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

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

Waugh et al. 2017

US CLIVAR Summit
August 6-8 2019
Stratospheric Network for the Assessment of Predictability (SNAP)

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 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.

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

- **Solar Variability**
  - Days to Decades
  - O$_3$ variability (SH spring, NH spring, tropics all year)

- **QBO**
  - ~ 28 months

- **Tropical-Extratropical connections**
  - e.g. Holton-Tan

- **Polar Vortex Variability**
  - Days to Weeks

- **Sea ice, sea surface temperature and Eurasian snow cover influence on planetary waves**
  - (e.g., ENSO, MJO)

- **Tropical convection influence on planetary waves**
  - (e.g., ENSO, MJO)

- **Planetary wave reflection**

- **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

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].
Stratosphere-troposphere coupling in the extratropics

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.

Waugh et al. 2017
Disruption of the Polar Vortex (SSW)

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].

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**Butler et al. 2017**
Stratospheric impacts on the surface

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

Switzerland

Cold and snowy weather from end of February into March 2018

London

Italy

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

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.

Domeisen et al. (2019, Part II)
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:

• 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

- 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
How well do models simulate stratosphere-troposphere coupling?

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?**

*Riddle et al. 2013*

*Furtado et al. 2015*