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Enhanced upward motion through the troposphere over the tropical western Pacific and its implications for the transport of trace gases from the troposphere to the stratosphere

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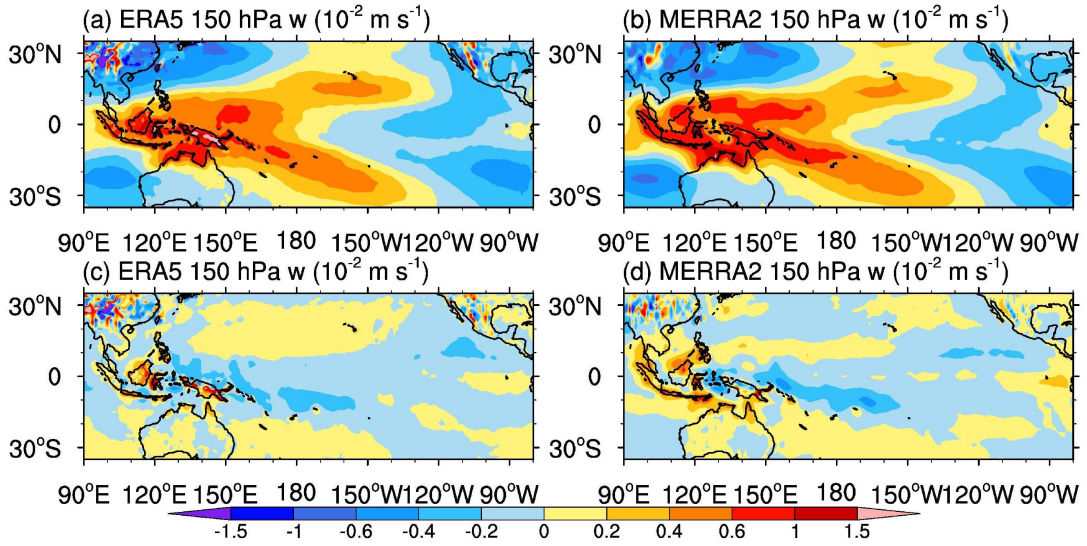

Fig. S1. The climatological mean values of 150 hPa *w* (10^{-2} m s^{-1}) in NDJFM during 1958-2017 using ERA5 data (a) and during 1980-2017 using MERRA2 data (b). (c) and (d) show the difference between the climatological mean 150 hPa w using JRA55 data and ERA5 data (c) and MERRA2 data (d).

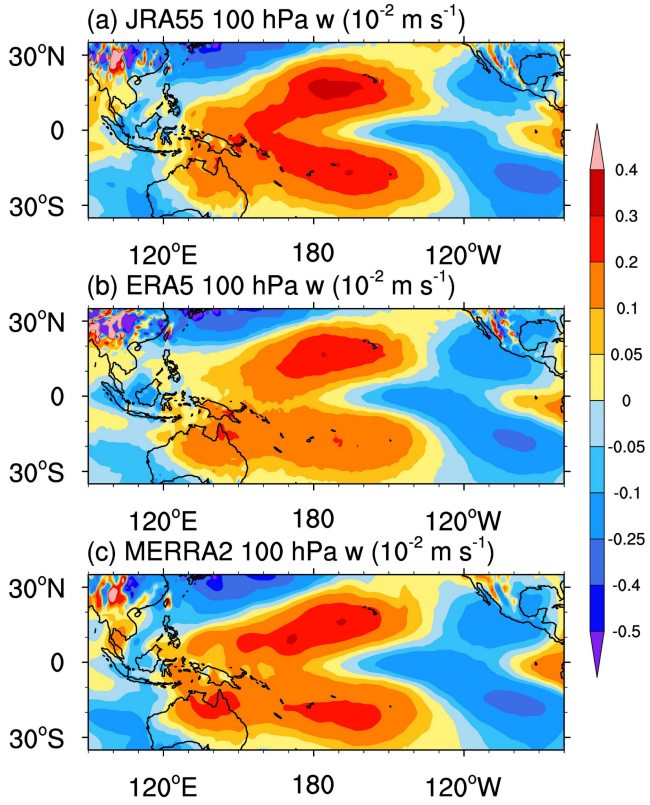

Fig. S2. The climatological mean values of 100 hPa *w* (10^{-2} m s^{-1}) using JRA55 data in NDJFM during 1958-2017 (a); using ERA5 data in NDJFM during 1958-2017 (b); and using MERRA2 data in NDJFM during 1980-2017 (c).

