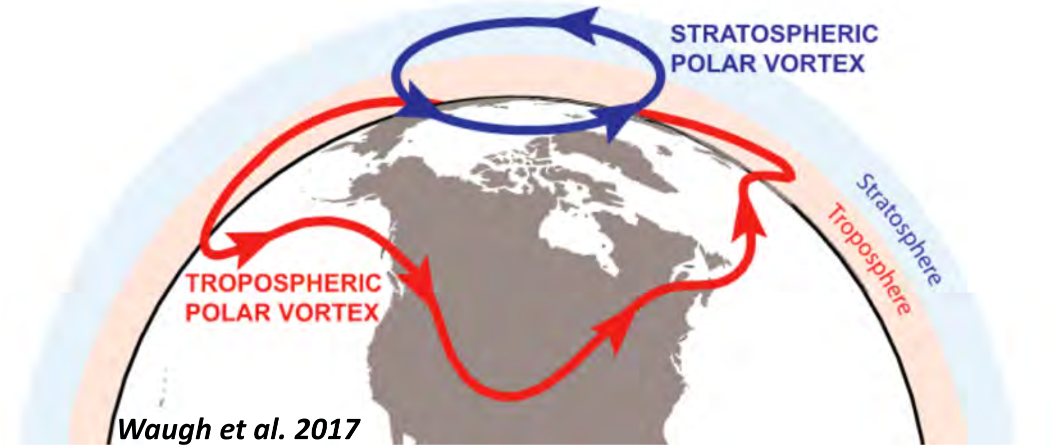
The role of the stratosphere in sub-seasonal to seasonal predictability

Dr. Amy H. Butler
NOAA/Chemical Sciences Division and CIRES/CU-Boulder



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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

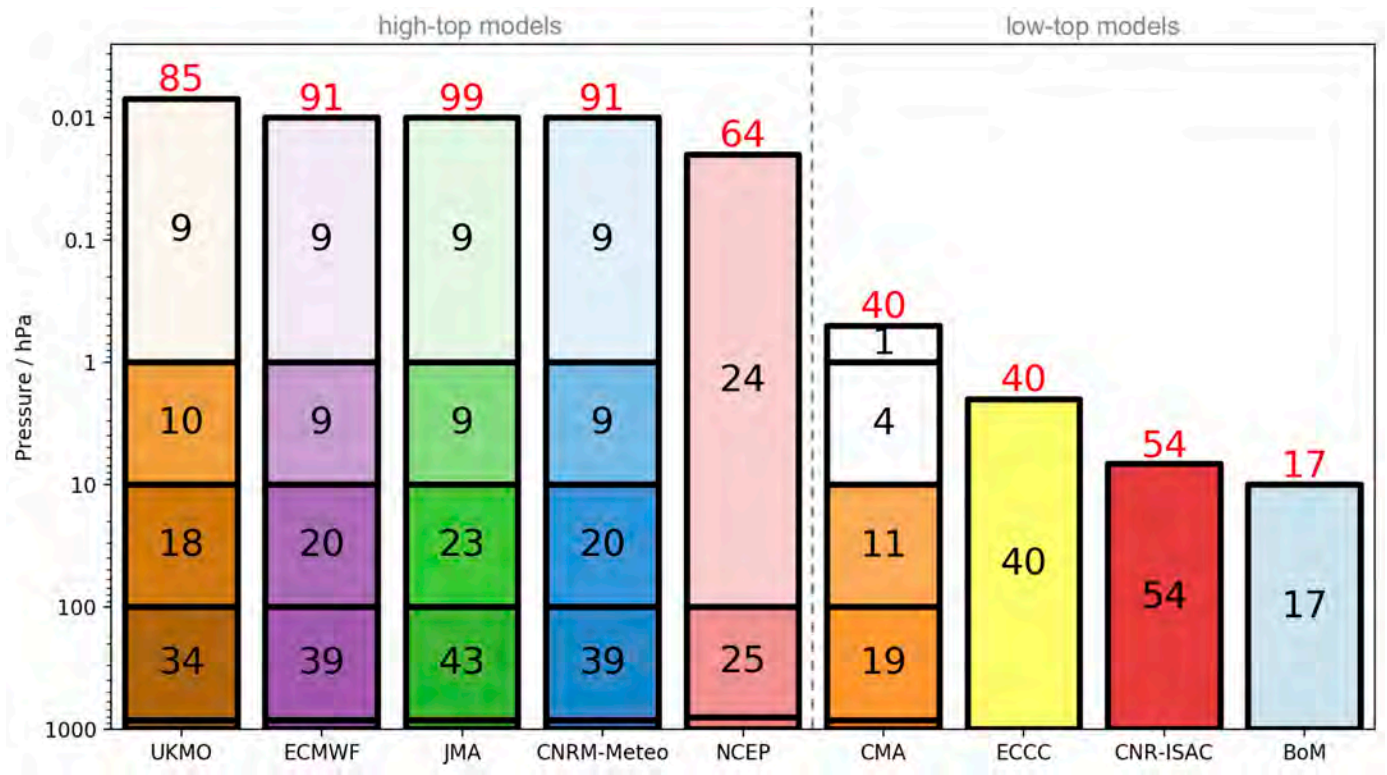
SPARC Stratosphere-troposphere Processes And their Role in Climate

