Supporting Information for "Role of the Tropics and its Extratropical Teleconnections in State-Dependent Improvements of U.S. West Coast UFS Precipitation Forecasts"

Wei-Ting Hsiao[1], Elizabeth A. Barnes[1], Eric D. Maloney[1], Stefan N. Tulich[2,3], Juliana Dias[3], and George N. Kiladis[3]

[1]Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, USA

[2]CIRES, University of Colorado Boulder, Boulder, Colorado, USA

[3]Physical Sciences Laboratory, NOAA, Boulder, Colorado, USA

Contents of this file

Introduction The supporting information includes a section of text describing experimental settings in detail and nine supplementary figures that are mentioned but not present in the main paper.

Corresponding author: Wei-Ting Hsiao, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, USA (WeiTing.Hsiao@colostate.edu)

Text S1.

Model and Experimental Setup

In this study, we utilize the nudging simulations of Dias, Tulich, Gehne, and Kiladis (2021) conducted using a leading U.S. forecast model. Specifically, version 15.1.1 of the NOAA/ National Centers for Environmental Prediction Global Forecast System (NOAA/NCEP GFS v15.1.1) is used with C128 horizontal resolution and 64 vertical levels from the surface to 1 hPa. Other operational settings such as the lower boundary condition and physical parameterizations used are provided in detail here: `https://www.emc.ncep.noaa.gov/emc/pages/numerical_forecast_systems/gfs/implementations.php`. As described in more details below, three sets of simulations are conducted: ***ERAI-R***, where the whole globe in the model is nudged toward the observed state represented by ERA-Interim reanalysis (Dee et al., 2011) at all lead times; ***FREE***, where the model freely evolves after initialization to produce forecasts (one can think of this as the default forecast behavior), and ***NUDGE***, where only the tropics are nudged at all lead times toward the reanalysis. Differences in forecast errors between FREE and NUDGE relative to ERAI-R thus indicate how representation of the tropics can affect forecast performance.

The incremental analysis update (IAU; Bloom et al., 1996) scheme is utilized to nudge the model toward the observed state to create the ERAI-R simulation. Briefly, the IAU is implemented with 6-hour cycles using the following procedure: the differences in the observations and the forecasted fields are computed at the end of a 3-hour free forecast as a forcing tendency, and the forecast is run again for 6 hours with the forcing applied (see Fig. 1 in Dias et al., 2021). The fields of zonal and meridional winds, mass, temperature, and specific humidity are nudged. When the whole globe is nudged, a good approximation of the observed state is produced (including the precipitation field which is not nudged), here referred to as ERAI-R.

A set of hindcasts, FREE, are performed to evaluate the forecast performance of the model in a free-running mode (i.e. with no nudging). In this setting, the model is run freely out to 30 days from the restart points provided by ERAI-R. Another set of hindcasts, NUDGE, are performed to assess the effect on S2S forecast performance in the extratropics when the tropics are represented accurately. The design of NUDGE is the same as FREE, except that the nudging method used in ERAI-R is applied within 30°S-30°N using a weighting function that is unity between 10°S-10°N and is reduced to zero toward 30°S and 30°N following a hyperbolic tangent curve. Note that the same form of tropical nudging was used in Jung, Miller, and Palmer (2010).

All three sets of simulations are run during November 1999 to April 2018 for the extended boreal winter (November to April). At the beginning of each season, the model is initialized with the ensemble mean fields from Global Ensemble Forecast System version 12 (GEFSv12) on November 1st. The hindcast runs (FREE and NUDGE) are initialized every 5 days afterward using the restart files output from ERAI-R until the end of March in the following year. Thus, 31 hindcasts are performed for each extended boreal winter with 620 hindcasts in total. The 3-hourly output from the model is regridded to 1° by 1° horizontal grid spacing and averaged to daily means prior to the subsequent analysis.

