

THE STRATOSPHERE AND PREDICTABILITY



Andrew Charlton-Perez

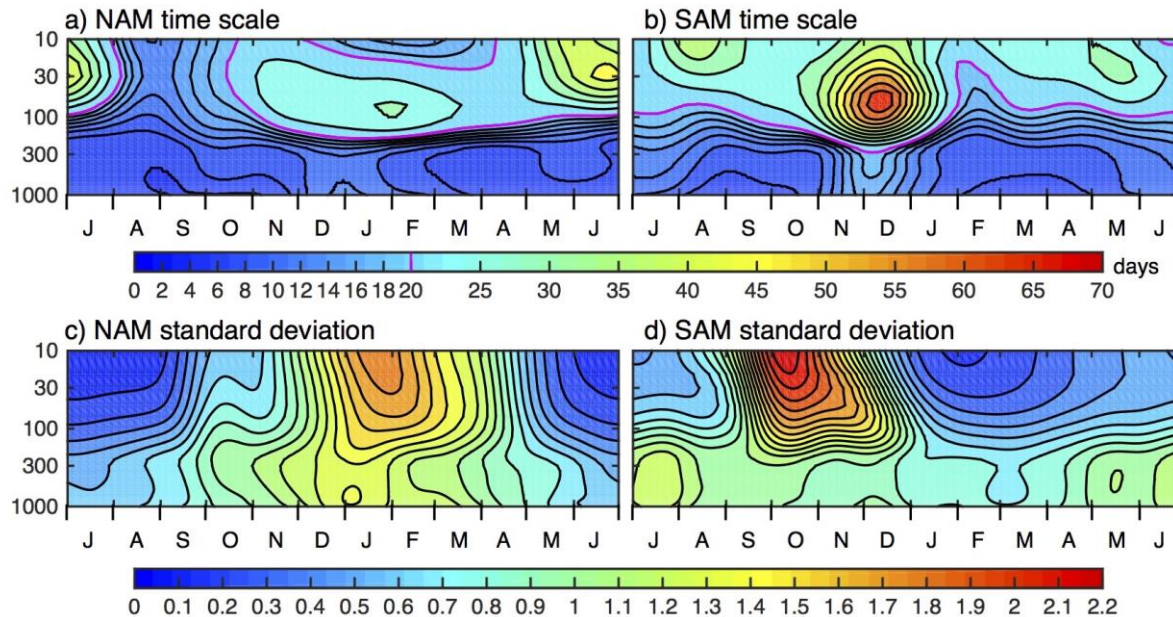
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OUTLINE

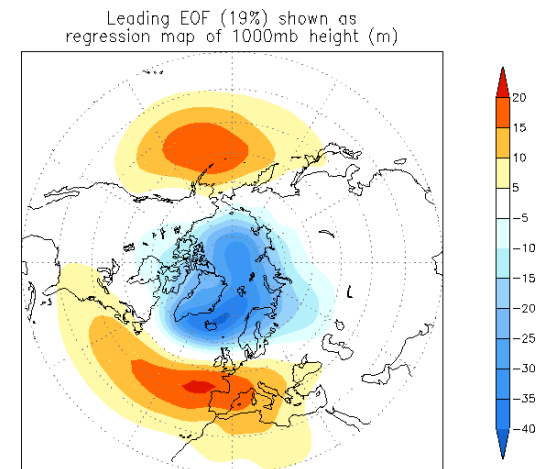
1. Why might you be interested in the stratosphere if you are interested in predictability?
2. What do we know about the dynamics of stratosphere-troposphere coupling?
3. What don't we know?

WHY CARE ABOUT THE STRATOSPHERE?

WHY THE STRATOSPHERE?



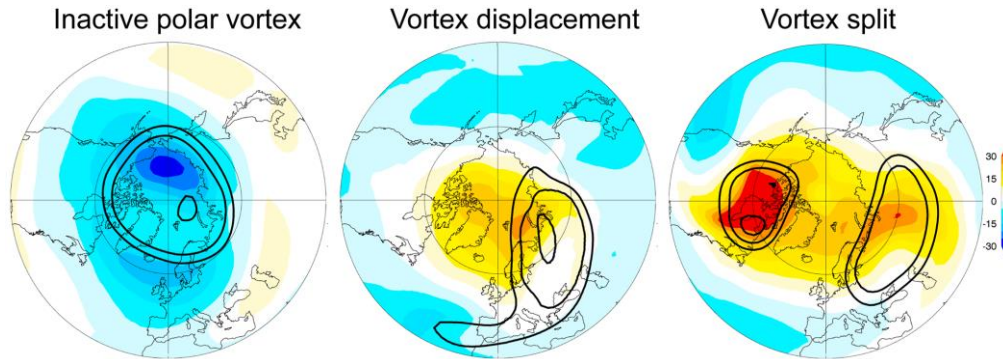
Source: Ed Gerber (NYU)



Source: NOAA/CPC

On the largest scales, the stratosphere has significant memory

SUDDEN STRATOSPHERIC WARMINGS (SSWS)

