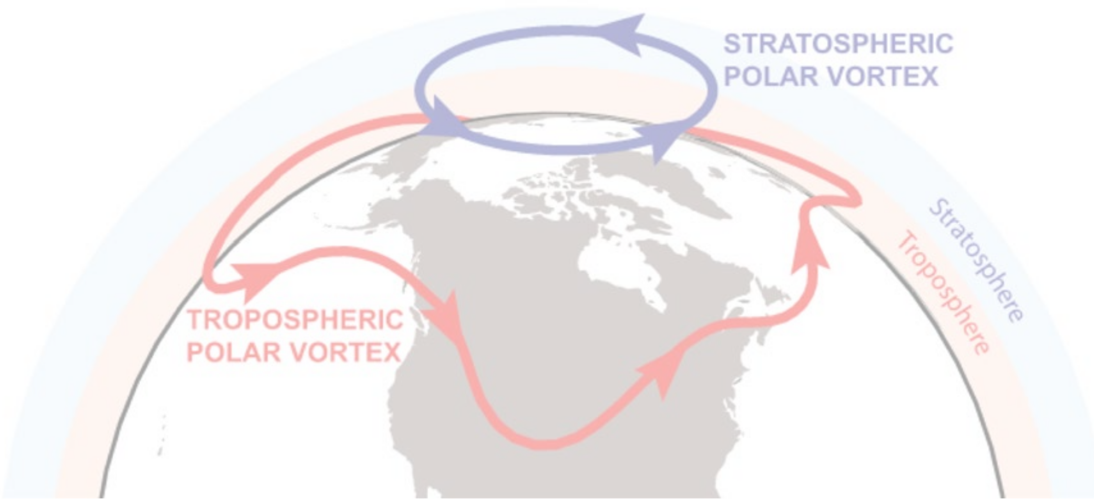
The role of the stratosphere in subseasonal to seasonal predictability

Amy H. Butler

NOAA/Chemical Sciences Division and CIRES/CU-Boulder

Andrew Charlton-Perez (U. Reading), Daniela Domeisen (ETH Zurich), Chaim Garfinkel (Hebrew U.), Ed Gerber (NYU), Peter Hitchcock (LMD/Cornell U.), Alexey Karpechko (FMI), Amanda Maycock (U. Leeds), Michael Sigmond (ECCC), Isla Simpson (NCAR), and Seok-woo Son (Seoul National U.)



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Stratospheric Network for the Assessment of Predictability (SNAP)

Team

Activity Leaders

Andrew Charlton-Perez
University of Reading, UK
a.j.charlton@reading.ac.uk

Amy Butler
NOAA Chemical Sciences Division, USA
Amy.Butler@noaa.gov

Steering Committee

Mark Baldwin, University of Exeter, UK
Daniela Domeisen, GEOMAR, Germany
Chaim Garfinkel, Hebrew University, Israel
Peter Hitchcock, NCAR, USA
Erik Kolstad, Bjerknes Centre, Norway
Jeff Knight, Met Office, UK
Craig Long, NOAA CPC, USA
Andrea Lopez Lang, University at Albany, USA
Andrew Marshall, BOM, Australia
Isla Simpson, NCAR, USA
Aditi Sheshadri, Columbia University, USA
Seok-Woo Son, Seoul National University, Korea
Lantao Sun, NOAA ESRL, USA
Masakazu Taguchi, Aichi University of Education, Japan
Om Tripathi, USA

WCRP World Climate Research Programme

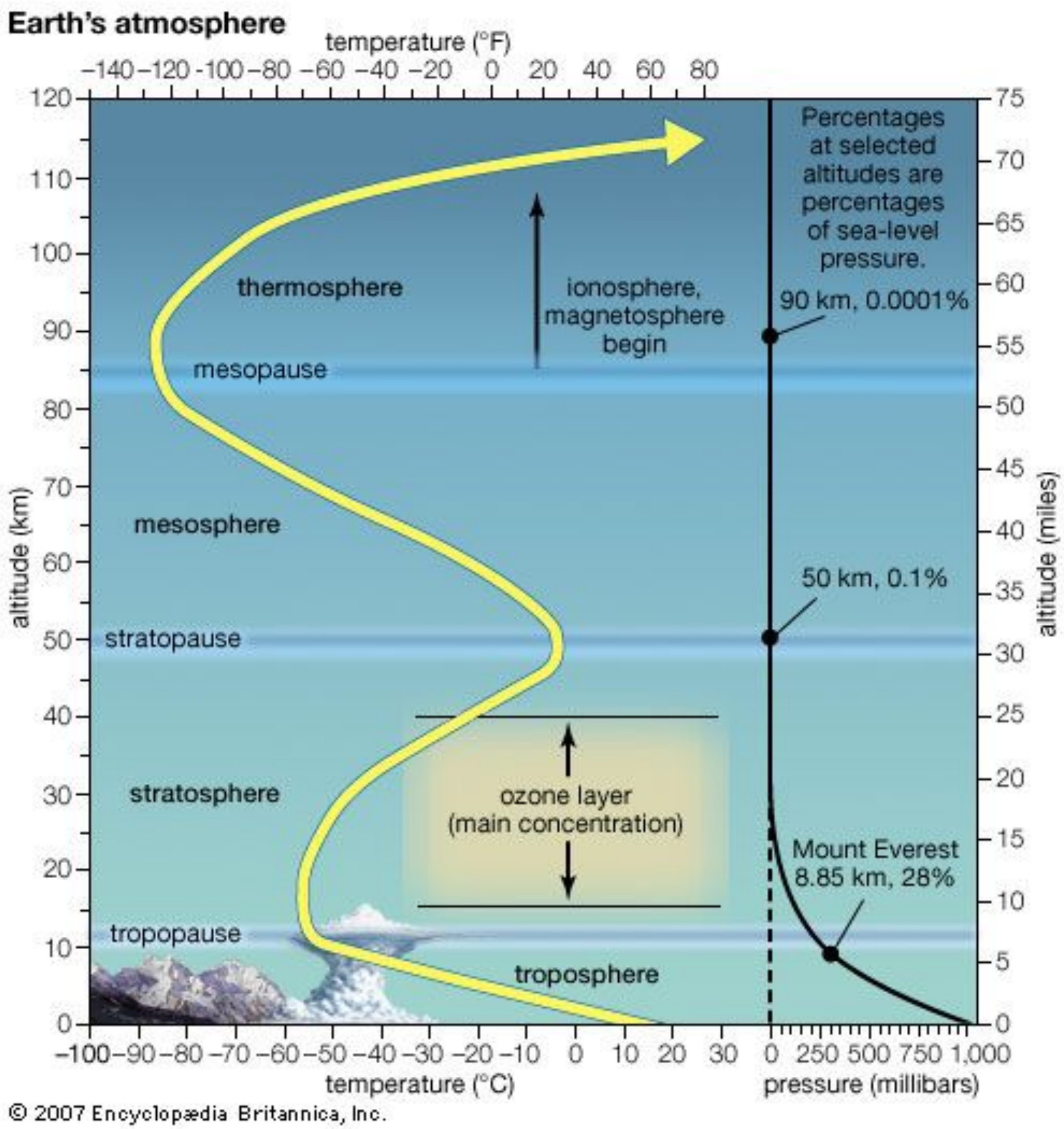
SPARC Stratosphere-troposphere Processes And their Role in Climate

A WCRP/SPARC activity to assess stratospheric predictability and its tropospheric impact.

- **Phase 1**: Funded by UK NERC International Opportunities Fund to perform international investigation of stratospheric predictability on S2S timescales [Tripathi et al. 2015]
- **Phase 2 (ongoing):** Create an international collaboration to examine the role of the stratosphere in surface climate predictability, using the WWRP/WCRP S2S database.

www.sparcsnap.org

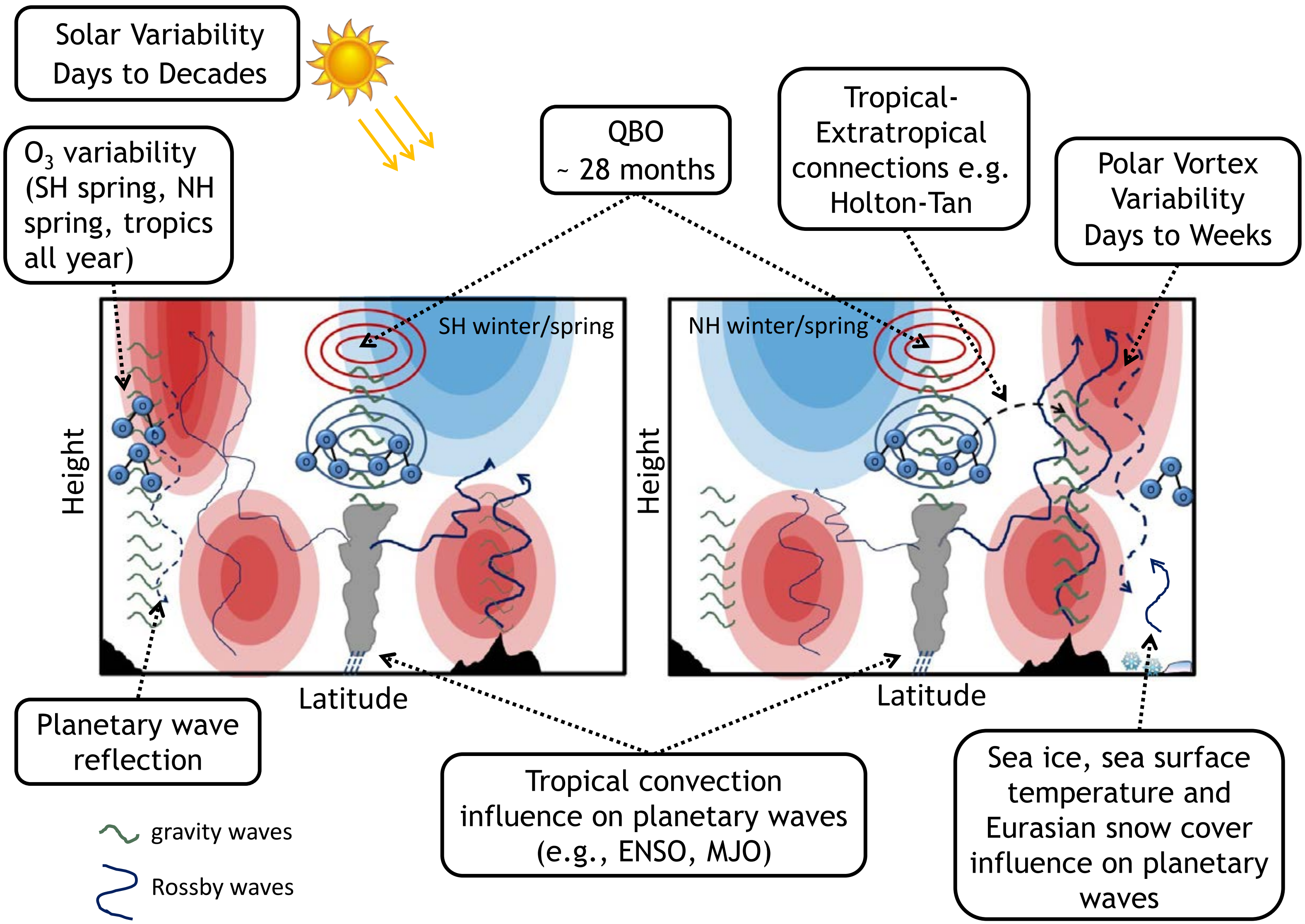
The Stratosphere



- Highly stratified air
- Home of the ozone layer
- 6 to 30 miles above the surface
- Contains ~20% of atmosphere's mass

The stratosphere is NOT a passive bystander to the troposphere.

