Reconciling opposing Pacific Walker circulation trends in observations and climate model projections

Eui-Seok Chung[1,2], Axel Timmermann[1,2], Brian Soden[3], Kyung-Ja Ha[1,4], Lei Shi[5], and Viju John[6]

[1]Center for Climate Physics, Institute for Basic Science, South Korea, [2]Pusan National University, South Korea, [3]Rosenstiel School of Marine and Atmospheric Science, University of Miami, USA, [4]Department of Atmospheric Sciences, Pusan National University, South Korea, [5]NOAA/NCEI, USA, [6]EUMETSAT, Germany

1. Introduction

Due to availability of the long-term historical records of sea level pressure (SLP) over the equatorial Pacific, model-simulated changes in the Pacific Walker circulation (PWC) have mainly been assessed by comparing observed and simulated SLP variations [e.g., Vecchi et al., 2006; Power and Kociuba, 2011; Tokinaga et a., 2012]. While model-simulated weakening of the PWC has been supported by observed SLP changes on centennial time scales [e.g., Vecchi et al., 2006; Deser et al., 2010], SLP observations and reanalysis data sets suggest that PWC has strengthened, at least over recent several decades [e.g., Power and Kociuba, 2011; L'Heureux et al., 2013]. Although internal variability of the climate system has been invoked to explain the recent strengthening, the strengthening might have occurred as a result of anthropogenic warming [e.g., L'Heureux et al., 2013]. Given that large-scale circulation is tightly connected to hydrological cycle and climate feedbacks, the model-observation discrepancy in PWC changes would diminish confidence in model-projected future climate change. In this study, we examine whether anthropogenic warming is responsible for a strengthening of the PWC by analyzing satellite observed proxies for vertical motion along with output from a large ensemble simulation forced by the same radiative forcing [Kay et al., 2015].

