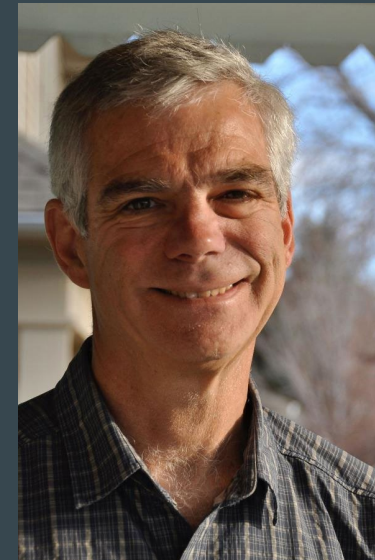


Assessing the Influence of UFS Tropical Forecast Errors on Higher Latitude Predictions Using Nudging Experiments

Juliana Dias, Stefan Tulich, Maria Gehne and George Kiladis,



Outline

- 1. Overview of tropical to extratropical teleconnections on sub-seasonal timescales.**
2. Relaxation experiments as a tool for diagnostics of how tropical forecast errors impact sub-seasonal midlatitude forecast errors.
 - 2.1 Mean Absolute Error (MAE)
 - 2.2 NE Pacific/Western USA anomaly pattern correlation (APC)

Tropical-to-extratropical teleconnections

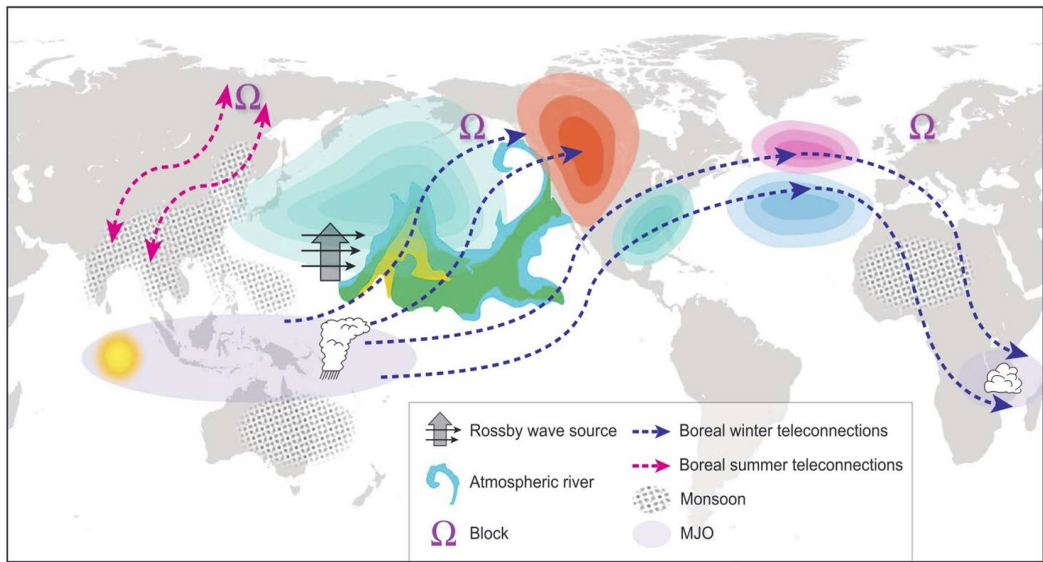


Figure: Schematic of tropical-NH interactions from Stan, C. et al. (2017). Review of tropical-extratropical teleconnections on intraseasonal time scales. *Rev. of Geoph.*, 55, 902–937.

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

Rossby wave source

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

divergent
horizontal
flow

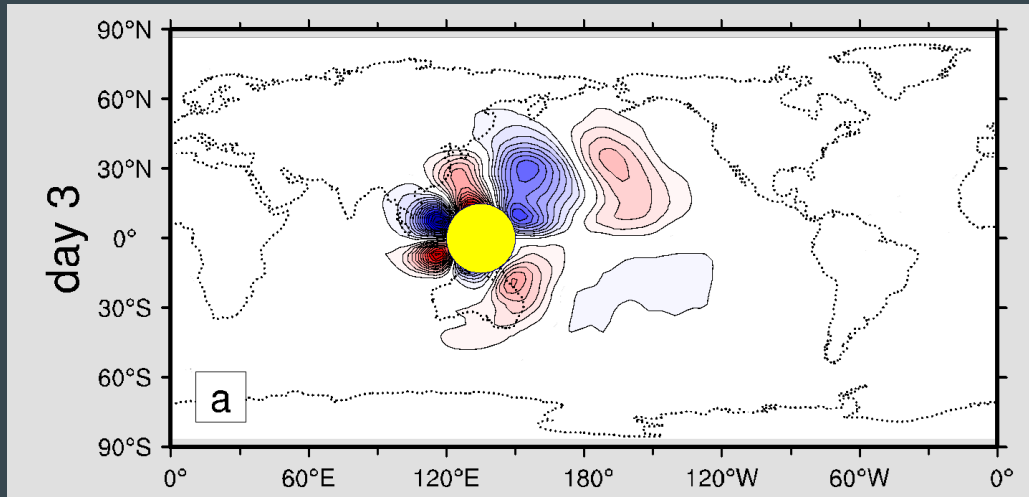
vortex
stretching

planetary and
relative vorticity
advection

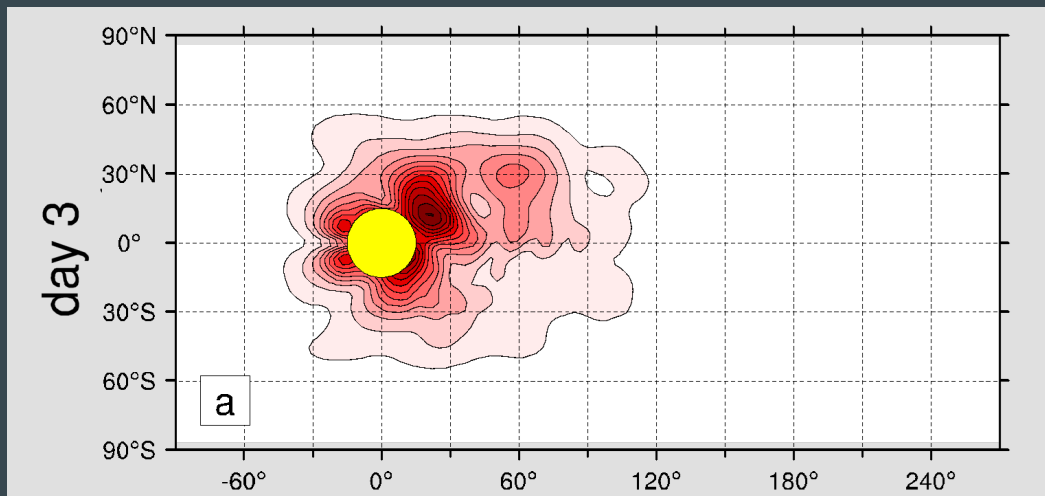
Tropical-to-extratropical teleconnections

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

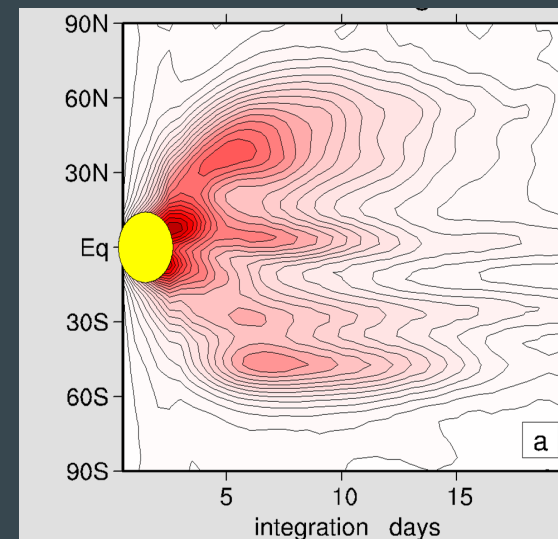


RMS v300 response in CAM3 to a 2-day pulse of heat

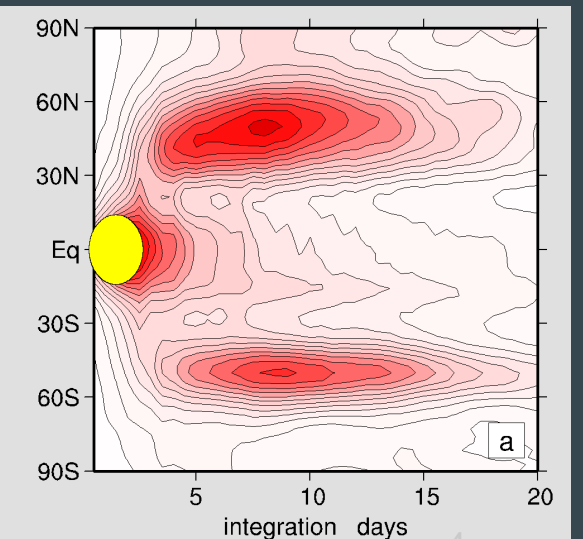


RMS response of ensemble mean to 2-day pulses as a function of time:

(a) v300



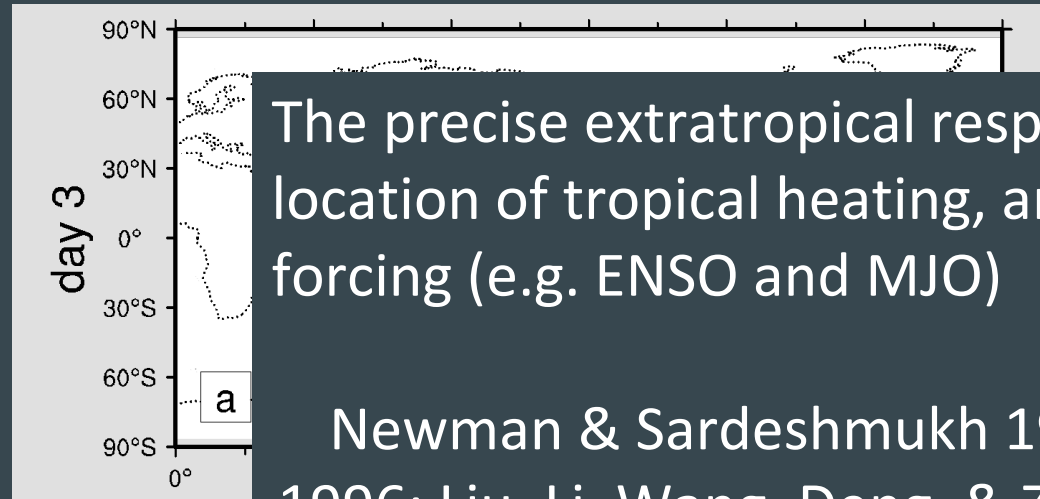
(b) SLP



Tropical to extratropical teleconnections

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.