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

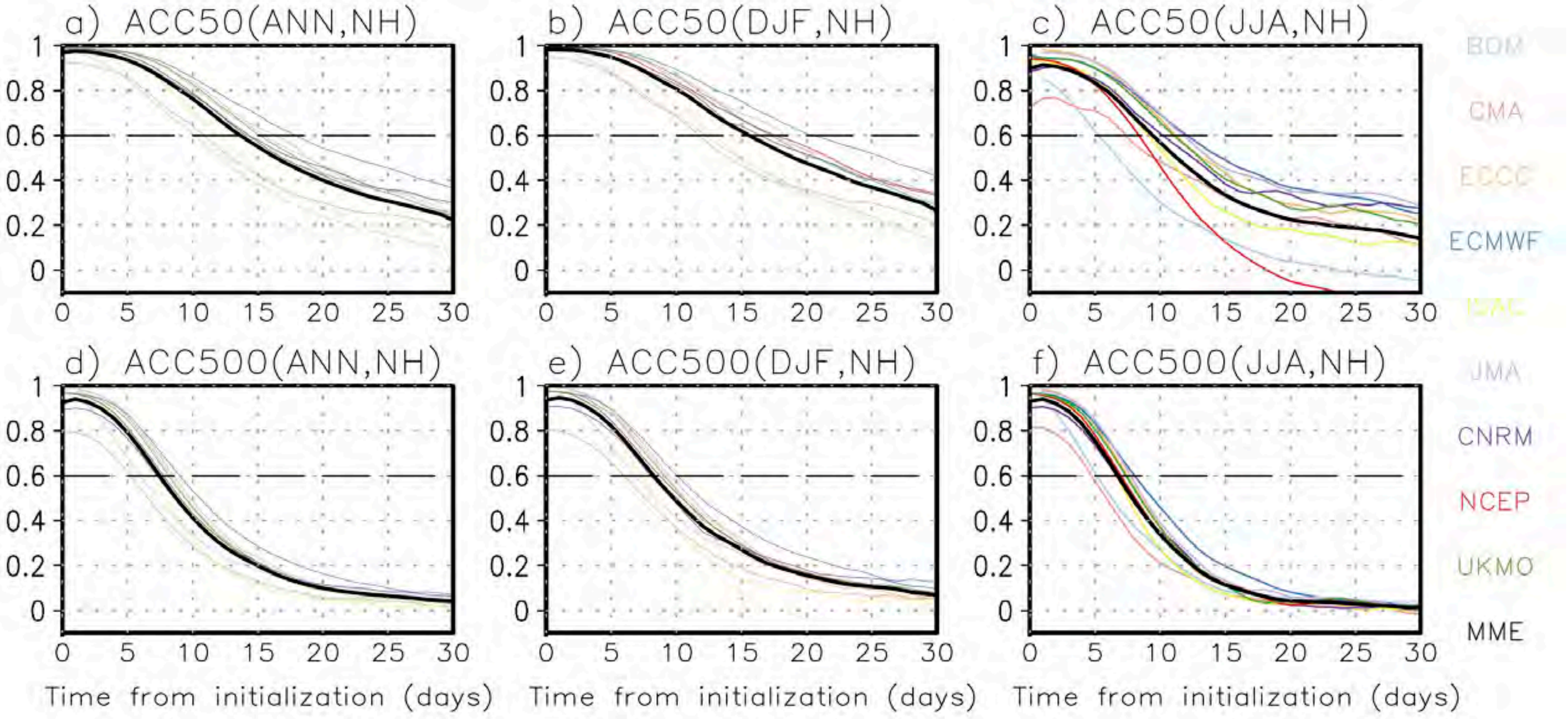
The WWRP/WCRP S2S prediction project



The majority of S2S prediction systems now have high model lids and are more vertically resolved above 100 hpa.

Domeisen et al. (2019), Part I

The stratosphere has longer memory than the troposphere



50 mb: 14 +/- 2.4 days
500 mb: 7.5 +/- 1.2 days

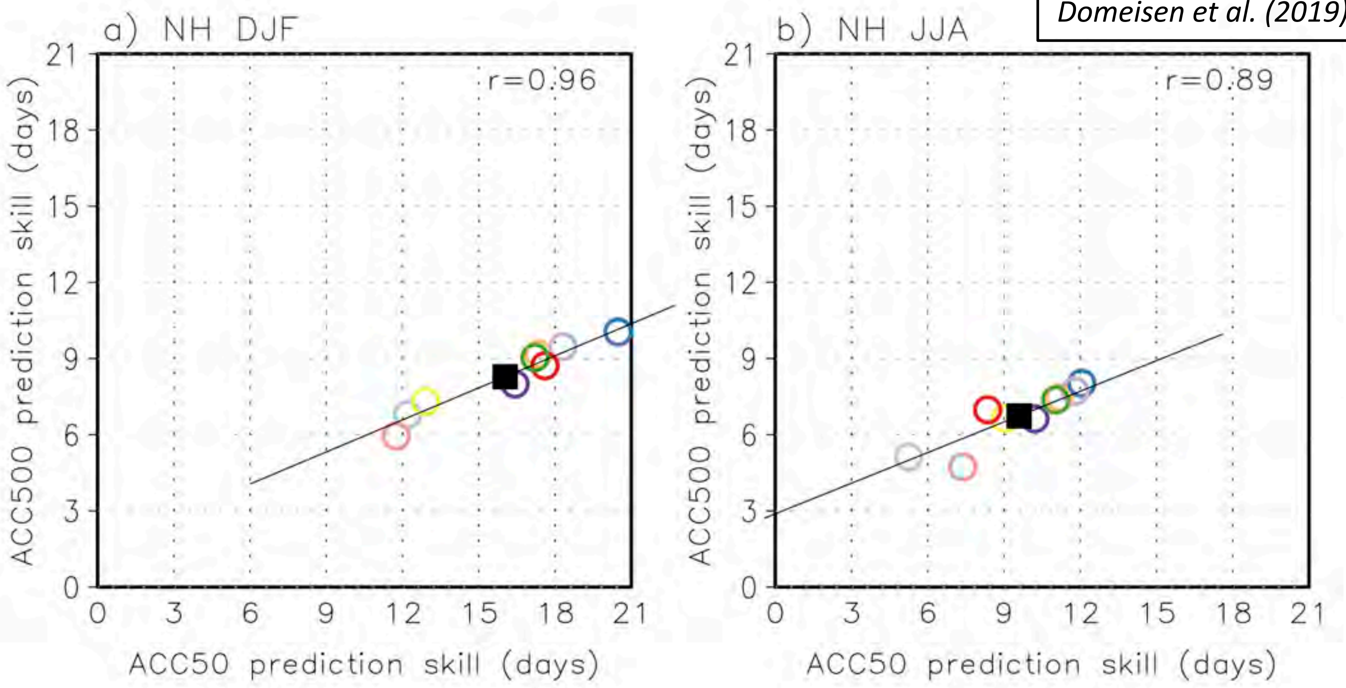
50 mb: 16 +/- 2.9 days
500 mb: 8.3 +/- 1.3 days