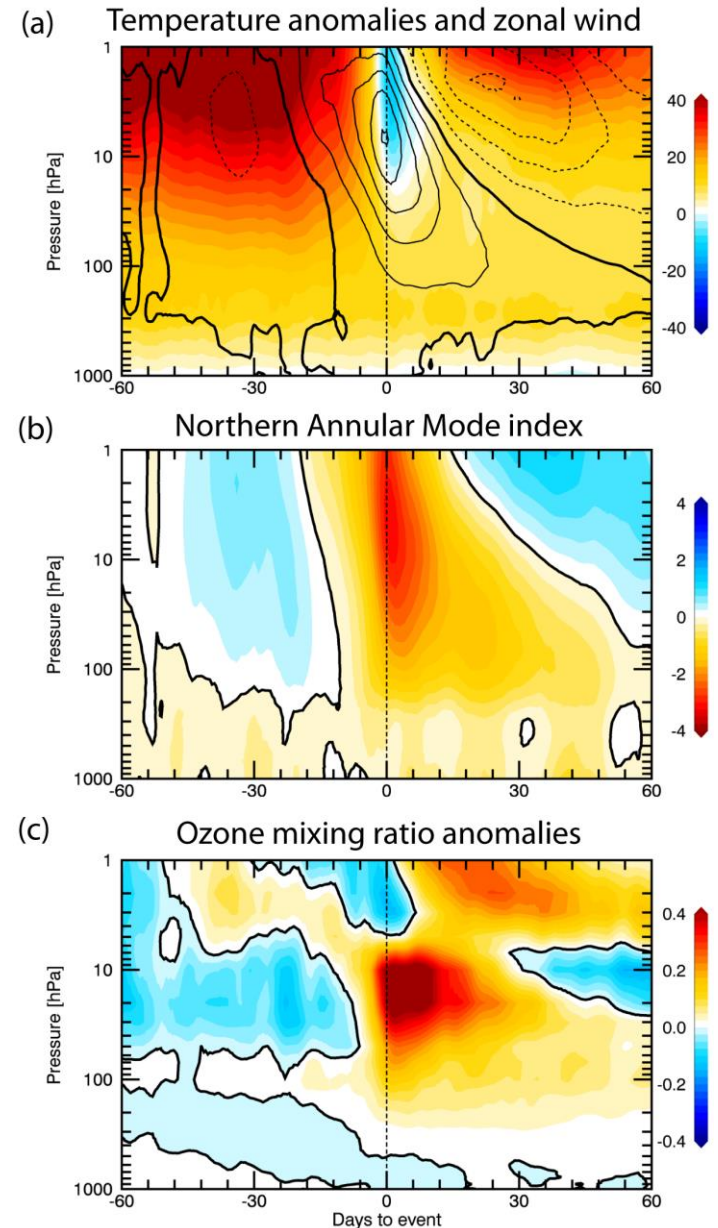


Source: Butler et al. doi:10.5194/essd-9-63-2017

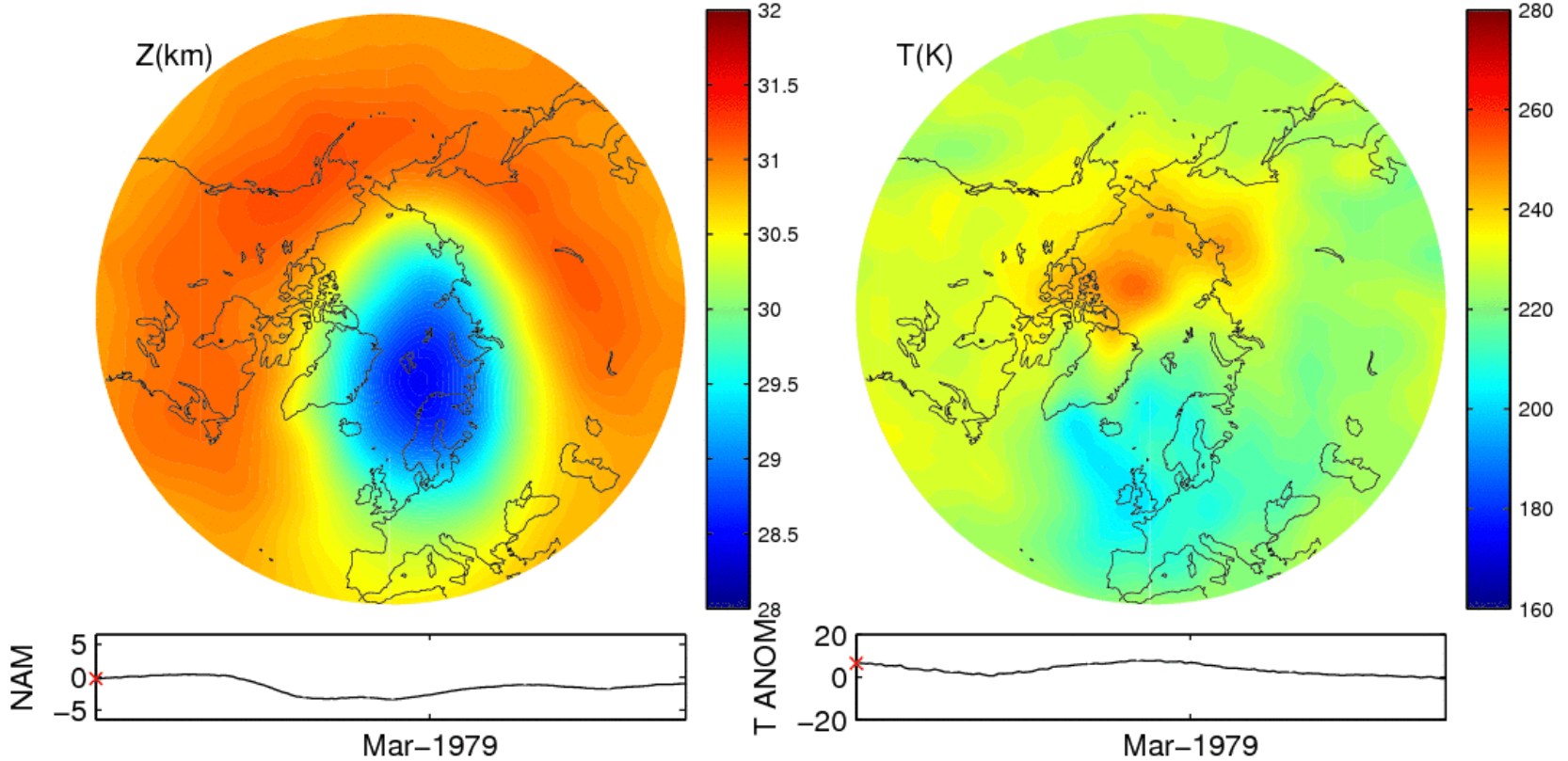
Also see the SSW compendium website:

