Supplementary Information

ENSO teleconnections with the NAE sector during December in CMIP5/CMIP6 models: impacts of the atmospheric mean state

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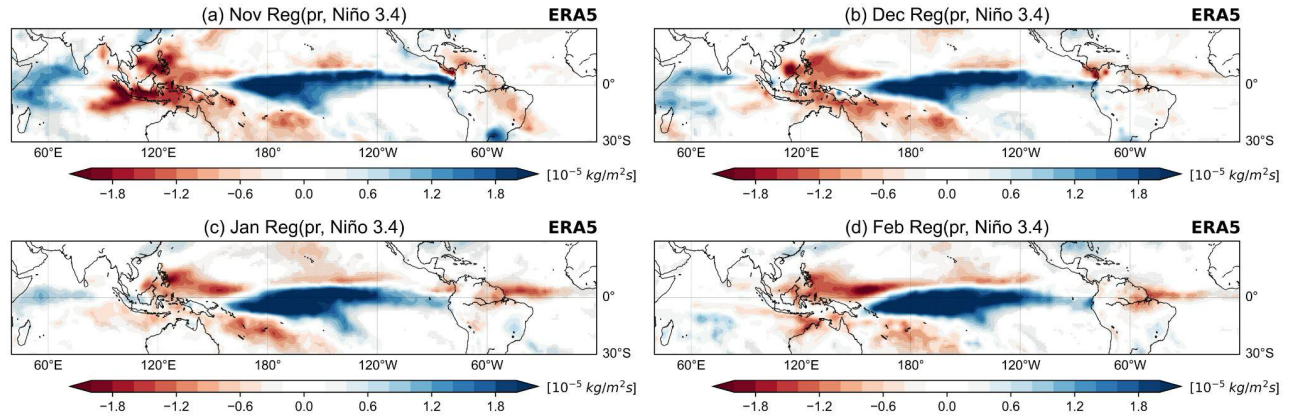

Fig. S1: ENSO-related precipitation anomalies for the reference dataset during the extended boreal winter season. *ERA5 precipitation anomalies (units 10^{-5} kg/m^{2}s) regressed against the normalized Niño 3.4 precipitation index for (a) November, (b) December, (c) January, (d) February. The light-gray stippling indicates the grid points in which the regression is significant at the 95% level of confidence with respect to a two-tailed t-test. The units of regression are specified per standard deviations.*

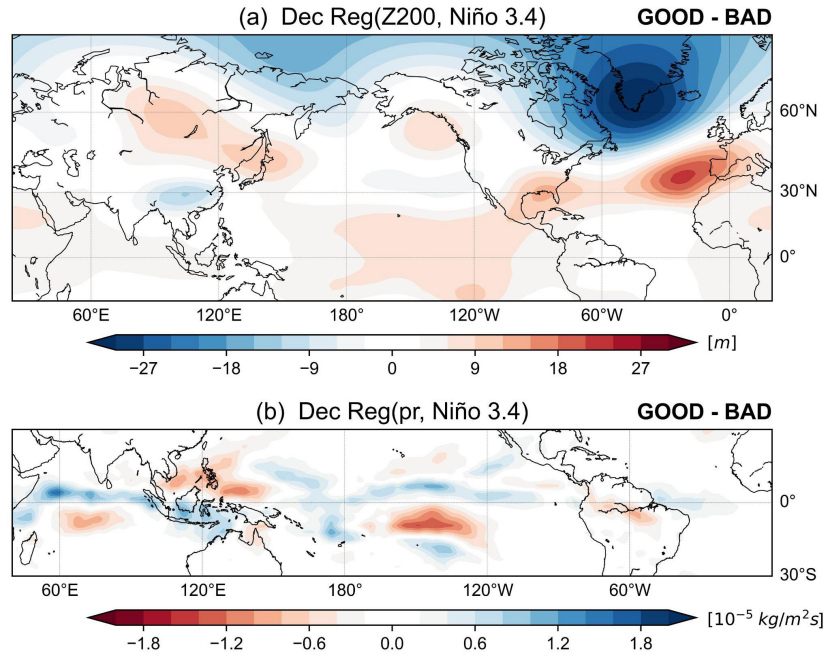

Fig. S2: ENSO teleconnection and ENSO-related precipitation anomalies stratified by clustered groups. *(a) Difference between the ensemble averages of 200 hPa geopotential height anomalies (Z200, units m) regressed against the normalized Niño 3.4 precipitation index of the ensemble mean of good models (GOOD) and ensemble mean of bad models (BAD). (b) as in (a) but for the regression of precipitation anomalies (units 10^{-5} kg/m^{2}s). The units of regression are specified per standard deviations.*