50 mb: 9.6 +/- 2.2 days
500 mb: 6.7 +/- 1.1 days

Domeisen et al. (2019), Part I

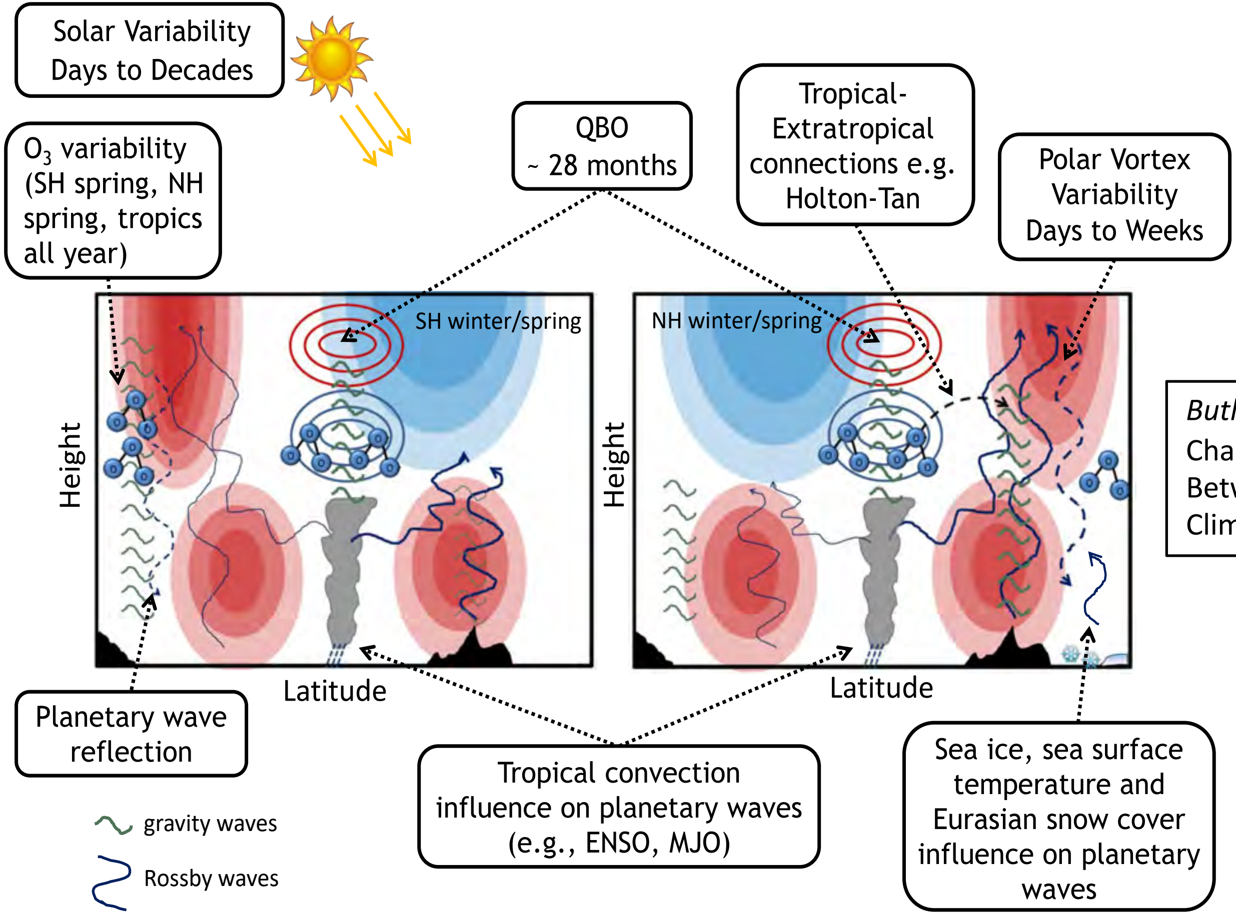
Models with longer prediction skill in the stratosphere have longer prediction skill in the troposphere

Domeisen et al. (2019), Part I



*Note that the direction of causality cannot be inferred

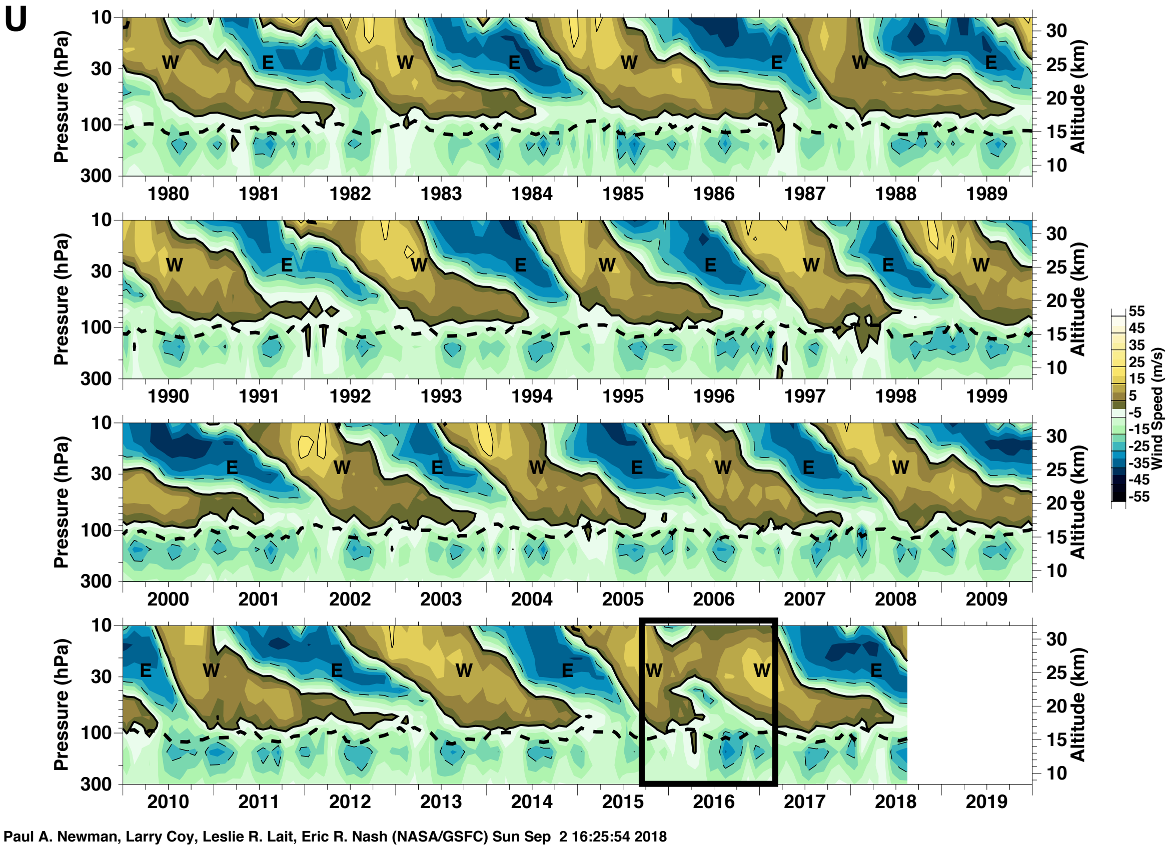
Stratospheric processes relevant to S2S prediction



