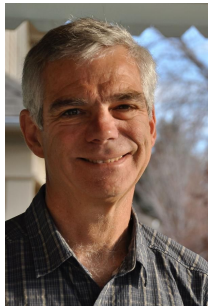
Tropical origins of Weeks 2-4 forecasts errors during Northern Hemisphere cool season

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

01/20/2023





[1] NOAA Physical Sciences Laboratory
[2] CIRES, University of Colorado

Background: S2S teleconnections

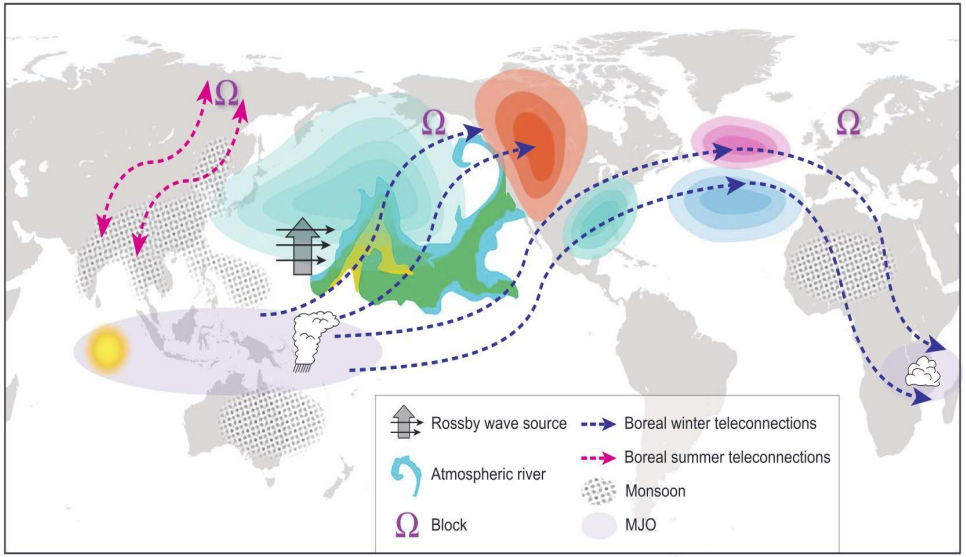


*Figure: Schematic of tropical-NH interactions from **Stan, C. et al. (2017).** Review of tropical-extratropical teleconnections on intraseasonal time scales. Rev. of Geoph., 55, 902–937.*

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

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

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

Background: S2S teleconnections

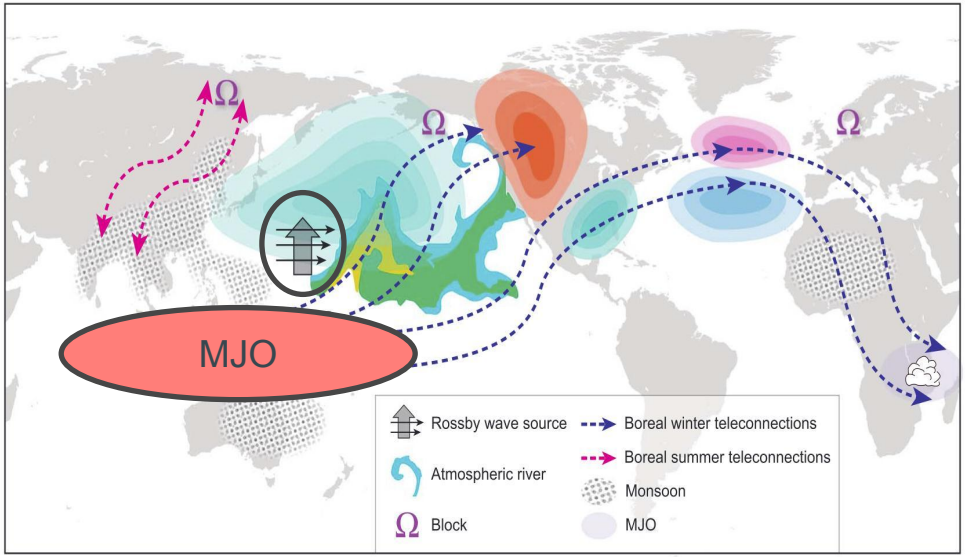


*Figure: Schematic of tropical-NH interactions from **Stan, C. et al. (2017).** Review of tropical-extratropical teleconnections on intraseasonal time scales. Rev. of Geoph., 55, 902–937.*

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

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

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

Background: MJO teleconnections

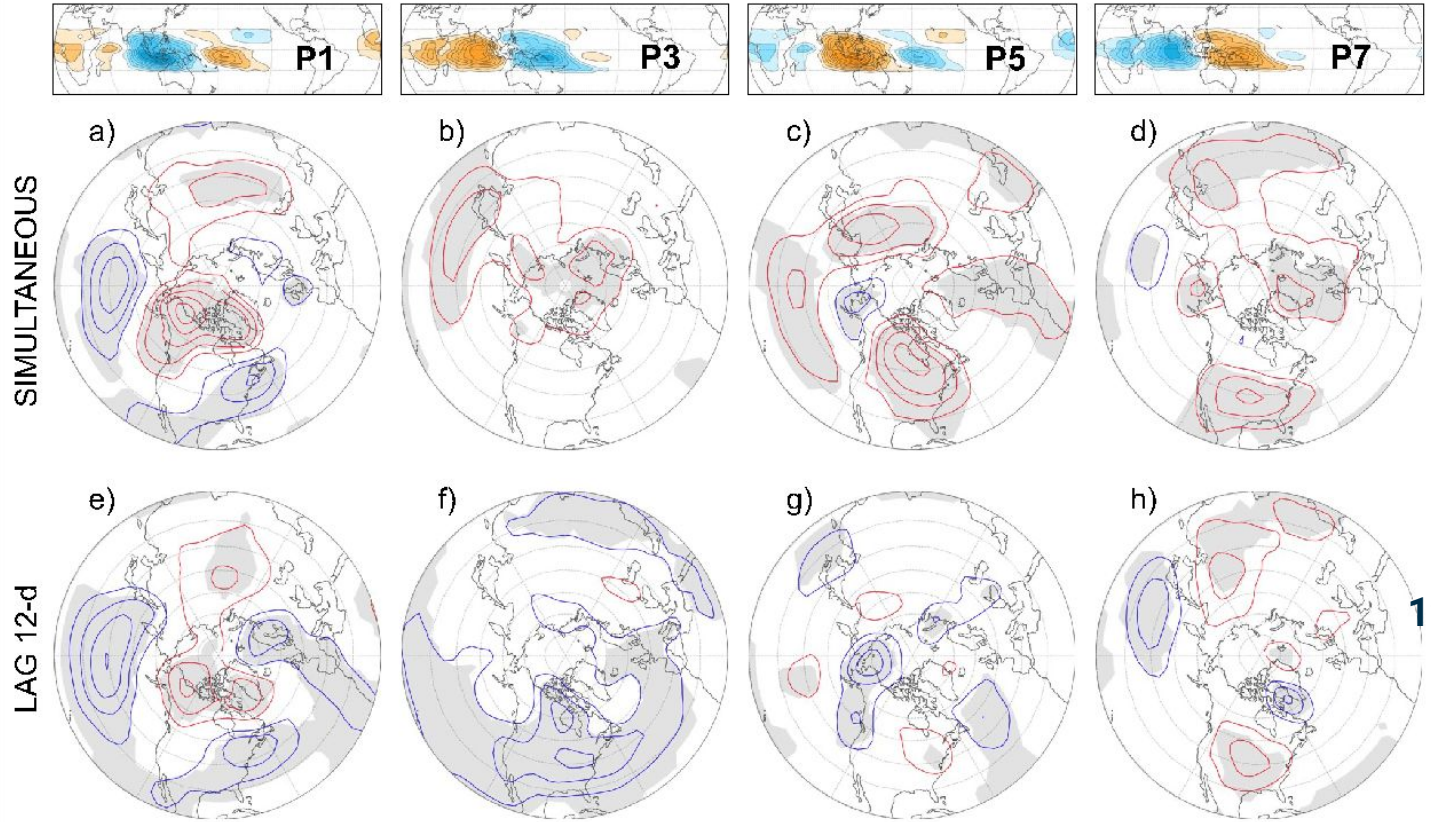
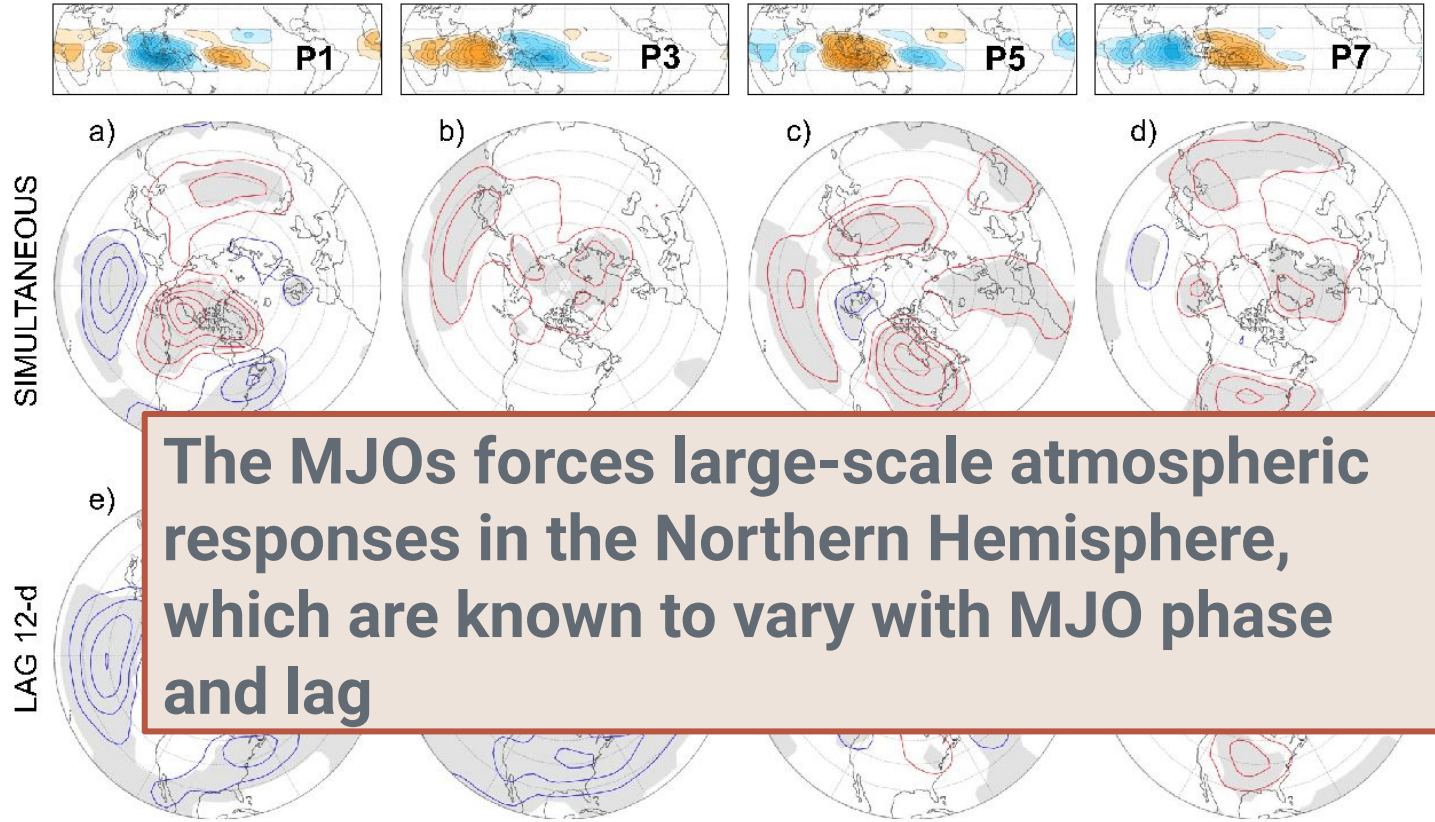