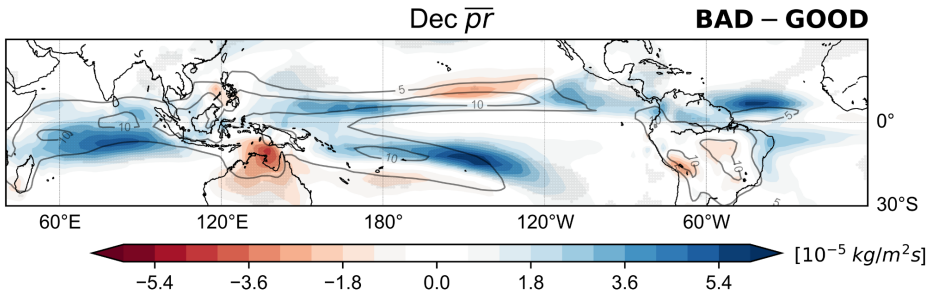

Fig. S3: Inter-Tropical Convergence Zone (ITCZ) stratified by clustered groups. *Difference between the ensemble averages of bad and good models (BAD - GOOD) of the December climatology, denoted by the overbar, for precipitation (units 10^{-5} kg/m^{2}s). The contour lines represent the precipitation climatology for good models (units 10^{-5} kg/m^{2}s). The light-gray stippling indicates the grid points in which the difference is significant at the 95% level of confidence with respect to one-sample t-test.*

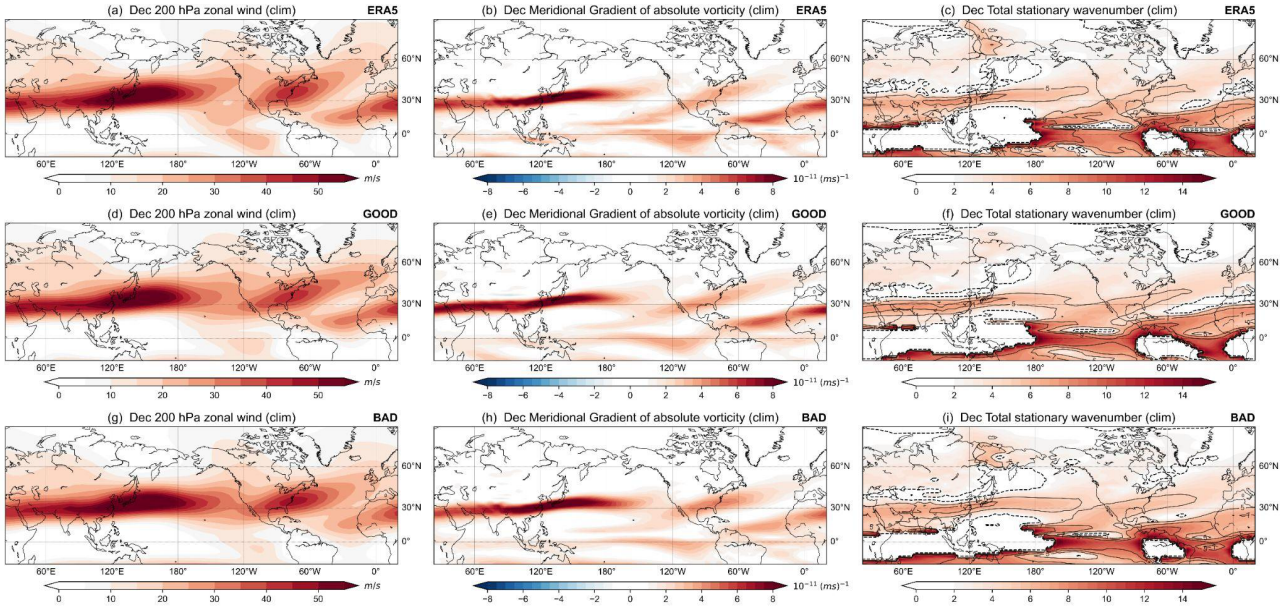

Fig. S4: Atmospheric waveguide in the reference dataset and clustered groups. *ERA5 December (a) climatological 200 hPa zonal wind (units m/s), (b) meridional gradient of absolute vorticity (units 10^{-11} 1/ms), and (c) total stationary wavenumber K. (d)-(e)-(f) and (g)-(h)-(i) as in (a)-(b)-(c) but for the ensemble average of good (GOOD) and bad (BAD) models. Solid contour lines in (c)-(f)-(i) indicate the total stationary wavenumber at 5,7, and 9, while dashed lines indicate regions where the stationary wavenumber is imaginary (i.e., regions where meridional Rossby wave propagation is not permitted). The white color at the equator (south of 10°N) in (c)-(f)-(i) indicates the zero wind regions, where the total stationary wavenumber is singular.*