Butler et al. (2019), Chapter 11, The Gap Between Weather and Climate Forecasting

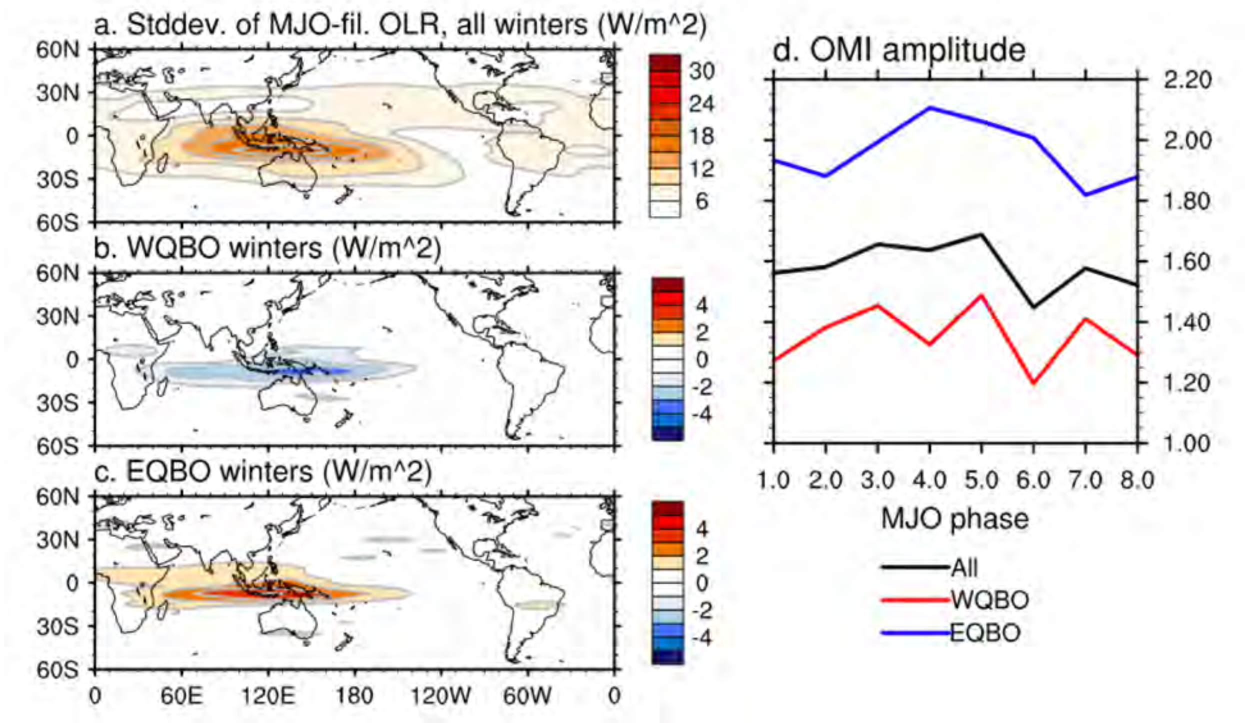
Stratosphere-troposphere coupling in the tropics

