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On the forcings of the unusual Quasi-Biennial Oscillation structure in February 2016

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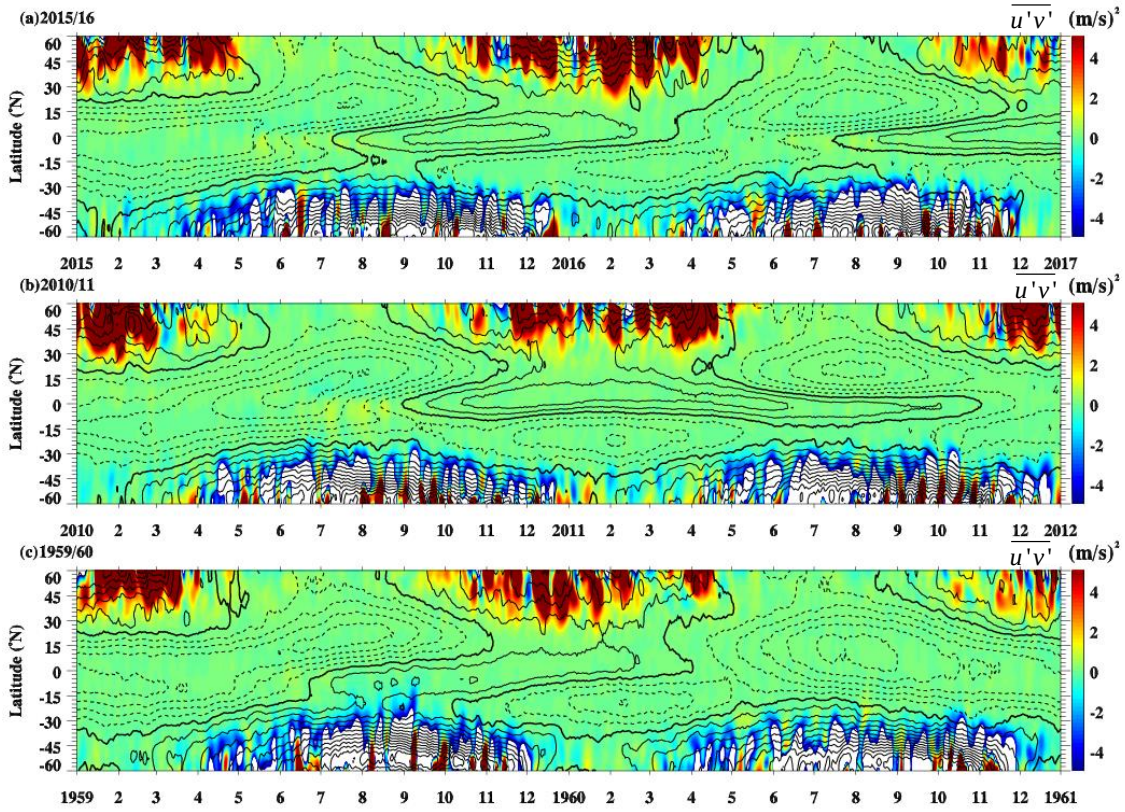

Figure S1. The latitude-time cross section of eastward propagating Rossby waves (with periods of 5-70 days) horizontal momentum flux in (a) 2015/2016, (b) 2010/2011 and (c) 1959/1960 at 40 hPa. Color shadings denote the horizontal momentum flux. Contour lines denote zonal mean zonal wind. The interval value of contour is 5 m/s.

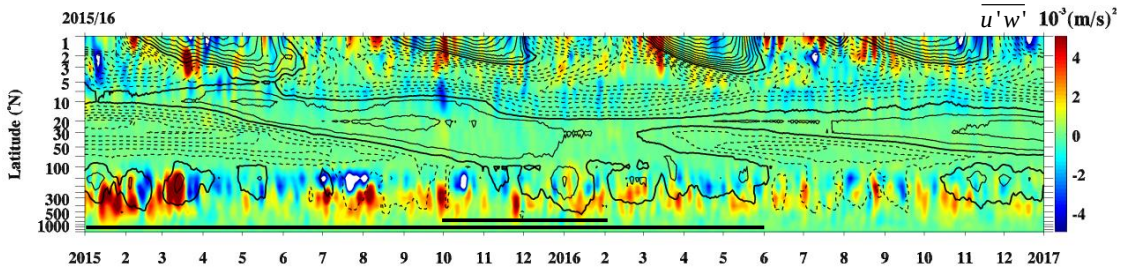

Figure S2. Temporal evolution of Rossby wave activity as vertical momentum flux averaged over 10°S-10°N (a) the daily altitude-time cross section from 2015 to 2016. Color shading denotes the vertical momentum flux. Contour denotes zonal mean zonal wind. The interval value of contour is 5 m/s. The horizontal dashed lines denote the altitudes of 20 and 40 hPa. The horizontal solid lines denote the El Niño period (single line) and strong El Niño period (double lines).

