

# THE STRATOSPHERE AND PREDICTABILITY



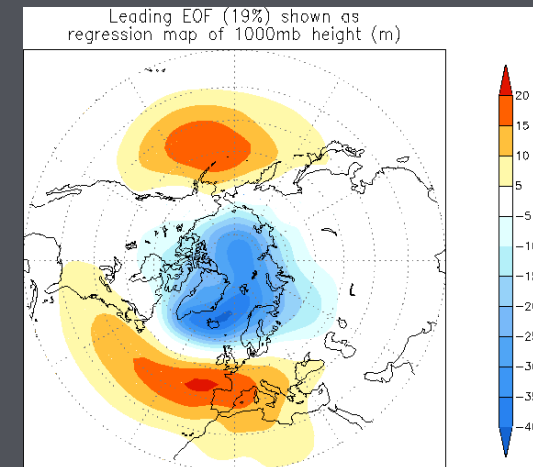
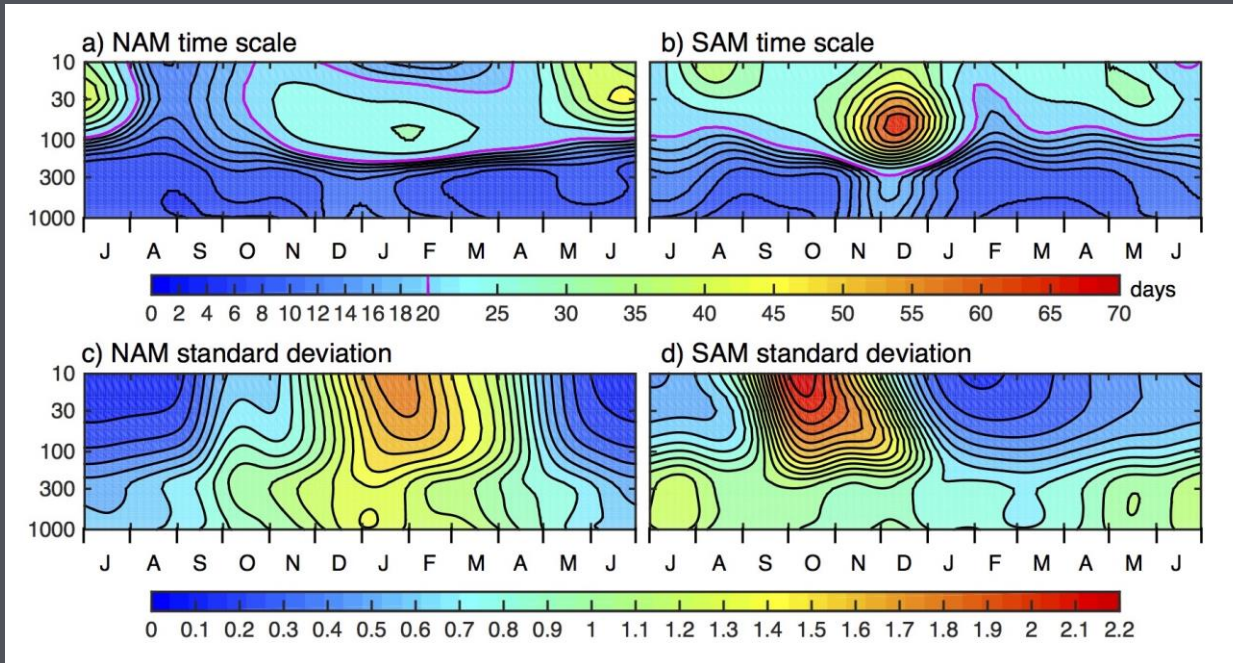
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# OUTLINE

1. Why might you be interested in the stratosphere if you are interested in predictability?
2. What do we know about the dynamics of stratosphere-troposphere coupling?
3. What don't we know?

# WHY CARE ABOUT THE STRATOSPHERE?

# WHY THE STRATOSPHERE?

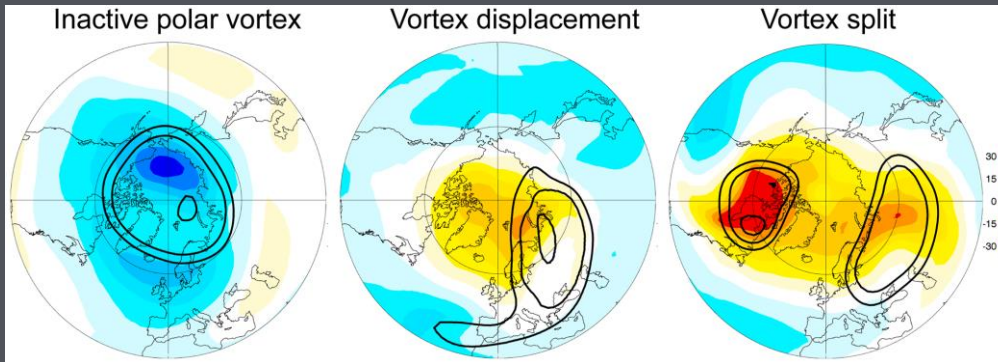


Source: NOAA/CPC

Source: Ed Gerber (NYU)