The Quasi-Biennial Oscillation



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

The QBO influence on Madden-Julian Oscillation



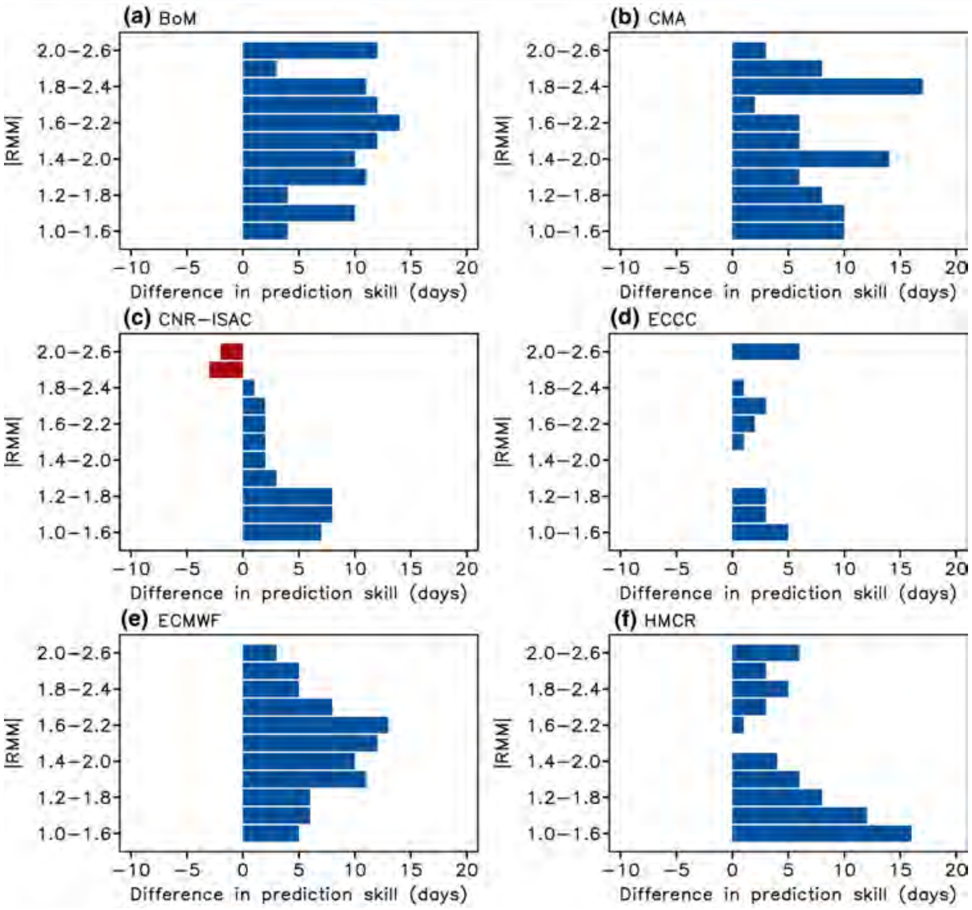
Yoo and Son 2016

See also:
Garfinkel and Hartmann 2011,
Liess and Geller 2012,
Son et al. 2017

Stronger, more organized MJO convection when 50 hPa QBO index is easterly.

During EQBO, MJO convection propagates more slowly [Nishimoto and Yoden 2017]

The phase of QBO influences the prediction skill of the MJO

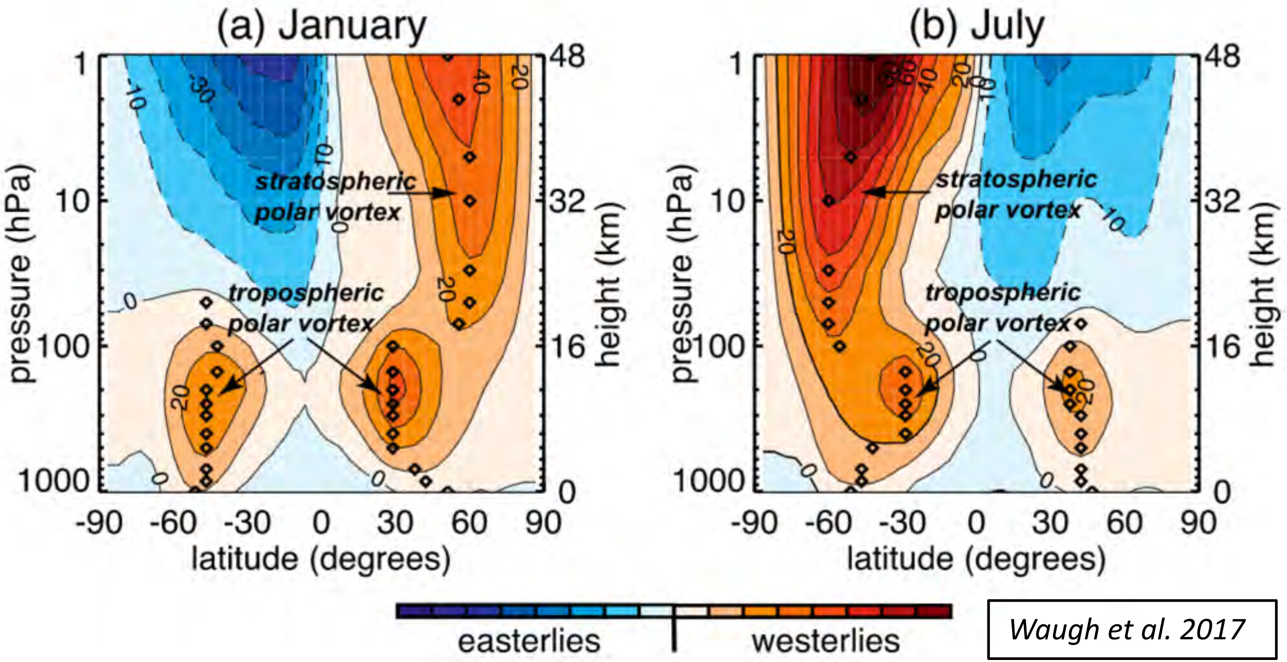


Most S2S models show increased skill of the MJO during EQBO winters compared to WQBO winters [Lim et al. 2019].

This may be tied to higher amplitude and longer persistence MJO events during EQBO winters [Marshall et al. 2017].

Lim et al. (2019), Differences in MJO prediction skill between EQBO and WQBO winters for different MJO amplitudes

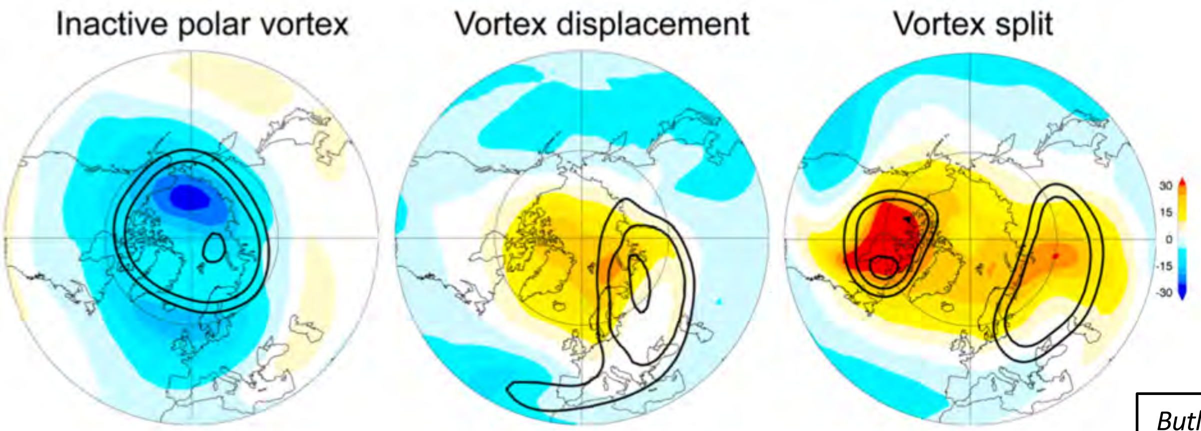
Stratosphere-troposphere coupling in the extratropics



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.

