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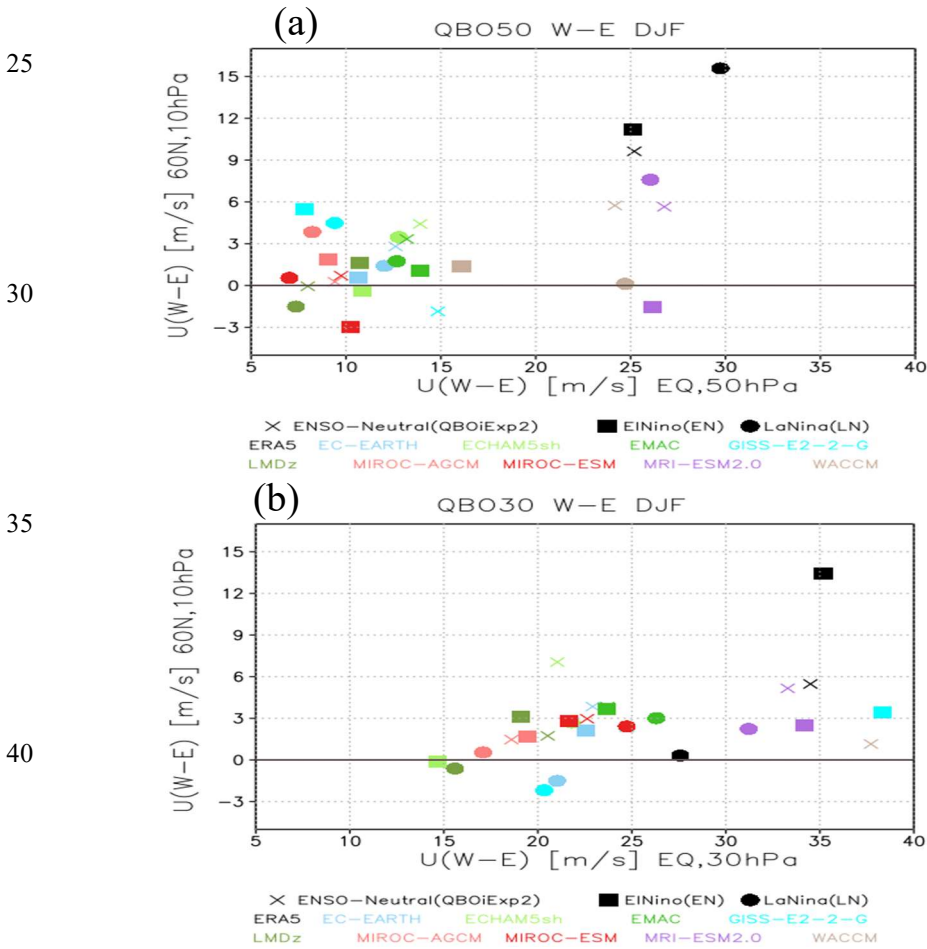
QBOi El Niño–Southern Oscillation experiments: teleconnections of the QBO

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45 **Figure S1: Relationship between QBO-W minus QBO-E composite differences in the zonal-mean zonal wind (in m s^{-1}) of polar vortex at 60° N and 10 hPa QBO-W minus QBO-E differences in the zonal-mean zonal wind at the QBO definition region of (a) 50 hPa (QBO50) and (b) 30 hPa (QBO30). Crosses, filled squares, and filled circles indicate ENSO-neutral / QBOiExp2 (CTL), El Niño / EN, and La Niña / LN winters in ERA5 or experiments in QBOi models, respectively.**