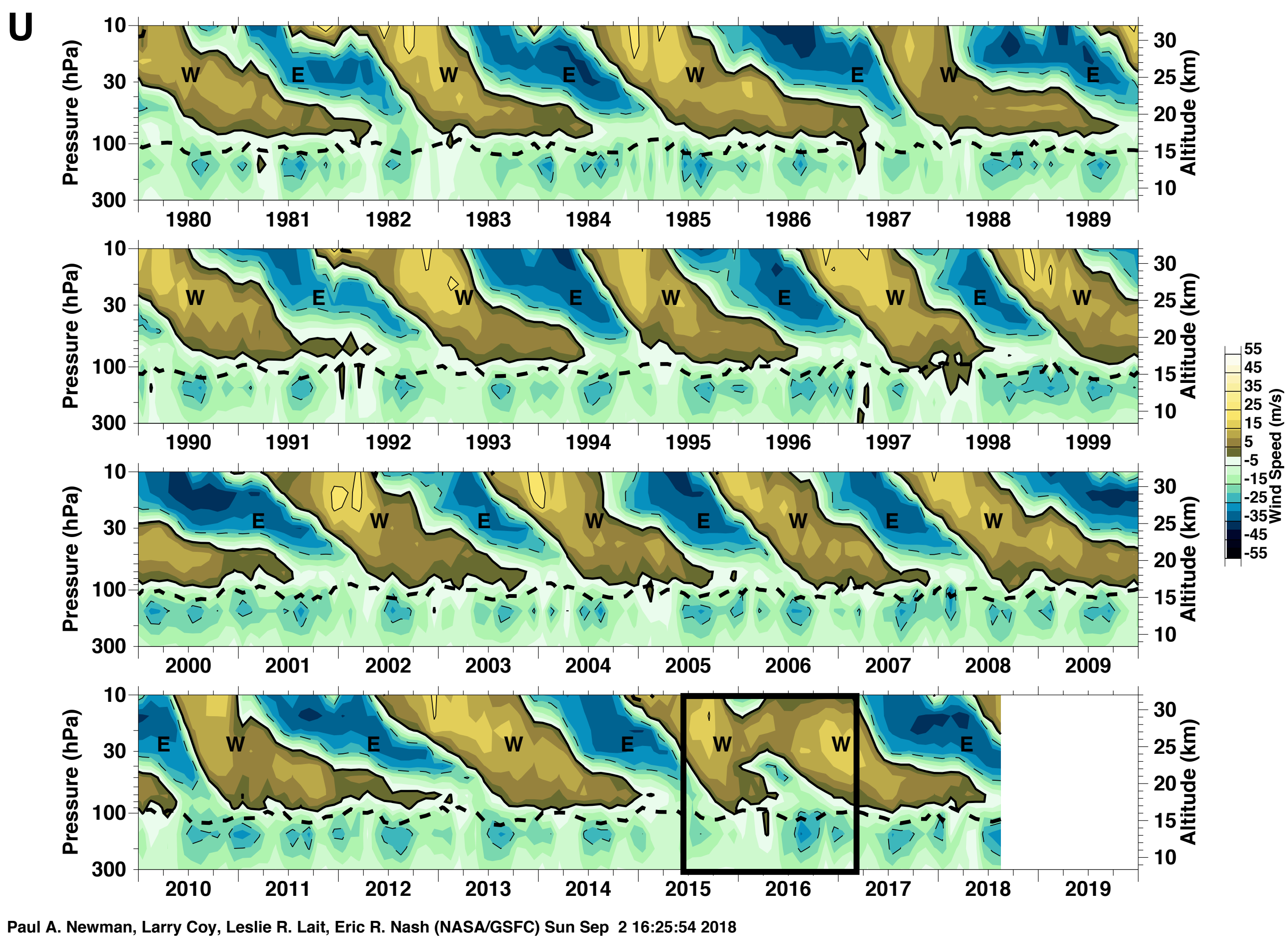
Phenomena relevant to stratosphere-troposphere coupling



S2S book chapter

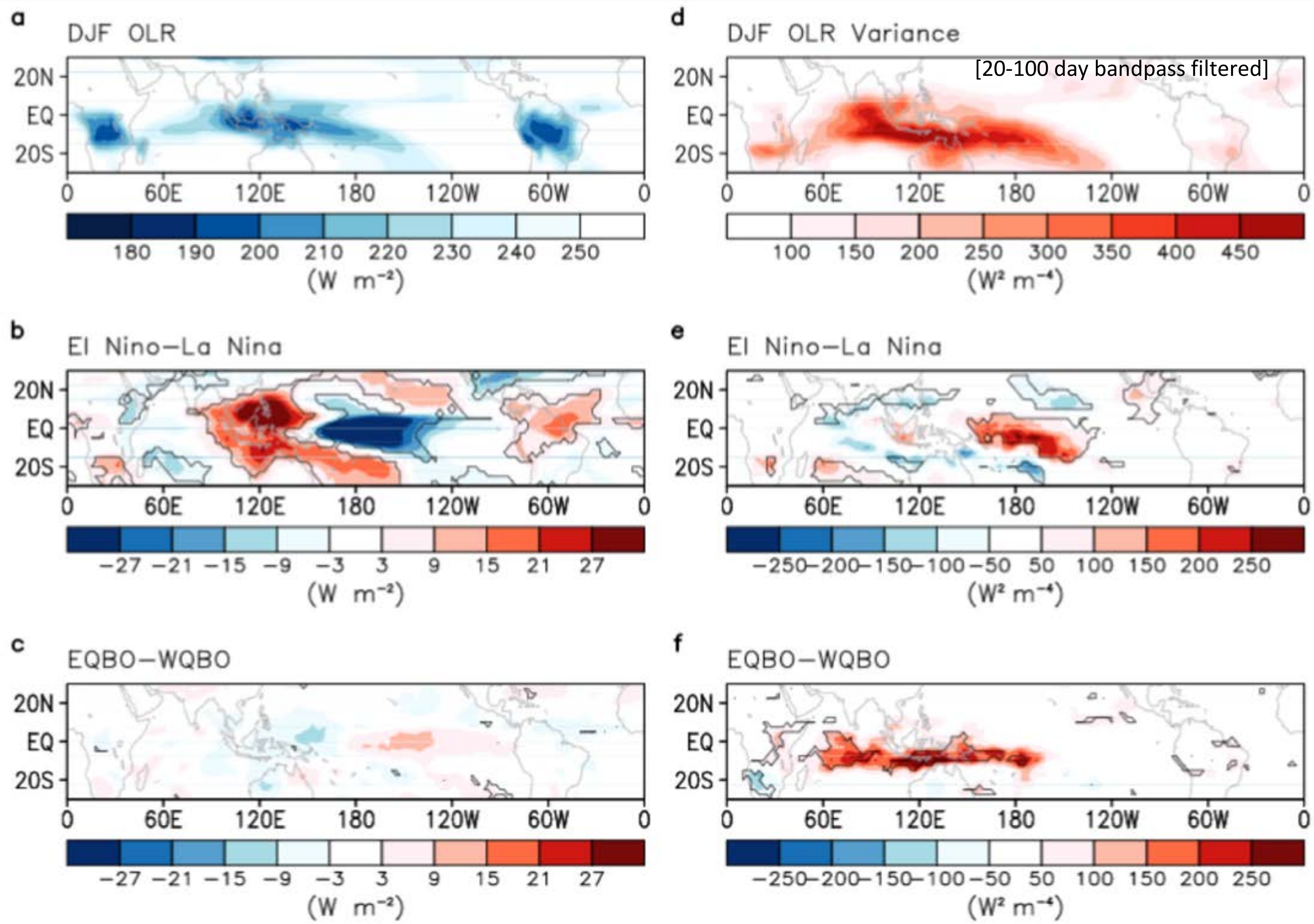
Stratosphere-troposphere coupling in the tropics

The Quasi-Biennial Oscillation



- Roughly 28 month oscillation of descending easterly and westerly zonal jets
- Driven tropical tropospheric waves.
- Generally highly predictable (notable exception occurred in 2016)