On the largest scales, the stratosphere has significant memory

# SUDDEN STRATOSPHERIC WARMINGS (SSWS)

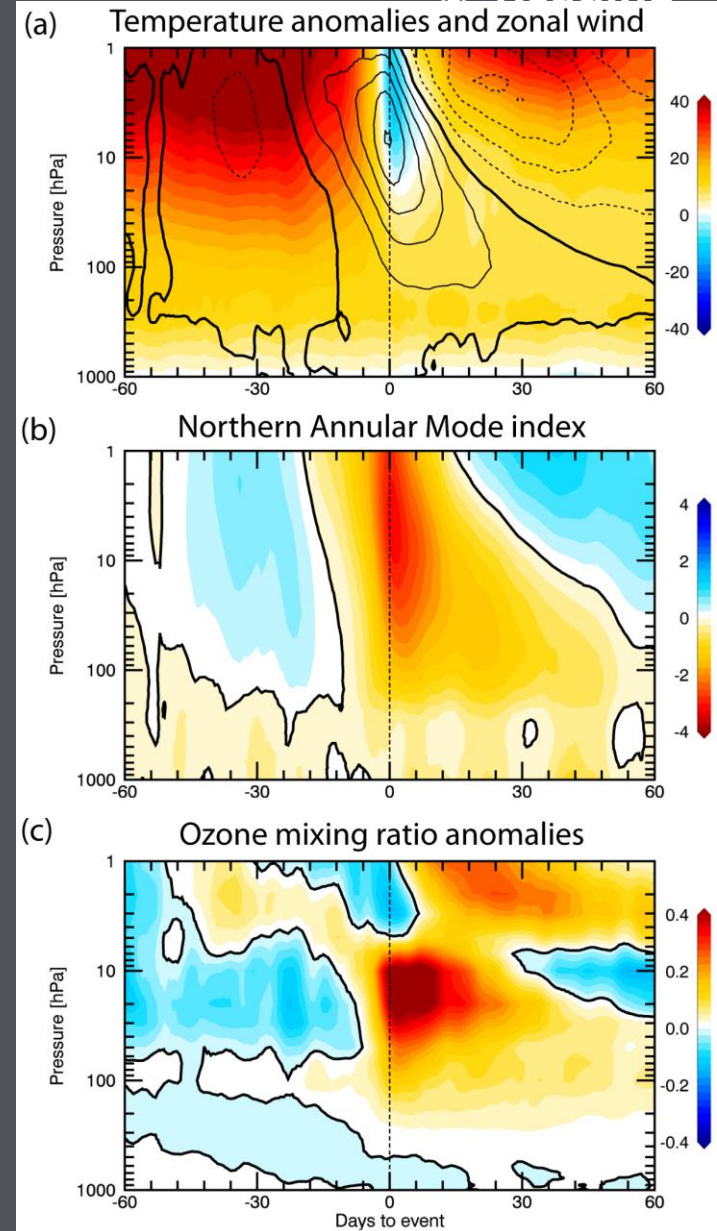


Source: Butler et al. doi:10.5194/essd-9-63-2017

Also see the SSW compendium website:

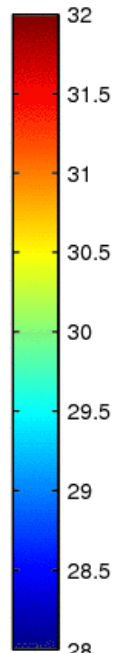
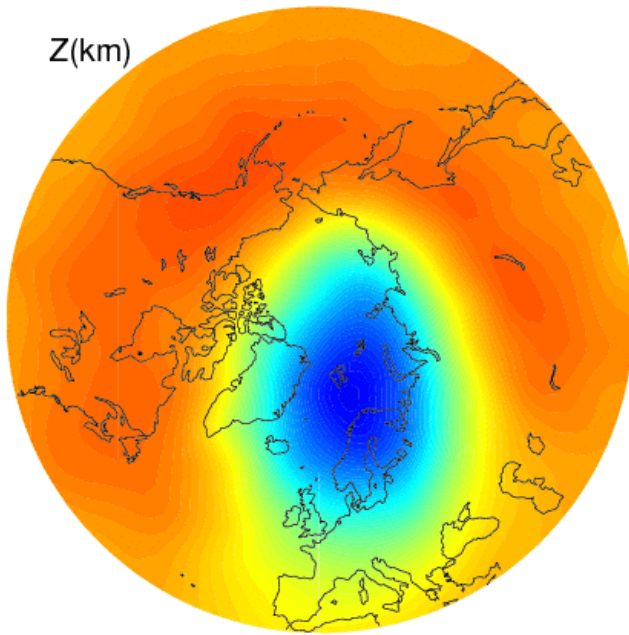
<https://www.esrl.noaa.gov/csd/groups/csd8/sswcompendium/>

Significant variability in the extra-tropical stratosphere is in the form of SSW events where the normally strong and stable vortex is significantly weakened

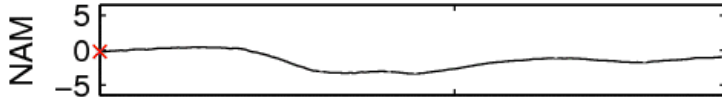
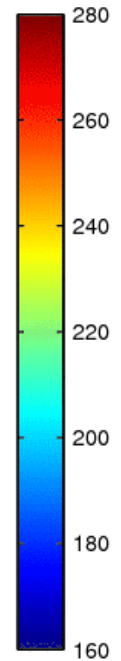
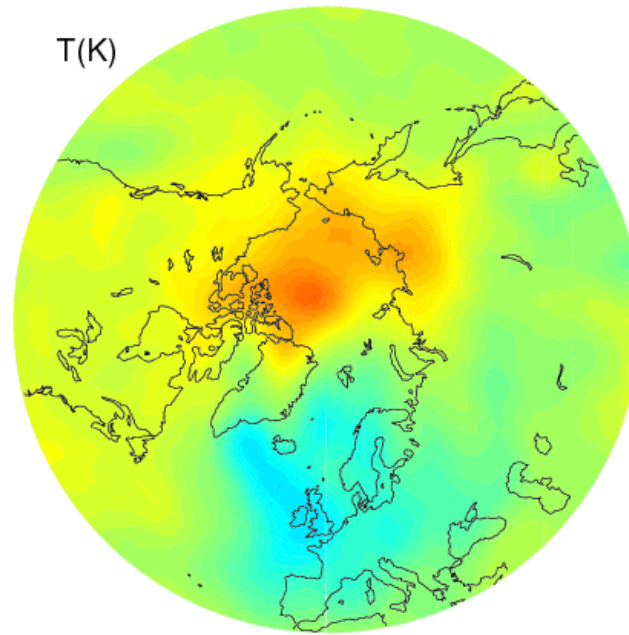


February 12, 1979 00:00:00

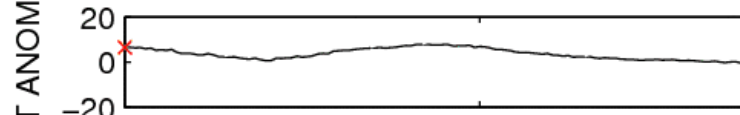
Z(km)



T(K)