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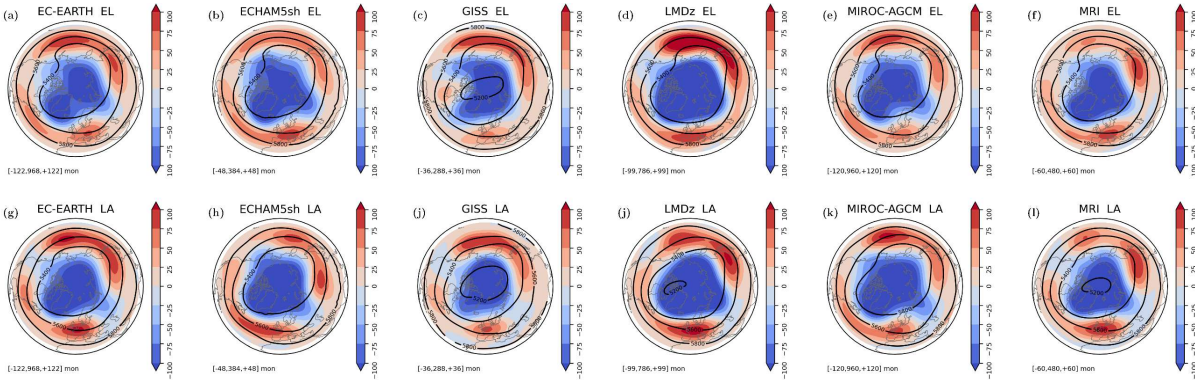
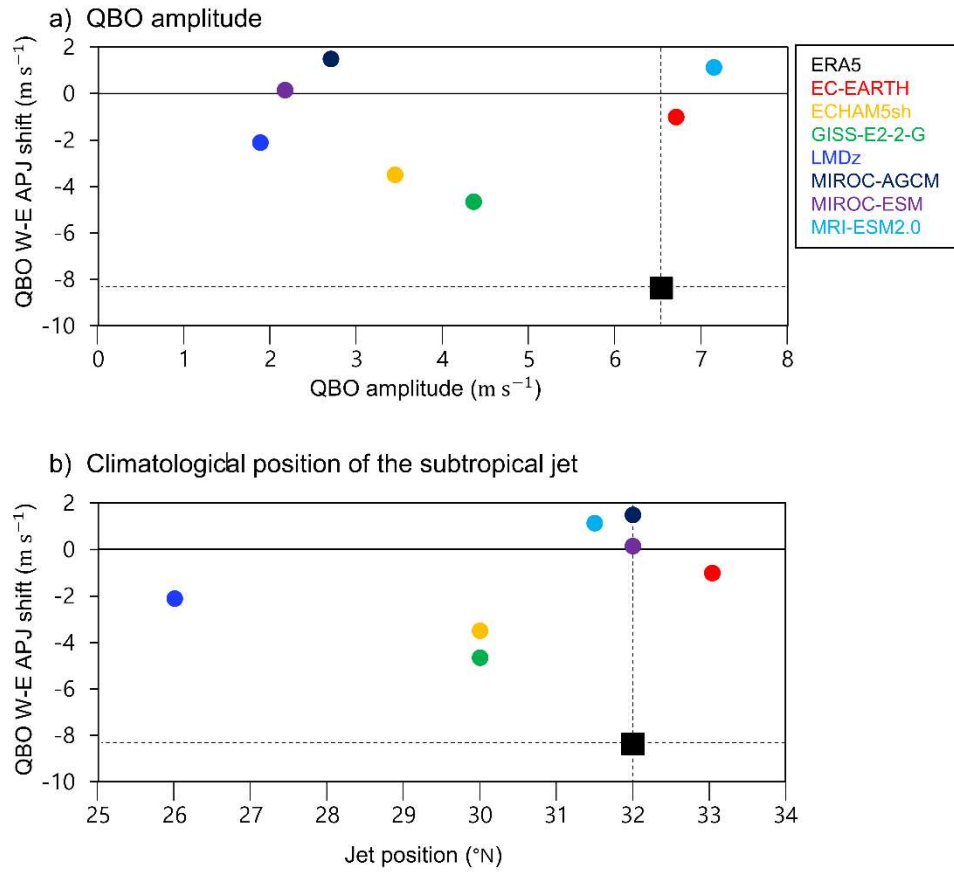


Figure S2: Northern annular mode (NAM) stereographic maps at 500 hPa for EN and LN experiments in the QBOi models, based on daily geopotential height data (m). Contour lines indicate geopotential height during neutral NAM conditions. Colors represent positive (strong vortex, above the 90th percentile) minus negative (weak vortex, below the 10th percentile) year-around anomalies based on the NAM index. Negative anomalies indicate lower geopotential heights.



70 Fig. S3. Relationship between QBO-W minus QBO-E differences in the APJ shift index and (a) QBO amplitude, and (b) subtropical jet latitude for the CTL experiment / ENSO-neutral winters.

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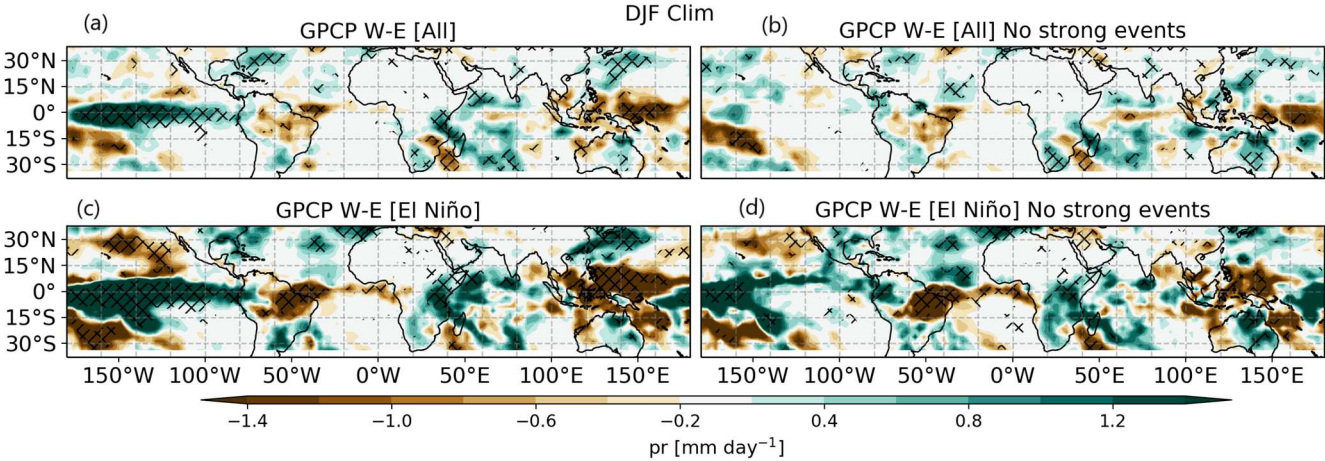