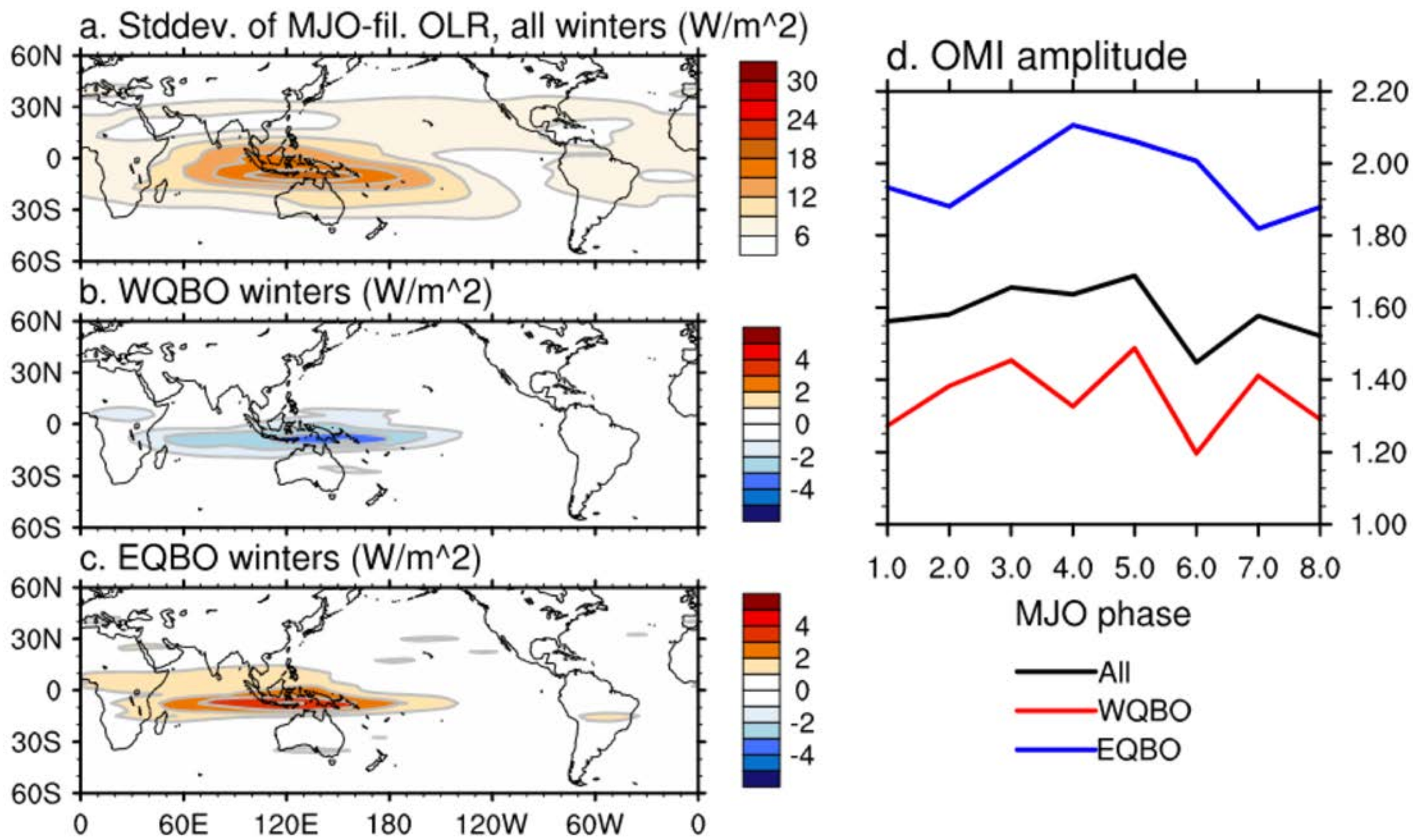
The QBO influence on tropical convection



Son et al. 2017

- In EQBO, deep tropical convection is enhanced in the western Pacific and weakened in the eastern Pacific.
- Interannual influence of QBO is weaker than ENSO, but sub-seasonal effect is comparable to or stronger than ENSO.

The QBO influence on Madden-Julian Oscillation

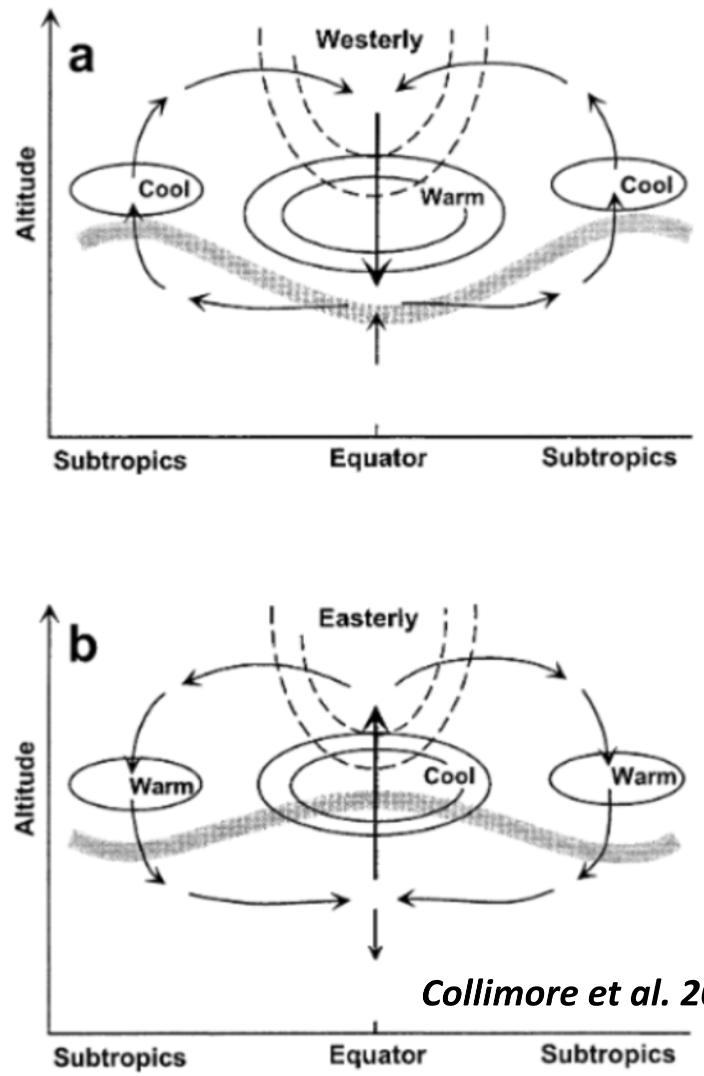


Yoo and Son 2016

Stronger, more organized MJO convection when 50 hPa QBO index is easterly.
During EQBO, MJO convection propagates more slowly [Nishimoto and Yoden 2017]

Why does the QBO influence tropical convection?

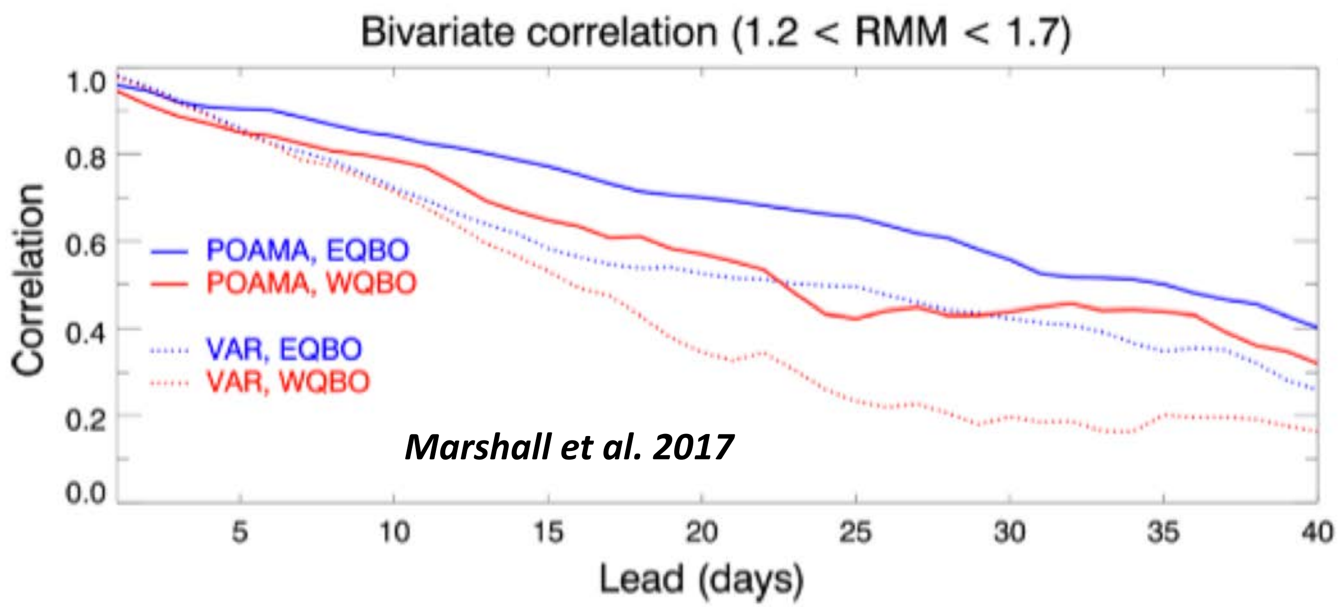
- QBO has associated **secondary circulation**.
- Anomalous temperature changes associated with QBO could affect **static stability/tropopause height** in the tropical upper troposphere.
- Cold anomalies during EQBO could destabilize upper troposphere, allowing deeper convection; absolute **vertical wind shear** is also reduced.
- **Radiative processes** could play a role, as tropical cirrus are enhanced during EQBO due to cold tropopause, causing more longwave heating into troposphere and destabilizing upper troposphere.



