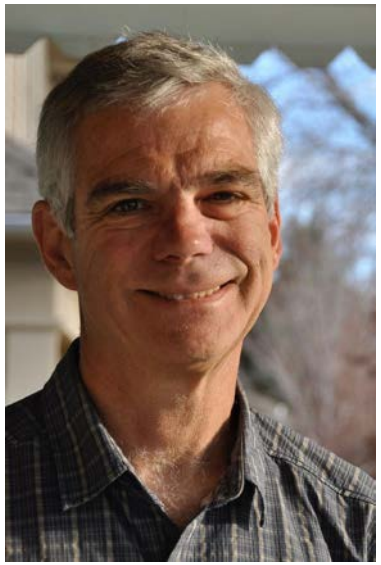
Assessing the Influence of UFS Tropical Forecast Errors on Higher Latitude Predictions Using Nudging Experiments

Juliana Dias[1], Stefan Tulich[1,2], Maria Gehne[1,2] and George Kiladis[1]



1. NOAA Physical Sciences Laboratory/ 2. University of Colorado, CIRES

Tropical-to-extratropical teleconnections

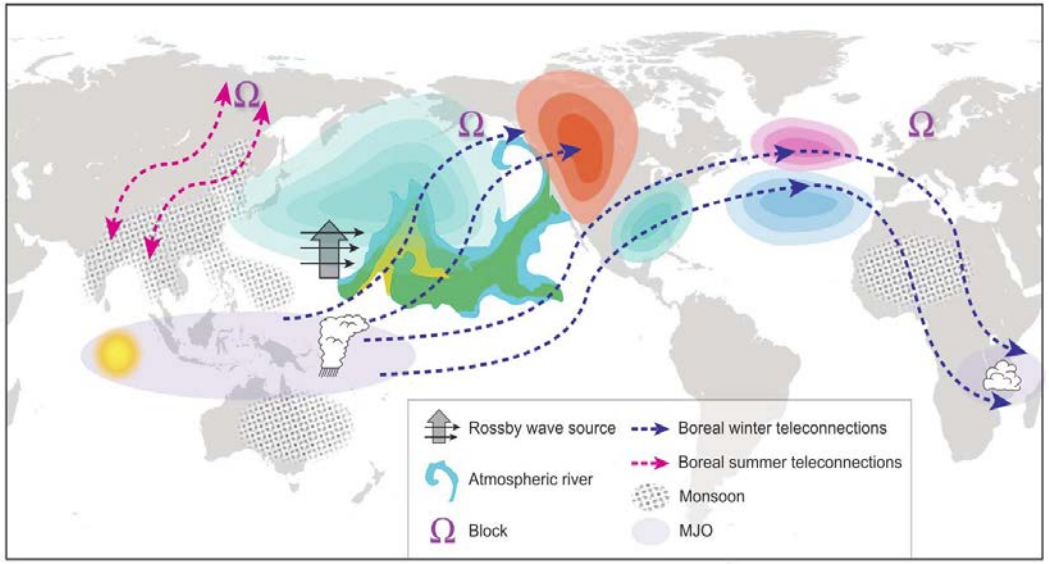


Figure: Schematic of tropical-NH interactions from ***Stan, C. et al. (2017).*** *Review of tropical-extratropical teleconnections on intraseasonal time scales. Rev. of Geoph., 55, 902–937.*

- The atmospheric response to variations in tropical latent heating extends well beyond its source region.

Rossby wave source

$$S = -\nabla\cdot(\boldsymbol{v}_\chi\zeta) = -(\zeta\nabla\cdot\boldsymbol{v}_\chi + \boldsymbol{v}_\chi\cdot\nabla\zeta)$$

divergent horizontal flow

vortex stretching

planetary and relative vorticity advection

[Hoskins & Karoly 1981 Sardeshmukh and Hoskins 1988; Grimm and Silva Dias 1995; Newman and Sardeshmukh 1998, Matthews, Hoskins, & Masutani, 2004, Branstator 2014]

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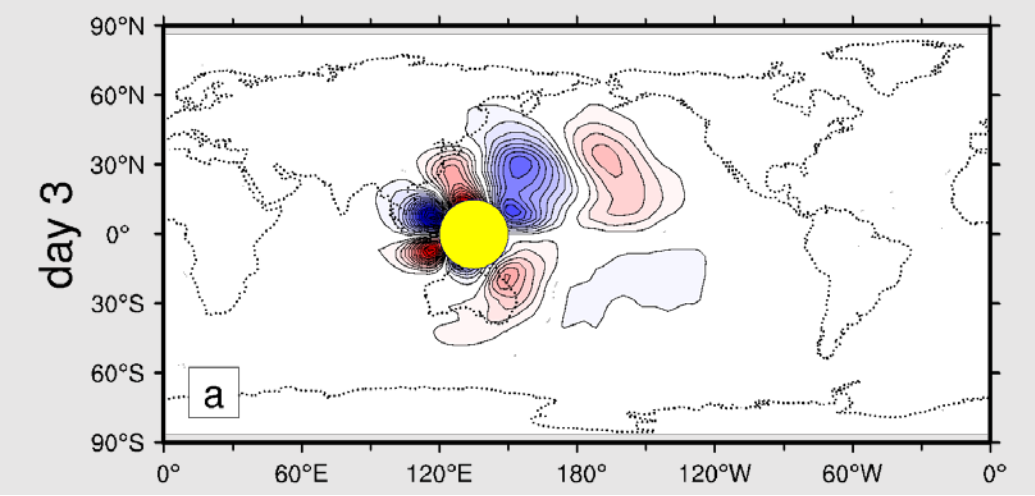
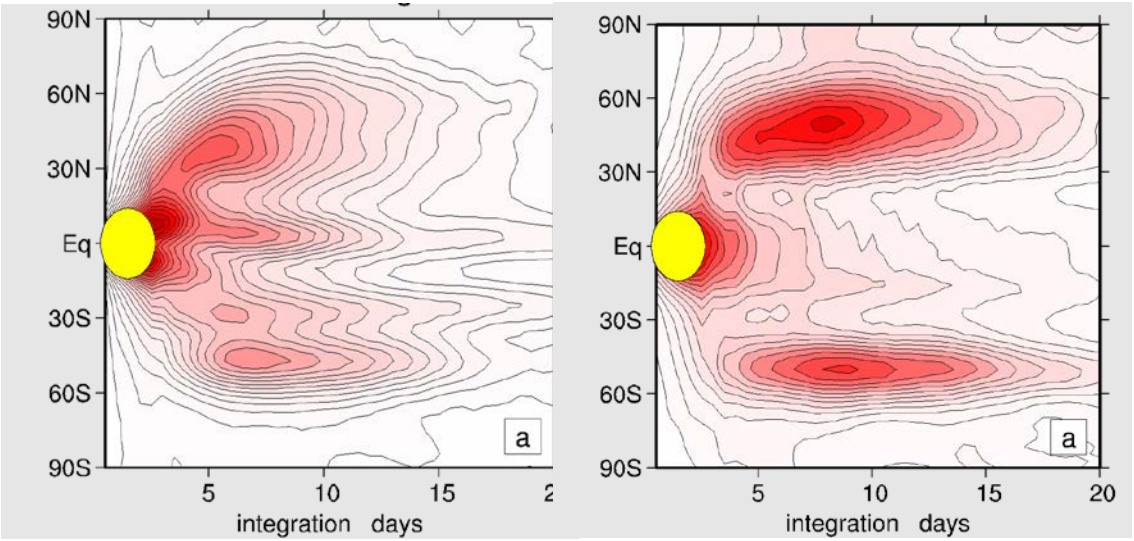
Branstator, G. (2014). Long-lived response of the midlatitude circulation and storm tracks to pulses of tropical heating. Journal of Climate, 27(23), 8809-8826.