Figure S4. Composite differences in GPCP (1979–2021) precipitation (mm day⁻¹) during DJF between QBO-W and QBO-E phases, for (top) all winters and (bottom) only El Niño winters. The left panels include the three strongest El Niño events, while the right panels exclude them.

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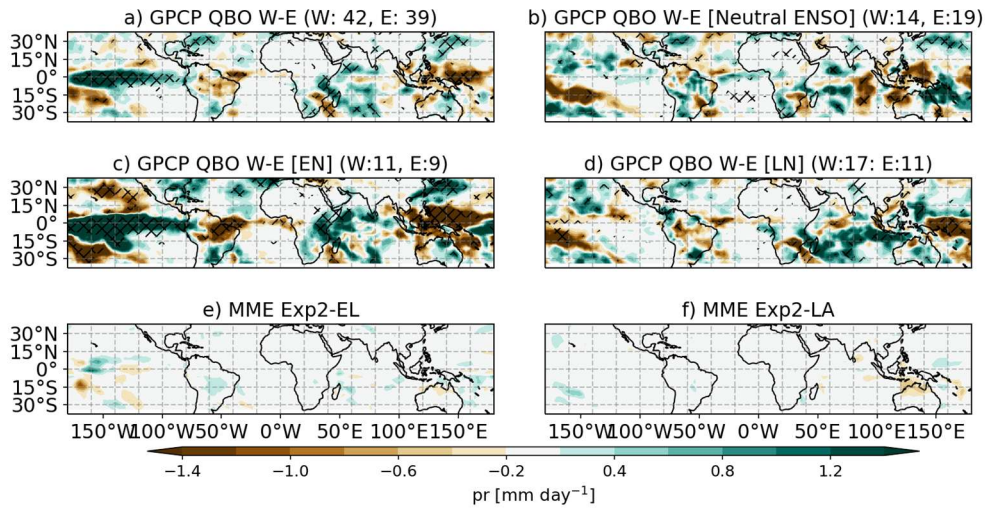
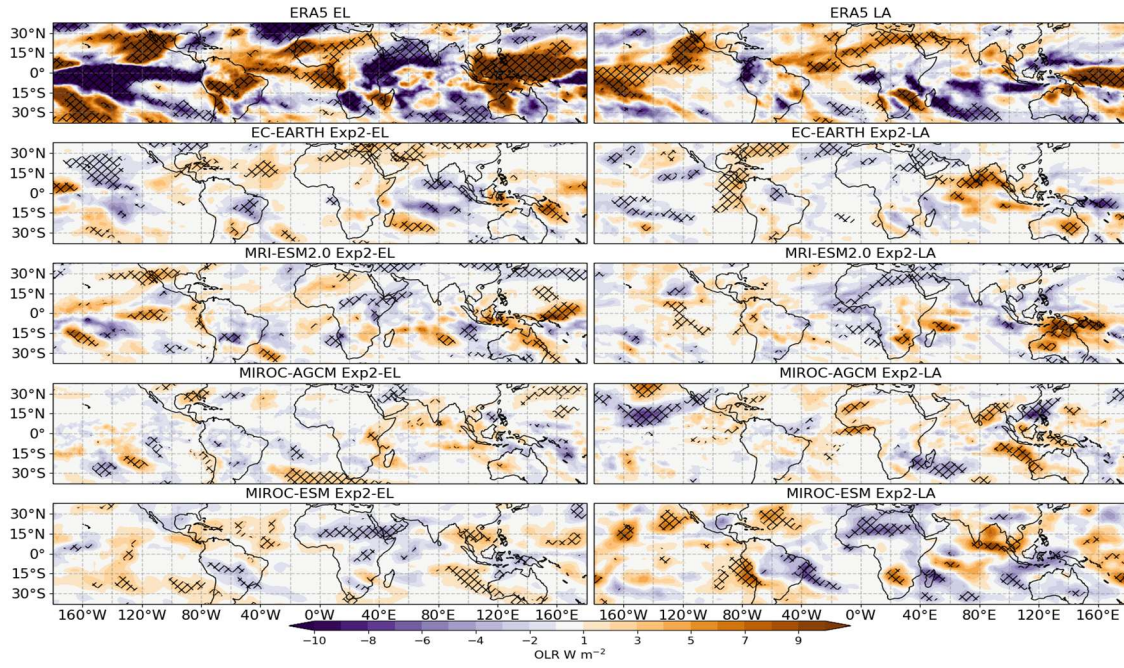
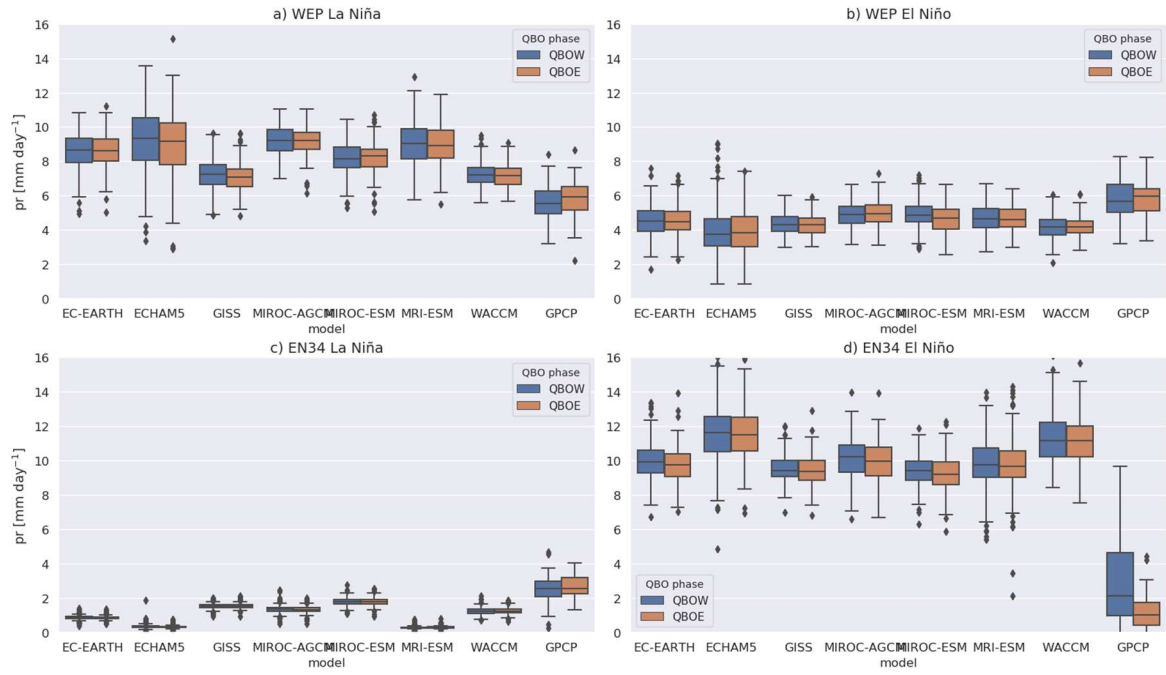


