# Tropical origins of subseasonal forecast errors for high-impact precipitation events over California during winter 2022–2023

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[2]Cooperative Institute for Research in the Environmental Sciences, University of Colorado - Boulder

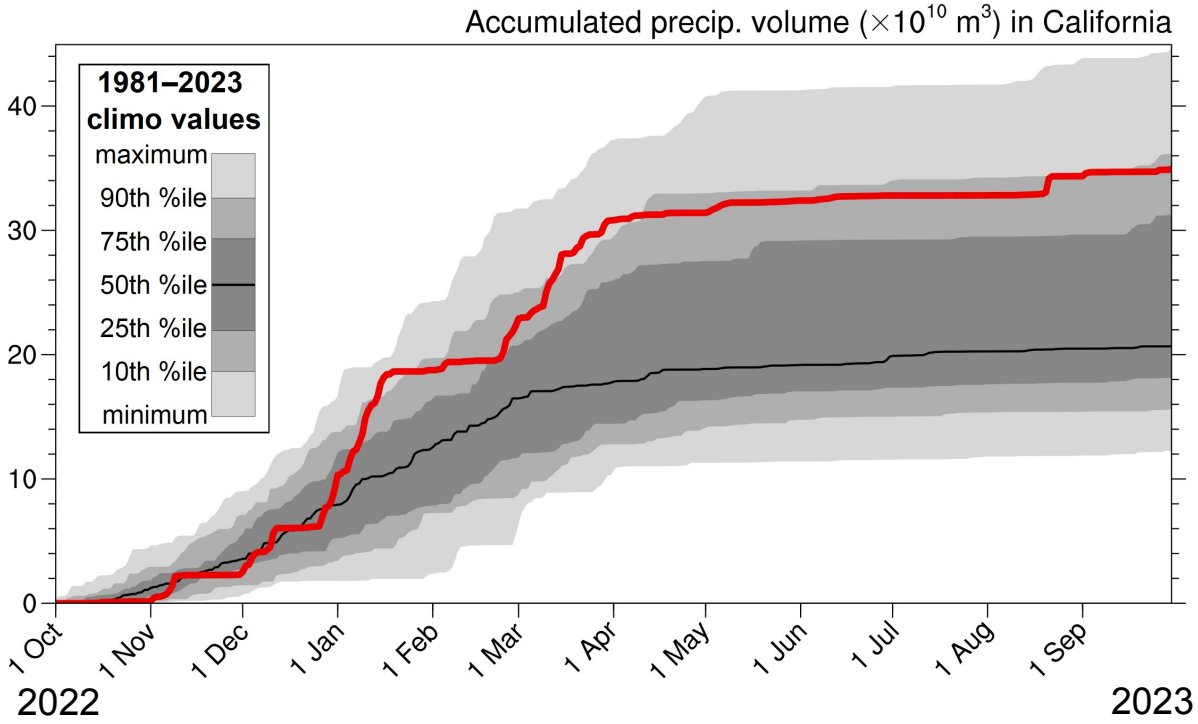
[3]NOAA Climate Prediction Center

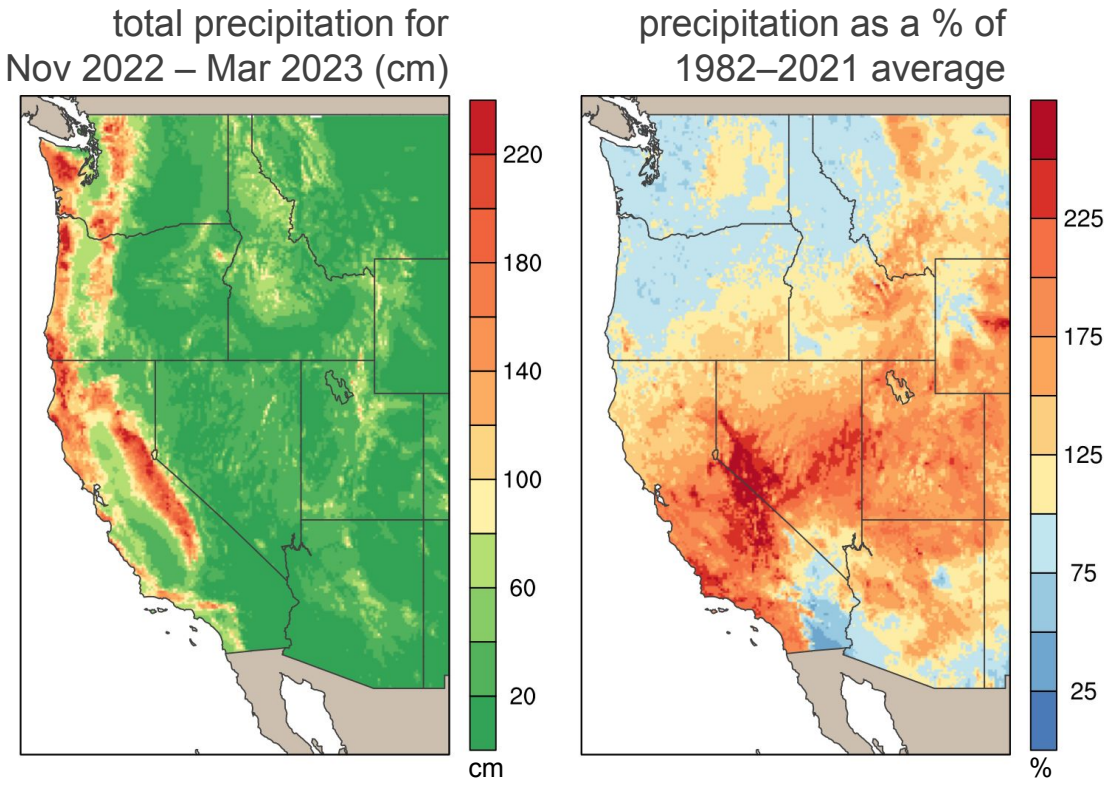
S2S Community Workshop

Boulder, Colorado, USA

6 June 2024

# Extreme wet conditions in California during winter 2022–2023 ameliorated drought and caused high-impact flooding

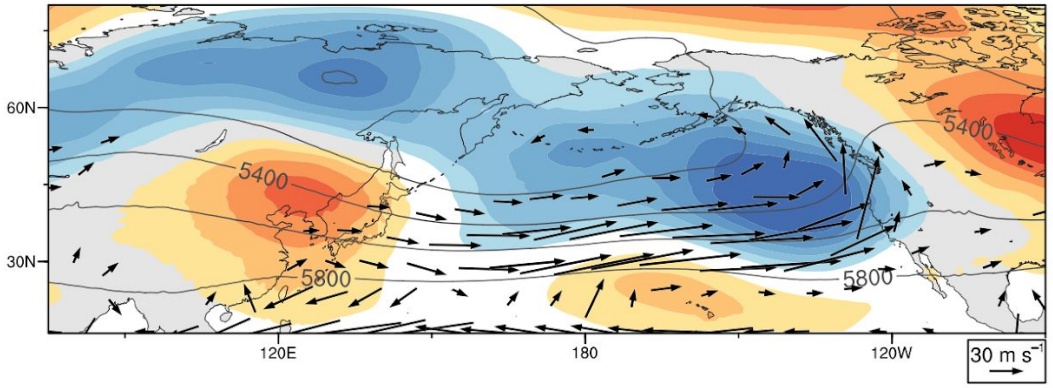


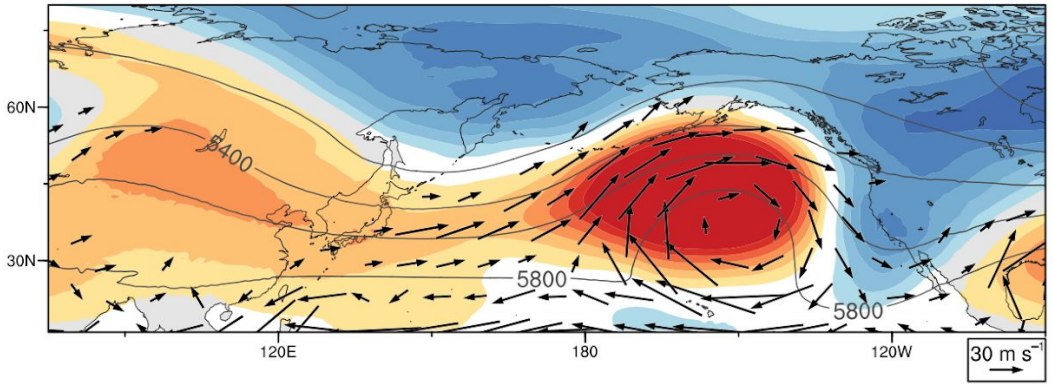

Data source: PRISM

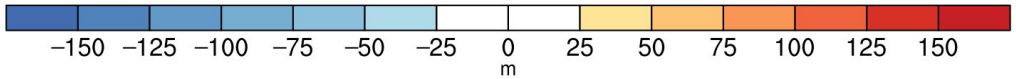
Precipitation episodes were characterized by serial clustering of synoptic systems within persistent large-scale flow patterns preceded by Madden-Julian Oscillation (MJO) events

**30 Dec 2022 – 13 Jan 2023**



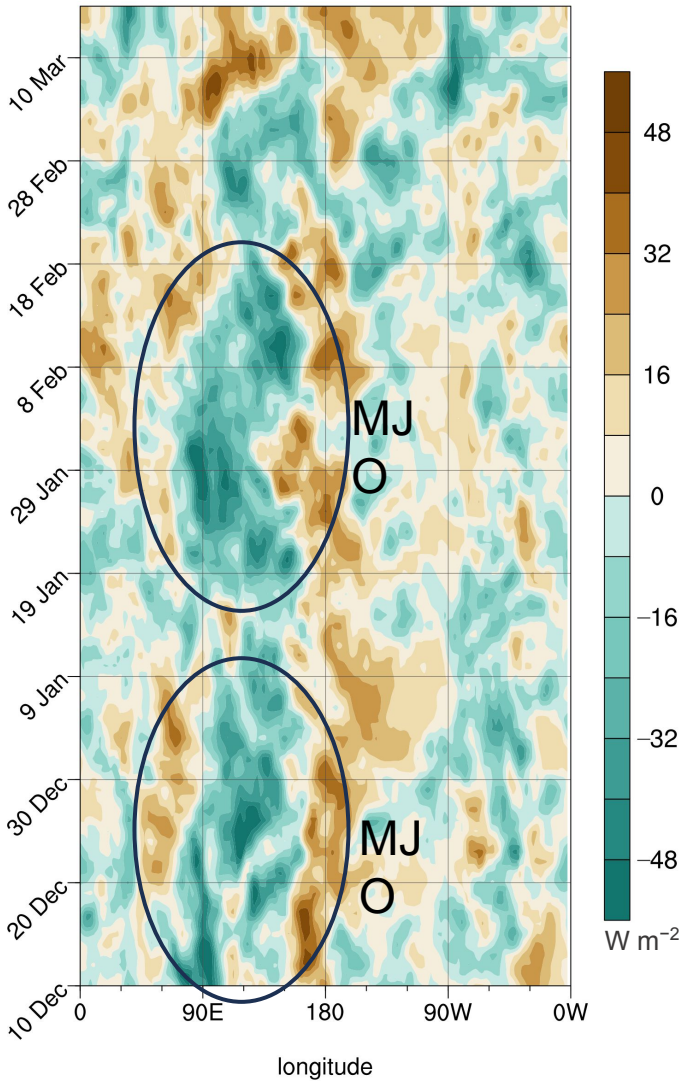

**17 Feb – 2 Mar 2023**




*500-hPa Z (contour) & Z anomaly (shading);*
*850-hPa moisture flux vectors from ERA5*

*OLR anomaly: 15°S–15°N*



These patterns and the associated western U.S. precipitation were poorly represented in weeks 3–4 forecasts

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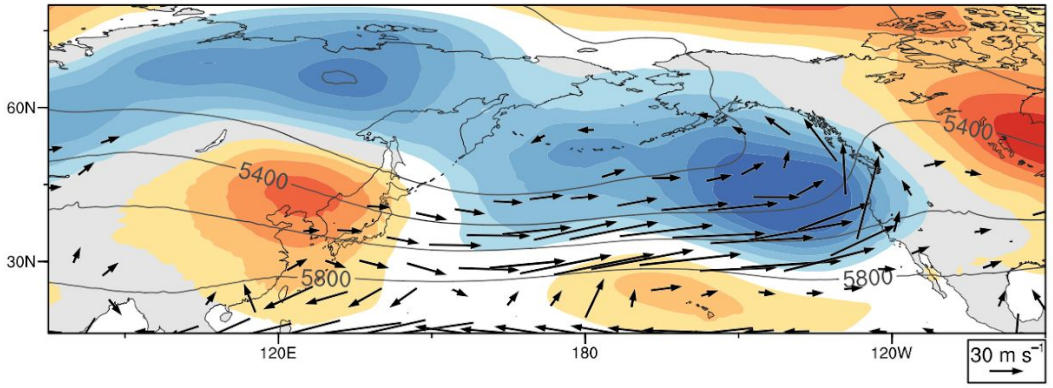