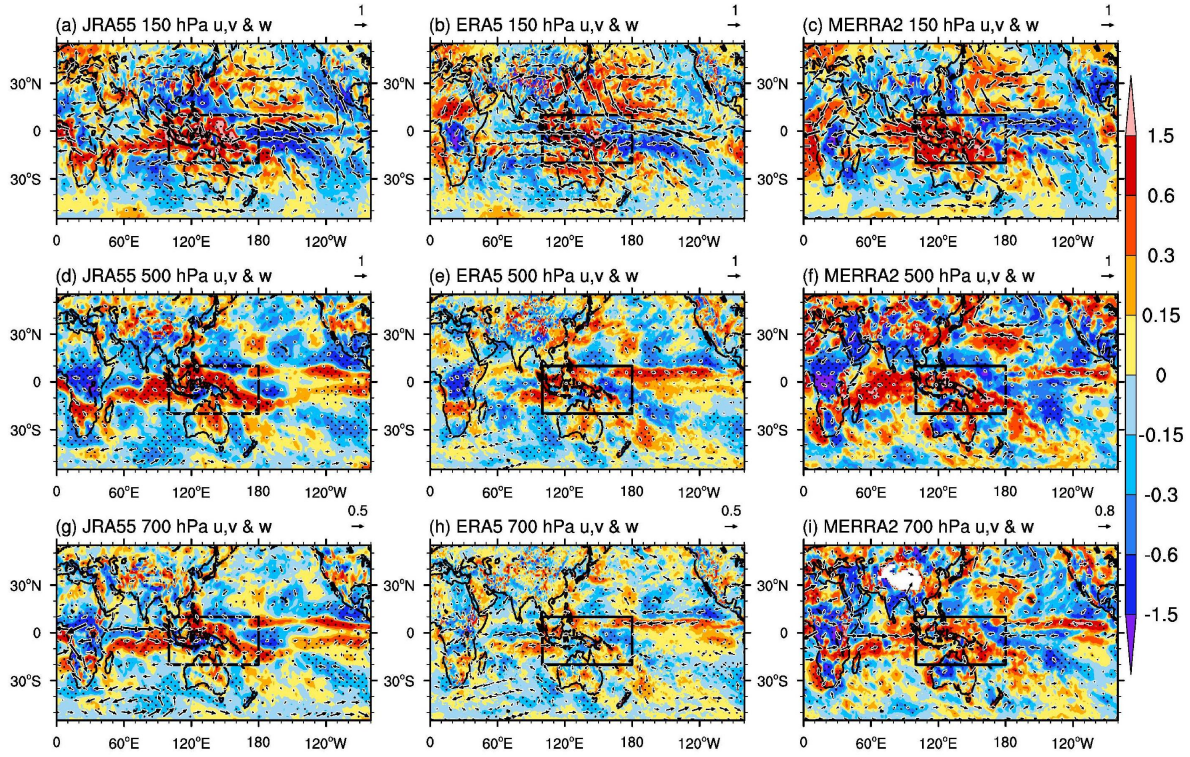

Fig. S3. The trends of the vertical velocity and horizontal winds at 150 hPa (a-c), 500 hPa (d-f), and 700 hPa (g-i) using JRA55, ERA5, and MERRA2 data in NDJFM during 1980-2017. (a), (d), and (g) show the trends of vertical velocity (shading, units: 10^{-4} m s^{-1} a^{-1}) and horizontal winds (arrows, units: 10^{-1} m s^{-1} a^{-1}) at 150 hPa (a); 500 hPa (d); and 700 hPa (g) using JRA55 data. (b), (e), and (h) are the same as (a), (d) and (e) but using ERA5 data. (c), (f), and (i) are the same as (a), (d) and (e) but using MERRA2 data. The trends of the vertical velocity over the dotted region are statistically significant at the 95% confidence level.

