A Diagnostic Toolbox for Evaluating Stratosphere-Troposphere Coupling Processes in NOAA's UFS

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Unifying Innovations in Forecasting Capabilities Workshop (July 2022)

CIRES

University of Colorado Boulder

NOAA

“Big Picture” Motivation

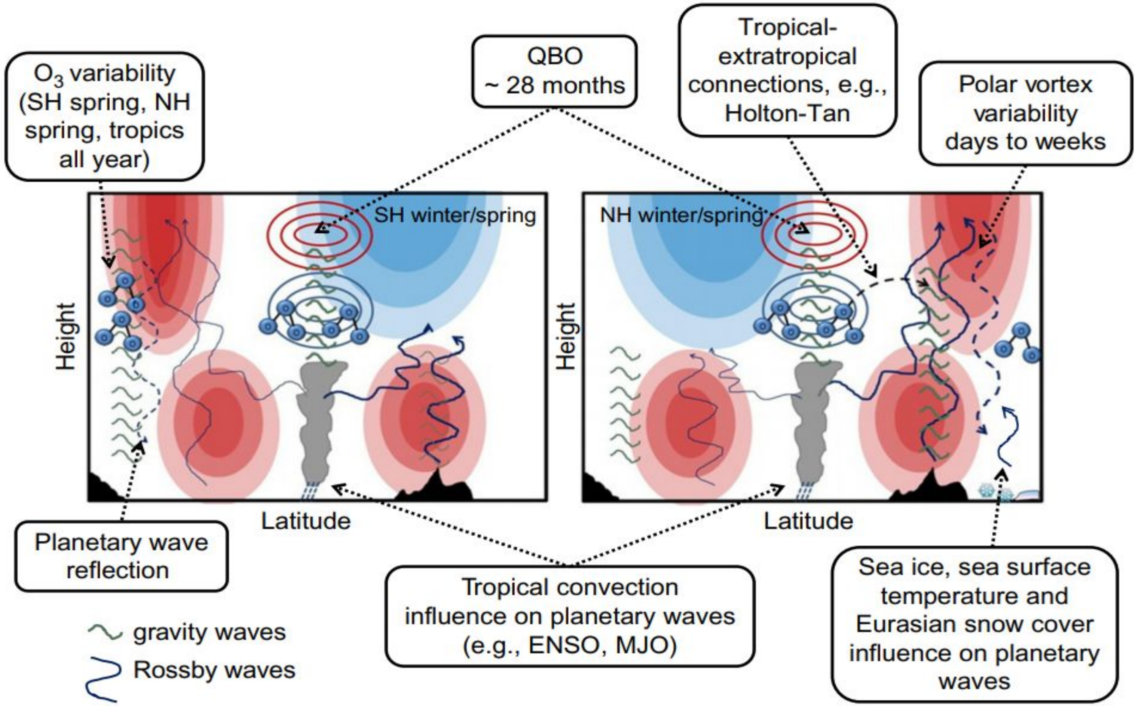
Why evaluate the stratosphere?

	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” Nature Communications Earth & Environment, 2020

UFS-Specific Motivation

Why evaluate the stratosphere?



Schematic from Butler et al., 2019, "Sub-seasonal Predictability and the Stratosphere"

UFS-Specific Motivation

Recent and potential future changes to UFS can impact the representation of stratosphere-troposphere coupling processes:

- Changes to model lid height and vertical resolution
- Changes to horizontal resolution
- Updated gravity wave physics
- Coupled/interactive chemistry processes

Radiative and dynamical controls on the stratospheric circulation are well understood, so **investigating the stratosphere can help to better understand and tune updates to the UFS.**