Figure S5. As in Figure 8, but showing observed QBO signals (QBO-W minus QBO-W precipitation differences) during DJF for a) all periods, b) ENSO-neutral, c) El Niño, and d) La Niña winters based on GPCP data. QBOi models are composited into a multi-model mean, regridded to the GPCP grid, and a multi-model mean ensemble (MME) differences are shown for e) EN and f) LN experiments. The degree of model agreement—defined as grid points where at least 75 % of models agree on the sign of the signal—is indicated by hatching. The number of months used for each observed composite is shown in parentheses in the GPCP panels.



135 **Figure S6:** As Fig. 8, but for outgoing longwave radiation (OLR; W m^{-2}). ERA5 data are used as the observational benchmark. Only a subset of QBOi models provide OLR output for these experiments.



140 **Figure S7: (Left) Box plots of deseasonalized precipitation (mm day⁻¹) for the western equatorial Pacific (WEP) region (5° S–5° N, 120°–170° E) and the EN3.4 region (5° S–5° N, 170°–120° W) for (a, c) LN and (b, d) EN experiments in QBOi models, together with El Niño and La Niña winters in GPCP data, separated by dataset and QBO phase. QBO phases are classified using deseasonalized DJF mean zonal-mean zonal wind at 50 hPa, averaged over 5° S–5° N, with values ≥ 2 m s⁻¹ indicating QBO-W and ≤ -2 m s⁻¹ indicating QBO-E.**