2. Model-simulated forced response

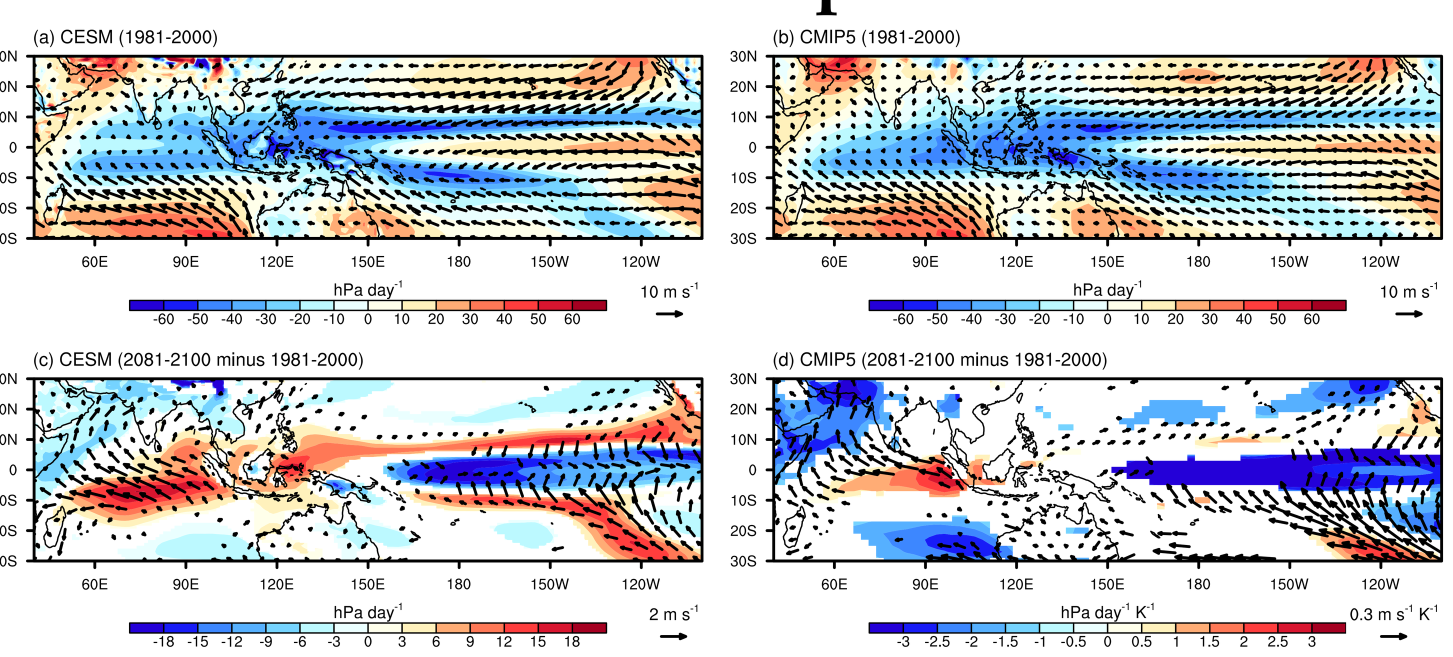

Figure 1: (a,b) Spatial distribution of the surface winds (vectors) and 500-hPa vertical velocity (shading) averaged over the period 1981-2000 and (c,d) their change between 1981-2000 and 2081-2000 for (a,c) the CESM ensemble mean and (b,d) the average of CMIP5 models under the RCP8.5 scenario. The changes in surface winds and vertical velocity in each CMIP5 model are normalized relative to the corresponding global-mean surface warming before computing the multi-model mean changes to account for inter-model discrepancy in climate sensitivity.