Disruption of the Polar Vortex (SSW)



Butler et al. 2017

Planetary-scale atmospheric waves from the troposphere can propagate into the stratosphere and **break**.

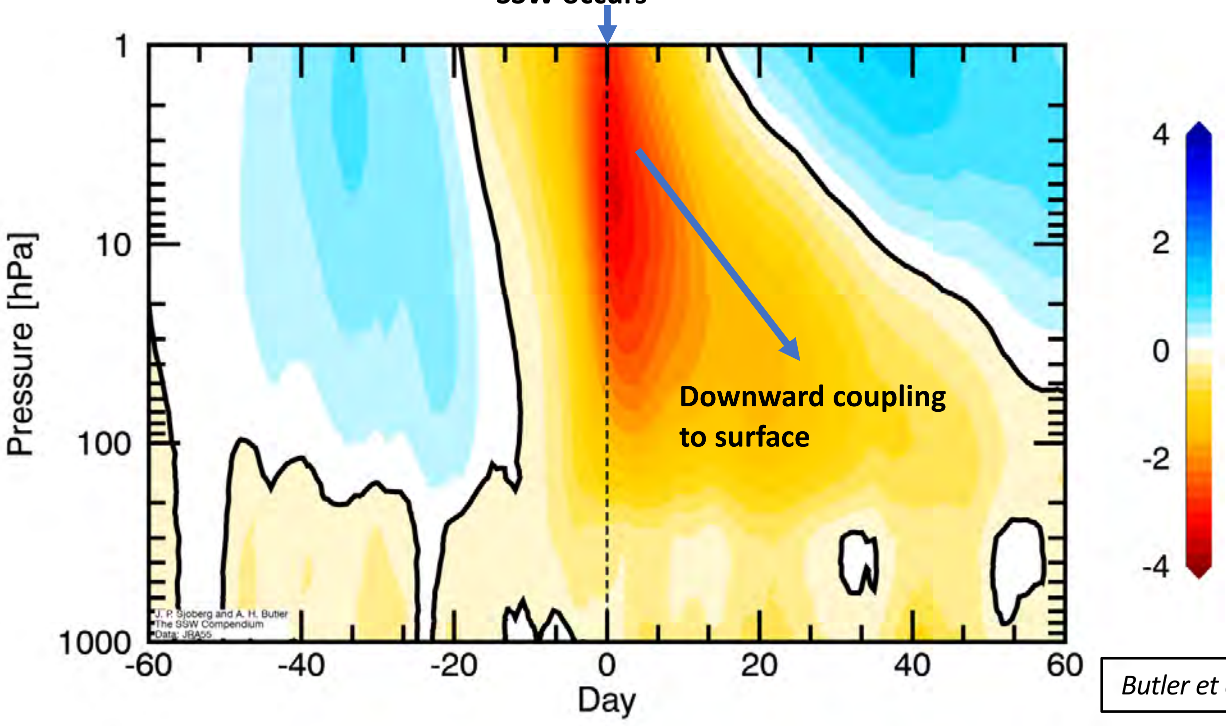
If there is strong enough wave-breaking, the **polar vortex rapidly slows down** and sometimes reverses direction, in an event called a **sudden stratospheric warming**.

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

Disruption of the Polar Vortex (SSW)

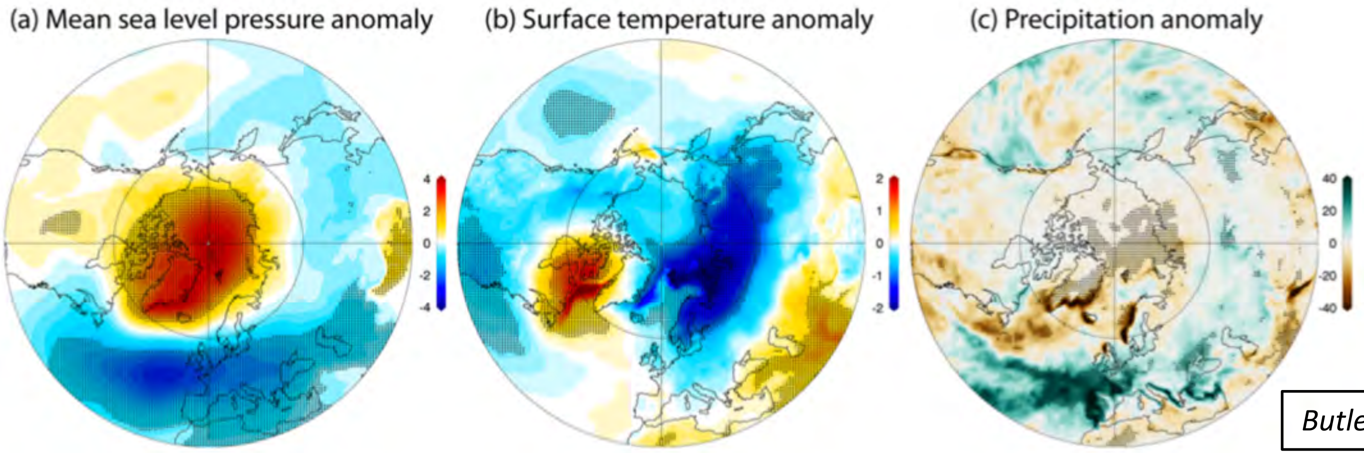
There are significant surface weather impacts that **persist** for **days to weeks** after the polar vortex breaks down [e.g. Baldwin and Dunkerton 2001].

SSW occurs



Butler et al. 2017

Stratospheric impacts on the surface



Butler et al. 2017

Days 0-60 after historical SSWs

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 **source of potential predictability of winter weather** on sub-seasonal to seasonal timescales.