Collimore et al. 2003

Some Refs: Gray et al. 1992, Giorgetta et al. 1999, Collimore et al. 2003, Yang et al. 2010, Nie and Sobel 2015, Yoo and Son 2016, Son et al. 2017; Hendon and Abhik 2018

QBO influence on tropical predictability

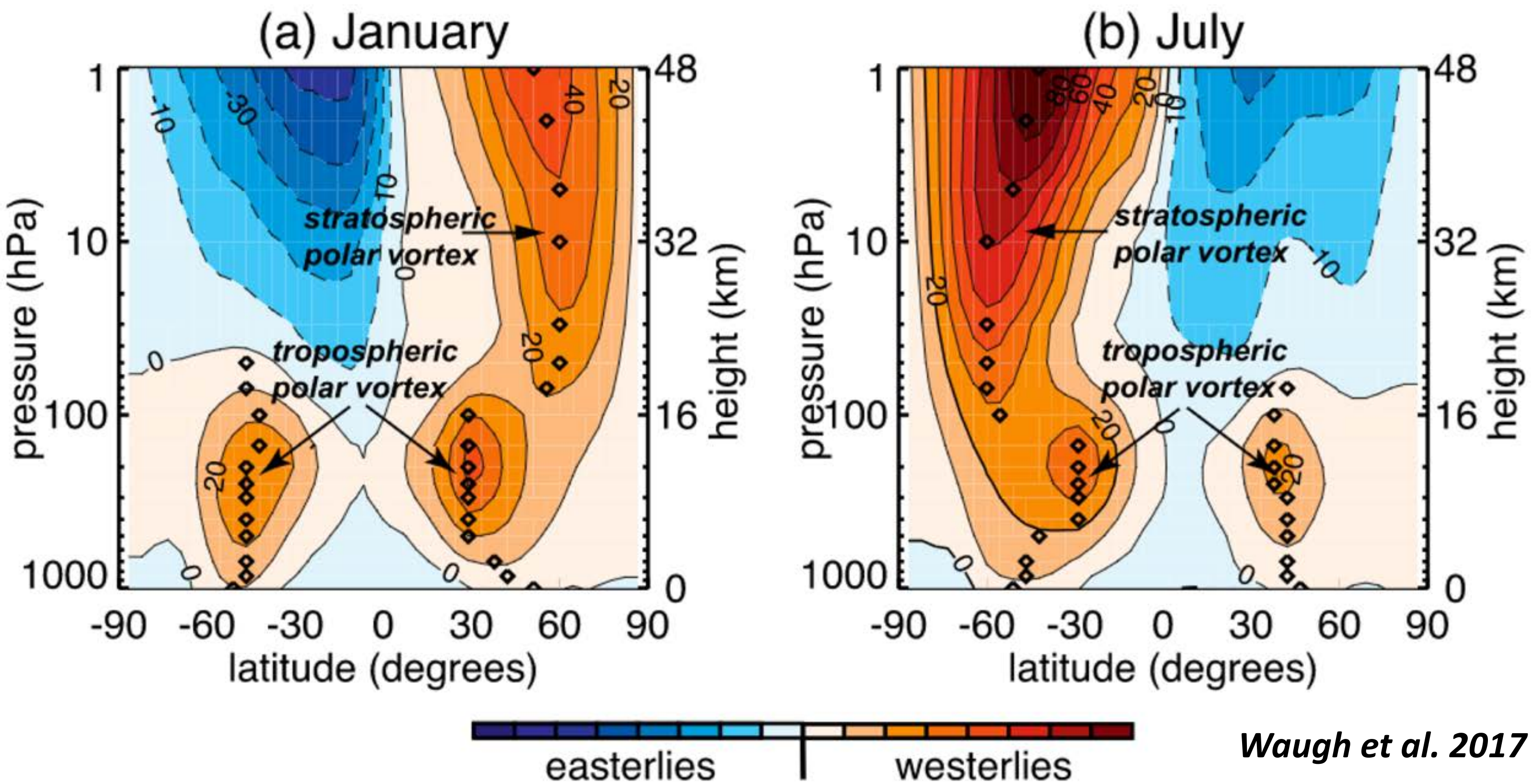


Skill of ensemble mean RMM index as a function of lead time for forecasts initialized when the RMM is between 1.2-1.7, for easterly (blue) and westerly (red) QBO phase

- MJO amplitude is better predicted at longer leads during EQBO
- Not simply because convection is stronger during EQBO (here, RMM index at initial time is fixed to given amplitude range).

QBO could be untapped source of MJO predictability.

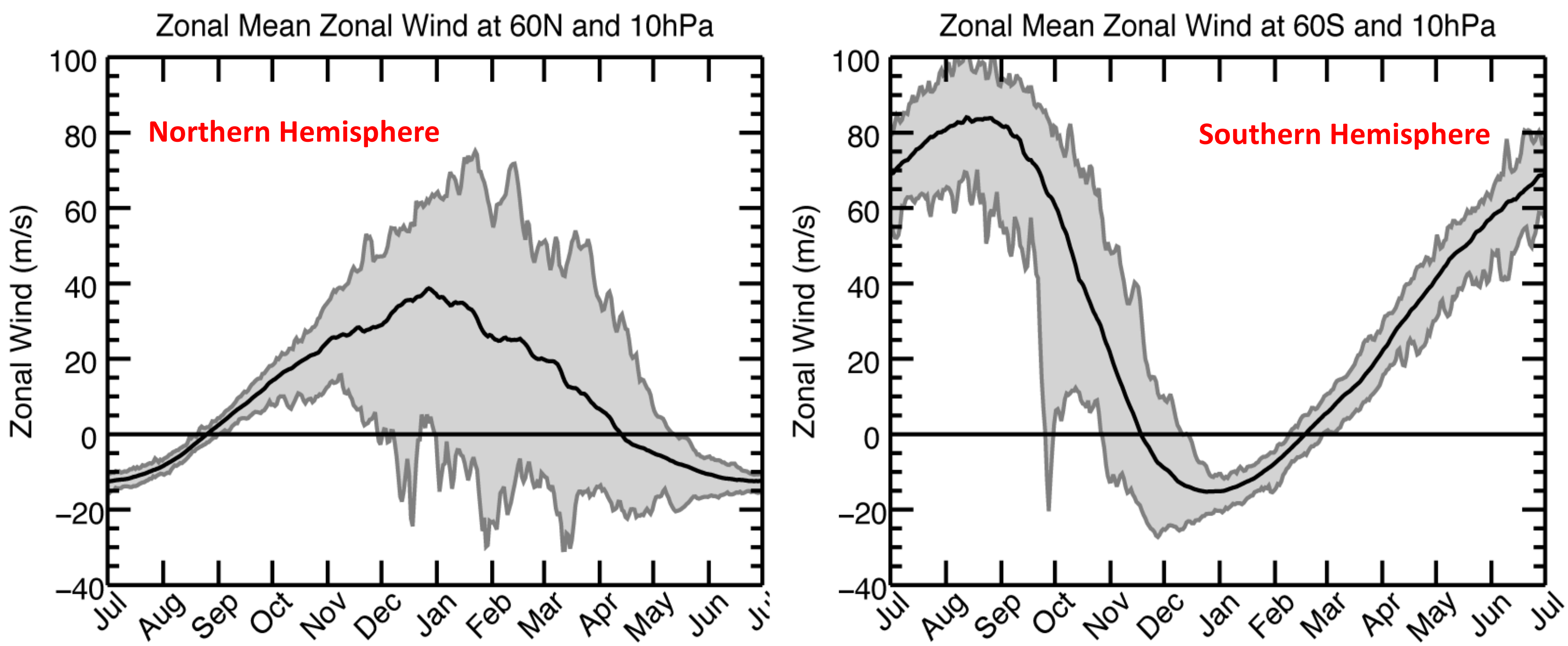
Stratosphere-troposphere coupling in the extratropics



Waugh et al. 2017

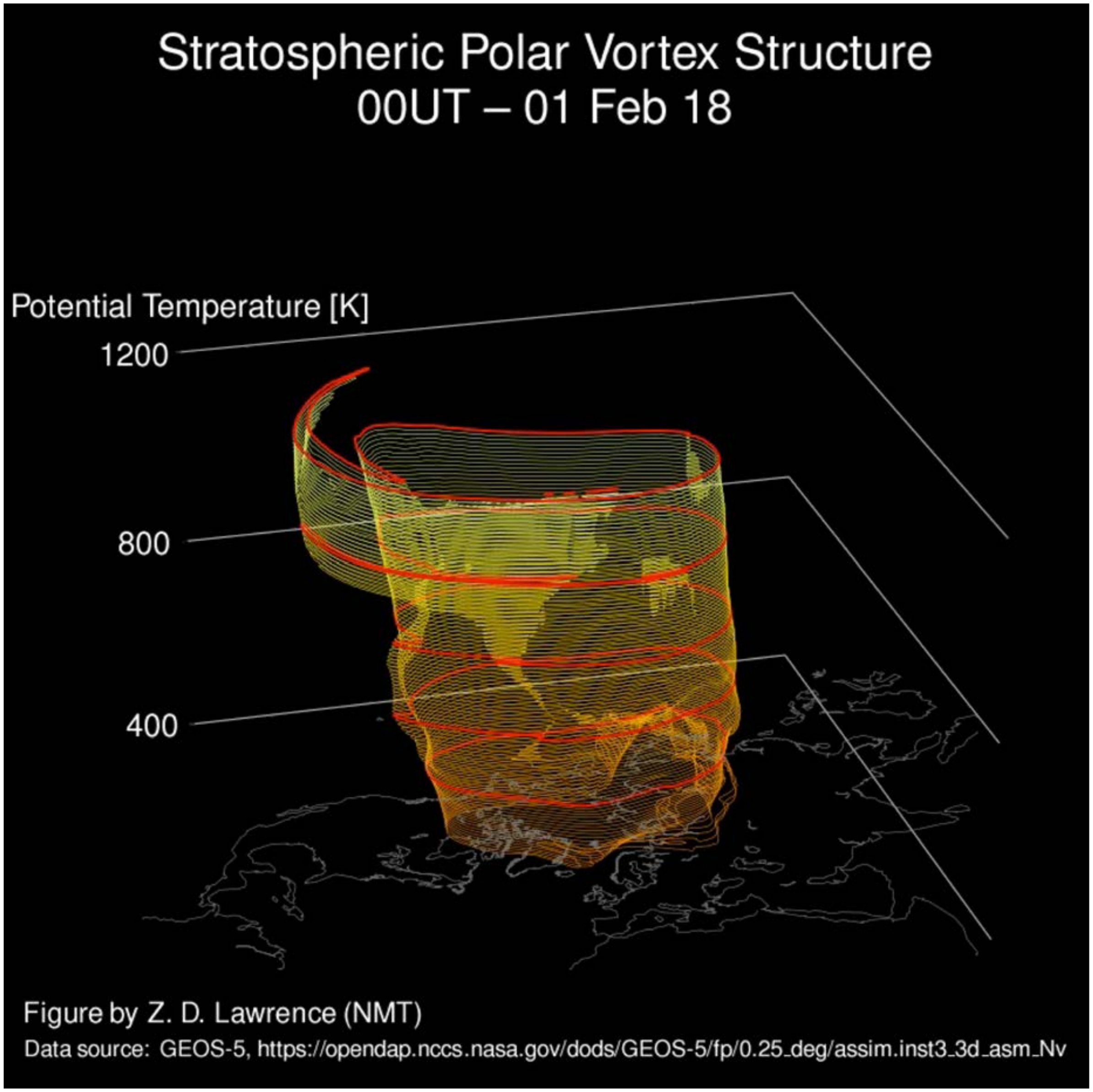
Seasonal evolution and variability of the extratropical stratosphere is strongly controlled by *radiation*, *ozone chemistry*, and *momentum transport* by waves propagating up from the troposphere.

