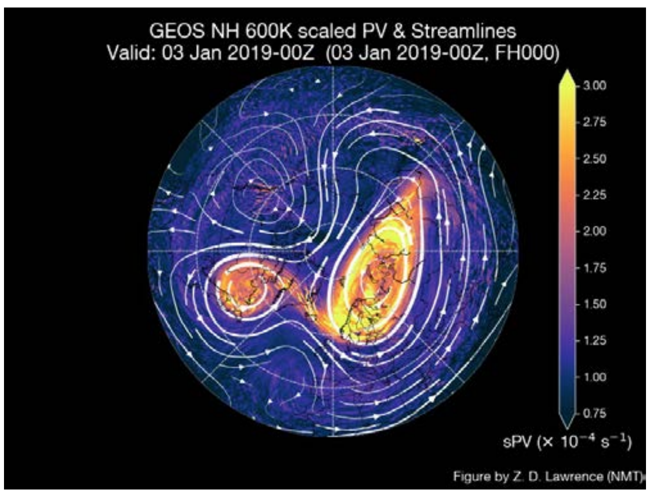
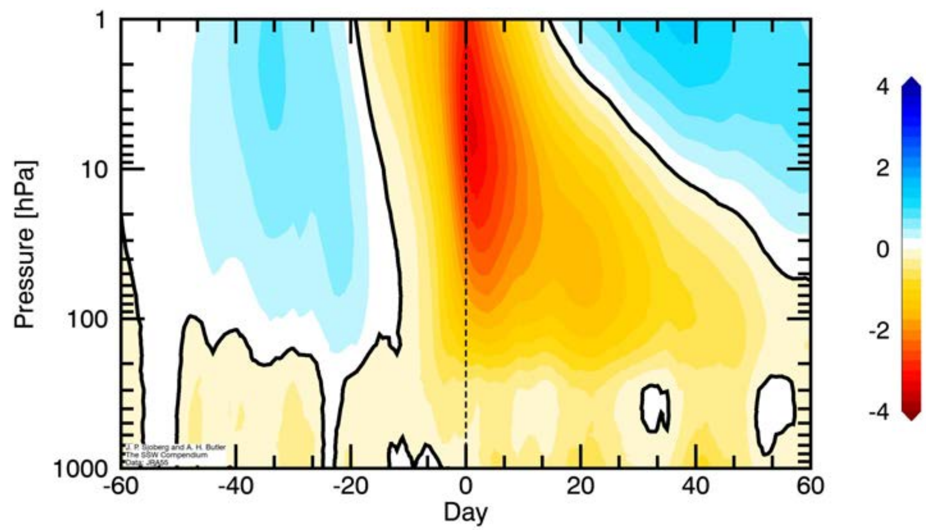
Quantifying stratospheric biases and the role of stratosphere-troposphere coupling in S2S models