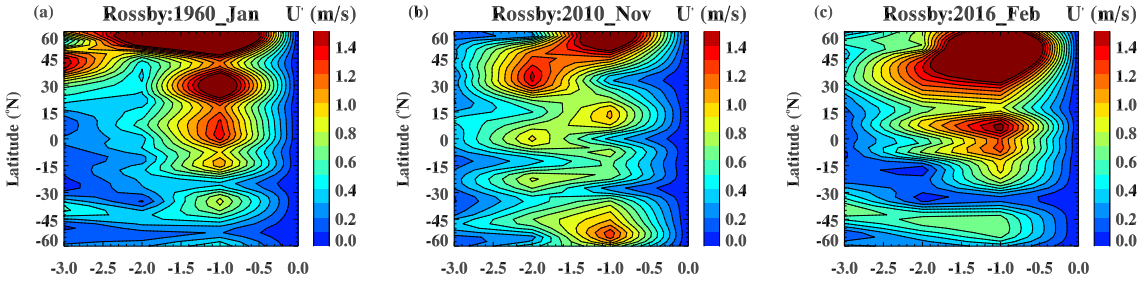

Figure S3. The wavenumber spectrum result of Rossby w2040 in zonal wind perturbation at 40 hPa in (a) January 1960, (b) November 2010 and (c) February 2016, respectively.

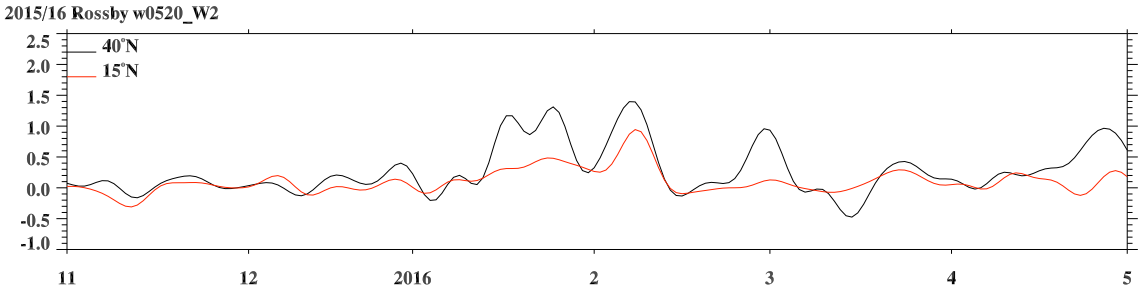

Figure S4. The temporal variation of Rossby w0520 (with wavenumber -2) horizontal momentum flux at 15°N (red lines) and 40°N (black lines) from December 2015 to April 2016 at 40 hPa. The unit is m^2/s^2.