Mar-1979



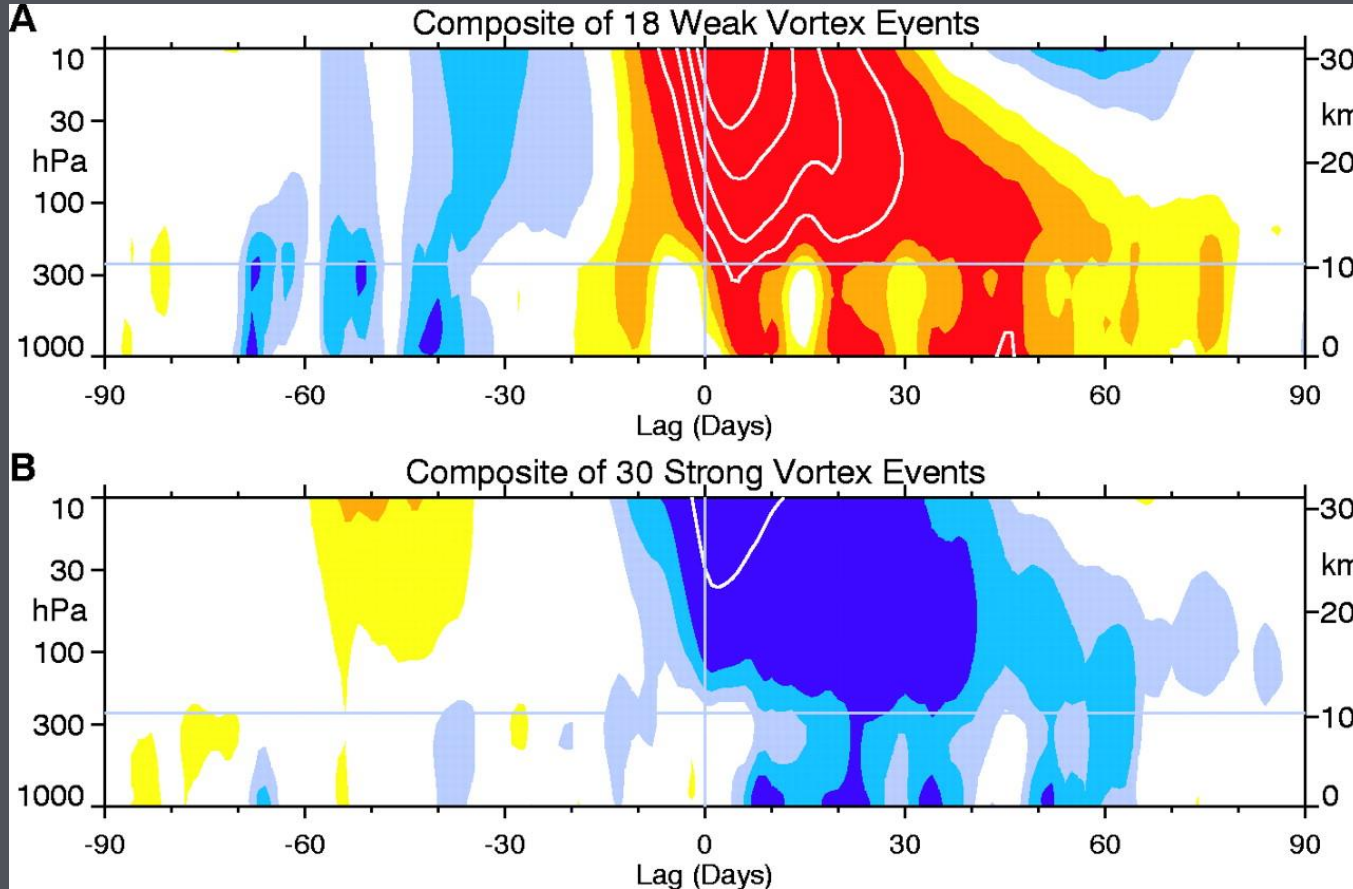
Mar-1979

Vortex Displacement

Vortex Split

Source: Patrick Martineau

# SSW/ANNULAR MODE COUPLING



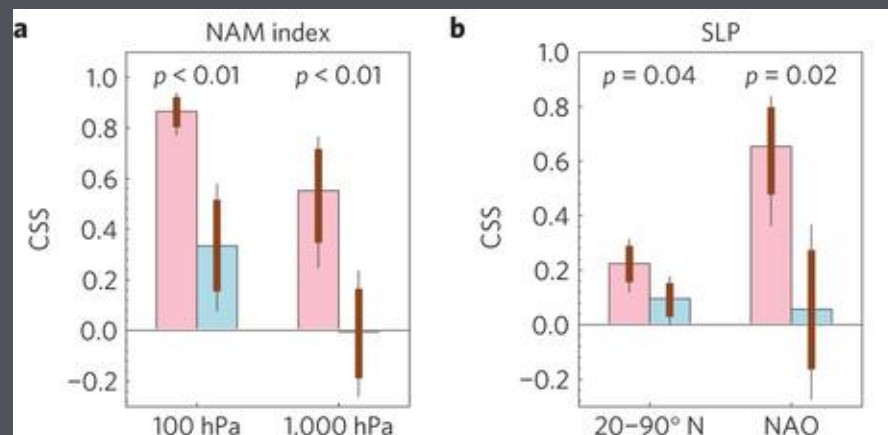
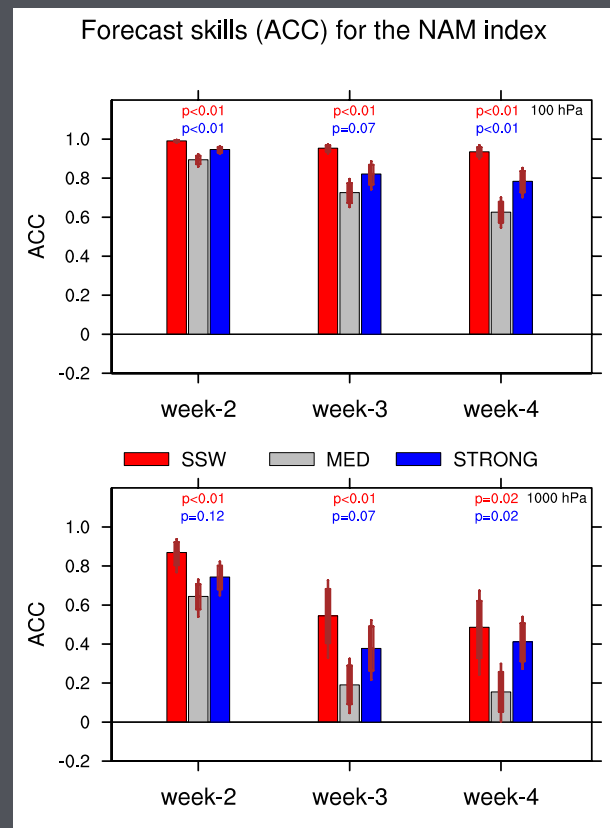
Following extreme events in the stratospheric NAM (and SAM) the tropospheric NAM is more likely to have the same phase.

Source: Baldwin and Dunkerton, doi:10.1126/science.1063315

# CAN WE CAPTURE THIS EFFECT?

On sub-seasonal and seasonal timescales forecasts initialised during SSWs or when the vortex is anomalously strong are significantly more skillful in the troposphere.