The Stratospheric Polar Vortex



- In NH, variability is strongest in late winter (JFM) and largely driven by tropospheric wave forcing.
- The winds in the summer hemisphere turn easterly when sunlight returns to the poles in spring.
- The SH polar vortex has weaker variability due to weaker wave driving, and **ozone chemistry** is a key driver of stratosphere-troposphere coupling in spring (OND).

Disruption of the Polar Vortex (SSW)



Atmospheric waves from the troposphere can propagate into the stratosphere and **break**, sort of like ocean waves on a beach.

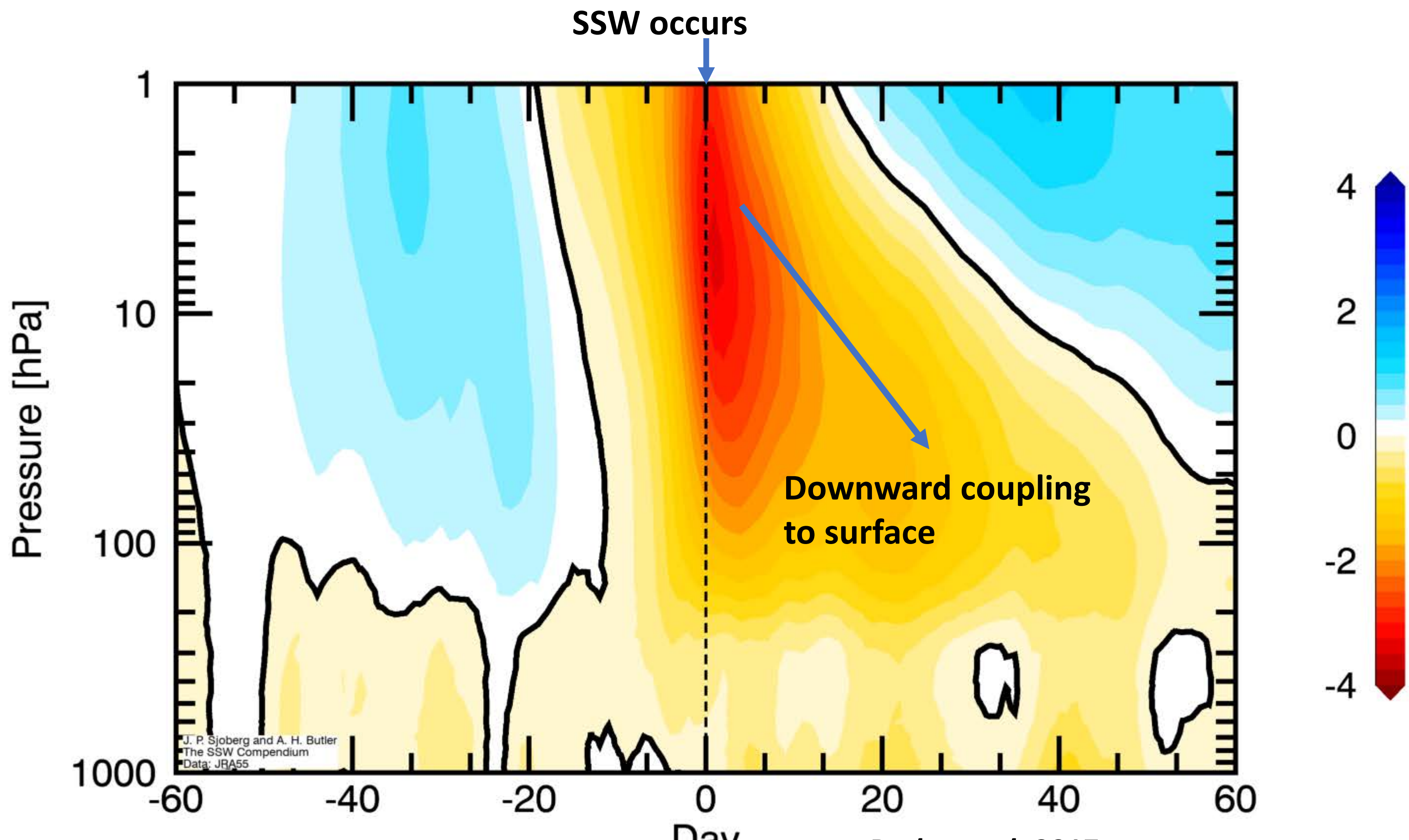
If there is enough "wave breaking", the **polar vortex rapidly slows down** and sometimes reverses direction, in an event called a **sudden stratospheric warming**.

The vortex can be **displaced** off the pole or **split** into two smaller vortices.

This happens ~6 times per decade in the NH.

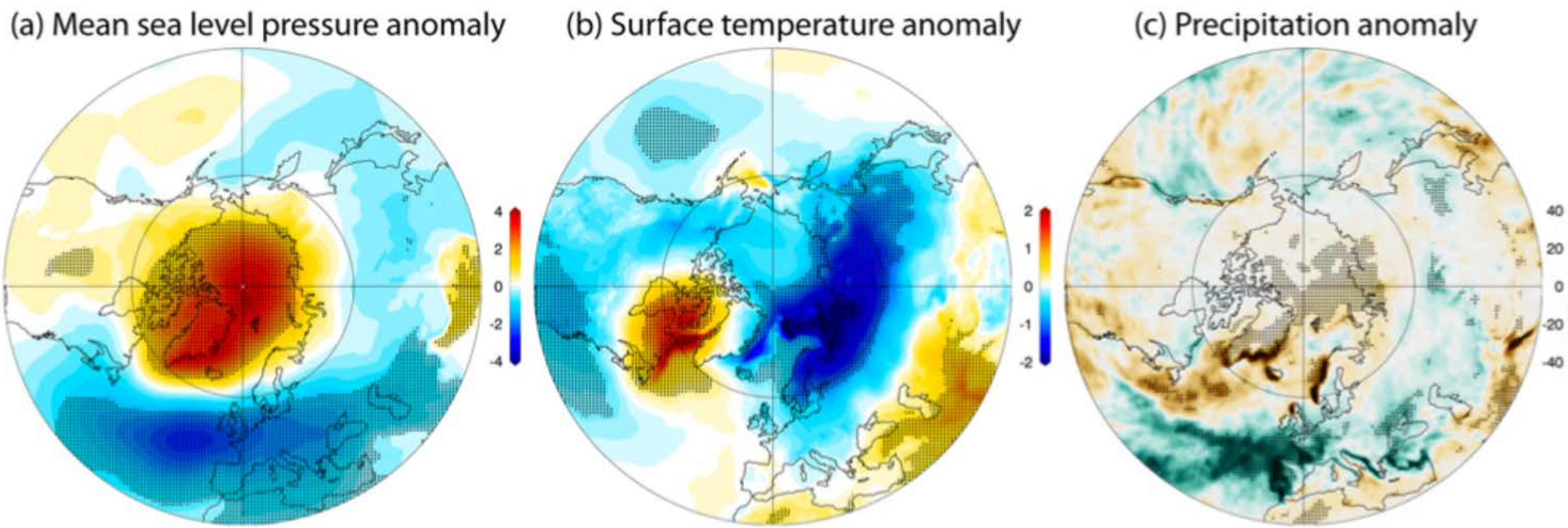
Disruption of the Polar Vortex (SSW)

There are significant surface weather impacts that **persist** for **days to weeks** after the polar vortex breaks down [e.g. Baldwin and Dunkerton 2001].



Butler et al. 2017

Stratospheric impacts on the surface



Days 0-60 after historical SSWs

Butler et al. 2017

Biggest impacts are downstream of the **North Atlantic** jet, but possible impacts over eastern USA as well due to **Greenland blocking** pattern. Also influence over Greenland/**Arctic** warmth.

These events are a **major source of potential predictability of winter weather** on subseasonal to seasonal timescales.

Stratospheric impacts on the surface

Switzerland

London

Italy

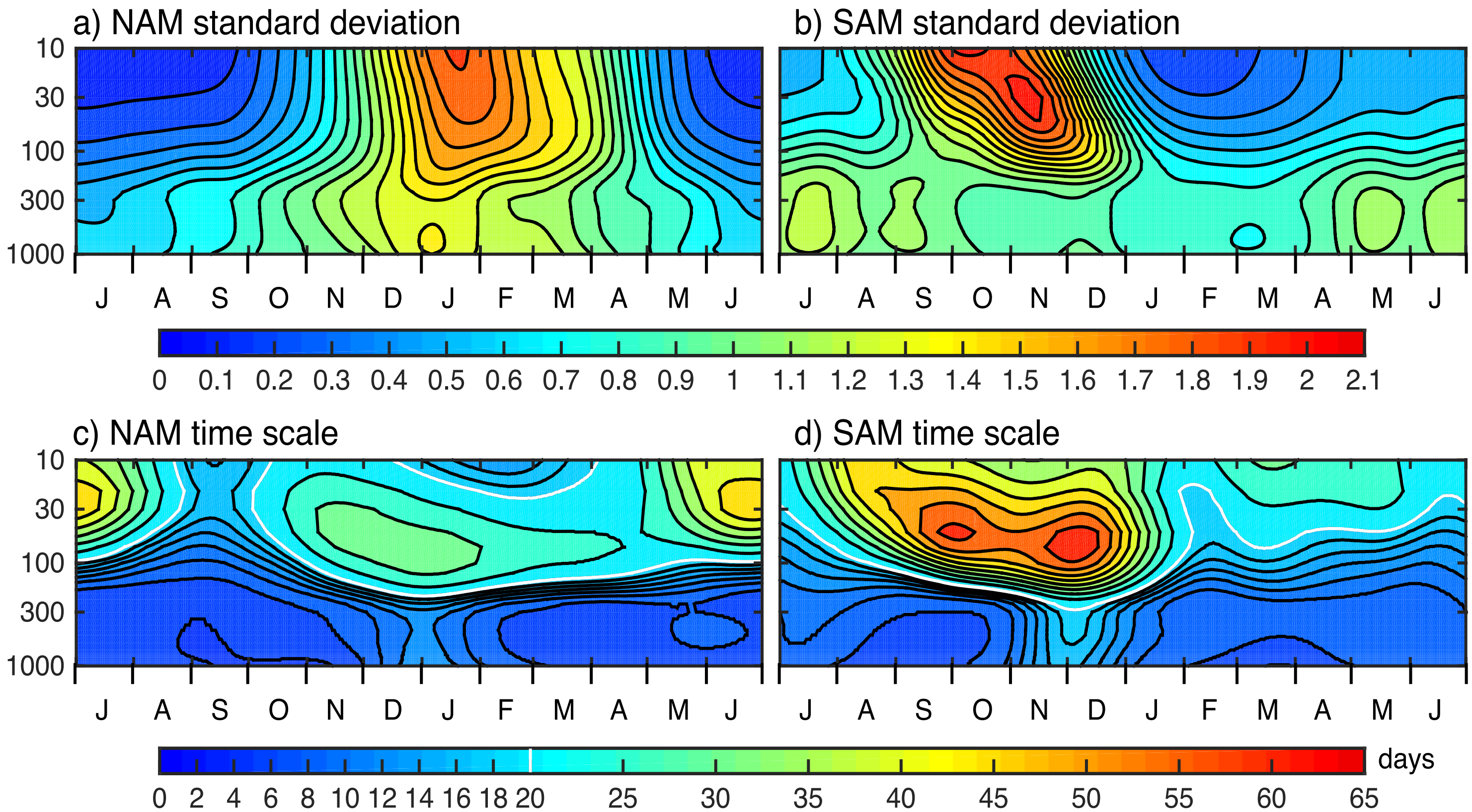
Rome's Fori Imperiali is shrouded by snow on Feb. 26, 2018. (Angelo Carconi/EPA-EFE/REX/Shutterstock)