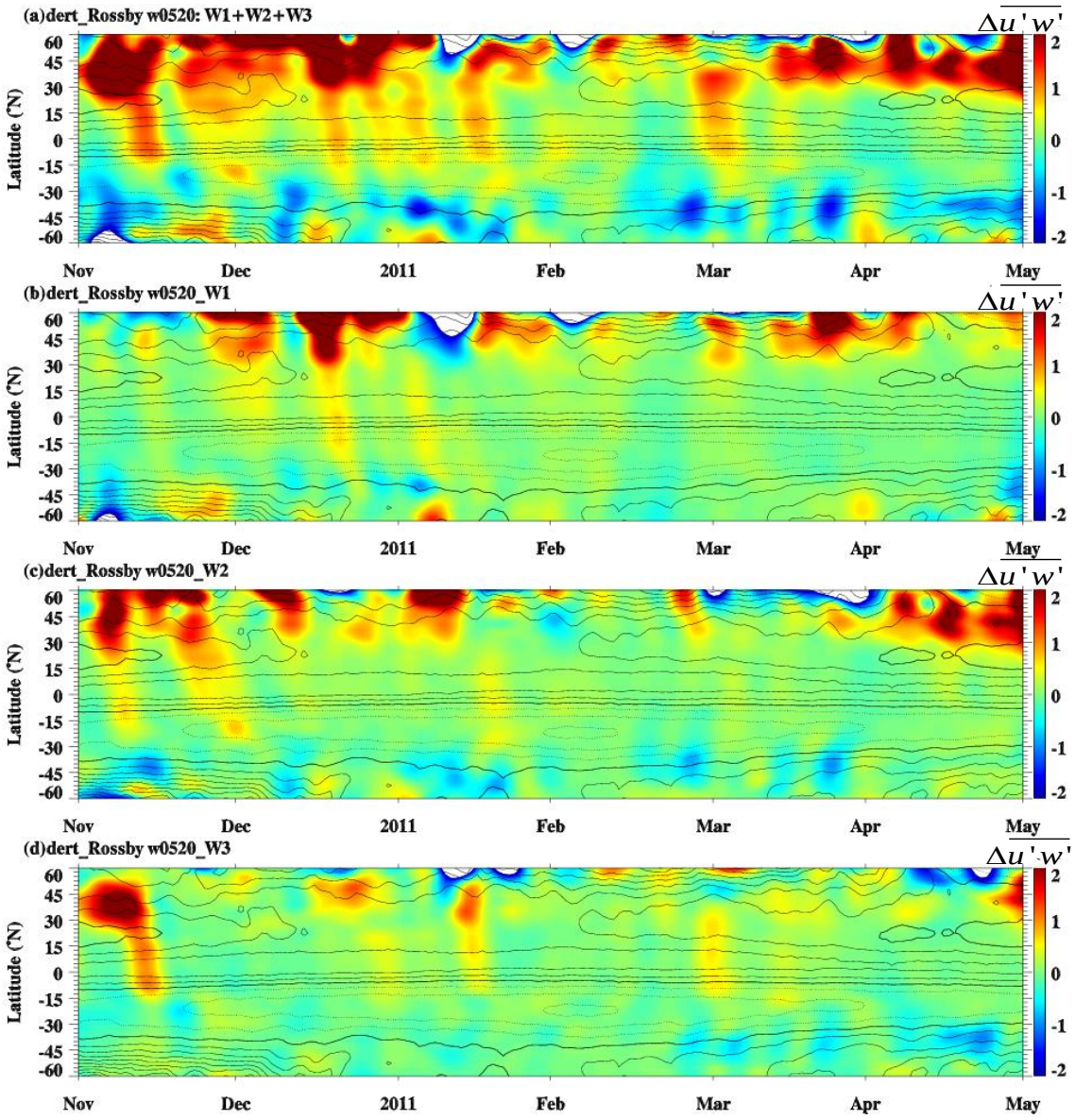

Figure S5. The latitude-time cross section of Rossby w0520 horizontal momentum fluxes (a) W1+W2+W3, (b) W1, (c) W2 and (d) W3 from November 2010 to April 2011 at 40 hPa. Color shadings denote the anomalies with respect to the monthly climatology. Contour lines denote zonal mean zonal wind. The interval value of contour is 5 m/s.