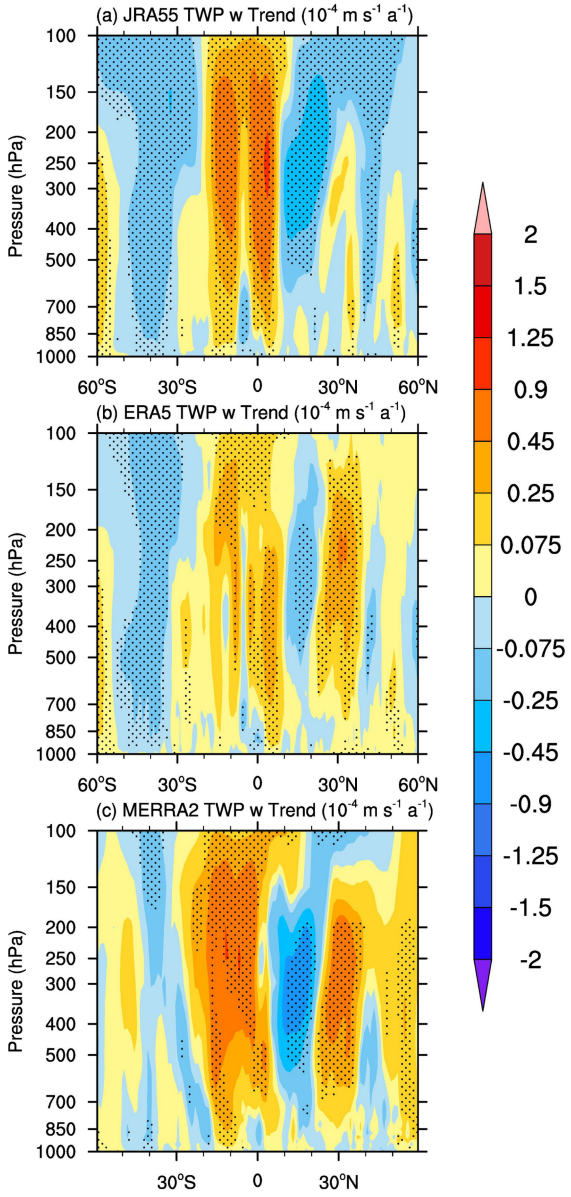

Fig. S4. Latitude-pressure cross sections of the trends of the vertical velocity (10^{-4} m s^{-1} a^{-1}) in NDJFM using (a) JRA55 data during 1958-2017; (b) ERA5 data during 1958-2017; and (c) MERRA2 data during 1980-2017 over the TWP (100°E-180°E). The trends of the vertical velocity over the dotted region are statistically significant at the 90% confidence level.

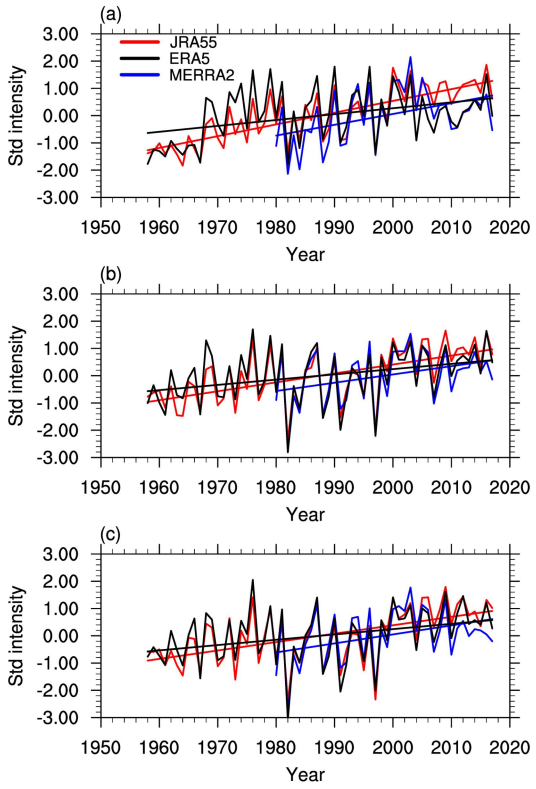

Fig. S5. The time series of the standardized intensity of the upward motion over the tropical western Pacific (20°S-10°N, 100°E-180°E) at (a) 150 hPa; (b) 500 hPa; and (c) 700 hPa extracted from JRA55 (red), ERA5 (black) and MERRA2 (blue) datasets after removing the ENSO signal using linear regression method. The straight lines in each figure indicate the linear trends. The linear trends of the upward motion intensity over the TWP at all levels from three datasets are statistically significant at the 95% confidence level.