A report from the SPARC/SNAP community

Presented by: SNAP Co-Chair Amy H. Butler

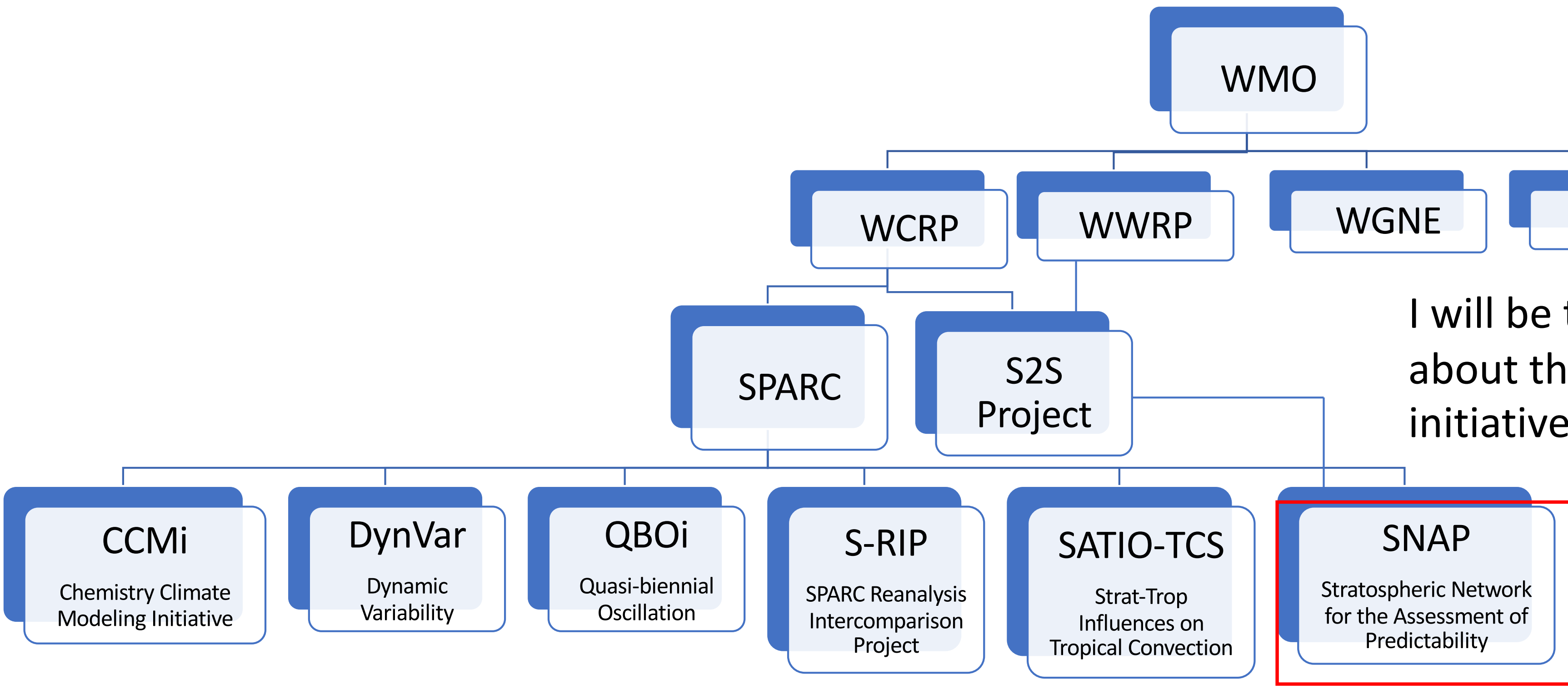
NOAA Chemical Sciences Laboratory





WGNE-36 meeting, 2021

Initiatives within SPARC that address Predictability and Dynamics



I will be talking about the SNAP initiative today

Stratospheric Network for the Assessment of Predictability (SNAP)

Activity Leaders

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A WCRP/SPARC international activity and the Stratosphere sub-project of the WWRP/WCRP S2S Prediction Project.

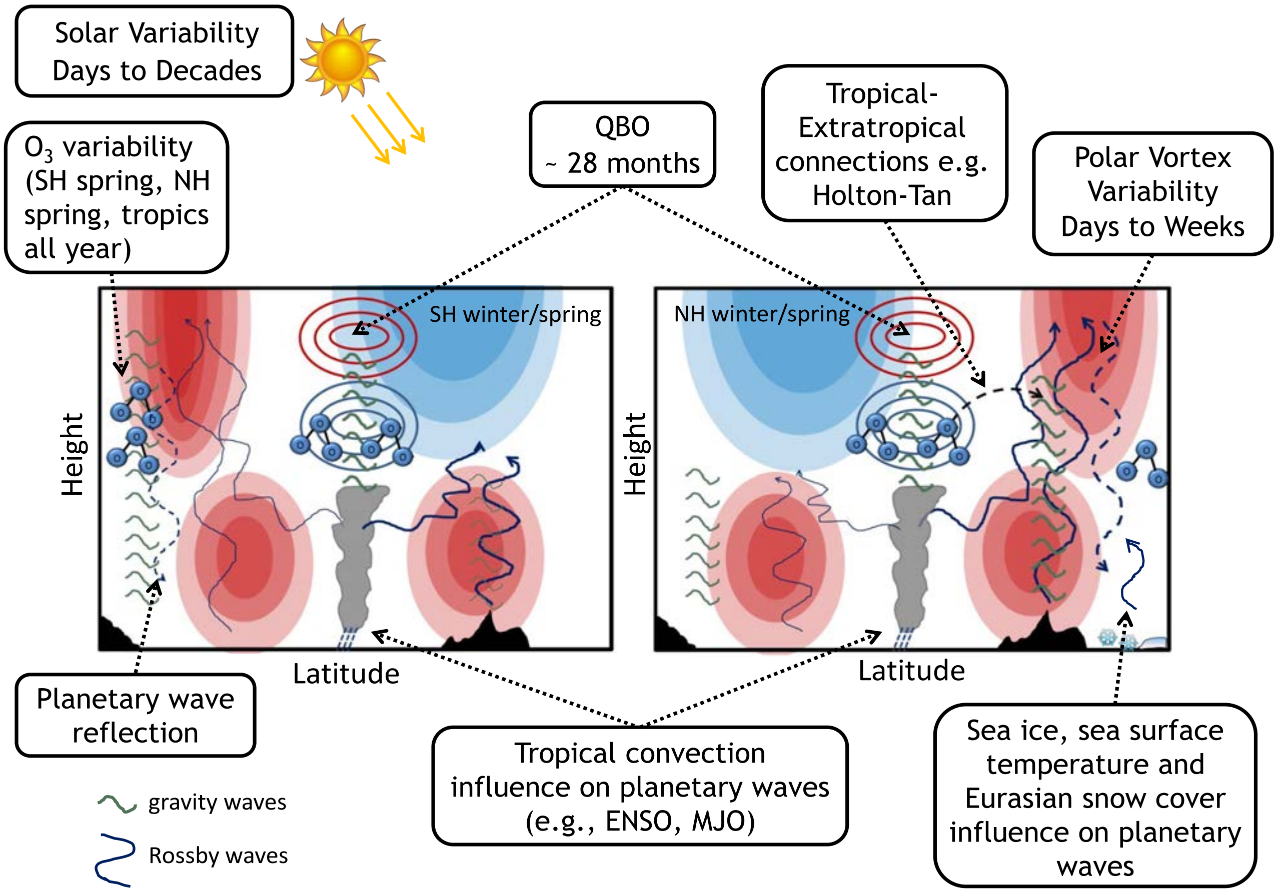
Goal: To assess stratospheric predictability and its tropospheric impact.