3. Comparison of model-simulated PWC changes with reanalyses and in situ observations

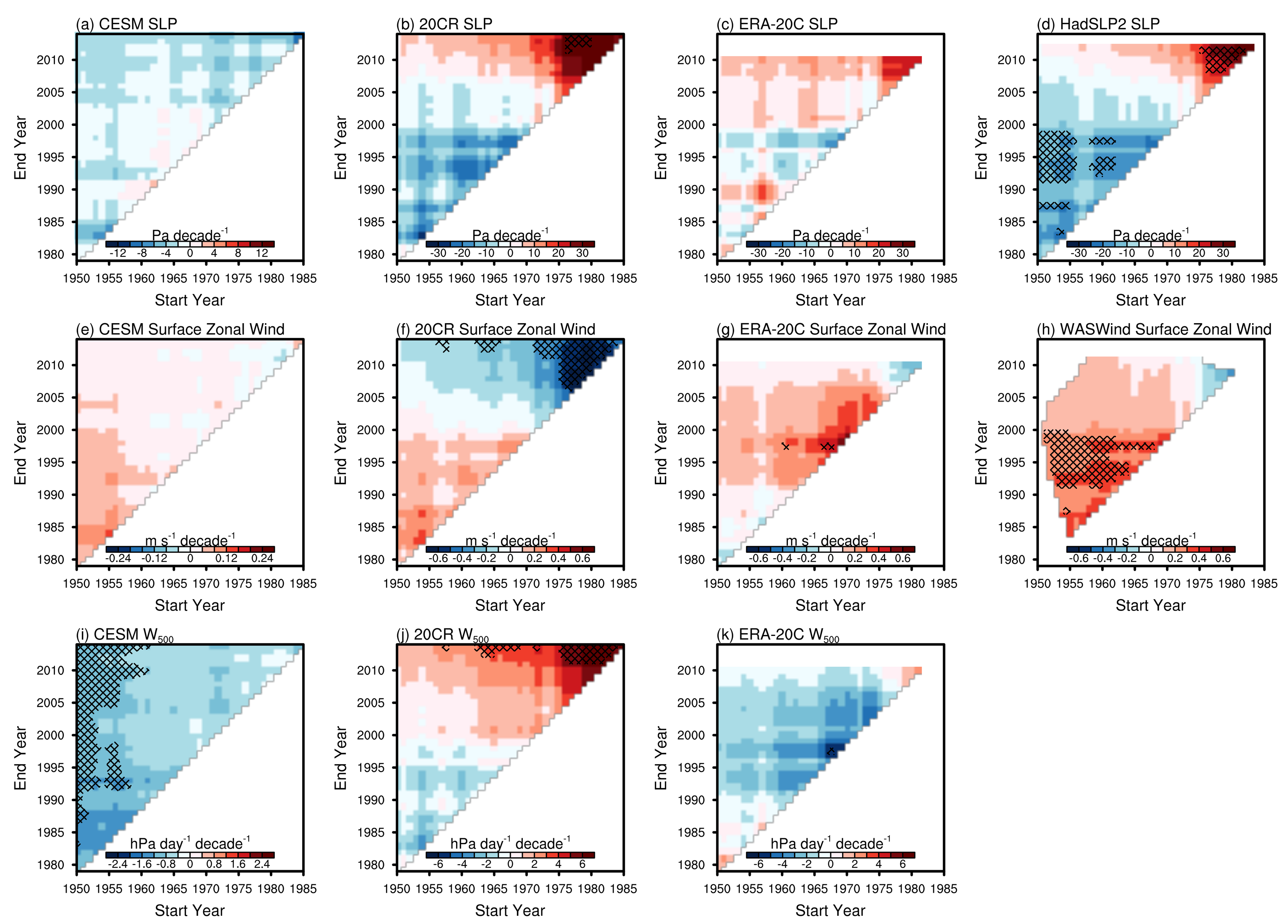

Figure 2: (a-d) Trends in the SLP difference between 5°S-5°N, 160°W-80°W and 5°S-5°N, 80°E-160°E, (e-h) surface zonal wind averaged over 6°S-6°N, 180°E-150°W and (i-k) the difference in vertical velocity at 500 hPa between 10°S-10°N, 180°-100°W and 10°S-10°N, 100°E-150°E for (a,e,i) the ensemble mean of the CESM large ensemble simulation, (b,f,j) 20CR, (c,g,k) ERA-20C and (d,h) in situ observations. For CESM, cross-hatching indicates that the absolute value of the ensemble-mean trend is greater than the standard deviation of trends across the individual ensemble members. In the case of the reanalyses and observations, cross-hatching denotes the grid points for which the computed trends are significant at the 95% confidence level.

References

Deser, C., Phillips, A. S., & Alexander, M. A. (2010). Twentieth century tropical sea surface temperature trends revisited. *Geophys. Res. Lett.*, *37*, L10701.

Kay, J. E., et al. (2015), The Community Earth System Model (CESM) Large Ensemble Project: A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability. *Bull. Am. Meteor. Soc.*, *96*, 1333-1349.

L'Heureux, M. L., Lee, S., & Lyon, B. (2013). Recent multidecadal strengthening of the Walker circulation across the tropical Pacific. *Nature Clim. Change*, *3*, 571-576.

Power, S. B., & Kociuba, G. (2011). What caused the observed twentieth-century weakening of the Walker circulation? *J. Clim., 24*, 6501-6514.

Tokinaga, H., Xie, S.-P., Deser, C., Kosaka, Y., & Okumura, Y. M. (2012). Slowdown of the Walker circulation driven by tropical Indo-Pacific warming. *Nature*, *491*, 439-443.

Vecchi, G. A., Soden, B. J., Wittenberg, A. T., Held, I. M., Leetmaa, A., & Harrison, M. J. (2006). Weakening of tropical Pacific atmospheric circulation due to anthropogenic forcing. *Nature*, *441*, 73-76.