<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

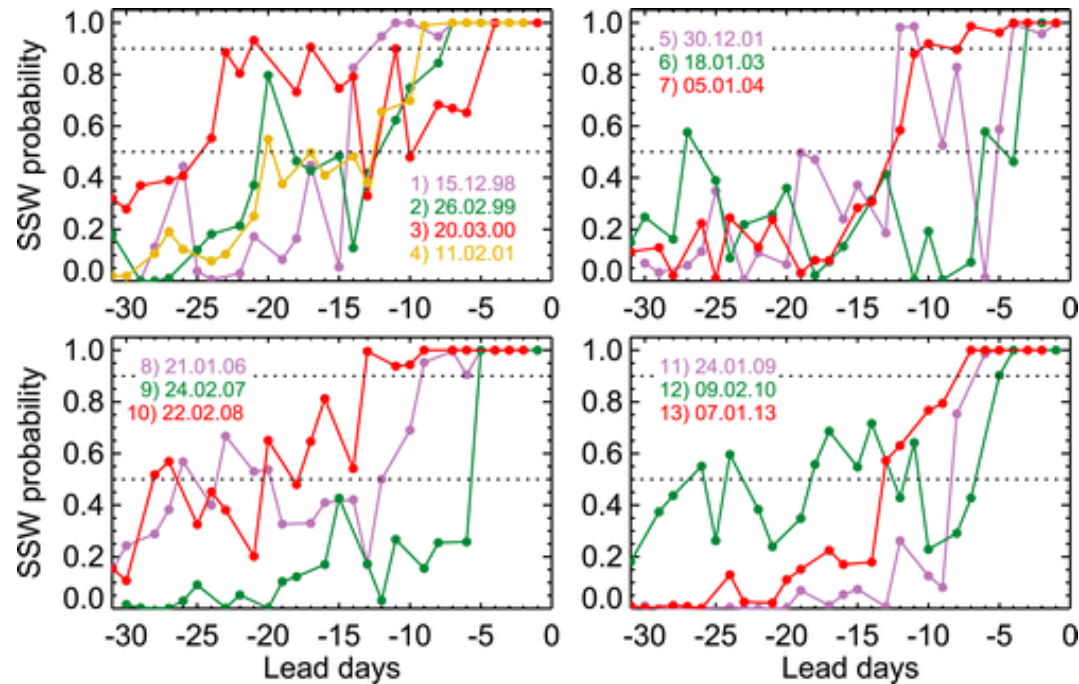


Vortex Displacement

Vortex Split

Source: Patrick Martineau

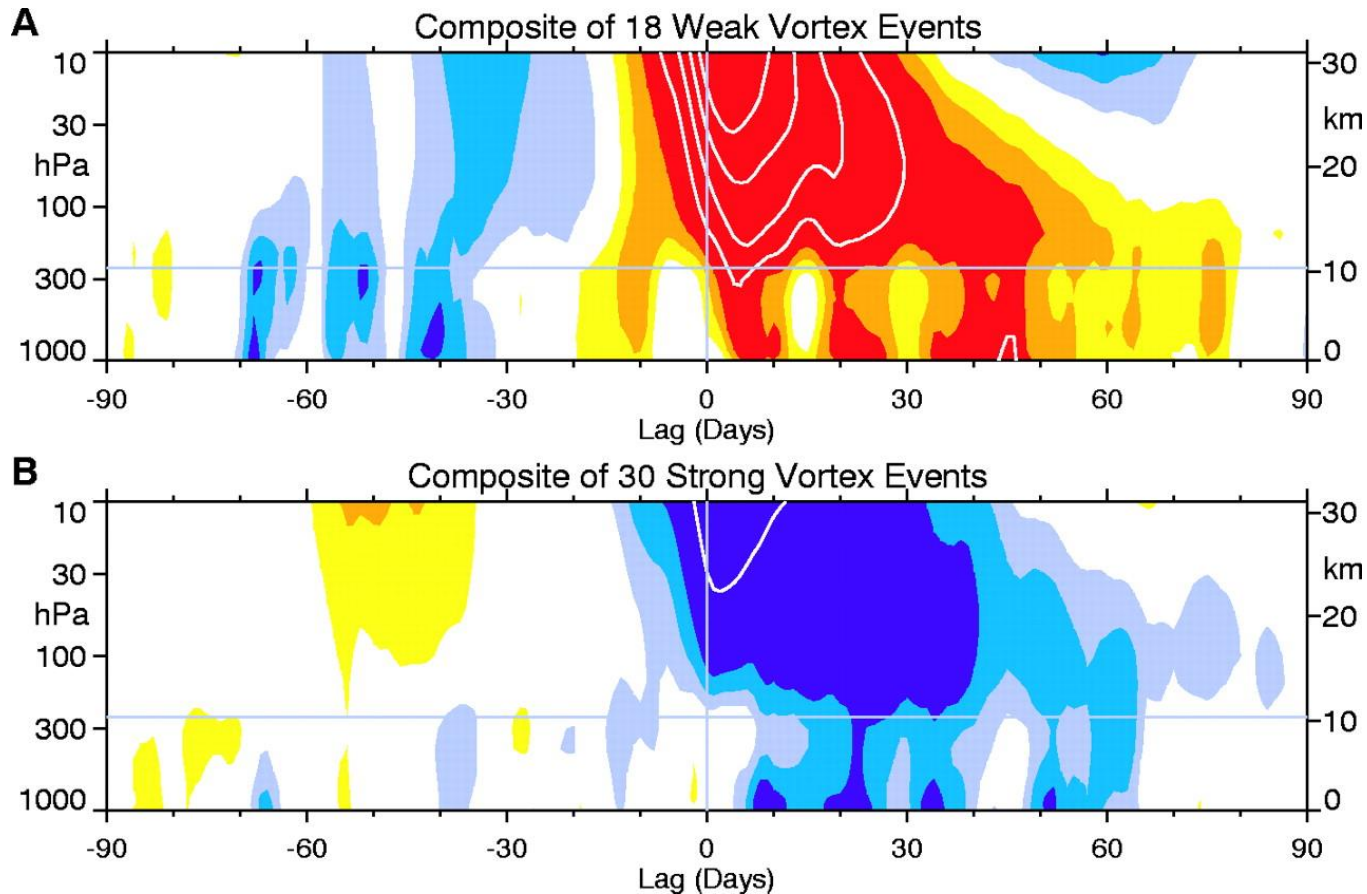
CAN WE PREDICT SSW EVENTS?



- Between 8-12 days prior to an SSW event forecast models usually indicate a greater than 0.5 probability of an SSW event occurring (although not for all events and there is sometimes some difference in the timing of events).
- Tropospheric forecast uncertainty likely influences some events.

Source: Karpechko (2018), doi: [10.1175/MWR-D-17-0317.1](https://doi.org/10.1175/MWR-D-17-0317.1)

SSW/ANNULAR MODE COUPLING



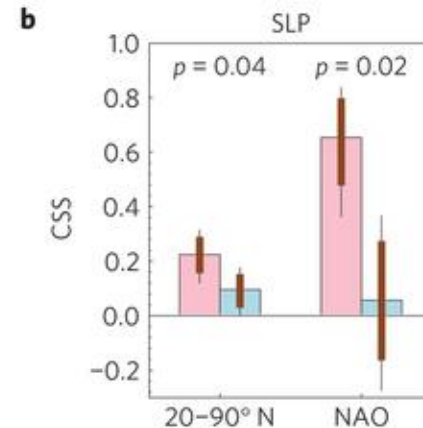
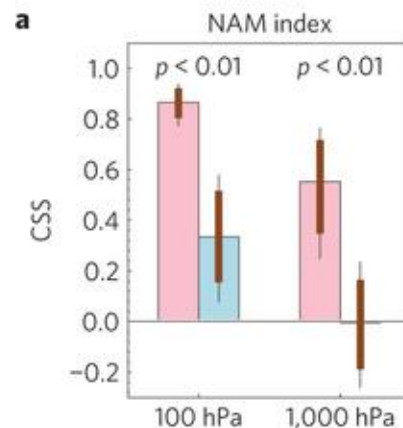
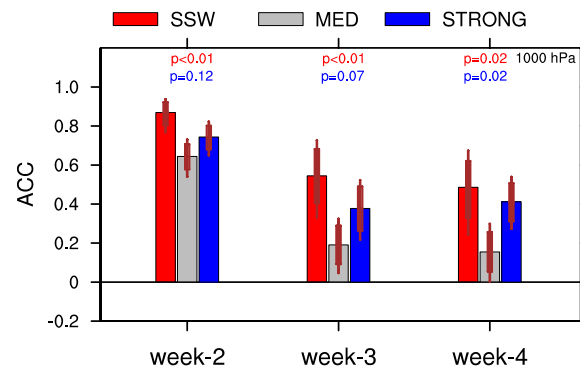
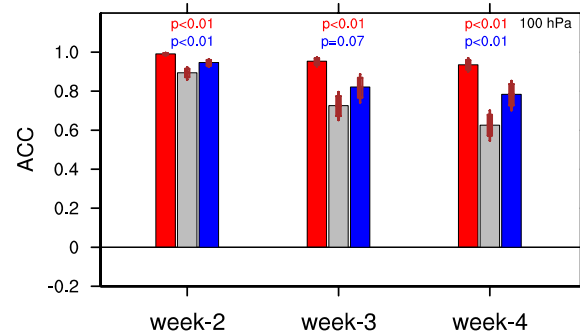
Following extreme events in the stratospheric NAM (and SAM) the tropospheric NAM is more likely to have the same phase.