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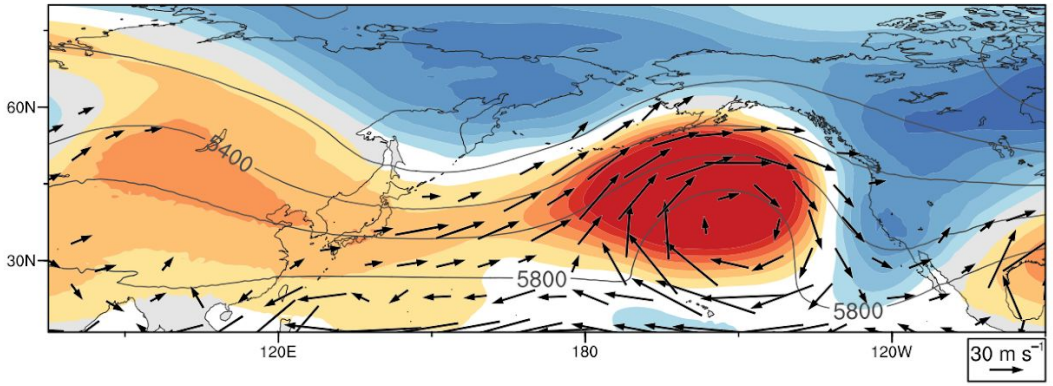


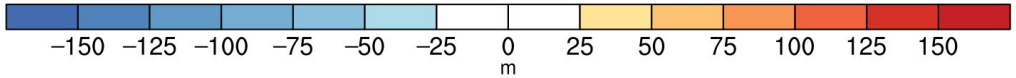


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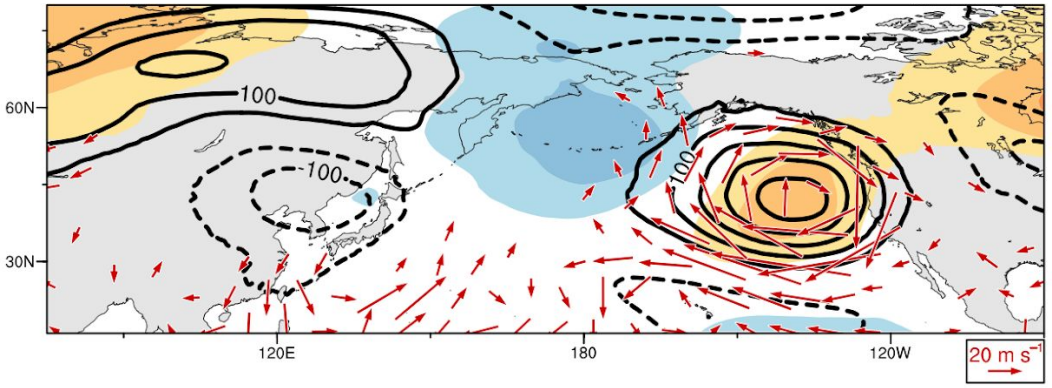
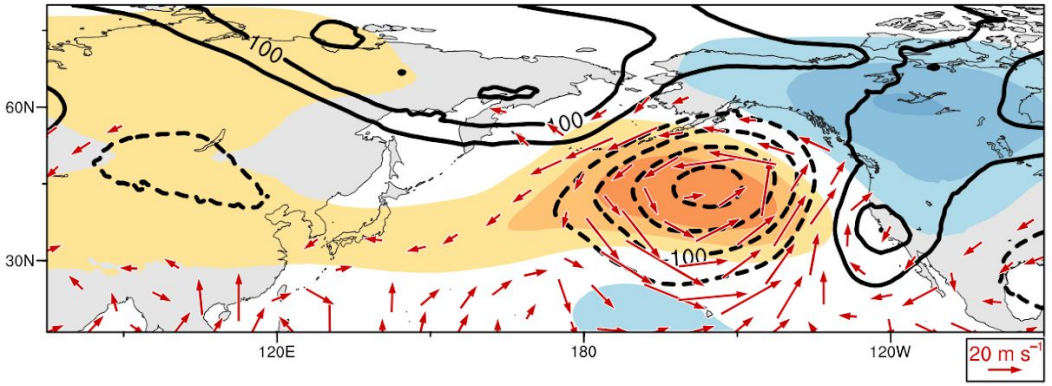
GEFSv12 forecast initialized 15 Dec 2022




GEFSv12 forecast initialized 2 Feb 2023




*500-hPa Z anomaly (shading) & Z errors (contours);*
*850-hPa moisture flux error vectors from GEFSv12 forecast*

## Hypothesis

Errors in the tropics, particularly those related to the MJO, played a major role in the development of errors in subseasonal forecasts for the California precipitation events.

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## Method

- Reforecast experiments conducted in which model state variables in the tropics are nudged to ERA5 reanalysis
- 35-day reforecasts run with the NOAA Unified Forecast System version HR1 with C96 resolution (~1° lat/lon), including the effects of air-sea coupling.
- 30-member ensemble forecasts initialized with ERA5 at 0000 UTC 15 Dec 2022 & 0000 UTC 2 Feb 2023
- Impacts of nudging diagnosed through analysis of ensemble means

## Hypothesis

Errors in the tropics, particularly those related to the MJO, played a major role in the development of errors in subseasonal forecasts for the California precipitation events.

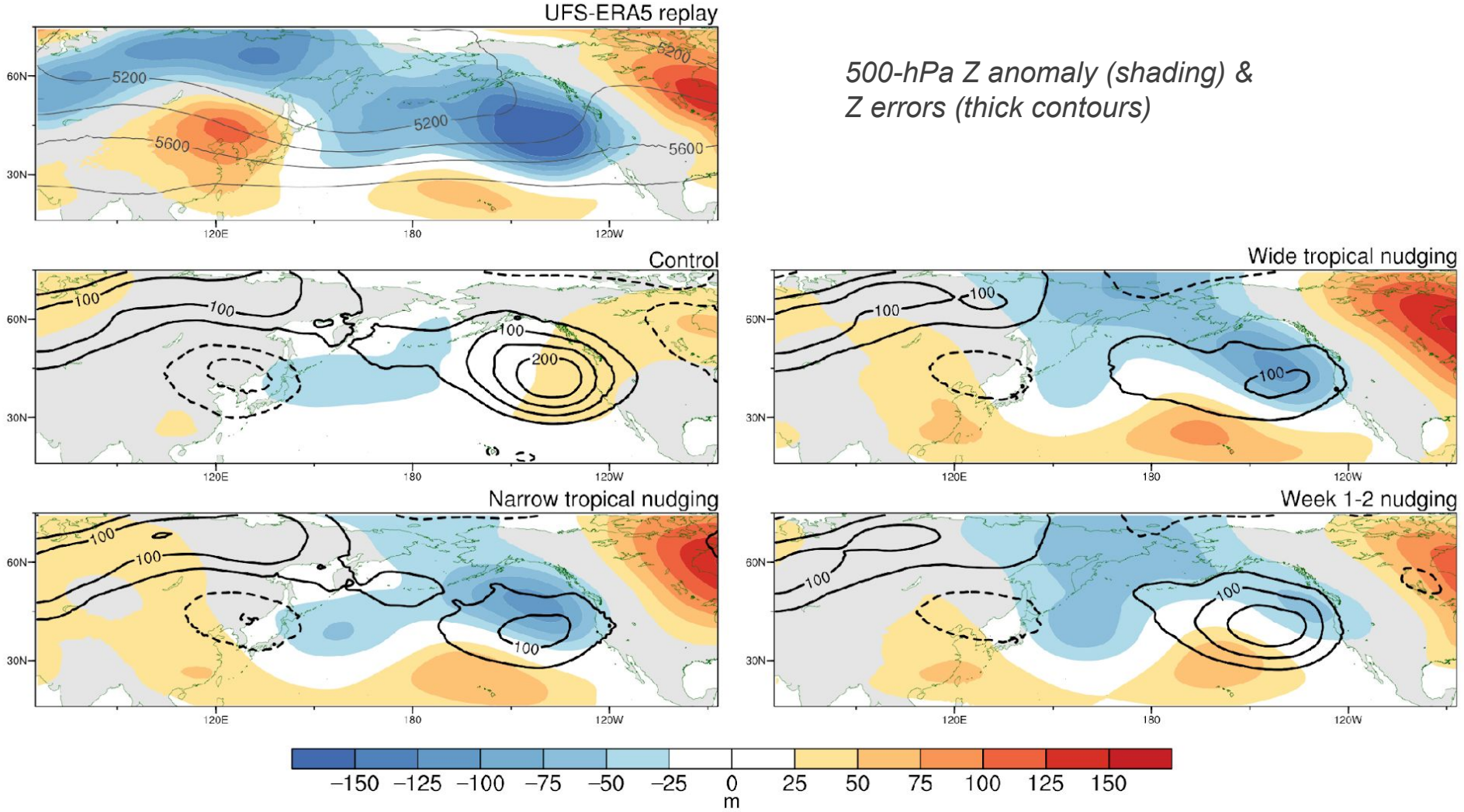
## Reforecast experiments

| | |
|---|---|
| **Wide tropical nudging** | Model state variables in the tropics from 10°S and 10°N are fully nudged to the ERA5 reanalysis, with the degree of nudging reduced to zero between 10° S/N and 30°S/N |
| **Narrow tropical nudging** | Full nudging is restricted to 5°S–5°N, and tapers to zero 20°S/N. |
| **Weeks 1–2 nudging** | Full nudging between 10°S/N for weeks 1–2 of the forecast; no nudging thereafter. |
| **Control** | Model is run freely without nudging. |
| **UFS-ERA5 replay** | Model is nudged to ERA5 globally; serves as the verification dataset. |

*See Dias et al. (2021) for more details on the methods

# Nudging the tropics improves forecasts of the extratropical flow in weeks 3–4

Forecast initialized at 0000 UTC 15 Dec 2022, valid: 30 Dec 2022 – 12 Jan 2023




*500-hPa Z anomaly (shading) &*
*Z errors (thick contours)*

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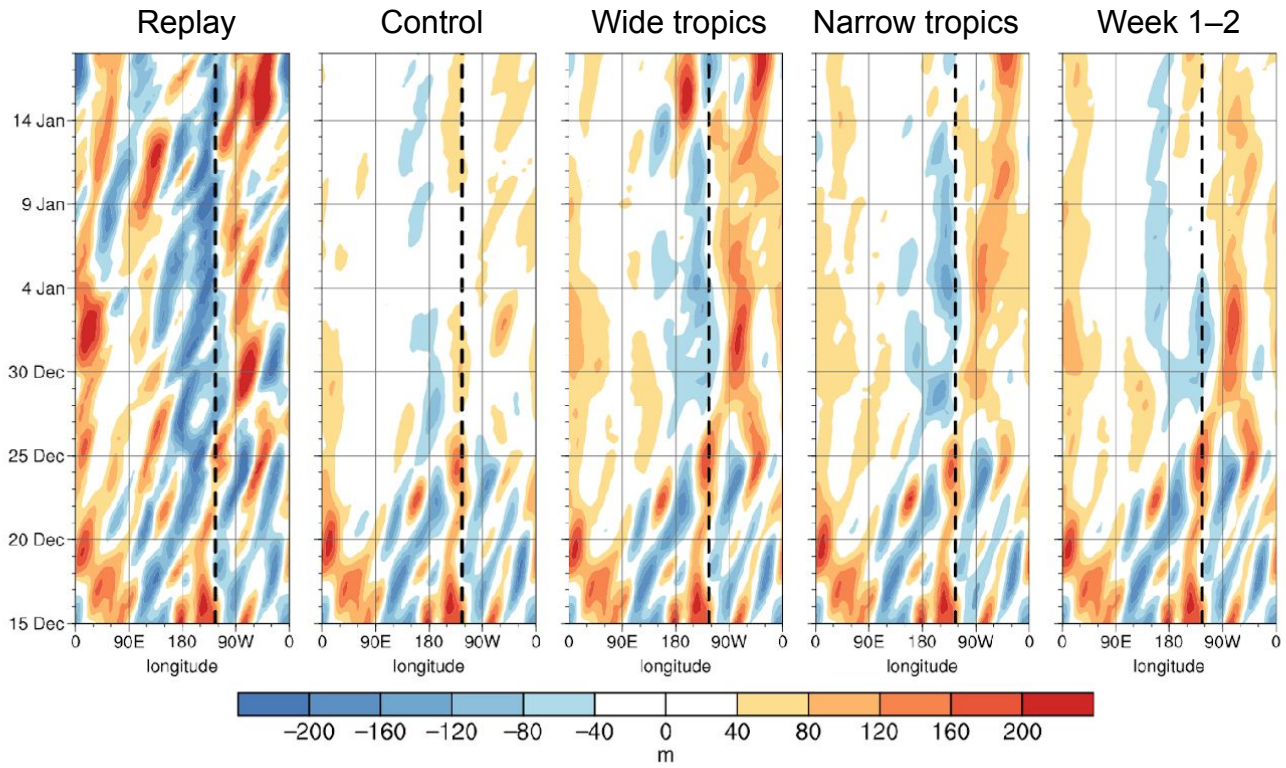
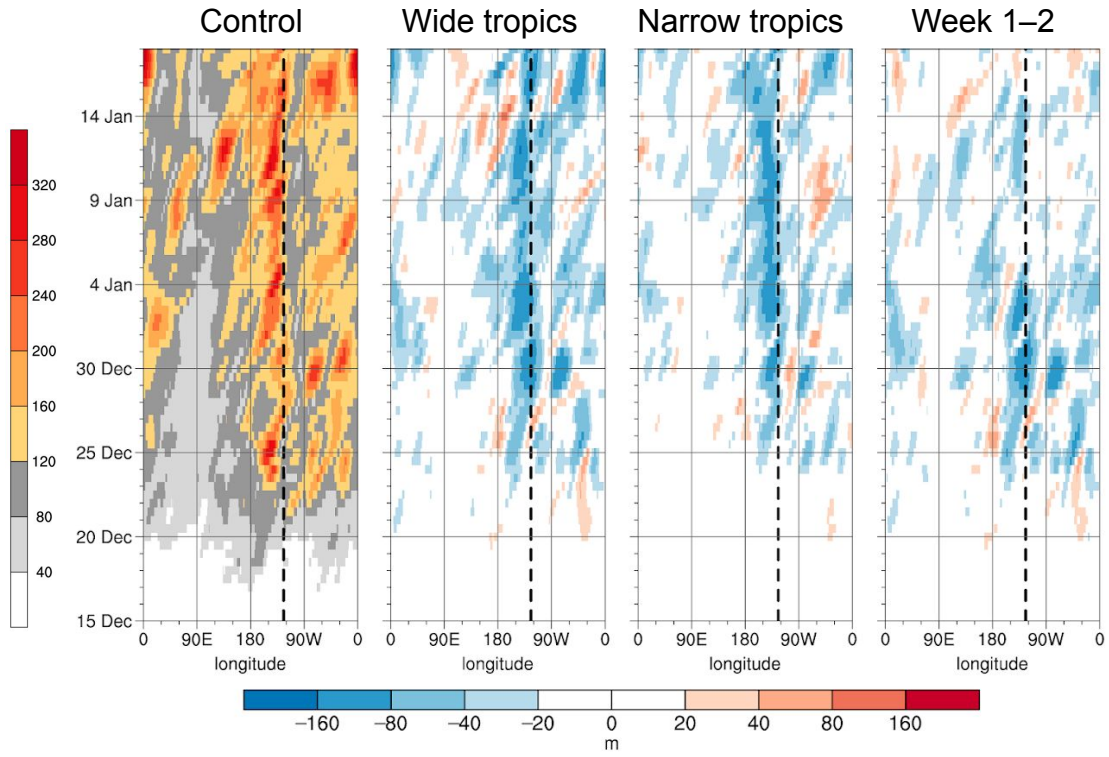