Diagnostic Toolbox

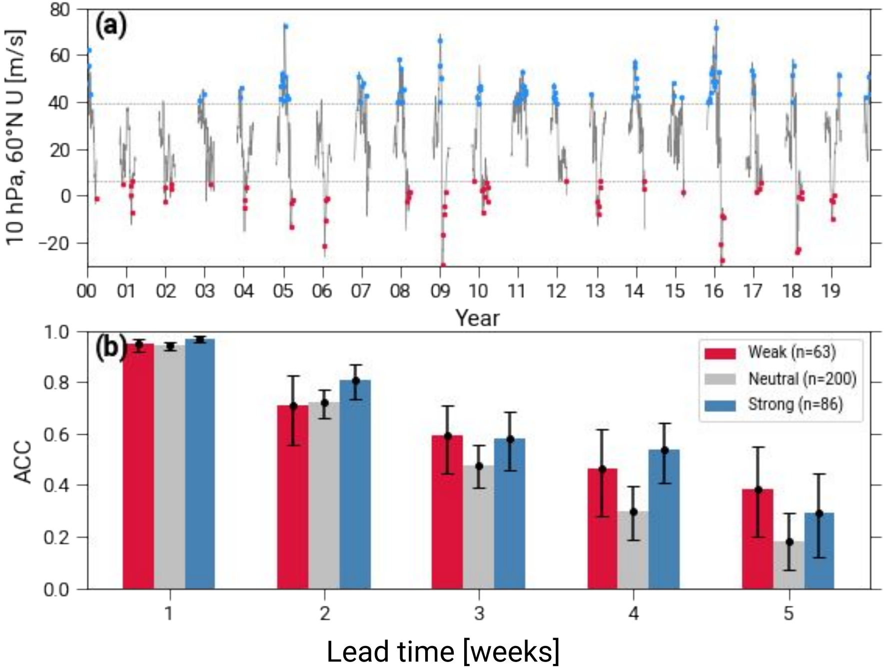
We have developed a diagnostic toolbox that can be used to assess relevant stratospheric and stratosphere-troposphere coupling processes.

- Zonal mean biases/errors
- QBO characteristics
- Sudden stratospheric warmings / Strong vortex events
- Annular modes + NAO
- QBO-MJO interactions
- Wave-mean flow diagnostics
- Polar vortex geometry
- Sinuosity & circulation variability

These diagnostics have been applied to GEFSv12 and recent UFS prototype (p5-p7) hindcasts.

GEFSv12: S2S Skill Associated with the Stratosphere

Boreal Winter NAO Correlation Skill: Dependence on Polar Vortex ICs

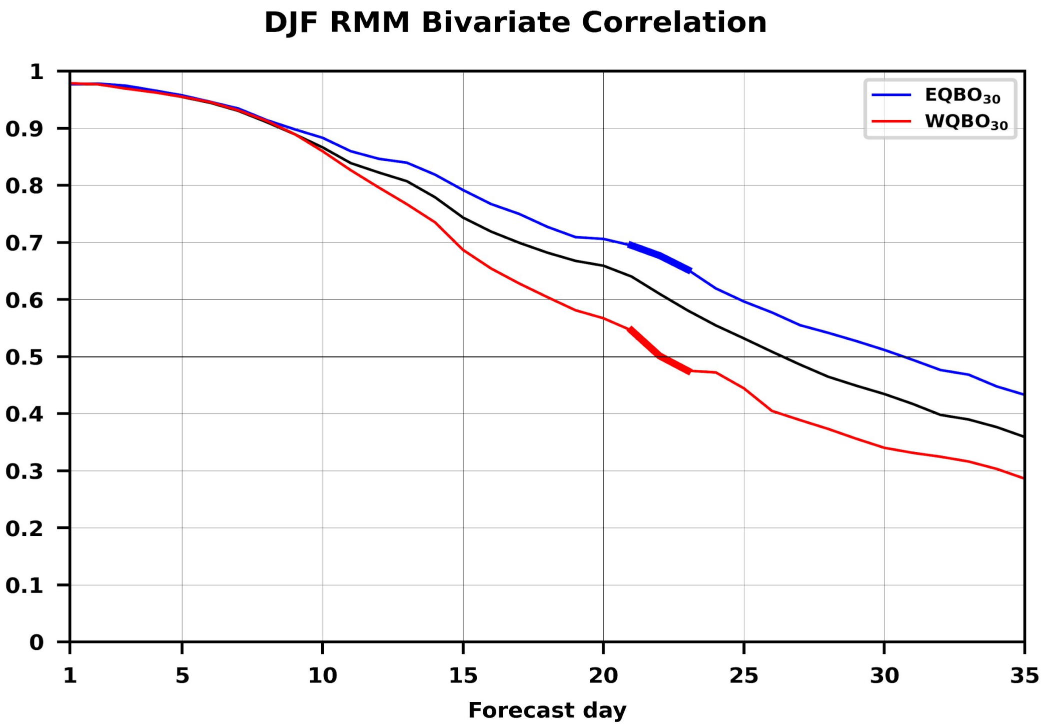


GEFSv12 shows enhanced NAO correlation skill for forecasts initialized during strong/weak stratospheric polar vortex states.