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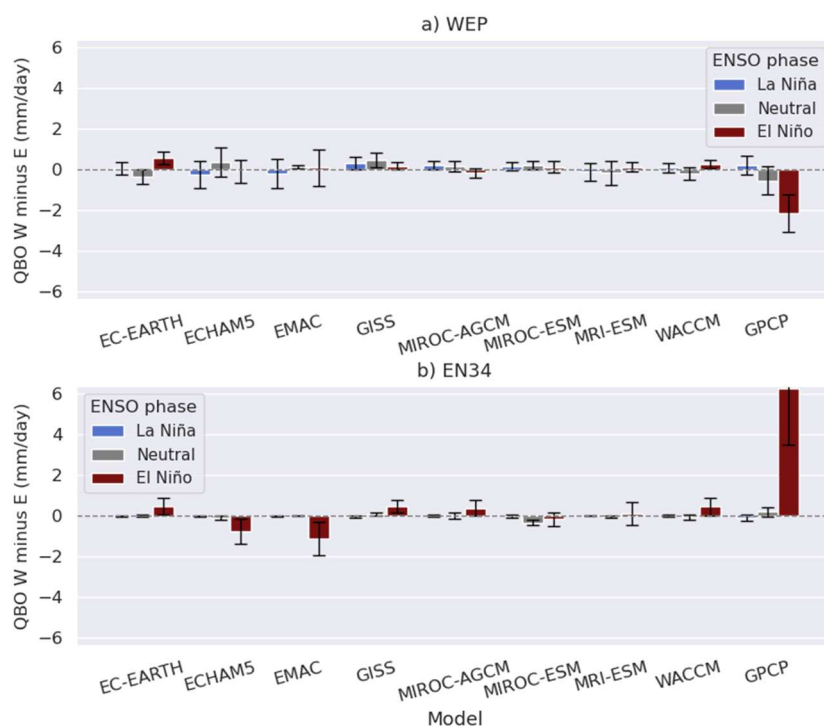


Figure S8: Same as Fig. 9, but with y-axis limits set according to the GPCP scale.

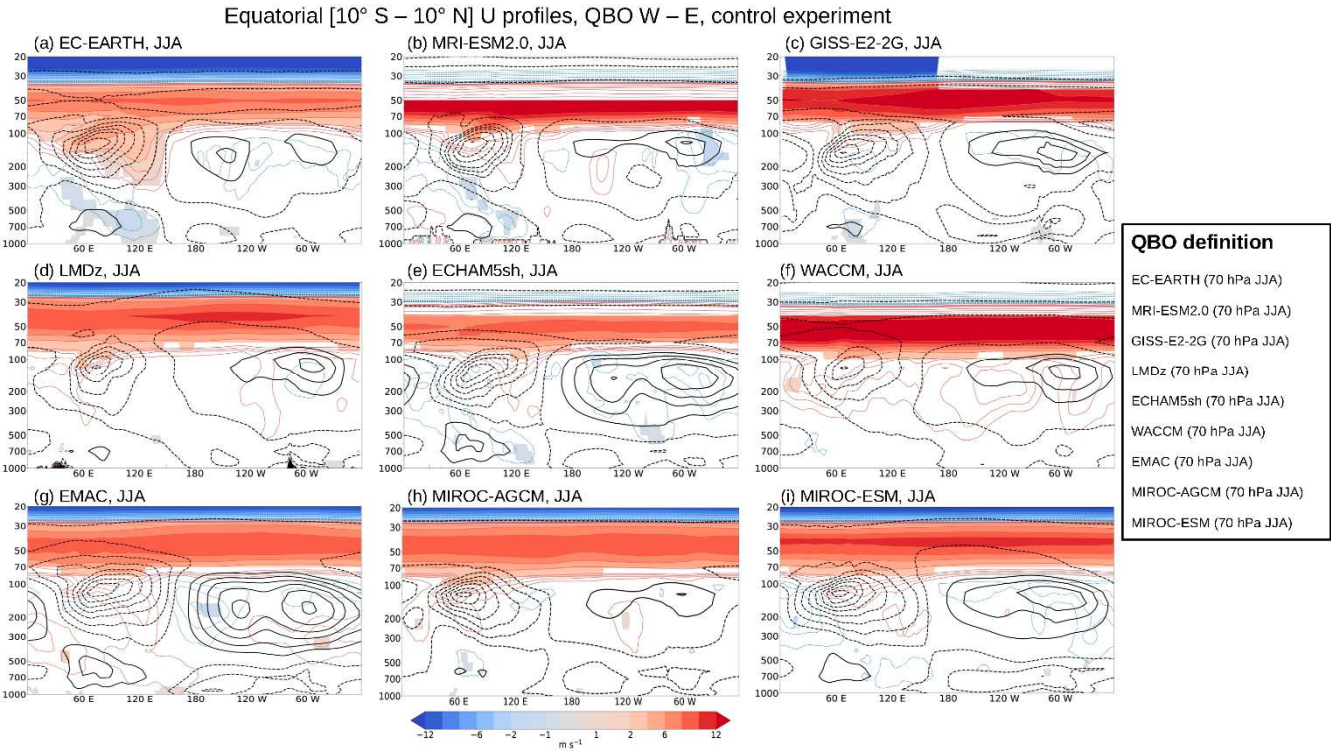


Figure S9: Climatology (black contours) and QBO-W minus QBO-E differences (shading and colored contours) in equatorial zonal wind (longitude–pressure section), averaged over 10° S– 10° N, from the CTL experiment in the QBOi models. Black contours are drawn at 4 m s^{-1} intervals. Colored contours follow the same intervals as the shading, with red contours indicating positive differences and blue contours indicating negative differences. The target season is JJA for all models, with the QBO phase defined at 70 hPa during JJA. Only differences statistically significant at the 95% confidence level are shaded.