Ensemble mean v300 response in CAM3 to a 2-day pulse of heat



RMS response of ensemble mean to 2-day pulses as a function of time:

(a) v300 (b) SLP



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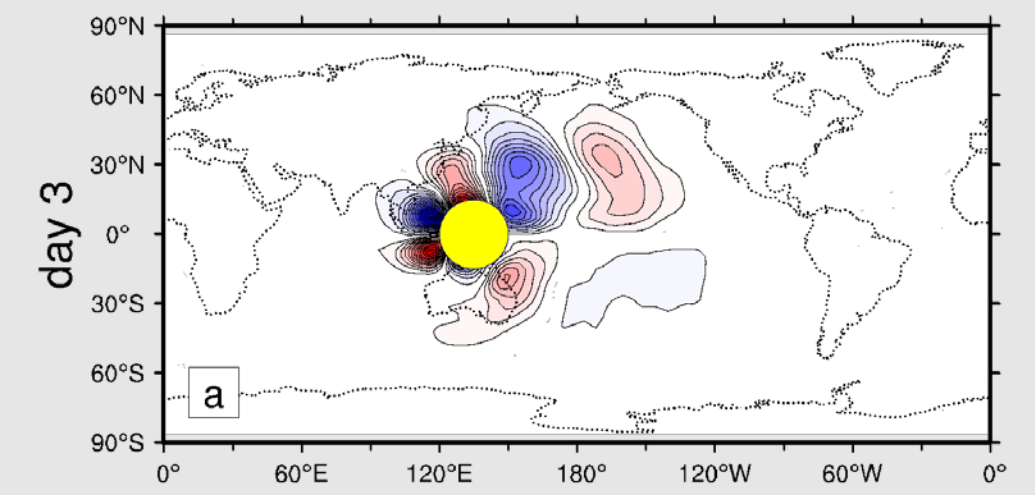

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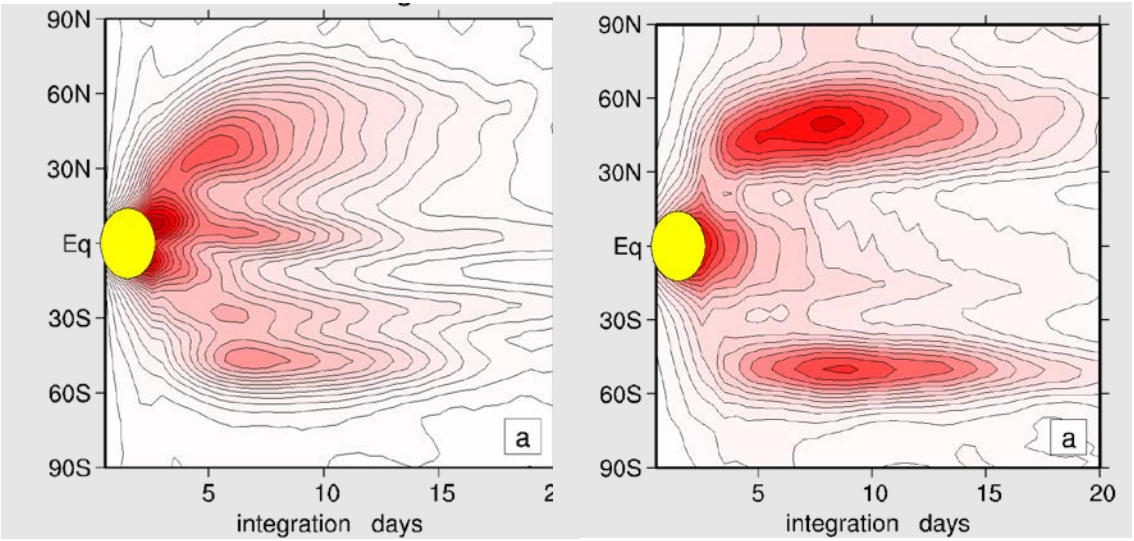

The precise extratropical response depends on season, frequency and location of tropical heating, and it is modulated by lower frequency forcing (e.g. ENSO and MJO)

Newman & Sardeshmukh 1998, Berbery & Nogues-Paegle 1993; Hsu 1996; Liu, Li, Wang, Deng, & Zhang 2016; Roundy, MacRitchie, Asuma, & Melino, 2010

Do extra-tropical forecasts draw skill from the tropics?

Relaxation types of experiments* have shown that a reduction of tropical forecast errors improves medium to extended range skill scores particularly over the North Pacific, North America, and the North Atlantic.

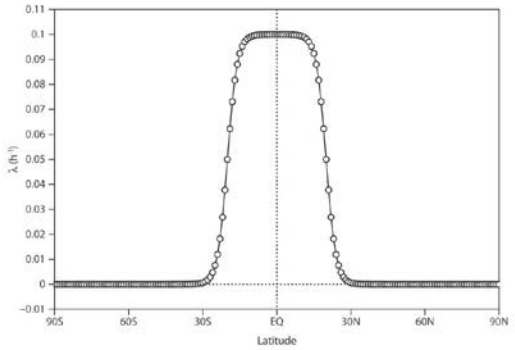

FIG. 1. Latitudinal dependence of λ in Eq. 1 (h^{-1}) for the tropical relaxation experiment (TROP/0.1).

$$-\boldsymbol{\lambda}(x - xa)$$

model state

analysis

[*Haseler 1982, Klinker 1990, Ferranti et al 1990, Jung et al. 2010a, Hansen et al. 2016, *Figures from Jung, T. et al., 2010: Diagnosing the Origin of Extended-Range Forecast Errors. Mon. Wea. Rev.]*

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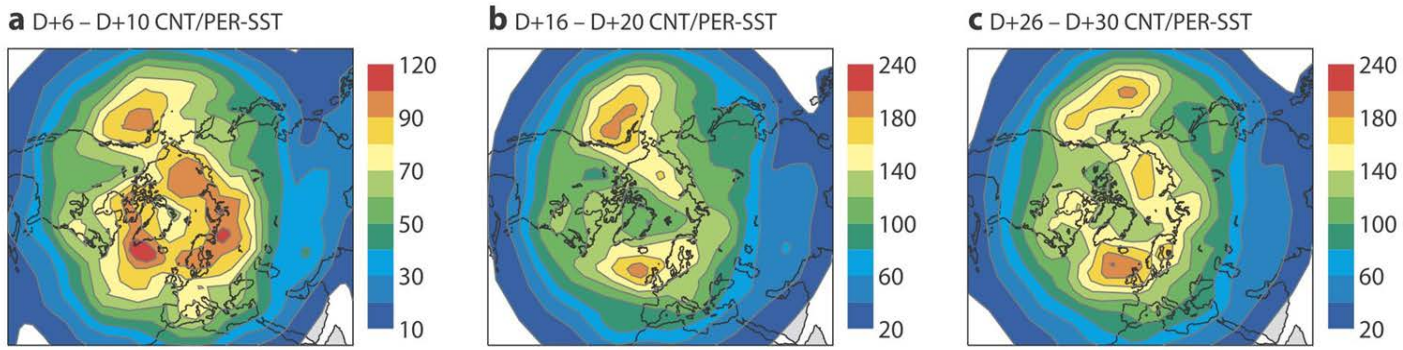

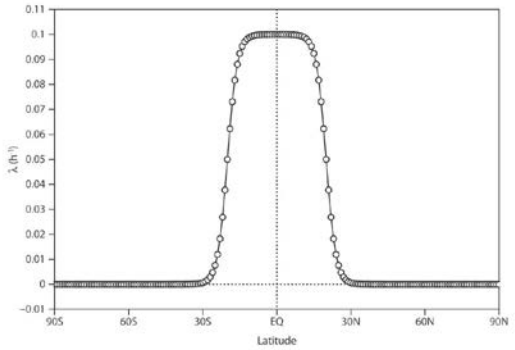

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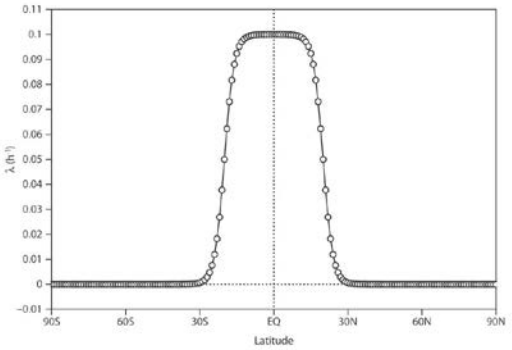