Figure from: Hall, N.M.J., Le, H.H. & Leroux, S. The extratropical response to a developing MJO: forecast and climate simulations with the DREAM model. Clim Dyn 55, 813–829 (2020).

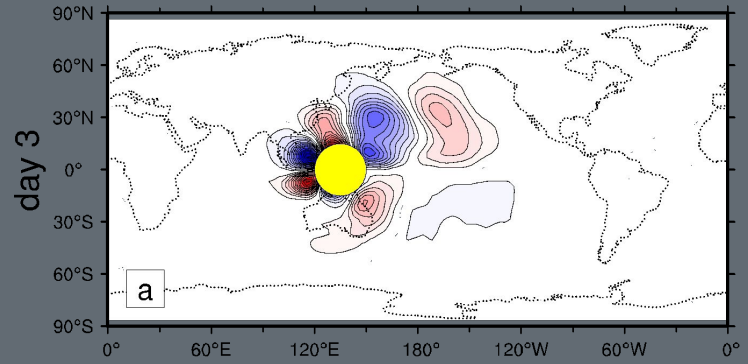
Background: MJO teleconnections



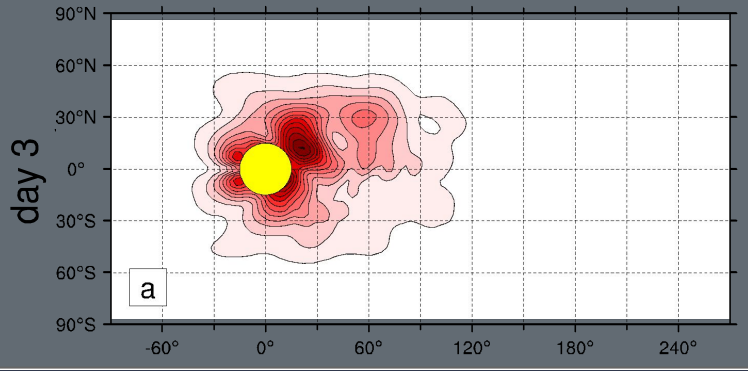
The MJOs forces large-scale atmospheric responses in the Northern Hemisphere, which are known to vary with MJO phase and lag

Background: Higher frequency teleconnections

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

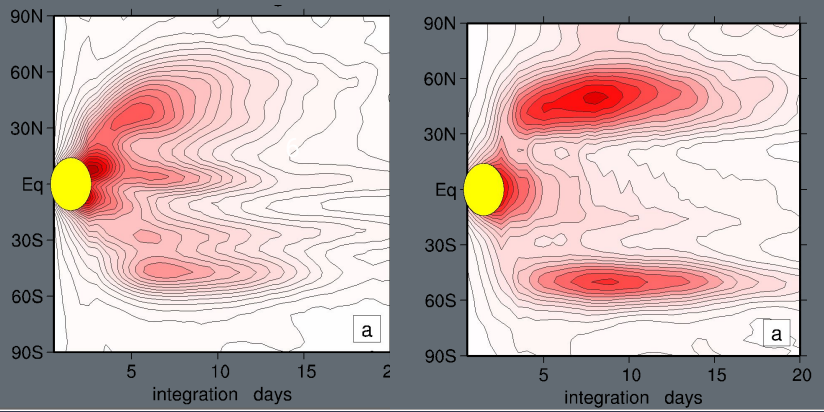


RMS v300 response in CAM3 to a 2-day pulse of heat



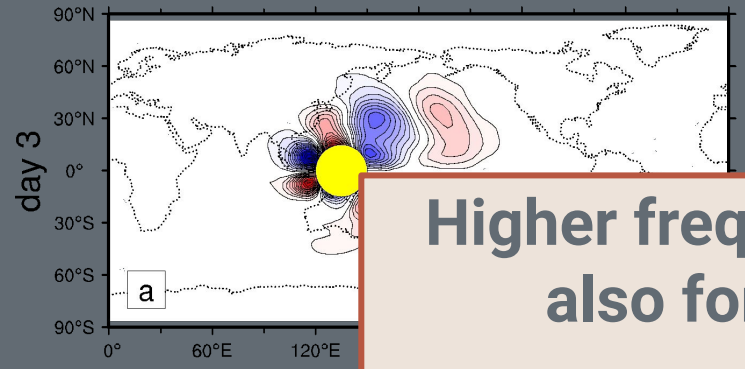
Branstator, G. (2014). Long-lived response of the midlatitude circulation and storm tracks to pulses of tropical heating. Journal of Climate, 27(23), 8809-8826.