While these differences between composites are generally not statistically significant, they have been shown to be for other prediction systems with increased number of hindcasts/ensembles.

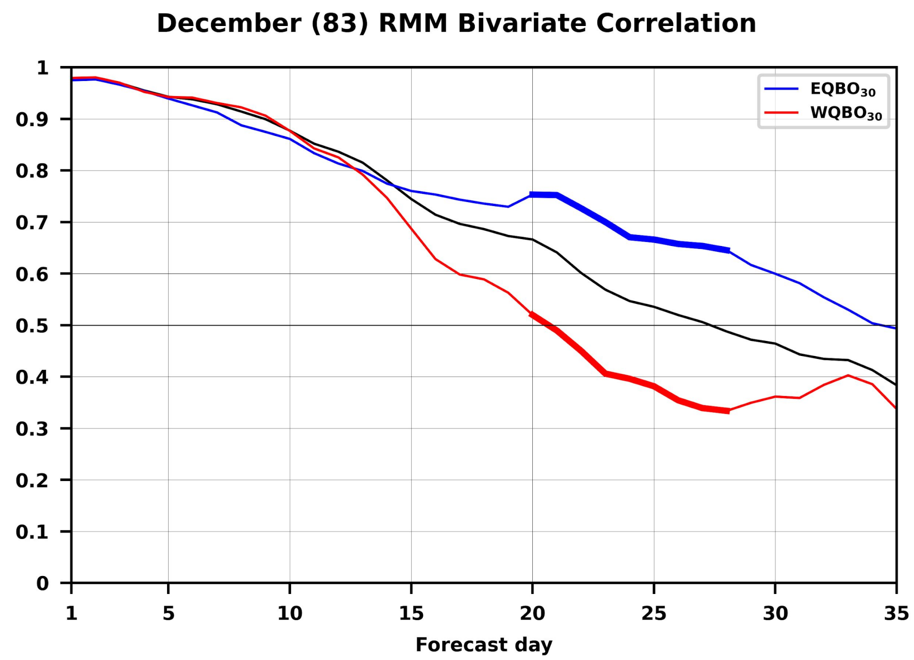
GEFSv12: S2S Skill Associated with the Stratosphere

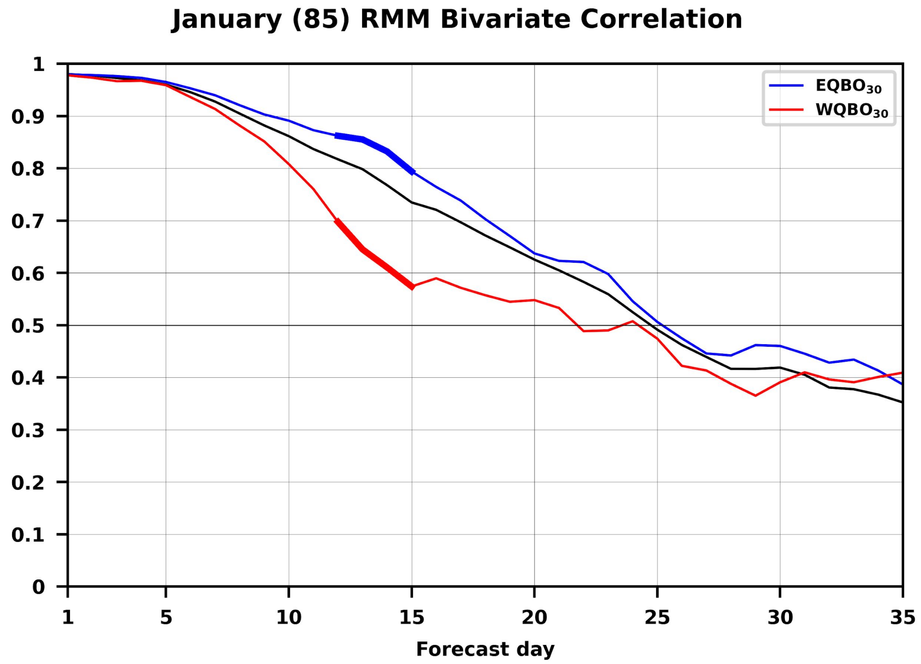
Boreal Winter MJO Correlation Skill: Dependence on QBO ICs