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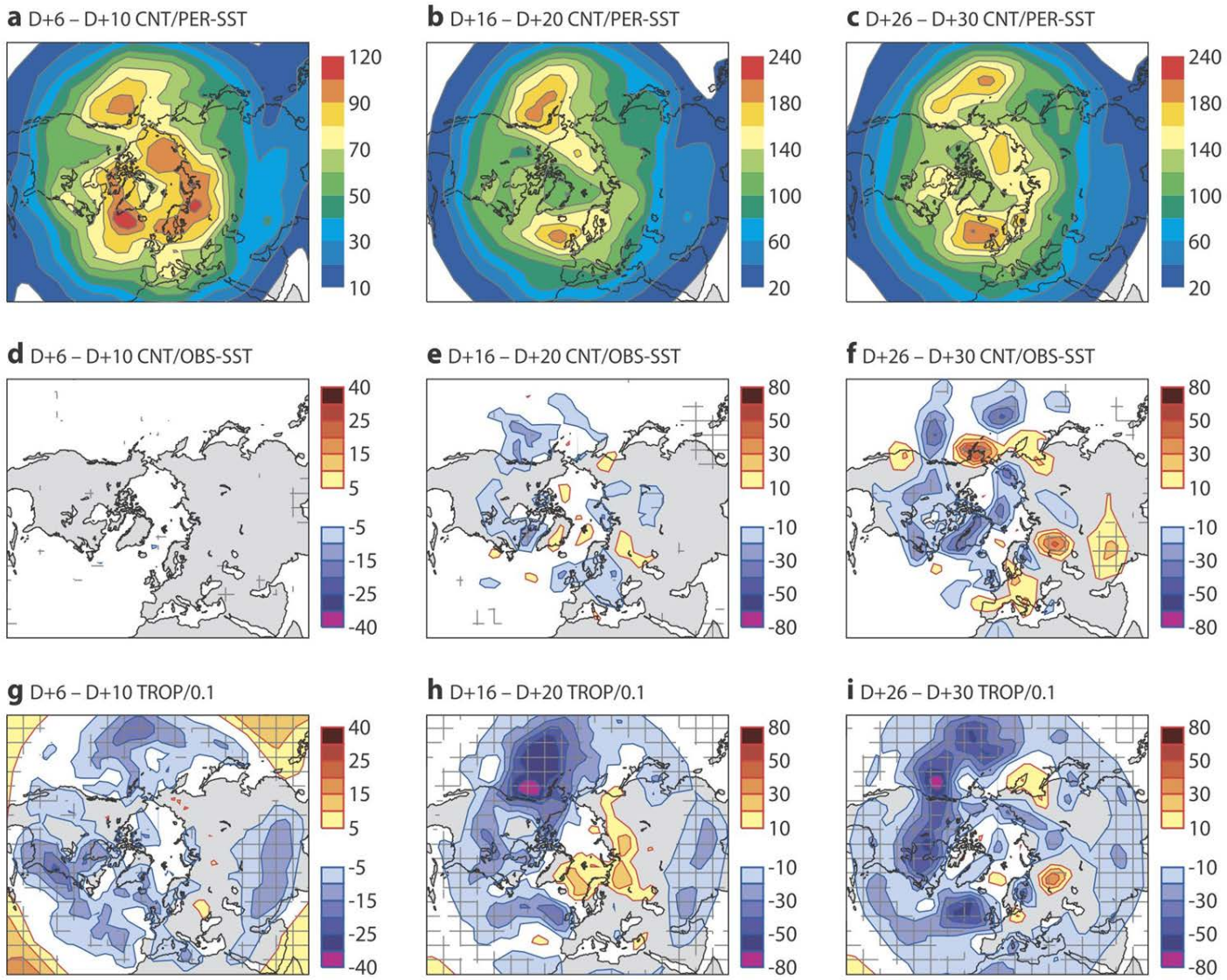
$$-\boldsymbol{\lambda}(x - xa)$$

model state analysis

Blue shading indicates regions where forecast errors are reduced when nudging SST to observations (middle row) and nudging the tropics to analysis (bottom row)



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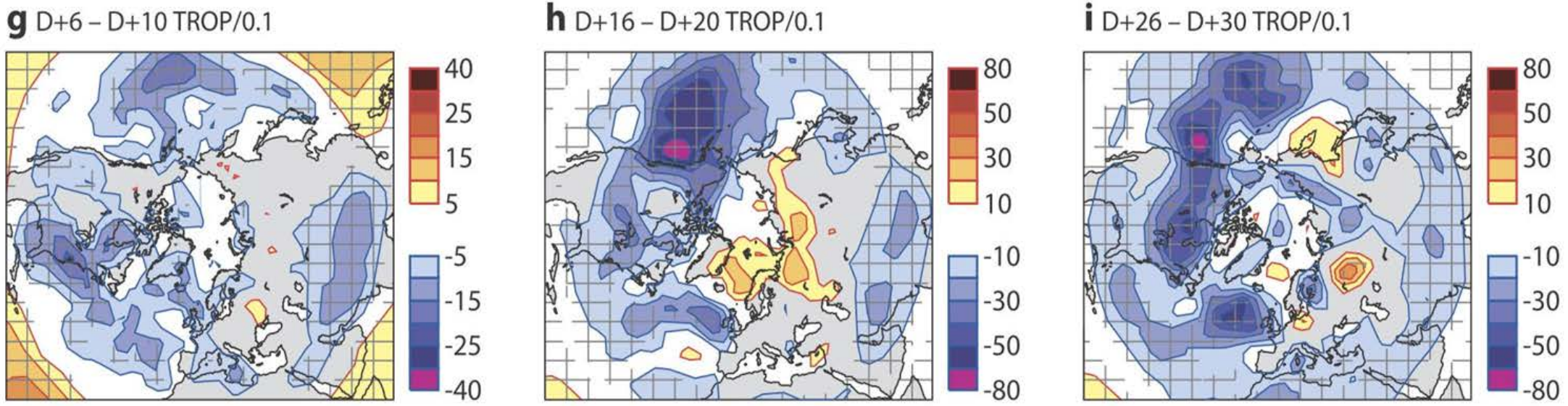
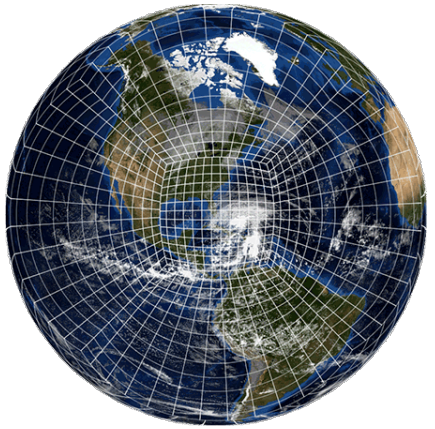


- Does tropical nudging applied to the UFS produce consistent results with previous studies?
- Do improvements in remote skill seen on dynamical variables extend to precipitation subseasonal predictions?
- How much of the change in remote skill depends on tropical model errors versus on the initial state?

How much of this is achievable (e.g. via model improvement) versus how much is not (e.g. intrinsic predictability barriers) ?