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.

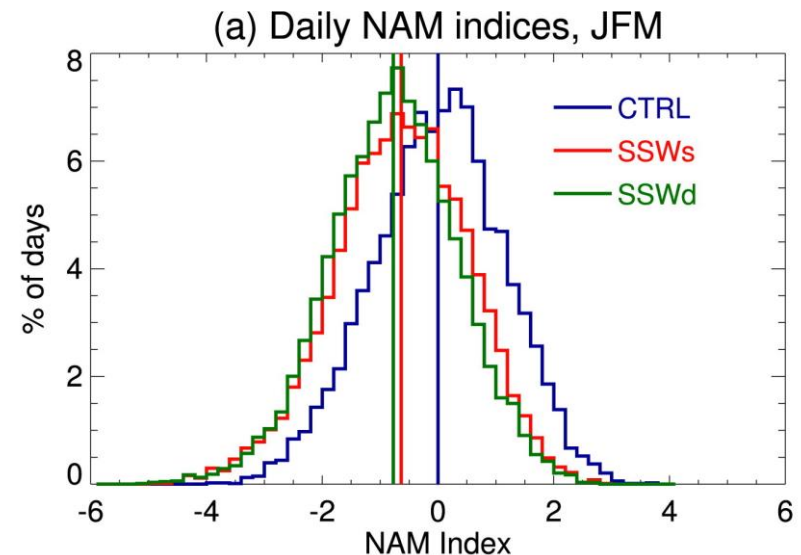
Forecast skills (ACC) for the NAM index



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

IS THIS A REAL INFLUENCE?

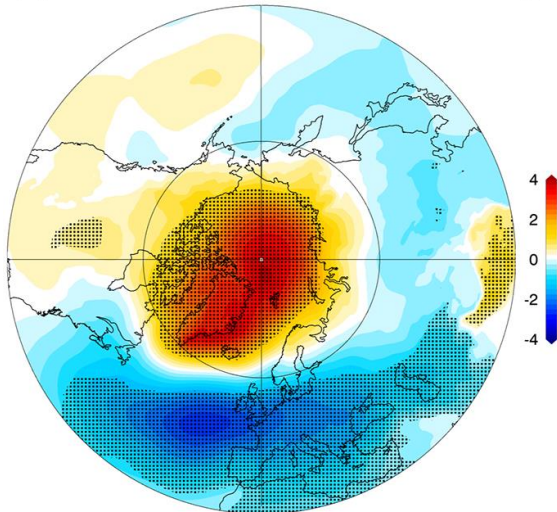
- Reasonable to ask if the tropospheric response is driven by the stratospheric state.
- Reproduce the same SSW event 100 times in a model by nudging (with different tropospheric state)
- Clear influence shown in shift of tropospheric PDF



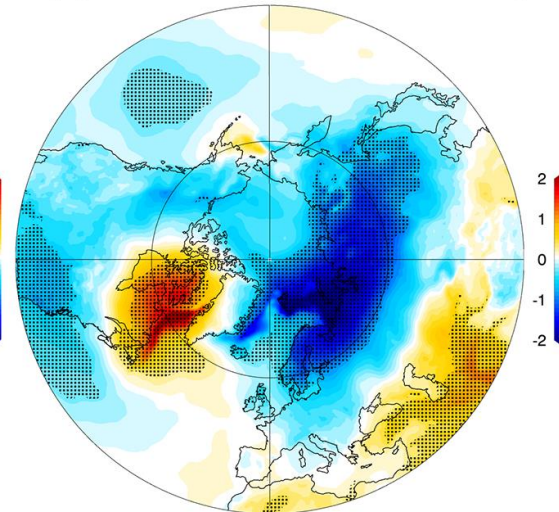
Source: Hitchcock and Simpson,
doi: 10.1175/JAS-D-14-0012.1

SURFACE IMPACT

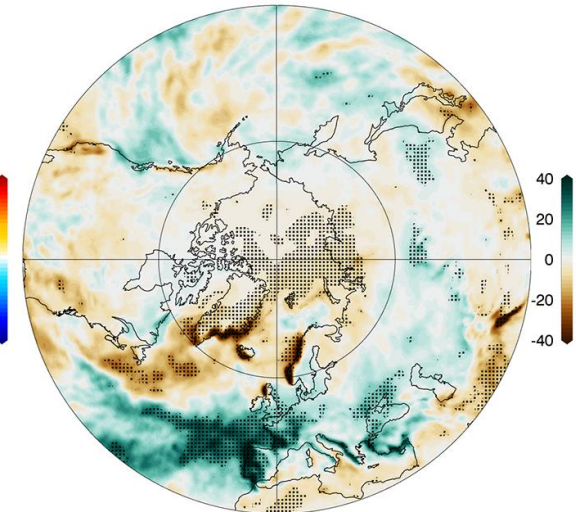
(a) Mean sea level pressure anomaly



(b) Surface temperature anomaly



(c) Precipitation anomaly



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?