References

Bloom, S. C., Takacs, L. L., da Silva, A. M., & Ledvina, D. (1996, June). Data assimilation using incremental analysis updates. *Mon. Weather Rev.*, *124*(6), 1256–1271.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., ...

Vitart, F. (2011, April). The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Quart. J. Roy. Meteor. Soc.*, *137*(656), 553–597.

Dias, J., Tulich, S. N., Gehne, M., & Kiladis, G. N. (2021, June). Tropical origins of weeks 2-4 forecasts errors during northern hemisphere cool season. *Mon. Weather Rev.*, *-1*(aop).

Jung, T., Miller, M. J., & Palmer, T. N. (2010, June). Diagnosing the origin of Extended-Range forecast errors. *Mon. Weather Rev.*, *138*(6), 2434–2446.

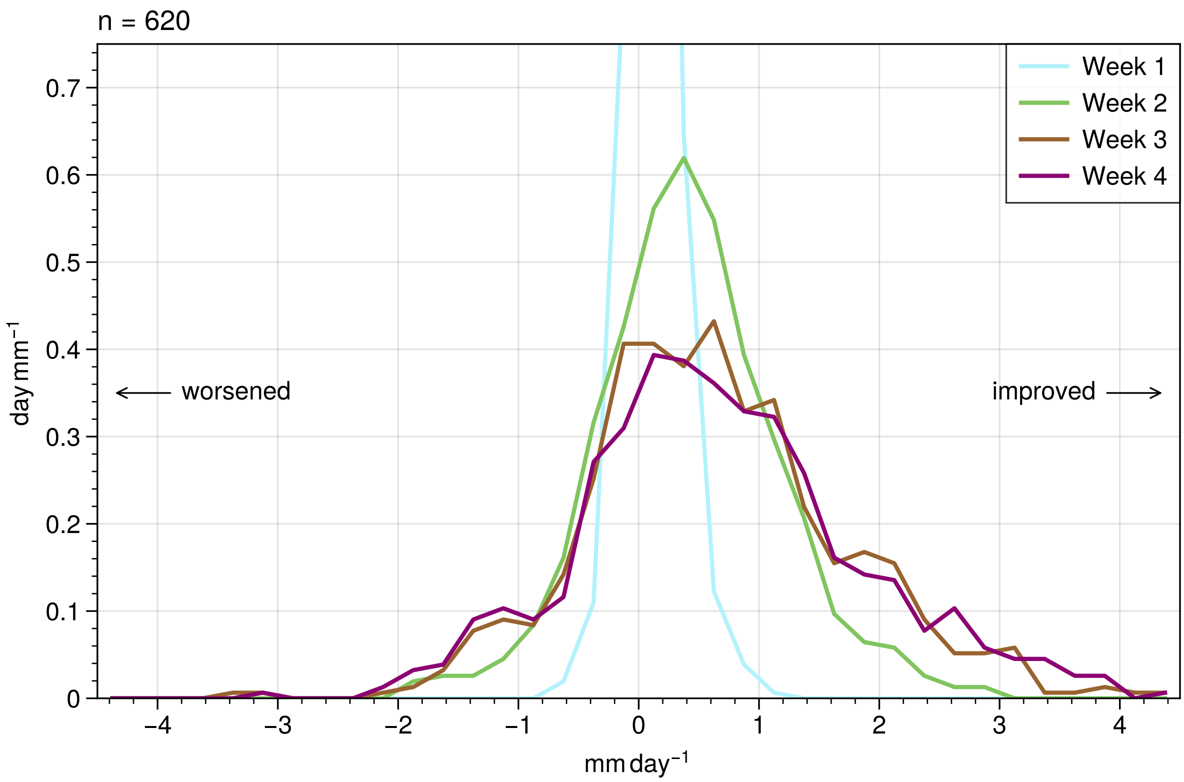

Figure S1. The weekly-averaged MAE reduction in predicted U.S. West Coast precipitation (MAE of FREE minus MAE of NUDGE). The Week-1 distribution is not fully shown as it has a high peak (2.2 day mm^{-1}). Note the greater positive skewness of the Week-3 and Week-4 distributions, indicating that MAE tends to be more strongly improved in response to tropical nudging.