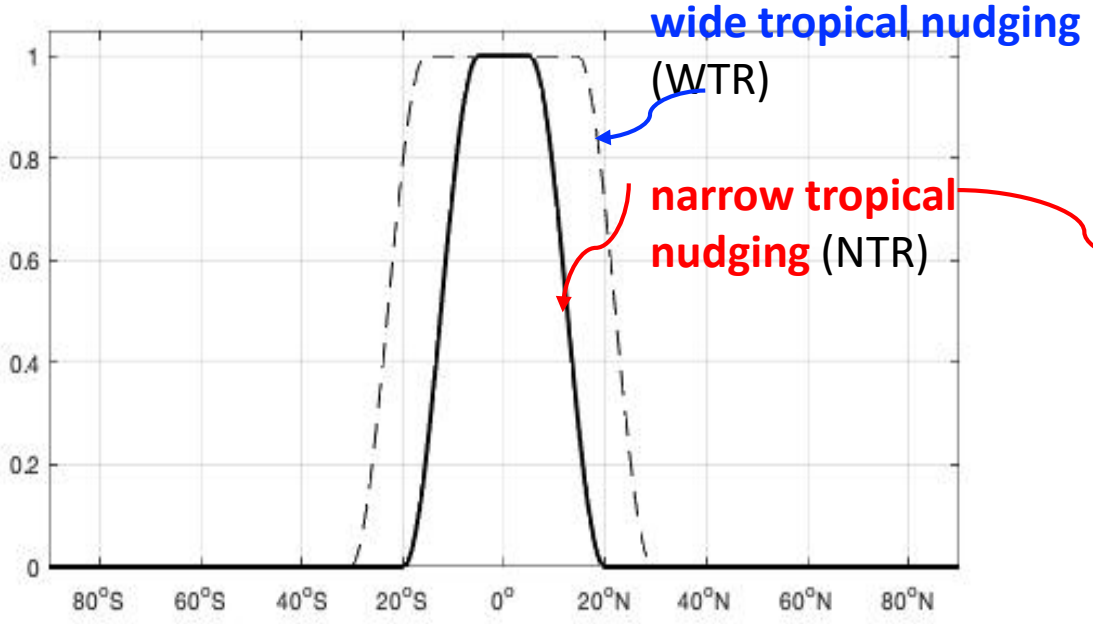
Relaxation experiments in the UFS

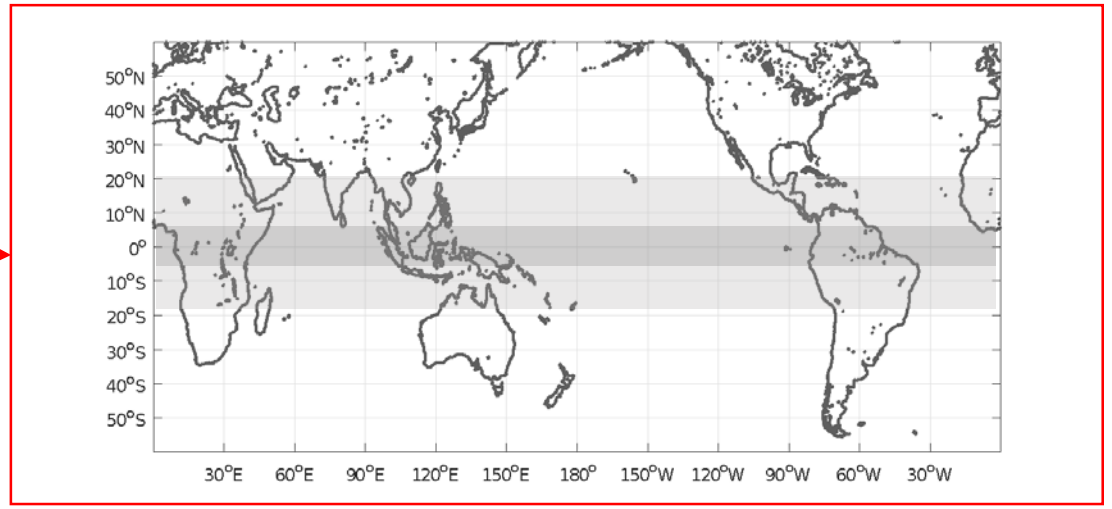


Summary of the implementation

- ~GFS v15.1.1 (FV3), prescribed SSTs;
- We use incremental analysis update or “replay”, as opposed to adding Newtonian terms to the prognostic equations;
- Experiments are run on Gaea;
- C128 (~1deg) resolution;
- We relax variables to ERAi reanalysis;
- If ``all variables” are nudged, it means that zonal and meridional winds, temperature, specific humidity and pressure thickness between model layers are nudged to ERAi.

Relaxation experiments in the UFS: setup



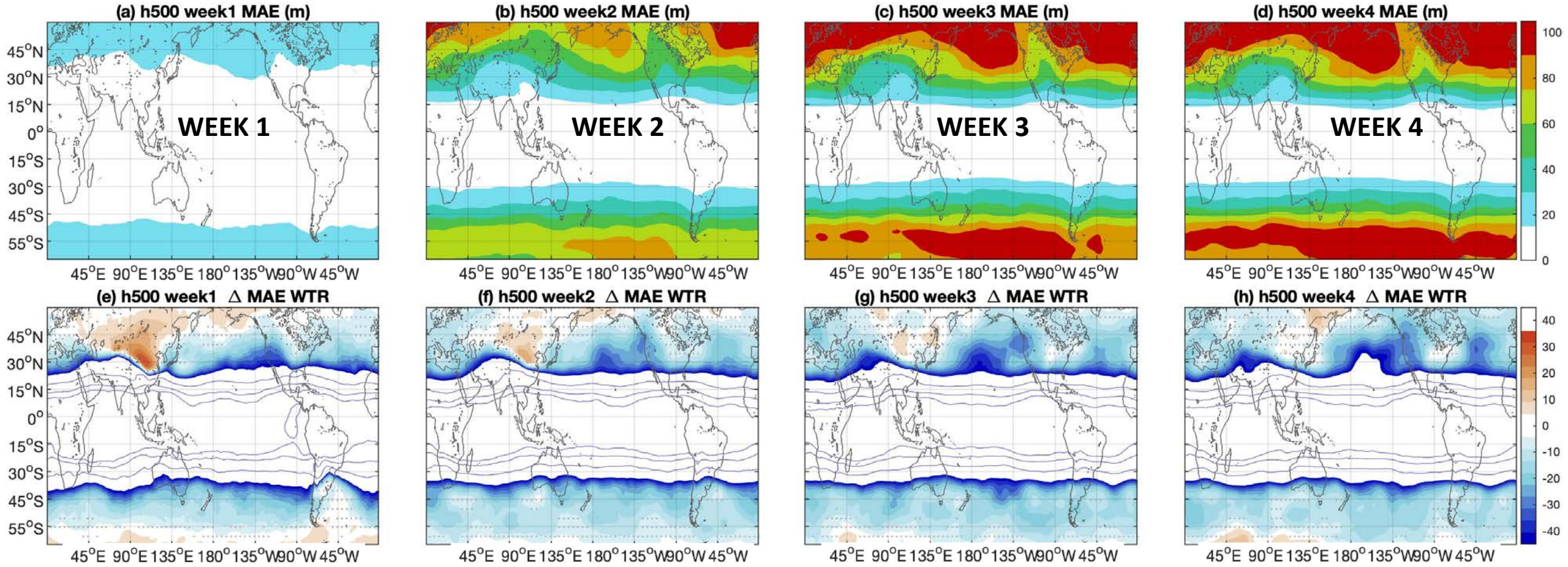


1) Free reforecast (CNT)
2) **Wide Tropical Nudging (WTR)** – all variables
3) **Wide Tropical Nudging (WTRuv) – u,v only**
4) **Narrow Tropical Nudging (NTR) – all variables**

- experiment period: Nov-Mar 1999-2018
- initializations every 5 days (620 reforecasts)
- Forecast range: 30 days

Does tropical nudging reduce remote errors?