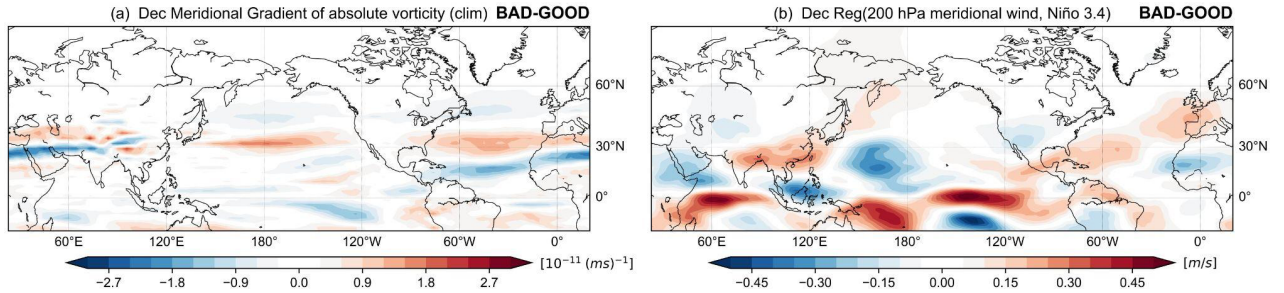

Fig. S5: Attribution of TRWS differences in bad and good models. *(a) Difference between bad and good models (BAD-GOOD) of the December climatology of the meridional gradient of absolute vorticity (units 10^{-11} 1/ms). (b) as in (a) but for the 200 hPa meridional irrotational wind anomalies (units m/s) regressed against the normalized Niño 3.4 precipitation index. Regression units are specified per standard deviation.*

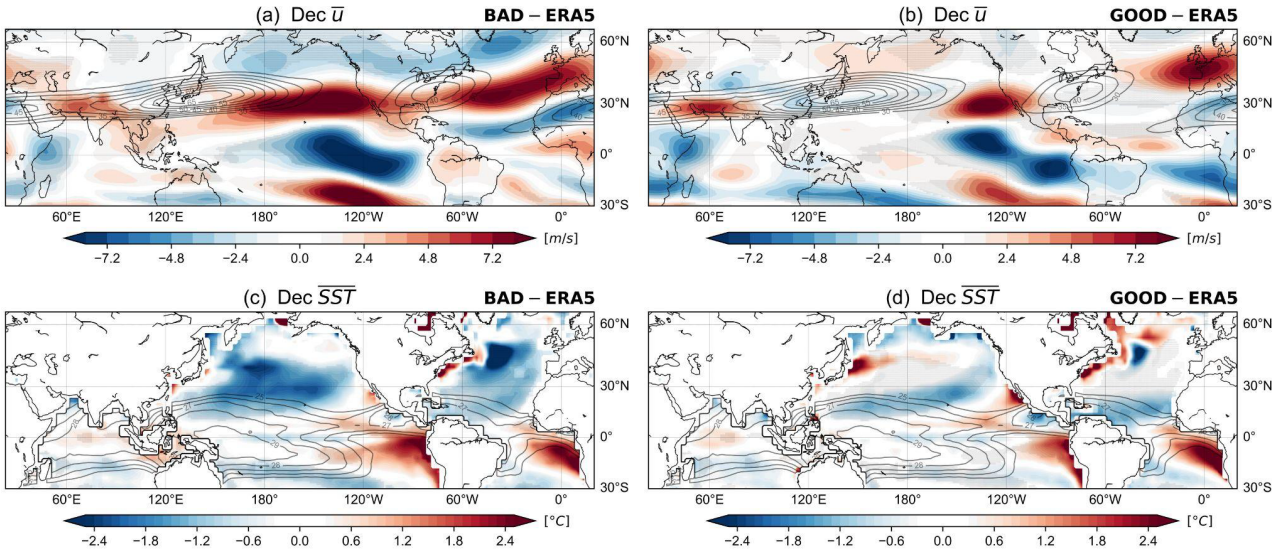

Fig. S6: Jet stream and surface ocean mean state biases in clustered groups. *(a) Difference (i.e., bias) between the ensemble averages of bad models and ERA5 (BAD - ERA5) of the December climatology, denoted by the overbar, for the 200 hPa zonal wind (units m/s). (b) As in (a) but for good models (GOOD - ERA5). (c)-(d) as in (a)-(b) but for the climatology of SST (units °C). The contour lines in (a)-(b) represent the 200 hPa zonal wind climatology for ERA5 (units m/s), while the contour lines in (c)-(d) represent the SST climatology for ERA5 (units °C). The light-gray stippling indicates the grid points in which the difference is significant at the 95% level of confidence with respect to one-sample t-test.*