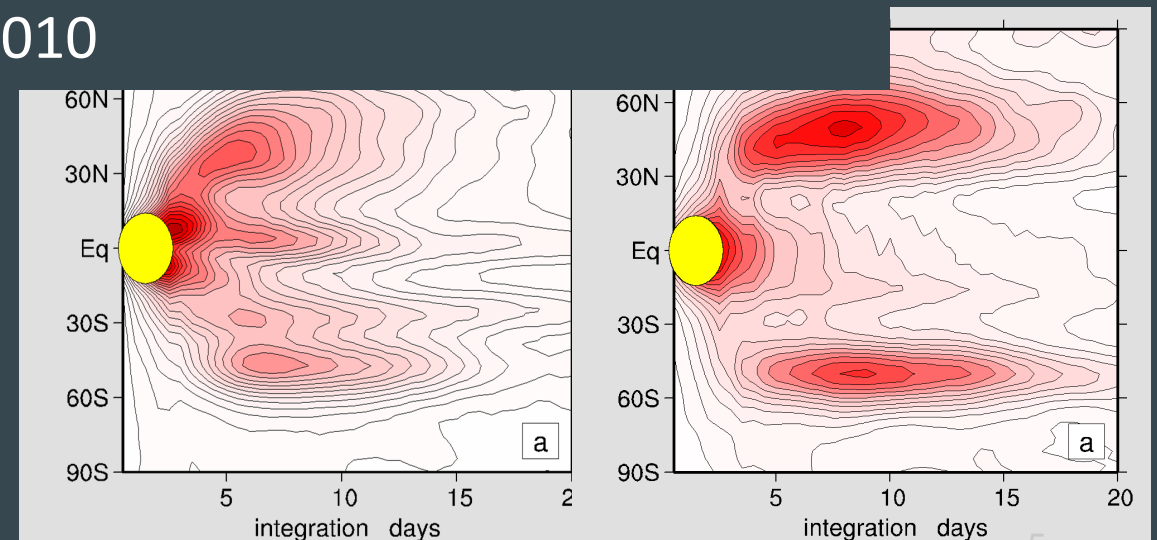
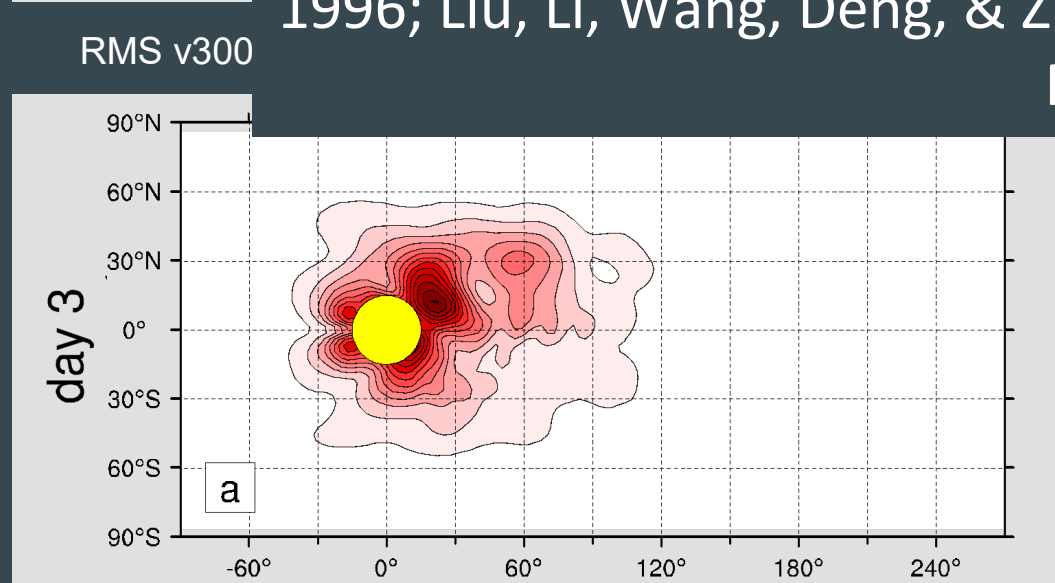
Ensemble mean v300 response in CAM3 to a 2-day pulse of heat



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 & Nogués-Paegle 1993; Hsu 1996; Liu, Li, Wang, Deng, & Zhang 2016; Roundy, MacRitchie, Asuma, & Melino, 2010

function of time:

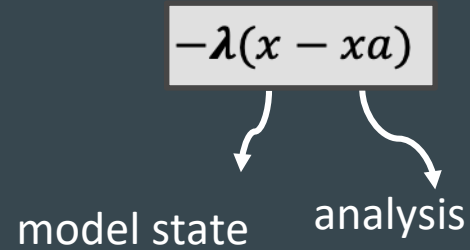
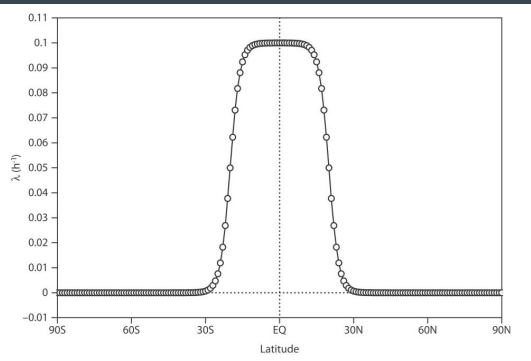
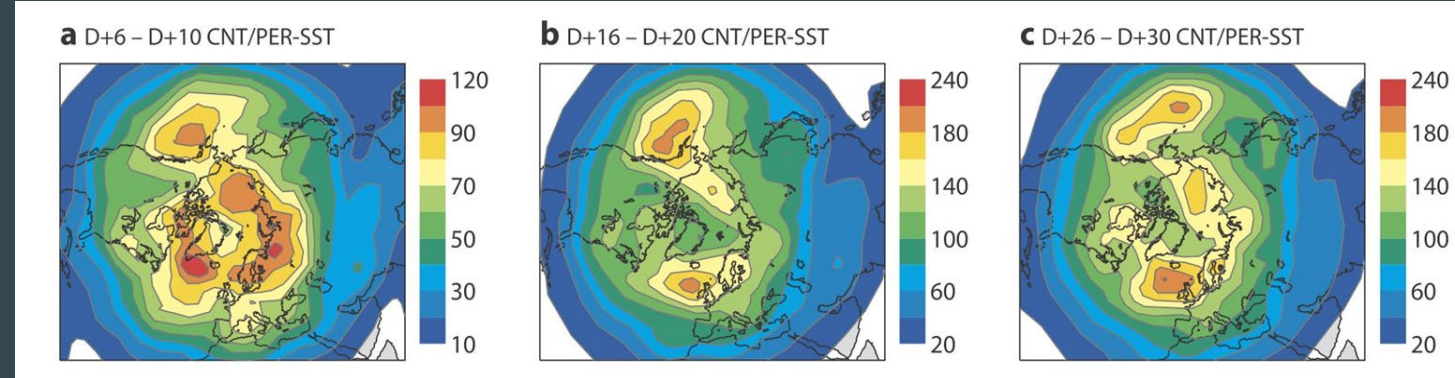


Outline

1. Overview of tropical to extratropical teleconnections on sub-seasonal timescales.
- 2. Relaxation experiments as a tool for diagnostics of how tropical forecast errors impact sub-seasonal midlatitude forecast errors.**

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.

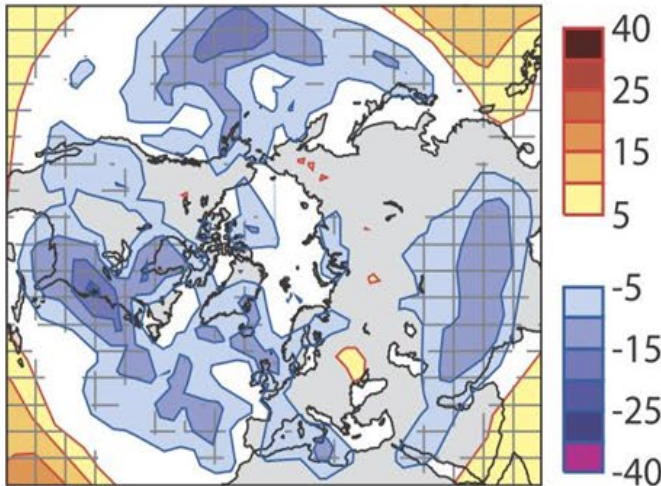


Blue shading indicates regions where forecast errors are reduced when nudging SST to observations (middle row) and nudging the tropics to analysis (bottom row)

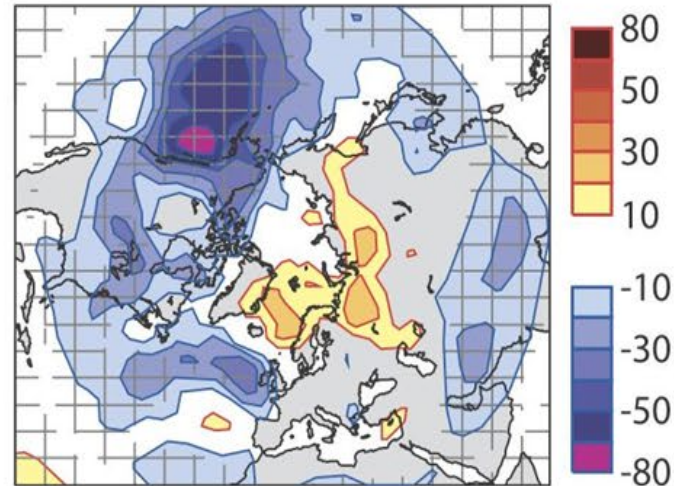
[*Haseler 1982, Klinker 1990, Ferranti et al 1990, Jung et al. 2010a, Hansen et al. 2016, *Figures from Jung, T. et al., 2010: Diagnosing the Origin of Extended-Range Forecast Errors. Mon. Wea. Rev.*]

Do extra-tropical forecasts draw skill from the tropics?

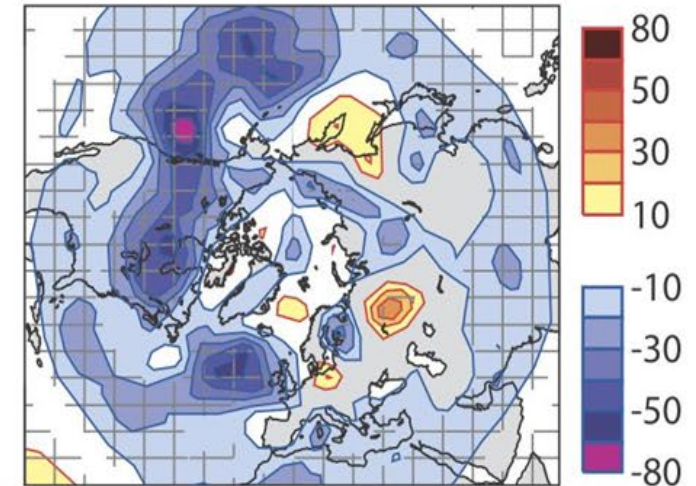
g D+6 – D+10 TROP/0.1



h D+16 – D+20 TROP/0.1



i D+26 – D+30 TROP/0.1

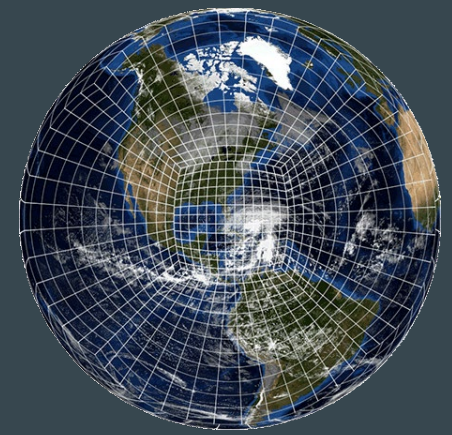


- Is there a similar imprint on surface variables (precipitation and temperature)?
- What is the role of the subtropics?
- What is the role of tropical mean state versus variability?
- Is the error reduction sensitive model dependent, to model resolution? Or to what (re)analysis is used?
- How are the error amplitude and patterns modulated by ENSO and MJO?