Stratosphere-troposphere coupling processes linked to global extremes

	stratospheric precursor	tropospheric extreme event	impact	affected region
Northern Hemisphere	sudden stratospheric warming	(marine) cold air outbreak	infrastructure damage, health impacts	Arctic, northern Europe, North Atlantic
		increased storminess	flooding, wind damage	southern Europe
		regional sea ice changes	shipping impacts, resource extraction	Arctic
	strong vortex event	storm series	flooding, wind damage	northern Europe, North Atlantic
		drought	agricultural damage	southern Europe
	wave reflection	cold air outbreak	health impacts	North America
tropics	Quasi-Biennial Oscillation	changes in the Madden-Julian Oscillation	precipitation extremes	tropics, subtropics
		atmospheric rivers	flooding	western North America
		changes in the monsoon	drought / flooding, agricultural impacts	India, Southeast Asia
Southern Hemisphere	early vortex weakening	heat, drought	wildfires, agricultural losses	Australia, Antarctica
		cold spell	health impacts	southeastern Africa, South America
	ozone anomalies	poleward shift of storm track	sea ice changes	Southern Ocean
		increased UV radiation	health impacts	Australia
		hot spells	health impacts	southern Africa, Australia, South America

Domeisen and Butler, "Stratospheric drivers of extreme events at the Earth's surface", Communications Earth & Environment, 2020

Stratosphere-troposphere coupling processes important to S2S forecast skill



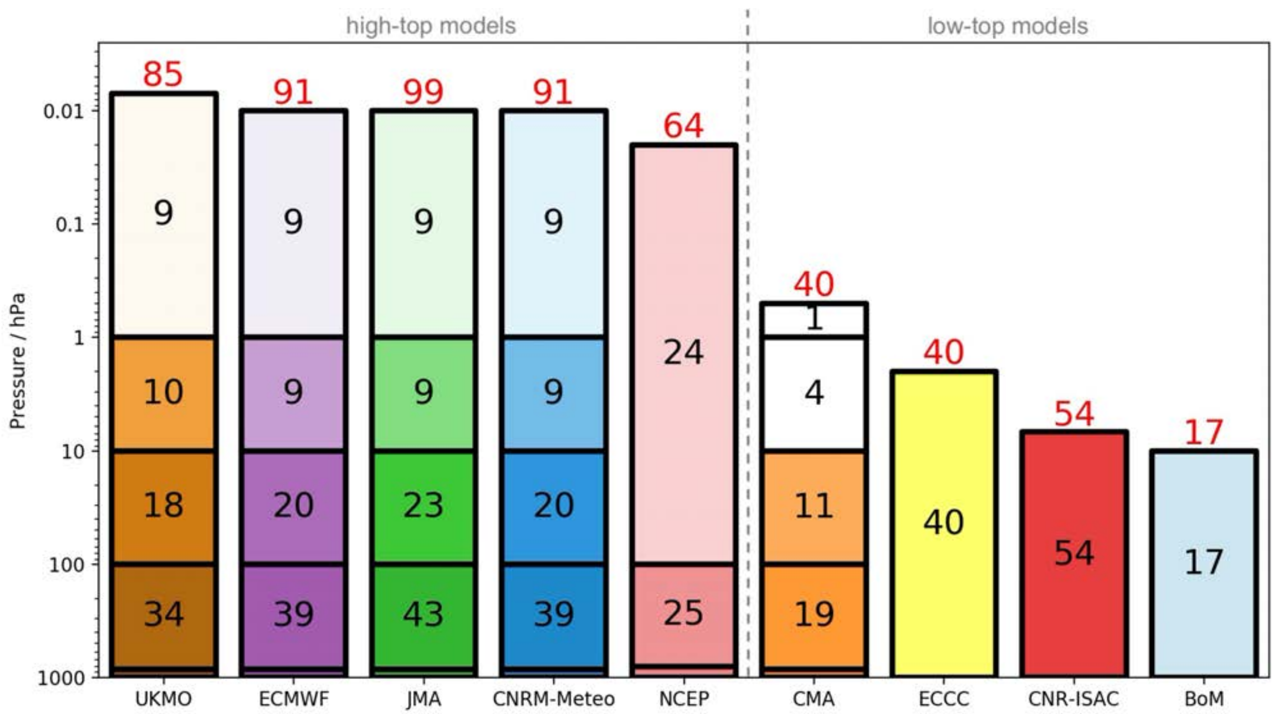
What are the biases linked to these processes in S2S models?