RMS response of ensemble mean to 2-day pulses as a function of time:
(a) v300 **(b) SLP**



Background: Higher frequency teleconnections

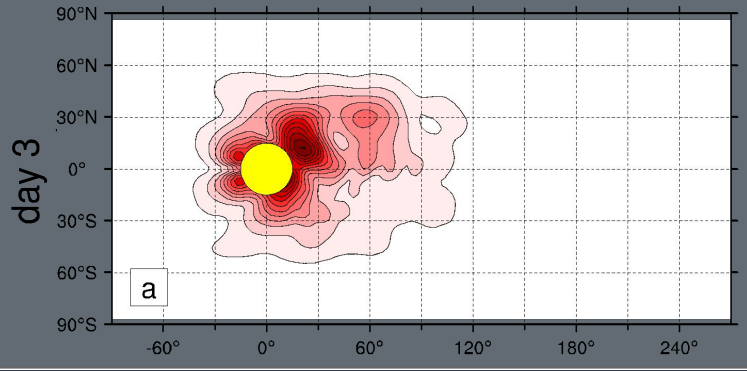
Ensemble mean v300 response in CAM3 to a 2-day pulse of heat



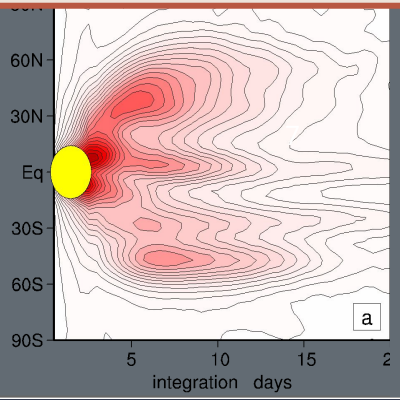
Branstator, G. (2014). Long-lived response of the midlatitude circulation and storm tracks to pulses of tropical heating. Journal of Climate, 27(23),

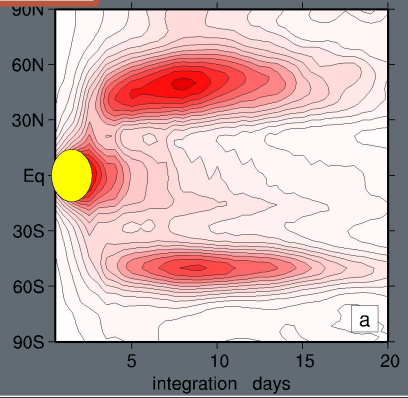
Higher frequency heat sources can also force teleconnections

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



ulses as a function of time: SLP





Background: Tropical Relaxation experiments

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.

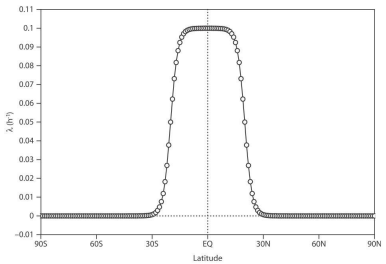
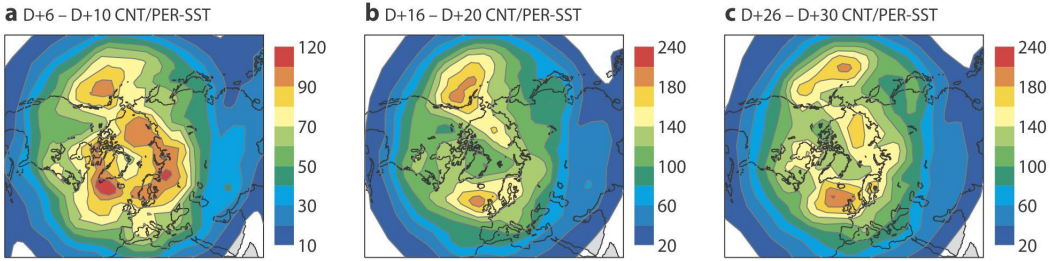


FIG. 1. Latitudinal dependence of λ in Eq. 1 (h^{-1}) for the tropical relaxation experiment (TROP/0.1).

$$-\lambda(x - xa)$$

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)

[*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.*]

Background: Tropical Relaxation experiments

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.

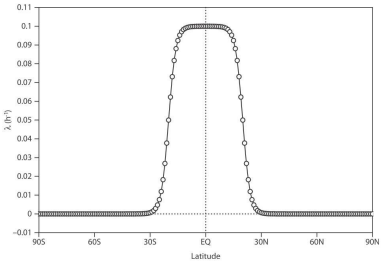
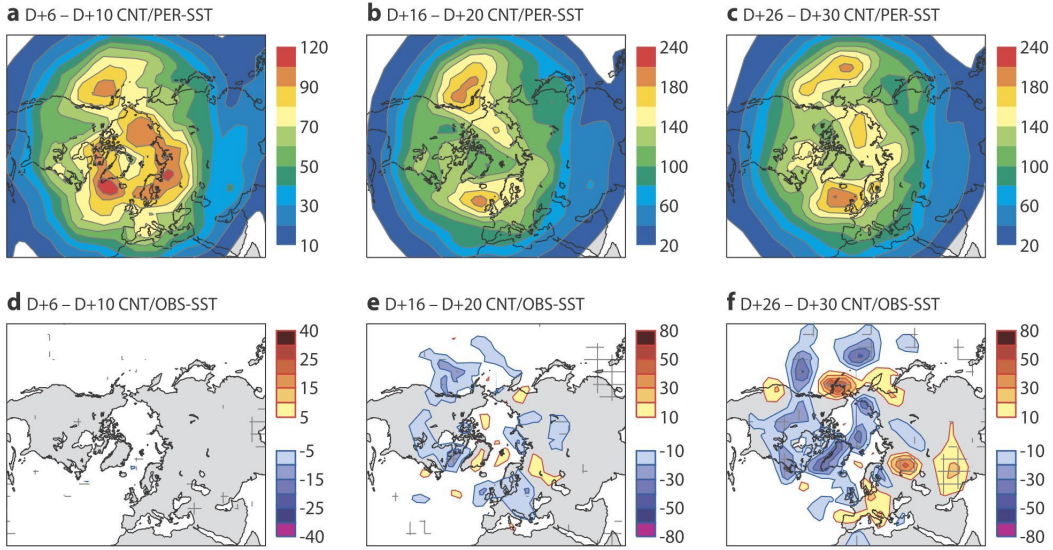


FIG. 1. Latitudinal dependence of λ in Eq. 1 (h^{-1}) for the tropical relaxation experiment (TROP/0.1).

$$-\lambda(x - xa)$$

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)

[*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.*]

Background: Tropical Relaxation experiments

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.

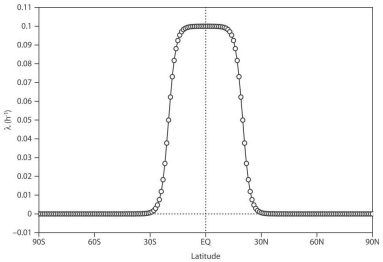
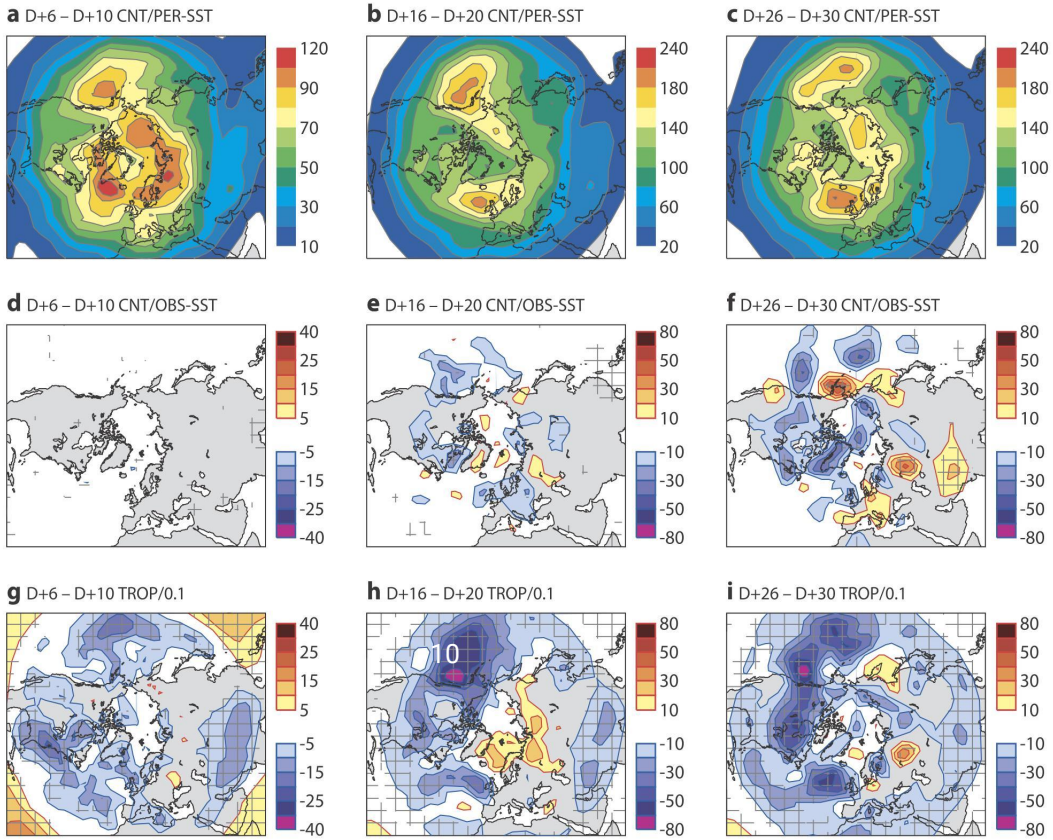