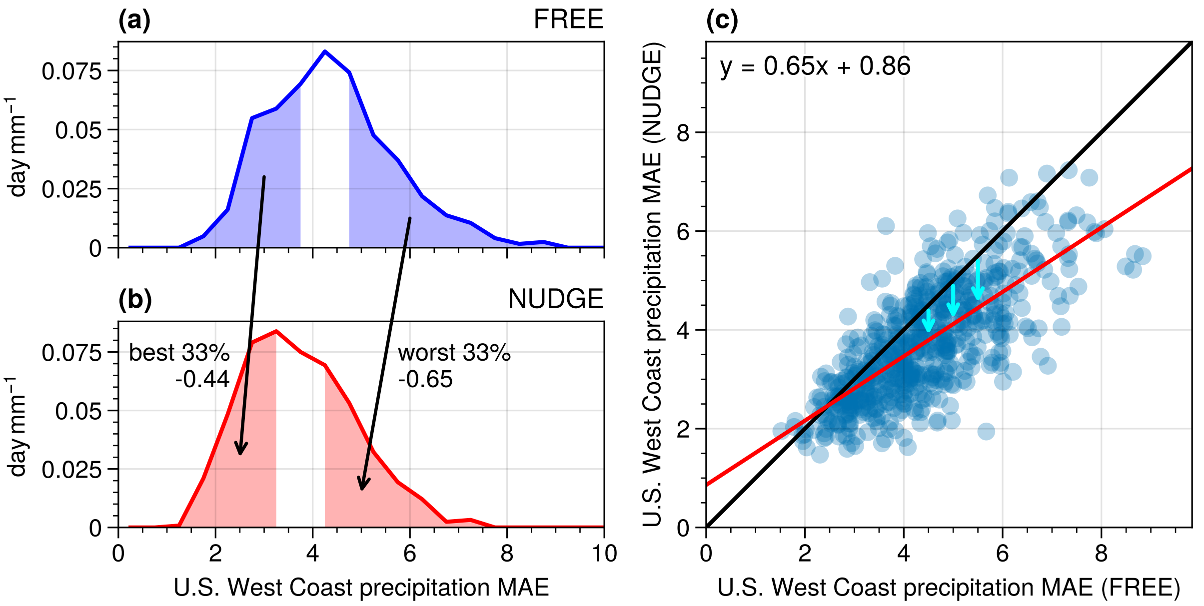

Figure S2. Distributions of U.S. West Coast precipitation MAE (mm day^{-1}) averaged over Weeks 3-4 in (a) FREE and in (b) NUDGE, and (c) a scatter plot of the two MAEs on individual initialization dates. For the distribution curves, the top and the bottom terciles in each set of runs are shaded, and the arrows annotated with numbers indicate the averaged improvement over each tercile between FREE and NUDGE. For the scatter plot, a linear regression of the data points is shown (red line; mathematical expression at the upper left corner) along with a reference one-to-one line (black), where the lengths of the cyan arrows demonstrate the magnitudes of improvements, which are larger when the MAEs in FREE are larger.