How can we isolate the role of the stratosphere on S2S predictive skill?

Butler et al. 2019, S2S book chapter
Image Credit: Isla Simpson

The WWRP/WCRP S2S Prediction Project

Vitart et al. (2017)



High-top model => model top above 0.1 hPa and several model levels above 1 hPa

Domeisen et al. (2020), JGR, Part I & II

The majority of S2S prediction systems now have high model lids and are more vertically resolved above 100 hPa. High-top models show higher stratospheric predictive skill, and high-top models better capture stratospheric pathways of teleconnections.

Current Projects within SNAP

Currently two ongoing international collaborative projects to:

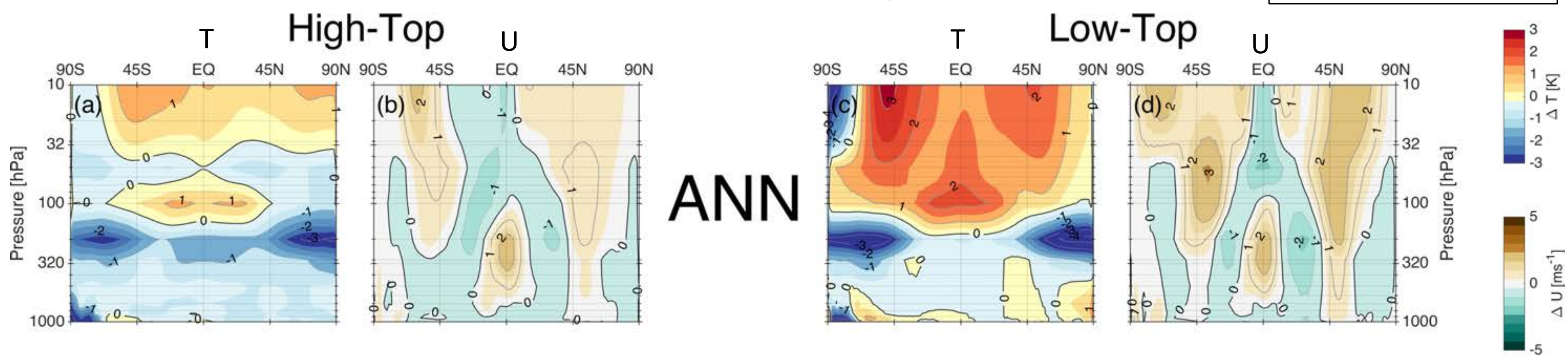
1) **Assess stratosphere biases in S2S forecast models**
   Lead: Zachary Lawrence, CIRES/NOAA PSL
   Researchers from 11 countries contributing to this analysis: Switzerland, Israel, Spain, United States, Finland, South Korea, United Kingdom, Japan, Australia, Norway, Argentina. Current status: two papers in prep; analysis for paper #1 completed, paper draft underway.

2) **Quantify contribution of stratospheric circulation to forecast skill**
   Stratospheric Nudging and Predictable Surface Impacts (SNAPSI)
   Lead: Peter Hitchcock, Cornell University
   10 modeling centers (many from S2S Prediction project + some SubX/NMME models) will perform targeted experiments

#1. Stratosphere biases in S2S forecast models

Week 4 S2S multi-model-mean biases compared to ERA-interim

Lawrence et al., in prep.



S2S models show systematic stratospheric biases which could limit predictive skill.