FIG. 1. Latitudinal dependence of λ in Eq. 1 (h^{-1}) for the tropical relaxation experiment (TROP/0.1).

$$-\lambda(x - xa)$$

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)



[*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.*]

Today's talk

We will use tropical relaxation techniques to look into the following questions:

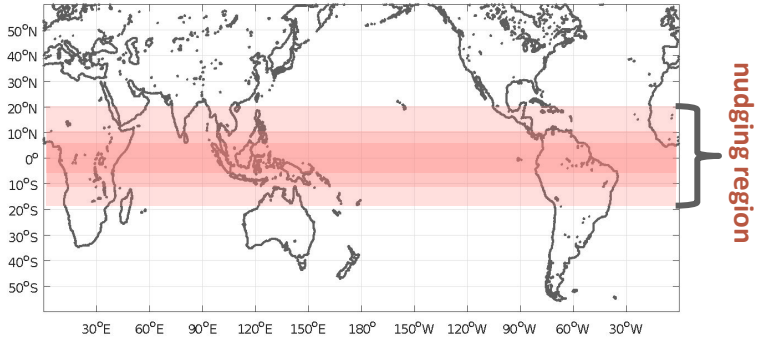
1) Do tropical errors influence **S2S precipitation predictions** outside the tropics?
2) Are the error modulations outside the tropics **dependent on the MJO?**

Then we will discuss our next steps…

Dias, J., Tulich, S. N., Gehne, M., & Kiladis, G. N. (2021). Tropical Origins of Weeks 2–4 Forecast Errors during the Northern Hemisphere Cool Season, *Monthly Weather Review*, *149*(9), 2975-2991. Retrieved Jan 19, 2023, from https://journals.ametsoc.org/view/journals/mwre/149/9/MWR-D-21-0020.1.xml

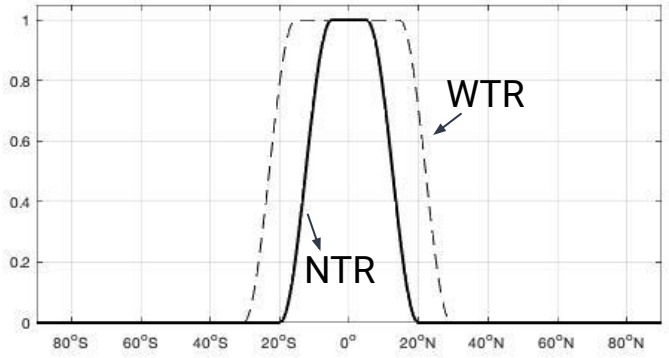
Hsiao, W.-T., Barnes, E. A., Maloney, E. D., Tulich, S. N., Dias, J., & Kiladis, G. N. (2022). Role of the tropics in state-dependent improvements of US West Coast NOAA Unified Forecast System precipitation forecasts. Geophysical Research Letters, 49, e2021GL096447. https://doi.org/10.1029/2021GL096447

Tropical relaxation experiments in the UFS



- UFS (~GFSv15) experiment period: Nov-Mar 1999-2018
- initializations every 5 days (620 reforecasts)
- 30 days reforecasts
- tropical predictions are nudged to ERAi reanalysis

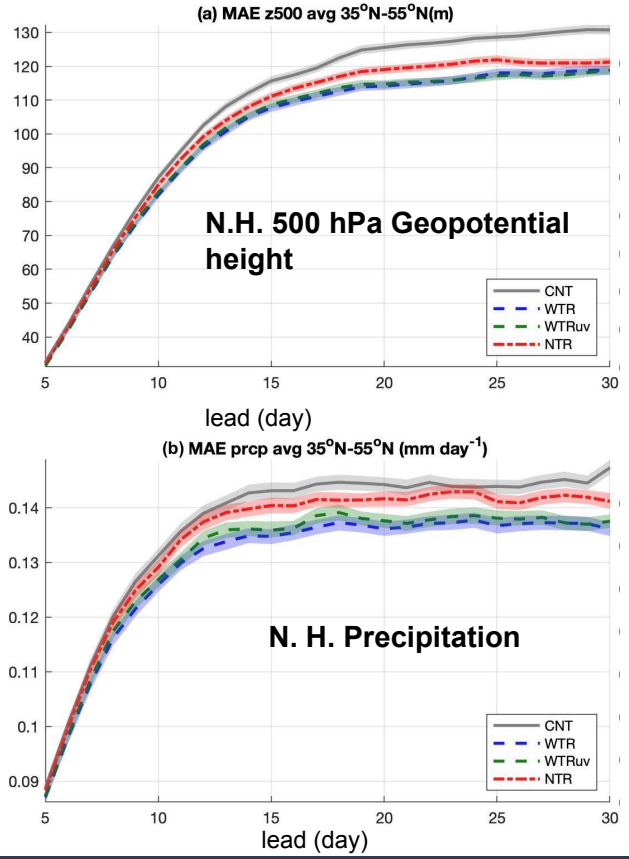
1) **Free reforecast (CNT)**
2) **Wide Tropical Nudging (WTR)** – all variables
3) **Wide Tropical Nudging (WTRuv) – u,v only**
4) **Narrow Tropical Nudging (NTR) – all variables**



Tropical relaxation experiments in the UFS

- as expected from previous analogous studies*, weeks 2-4 midlatitude MAE are reduced when nudging the tropics;
- 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 over the **North Pacific – Western United States** are more strongly reduced, including precipitation MAE (~20-40% depending on lead);

MAE as a function of lead day



* e.g. *Jung, T. et al., 2010: Diagnosing the Origin of Extended-Range Forecast Errors. Mon. Wea. Rev*