STATIONARY ROSSBY WAVES

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

<https://youtu.be/J3S6a0LMNOs>

Videos: Issac Held

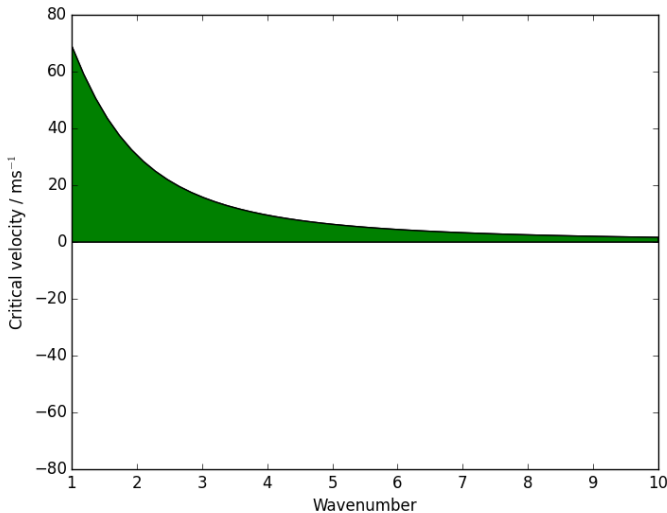
<https://youtu.be/8J4uw0UrTRw>

ROSSBY WAVES

Source: Matsuno, doi:10.1175/1520-0469(1971)028<1479:ADMOTS>2.0.CO;2

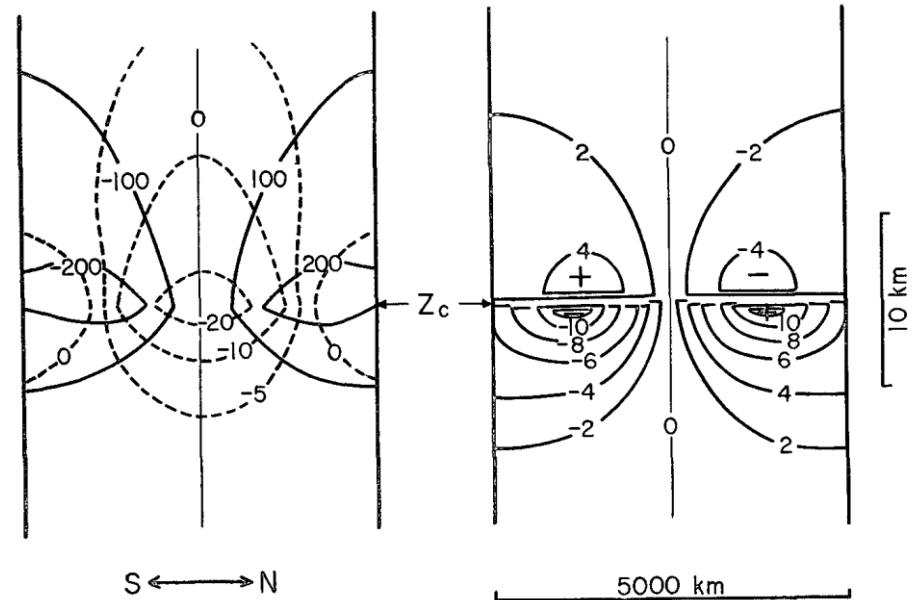
There are well developed theories for which Rossby wave can propagate in the vertical – usually low wavenumbers

Green indicates propagation



U changes (dashed)

T changes



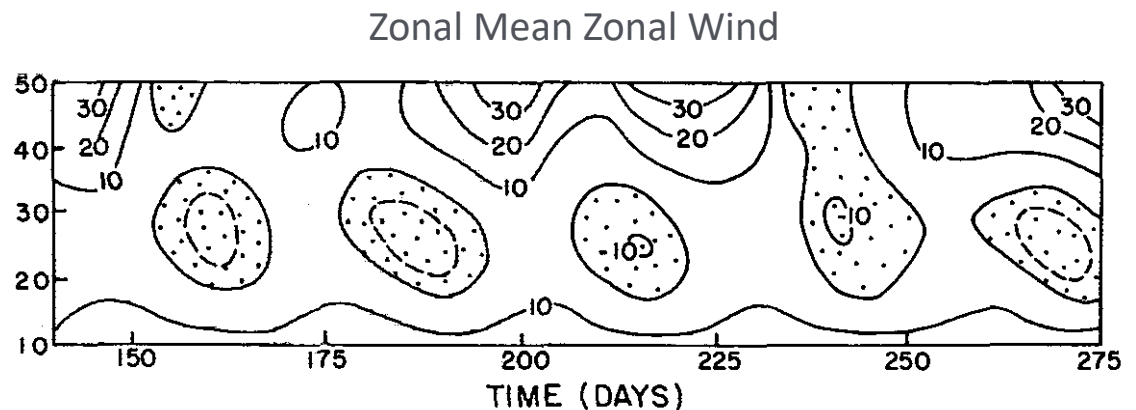
When waves encounter a critical line they cause changes to the mean winds and temperatures

Source: Charney and Drazin, doi: 10.1029/JZ066i001p00083

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



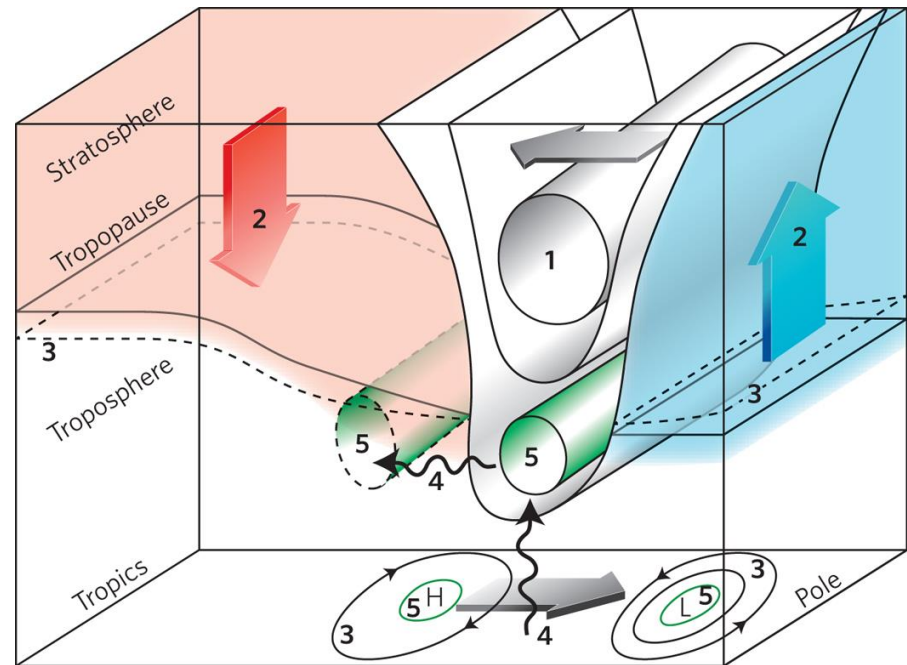
Source: Holton and Mass, doi: [10.1175/1520-0469\(1976\)033<2218:SVC>2.0.CO;2](https://doi.org/10.1175/1520-0469(1976)033<2218:SVC>2.0.CO;2)

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)