*500-hPa Z anomaly averaged for 35–55°N*

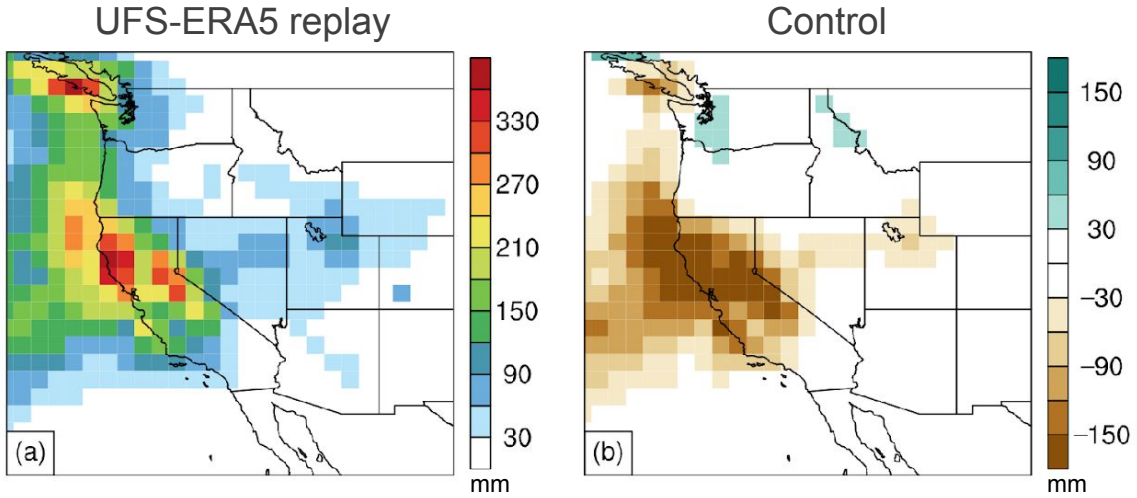



*MAE of 500-hPa Z in control forecast (leftmost) and differences in the MAE relative to the control forecast for the nudging experiments*

# Nudging the tropics improves forecasts of western U.S. precipitation in weeks 3–4

Forecast initialized at 0000 UTC 15 Dec 2022,
valid: 30 Dec 2022 – 12 Jan 2023

*(a) Accumulated precip. from UFS-ERA5 replay; (b) Error in precip. for control forecast*



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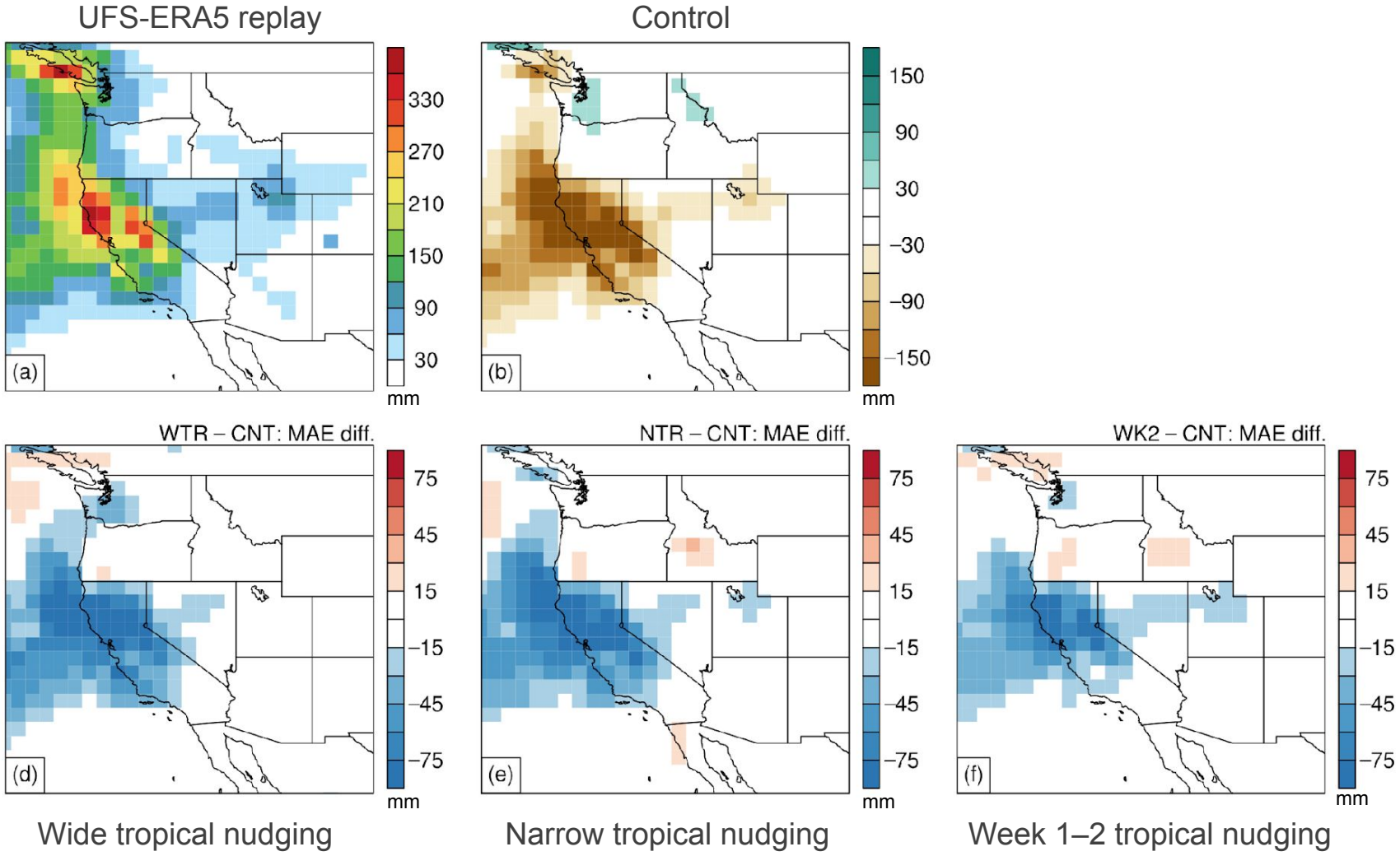
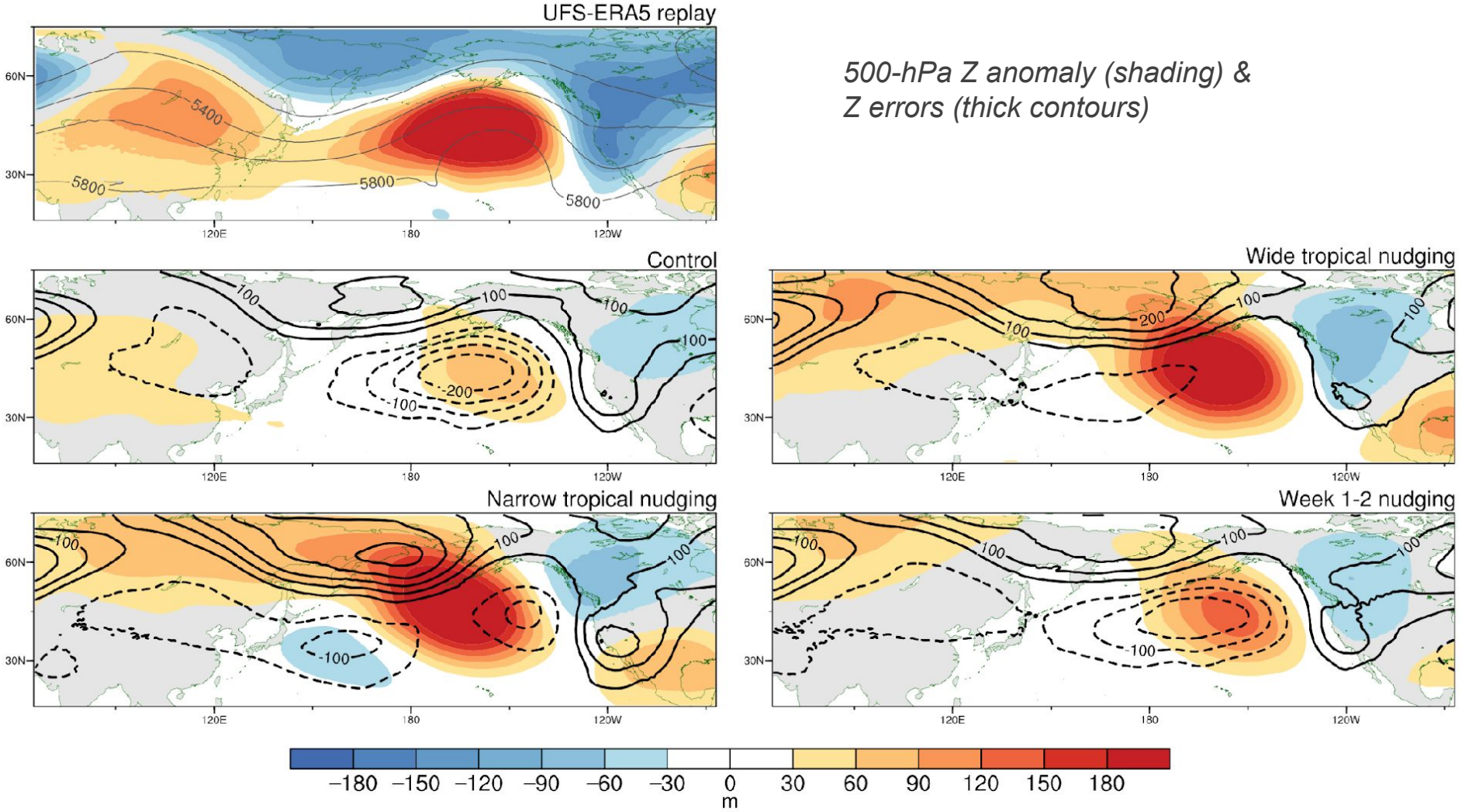
*(d)–(f) Difference in MAE for accum. precipitation relative to control forecast for the nudged forecasts*