Today's talk

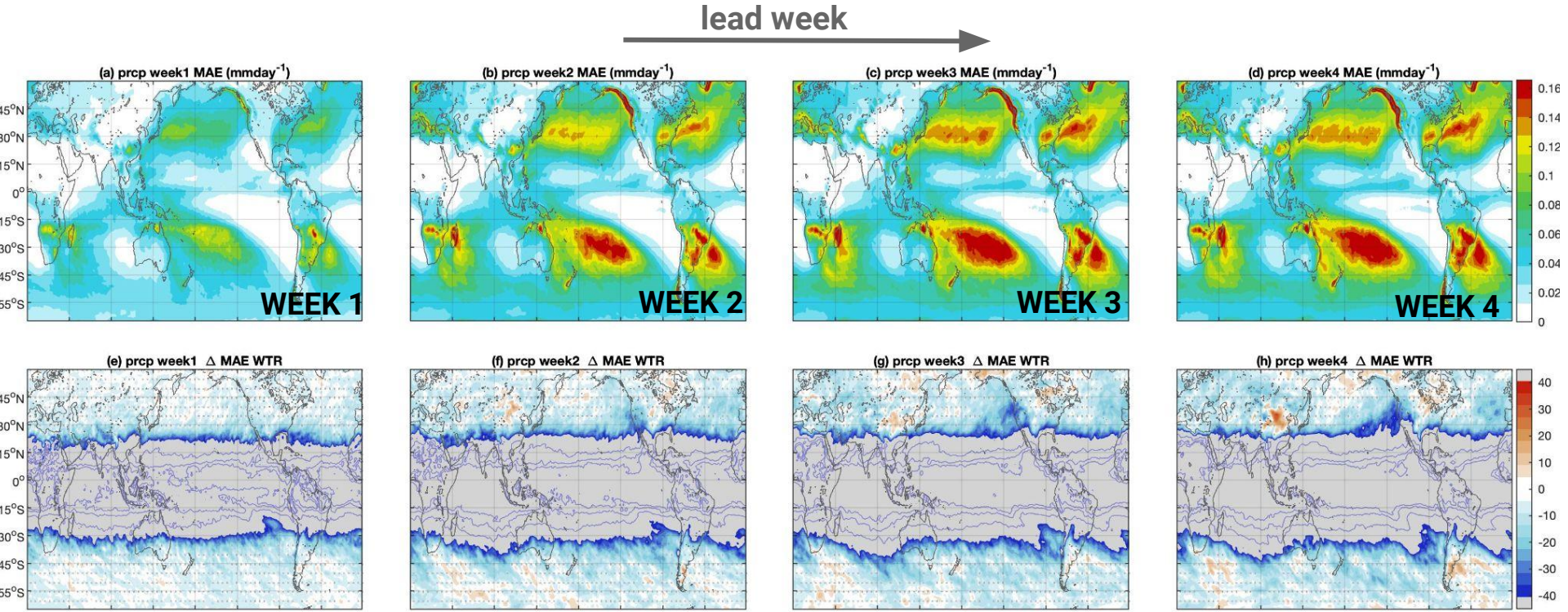
We will use tropical relaxation techniques to look into the following questions:

1) **Do tropical errors influence S2S precipitation predictions outside the tropics?**
2) Are the error modulations outside the tropics **dependent on the MJO?**

Then we will discuss our next steps…

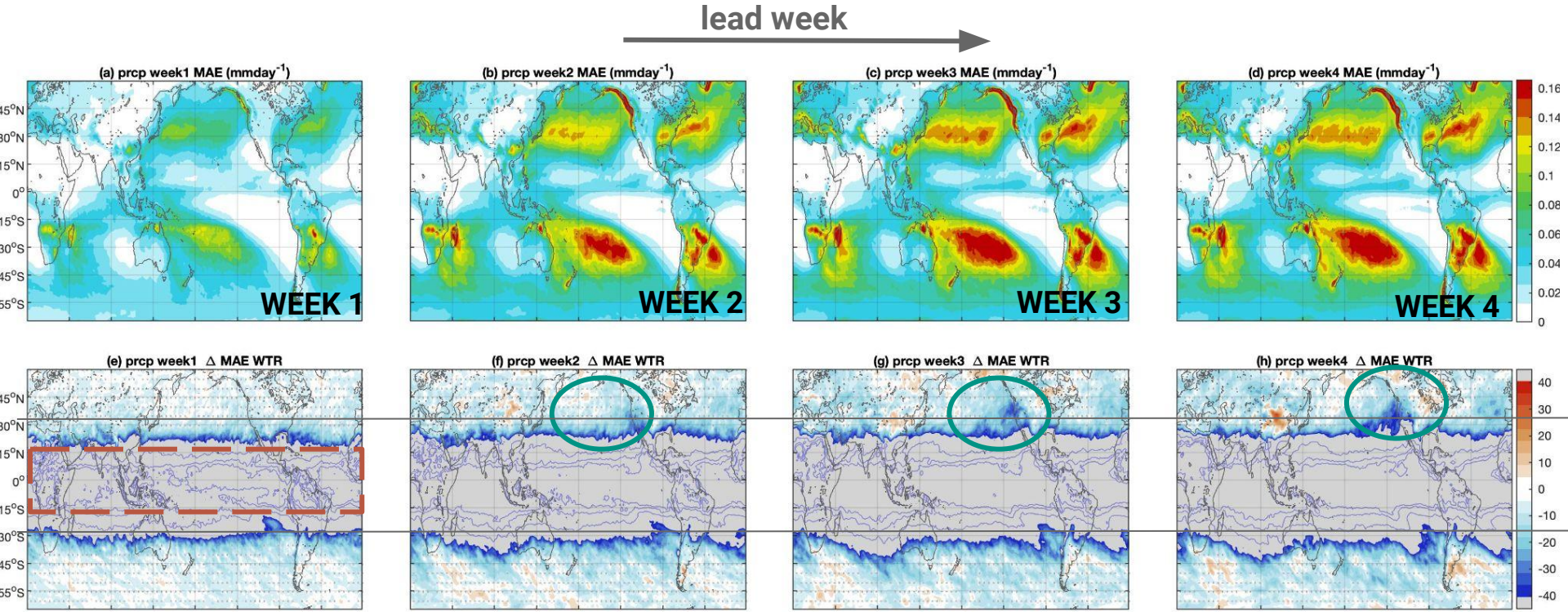
Dias, J., Tulich, S. N., Gehne, M., & Kiladis, G. N. (2021). Tropical Origins of Weeks 2–4 Forecast Errors during the Northern Hemisphere Cool Season, *Monthly Weather Review*, *149*(9), 2975-2991. Retrieved Jan 19, 2023, from https://journals.ametsoc.org/view/journals/mwre/149/9/MWR-D-21-0020.1.xml

Do tropical errors influence S2S precipitation predictions outside the tropics?



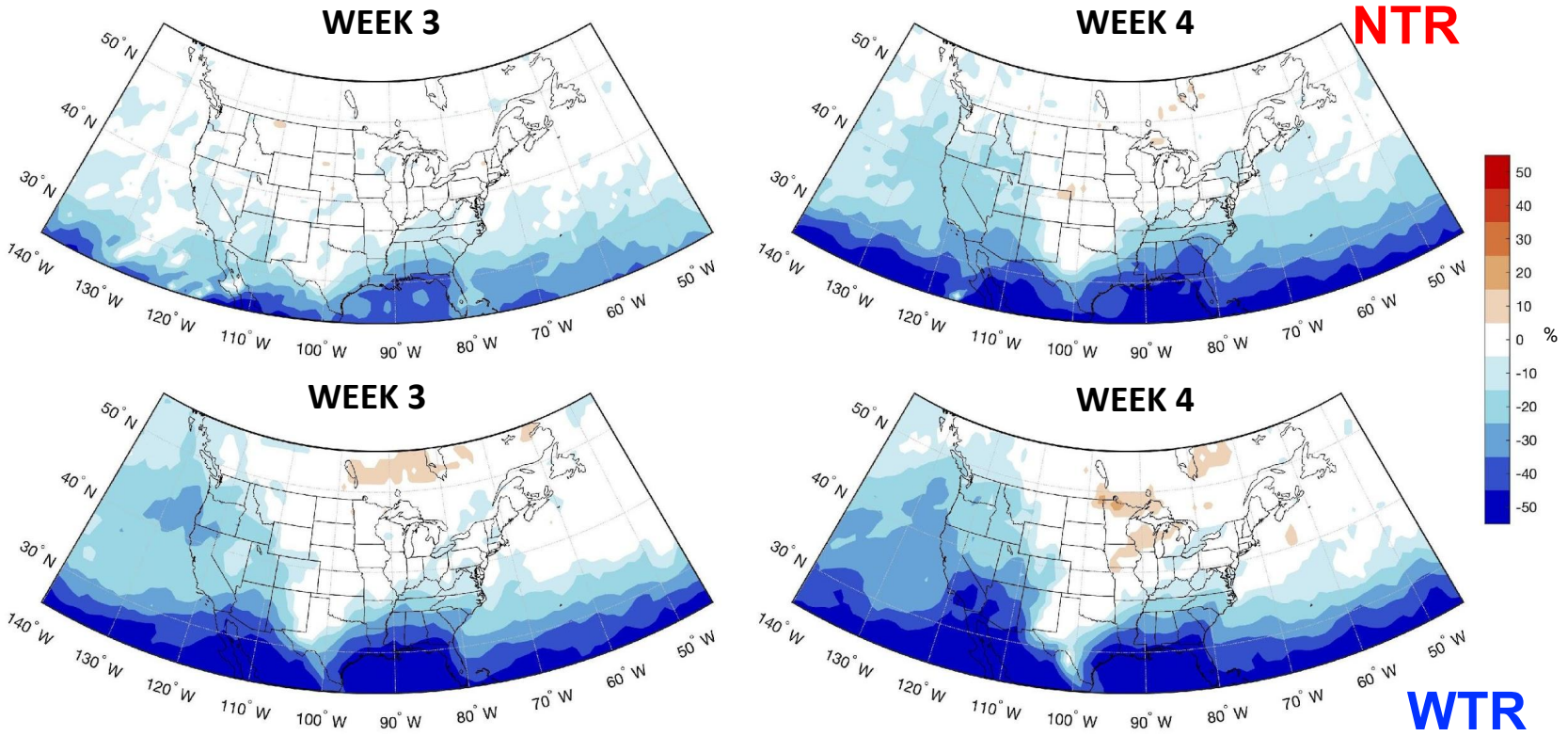
Blue shading denotes the precipitation △MAE (%) (NDJFM)

Do tropical errors influence S2S precipitation predictions outside the tropics?