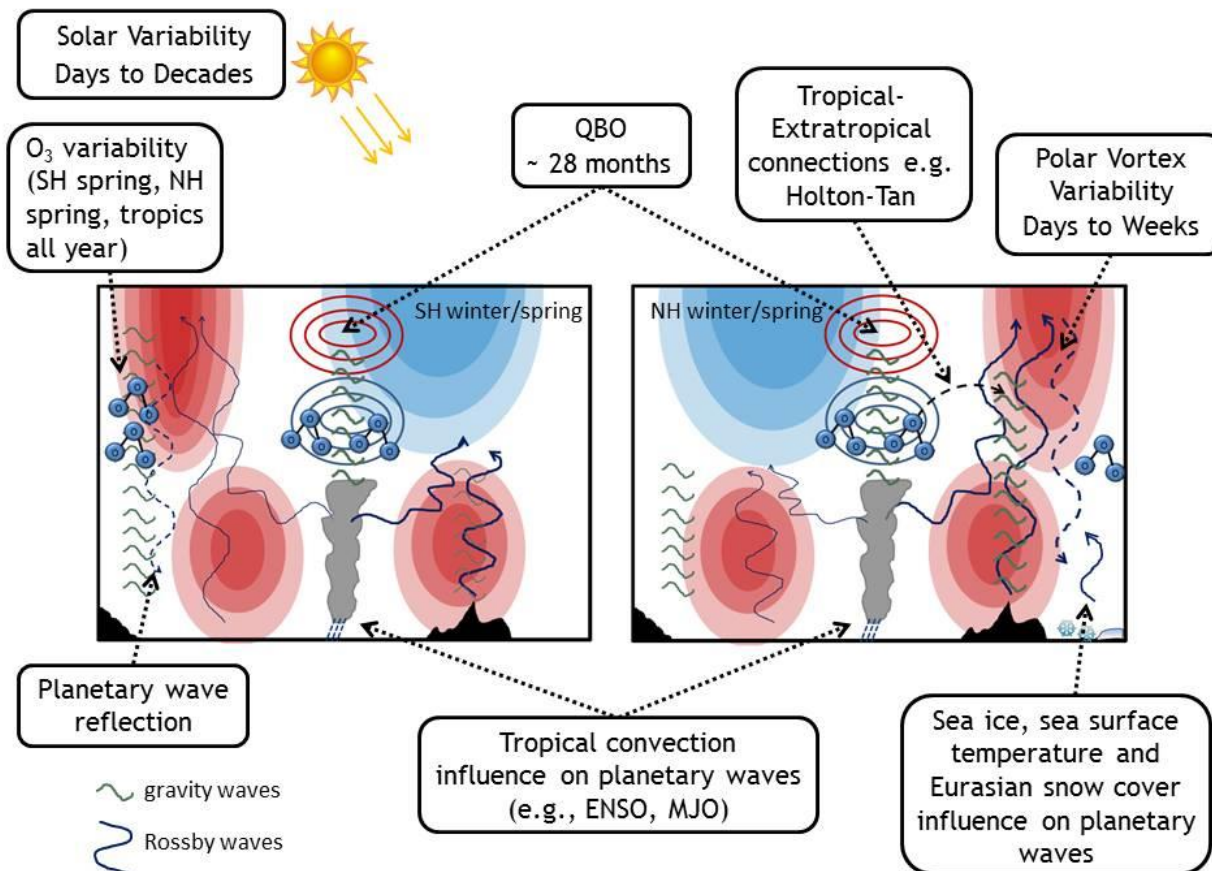
These changes extend to the surface instantaneously through non-local balanced adjustment to the changes



Source: Kidston et al., doi: [10.1038/ngeo2424](https://doi.org/10.1038/ngeo2424)

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

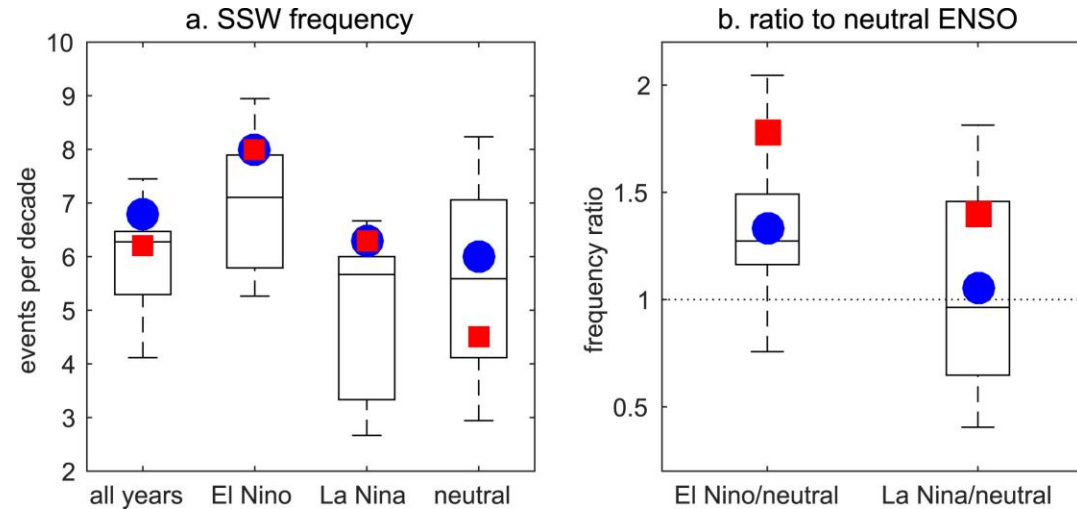
STRATOSPHERIC DRIVERS



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

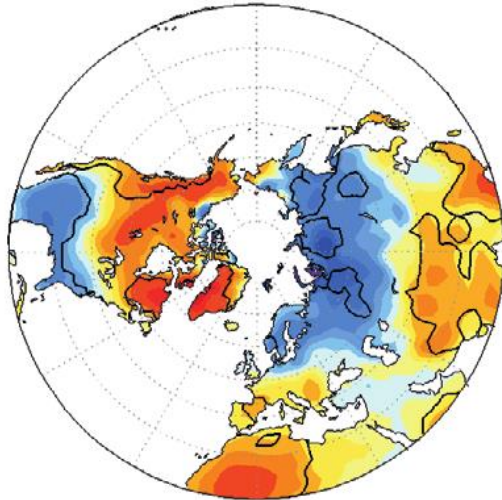
AN EXAMPLE: ENSO

SSW frequency is enhanced during El Niño years

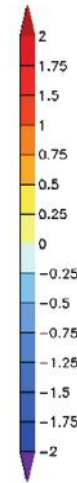
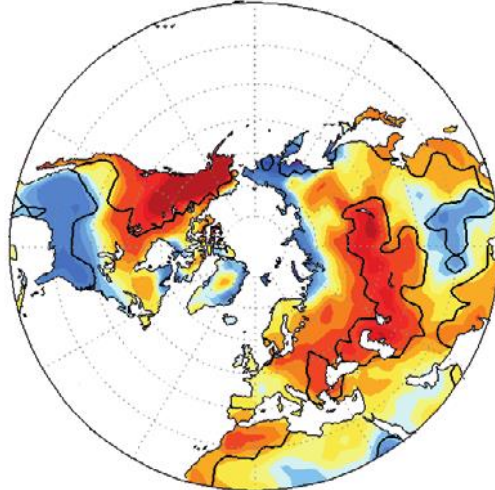