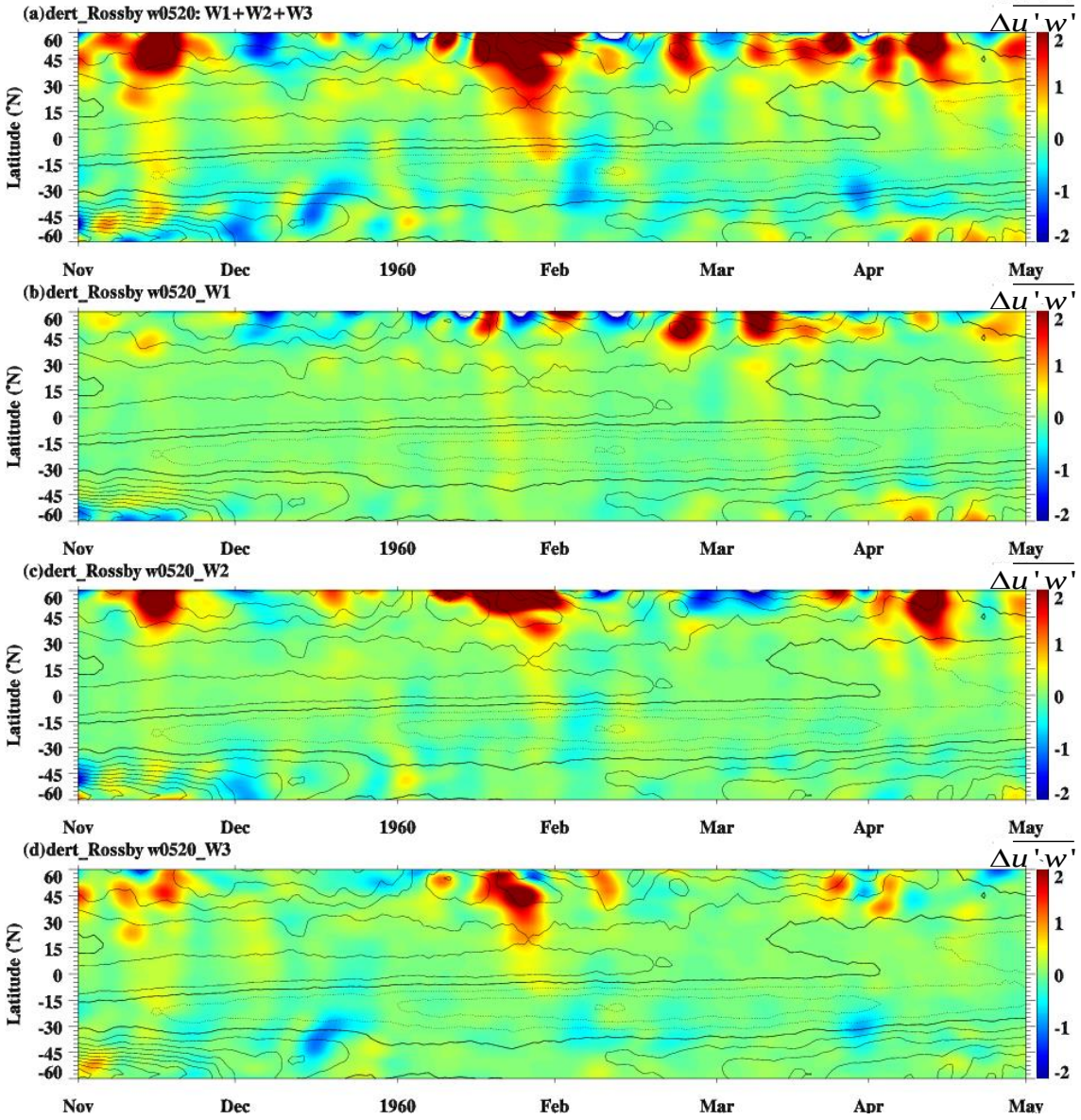

Figure S6. The latitude-time cross section of Rossby w0520 horizontal momentum fluxes (a) W1+W2+W3, (b) W1, (c) W2 and (d) W3 from November 1959 to April 1960 at 40 hPa. Color shadings denote the anomalies with respect to the monthly climatology. Contour lines denote zonal mean zonal wind. The interval value of contour is 5 m/s.