Source: Tripathi et al.,  
doi:10.1088/1748-9326/10/10/104007

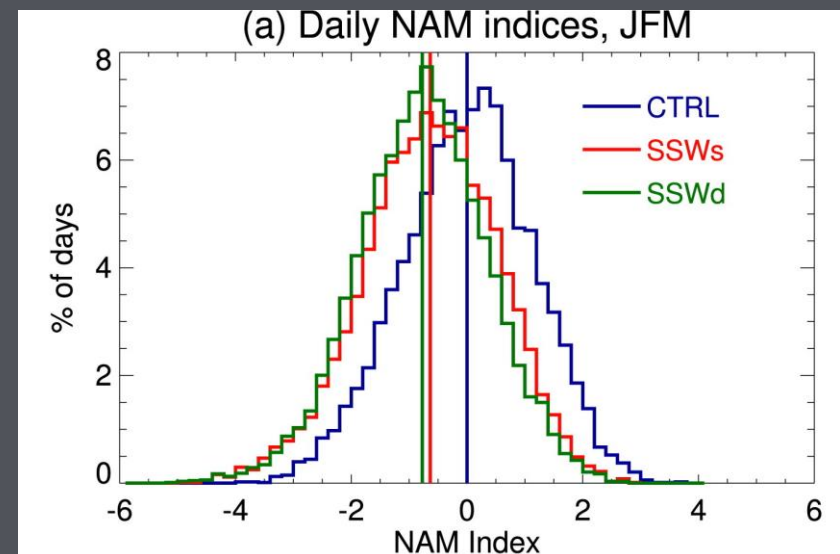


Source: Sigmund et al.,  
doi: 10.1038/ngeo1698



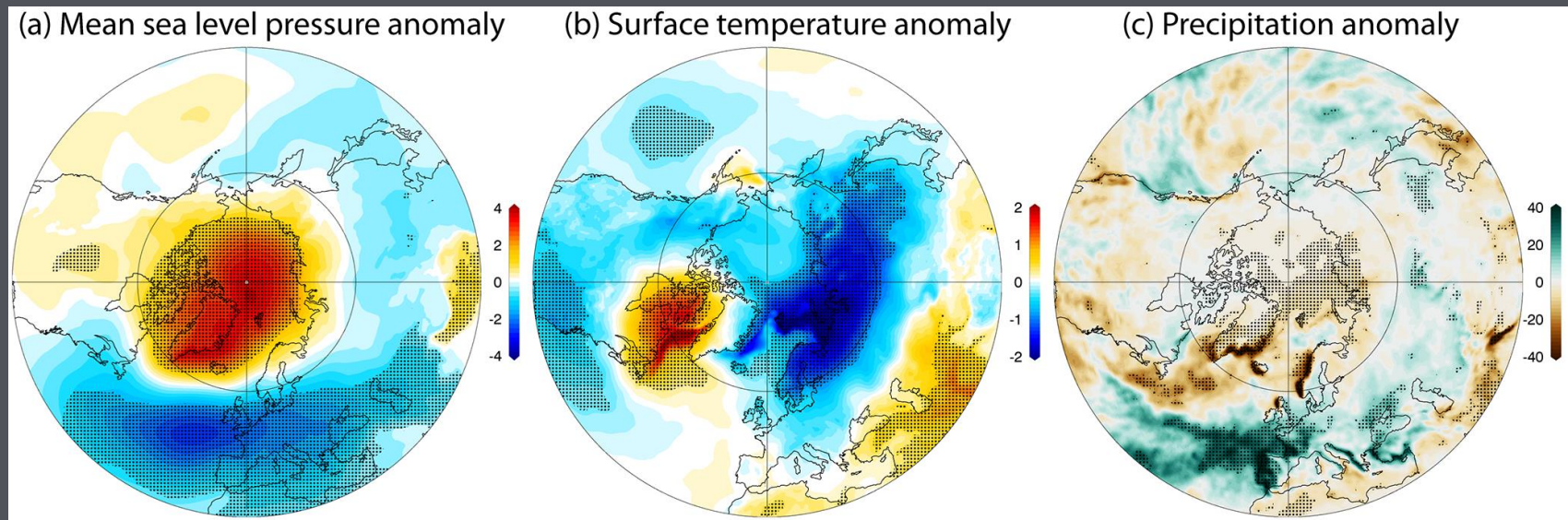
# IS THIS A REAL INFLUENCE?

- Reasonable to ask if the tropospheric response is driven by the stratospheric state.
- Reproduce the same SSW event 100 times in a model by nudging (with different tropospheric state)
- Clear influence shown in shift of tropospheric PDF



Source: Hitchcock and Simpson,  
doi: 10.1175/JAS-D-14-0012.1

# SURFACE IMPACT



Source: Butler et al. doi:10.5194/essd-9-63-2017

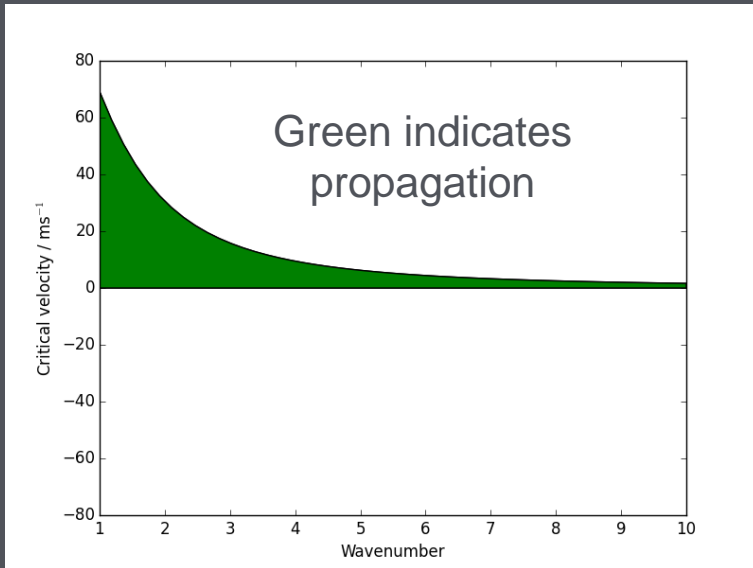
Also see the SSW compendium website:

<https://www.esrl.noaa.gov/csd/groups/csd8/sswcompendium/>

SSW (and strong vortex events) have significant impacts on a number of surface variables through the influence on the NAM (but note the bias toward the Atlantic sector)