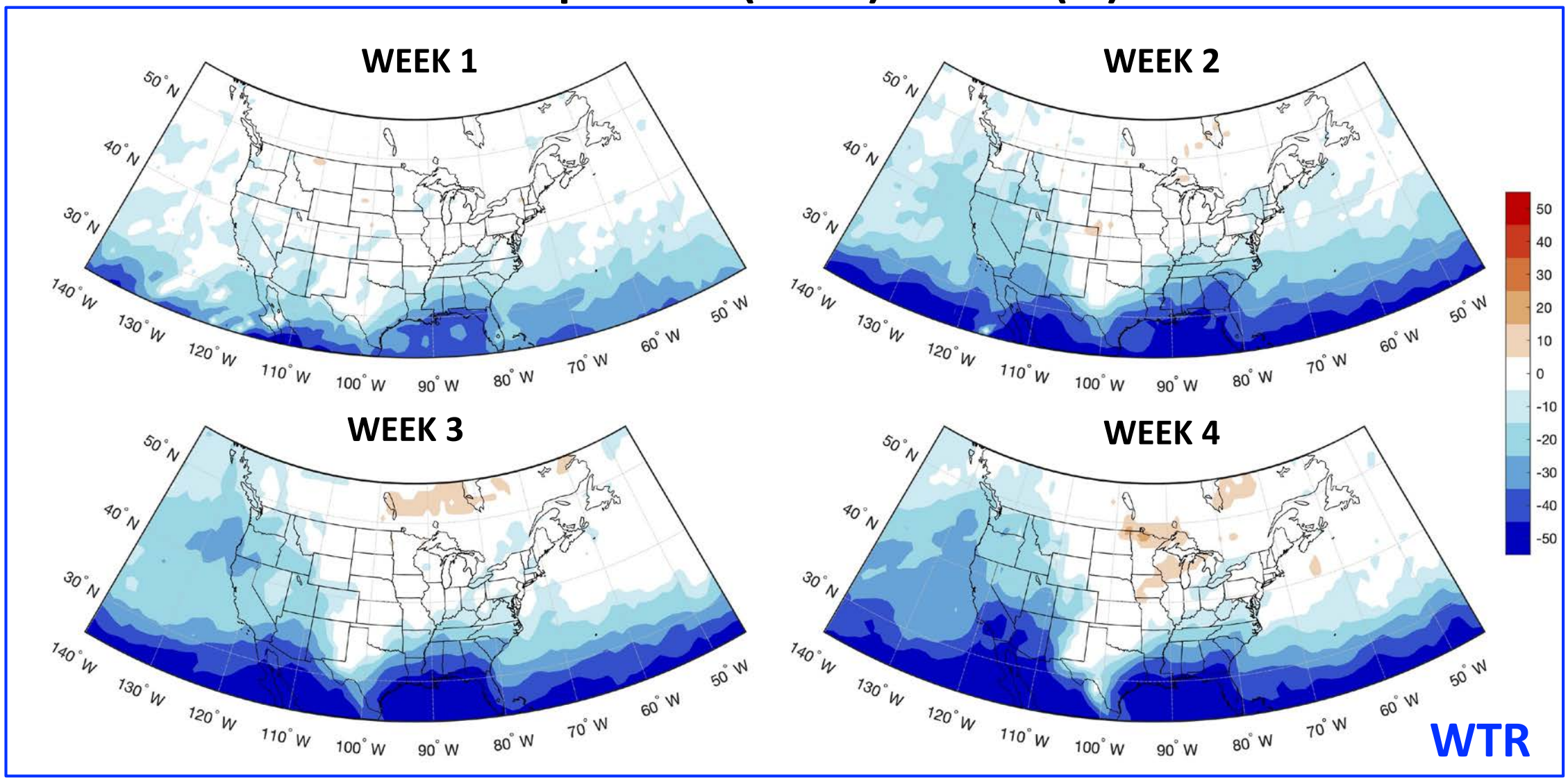
500hPa Geopotential height mean absolute error (MAE)



Blue shading denotes regions where Z500 MAE is reduced comparing WTR to CNT MAE

Does tropical nudging reduce remote errors?

Precipitation (PRCP) △MAE (%)



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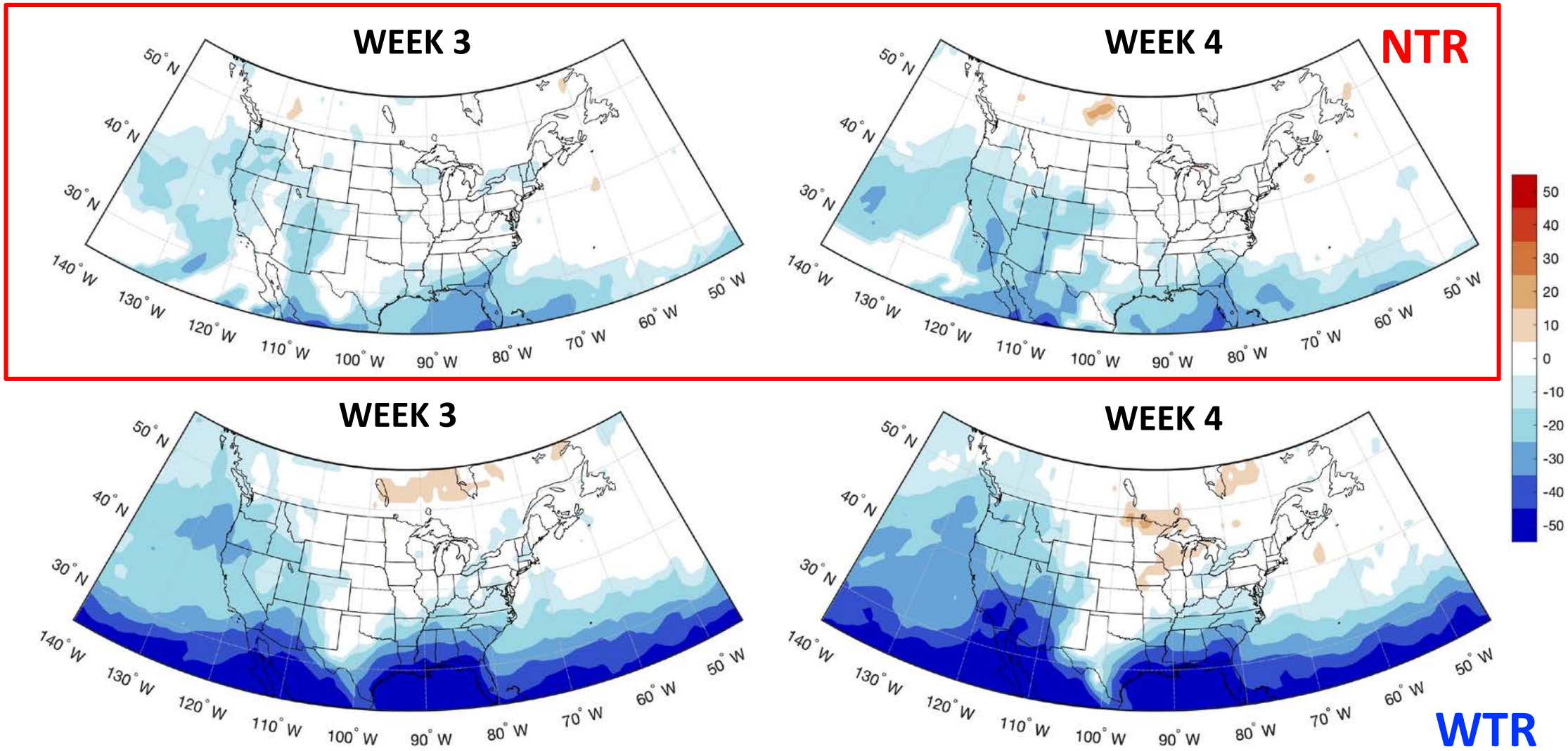
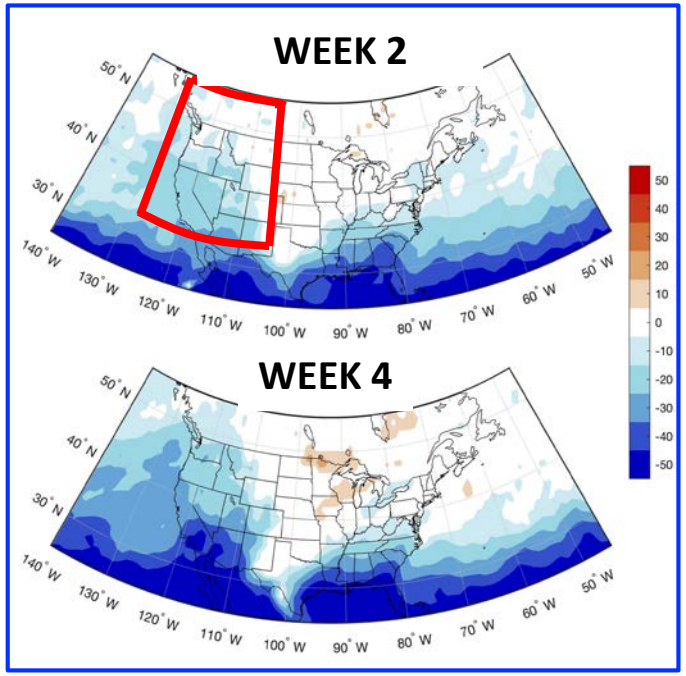
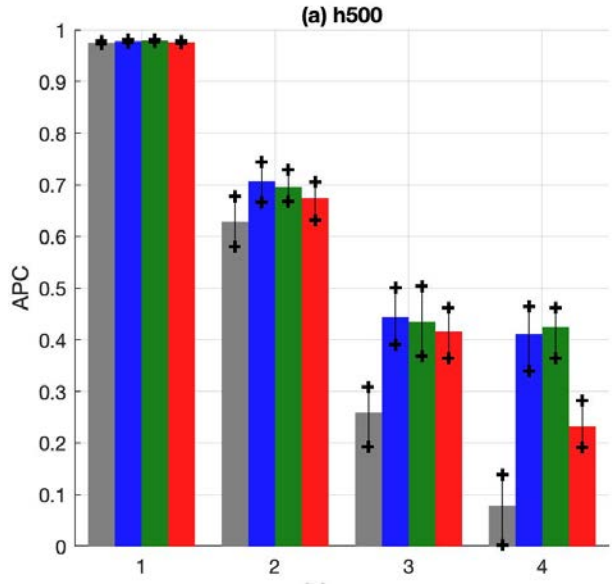