Boston

Heavy snow plastered Boston streets on Tuesday morning. (@JohnnyK/Twitter)

Cold and snowy weather from end of February into March 2018

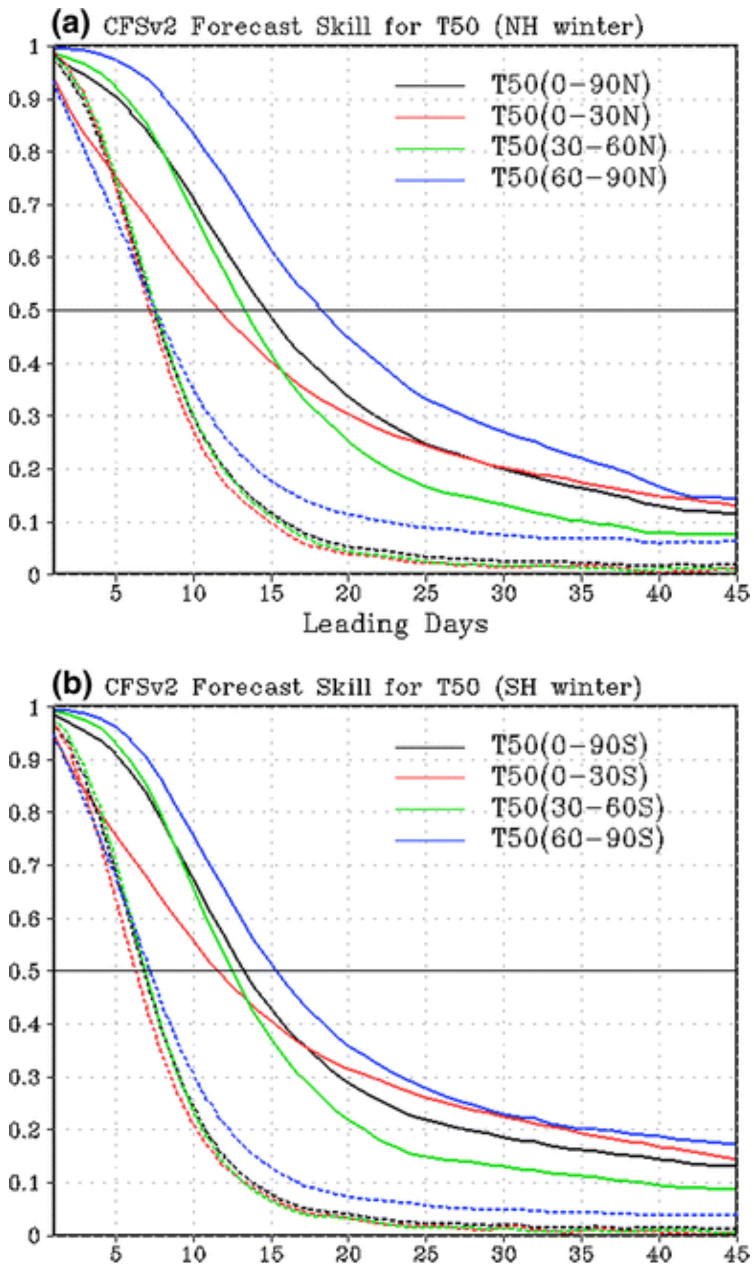
Predictability of the Polar Stratosphere



Updated from Gerber et al. 2010

- Decorrelation timescales of annular mode are ~1 month in NH wintertime stratosphere, and > 2 months in SH springtime stratosphere.
- Tropospheric timescales are typically < 10 days
- Peak persistence in troposphere coincides with enhanced variance in stratosphere

Predictability of the Polar Stratosphere



Forecast skill in the stratosphere is roughly twice that in troposphere.

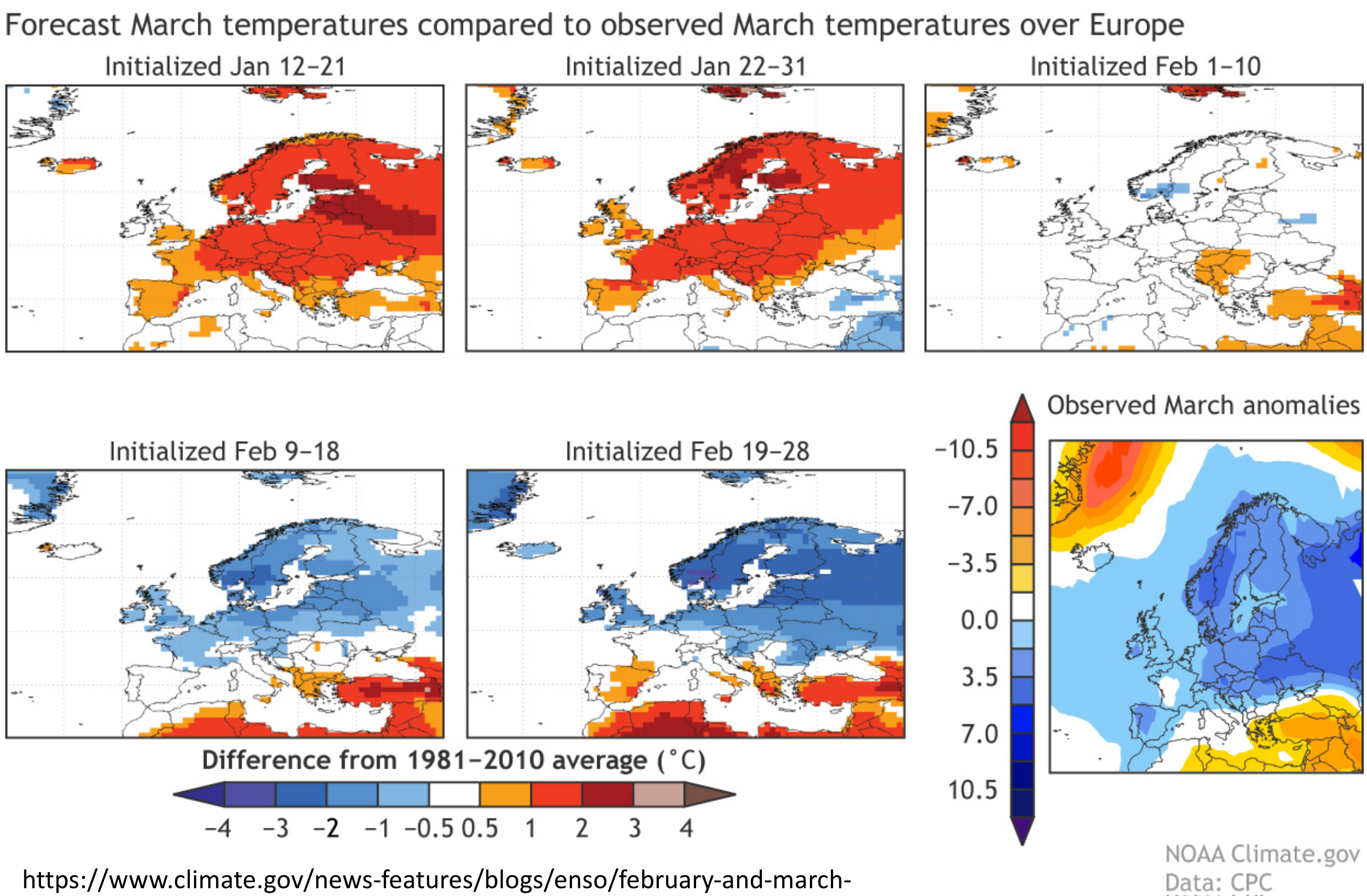
Linked to ability of models to capture and maintain anomalies in the zonal-mean circulation.

Models are unable to forecast tropospheric wave forcing beyond ~10-15 days, so wave-driven stratospheric extremes (like SSWs) are also not skillfully predicted beyond those timescales.

Zhang et al. 2013. Anomaly correlation as a function of lead-time, for T50 (solid) and T500 (dashed).