**SO HOW DOES THIS WORK?**

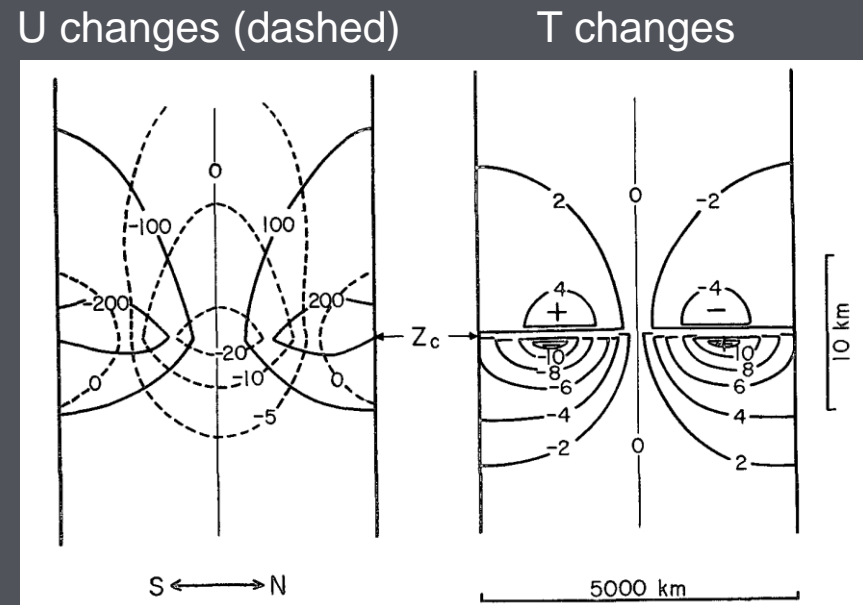
# ROSSBY WAVES



Stratospheric variability is usually understood in terms of the vertical propagation of Rossby waves

Based on: Charney and Drazin, doi: 10.1029/JZ066i001p00083

When waves encounter a critical line they cause changes to the mean winds and temperatures



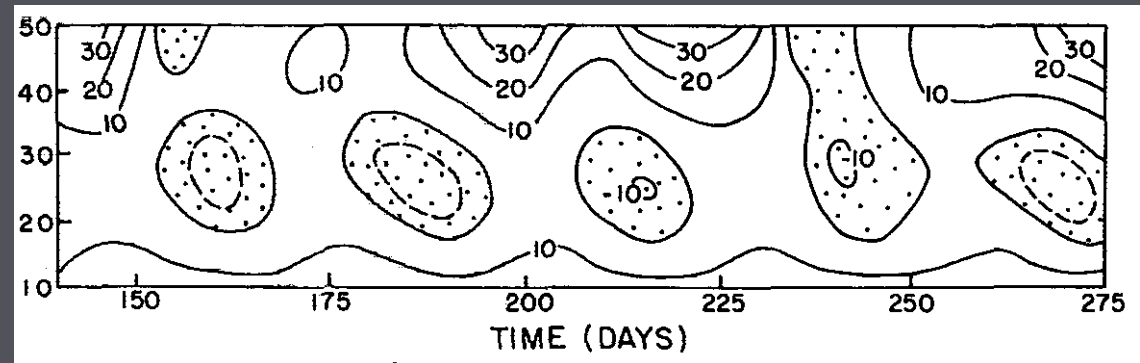
Source: Matsuno, doi:10.1175/1520-120469(1971)028<1479:ADMOTS>2.0.CO;2

# TRANSIENCE

Matsuno model suggests the need for a transient amplification of Rossby wave activity to cause a warming – links to external drivers (e.g. land cover)

In a range of simple models with fixed Rossby wave forcing, the stratosphere can generate vacillations

Zonal Mean Zonal Wind



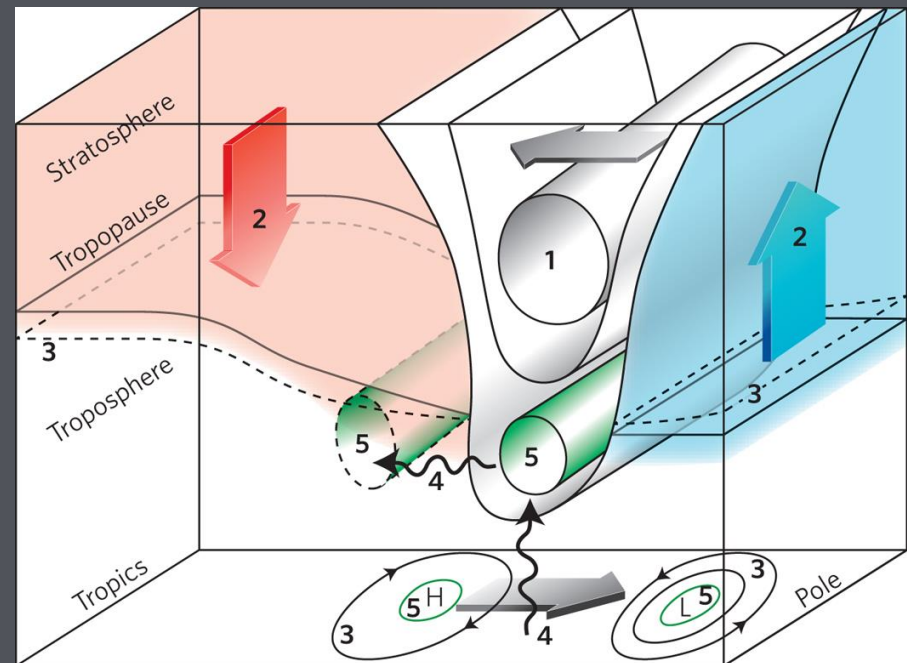
Source: Holton and Mass, doi: 10.1175/1520-0469(1976)033<2218:SVC>2.0.CO;2

Other authors point to the possibility of non-linear resonance effects associated particularly with vortex splitting cases.

# COUPLING TO THE TROPOSPHERE

Changes to the mean wind in the stratosphere are accompanied by changes to the meridional circulation and position of the tropopause (2 & 3 in the schematic)