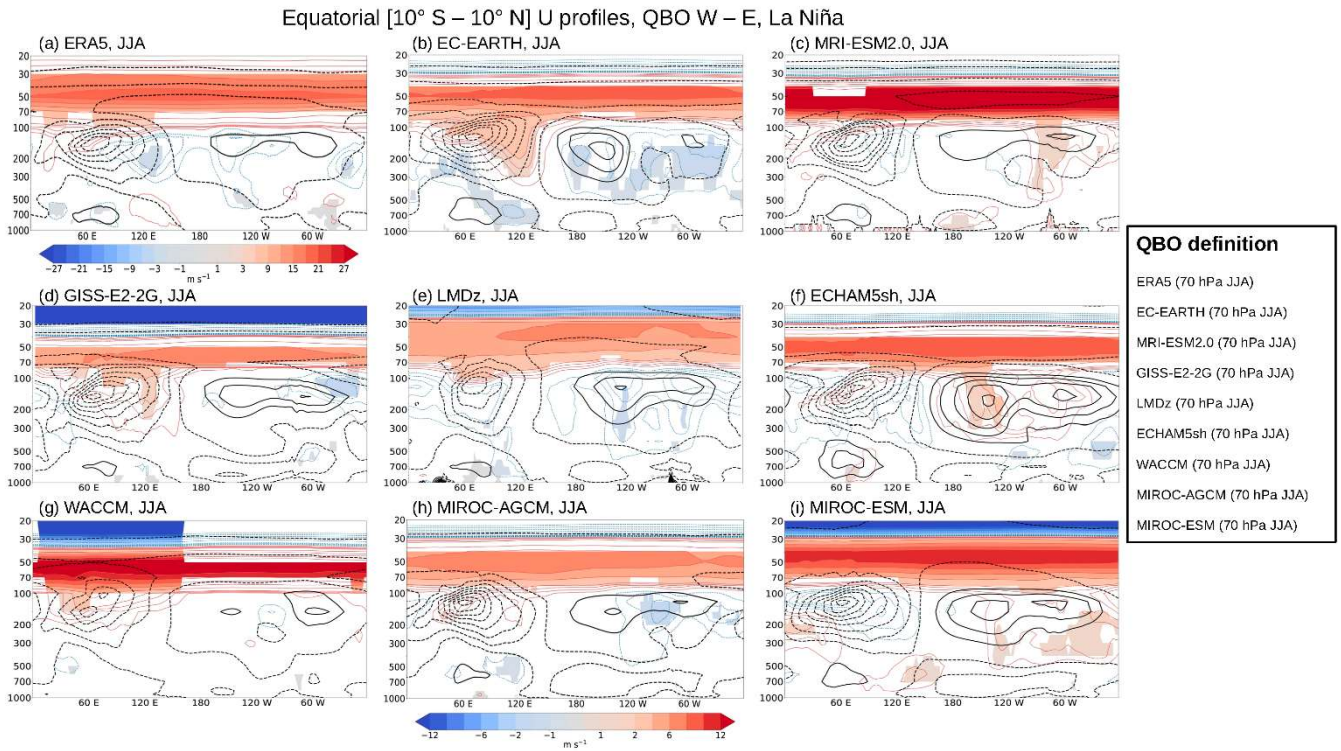


Figure S10: As in Fig. S9, but for the LN experiment. Note that the ERA5 color scale differs due to the larger QBO amplitude.