4. Satellite-inferred PWC Changes and the role of internal variability on the recent strengthening

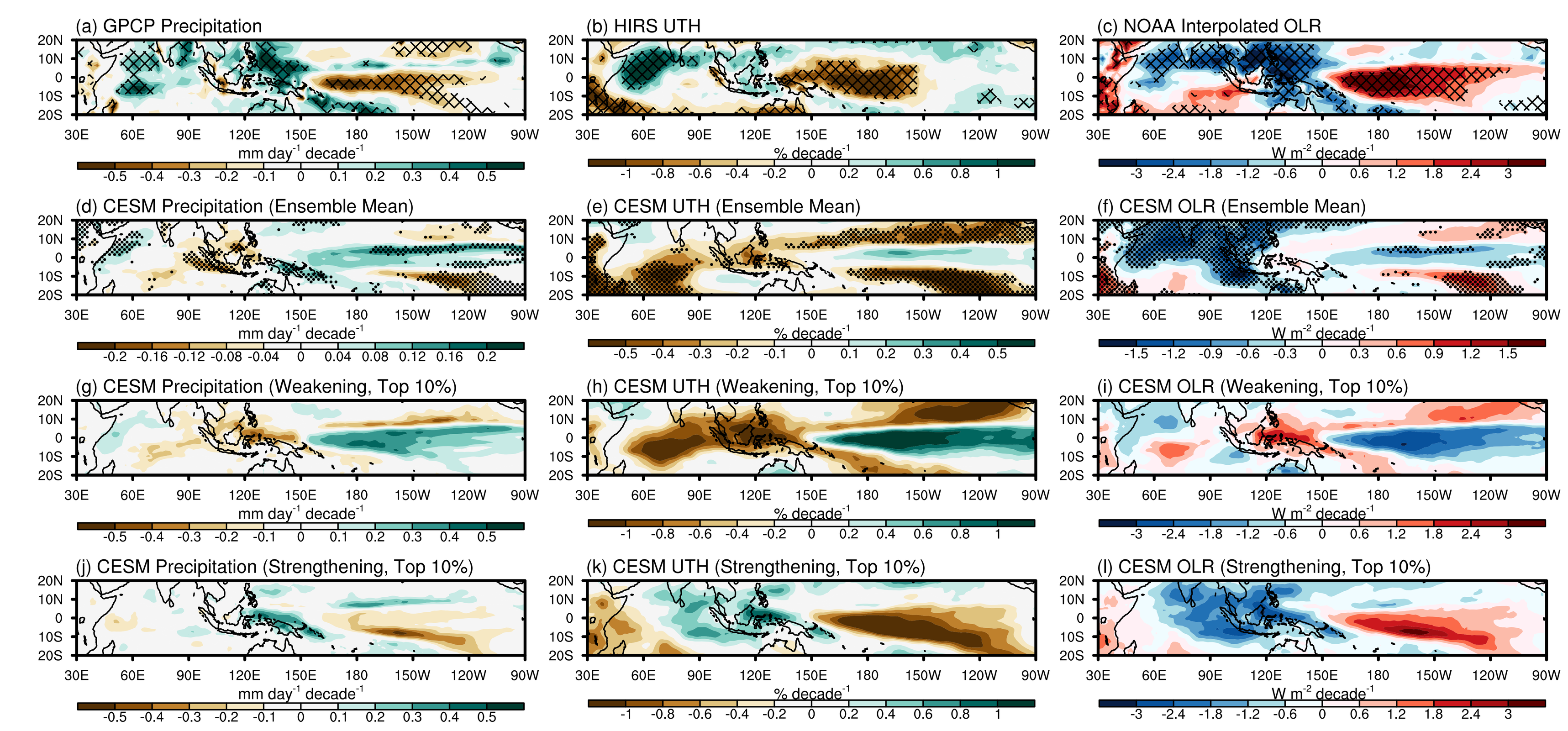

Figure 3: Spatial distribution of trends during 1979-2014 for (a,d,g,j) precipitation, (b,e,h,k) UTH and (c,f,i,l) OLR from (a-c) satellite observations, (d-f) the ensemble mean of the CESM large ensemble simulation, (g-i) the composite mean of ensemble members showing the largest weakening of the PWC and (j-l) the composite mean of ensemble members showing the largest strengthening of the PWC. Cross-hatching indicates that the observed trends are significant at the 95% confidence level. Stippling denotes that more than 70% of ensemble members exhibit the same sign as the ensemble mean.