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

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

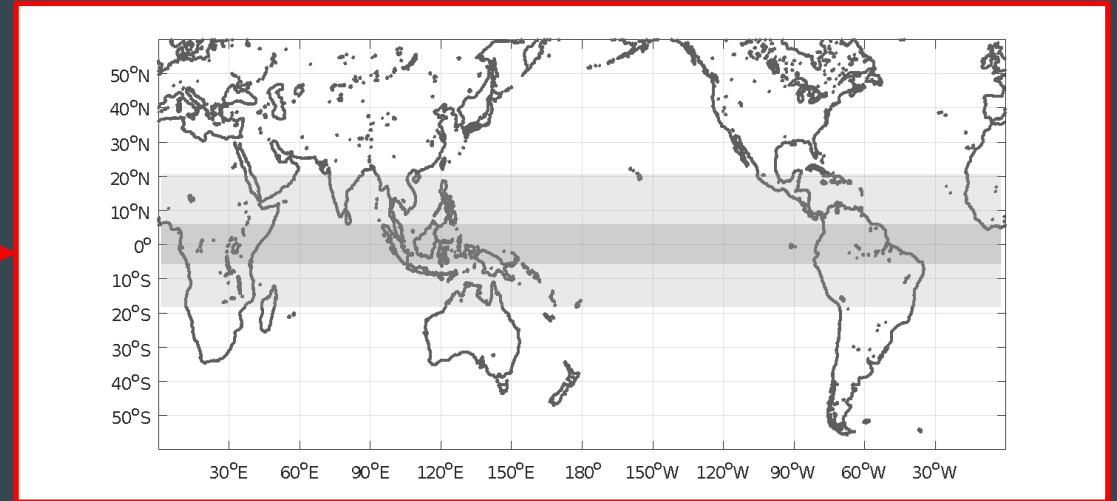
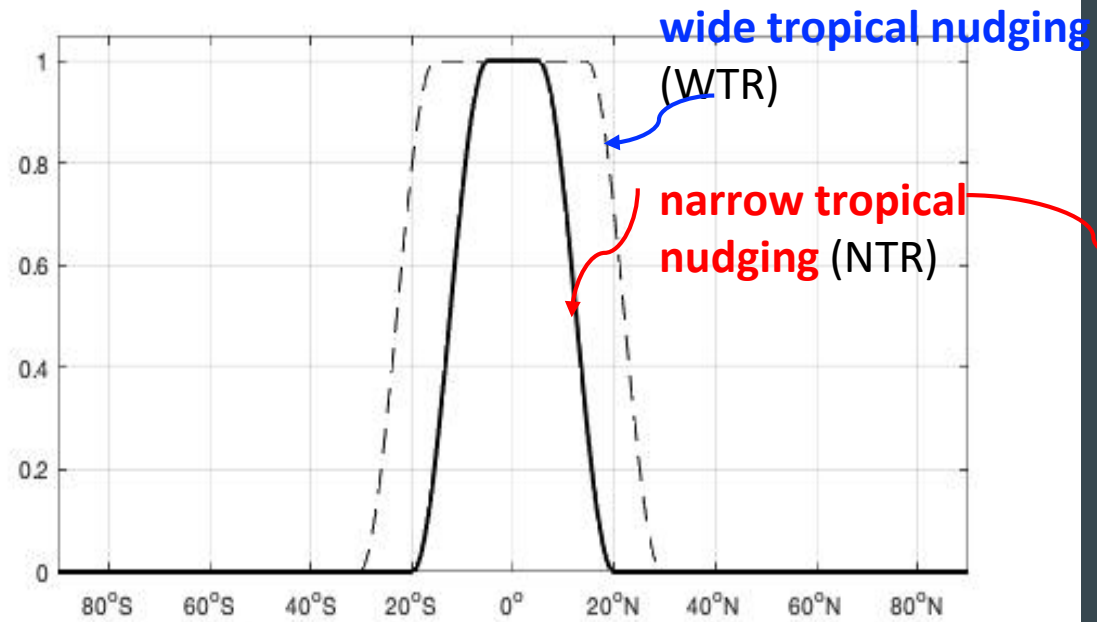
Relaxation experiments in the UFS



Summary of the implementation

- ~GFS v15 (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;
- Initialization every 5 days from Nov,1-Mar,31, out to Week 4;
- 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



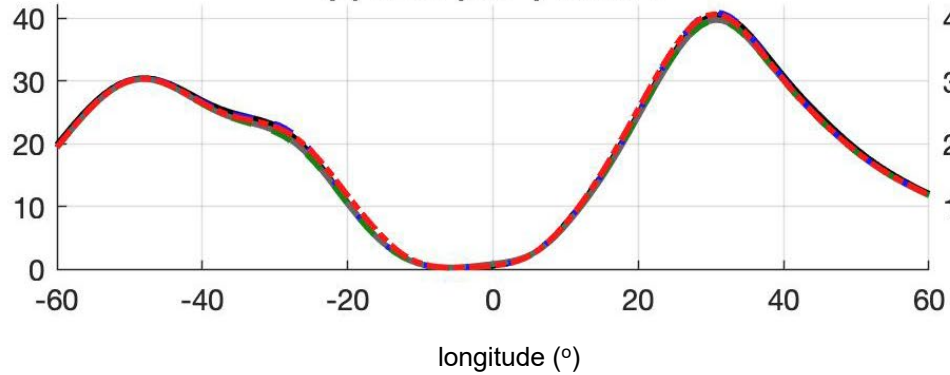
- 1) Free reforecast (CNT)
- 2) Wide Tropical Nudging (WTR) – all variables
- 3) Wide Tropical Nudging (WTRuv) – u,v only
- 4) Narrow Tropical Nudging (NTR) – all variables

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

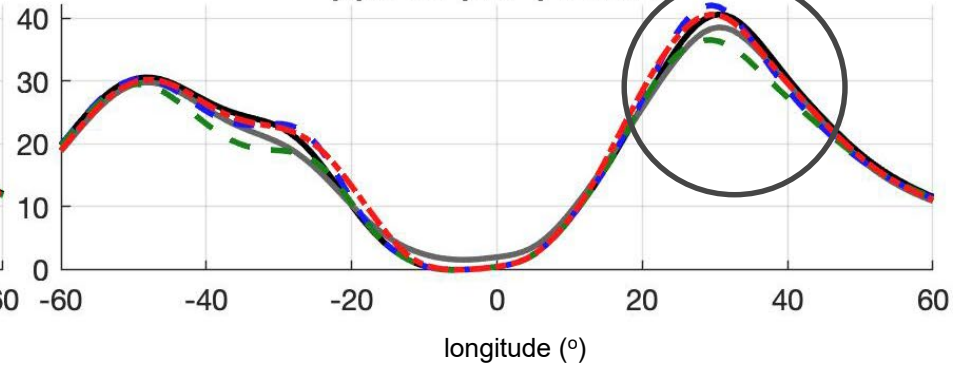
Tropical Nudging changes global model biases...

UFS zonal mean fields – week1 x week 4

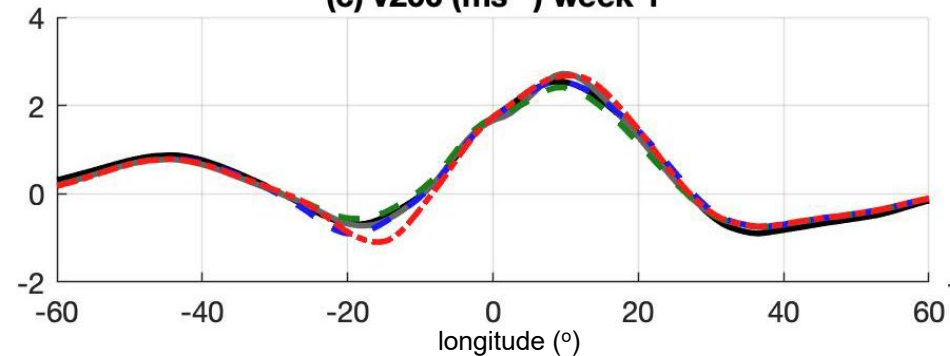
(a) u200 (ms^{-1}) week 1



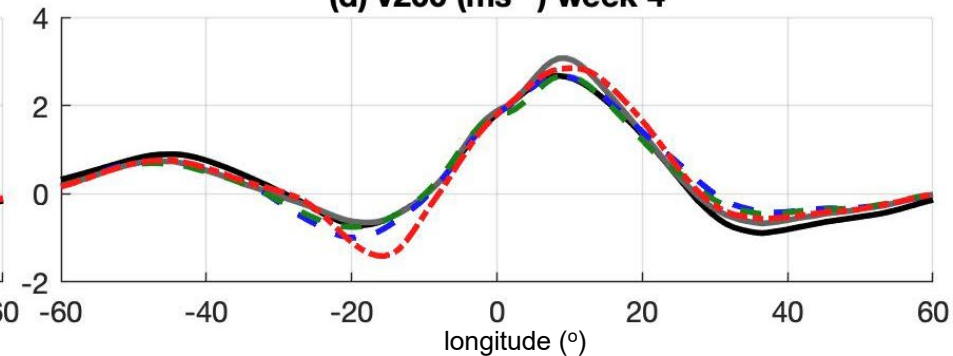
(b) u200 (ms^{-1}) week 4



(c) v200 (ms^{-1}) week 1



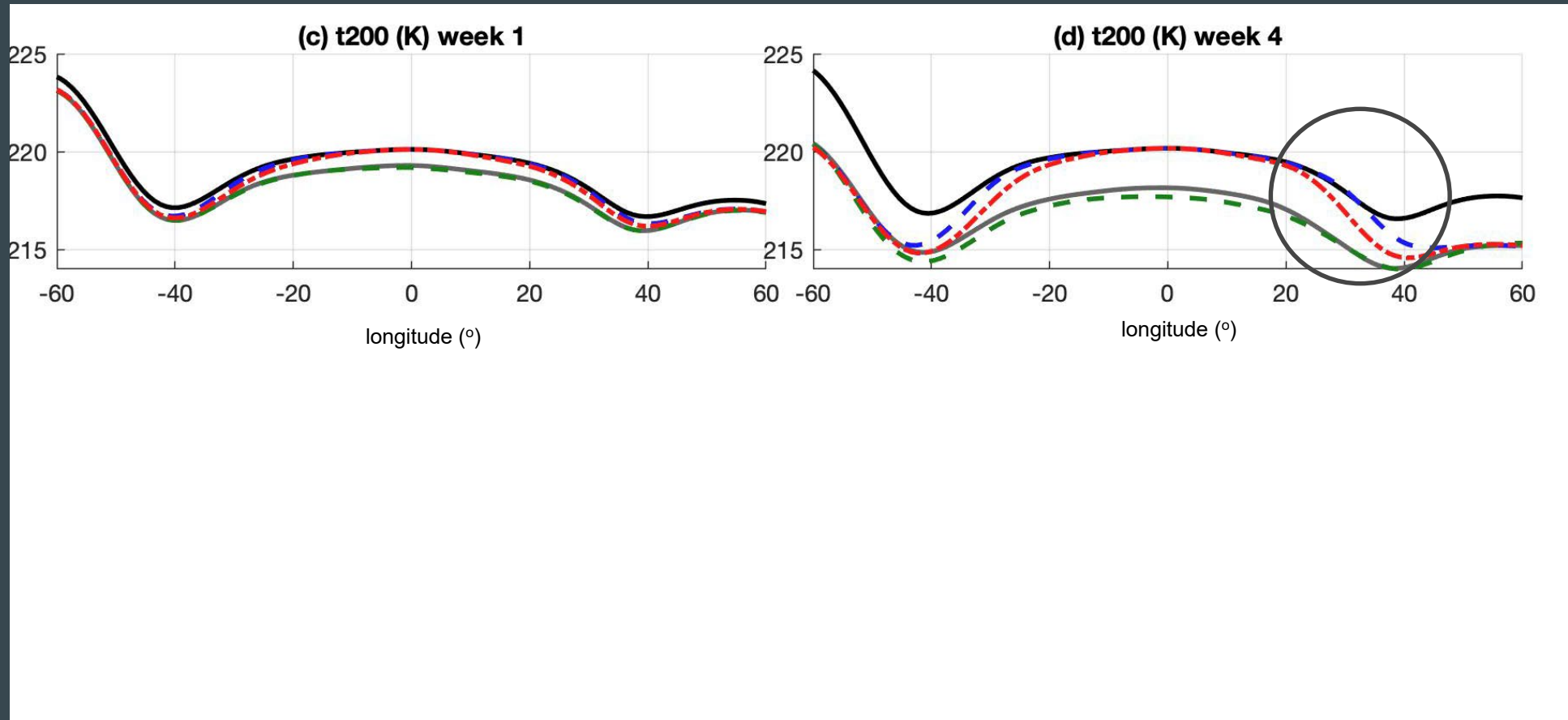
(d) v200 (ms^{-1}) week 4



— ERAI — CNT - - - WTR - - - WTRuv - - - NTR

Tropical Nudging changes global model biases...