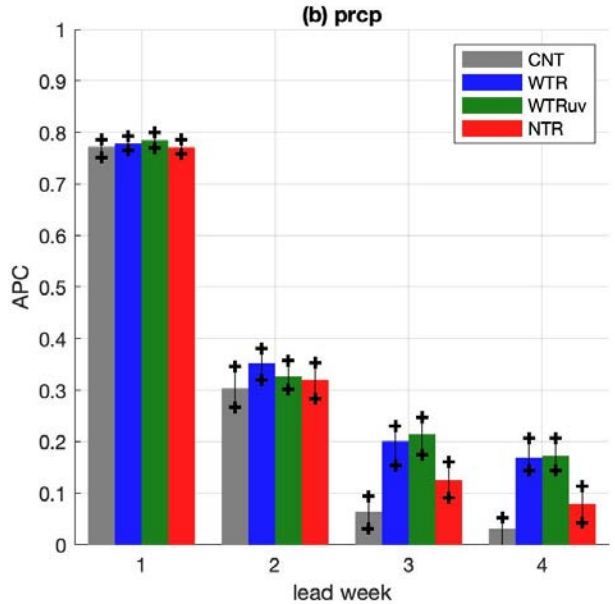
Western USA anomaly pattern correlation (APC)

Precipitation (PRCP) △MAE (%)



APC over "red" box





Tropical nudged reforecasts also lead to improved 500hPa Geopotential and precipitation anomalies, particularly at weeks 3-4

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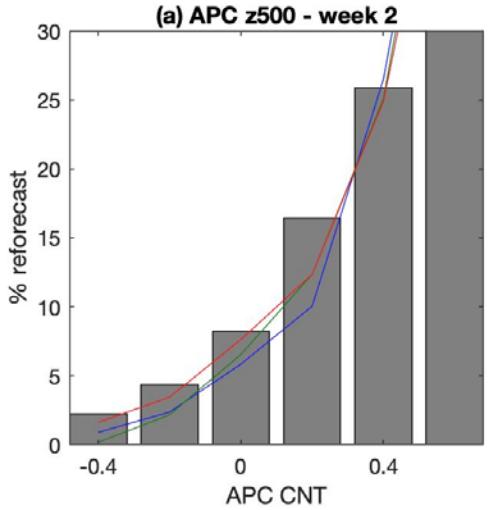
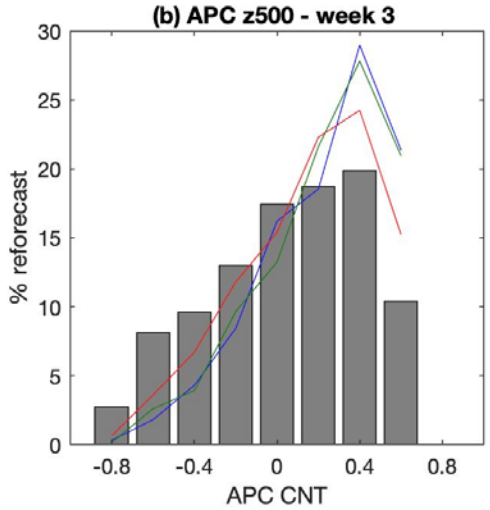
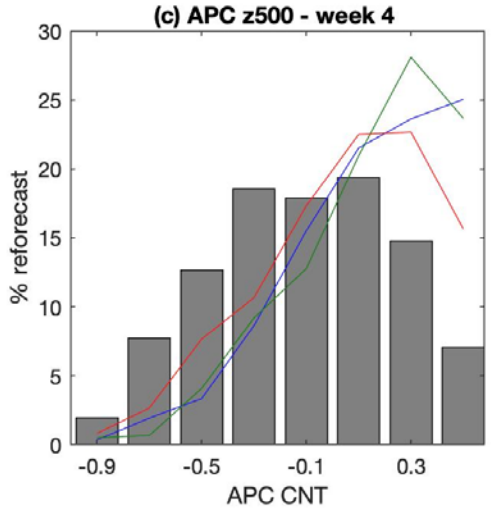
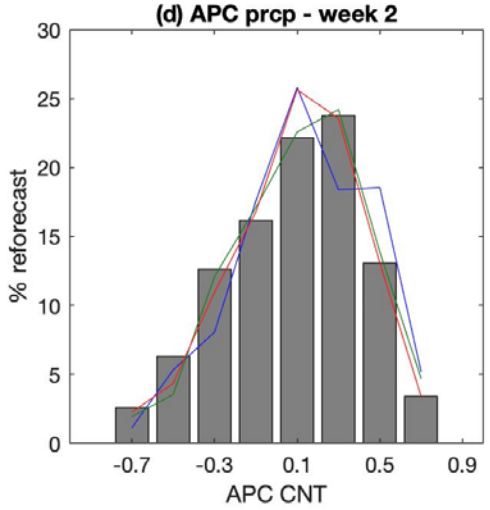
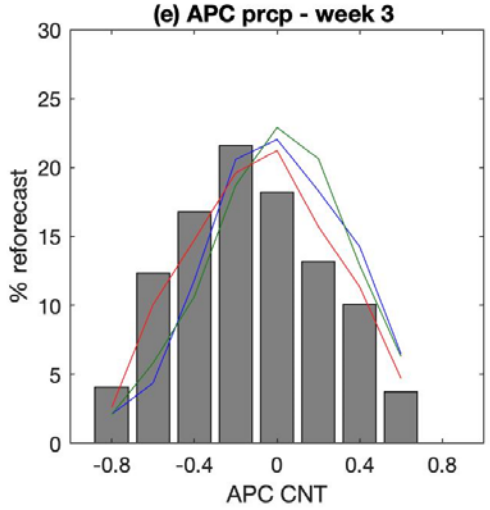
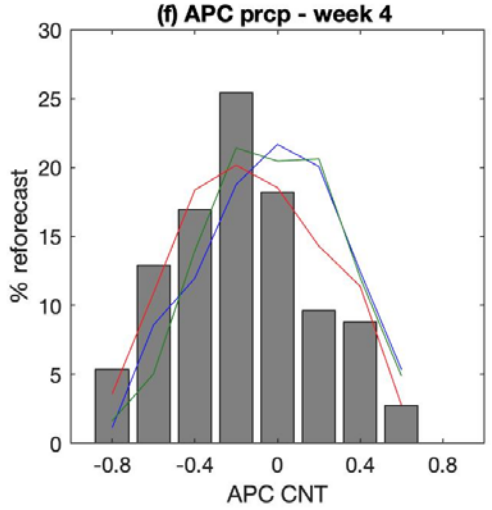