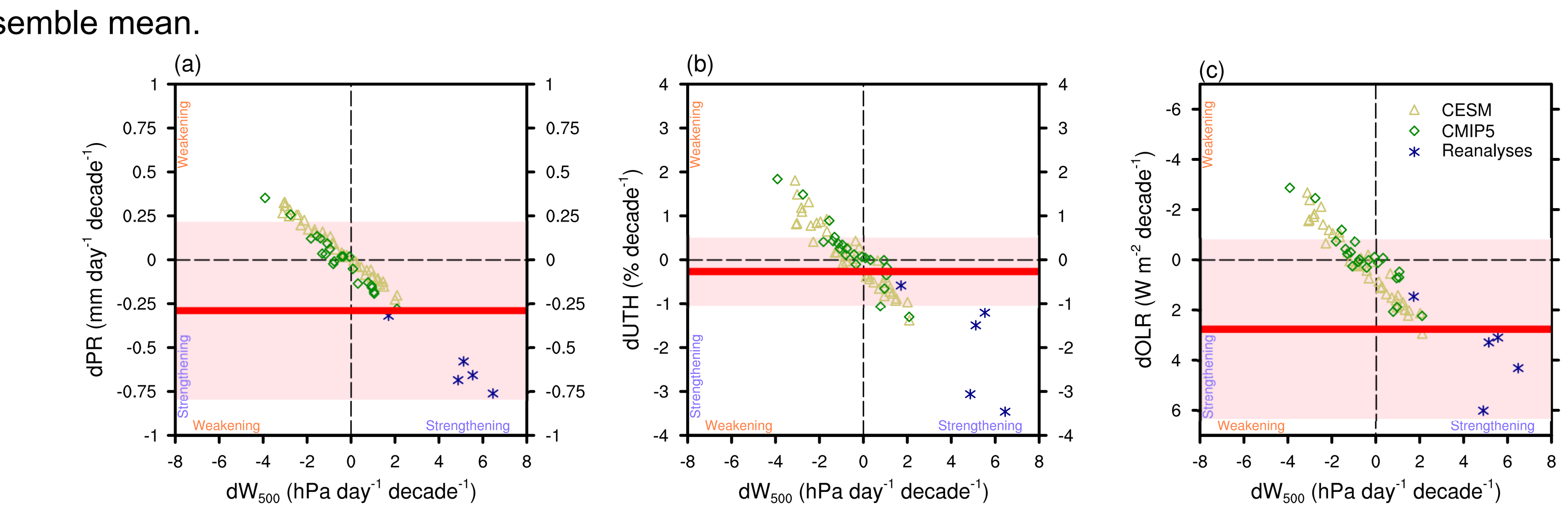

Figure 4: Scatter plots of trends in the difference of (a) precipitation, (b) UTH and (c) OLR between 10°S-10°N, 180°-100°W and 10°S-10°N, 100°E-150°E against the corresponding trends in vertical velocity difference at 500 hPa for (triangles) individual ensemble members of the CESM large ensemble simulation, (diamonds) individual CMIP5 models, and (asterisks) reanalysis data sets. The trends are computed over the period 1979-2014 except for ERA-20C (1979-2010) and MERRA-2 (1980-2014). The red lines and associated shading denote observed trends and their 95% confidence intervals. Note that the y axis is reversed for OLR.