GEFSv12 shows enhanced weeks 3-4 MJO correlation skill for easterly QBO inits compared to westerly QBO.

GEFSv12: S2S Skill Associated with the Stratosphere



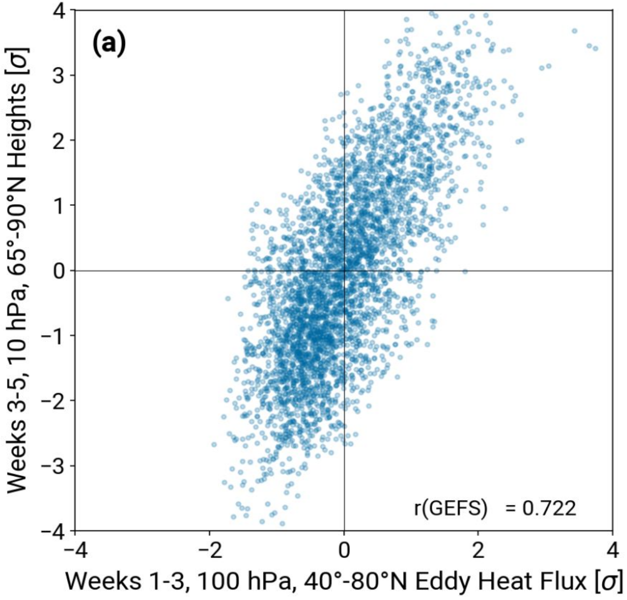


These differences in skill can be quite large for hindcasts initialized in specific months.

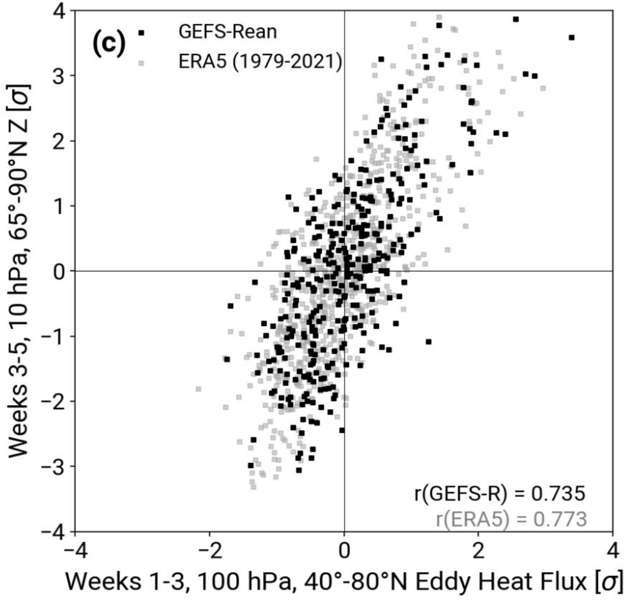
GEFSv12: Stratosphere-Troposphere Coupling

Upward Strat-Trop Coupling

GEFSv12



Reanalysis



r(GEFS) = 0.722

Corr (99% CI)

r(GEFS-R) = 0.735 (0.667, 0.789)

r(ERA5) = 0.773 (0.737, 0.805)