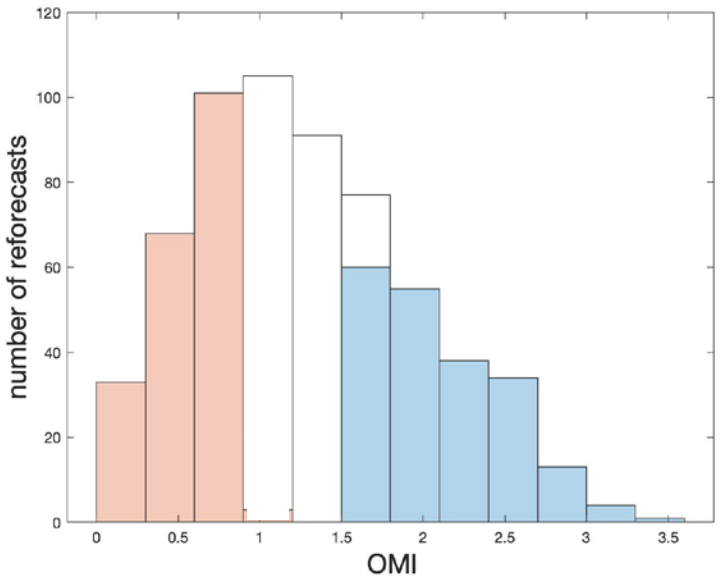






APC histograms become more skewed when tropical nudging is applied.

How does the MJO influence tropical to extratropical forecast errors?



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- UFS Week 2-4 precipitation skill over the midlatitudes is sensitive to initial MJO state

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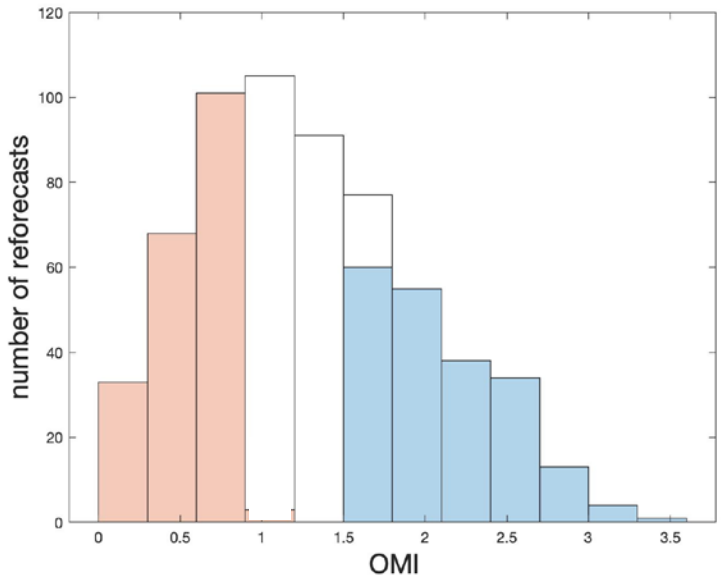

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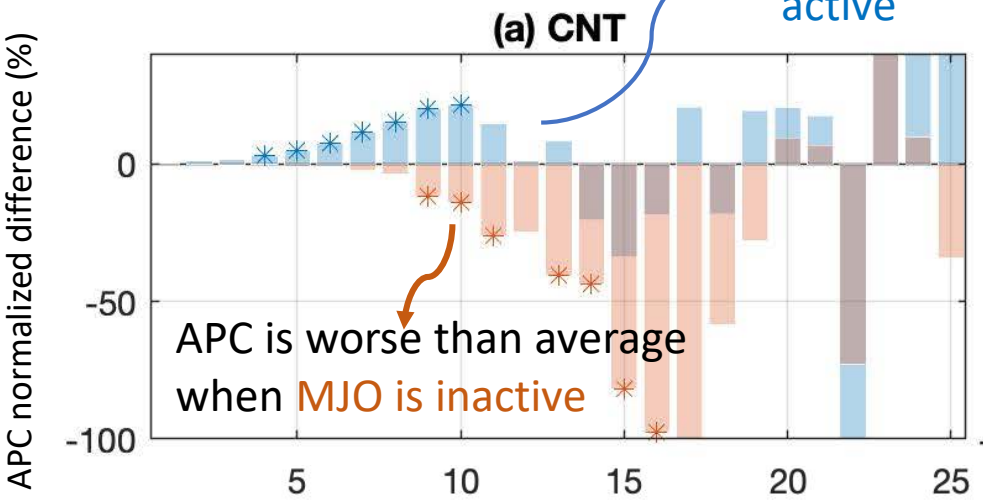

MJO Conditional skill:

100* (APC(OMI>1.5)/APC-1)

100* (APC(OMI<0.8)/APC-1)

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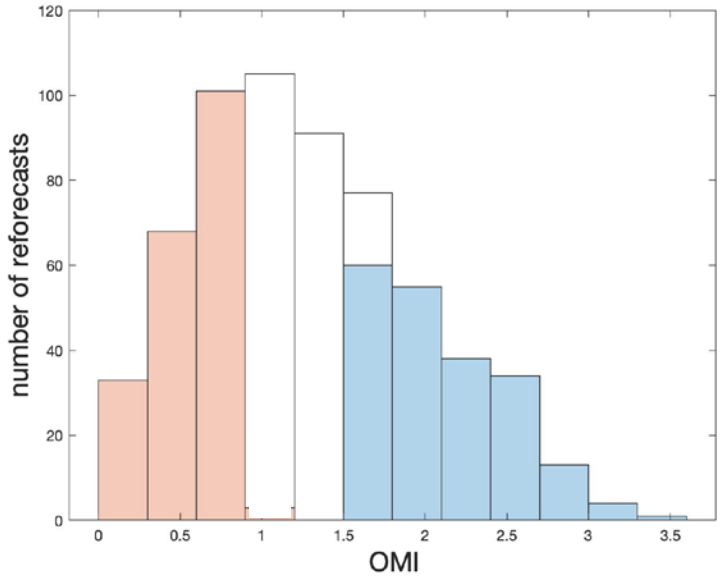

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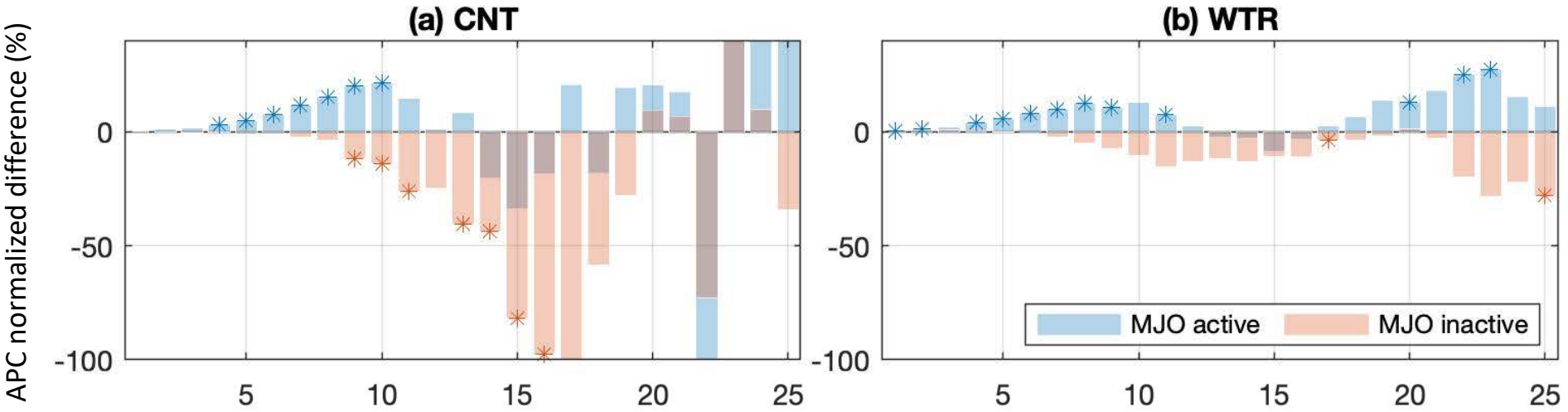
- **Improved Week 3-4 precipitation APC over the Western US**