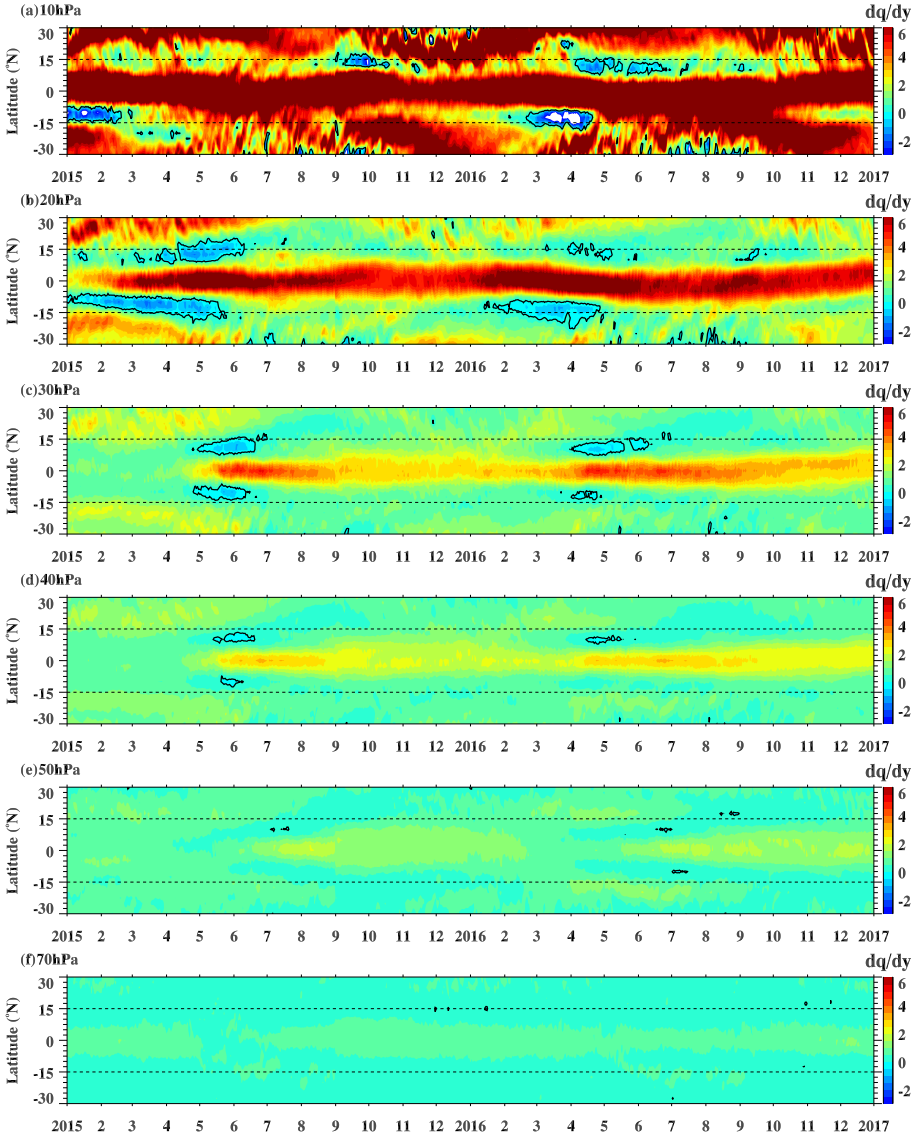

Figure S7. The meridional gradient of potential vorticity from January 2015 to December 2016 at (a) 10 hPa, (b) 20 hPa, (c) 30 hPa, (d) 40 hPa (e) 50 hPa and (f) 70 hPa in latitude-time cross section. The black contours denote the zero values. The unit is $10^{-3}m^{-1}s^{-1}$. The horizontal dashed lines denote 15°S and 15°N.