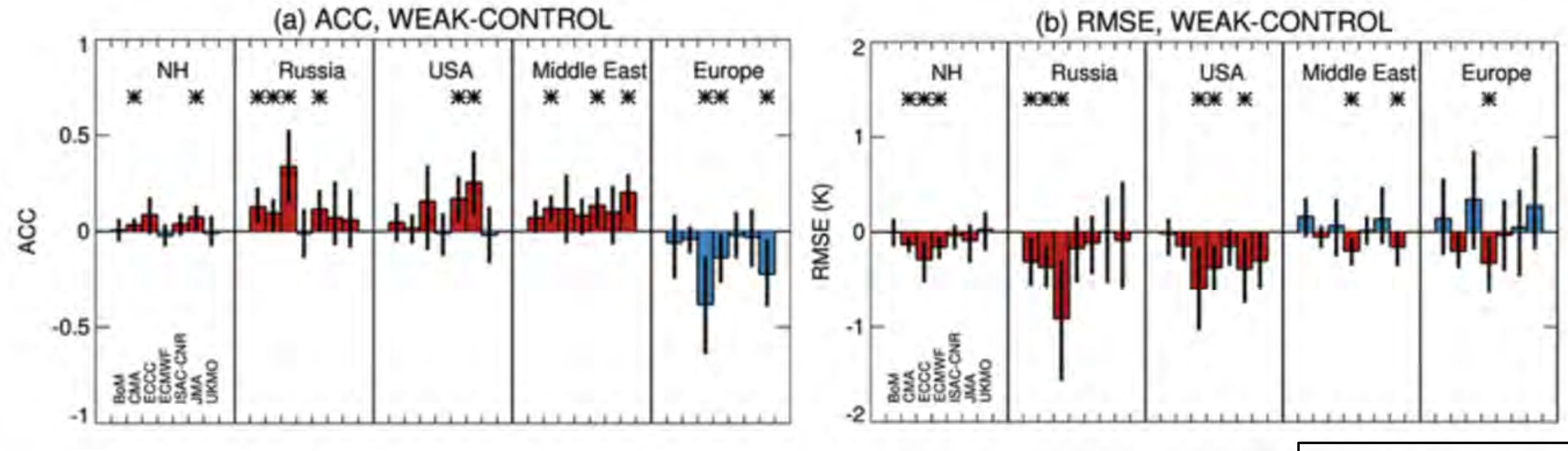
Stratospheric impacts on the surface

Cold and snowy weather from end of February into March 2018

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

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

Evidence for improvement in week 3-4 skill after polar vortex extremes

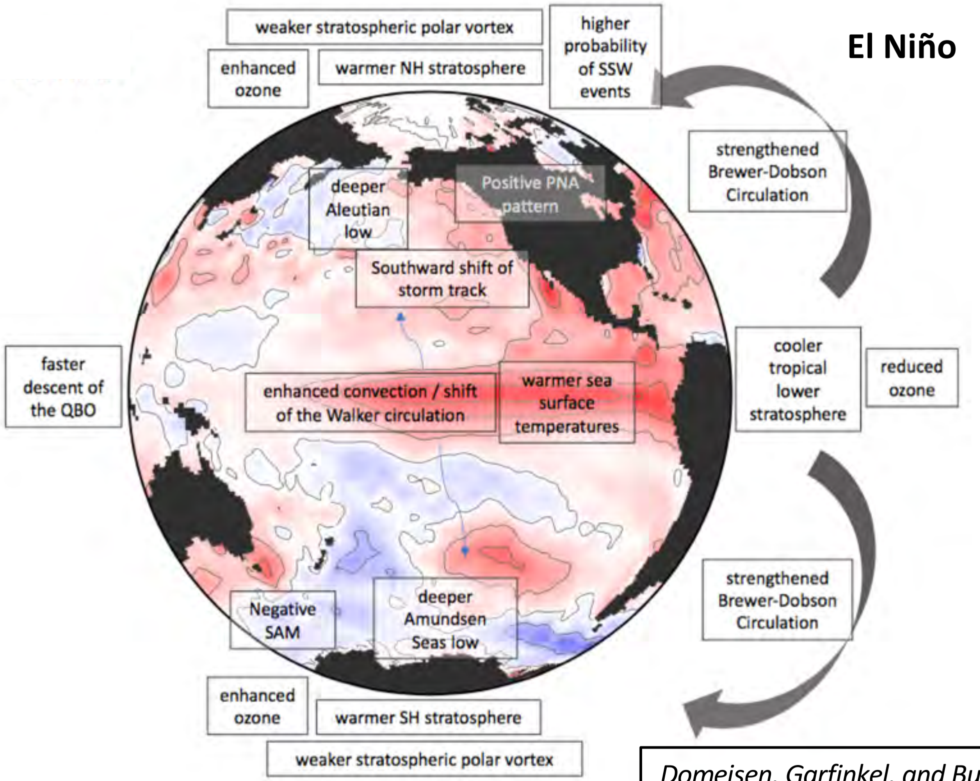


Domeisen et al. (2019, Part II)

Increases in week 3-4 near-surface temperature skill (ACC) and reduction in root mean square error (RMSE) in the S2S forecasts for certain regions following weak polar vortex (SSW) events.