# Nudging the tropics improves forecasts of the extratropical flow in weeks 3–4

Forecast initialized at 0000 UTC 2 Feb 2023, valid: 20 Feb – 2 Mar 2023




*500-hPa Z anomaly (shading) &*
*Z errors (thick contours)*

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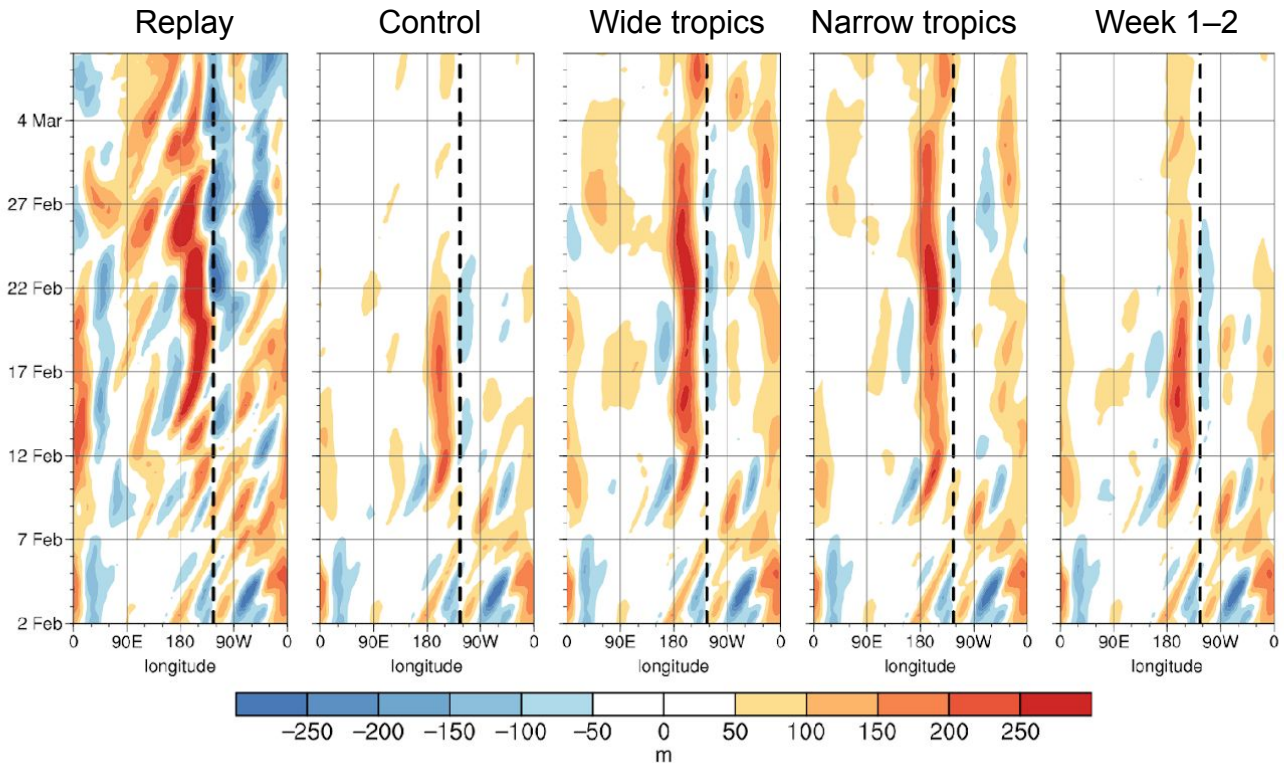
Forecast initialized at 0000 UTC 2 Feb 2023

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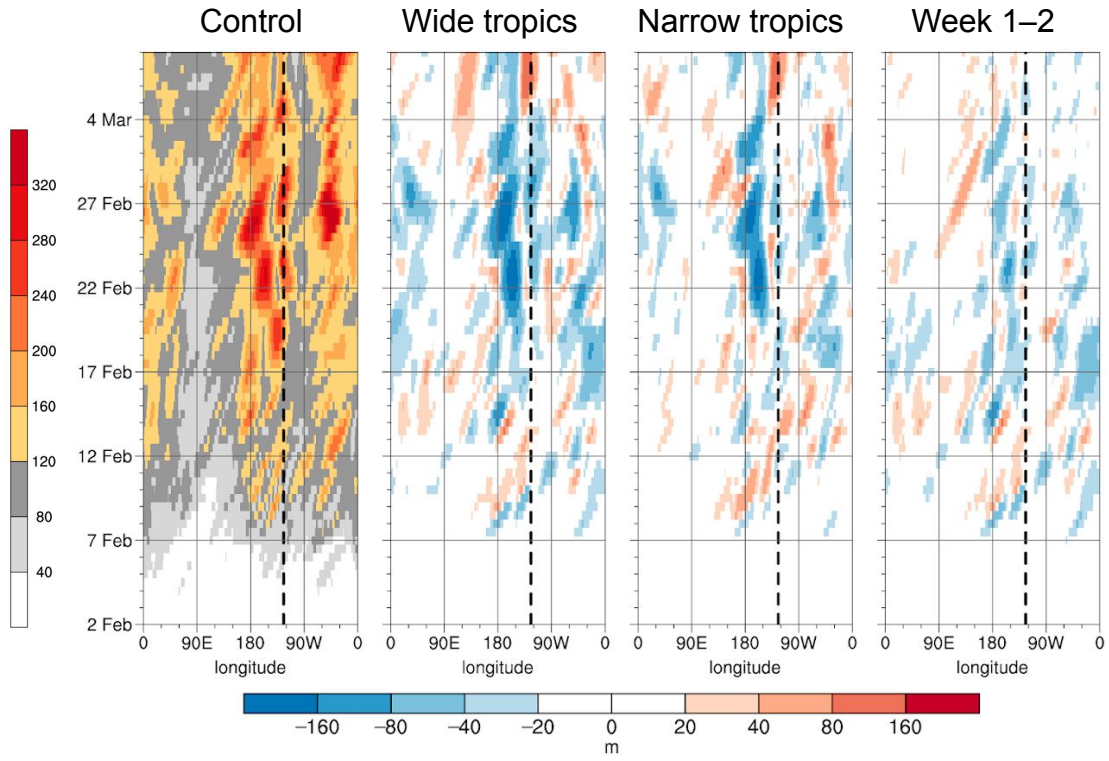


*MAE of 500-hPa Z in control forecast (leftmost) and differences in the MAE relative to the control forecast for the nudging experiments*

# Nudging the tropics improves forecasts of western U.S. precipitation in weeks 3–4

Forecast initialized at 0000 UTC 2 Feb 2023,
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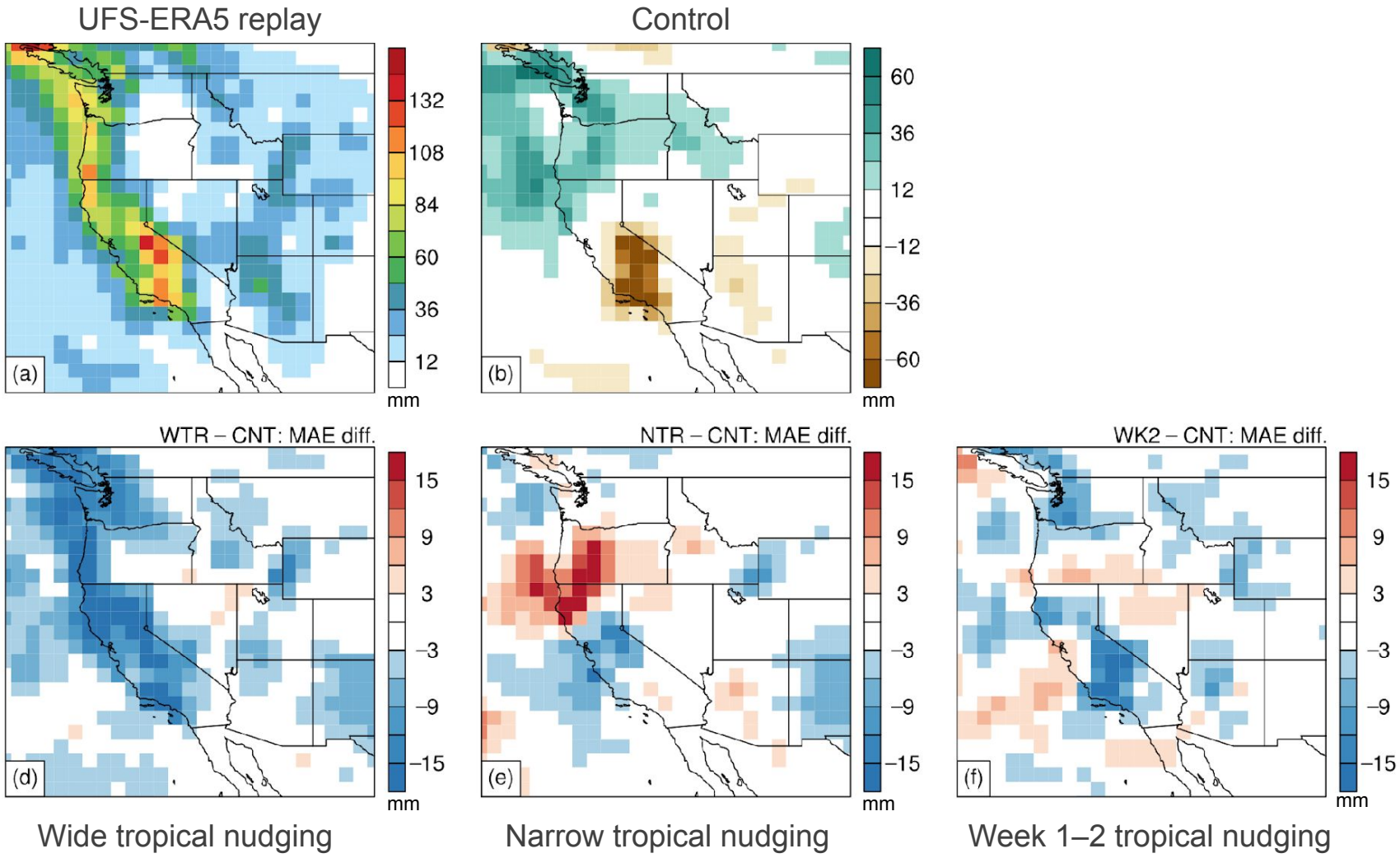
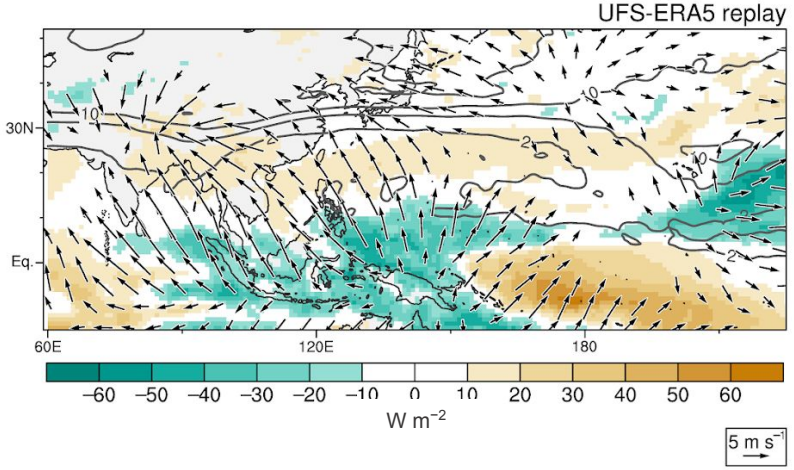
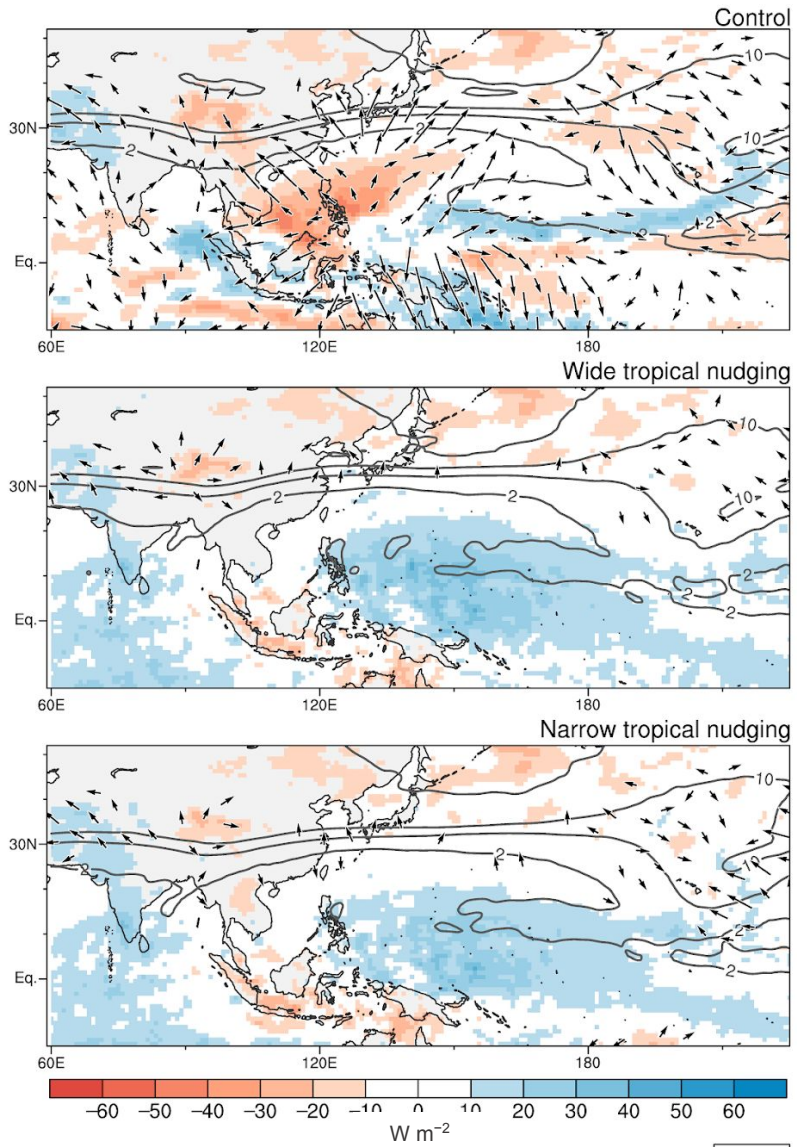


# Nudging corrects errors in tropical convection and divergent outflow associated with the MJO




*OLR anomalies (shading),*
*200-hPa abs. vorticity (contours),*
*200-hPa divergent wind (vectors)*