Blue shading denotes the precipitation △MAE (%) (NDJFM)

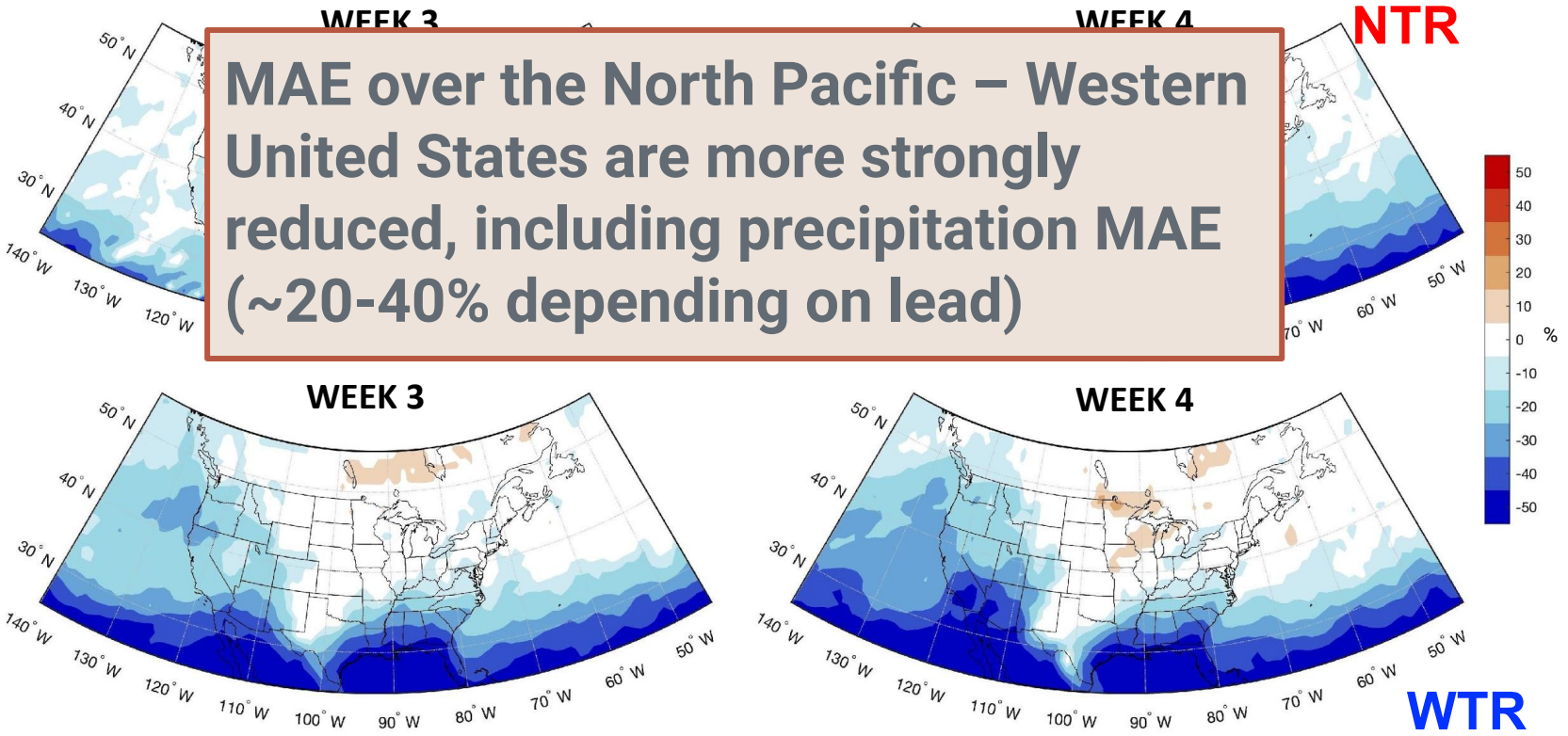
Do tropical errors influence S2S precipitation predictions outside the tropics?



Blue shading denotes the precipitation △MAE (%) (NDJFM)

Do tropical errors influence S2S precipitation predictions outside the tropics?

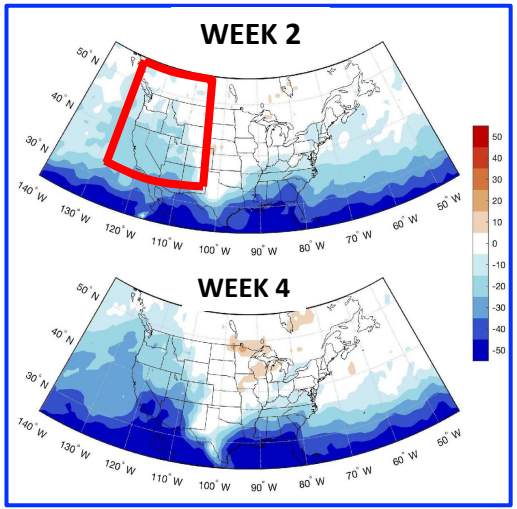
MAE over the North Pacific – Western United States are more strongly reduced, including precipitation MAE (~20-40% depending on lead)



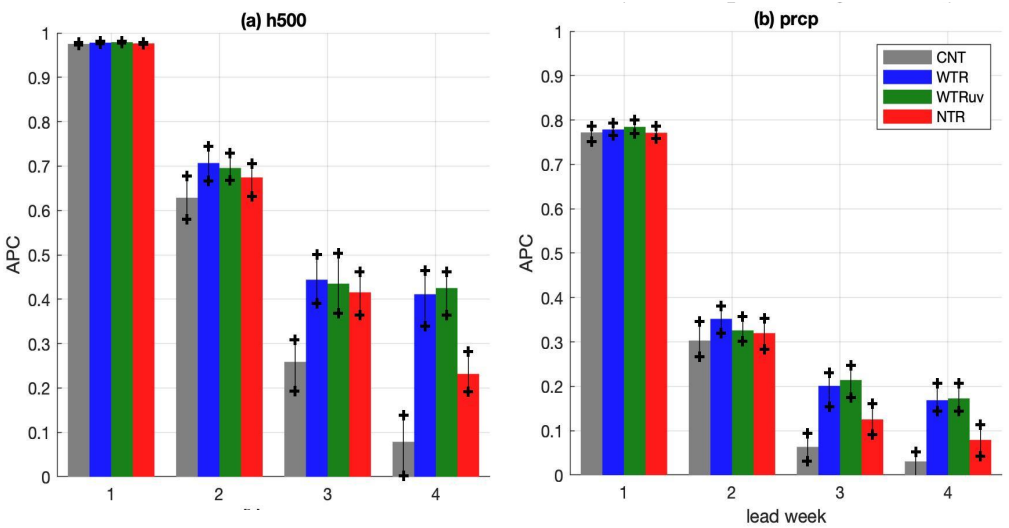
Blue shading denotes the precipitation △MAE (%) (NDJFM)

Do tropical errors influence S2S precipitation predictions outside the tropics?