UFS zonal mean fields – week1 x week 4



— ERAI — CNT - - - WTR - - - WTRuv - - - NTR

Outline

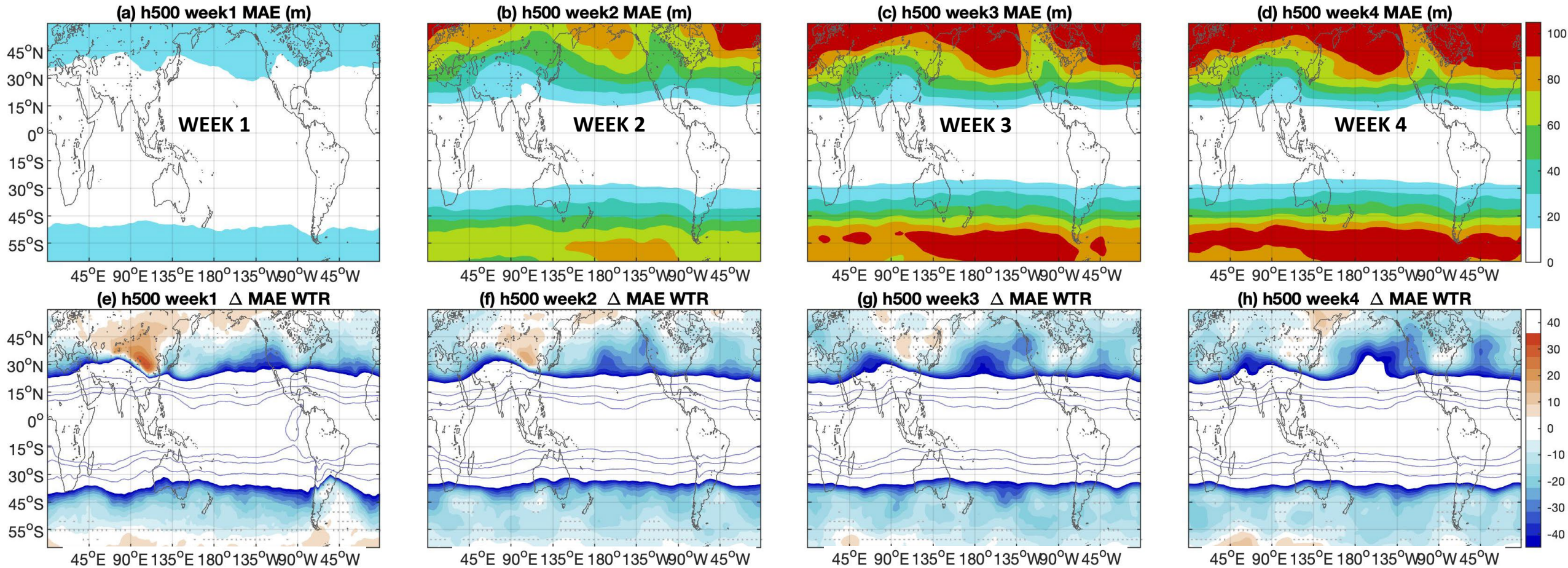
1. Overview of tropical to extratropical teleconnections on sub-seasonal timescales.
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2.1 Mean Absolute Error (MAE)

2.2 NE Pacific/Western USA anomaly pattern correlation (APC)

Does tropical nudging reduce remote errors?

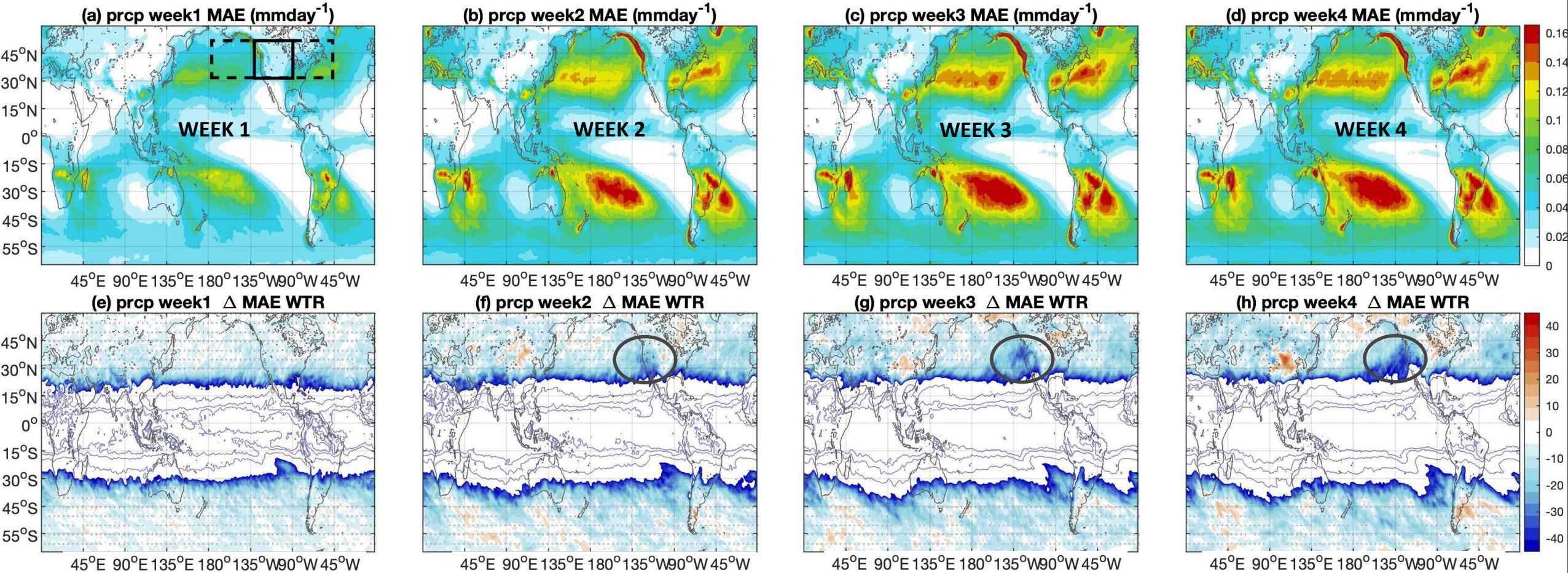
500hPa Geopotential height mean absolute error (MAE)



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

Does tropical nudging reduce remote errors?

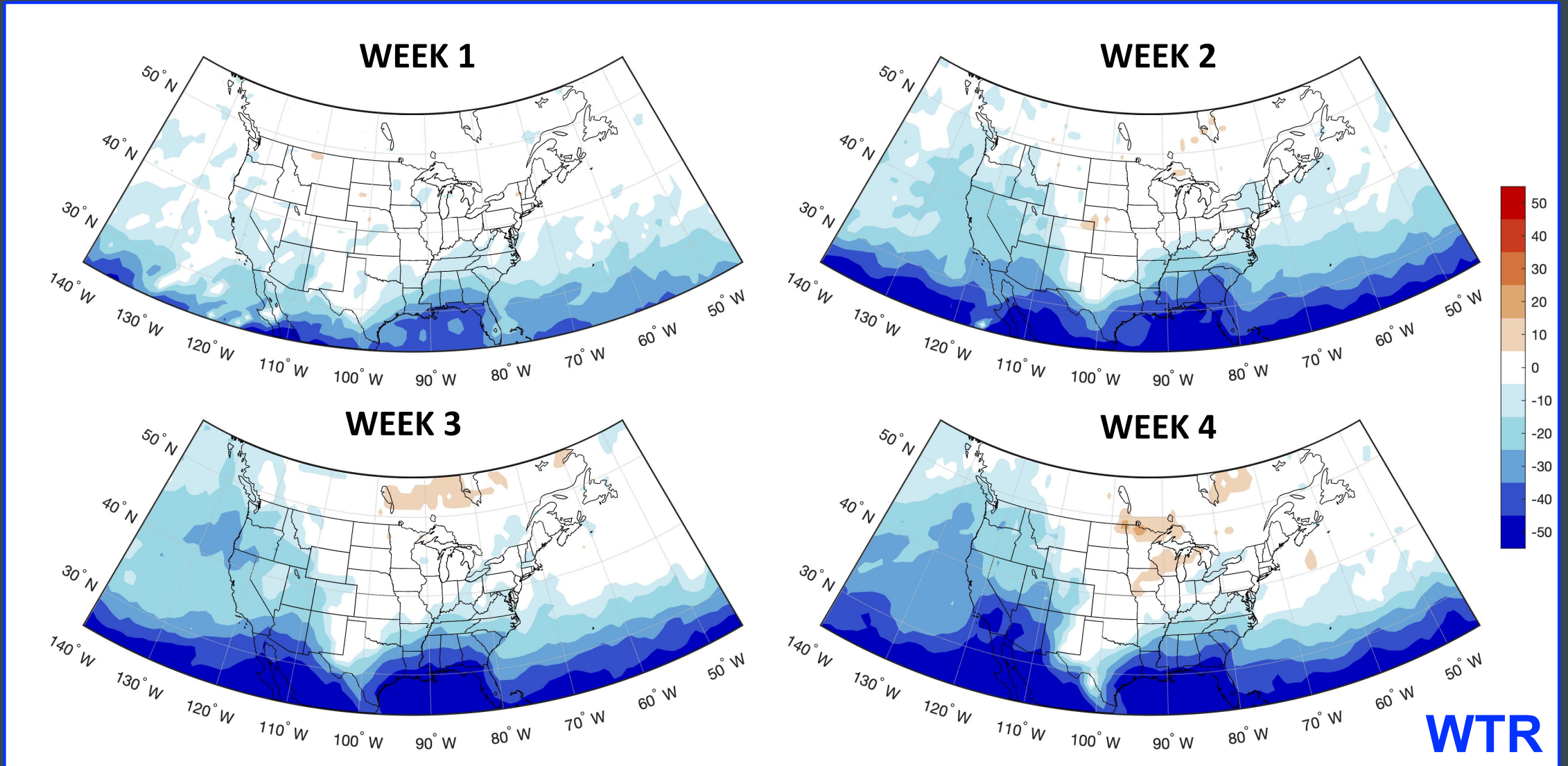
Precipitation (PRCP) mean absolute error (MAE)



Blue shading denotes regions where PRCP MAE is reduced comparing **TWR** to **CNT** MAE

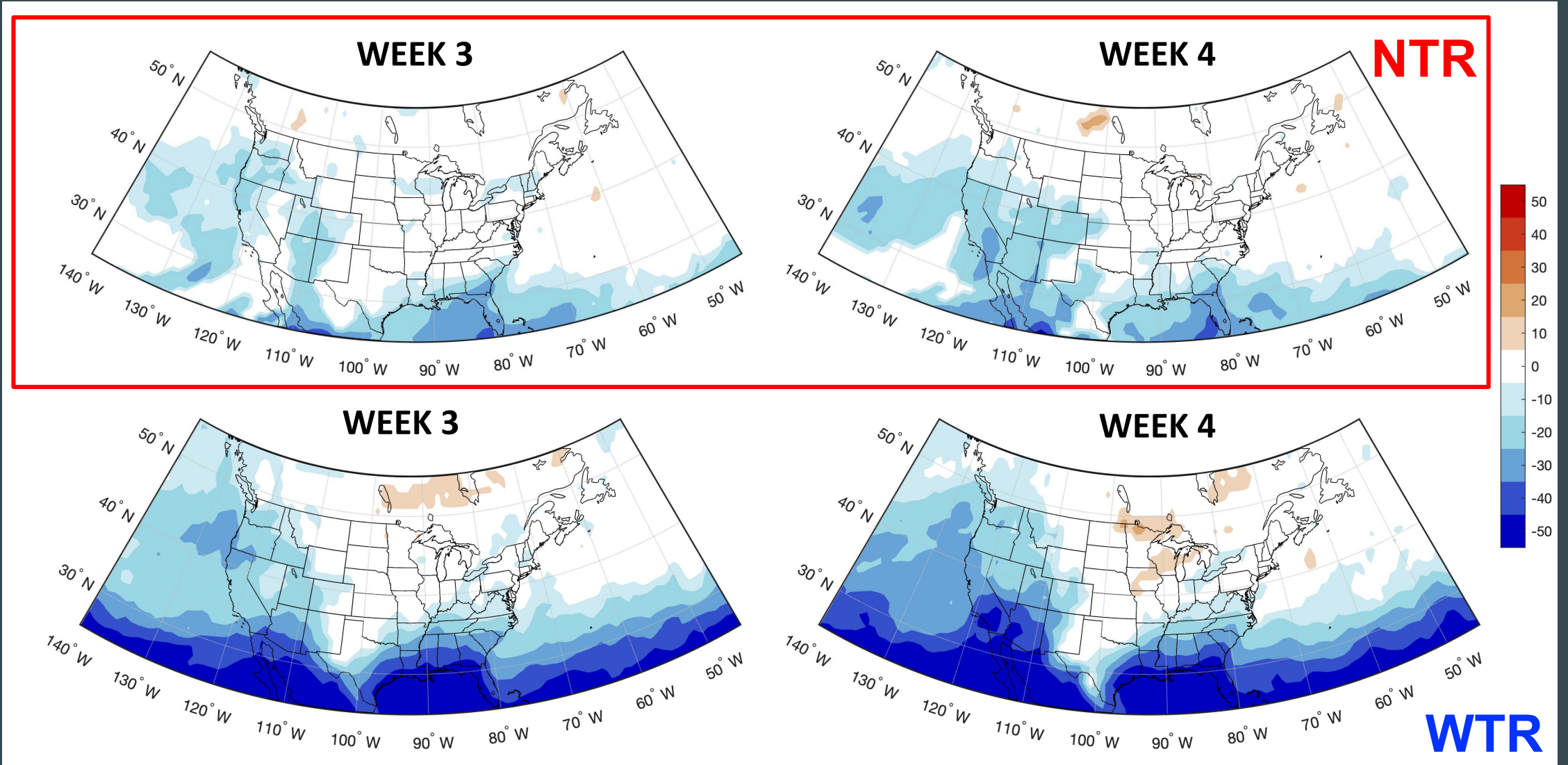
Does tropical nudging reduce remote errors?

