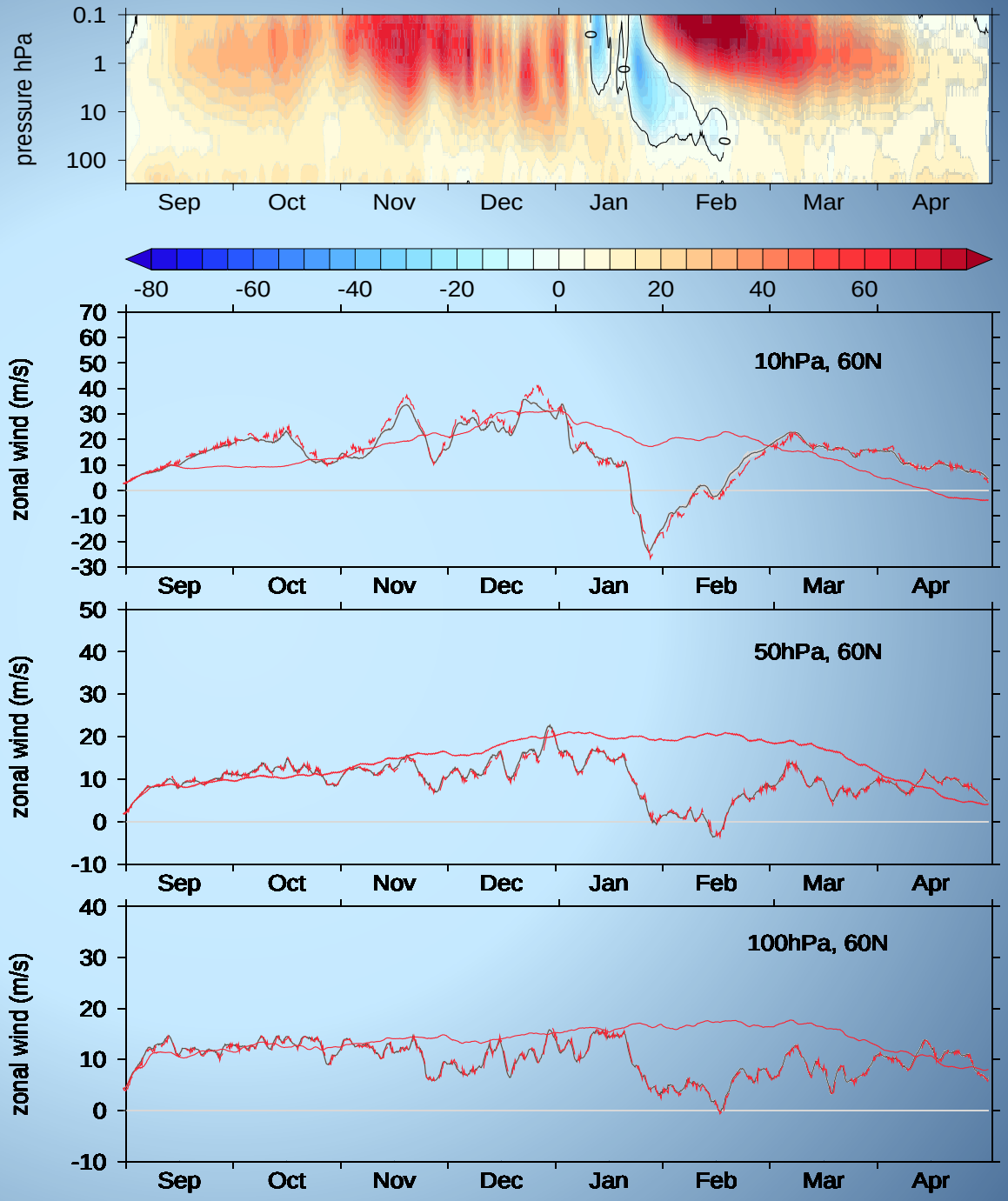
AllTrop-UpStrat-Eq minus AllTrop ('ERA-I' minus 'model')



Model has an easterly bias in the SAO region; waves penetrate deep into the mesosphere in early winter, weakening the vortex too early >> minor SSW in Dec

A fluke?