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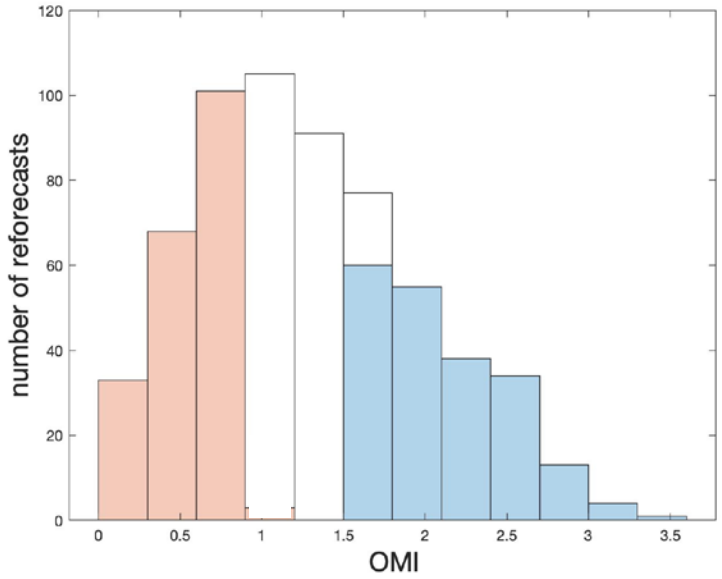

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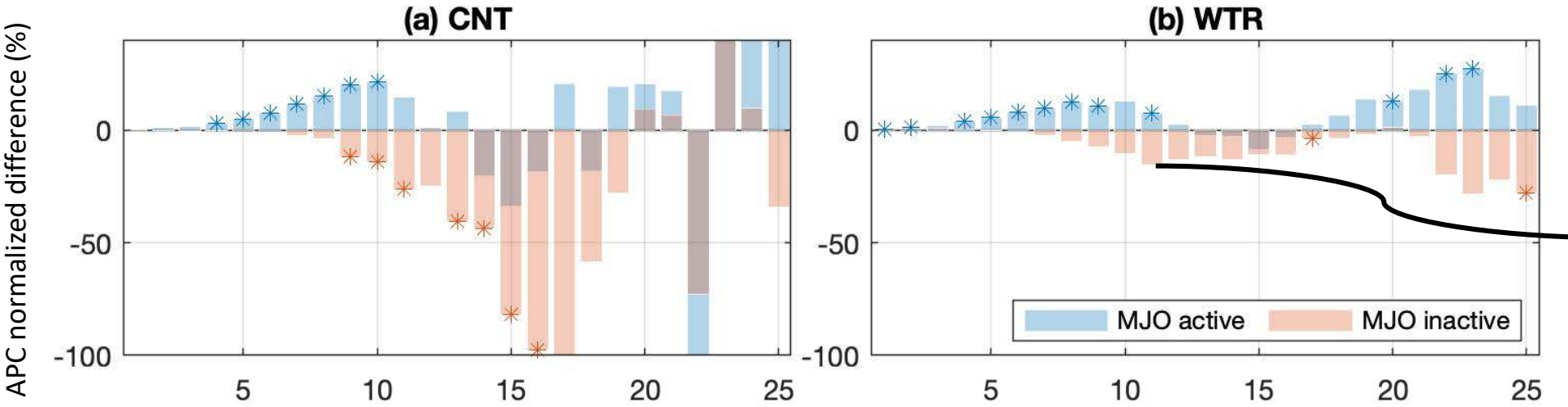


Tropical synoptic modes of variability (e.g. Kelvin waves, Easterly waves) might help week 2 remote skill when the MJO is weak.

Summary

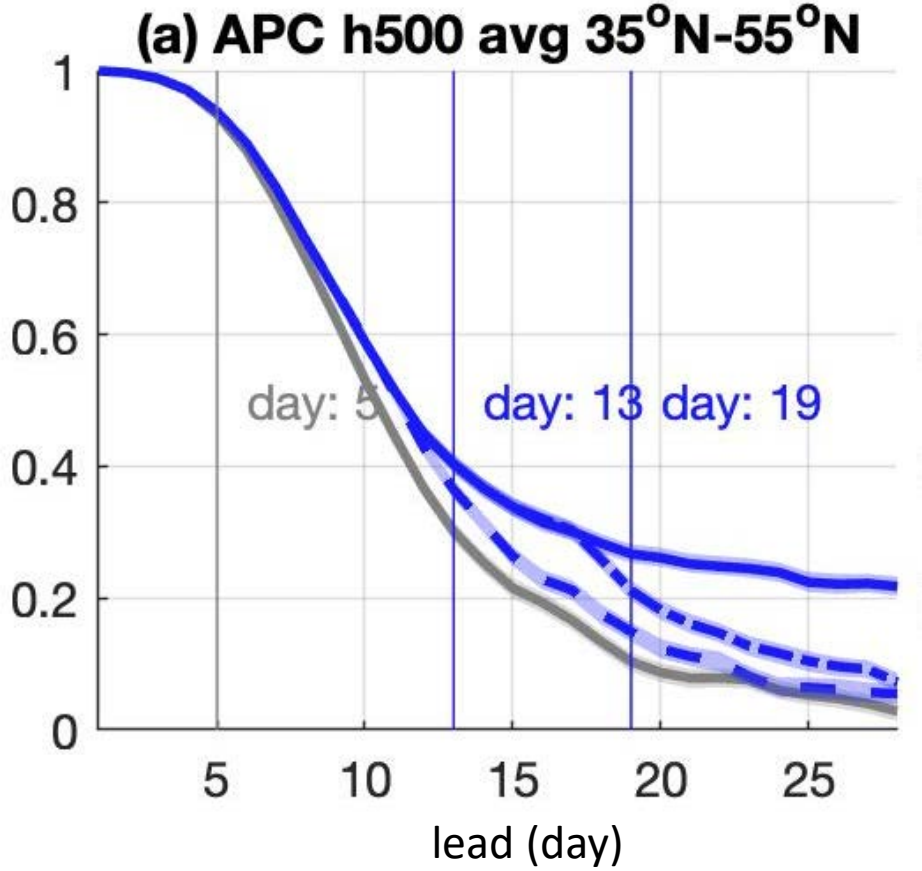
- UFS tropical nudging implies that week 2-4 Western USA **precipitation predictions** tend to be improved when tropical forecast errors are reduced;

- We used tropical nudged forecasts to show that UFS week 2-4 Western USA **precipitation predictions** is modulated by how well the MJO is represented.

- UFS tropical nudging experiments also indicate a ~5 days lag between tropics and extratropics. That is, improved tropical predictions on ~week 1, leads to improved predictions on ~week 2 and so on.

How much skill comes from instantaneous versus lagged nudging?

1. **WTR wk1: tropical nudging is applied only on the first 7 days of the 30 day forecast cycle**
2. **WTR wk2: similar to WTR wk1, except that tropical nudging is applied to the first 14 days.**



WTR
WTR wk1
WTR wk2

It takes about 5 days from "switching off" tropical nudging to see a change in remote skill