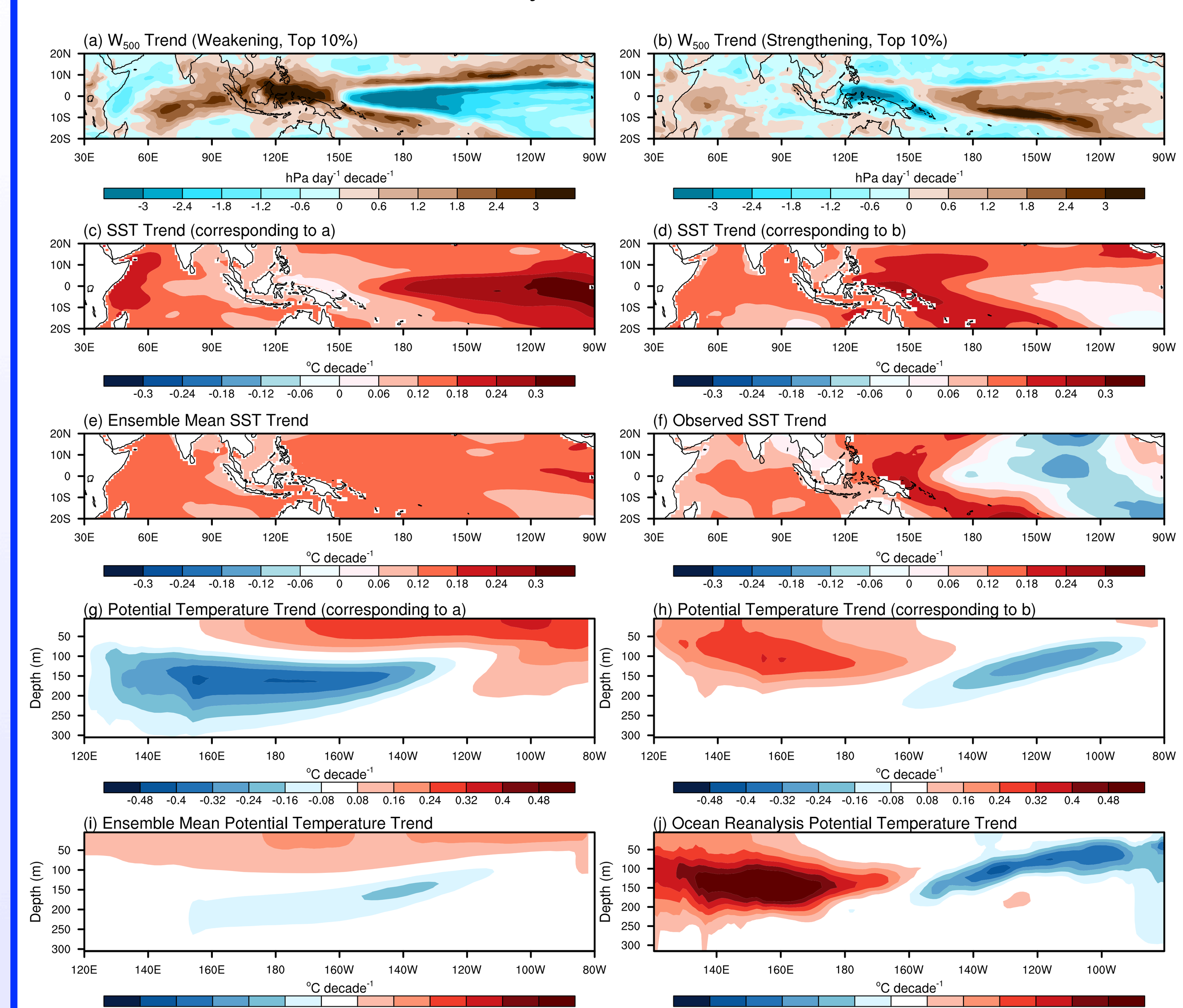

Figure 5: Spatial distribution of trends over the period 1979-2014 for (a,b) 500-hPa vertical velocity and (c-f) SST for (a,c) ensemble members showing the largest weakening of the PWC, (b,d) ensemble members showing the largest strengthening, (e) the ensemble mean, and (f) observations. (g-j) The same as c-f, but for ocean potential temperature trends averaged between 5°S and 5°N.

5. Summary

Based on a better spatio-temporal sampling and long-term stability of satellite observations compared to in situ observations, we analyzed independent satellite products, which are closely linked to the large-scale atmospheric circulation, along with the CESM large ensemble simulation. Our analysis shows that the CESM ensemble-mean trends over the satellite era are noticeably different from the satellite observations over the tropical Pacific, but satellite observations indicate a substantially weaker strengthening of the PWC than implied by the reanalyses. Furthermore, some ensemble members are found to reproduce a large part of the observed changes in the tropical Pacific whereas others forced with the same radiative forcing exhibit a modest weakening of the PWC. These findings clearly indicate a dominant role of internal variability on the recent strengthening of the PWC.

Acknowledgments. This work was supported by the Institute for Basic Science (IBS) under IBS-RS028-D1.