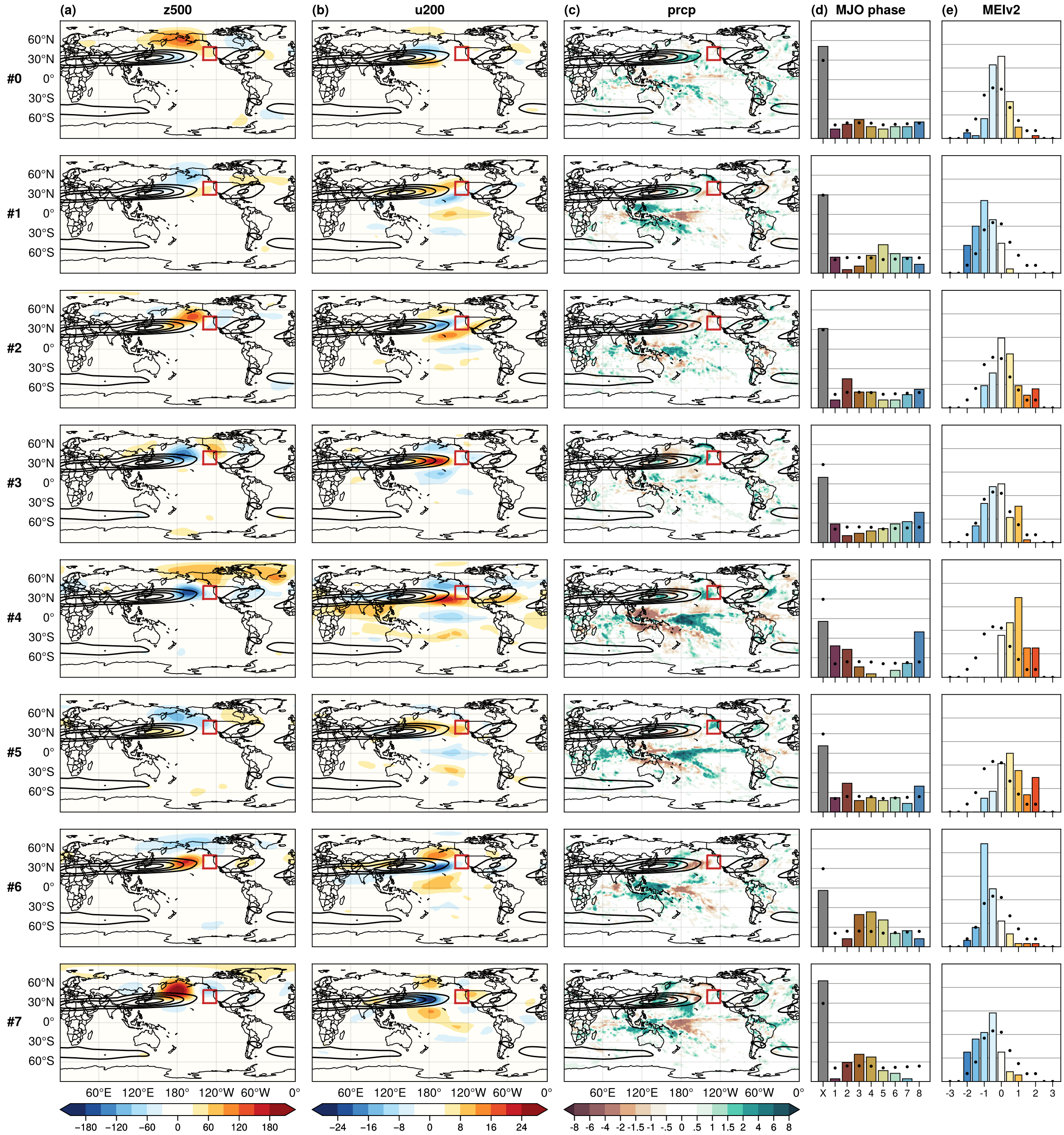

Figure S3. The composite anomalies from each cluster at Day 1 in ERAI-R: (a) z500 (m), (b) u200 (m s^{-1}), (c) precipitation (mm day^{-1}), and the distribution of (d) MJO phases, and (e) MEIv2, where each row represents a cluster. (d) and (e) are as constructed in a similar manner to the panels in Figure 3. In (a), (b), and (c), the red boxes represent the U.S. West Coast averaging region, and the black contours are the mean u200 from the extended boreal winter, with levels 30, 40, 50, 60, and 70 m s^{-1}.