Forecast initialized at 0000 UTC 2 Feb 2023, valid: 5–15 Feb 2023




*OLR errors (shading) and 200-hPa divergent wind errors (vectors)*

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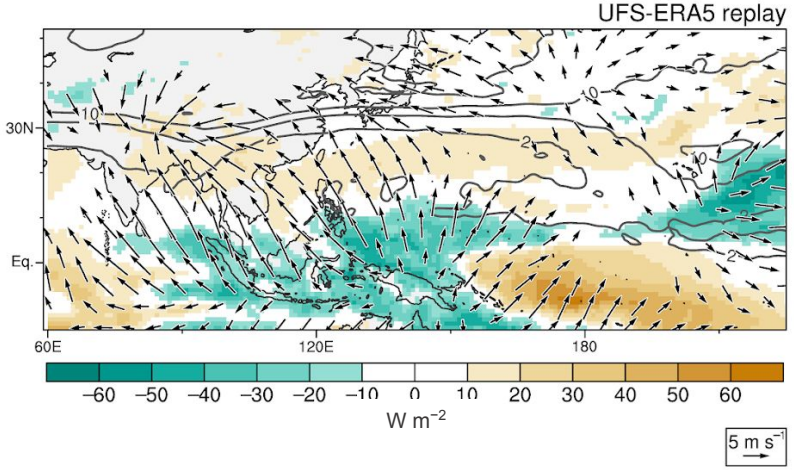


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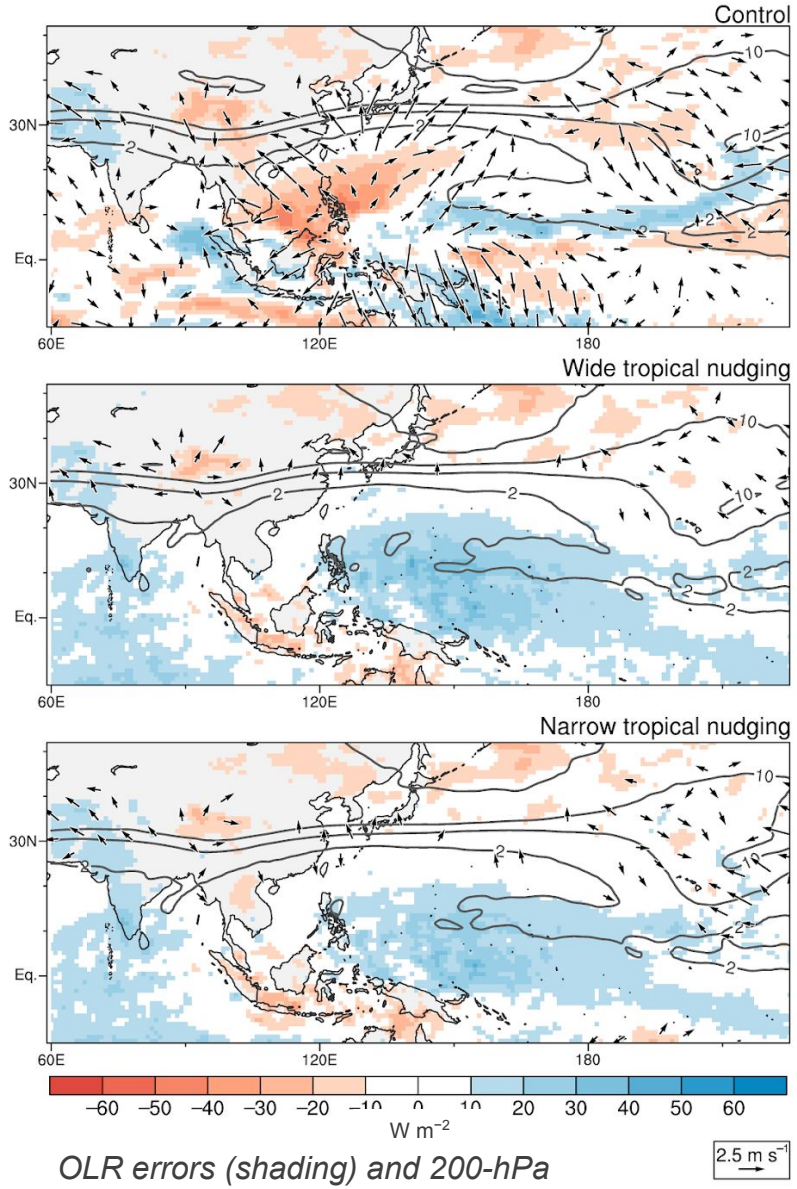
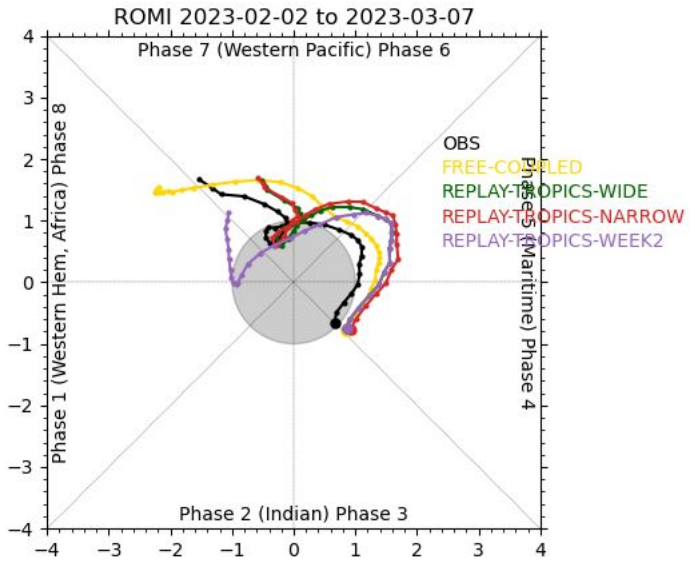
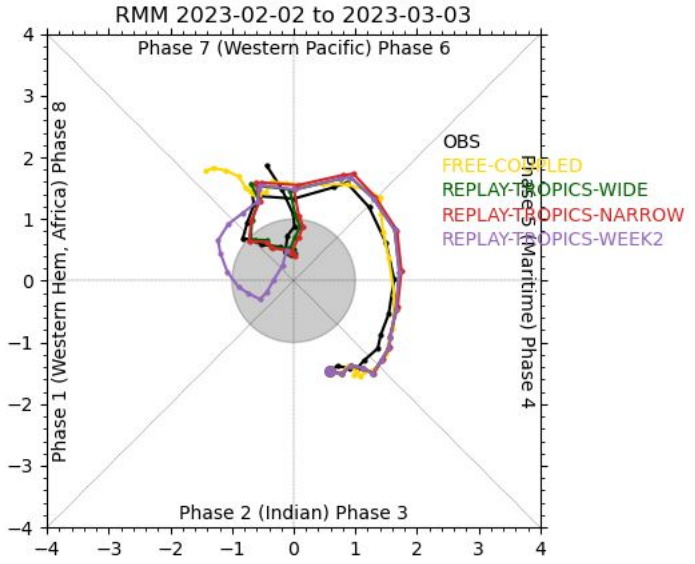



*OLR errors (shading) and 200-hPa divergent wind errors (vectors)*

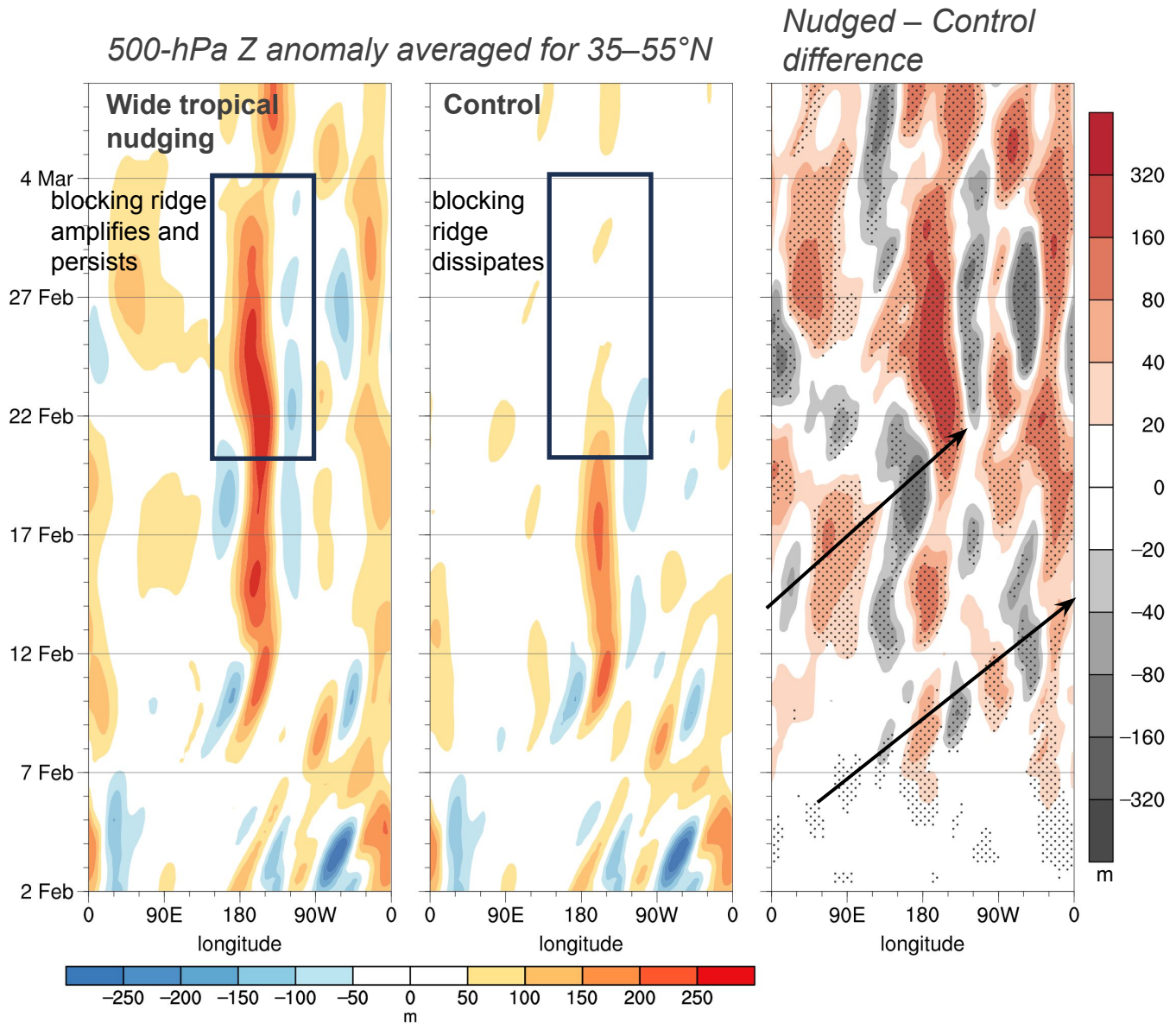
# …though the MJO seems to be captured well regardless of nudging