Precipitation (PRCP) Δ MAE (%)



Does tropical nudging reduce remote errors?

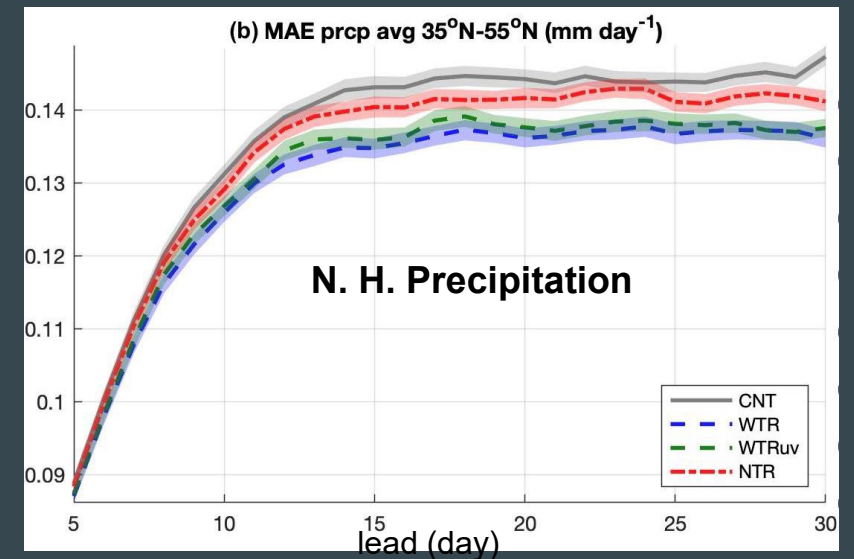
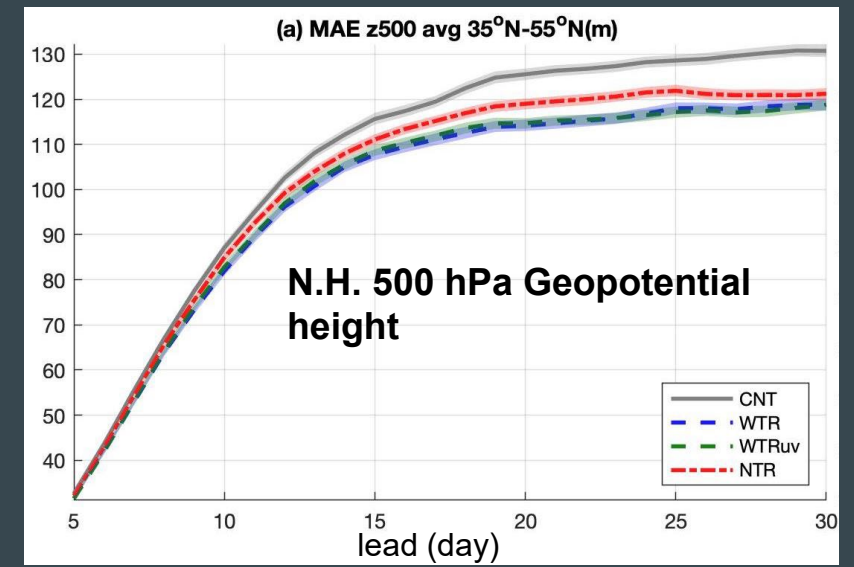
Precipitation (PRCP) Δ MAE (%)



MAE analysis summary

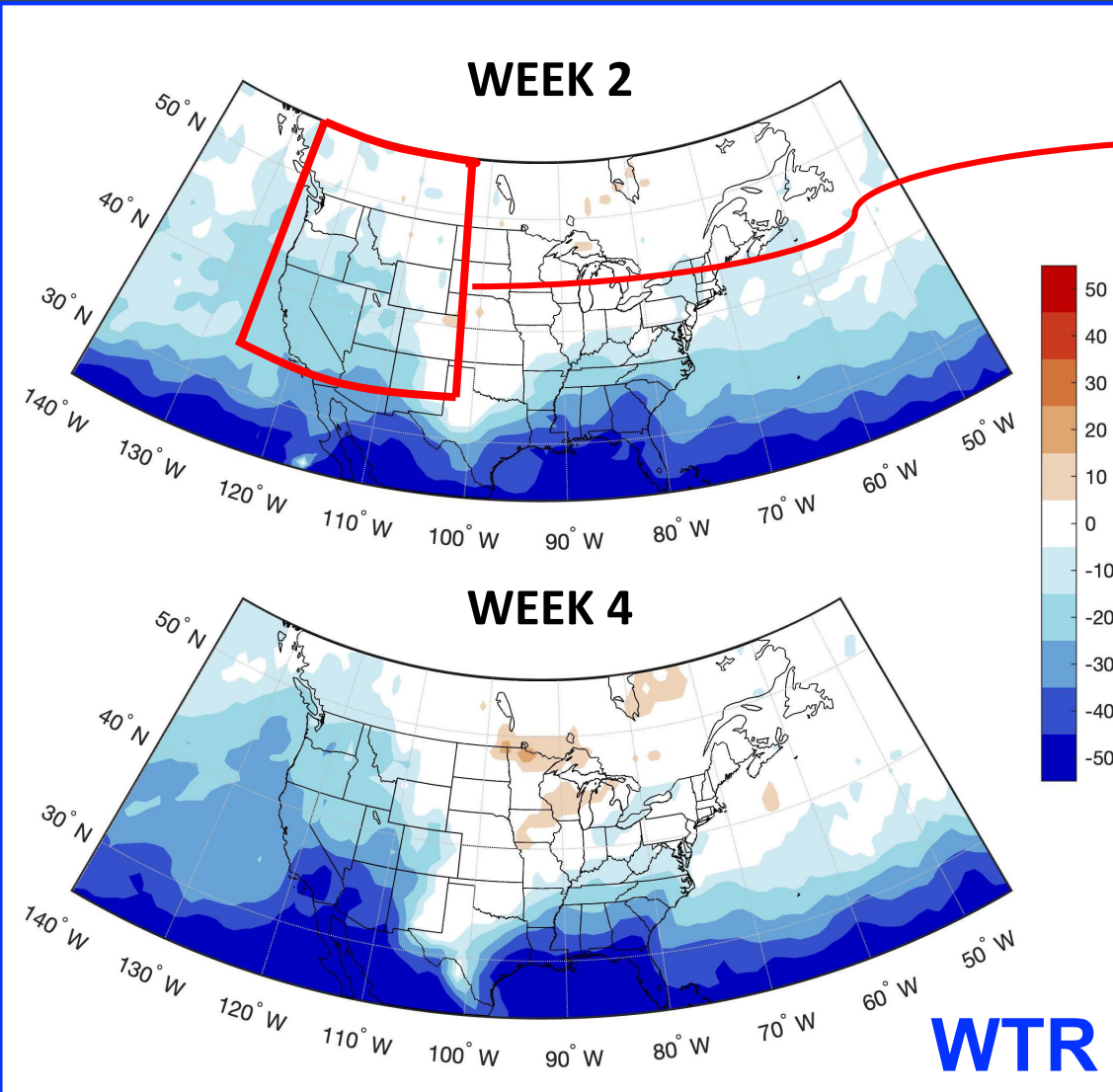
- as expected, subseasonal midlatitude MAE are reduced when nudging the tropics;
- MAE over the **North Pacific – Western United States** are more strongly reduced, including precipitation MAE (~20-40% depending on lead);
- MAE reductions are significant even when full nudging is applied only over 5°S-5°N;
- MAE remote changes are not particularly sensitive to nudging all variables versus zonal and meridional winds only (**WTR** x **WTRuv**) – suggesting a dynamical link between tropics and extratropics;

MAE as a function of lead day

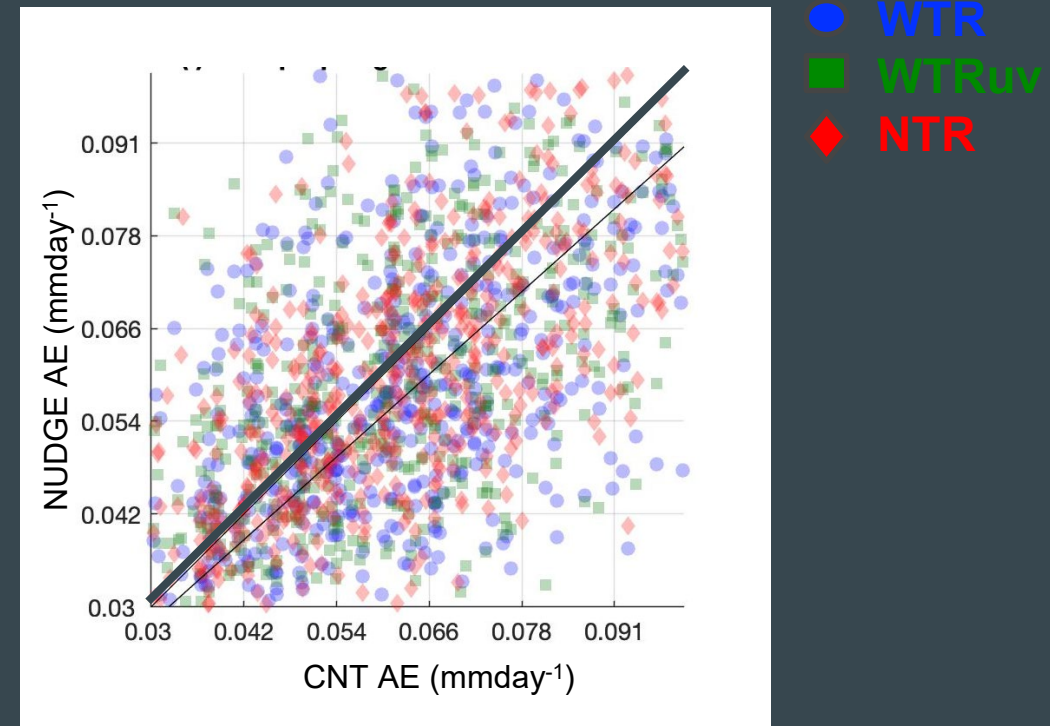


When does tropical nudging reduce remote errors?