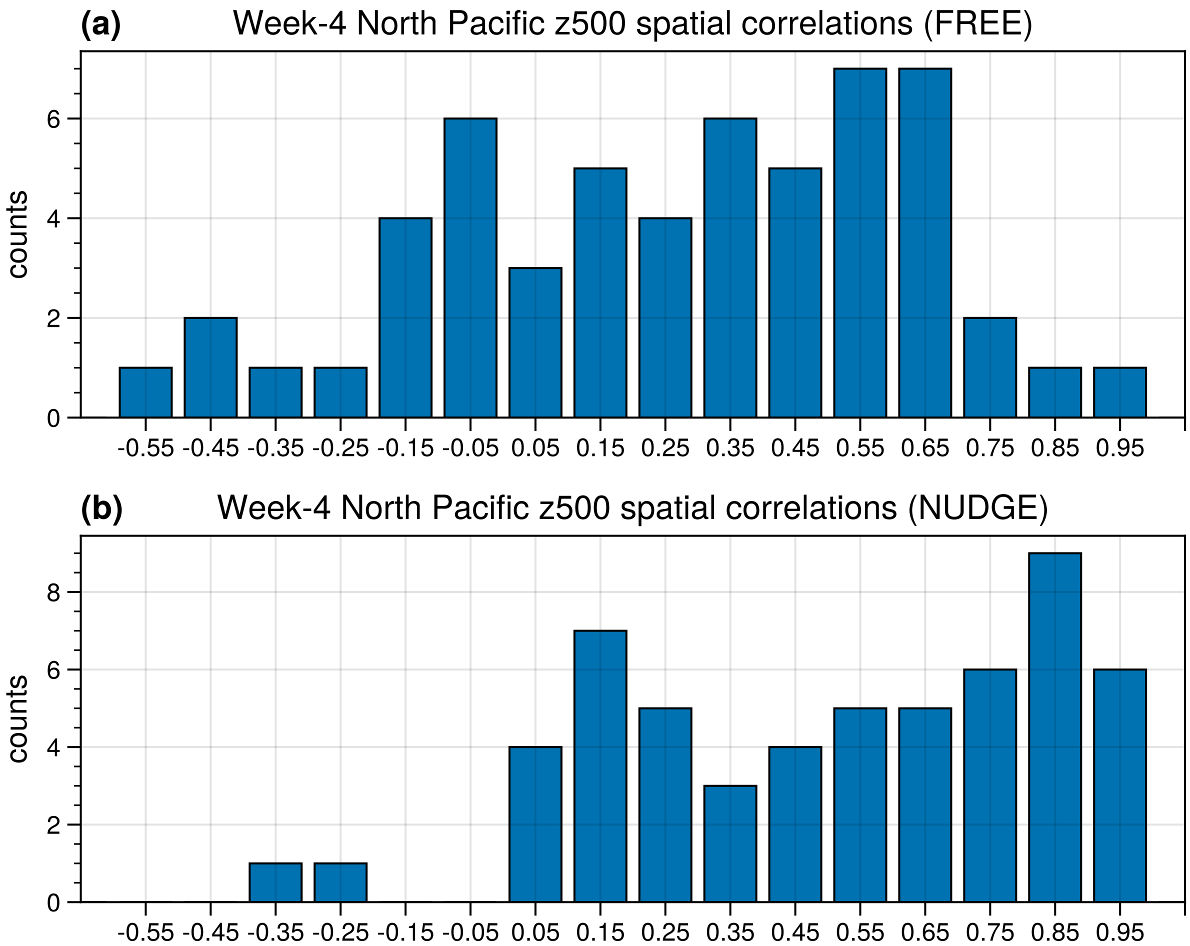

Figure S4. Histograms of North Pacific (20°N-70°N, 150°E-120°W) Week-4 z500 spatial correlation coefficients between ERAI-R and (a) FREE and (b) NUDGE binned with interval 0.1.