Source: Polvani et al., doi:10.1175/JCLI-D-16-0277.1

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

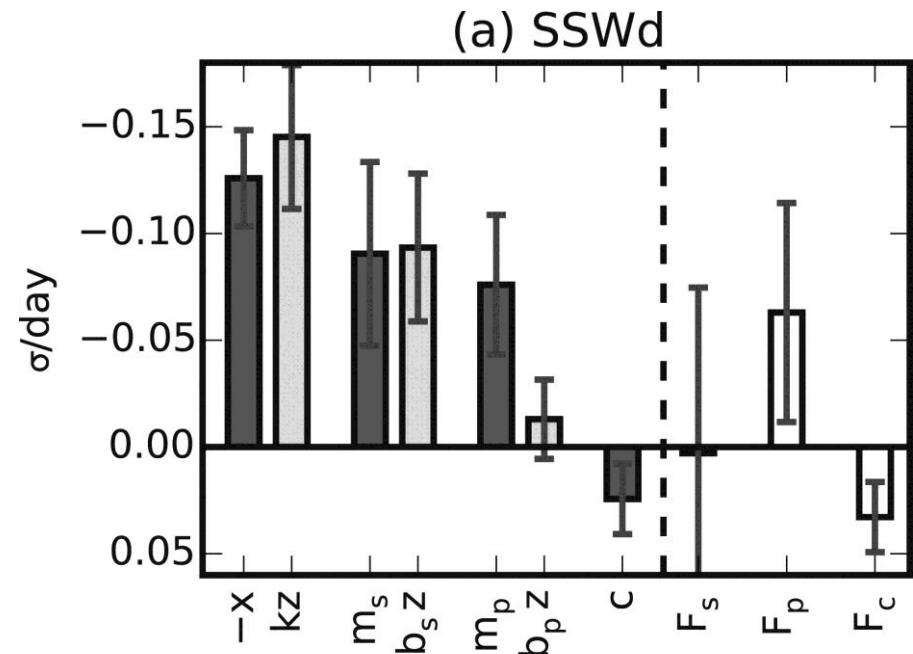
For references and explanations see the chapter I shared

WHAT DON'T WE KNOW?

DOWNWARD COUPLING

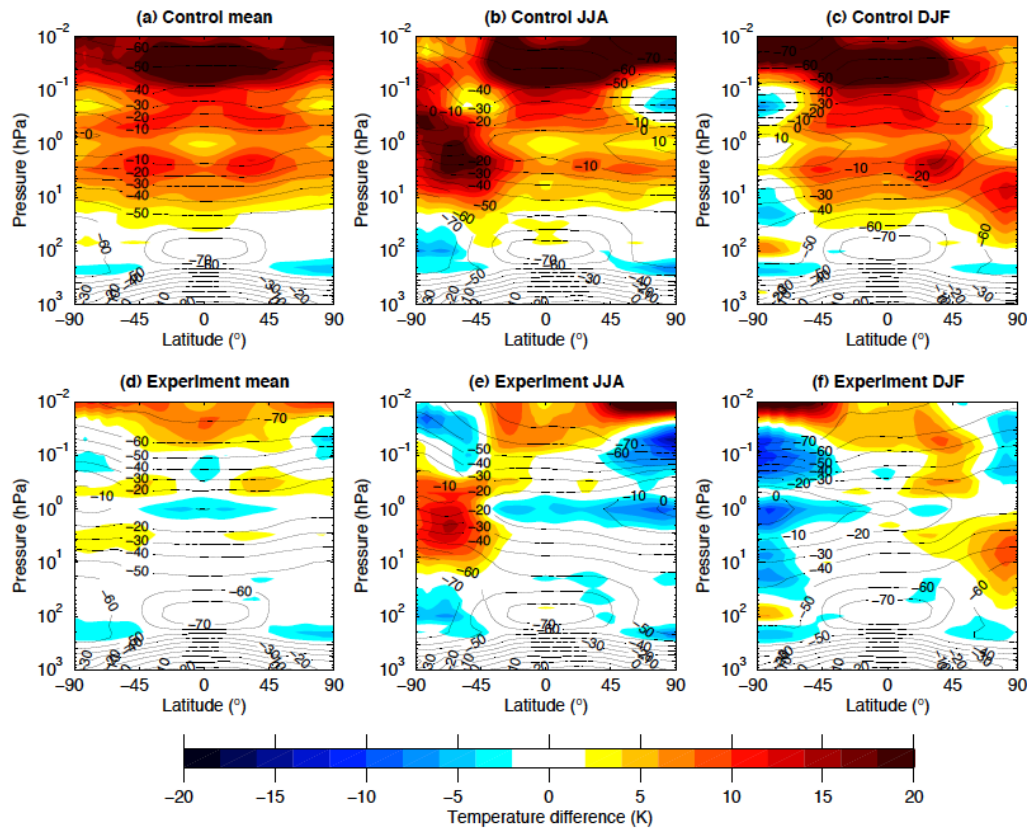
There is still a great deal of uncertainty about the mechanisms for downward coupling and the role of different processes in triggering the critical eddy feedback

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



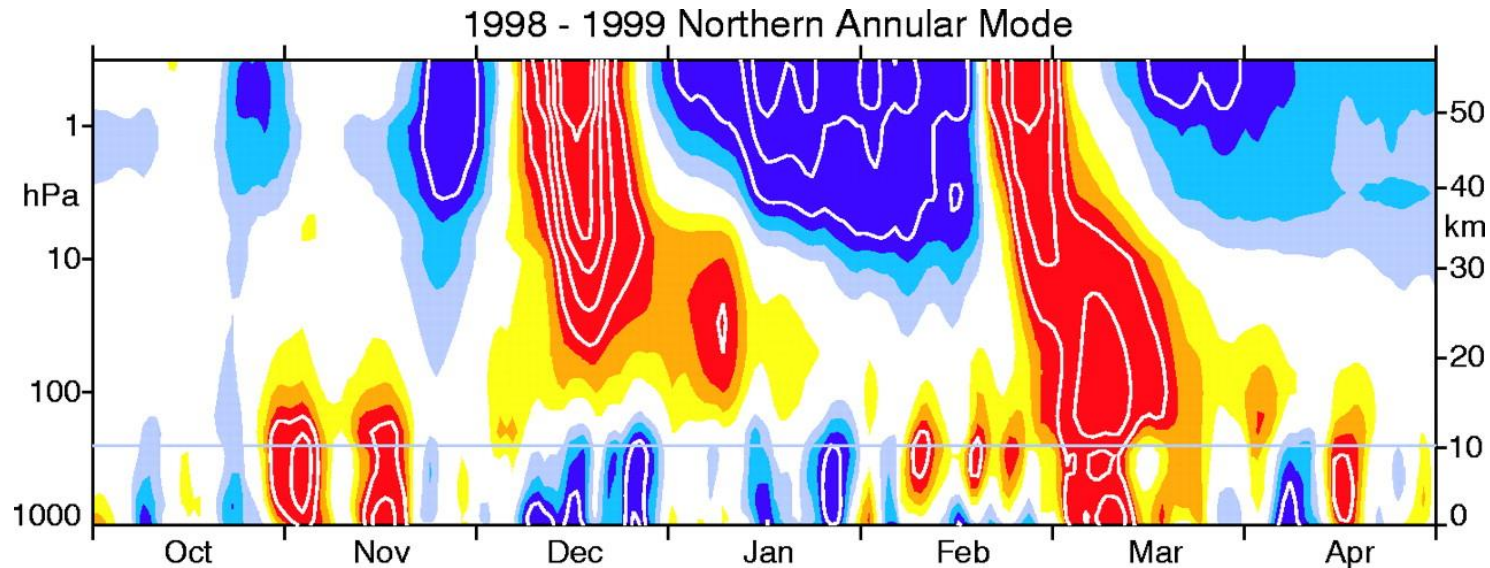
There can still be large mean-state stratospheric biases in models – this likely influences their ability to capture stratospheric predictability and stratosphere-troposphere coupling