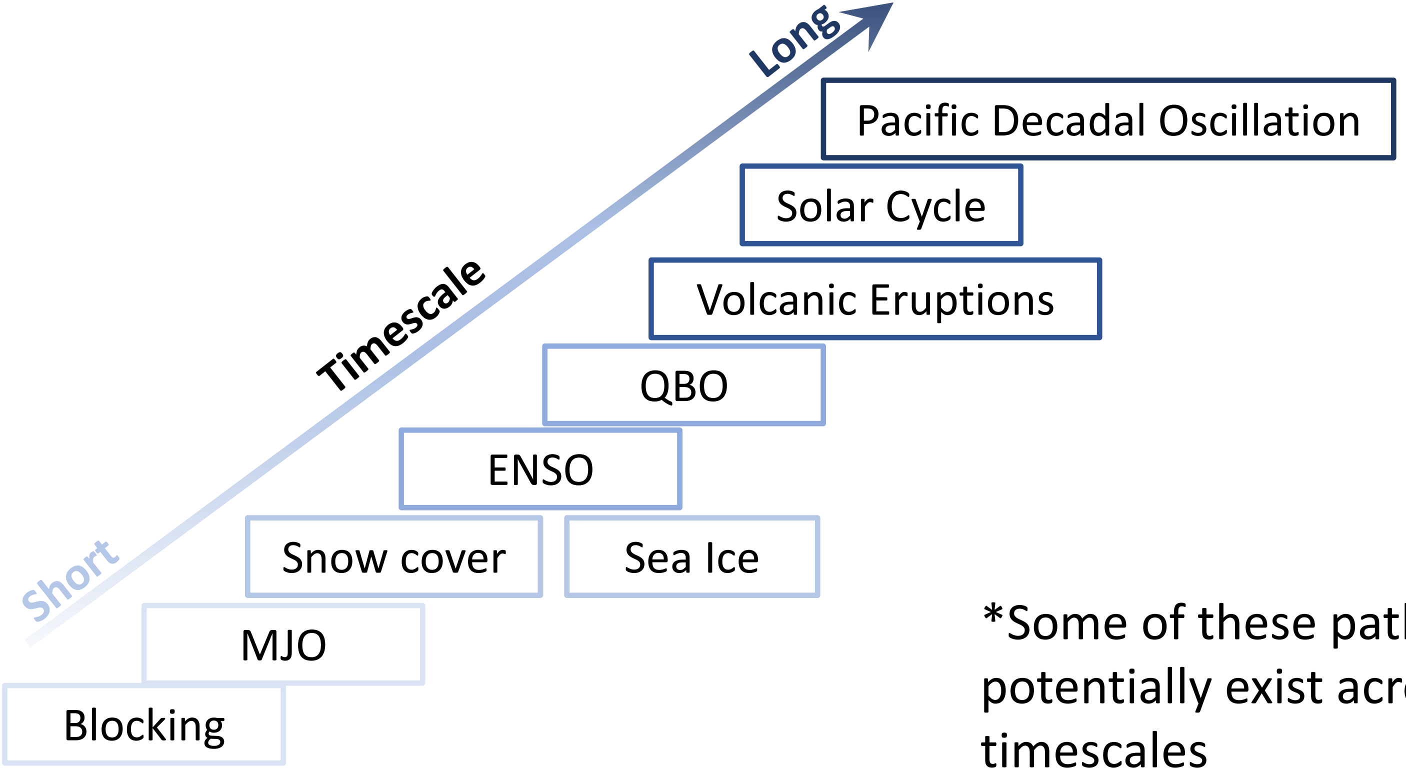
Extended prediction skill based on known stratosphere teleconnections

- 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



Domeisen, Garfinkel, and Butler 2019

Extended prediction skill based on known stratosphere teleconnections



*Some of these pathways potentially exist across timescales

Where can efforts for model improvements be focused?

- Stratospheric biases:
  Model top, vertical resolution, small-scale wave parameterizations, chemistry-climate interactions *[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 (blocking), 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, Butler et al. 2016, Garfinkel et al. 2018]*

Stratospheric variability is a potential source of S2S predictability that is just beginning to be realized as models start to have better stratospheric physics

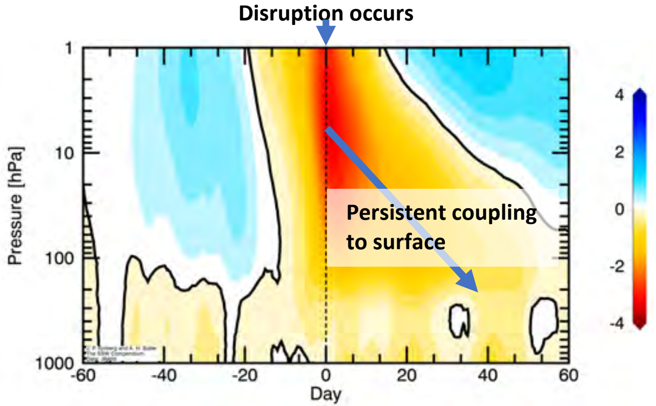
Tropospheric skill following stratospheric extremes is significantly enhanced

- 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. [e.g., Mukougawa et al. 2009; Sigmond et al. 2013, Tripathi et al. 2015]

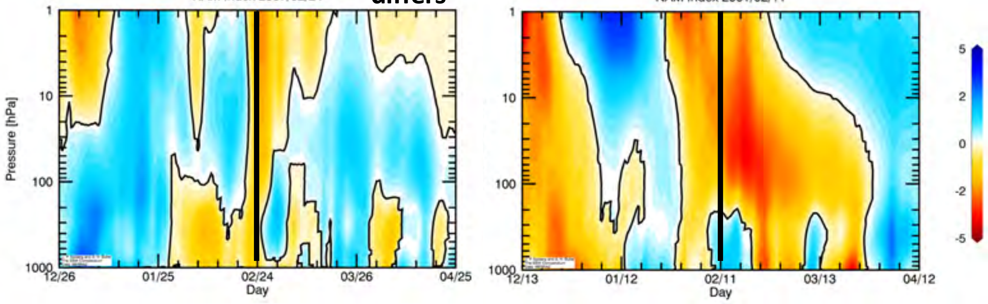
Understanding limitations of polar vortex disruptions for predictability

Composite or Mean response

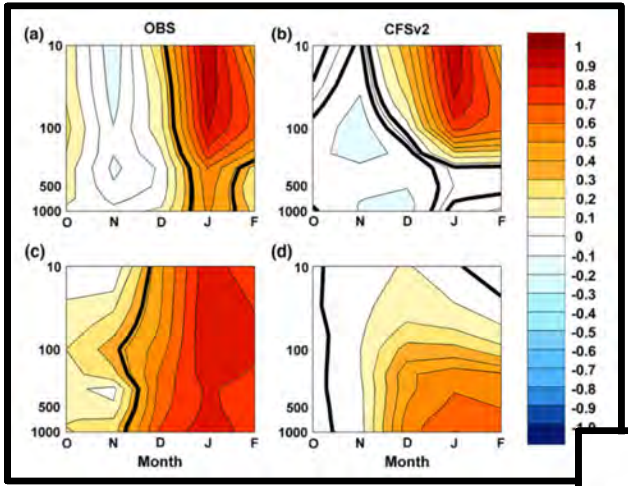


- Coupling from the stratosphere to the surface after a polar vortex disruption doesn't always occur
- Strongest surface impacts have been seen when stratospheric signal descends to lowermost stratosphere.
- Coupling could depend on how "receptive" troposphere is to stratospheric signals- i.e., ENSO, MJO teleconnections

For any particular event the coupling is noisy- downward coupling doesn't always occur; timing differs



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