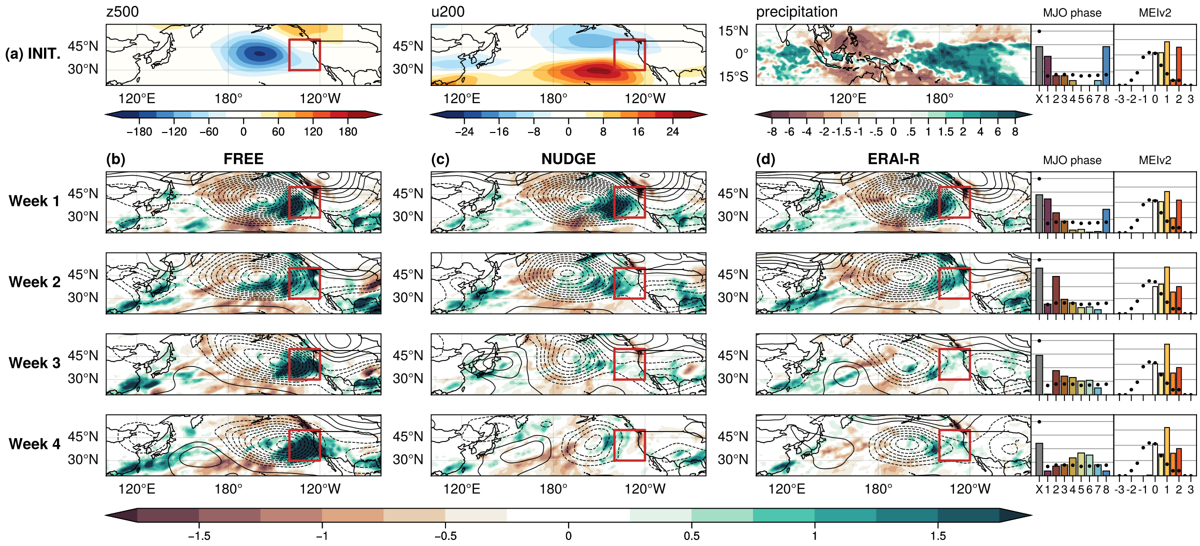

Figure S5. As Figure 3, but of the subset of hindcasts with an improvement greater than or equal to 1 mm day^{-1} from Cluster #4.