Precipitation (PRCP) △MAE (%)



APC over "red" box



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

Today's talk

We will use tropical relaxation techniques to look into the following questions:

1) Do tropical errors influence S2S precipitation predictions outside the tropics?
2) **Are the error modulations outside the tropics dependent on the MJO?**

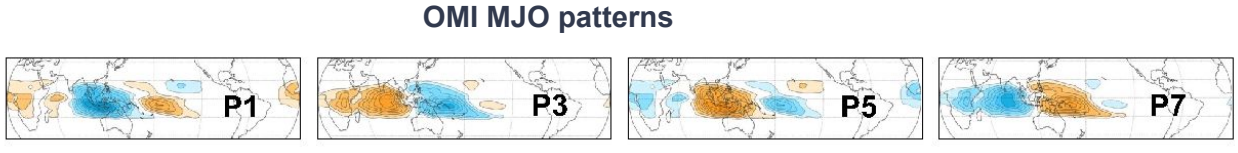
Then we will discuss our next steps…

Dias, J., Tulich, S. N., Gehne, M., & Kiladis, G. N. (2021). Tropical Origins of Weeks 2–4 Forecast Errors during the Northern Hemisphere Cool Season, Monthly Weather Review, 149(9), 2975-2991. https://journals.ametsoc.org/view/journals/mwre/149/9/MWR-D-21-0020.1.xml

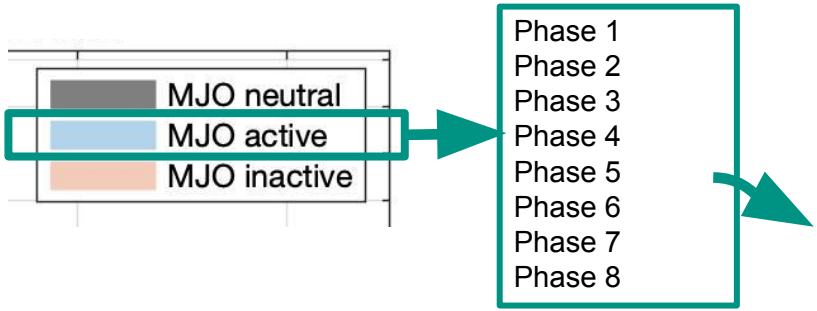
Hsiao, W.-T., Barnes, E. A., Maloney, E. D., Tulich, S. N., Dias, J., & Kiladis, G. N. (2022). Role of the tropics in state-dependent improvements of US West Coast NOAA Unified Forecast System precipitation forecasts. Geophysical Research Letters, 49, e2021GL096447. https://doi.org/10.1029/2021GL096447

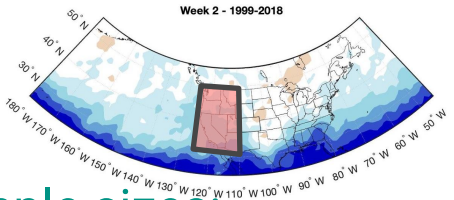
Are the error modulations outside the tropics dependent on the MJO?

- **We bin reforecasts depending on MJO amplitude and phase <u>at initialization</u>**



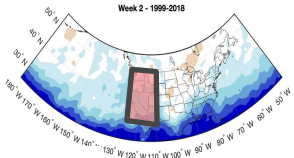
- **Weeks 1-4 APC are averaged depending on these MJO bins**



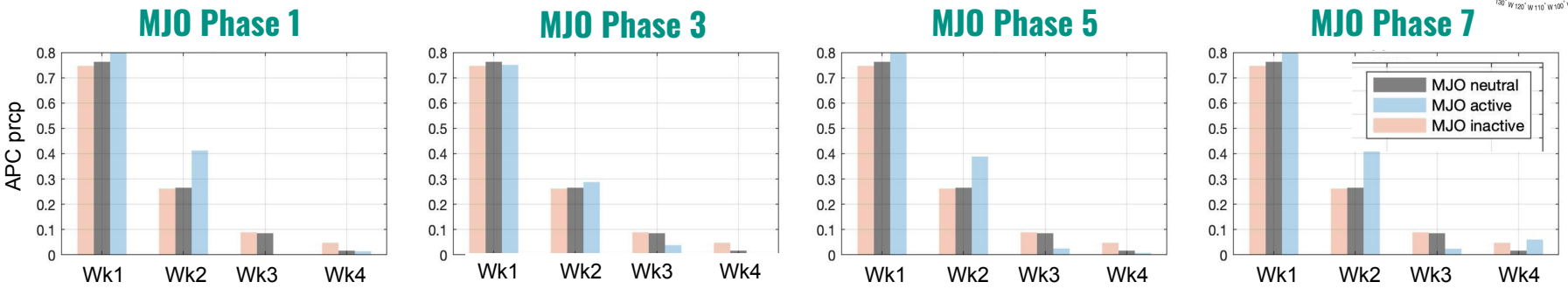


Note limited sample sizes:
620/3/8~25 cases per bin

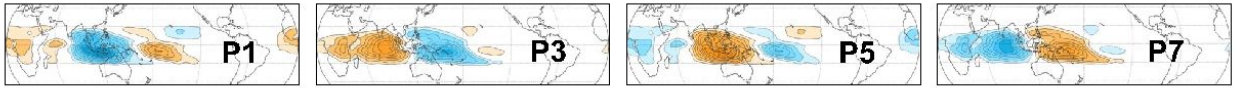
Are the error modulations outside the tropics dependent on the MJO?



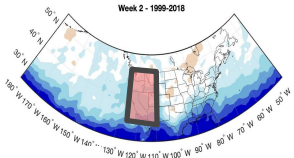
PRCP APC (WUSA) free reforecasts



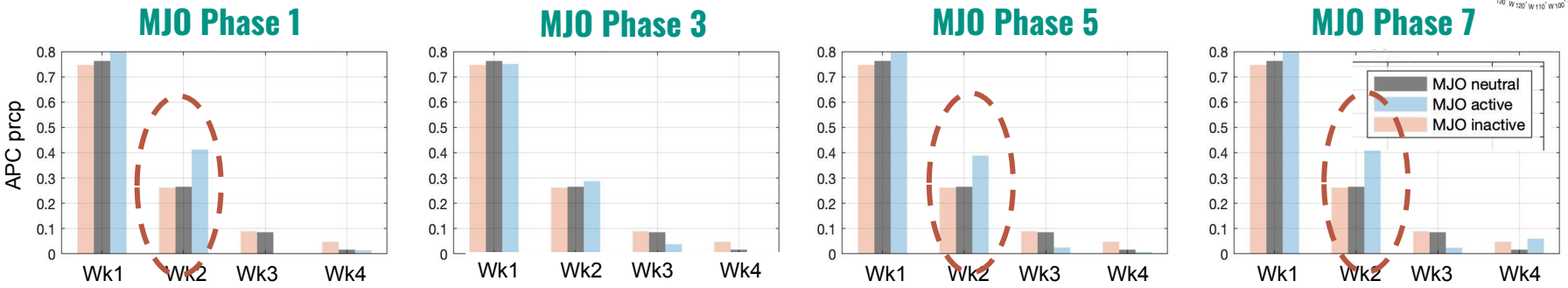
[no nudging!]



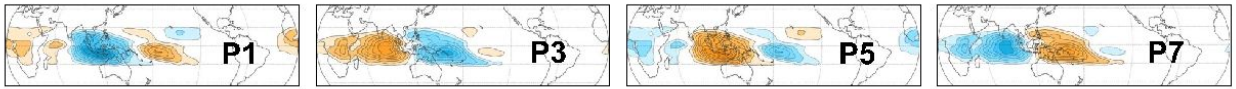
Are the error modulations outside the tropics dependent on the MJO?