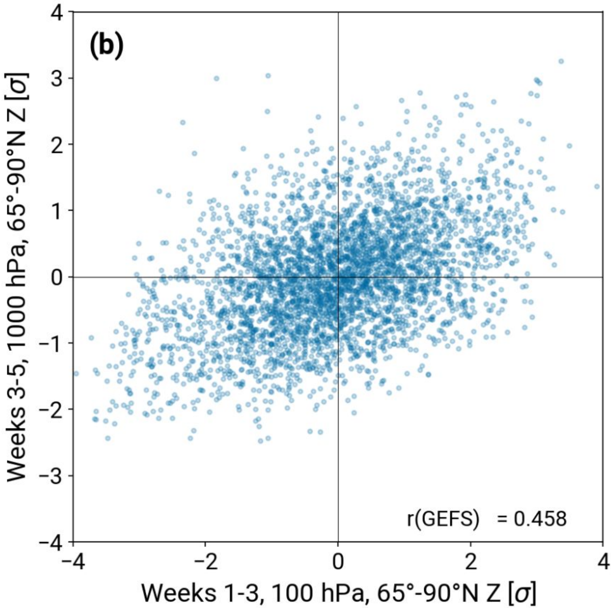
GEFSv12 exhibits realistic "upward" strat-trop coupling: Anomalous planetary wave forcing earlier in the forecasts are associated with anomalous strength in the vortex later in the forecasts.

The relationship measured with GEFSv12 matches closely to that obtained from reanalysis.

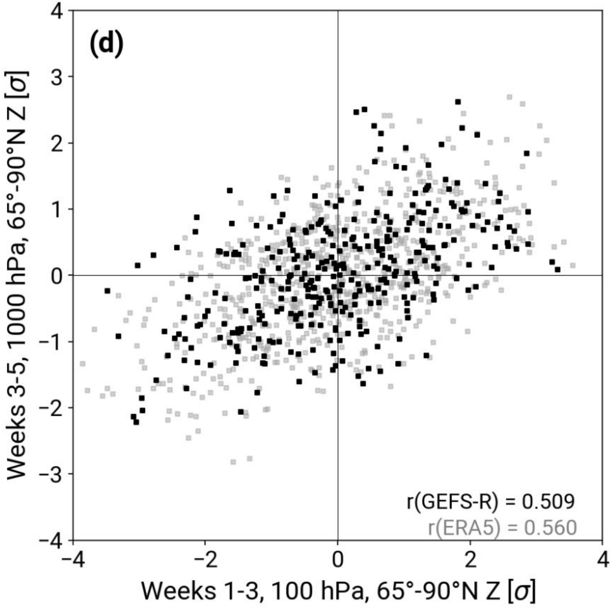
GEFSv12: Stratosphere-Troposphere Coupling

Downward Strat-Trop Coupling

GEFSv12



Reanalysis



r(GEFS) = 0.458

Corr (99% CI)

r(GEFS-R) = 0.509 (0.403, 0.605)

r(ERA5) = 0.560 (0.494, 0.618)

GEFSv12 exhibits realistic "downward" strat-trop coupling: Anomalous lower strat polar vortex earlier in the forecasts is associated with anomalous surface Northern Annular Mode later in the forecasts.