No – we can repeat AllTrop-UpStrat-Eq for a different winter (2005/6) and achieve the same remarkably accurate simulation



Red = control run ensemble-av
Dashed red = obs
Black =AllTrop-UpStrat-Eq ens-av

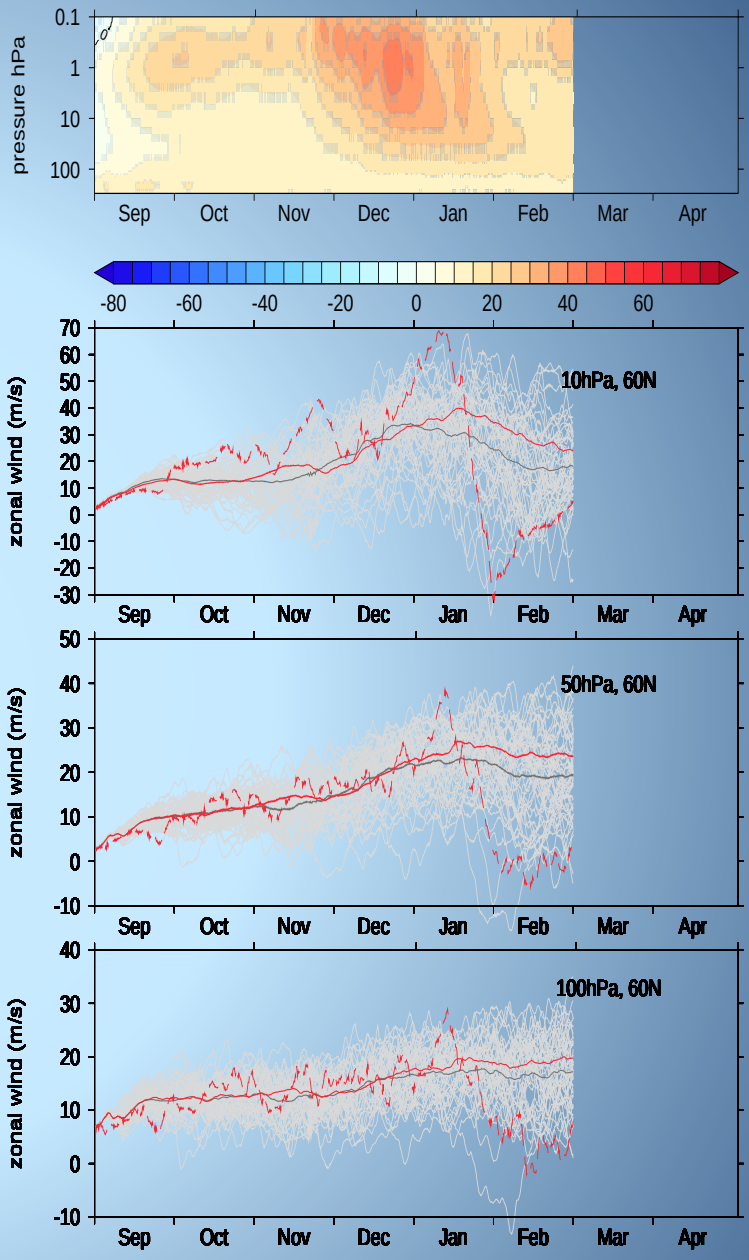
UpStrat-EqClim

- QBO in correct phase (initial conditions)
- SST forcing
- No relaxation in troposphere; only in stratosphere 0-30°N only; above 5 hPa level