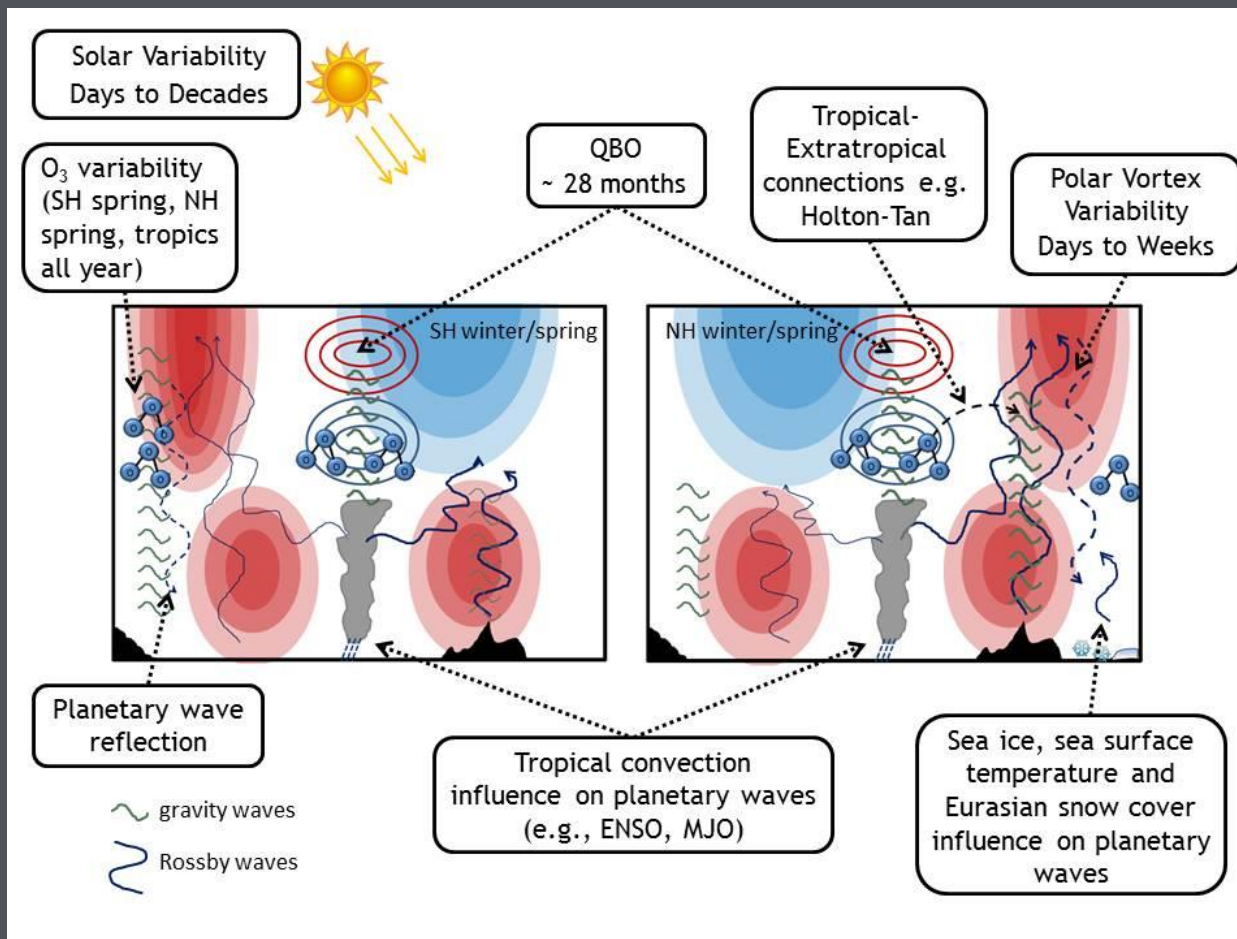
These changes extend to the surface instantaneously through non-local balanced adjustment to the changes



Source: Kidston et al., doi: 10.1038/ngeo2424

**On their own these balanced responses are weak and do not give the full tropospheric response. Tropospheric eddy feedbacks are critical**

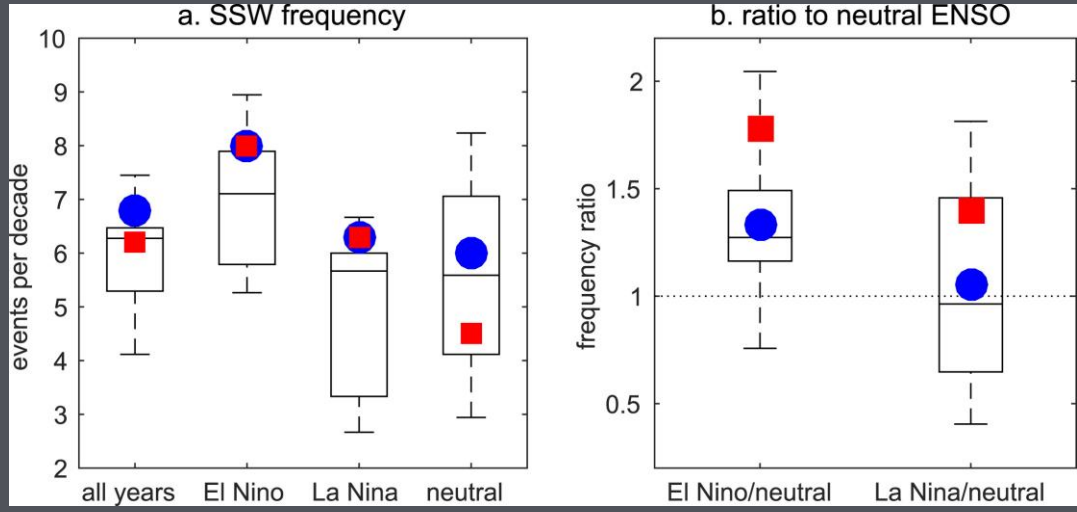
# STRATOSPHERIC DRIVERS



A number of different climate processes influence the likelihood of stratospheric variability on seasonal timescales and beyond

# EXAMPLE: ENSO

SSW frequency is enhanced during El Niño years

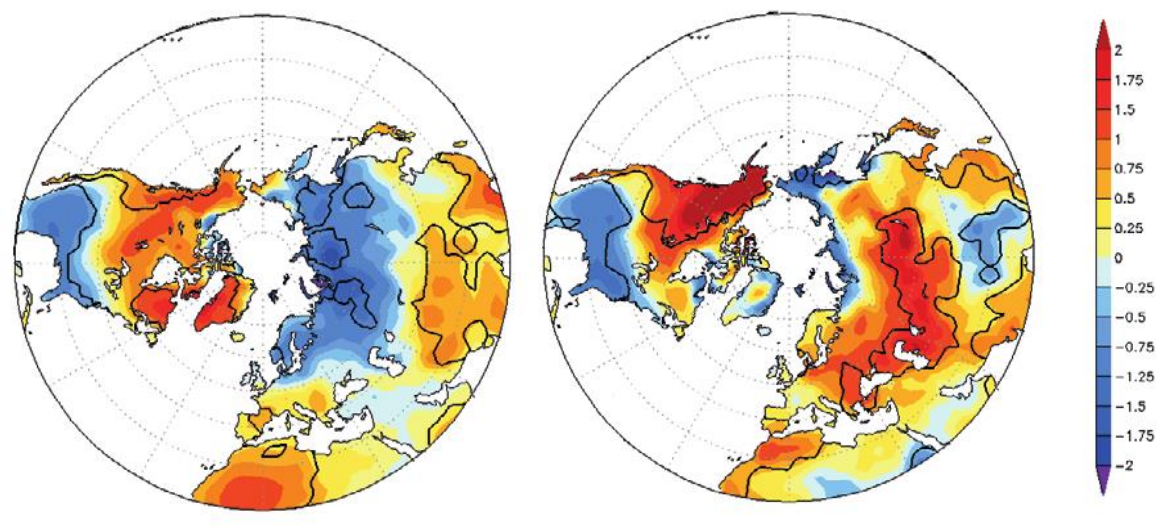


Source: Polvani et al., doi:10.1175/JCLI-D-16-0277.1

## El Niño-La Niña

Strat pathway active

Strat pathway inactive



Seasonal tropospheric anomalies in ENSO years are significantly different when the stratosphere is disturbed