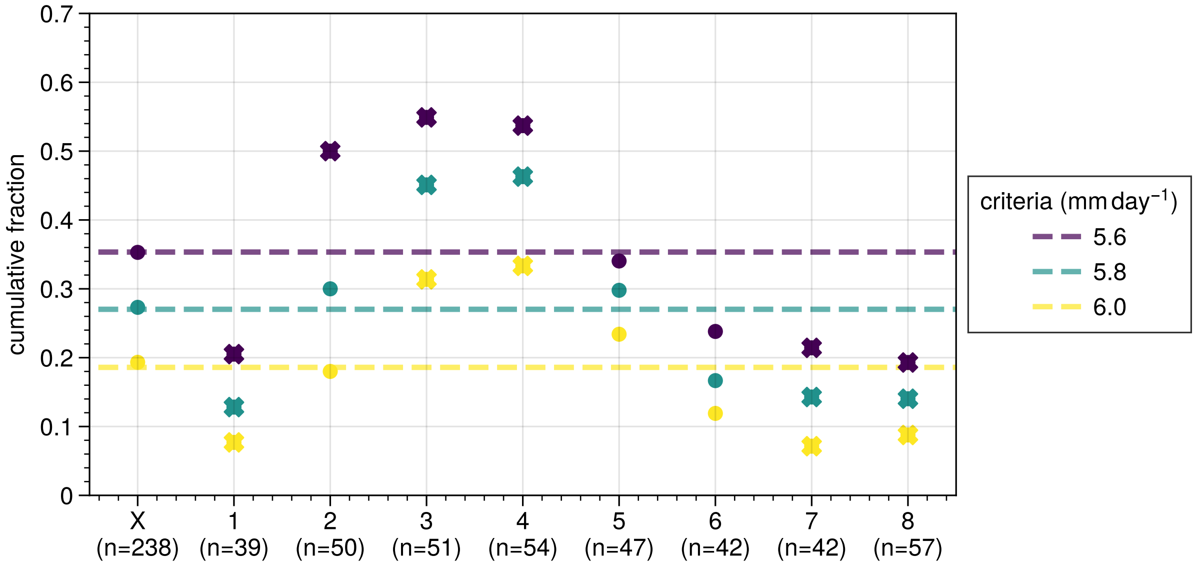

Figure S6. As Figure 2b, but showing the MAE reduction of Indo-Pacific warm pool region (10°S-10°N, 60°E-170°E) precipitation during Weeks 1-2 as a function of MJO phase, where X indicates the non-MJO conditions.

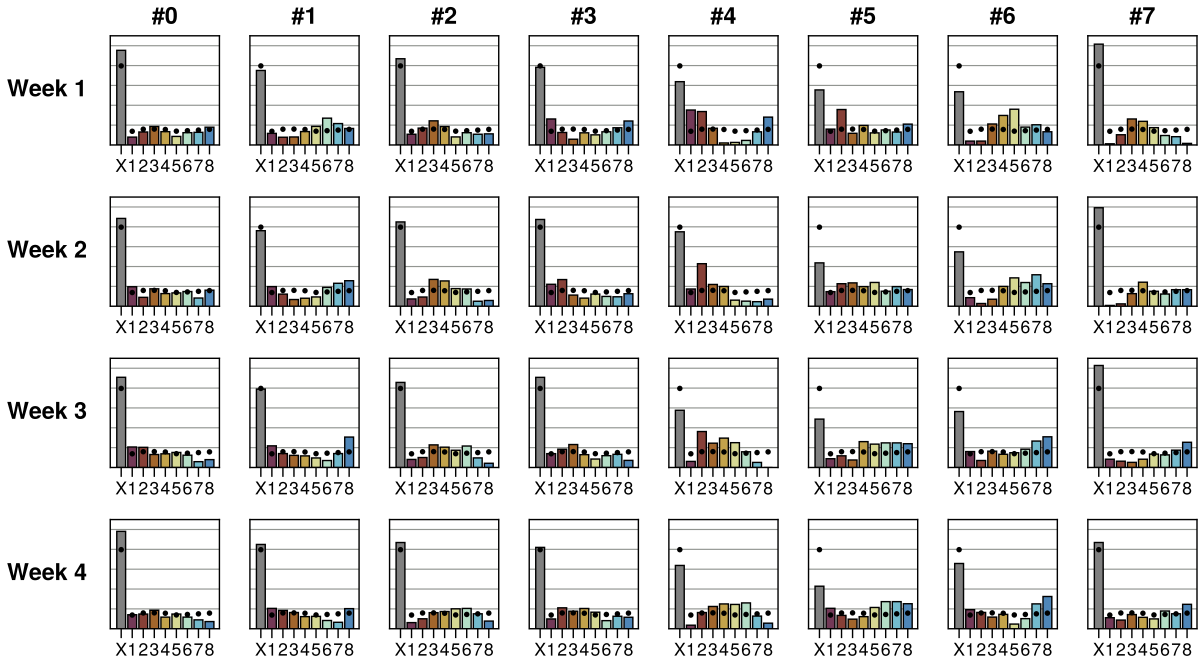

Figure S7. As the MJO panels in Figure 3, but showing the weekly distributions from all the clusters (columns).