Precipitation (PRCP) Δ MAE (%)



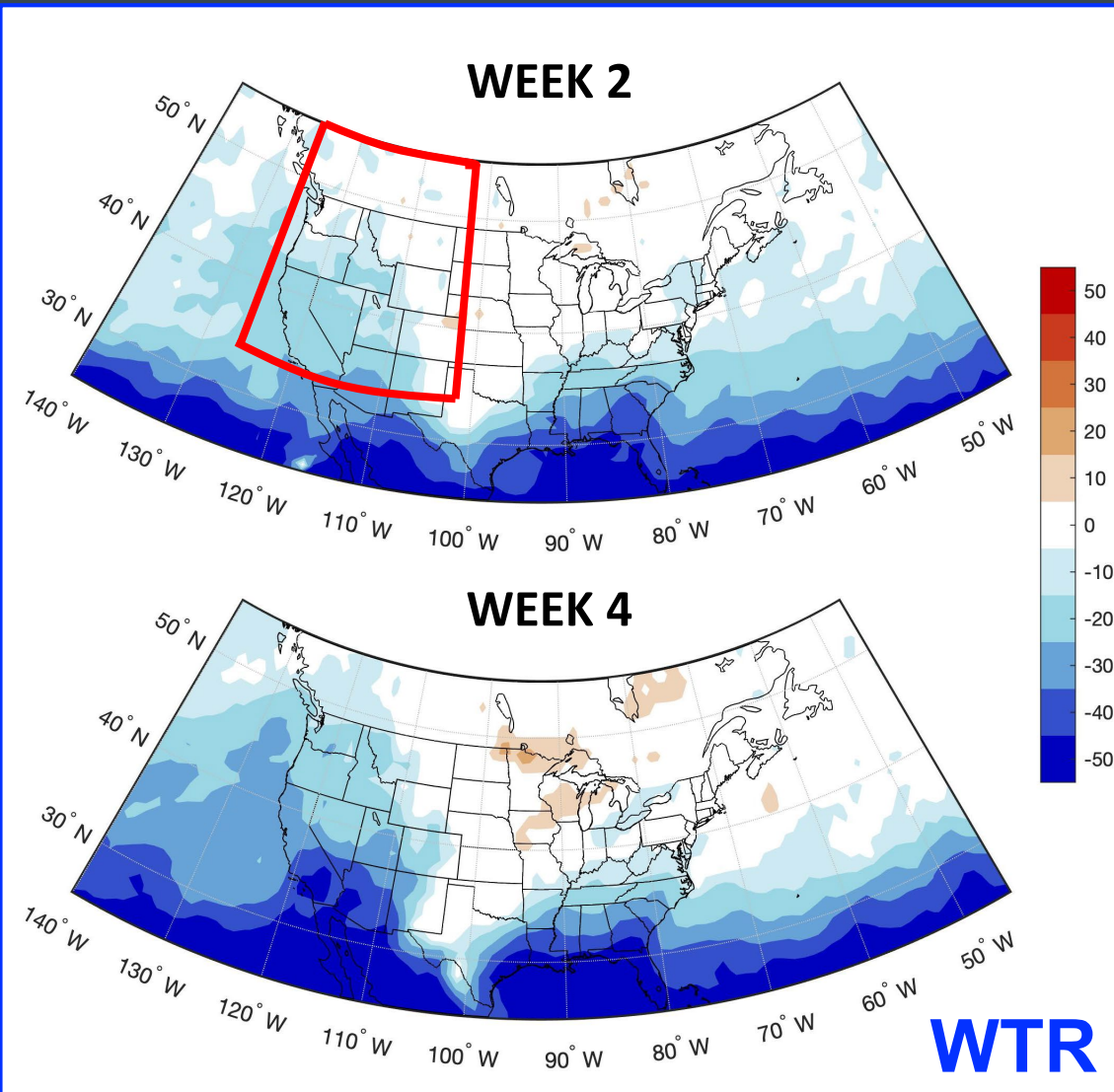
PRCP CNT AE x Nudge AE



while in average MAE is reduced, in some cases MAE is increased

When does tropical nudging reduce remote errors?

Precipitation (PRCP) Δ MAE (%)



- Understanding when tropical nudging is effective at reducing remote errors might lead to a better characterization of the tropical error source;
- How are anomalies influenced by the tropical error reduction?

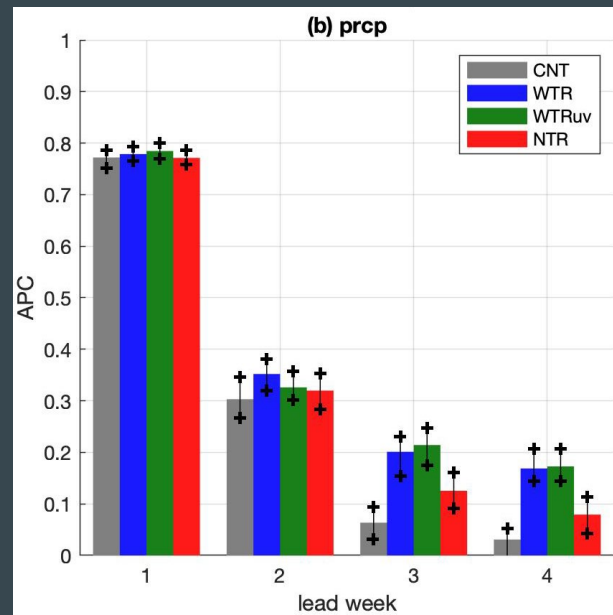
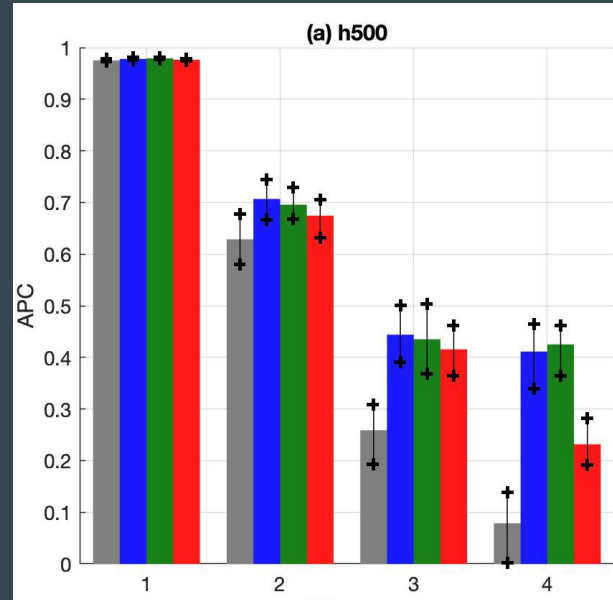
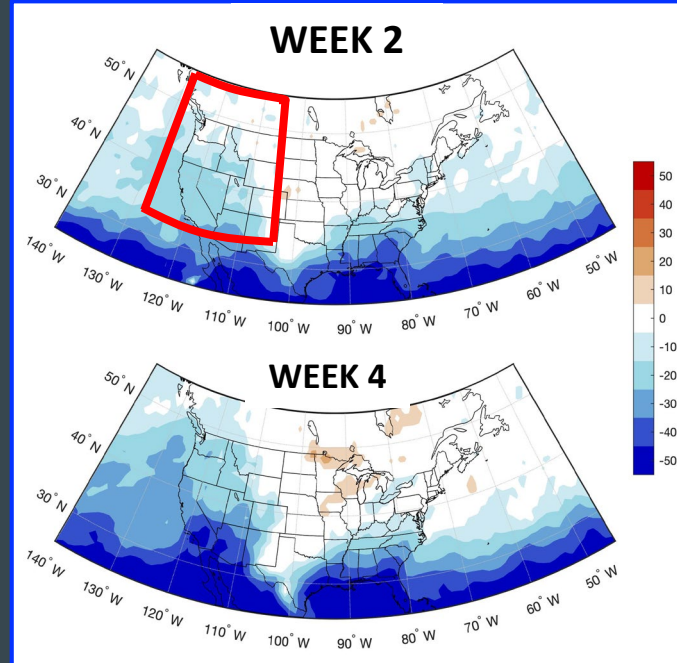
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NE Pacific/Western USA anomaly pattern correlation (APC)

APC over "red" box

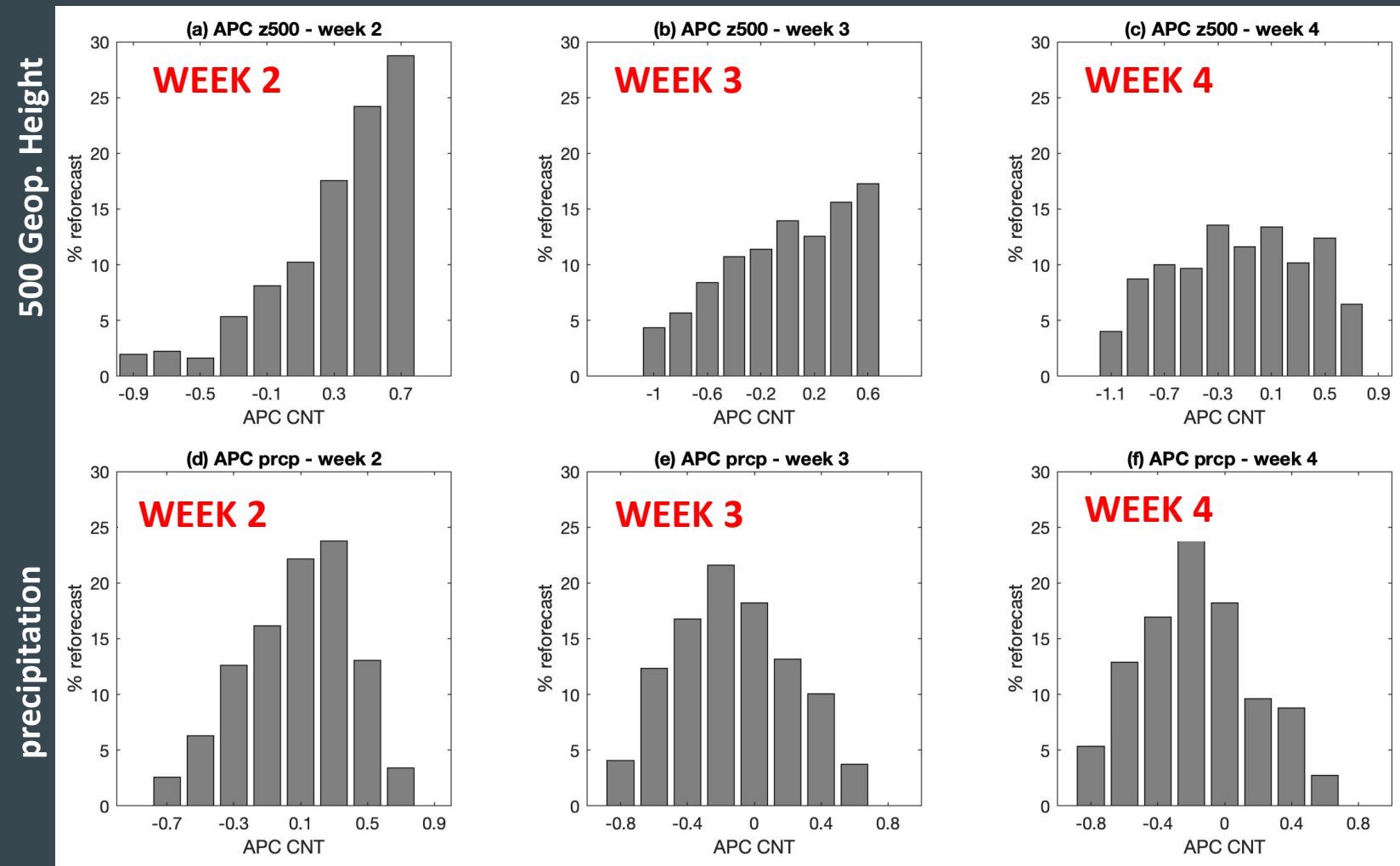
Precipitation (PRCP) Δ MAE (%)



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

How does tropical nudging impact skillful versus not skillful cases?