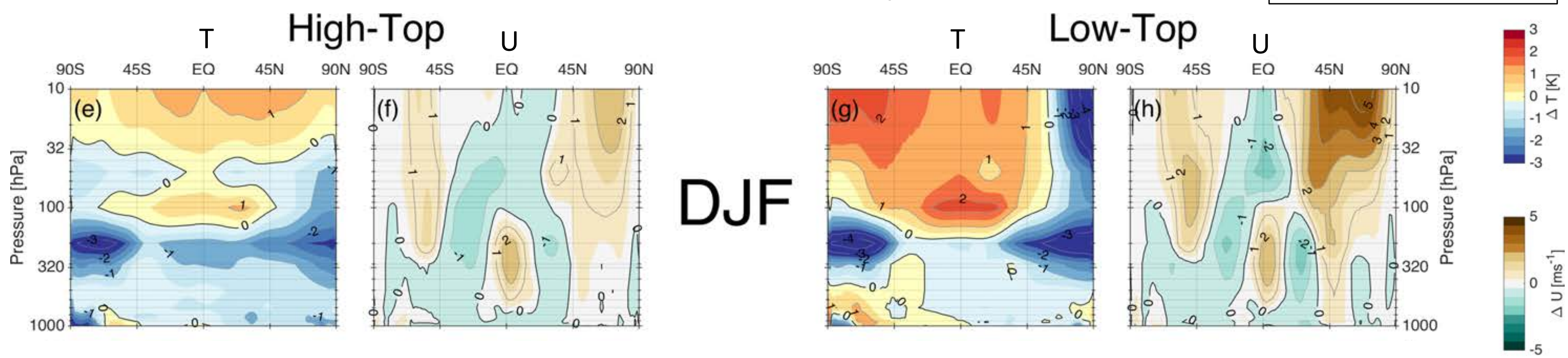
Biases may be linked to dynamic or radiative/model physics processes.

1) overall warm stratosphere bias
2) Extratropical UTLS cold bias

#1. Stratosphere biases in S2S forecast models

Week 4 S2S multi-model-mean biases compared to ERA-interim

Lawrence et al., in prep.



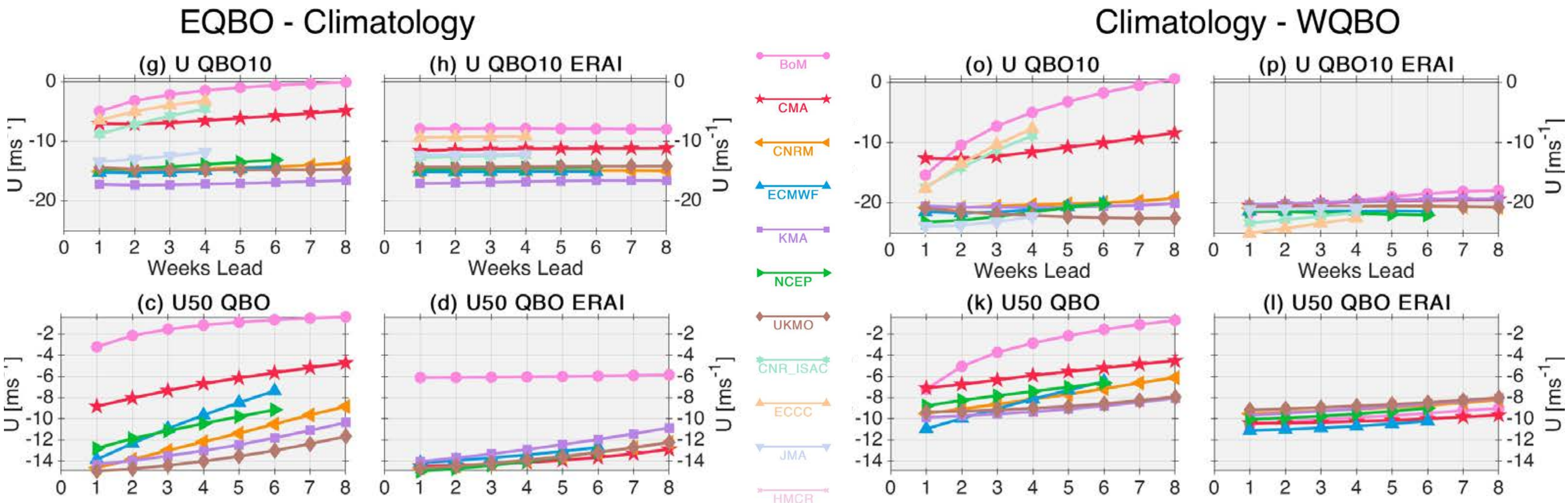
Biases may be linked to dynamic or radiative/model physics processes.