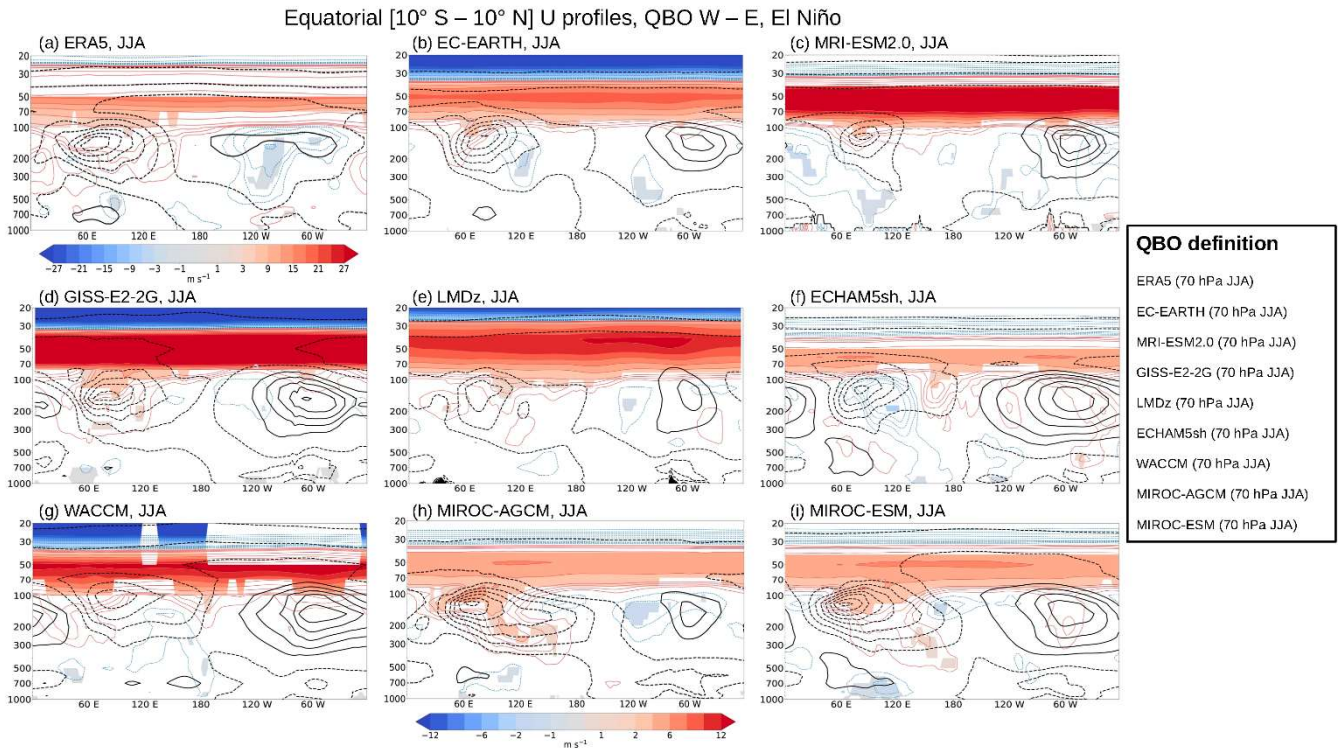
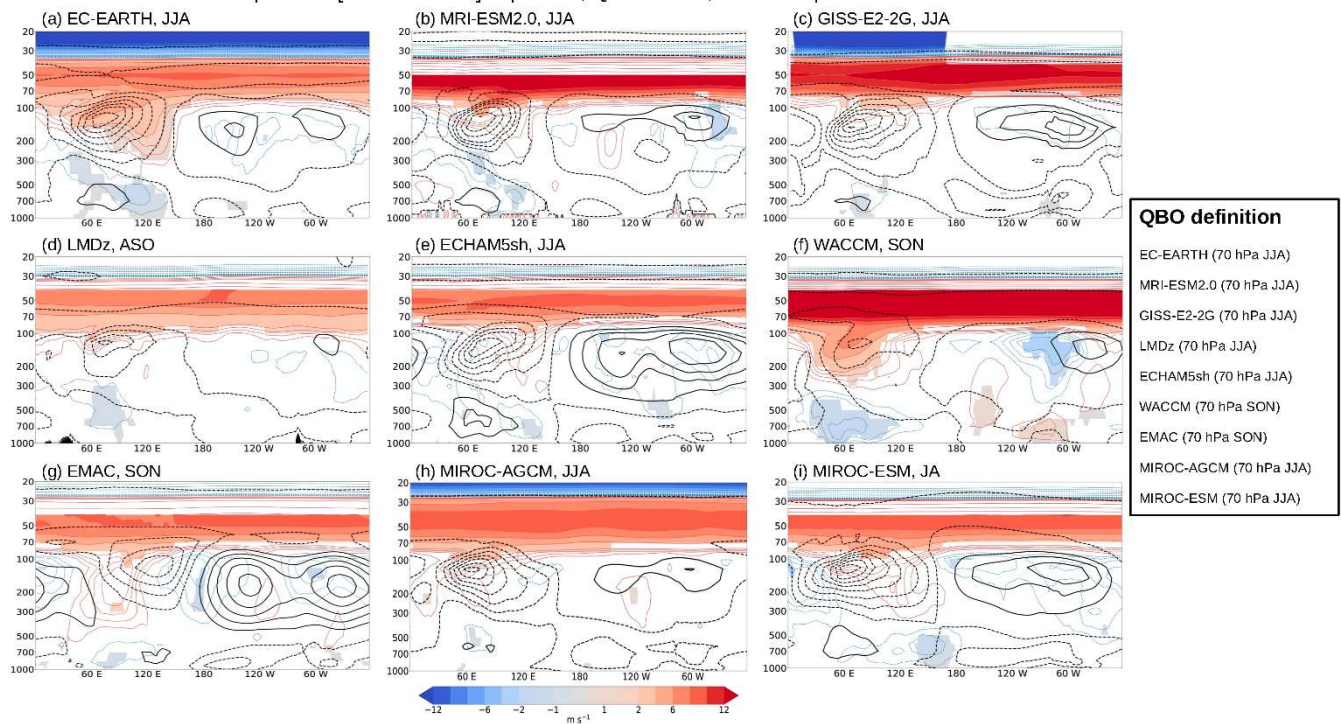