Inability to forecast SSWs >15 days out has big impacts on S2S timescales

Date of SSW: Feb 12, 2018



https://www.climate.gov/news-features/blogs/enso/february-and-march-madness-how-winds-miles-above-arctic-may-have-brought

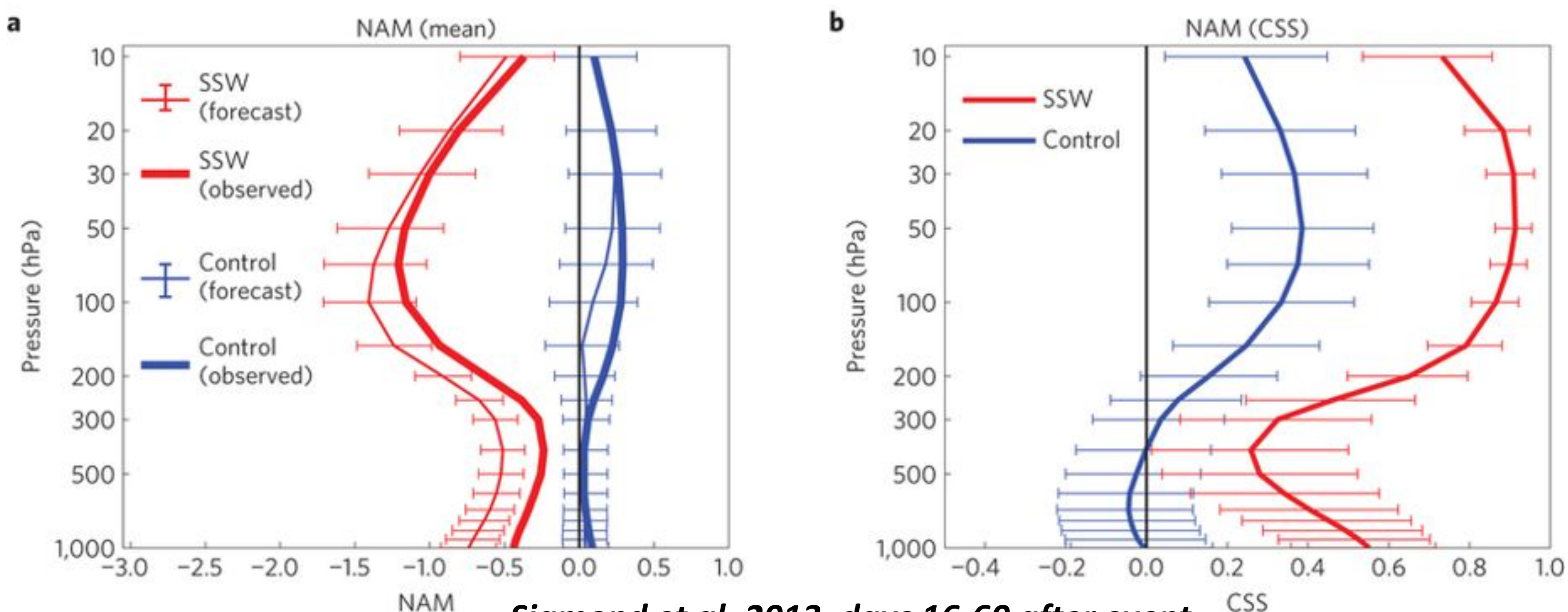
NCEP CFSv2 forecasts

Tropospheric skill following stratospheric extremes is significantly enhanced

- Nudging stratospheric state towards observations can substantially increase skill in extratropical troposphere

[Charlton et al. 2004; Scaife and Knight 2008; Douville 2009; Hansen et al. 2017; Jia et al. 2017]

- Splitting hindcasts into groups initialized during strong, weak, and neutral vortex conditions show enhanced S2S surface climate prediction for stratospheric extremes. [Mukougawa et al. 2009; Sigmond et al. 2013, Tripathi et al. 2015]

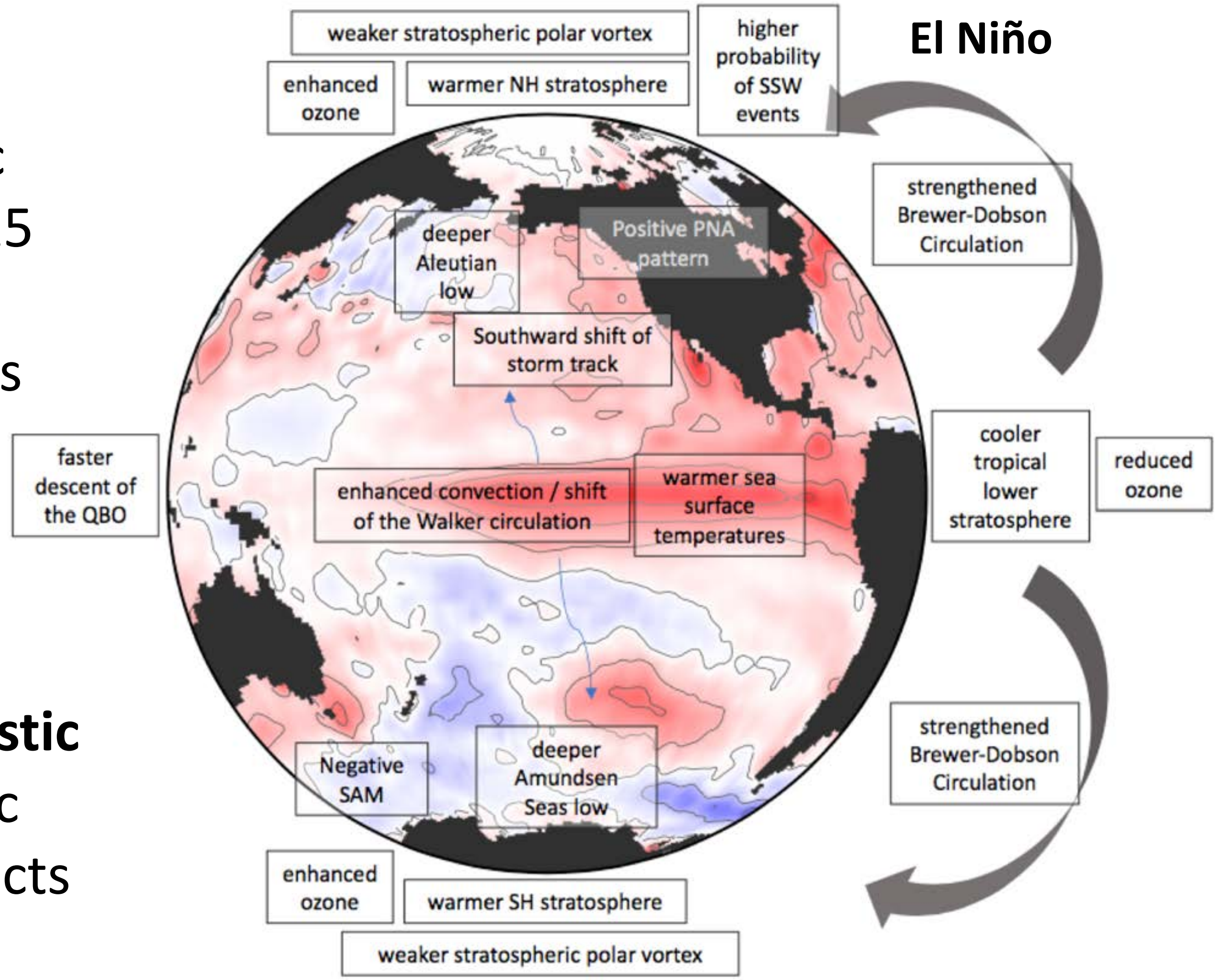


Sigmond et al. 2013, days 16-60 after event

Extended prediction skill based on known stratosphere teleconnections

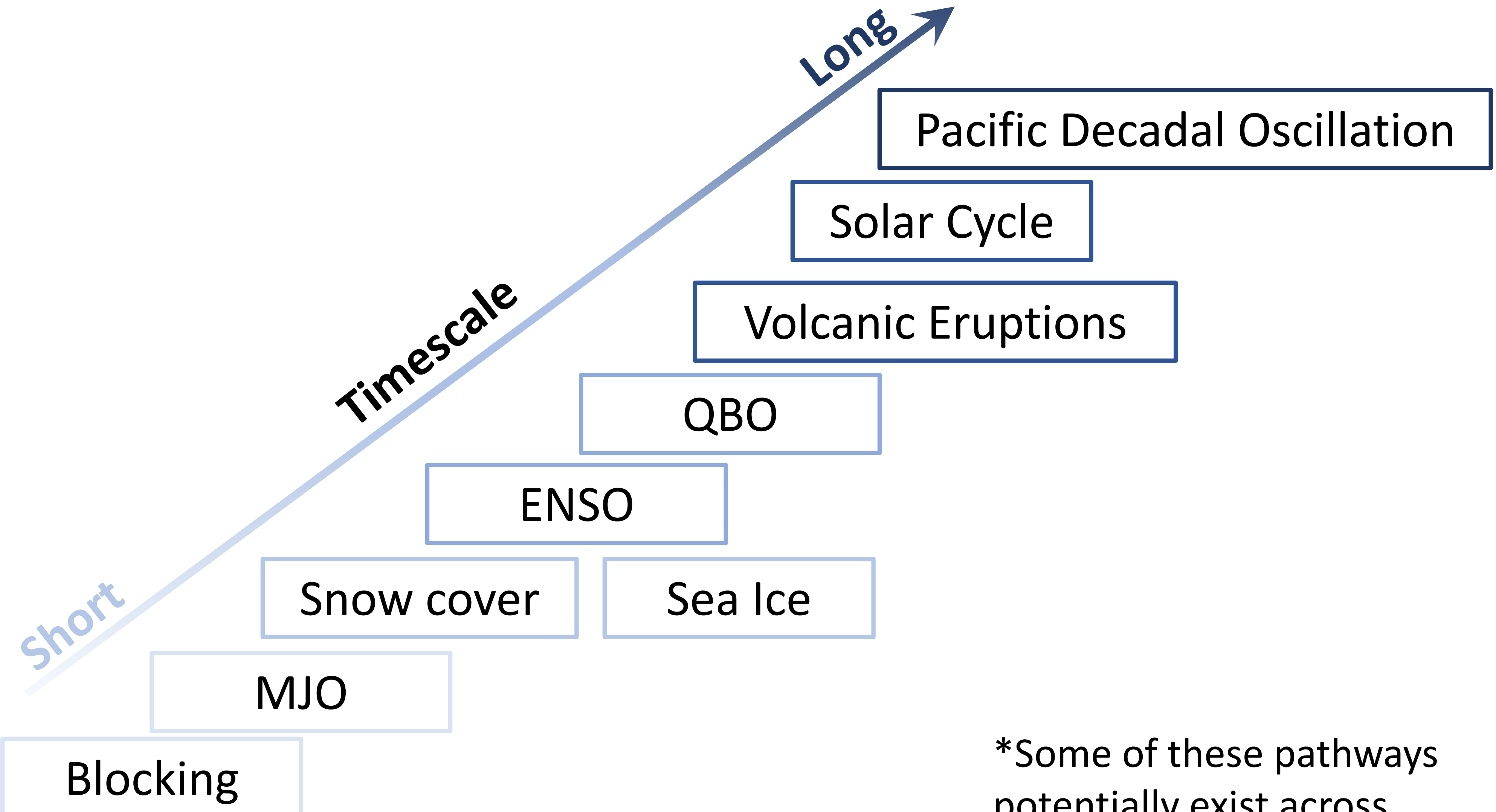
- Deterministically forecasting stratospheric extremes limited to 10-15 days
- ..But known relationships between tropospheric forcing and the stratosphere persist for weeks to seasons
- Could improve **probabilistic** forecasts of stratospheric extremes and their impacts on troposphere