3) NH polar vortex too strong and cold

4) Tropical stratospheric wind easterly bias

Biases are usually more severe in low-top models (model lids below 0.1 hPa)

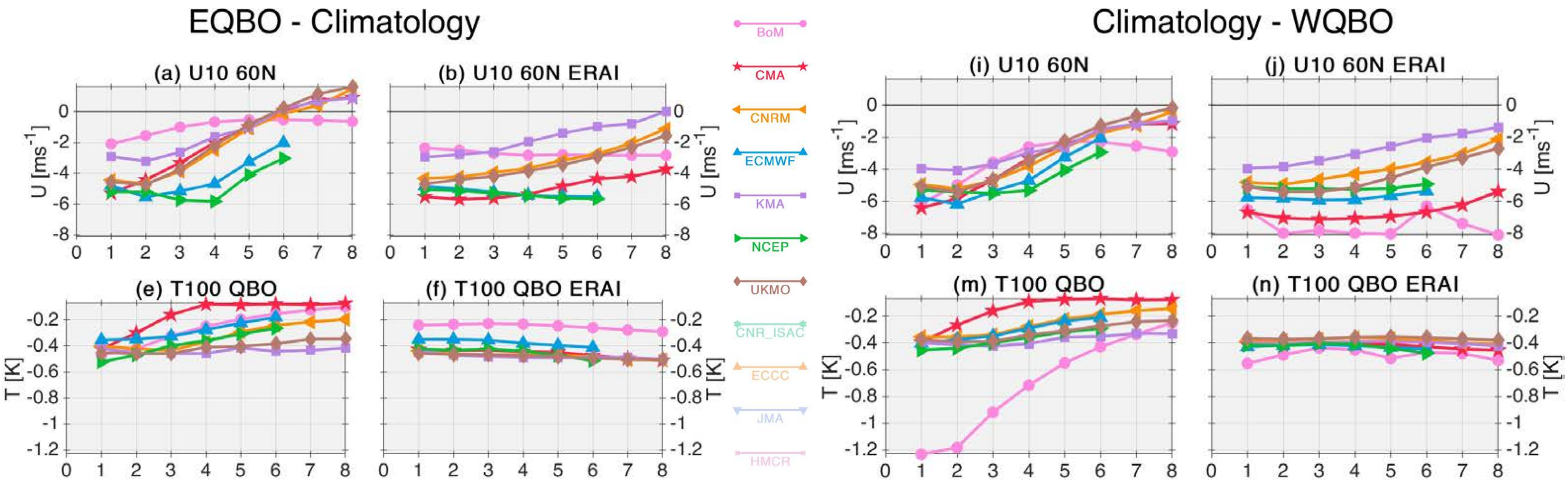
QBO biases in S2S forecast models



S2S models lose magnitude of initialized QBO winds. Tropical winds drift toward weak easterlies, no matter the phase of the QBO at initialization.

Lawrence et al., in prep.

Biases in QBO teleconnections in S2S models



Inability to maintain magnitude of initialized tropical stratospheric winds also degrades:

(a) ***QBO teleconnections to polar vortex/extratropics***

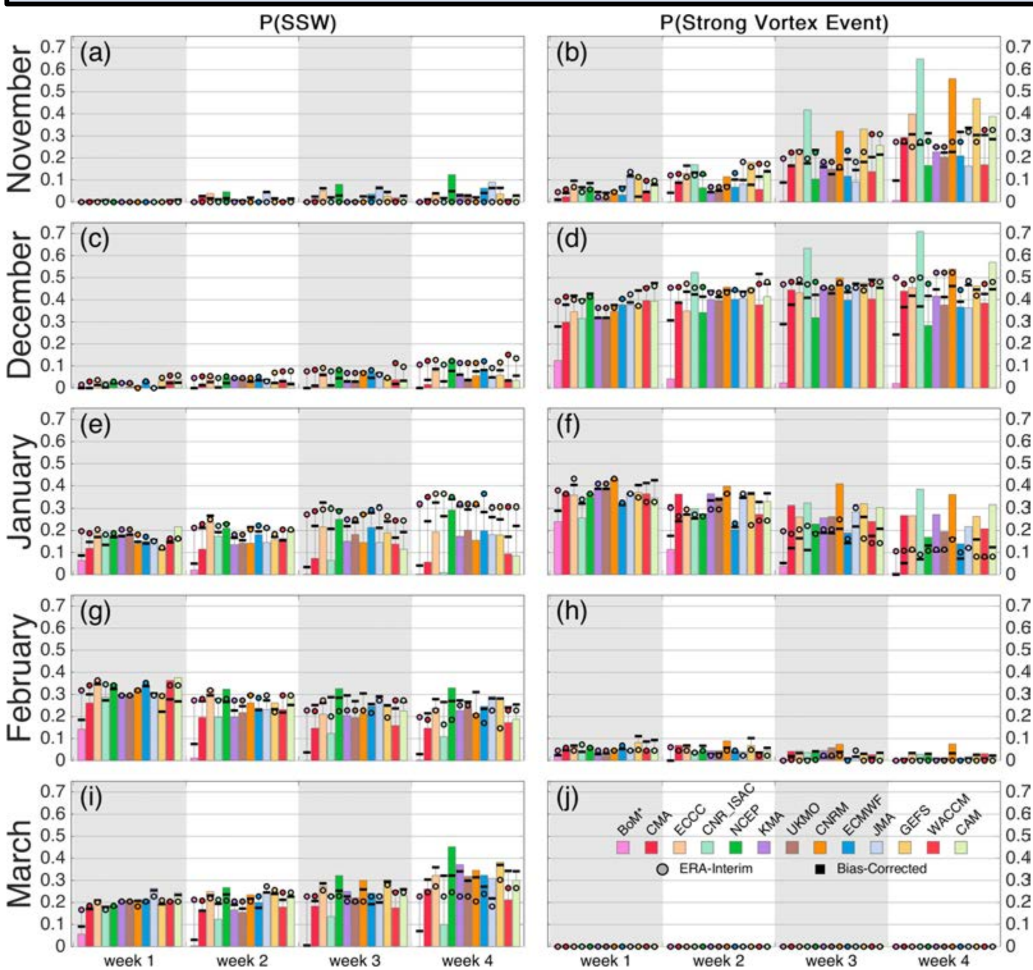
(b) ***QBO-related temperature anomalies in lower tropical stratosphere***