Histograms of CNT APC over Western USA

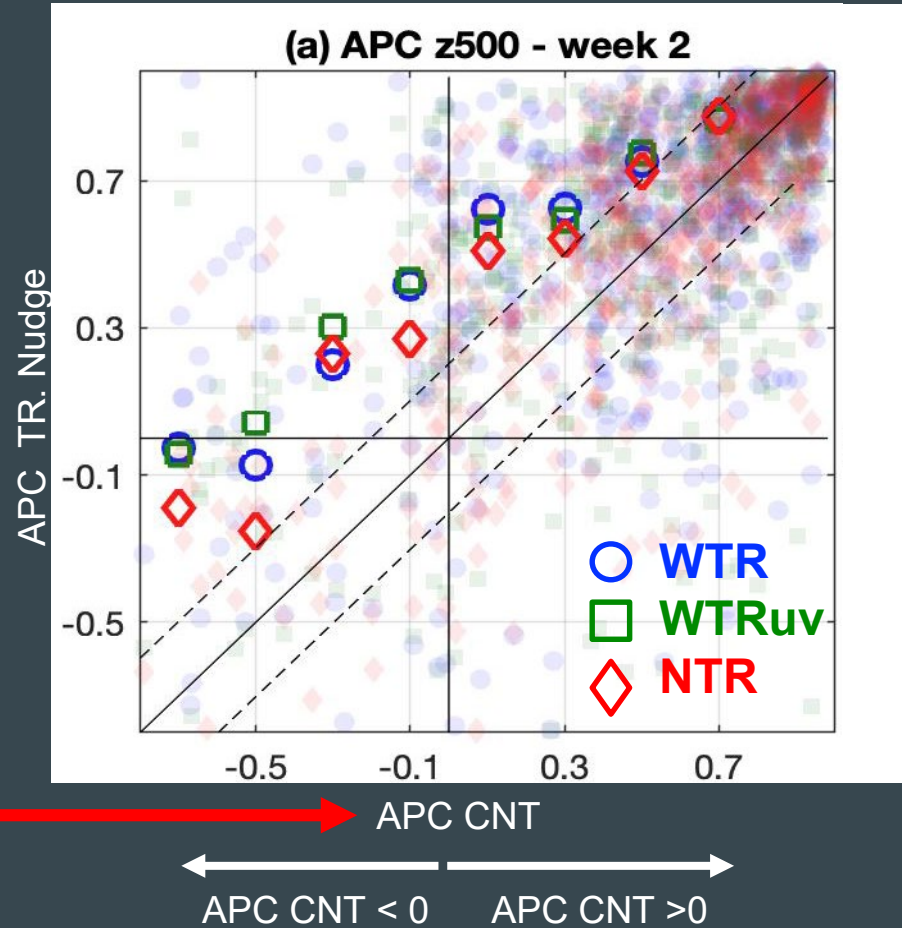
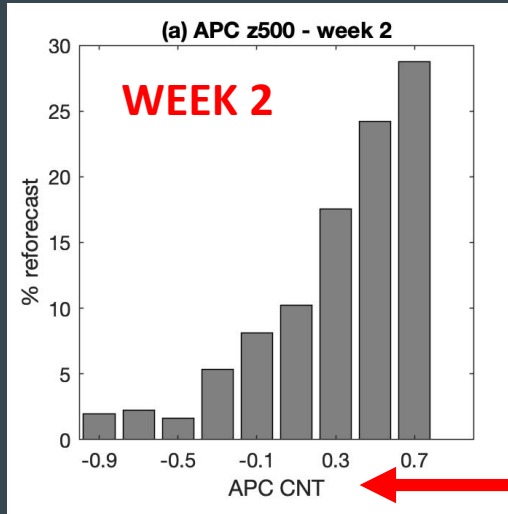


To answer this question we can look at how APC changes as a function of the CNT APC

* Illustration of percentage of reforecasts in each APC bins

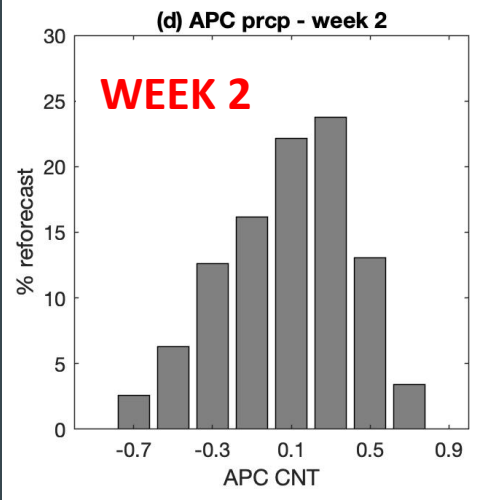
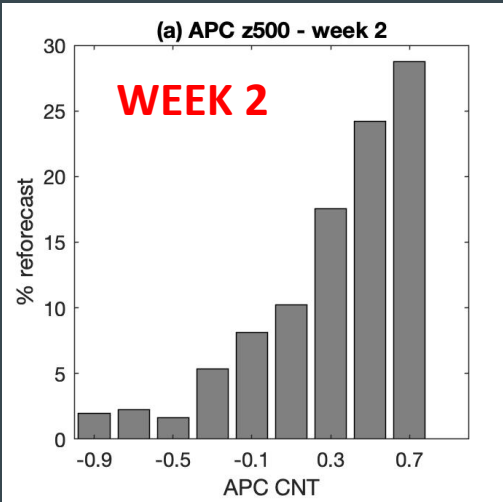
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Histogram of CNT APC over Western USA

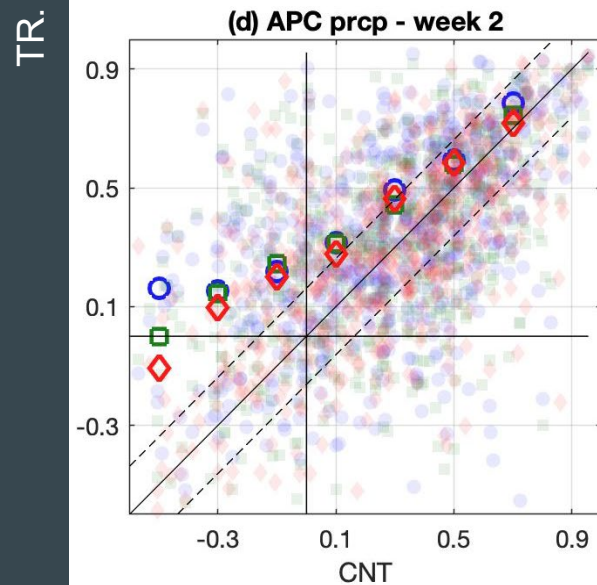
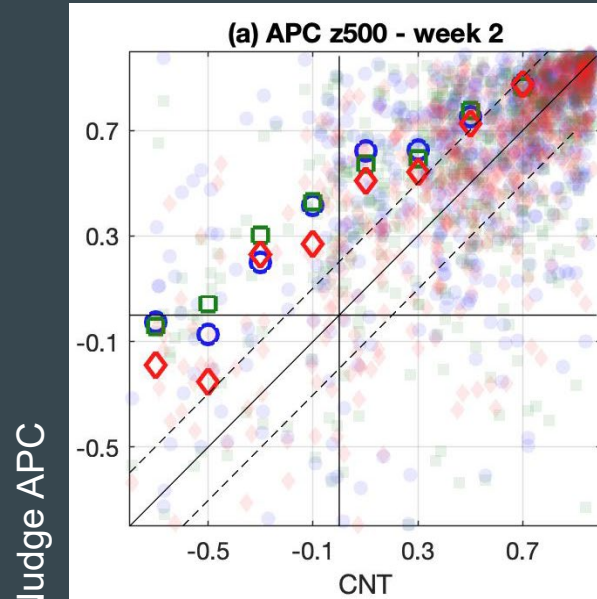


How does tropical nudging impact skillful versus not skillful cases?

Histogram of CNT APC over Western USA



Scatter of CNT x TNUD APC over Western USA

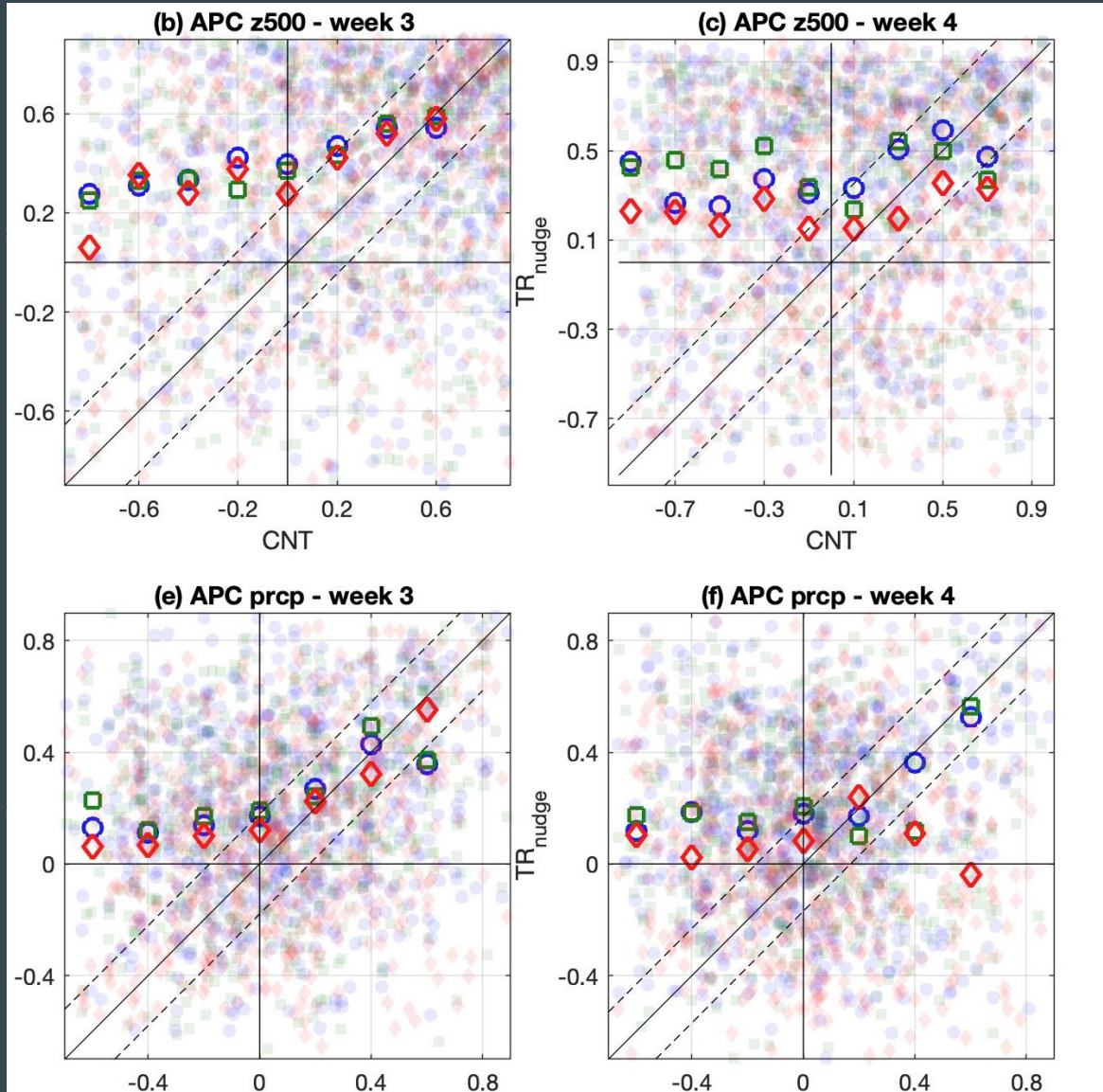


Tropical nudging tends to be more effective at improving low skill N.H Week 2 reforecasts

*light colored symbols show scatter of APC (CNT x TRNudge), dark symbols show median TRNudge APC in each CNT APC bin

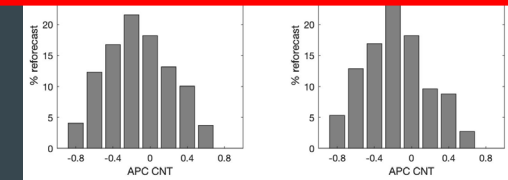
How does tropical nudging impact skillful versus not skillful cases?

Scatter of CNT x TNUD APC over Western USA



Tropical nudging tends to be more effective at improving low skill N.H Week 2-4 reforecasts;

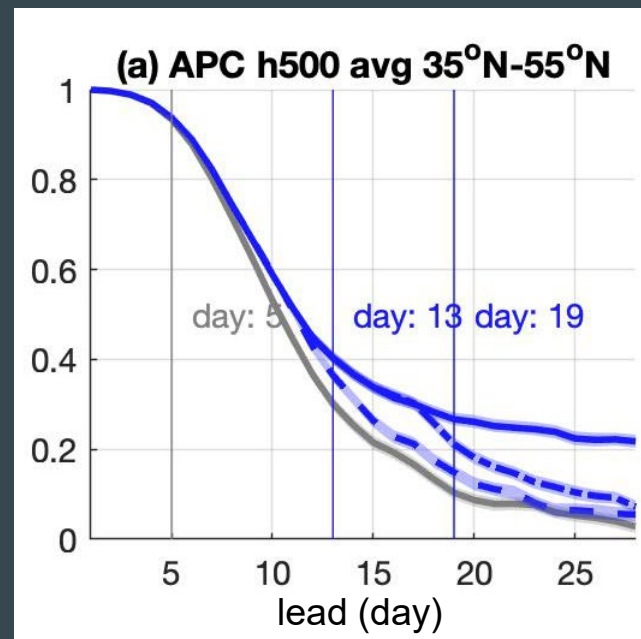
Does N.H skill improve because of error reduction in the tropics or because the northern boundary of the nudged region carries some skill from the N.H?