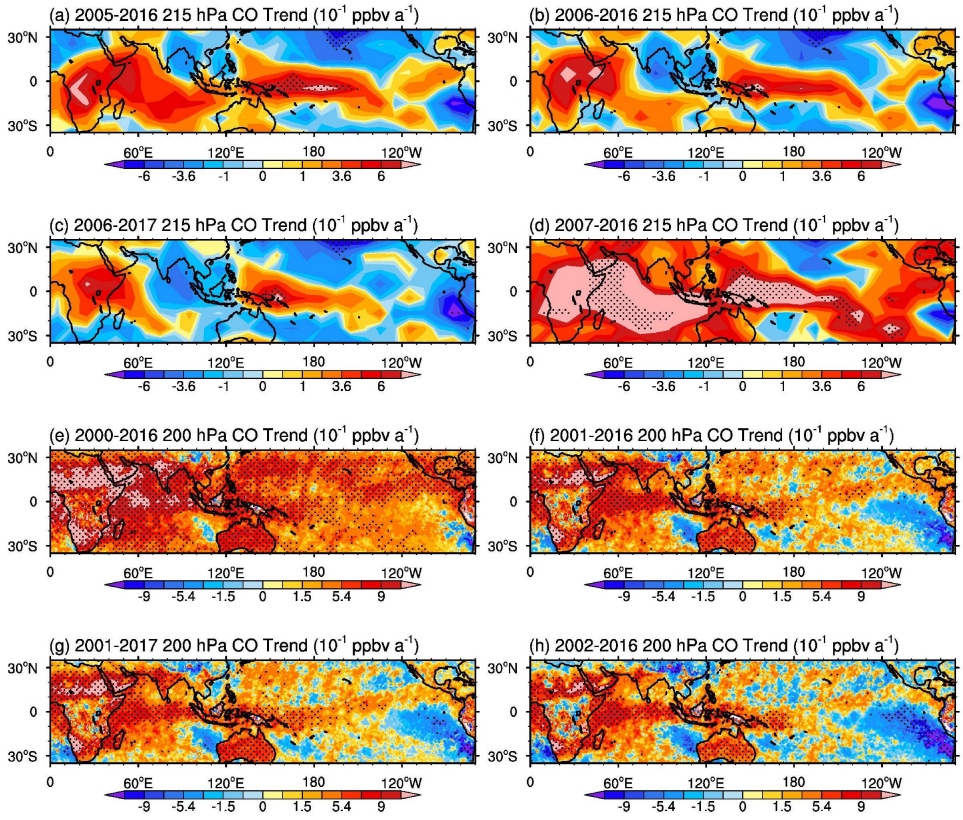

Fig. S6. The trends of CO derived from the MOPITT and MLS data. (a)-(d) The trends of CO (10^{-1} ppbv a^{-1}) at 215 hPa using MLS data in NDJFM during periods of (a) 2005-2016; (b) 2006-2016; (c) 2006-2017; and (d) 2007-2016. (e)-(h) The trends of CO (10^{-1} ppbv a^{-1}) at 200 hPa using MOPITT data in NDJFM during periods of (e) 2000-2016; (f) 2001-2016; (g) 2001-2017; and (h) 2002-2016. The trends of the CO over the dotted region are statistically significant at the 90% confidence level.