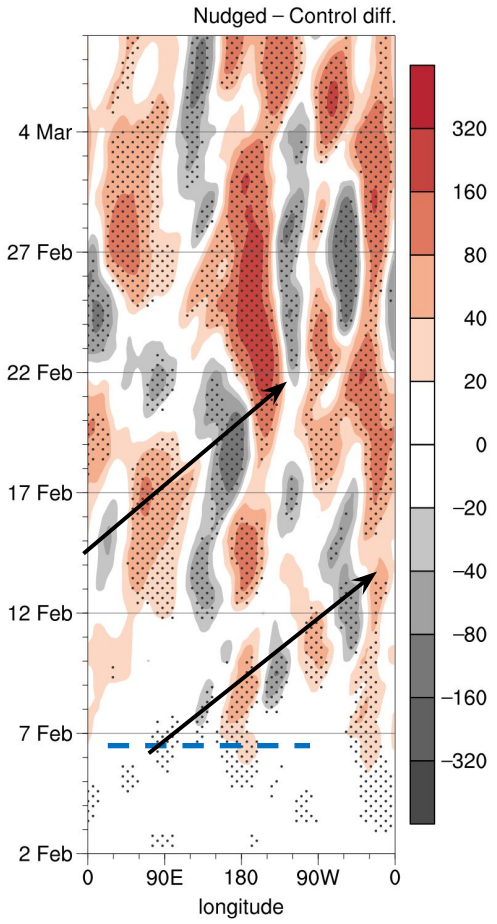



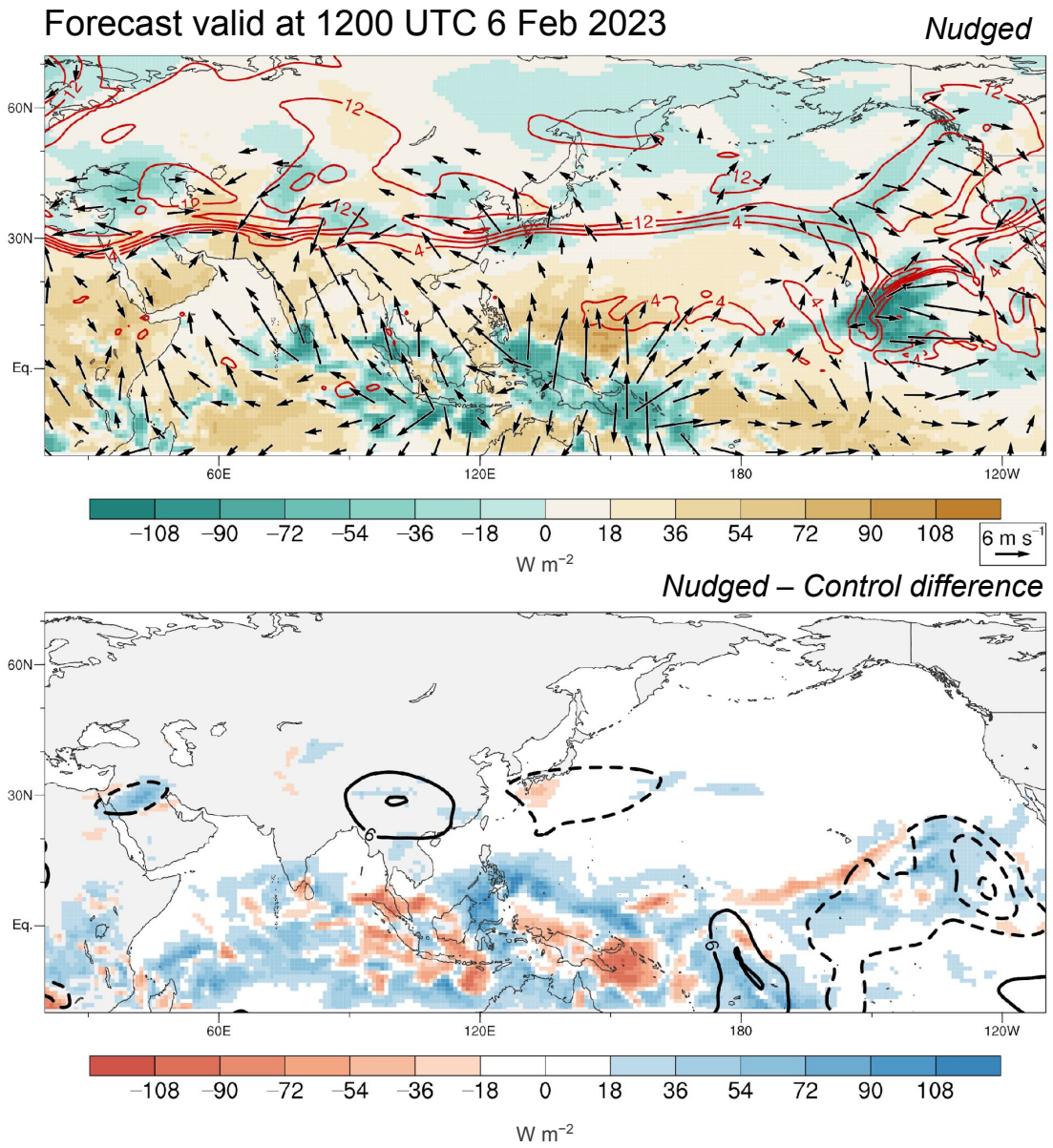
# How does a “perfect” representation of the tropics lead to improvements in subseasonal forecasts of the extratropical flow and western U.S. precipitation?

Forecast initialized at
0000 UTC 2 Feb 2023



# Comparison of the nudged and control forecasts




*OLR anomalies (shading), 200-hPa abs. vorticity (contours), 200-hPa divergent wind (vectors) from the nudged forecast*

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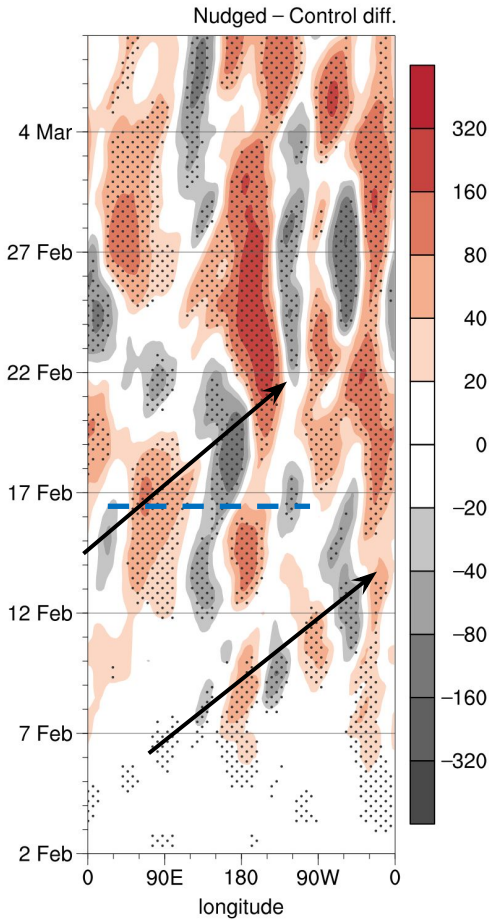


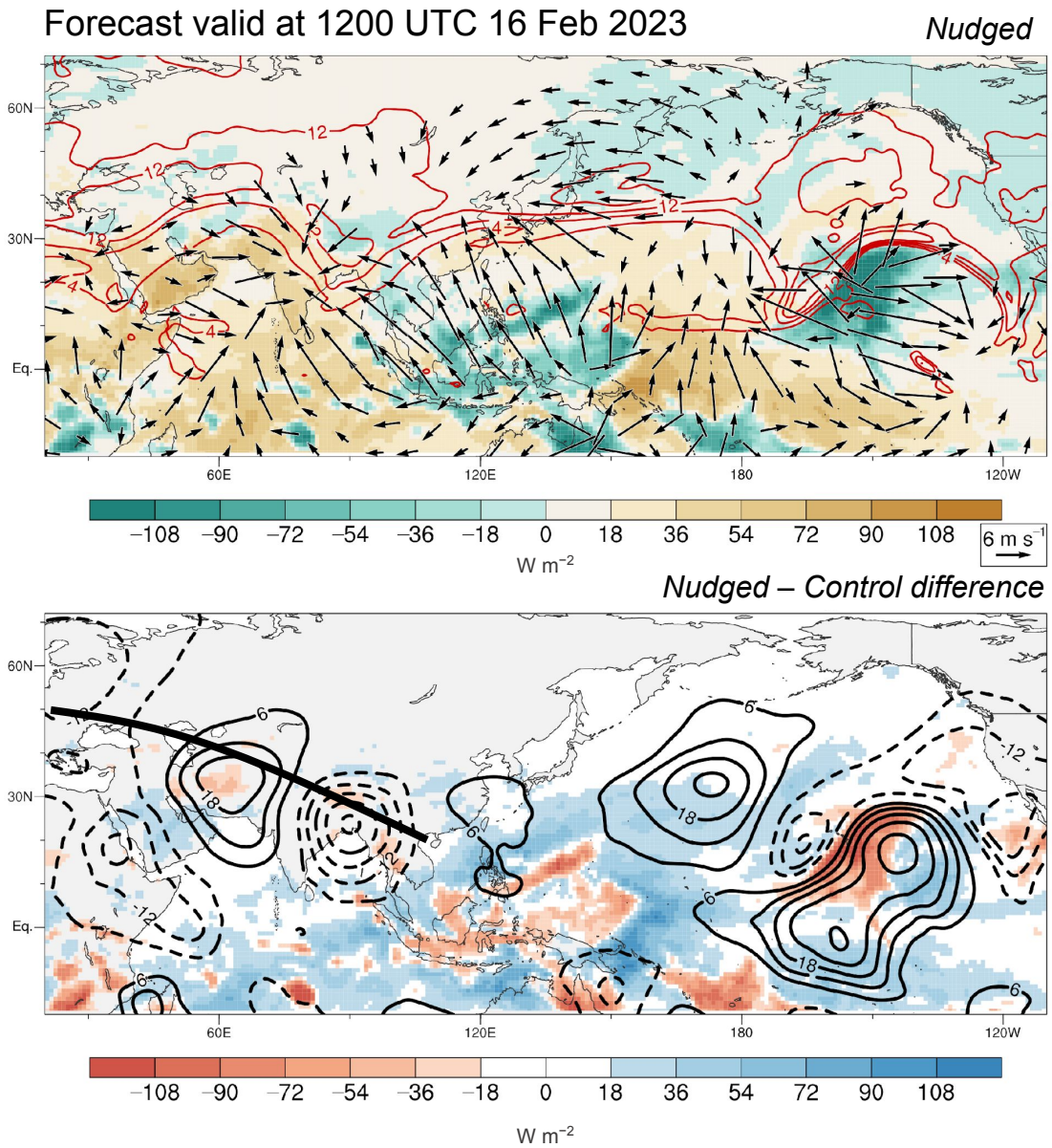


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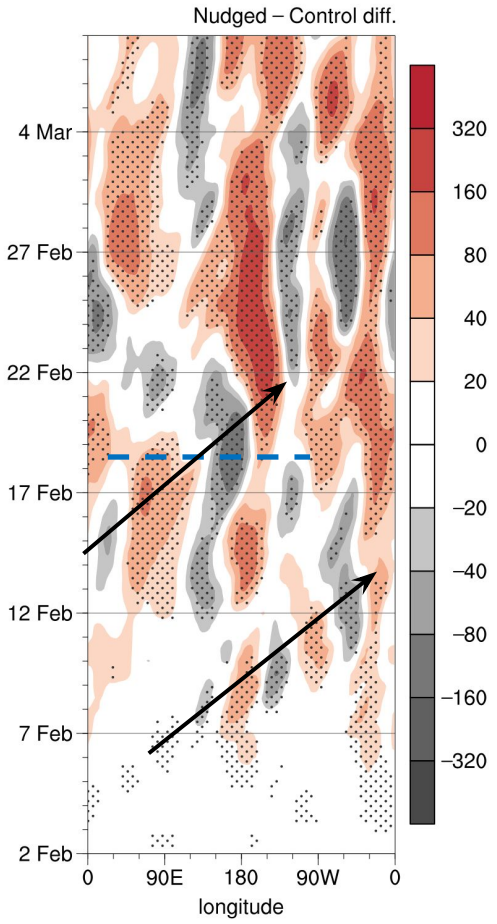


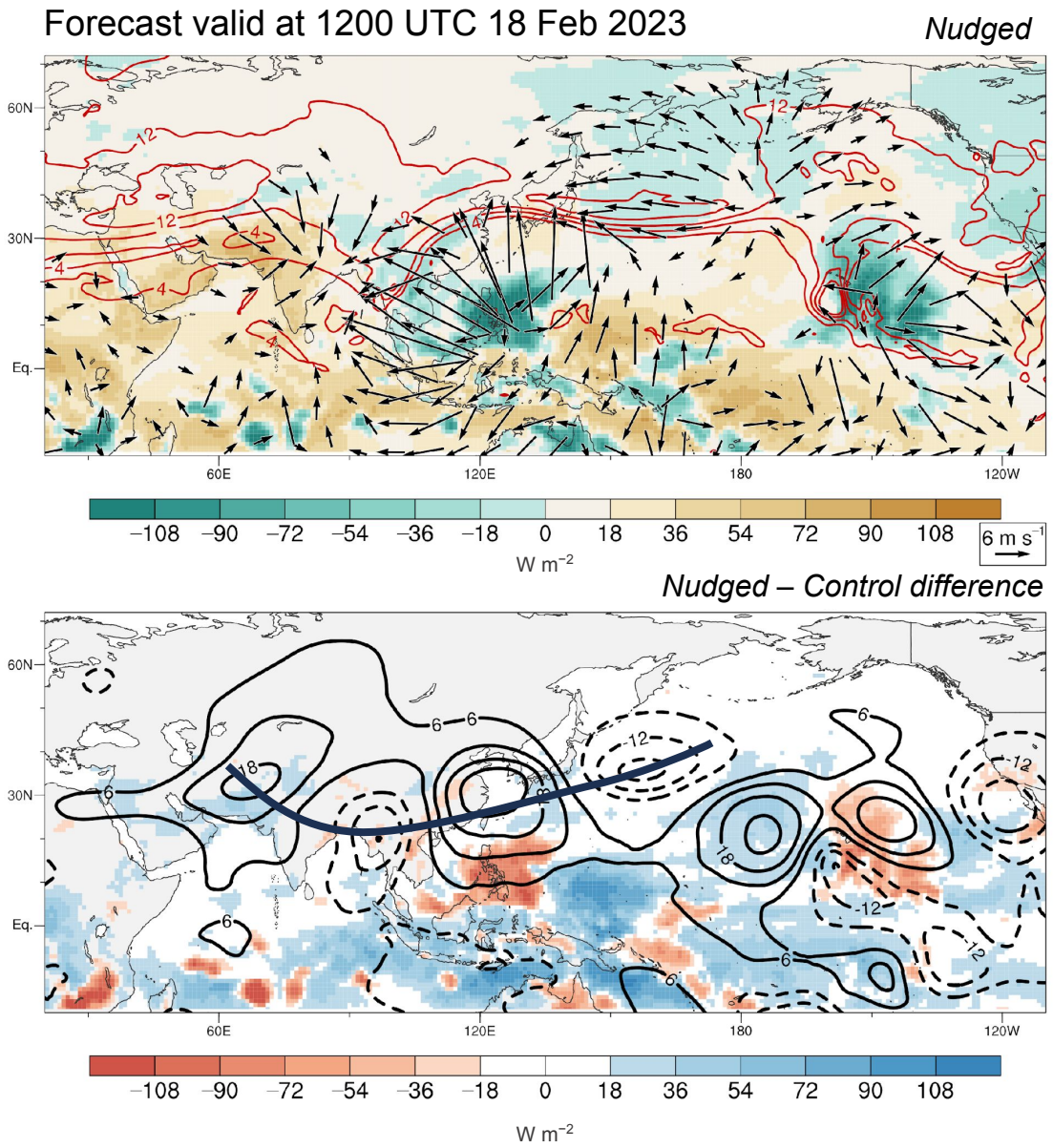


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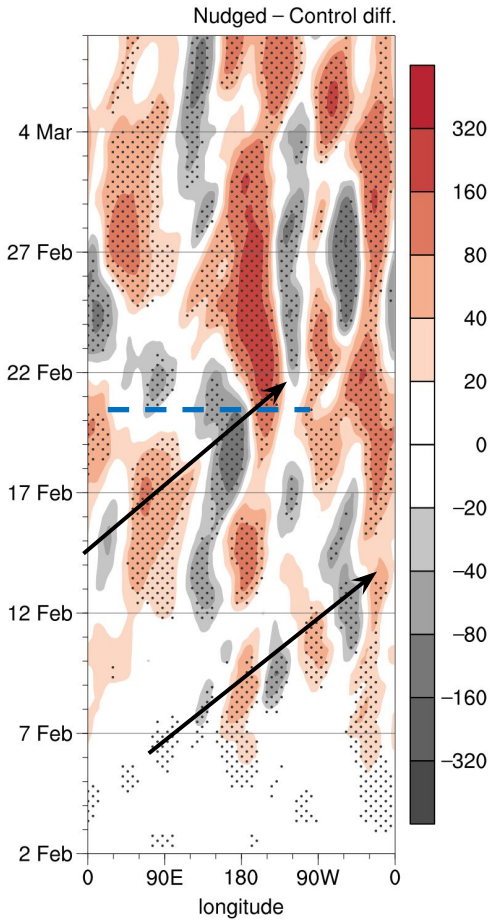