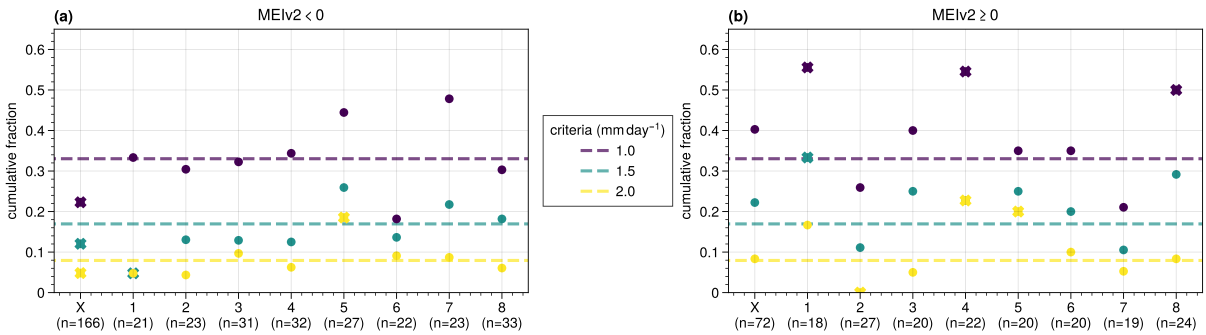

Figure S8. As in Figure 2b, but subsetting by MJO phases while (a) MEIv2 $<$ 0, and while (b) MEIv2 $\geq$ 0, where X indicates non-MJO conditions.

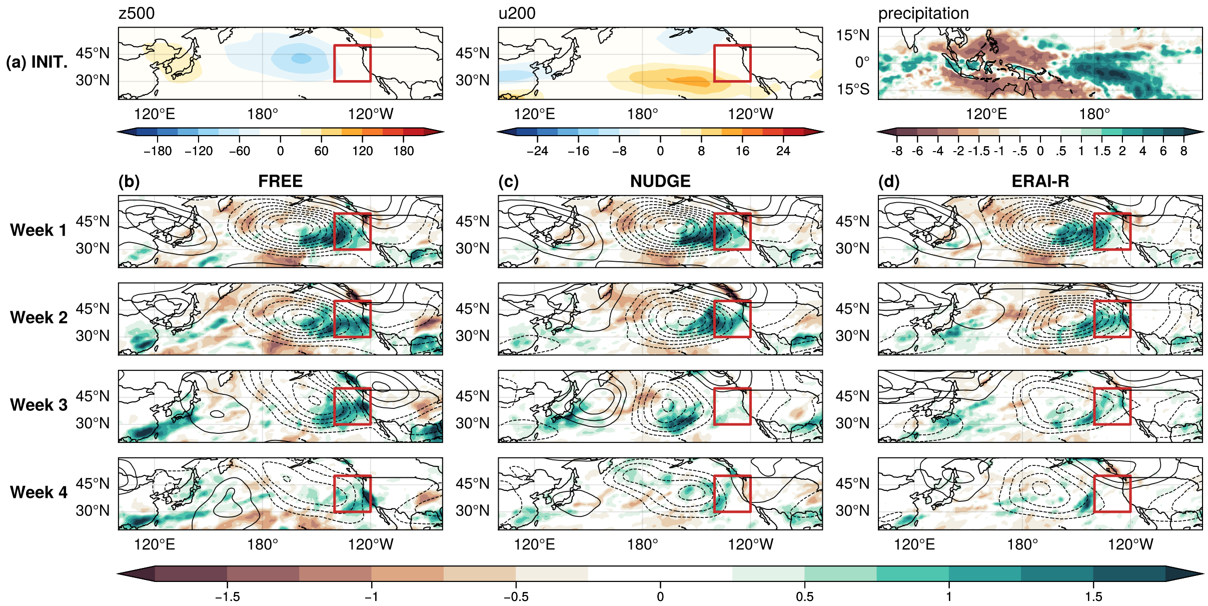

Figure S9. As in the left three columns of maps of Figure 3, except showing the composites for the subset of hindcasts with MEIv2 ≥ 0 and MJO phases 1 and 8. The sample number of this subset is 42.