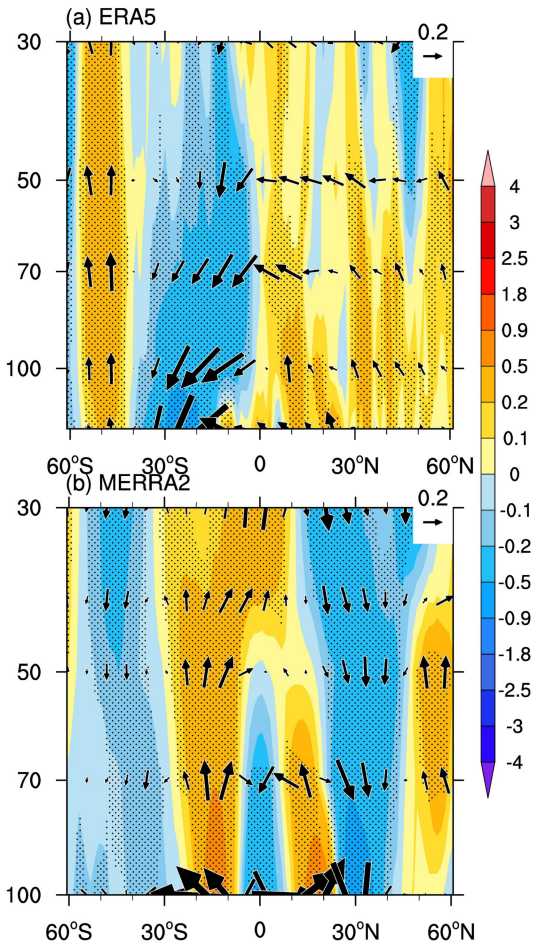

Fig. S7. The trends of the BD circulation (vectors) calculated using the TEM formula using ERA5 and MERRA2 data. (a) The trends of w* (10^{-5} m s^{-1} a^{-1}) and v* (10^{-2} m s^{-1} a^{-1}) in NDJFM during 1958-2017 using ERA5 data. (b) The trends of w* (10^{-5} m s^{-1} a^{-1}) and v* (10^{-2} m s^{-1} a^{-1}) in NDJFM during 1980-2017 using MERRA2 data. The shadings are the trends of the vertical velocities (10^{-5} m s^{-1} a^{-1}). The trends of the vertical velocity over the dotted regions are statistically significant at the 90% confidence level.

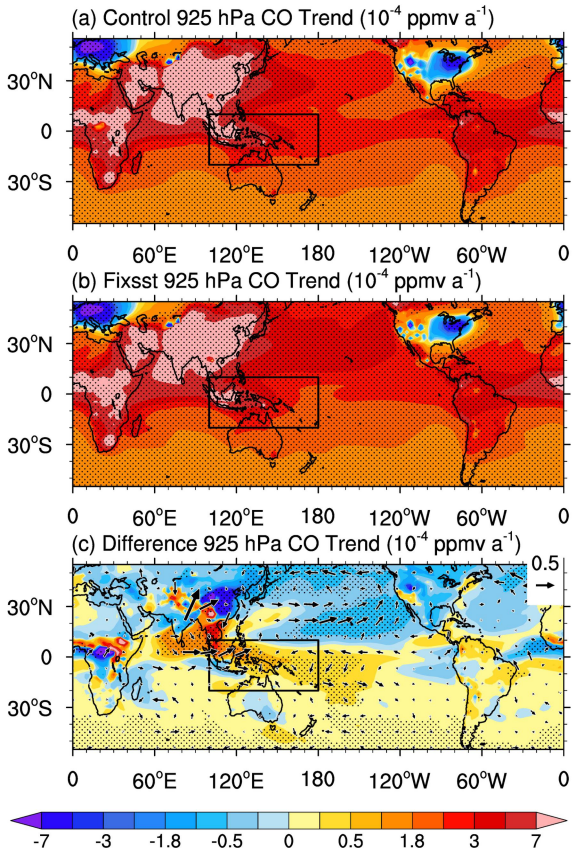

Fig. S8. The trends of CO (10^{-4} ppmv) at 925 hPa in NDJFM during 198-2017 in the (a) Control simulation, (b) Fixsst simulation, and (c) the difference between the Control and Fixsst simulations. The vectors in (c) denote the trends of the difference of 925 hPa horizontal winds (10^{-1} m s^{-1}) between the Control and Fixsst simulations. The trends of CO over the dotted region are statistically significant at the 95% confidence level.