El Niño



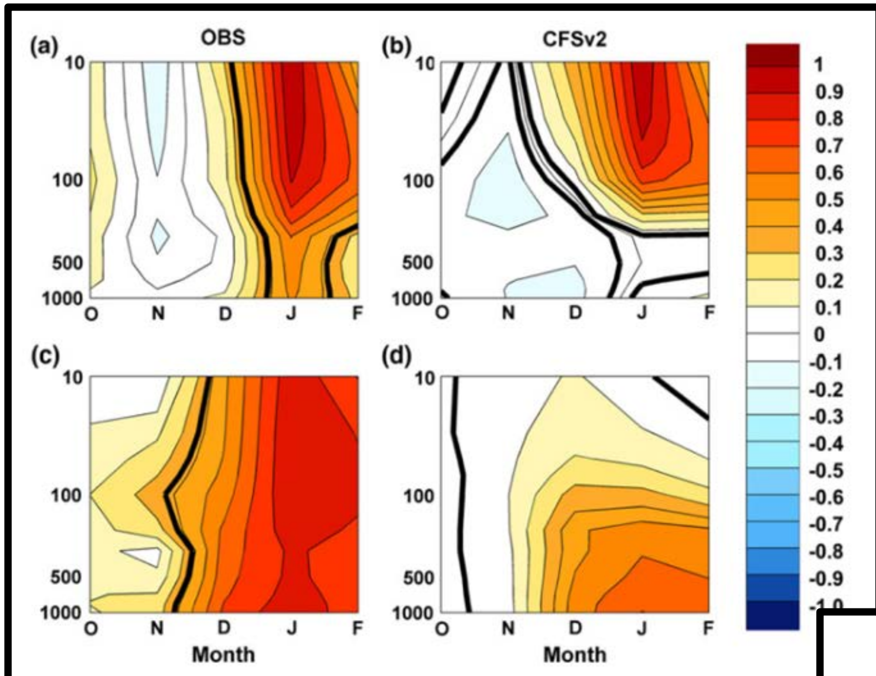
Domeisen et al. 2018, in review

Extended prediction skill based on known stratosphere teleconnections



*Some of these pathways potentially exist across timescales

How well do models simulate stratosphere-troposphere coupling?

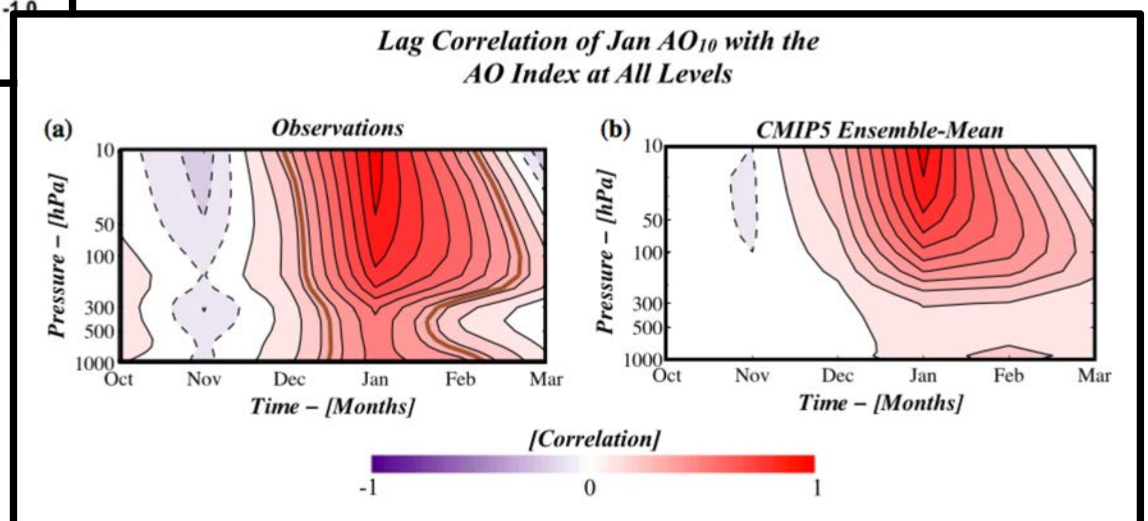


Riddle et al. 2013

Jan NAM at 10 hPa shows strong persistent relationship with NAM in troposphere (and vice versa) in observations….

But this relationship appears much weaker in CFSv2 and a large number of CMIP5 models. **Why?**

Furtado et al. 2015



How well do models simulate stratosphere-troposphere coupling?

- Stratospheric biases:

  Model top, vertical resolution, small-scale wave parameterizations

[Marshall and Scaife 2010, Maycock et al. 2011, Charlton-Perez et al. 2013, Shaw et al. 2014, Seviour et al. 2016]

- Tropospheric biases:

  precursors to stratospheric variability, tropospheric response to stratospheric forcing

[Garfinkel et al. 2012, 2013]

- Biases in pathways between troposphere and stratosphere:

  e.g., inability to capture observed QBO influences on extratropical surface in many models

[Scaife et al. 2014, Garfinkel et al. 2018]

Exploring stratospheric processes with the S2S Prediction Project

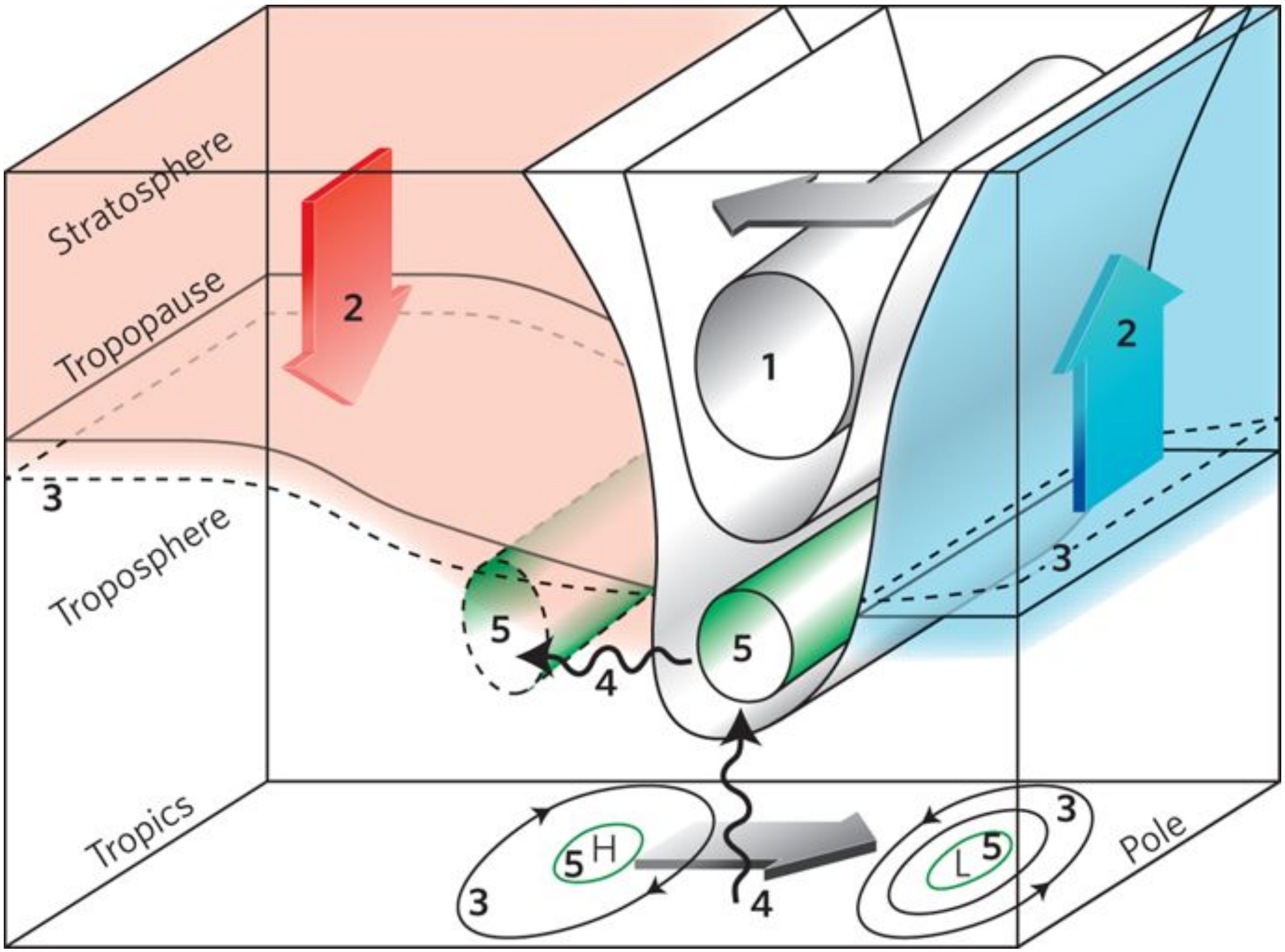
Subseasonal-to-Seasonal S2S Prediction Project

- SNAP currently has an international community effort to examine predictability of the stratosphere and its downward coupling to the troposphere (Daniela Domeisen will present overview of initial results)
- Always looking to get people involved in SNAP and future model simulations or analysis.

SNAP co-chairs:
amy.butler@noaa.gov or a.j.charlton-perez@reading.ac.uk

Stratosphere-troposphere coupling mechanisms

Shown for anomalous polar jet intensification



Kidston et al. 2015

1. Downward control exerts almost immediate influence down to tropopause
2. Anomalous momentum deposition results in anomalous circulation
3. Mass redistribution alters tropopause height and mean sea level pressure.
4. Tropospheric eddy eddies interact with changes to mean flow
5. Shift of the tropospheric jet