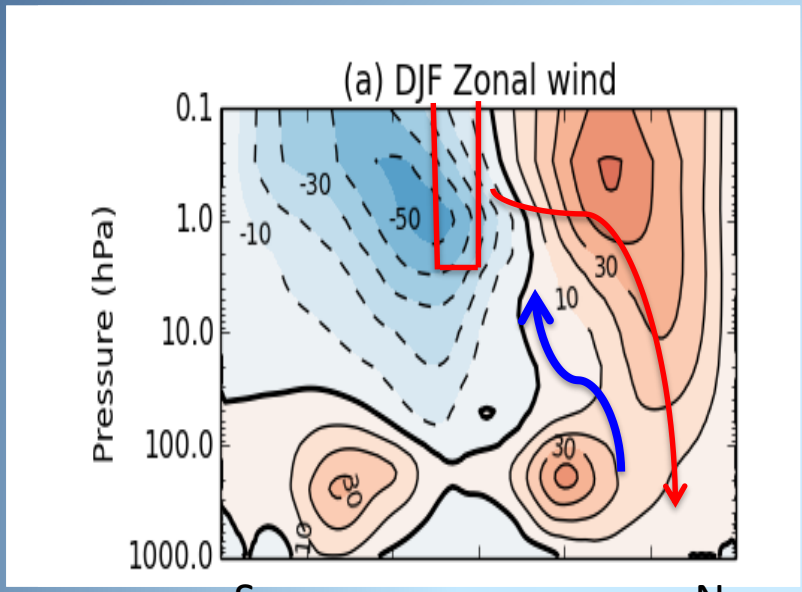
Lot of ensemble spread because SSTs only weakly constrain the tropospheric forcing

>> Improvement over control run

Experiment	Relaxation details	Correlation 10 hPa, 60°N	DJF SSWs	Jan SSWs
Control	None	0.19	22	1
AllTrop	To 2008/9 fields; surface to tropopause at all lats	0.56 (100%)	49 (100%)	5 (80%)
AllTrop-UpStrat-Eq	To 2008/9 fields; surface to tropopause at all lats plus above 5 hPa level at 0-30°N	0.99 (100%)	50 (100%)	50 (100%)
UpStrat-EqClim	To 2008/9 climatology; only above 5 hPa level at 0-30°N	0.41 (99%)	27 (57%)	9 (99%)



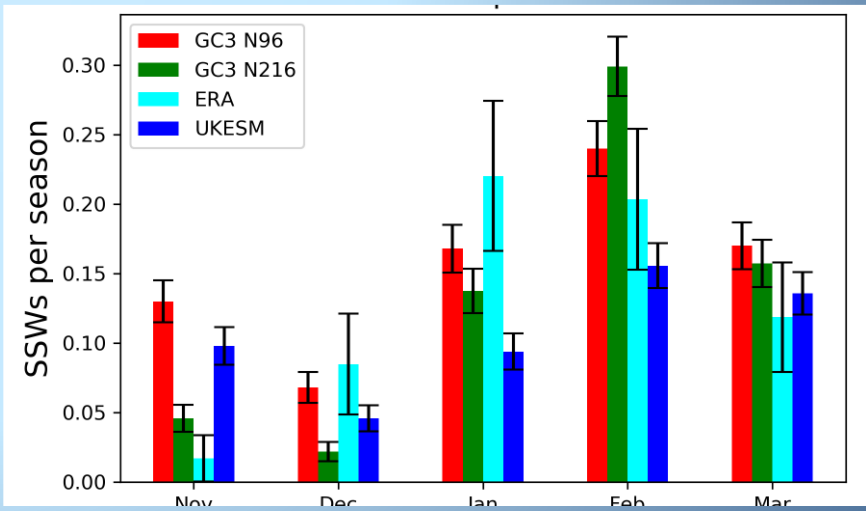
Summary



- **Teleconnections** exist from the equator to the winter polar stratosphere to the surface, especially over the North Atlantic region; more accurate stratospheric simulations will improve DJF seasonal forecasts

- Model experiments investigate 2 prime influences on SSWs:
  (a) tropospheric wave forcing,
  (b) background flow through which the waves propagate

- SSWs depend on accuracy of both (a) and (b)
- Results highlight sensitivity of the timing of SSW to the semi annual oscillation (SAO)
- The model has an intrinsic easterly SAO bias (not uncommon) and, as a result, the early winter vortex is weakened too early
- If this bias can be corrected then the timing of SSWs should be improved



SSWs in CMIP6 simulations