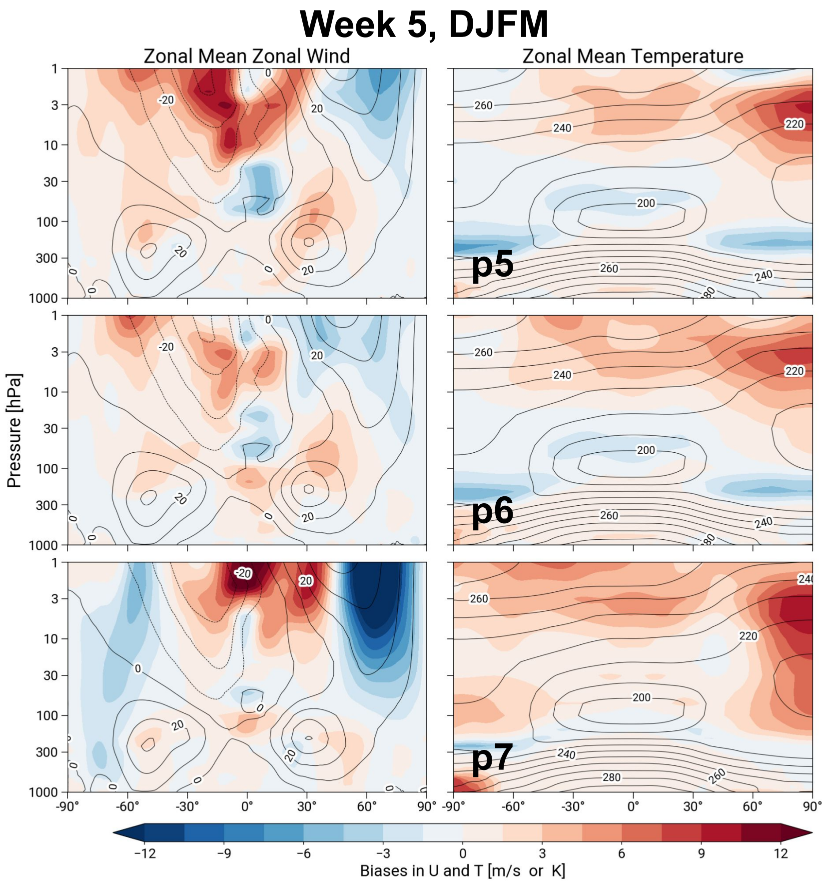
The relationship measured with GEFSv12 matches closely to that obtained from reanalysis.

UFS Prototypes: Relevant Changes from p5-p7

- UFSp5 → p6
  - Increase in model lid height from ~55km to ~80km
  - Increase in model vertical resolution from L64 to L127
  - Addition of parameterization for subgrid scale nonstationary gravity wave drag
- UFSp6 → p7
  - Initial conditions: CFSR → GEFSv12 Reanalysis
  - Update of gravity wave physics package "uGWD" from v0 to v1

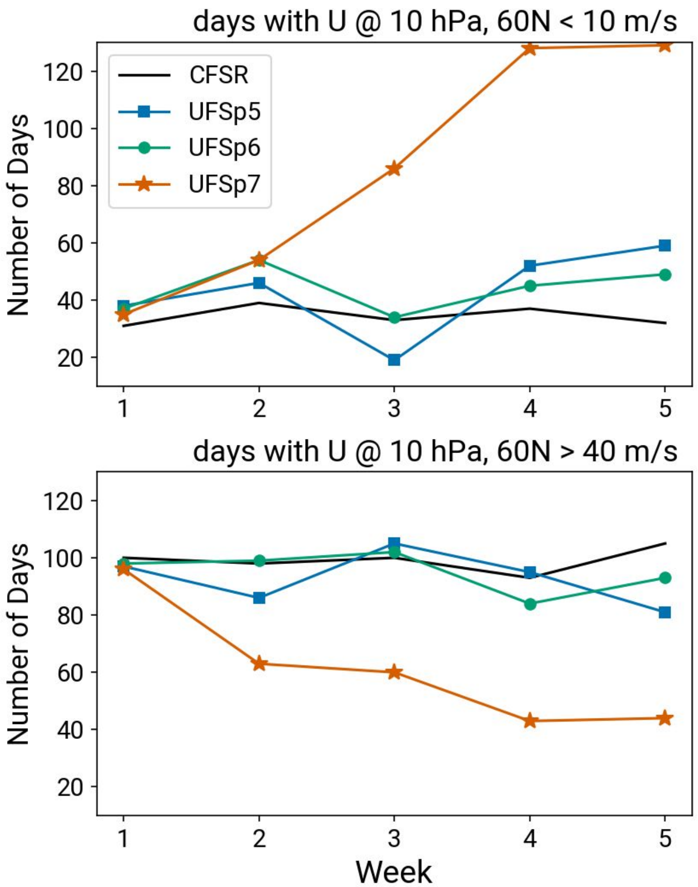
UFS prototype runs include only deterministic forecasts initialized twice per month from Apr 2011- Mar 2018