May have implications for how these models capture coupling between the QBO and MJO

(Lim et al. 2018, Kim et al. 2019)

Lawrence et al., in prep.

Influence of bias on NH polar vortex extremes



Without bias correction, S2S models underpredict risk of SSWs in Dec/Jan, and overpredict SSW risk in Feb/Mar at long leads. Strong vortex events are overpredicted in Jan.

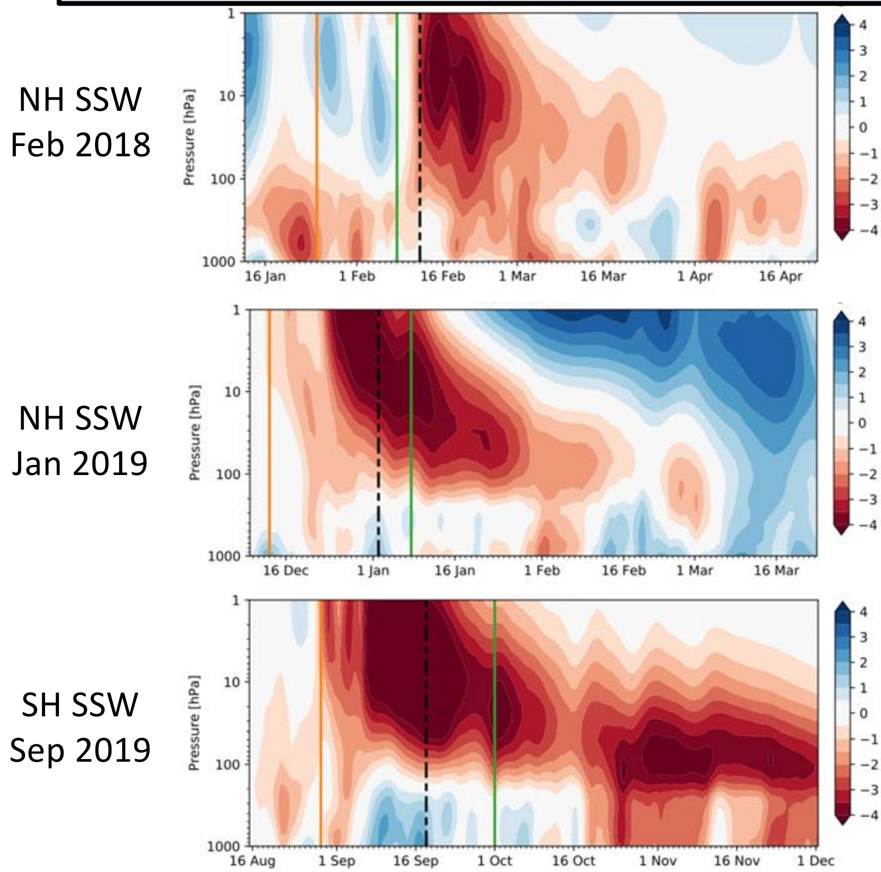
Bias correction improves extreme vortex risk estimates, but mean state biases likely dynamically alter the response- how to deal with this in terms of surface impacts?

Lawrence et al., in prep.