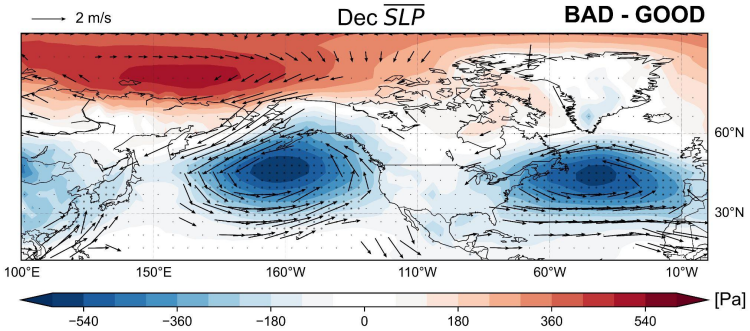

Fig. S7: Surface atmospheric mean state stratified by clustered groups. *Difference between the ensemble averages of bad and good models (BAD - GOOD) of the December climatology, denoted by the overbar, for the Sea Level Pressure (SLP) and 925 hPa wind. Shading indicates the climatology of SLP (units Pa), while vectors represent the 925 hPa climatological wind (units m/s) with a unit vector of 2 m/s. The light-gray stippling indicates the grid points in which the difference is significant at the 95% level of confidence with respect to one-sample t-test. Winds are displayed at the 90% level of confidence with respect to a one-sample t-test.*

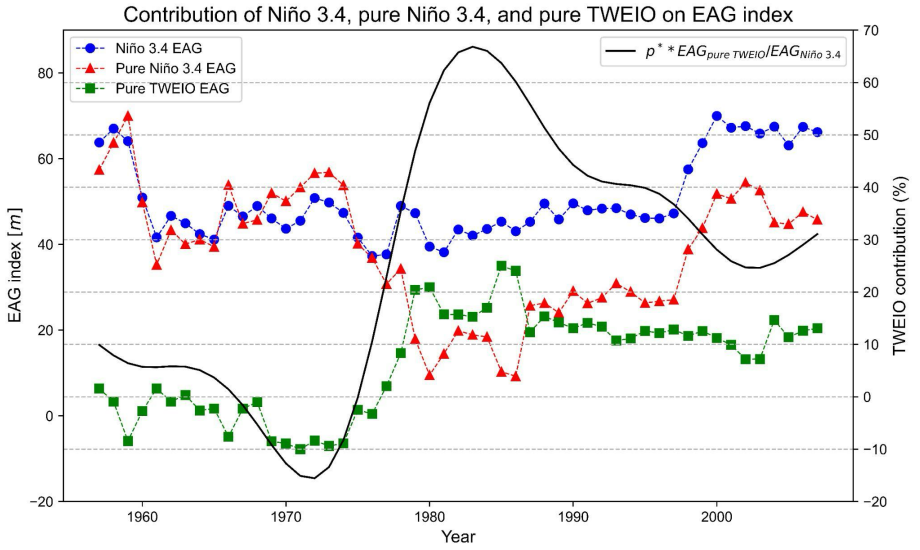

Figure S8: November contribution of the Niño 3.4, pure Niño 3.4, and pure TWEIO to the ERA5 EAG index from 1940 to 2024. *Values of the November Eastern Atlantic Gradient (EAG) of 200 hPa geopotential height anomalies [(25°N-40°N, 25°W-5°E) and (50°N-65°N, 50°W-10°W)] regressed against the Niño 3.4 ($EAG_{(Niño3.4)}$, blue scatters), the pure Niño 3.4 ($EAG_{(Pure\ Niño3.4)}$, red scatters), and the pure TWEIO ($EAG_{(Pure\ TWEIO)}$, green scatters) indices over a sliding window of 35 years from 1940 to 2024. The black line represents the contribution (%) of the pure TWEIO EAG index to the Niño 3.4 EAG index.*