Source: Butler, doi: 10.1088/1748-9326/9/2/024014



# STRATOSPHERIC PATHWAYS

The following sources of extra-tropical predictability on seasonal and longer timescale have been proposed to act on tropospheric climate via a stratospheric pathway:

- 1.The Madden-Julian Oscillation
2. ENSO
3. Eurasian snow cover
4. Sea-ice cover
5. The Quasi-Biennial Oscillation
6. The 11-year Solar Cycle
7. The Pacific Decadal Oscillation
8. Large volcanic eruptions

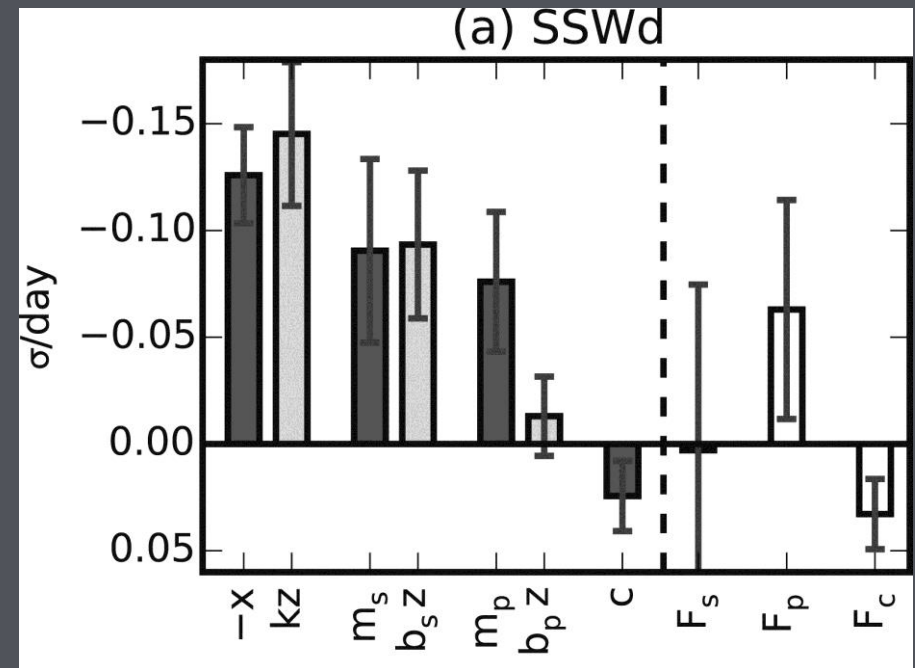
For references and explanations see the chapter I shared

# WHAT DON'T WE KNOW?

# DOWNWARD COUPLING

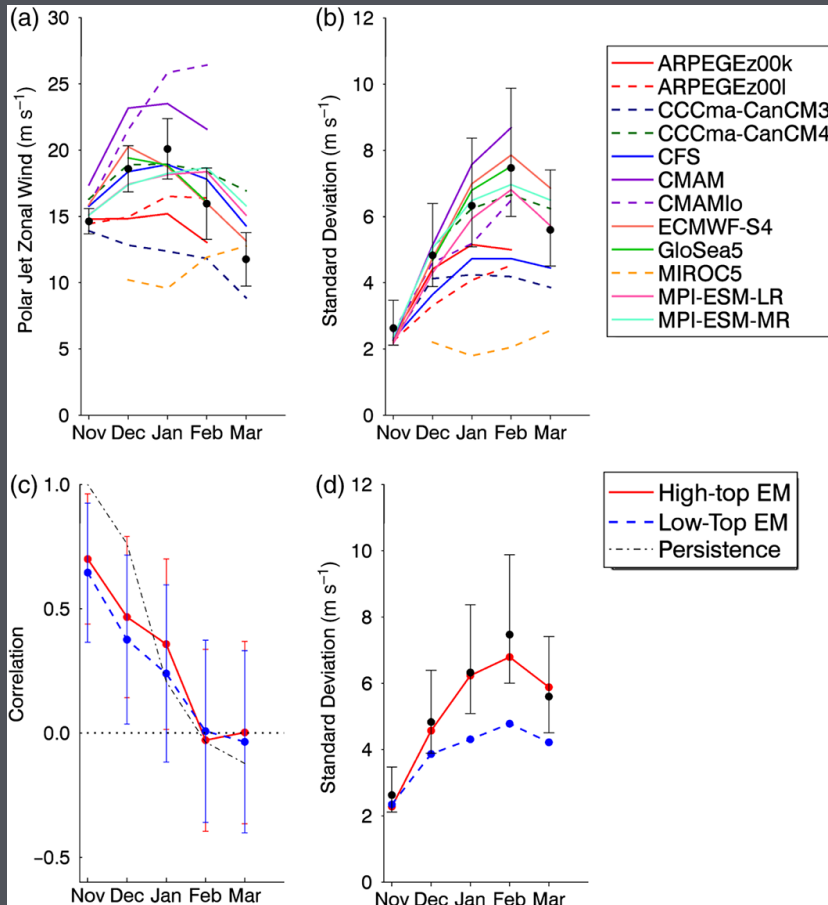
There is still a great deal of uncertainty about the mechanisms for downward coupling and the role of different processes in triggering the critical eddy feedback

Recent work highlights the role of planetary-scale waves in providing a link between the stratosphere and eddy-driven tropospheric jet