An example of the progress that can be made through a focus on stratospheric processes, but note the long standing bias in lower stratospheric temperature

Source: Hogan et al. (2017), doi: [10.21957/2bd5dkj8x](https://doi.org/10.21957/2bd5dkj8x)

See also doi: [10.21957/0vkp0t1xx](https://doi.org/10.21957/0vkp0t1xx)

COUPLING DIVERSITY

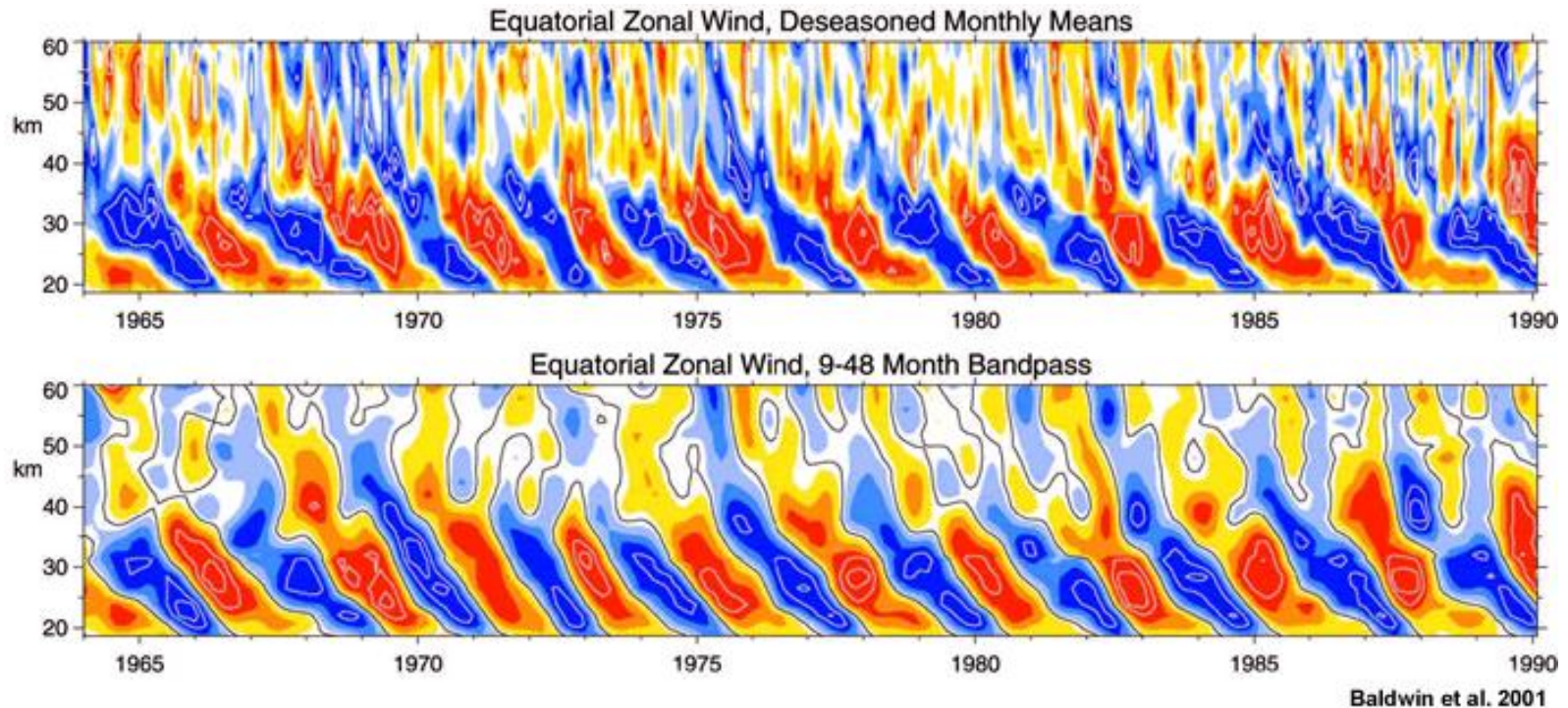


Source: Baldwin and Dunkerton, doi: [10.1126/science.1063315](https://doi.org/10.1126/science.1063315)

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?

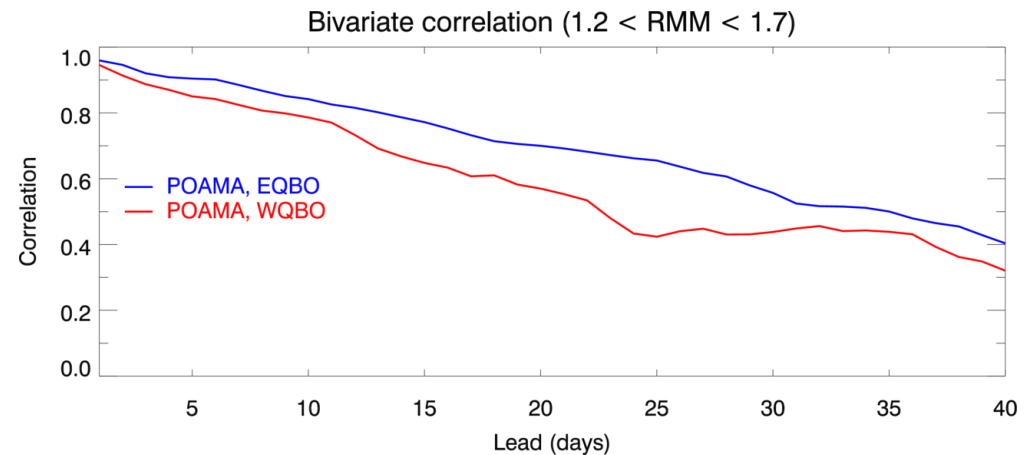
THE TROPICS: THE QBO



Source: Baldwin et al.,
doi: [10.1029/1999RG000073](https://doi.org/10.1029/1999RG000073)

QBO-MJO LINKS

- 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

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 papers used (invite only, e-mail me for an invite):

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