Initial conclusions on stratospheric model bias results

- Systematic biases often prevail even as systems raise model top and increase vertical resolution, though they are improved. These biases can be linked to radiative or dynamical processes in the models.
- Determining biases depends on time period/number of years of hindcasts, which is often quite short and may introduce noise.
- How best to remove/deal with these biases?
- Second part of analysis will consider biases in stratosphere-troposphere coupling and connections to skill
- Thanks to Zachary Lawrence and the SNAP Stratospheric Biases team for their efforts.

#2. Stratospheric Nudging and Predictable Surface Impacts (SNAPSI)



Annular modes for three case studies

Separating the influence of the stratosphere on the surface from other sources of predictability is currently difficult.

Thanks to the participation of 10 S2S modeling centers, SNAP (lead: Peter Hitchcock) plans to conduct modeling experiments to isolate the role of the stratosphere on predictable surface impacts following 2 NH major SSWs (2018, 2019) and 1 SH minor SSW (2019).

5 participating modeling centers have already completed these simulations.

Hitchcock et al., in prep, GMD

SNAPSI Experimental Design

For each of the three target events, four experiments are proposed:

- **Free:** Free running ensemble forecast
- **Nudged**: *Zonally symmetric* component of stratosphere nudged to **observed evolution**
- **Control**: *Zonally symmetric* component of stratosphere nudged to **climatology**
- **Full:** *Entire* stratospheric circulation nudged to **observed evolution**

Two initialization dates have been proposed for each event (with ideally 50-100 members)

- A later date to study surface extremes that occurred during the event
- An earlier date to study evolution and predictability of stratosphere
    - **no "Full" ensemble**

Details will be available via an experimental protocol paper, Hitchcock et al., in prep for GMD

Event	Initialization Date 1, no **full**	Initialization Date 2, **all experiments**
NH: 12 Feb 2018	25 Jan 2018	8 Feb 2018
NH: 2 Jan 2019	13 Dec 2018	8 Jan 2019
SH: 18 Sep 2019	29 Aug 2019	1 Oct 2019

SNAPSI Data Request

One limitation of current S2S output is lack of stratospheric data/dynamic metrics.

For SNAPSI we will request more output in the stratosphere and more fields to help us diagnose stratosphere-troposphere coupling processes. Data stored at CEDA.

Tier One variables (**needed** to meet core science goals) ~3.5 Tb from each model:

Basic Meteorological Fields (XYZT): u, v, t, z, omega, specific humidity

Zonally symmetric nudging tendencies (YZT): Zonal wind, temperature

'Surface' Quantities (XYT): Surface pressure, Sea-level pressure, 2m temperature, 10 m horizontal winds, Convective precipitation flux (accumulated), total precipitation flux (accumulated), Outgoing longwave radiation

Tier Two variables (**nice to have**):

Transformed Eulerian (Zonal) Mean (see Gerber and Manzini (2016)) (YZT): EP Fluxes (epfy, epfz, utenddivf), Residual circulation (vtem, wtem), Physics tendencies (net u tendency from physics, gravity waves, and advective)

Zonal Mean Thermodynamic Budget (YZT): Physics tendencies (net T tendency from physics radiation - shortwave heating, longwave heating), Ozone

Surface Quantities (XZT): Net surface wind stresses, sea-surface temperatures, sea-ice area fraction, sea-ice thickness, snow-depth water equivalent, soil moisture top 20cm, min/max 2m temperature

SNAPSI Analysis Strategy

Working groups will be formed around each of the core science goals:

1. Quantify stratospheric contributions to surface predictability

2. Attribute extreme events to stratospheric variability

3. Quantify mechanisms of stratospheric coupling

4. Quantify upward wave propagation that perturbs stratosphere

Additional science questions related to two SPARC initiatives:

5. QBOi (SPARC project focusing on the Quasi-Biennial oscillation)

Quantify tropical and extratropical wave forcing of the QBO

Diagnose decay of QBO in forecast models

6. SATIO-TCS (SPARC project focusing on stratospheric impacts on tropical convection)

Quantify impact of stratosphere on tropical convection, including evolution of MJO

Each group will write at least one community paper.

Conclusions

SNAP is an international group of researchers linked to both SPARC and the S2S Prediction Project, with the goal to investigate the role of the stratosphere in S2S prediction.

Two current projects are underway:

1) Investigation of stratospheric biases in S2S models
2) Stratospheric Nudging experiments

We hope these projects will 1) advance the state of knowledge about how biases in the S2S models affect stratosphere-troposphere coupling processes and their predictability, and 2) allow us to better quantify the contribution of the stratosphere to surface predictability.

We are always looking to expand engagement with researchers in other communities!

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