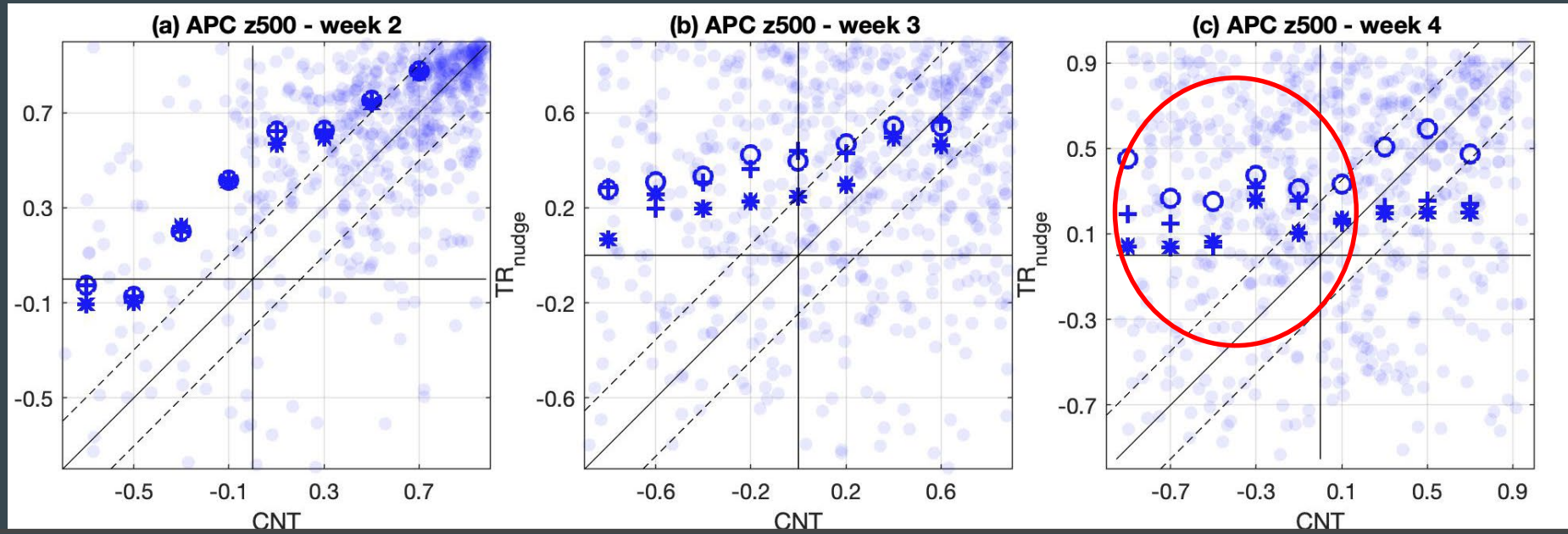
How much skill comes from the “boundary”?

Two new sets of reforecasts:

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.



How much skill comes from the “boundary”?

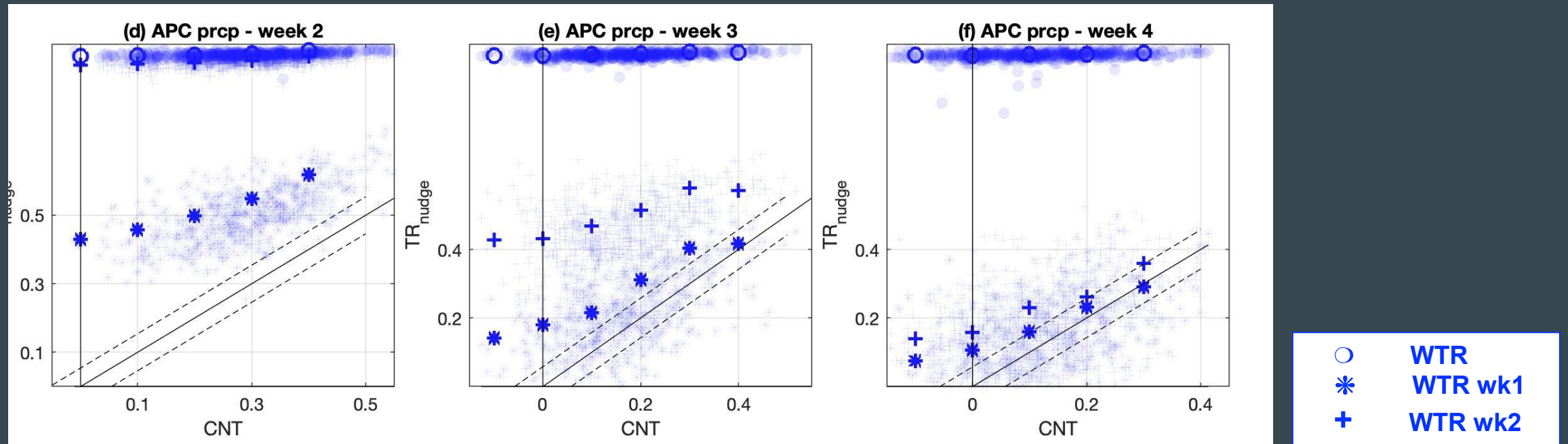


Tropical nudging tends to be more effective at improving low skill N.H Week 2-4 reforecast, including when nudging is applied only at the beginning of the forecast cycle.

- WTR
- * WTR wk1
- + WTR wk2

Is the additional skill coming from the tropics?

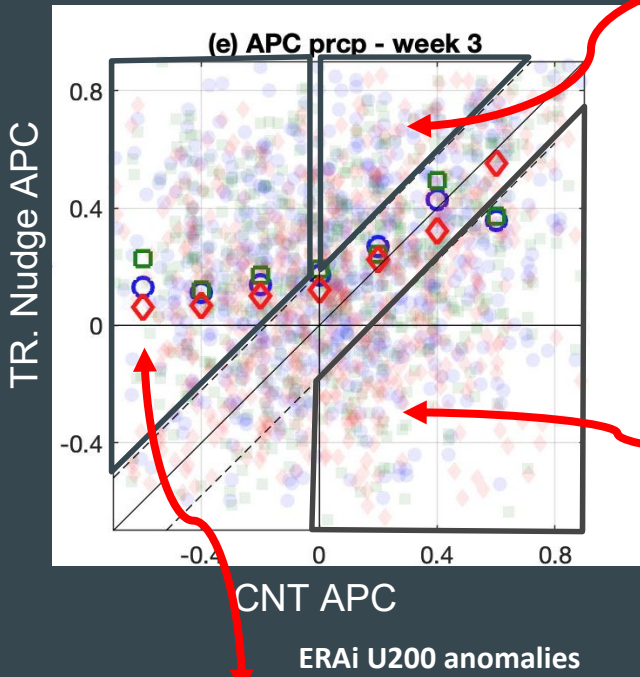
Scatter of CNT x TNUD APC over the tropics (20°S-20°N)



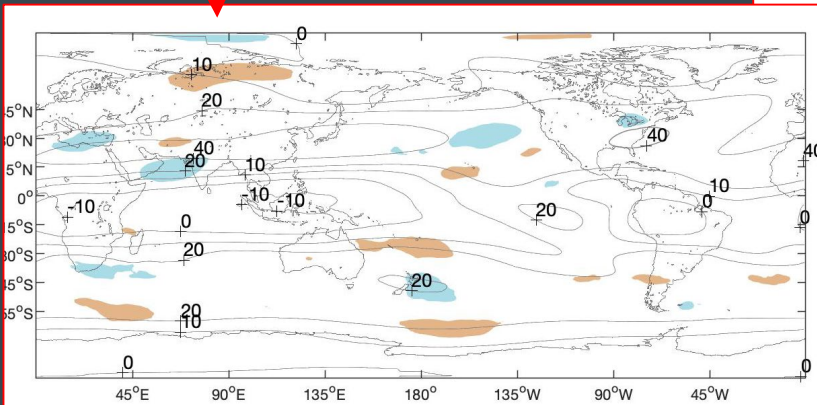
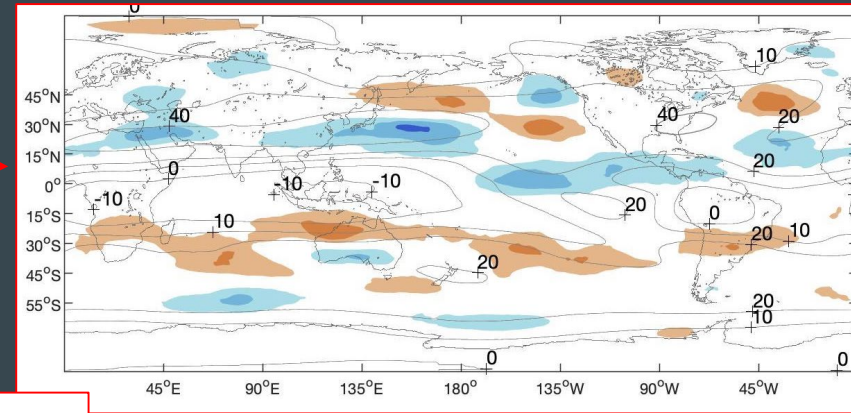
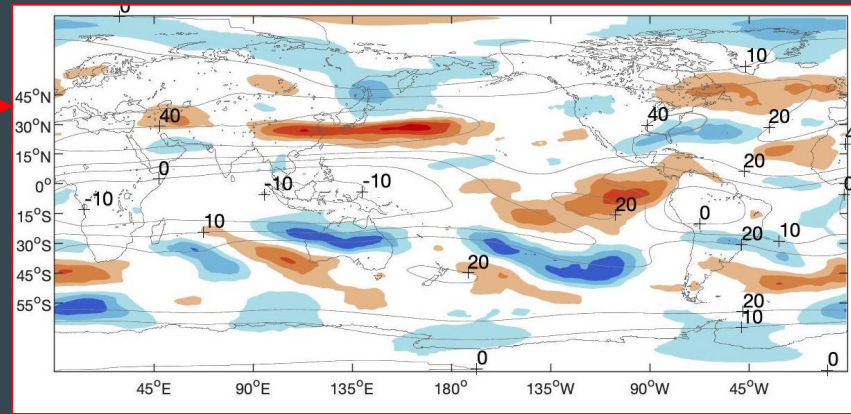
Yes? It appears that low skill N.H. weeks 3-4 forecasts benefit from a reduction of tropical errors on week 1.

Next steps...

Scatter of CNT x TNUD APC over Western USA

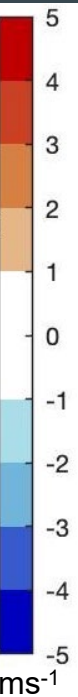


ERAi U200 anomalies



We are currently investigating the basic state controls of how tropical nudging changes remote week 2-4 prediction skill.

*Shading denotes U200 differences between dates where TR Nudge APC falls in each region highlighted in the scatter plot. Contours are the climatological U200.



Summary

- We produced 30 day UFS reforecasts initialized every 5 days for November-March from 1999-2018, relaxing the tropics to ERAi:
 - Wide tropics, nudging all variables (week1-4, week1, week1-2)
 - Wide tropics, nudging winds only
 - Narrow tropics, nudging all variables

And other experiments on the near future:

- Similar experiments for April-October;
- Tropical troposphere (stratosphere) only;
- Regional tropical nudging (Indo-Pacific region);

Summary

- Tropical nudging tend to have a positive impact in S2S N.H midlatitude predictions, particularly in the cases where the free forecast had no skill; including improvements on Western US precipitation predictions.
- When week 2-4 forecasts are skillful, tropical nudging often degrades the skill (~50% of the cases). The impact of tropical nudging in the N.H. might depend on the basic state (e.g. strength of the subtropical jets).
- By testing/understanding various nudging configurations, we hope to better characterize sources of tropical errors that are specifically related to week 2-4 N.H. predictions as well as what portion of these potential skill improvements is realizable.

some of the results presented here can be seen [here](#) (full manuscript in preparation)