PRCP APC (WUSA) free reforecasts

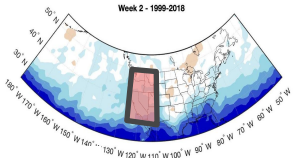


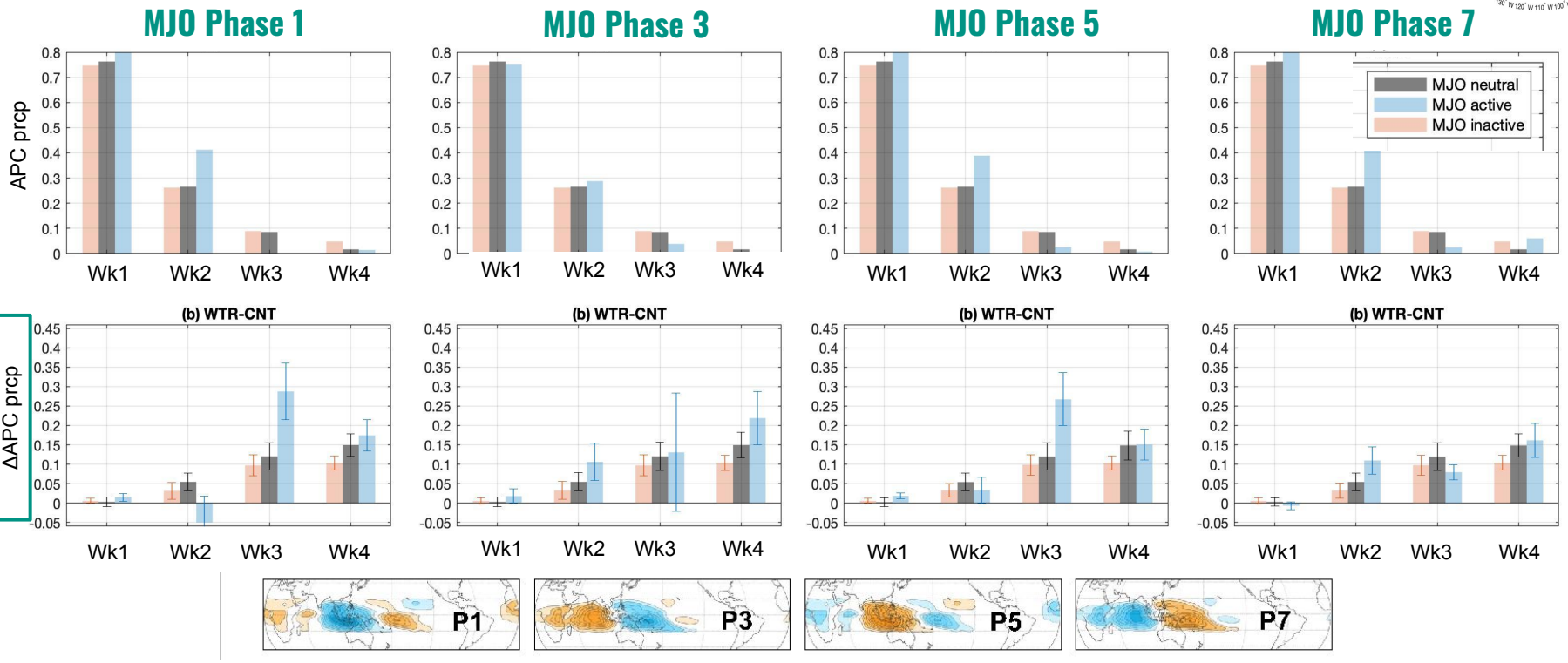
APC of Week 2 UFS precipitation predictions over Western USA tends to be higher when MJO is active at initialization time



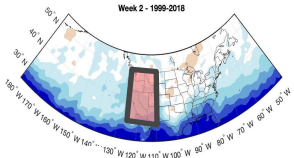
Are the error modulations outside the tropics dependent on the MJO?

PRCP APC (WUSA) free reforecasts





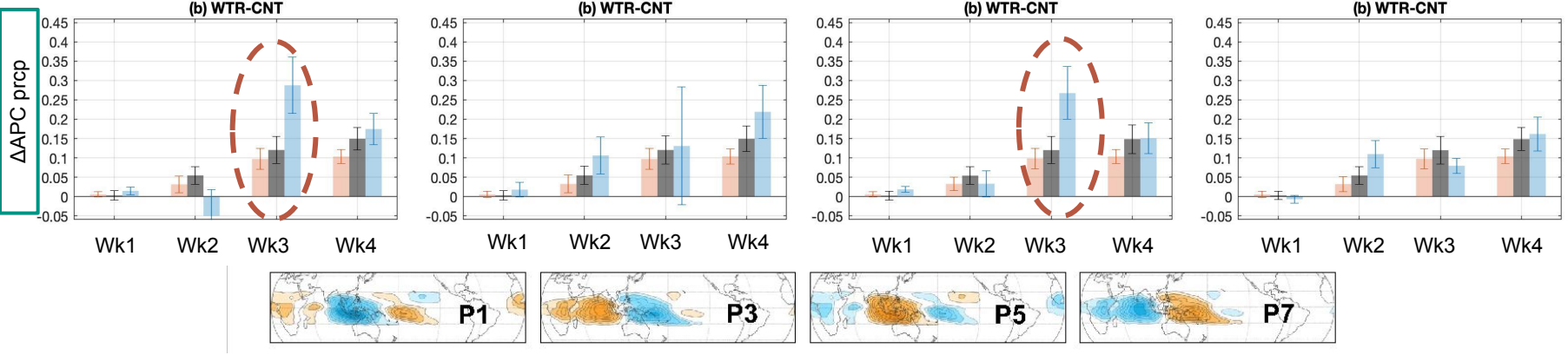
Are the error modulations outside the tropics dependent on the MJO?



PRCP APC (WUSA) free reforecasts

MJO Phase 1 | MJO Phase 3 | MJO Phase 5 | MJO Phase 7

With tropical nudging, skill of Week 3 UFS precipitation predictions over Western USA are improved when MJO is active at initialization time and in phases 1 and 5

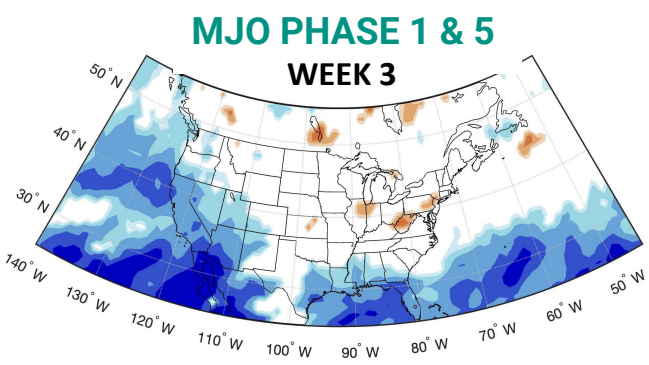


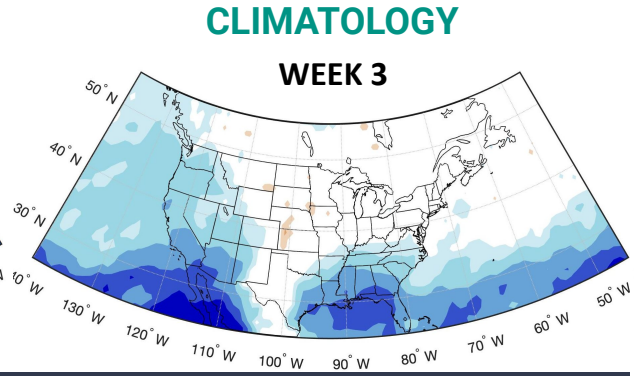
Summary

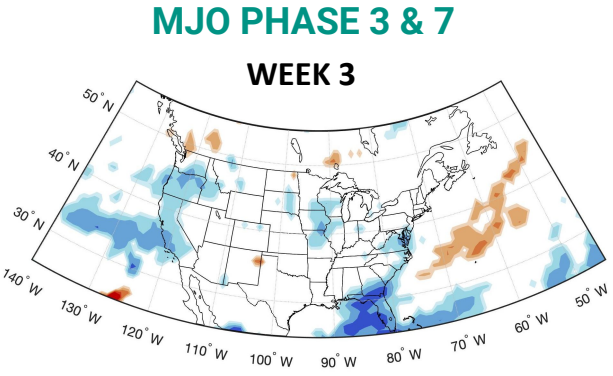
We produced 30-day UFS reforecasts initialized every 5 days for November-March from 1999-2018 where the tropical predictions are nudged to ERAi. Comparison between free and tropical nudged reforecasts suggests that:

- Tropical nudging tends to have a positive impact in S2S N.H midlatitude predictions, particularly on Western USA precipitation predictions.

- The MJO plays are role on how effective tropical nudging is in improving subseasonal predictions over the Northern Hemisphere







Current work and Next Steps

- Implementing nudging in the coupled UFS (Prototype 8);
- Similar set of reforecast experiments as shown here but with P8 (MJO is much improved in P8 in comparison to GFSv15) + relaxation to observed tropical SST and predicted SSTs;
- Entire tropics is relaxed to the predictable component of the tropical subseasonal variability (using a ML based filter/LIM);
- A set of MJO events will be used as basis for a limited experiment at full operational resolution;