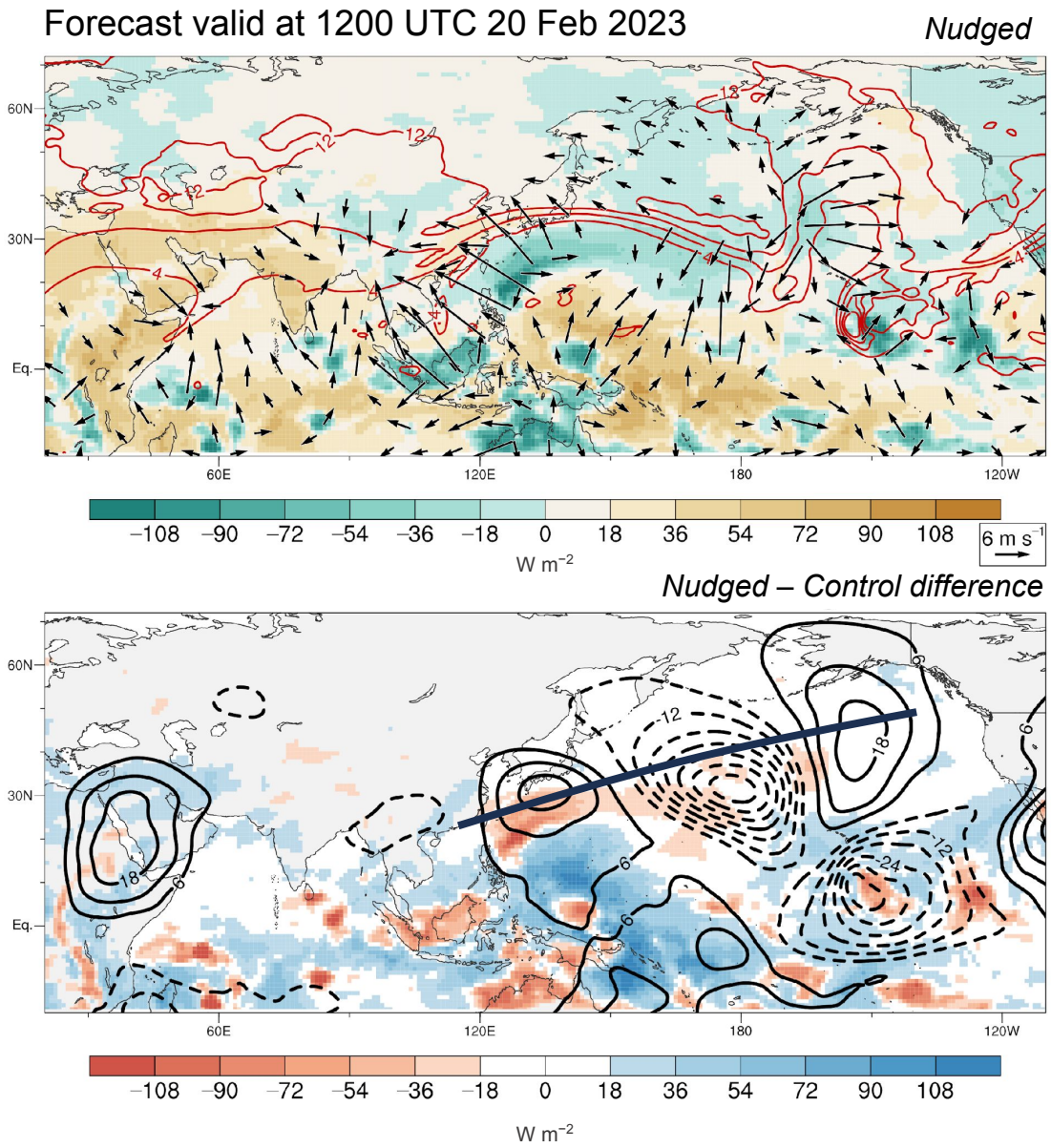


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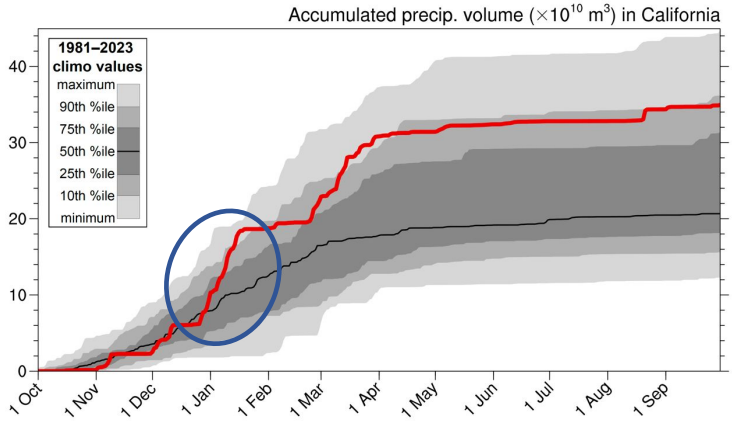
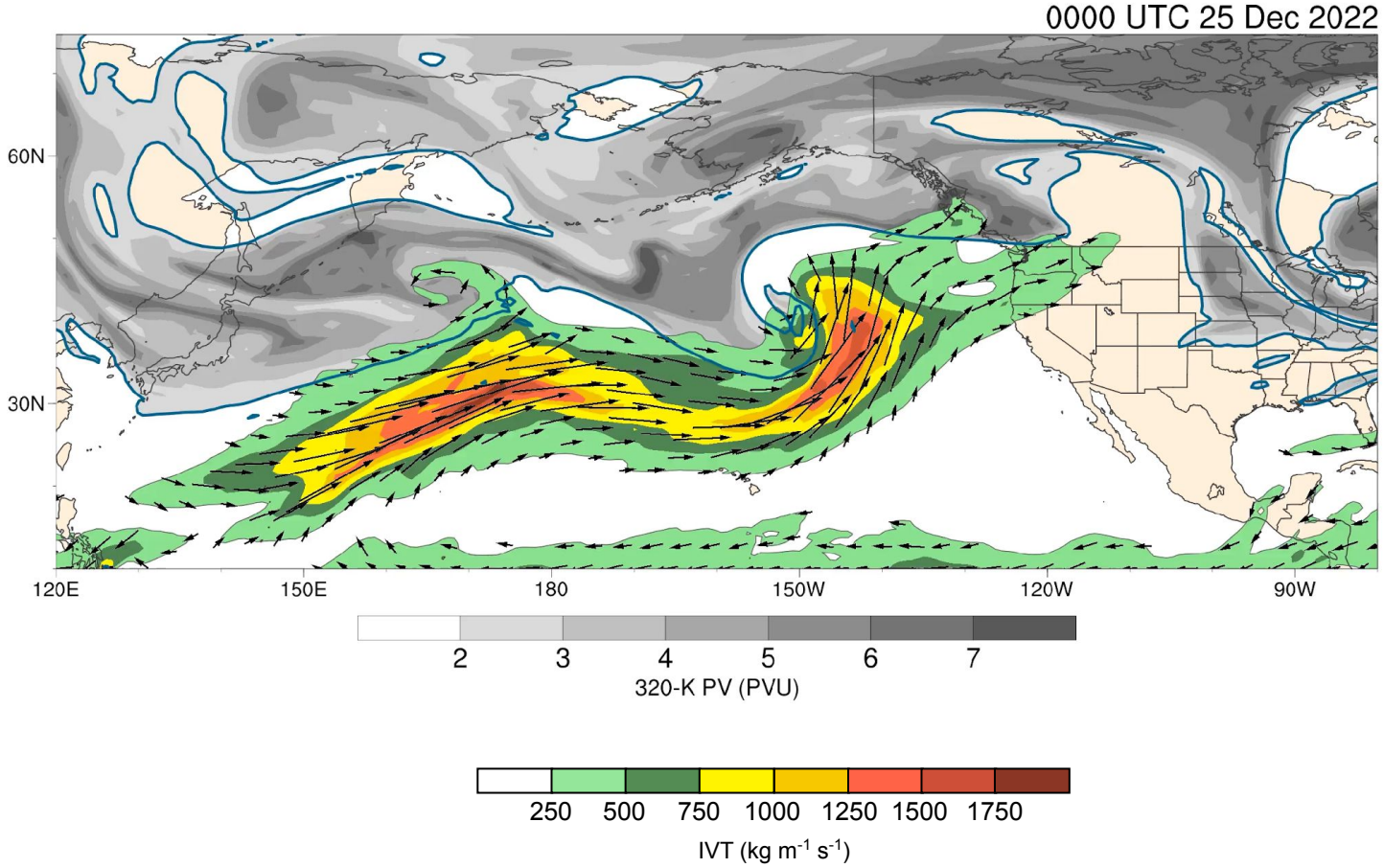
# Conclusions

- Nudging the tropics to reanalysis yields marked improvements in subseasonal (weeks 3–4) forecasts for the California precipitation events during winter 2022–23.
- The tropics played key role for the formation and persistence of the extratropical flow patterns that resulted in the events.
- The amplitude and propagation of the MJO, based on the ROMI and RMM indices, are represented well UFS forecasts regardless of nudging, but the control forecast exhibits significant errors in the structure/location of the convection and divergent outflow.
- MJO-related errors trigger errors in the extratropical flow that propagate and evolve as Rossby wave packets, culminating in large errors in weeks 3–4.
- The details of tropical phenomena and their interactions with the extratropical flow can strongly influence the downstream impacts.

Extra slides

# Most of the winter precipitation was produced in two prolonged episodes




Data source: ECMWF ERA5 reanalysis

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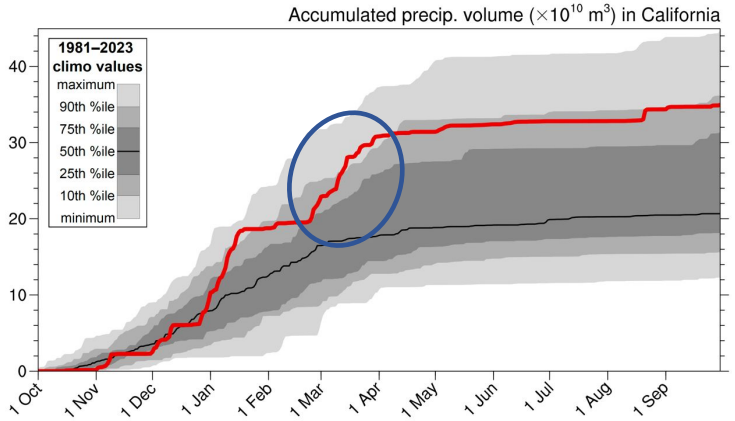