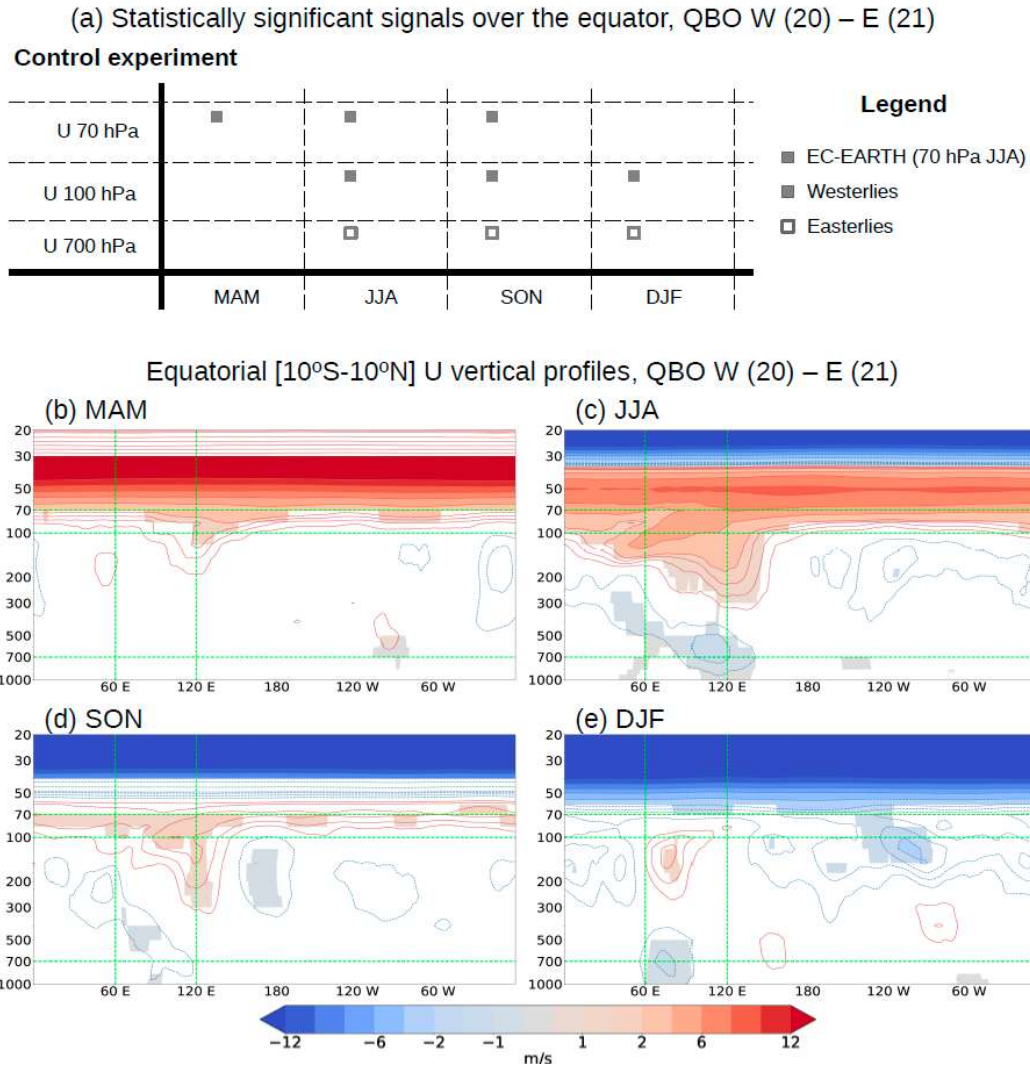
Figure S11: As in Fig. S9, but for the EN experiment. Note that the ERA5 color scale differs due to the larger QBO amplitude.

Equatorial [10° S – 10° N] U profiles, QBO W – E, control experiment



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Figure S12: As in Fig. 11, but for the CTL experiment. The EMAC model is used instead of ERA5, as ENSO-neutral years in the reanalysis are not considered.



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Figure S13: (a) Occurrence of statistically significant zonal wind signals by season and altitude over the equatorial band (10°S – 10°N , 60°E – 120°E) for the EC-EARTH CTL experiment. QBO-W minus QBO-E equatorial zonal wind (longitude–pressure section) for the EC-EARTH CTL experiment during (b) MAM, (c) JJA, (d) SON, and (e) DJF. Horizontal green dashed lines denote representative vertical levels (700, 100, and 70 hPa), while vertical green dashed lines indicate the longitudinal band (60°E – 120°E) used in the season–altitude diagram in panel (a).

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