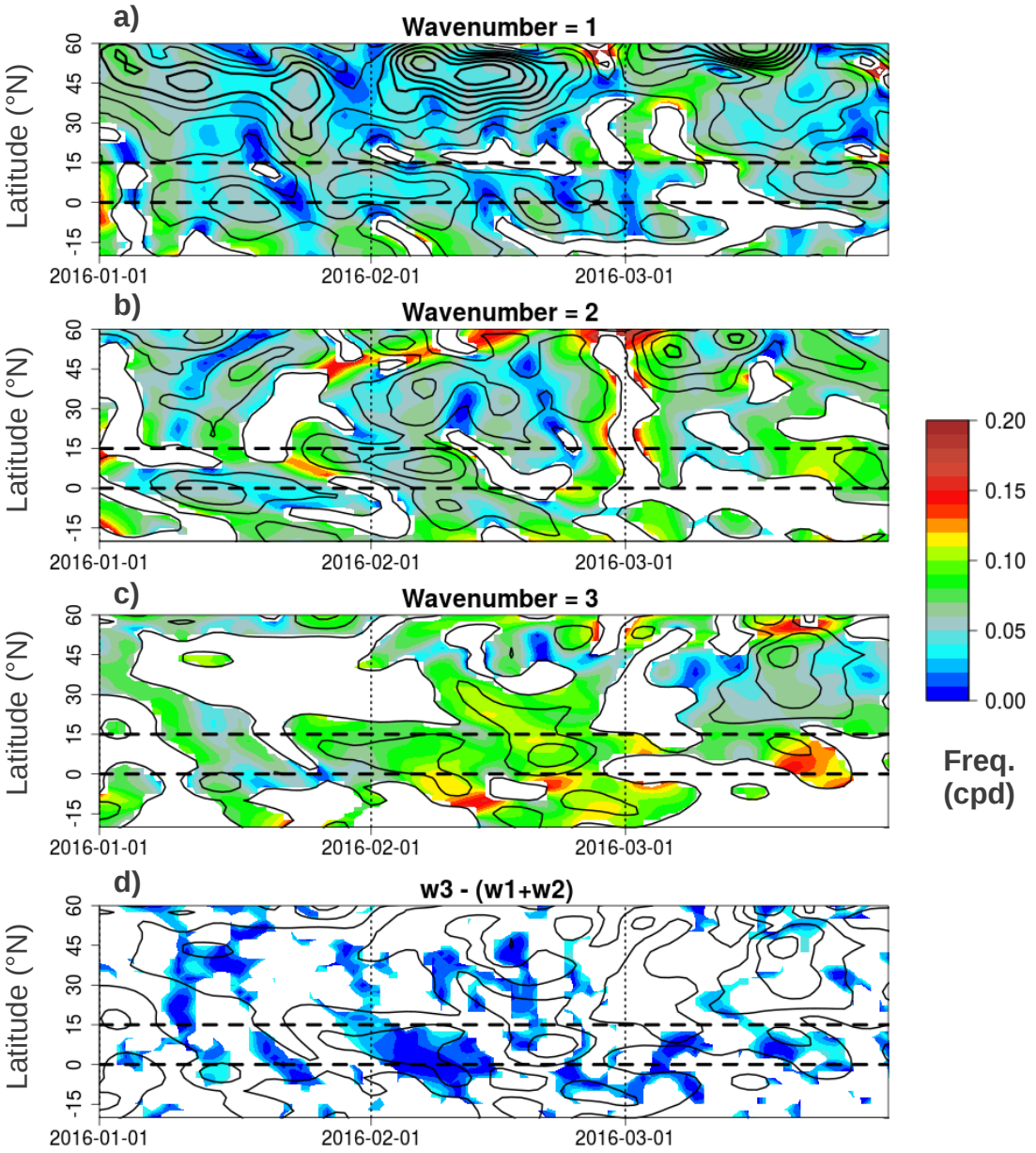

Figure S8. Time-latitude cross sections of 50 hPa Rossby w0540 wave frequencies as color shadings for January-March 2016: (a) W1, (b) W2 and (c) W3. In (d) the absolute difference in frequency of W3 - (W1+W2) is shown, indicating the deviation from resonant conditions. Black contours indicate amplitudes of the corresponding wavenumbers in (a-c), starting at 1 m/s with that same interval. In (d) the black contours repeat W3 amplitudes. In (a), (b) and (c), frequencies of waves with very low amplitude (below 1 m/s) are masked out. In (d), frequency differences above 0.04 cpd (i.e. far from resonant condition) are masked out for better visibility. Wave properties were obtained using zonal winds.

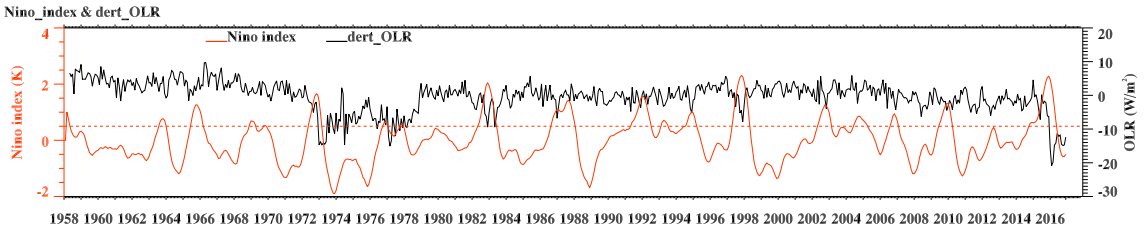

Figure S9. The monthly zonal mean OLR deviation from the monthly climatology averaged over 5°S-5°N and ENSO index from 1958 to 2016.