UFS Prototypes: Zonal Mean Biases



- p5 to p6: *Reduced biases* in tropical stratospheric winds from 100- 1 hPa; *slightly reduced* biases in polar vortex winds and polar cap temperatures from 10 - 1 hPa
- p6 to p7: *Reduced biases* in tropical stratospheric winds from 100 - 10 hPa; ***increased*** biases in tropical winds in upper stratosphere; ***dramatically enhanced*** weak vortex/warm polar cap bias

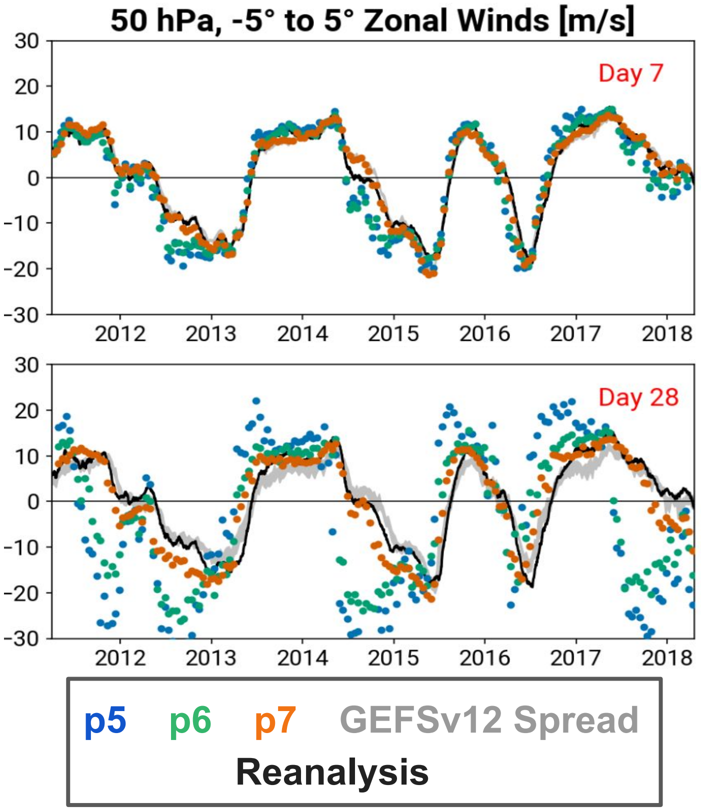
UFS Prototypes: Zonal Mean Biases

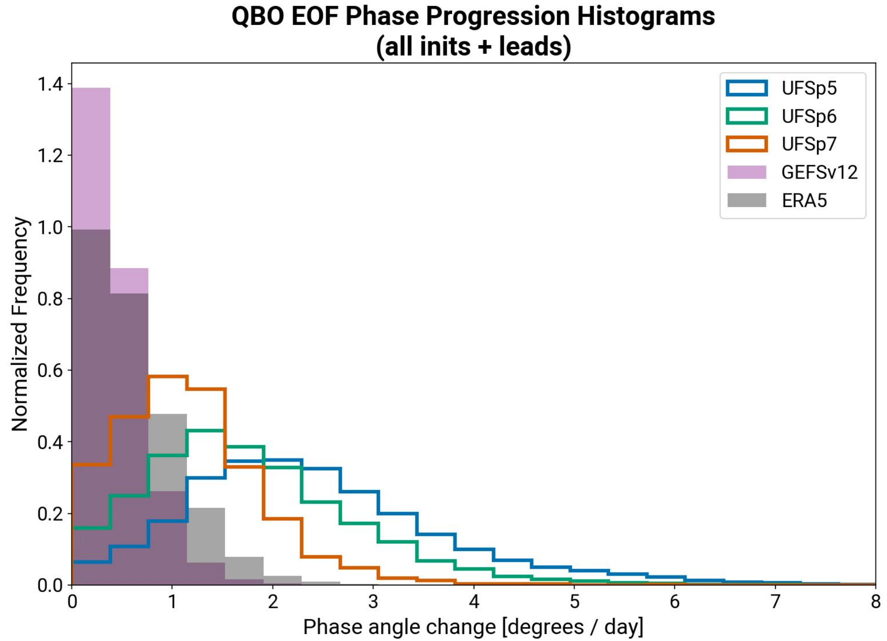


Using 10 and 40 m/s as arbitrary thresholds to measure strong/weak vortex states we see:

- By week 3 and beyond, **UFSp7 has over double the number of days with a weak polar vortex,** and roughly half the days with a strong vortex
- In contrast, **p5 and p6 have relatively stable counts** across lead times similar to reanalysis

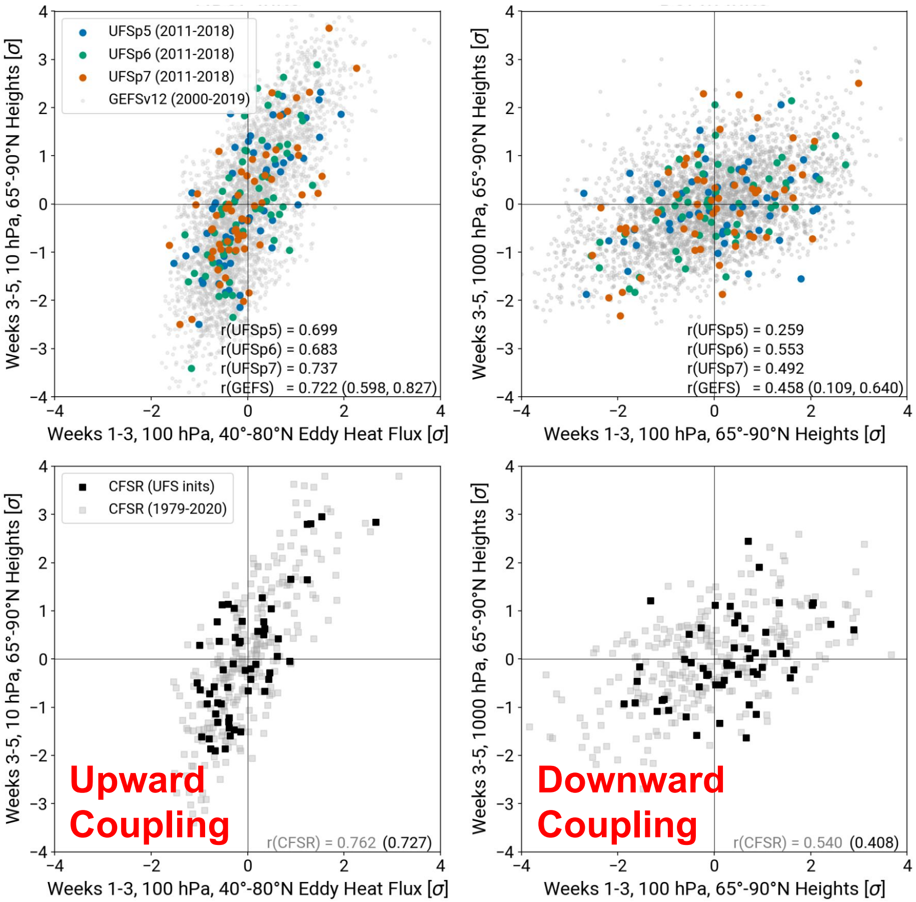
UFS Prototypes: Quasi-Biennial Oscillation (QBO)





QBO progresses too quickly in all three prototypes, though p7 shows improvement over p5 and p6 for levels between 100 - 10 hPa

UFS Prototypes: Stratosphere-Troposphere Coupling



- Sampling variability for estimating the downward coupling relationship in 2011-2018 is *large* (especially with only 2 inits per month, and deterministic runs)
- All UFS prototypes fall within this large sampling variability; cannot draw more robust conclusions

Conclusions & Next Steps

What have we accomplished?

- Development of diagnostic toolbox, and application to GEFSv12 + UFS prototypes
- Reports on UFS prototype results provided to model developers
- Relevant components of toolbox incorporated into METplus (thanks to Tina Kalb and Tara Jensen)

What's next?

- Paper on GEFSv12 results to be submitted soon
- Release of GEFSv12 datasets, including zonal mean diagnostics, NAO/MJO indices, etc.
- Release of new open-source tools on github ("pyzome")
- Transition of toolbox to CPC for future UFS stratosphere evaluations
- New realtime CPC webpage for verification/monitoring of stratospheric forecasts