Source: Hitchcock and Simpson, doi:10.1175/JAS-D-16-0056.1

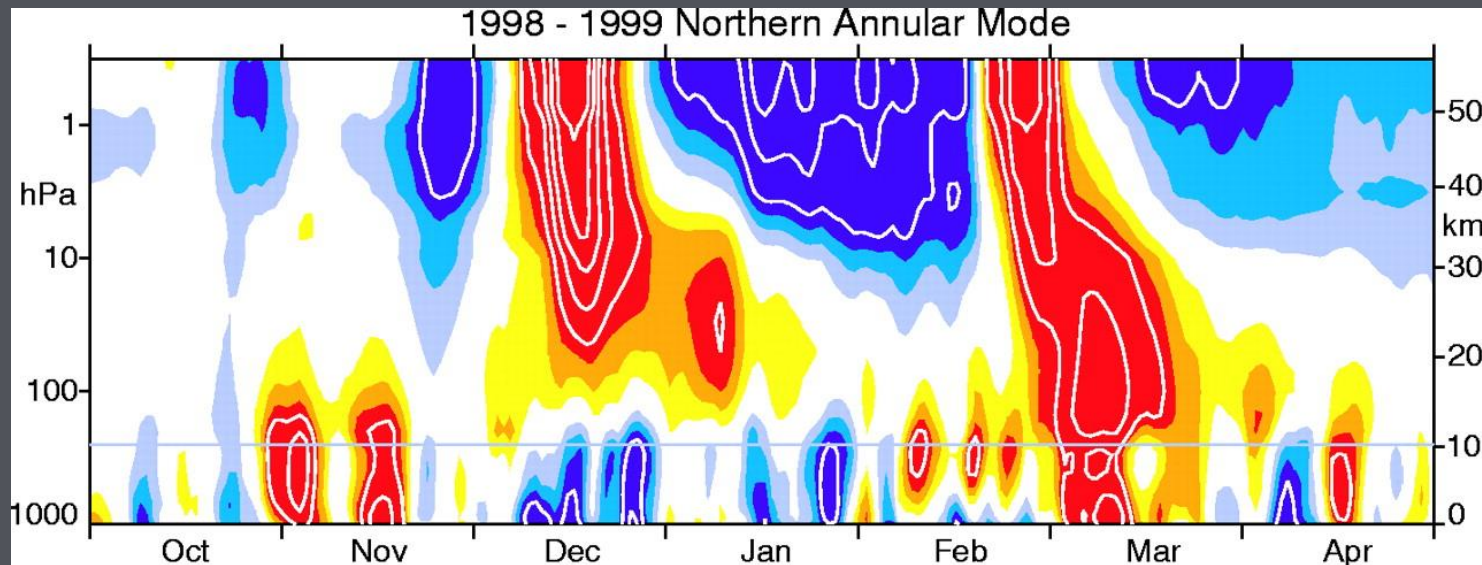
# MODEL BIASES



There can still be large mean-state stratospheric biases in models – this likely influences their ability to capture stratospheric predictability and stratosphere-troposphere coupling

Low-top models are known to have significantly reduced stratospheric variability

# COUPLING DIVERSITY



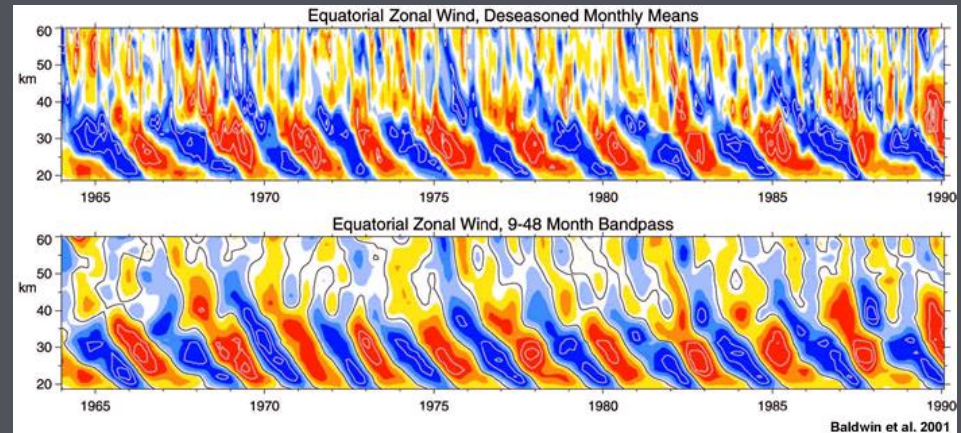
Source: Baldwin and Dunkerton, doi: 10.1126/science.1063315

For seemingly similar SSW or vortex intensifications the tropospheric response can be very different.

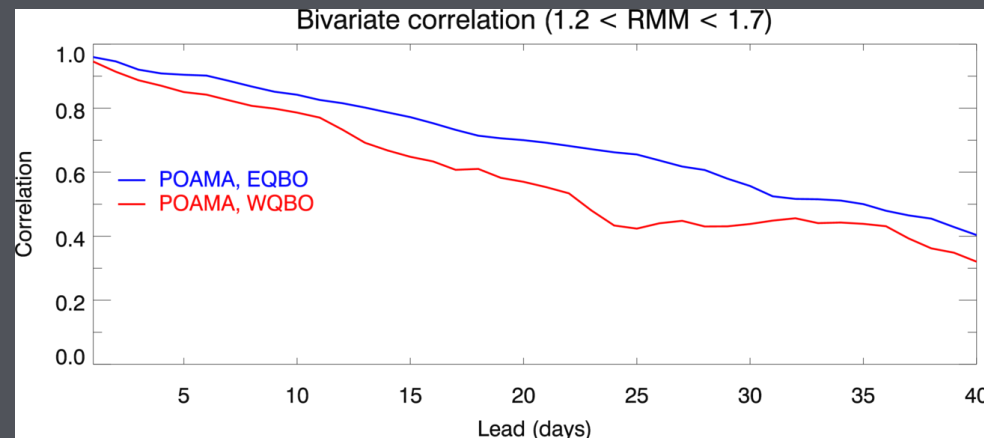
Is this just because of tropospheric variability or does the tropospheric state influence the strength of the coupling?

# THE TROPICS: A DIFFERENT EFFECT

- Recent work shows influences of the state of the QBO on the state of and predictability of the Madden-Julian Oscillation
- More work to be done here in understanding the mechanisms and implications.



Source: Baldwin et al.,  
doi: 10.1029/1999RG000073



Source: Marshall et al., doi:10.1007/s00382-016-3392-0

# TAKE HOME

- The stratosphere has long memory in winter associated with variability in the polar vortex
- This variability comes about through the interaction of vertically propagating Rossby waves and the mean flow
- Long-lasting stratospheric anomalies can influence the large-scale tropospheric state particularly in the North Atlantic
- Stratosphere-troposphere coupling can result in a pathway for remote influence of a number of drivers of climate variability to the North Atlantic

# MORE MATERIAL

- Along with a group of colleagues I've just written a draft chapter on the role of the stratosphere in sub-seasonal predictability which is available in your shared space (comments on this most welcome).
- Many of the figures come from this document – I've acknowledged the people who provided them on the slides
- Link to a Mendeley group containing all of the paper used:

<https://www.mendeley.com/community/ecmwf-predictability-stratosphere/>