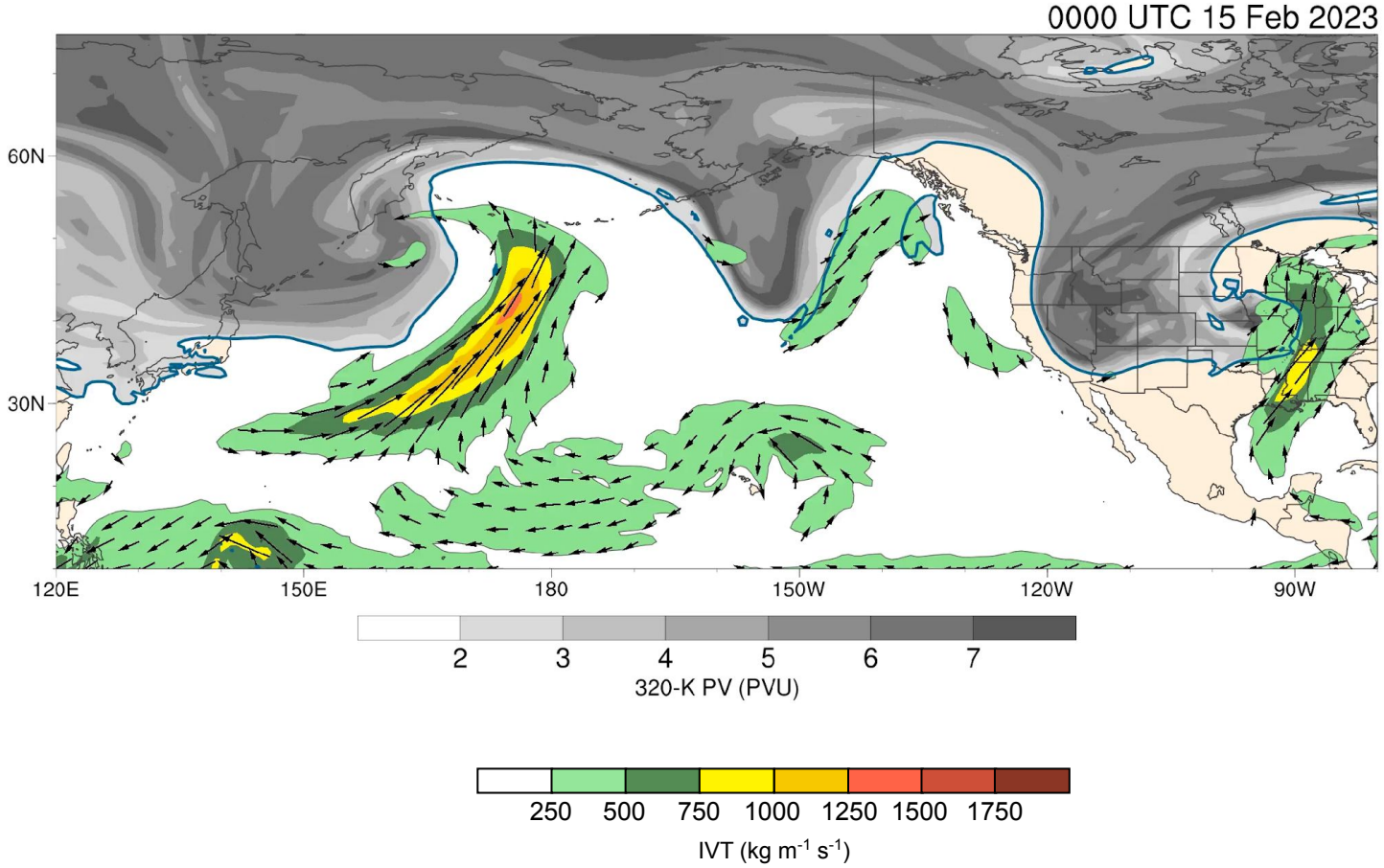


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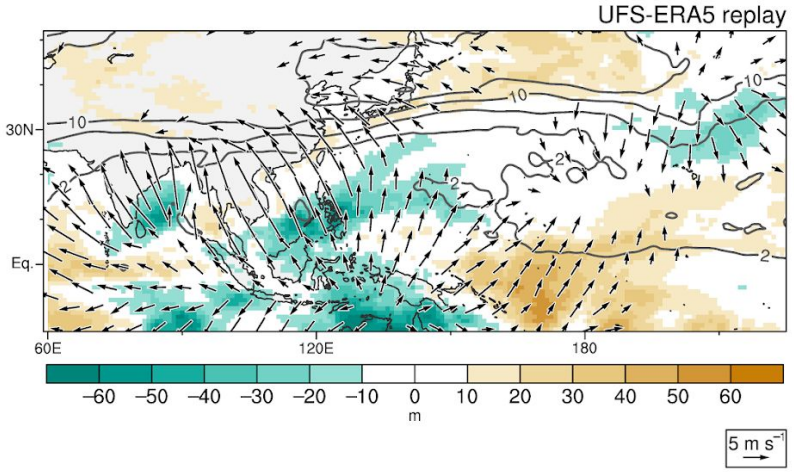


*OLR anomalies (shading),*
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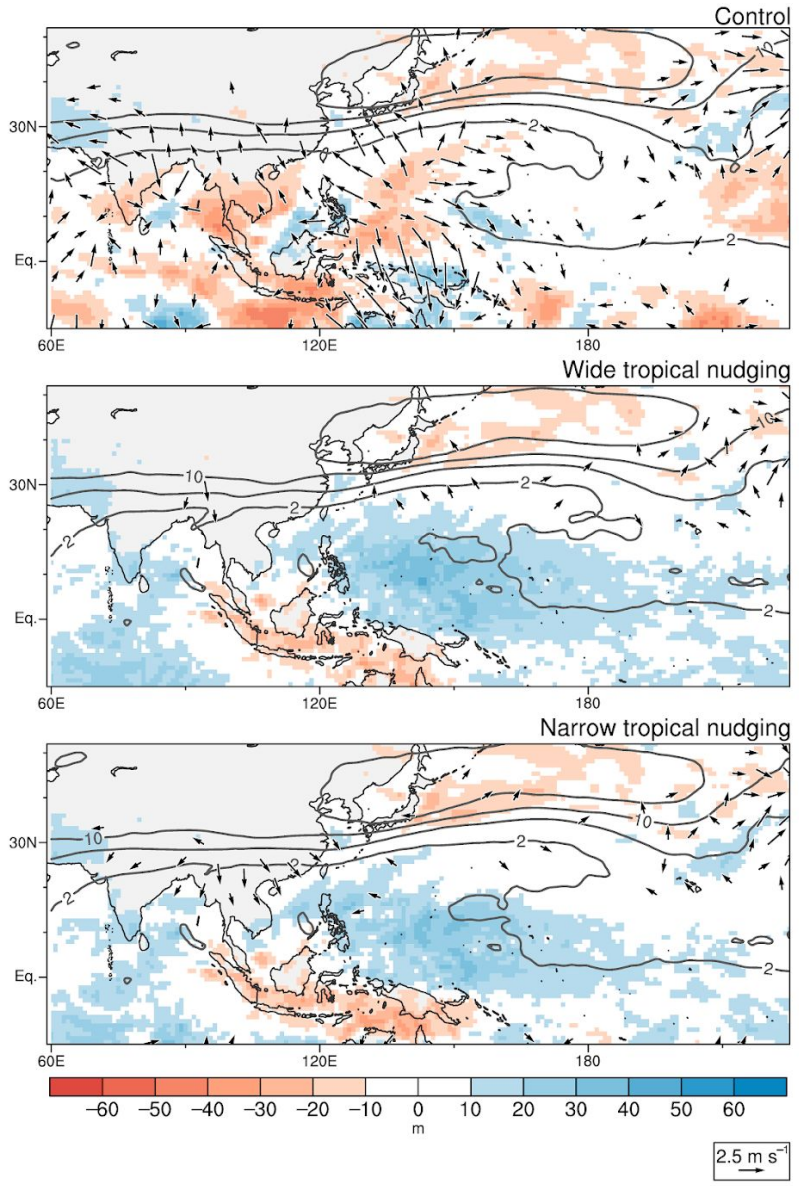
*200-hPa divergent wind (vectors)*

Forecast initialized at 0000 UTC 15 Dec 2022, valid: 18–28 Dec 2022

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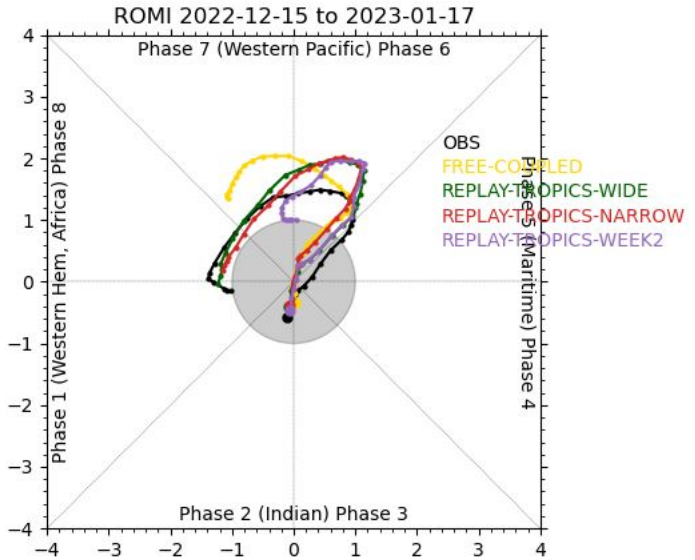
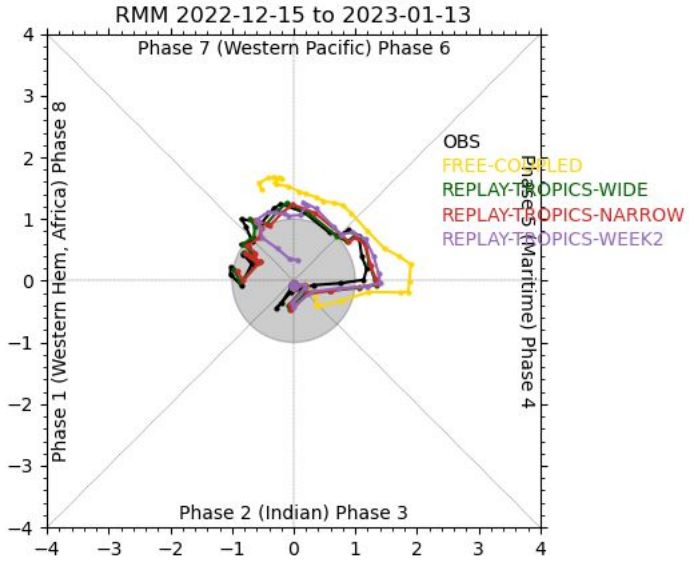
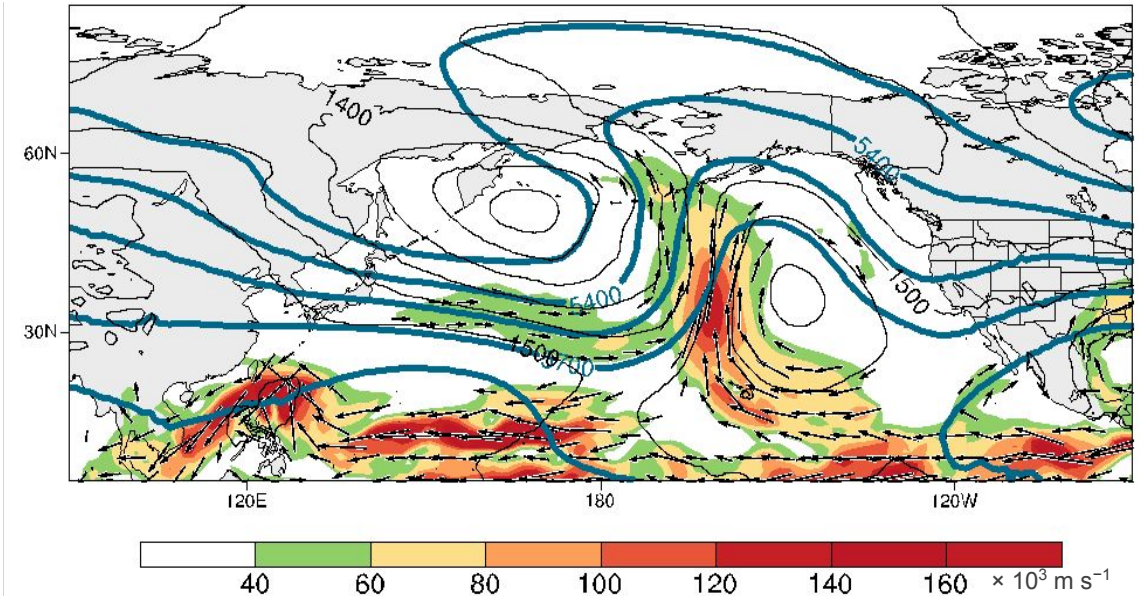


# Processes leading to subseasonal forecast improvements

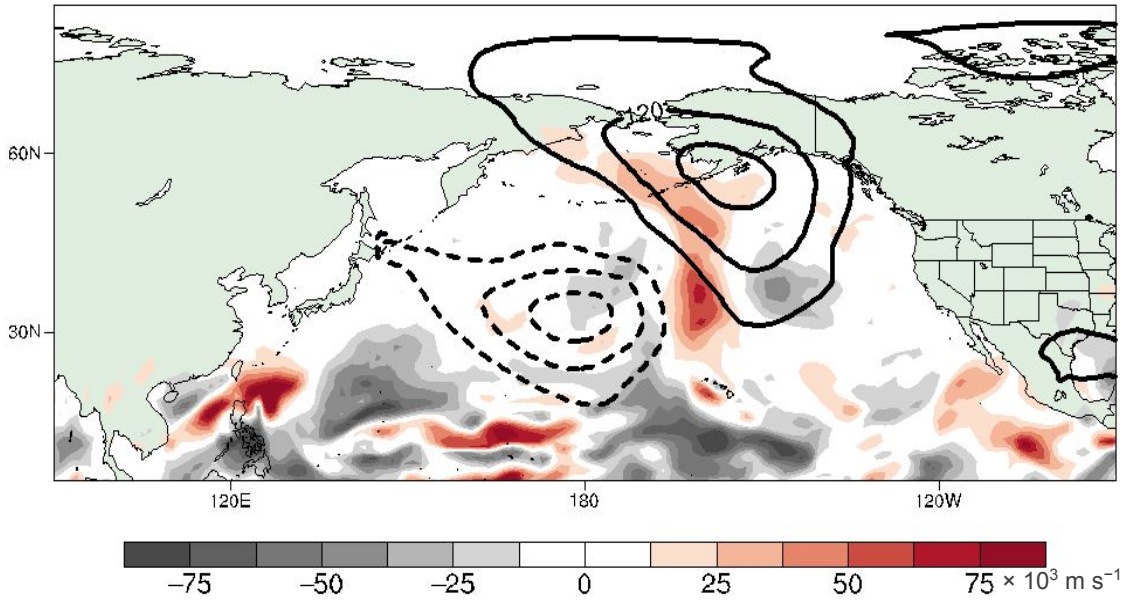
Forecast valid at 1200 UTC 21 Feb 2023

## Nudged forecast




*850-hPa water vapor flux (shading and vectors),*
*850-hPa Z (thin contours),*
*500-hPa Z (thick contours)*

## Nudged – Control differences




*Differences in the 850-hPa water vapor flux (shading) and 500-hPa Z (contours).*