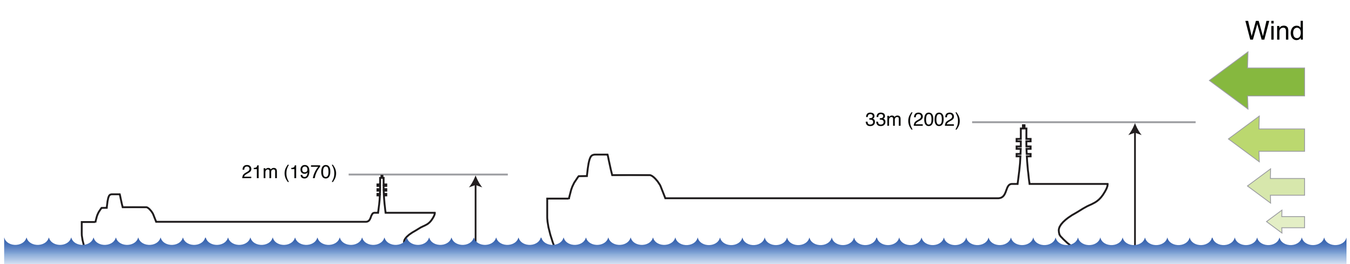
Walker Circulation Trends

The signal of the surface warming expected to result from increased atmospheric greenhouse gas concentrations has a characteristic pattern with more warming over land than over adjacent oceans and an intensification of warming at high Northern latitudes. This overall pattern is projected by climate models and also appears in the observed record over the last century. When focusing on somewhat finer details the picture is more complicated, however. Notably, the geographical pattern of long-term warming of the surface waters of the tropical Pacific is much less certain, as global climate projections among state-of-the-art models are not consistent, and even the observational record for the last century suffers from ambiguities.

The tropical Pacific is a region of strong coupling of the ocean temperatures to the overlying atmospheric circulation, and the uncertainties in trends and projections for warming are also reflected in uncertainties in the winds and rainfall. The atmospheric circulation in the region includes a component with rising motion over the warm western Pacific region and Maritime Continent, sinking over the cooler eastern equatorial Pacific and surface easterly winds along the equator. This circulation, named for the early 20th century British meteorologist **Sir Gilbert Walker**, has significant interannual variations coupled to the ocean temperatures through the familiar El Niño–La Niña cycle. The long term trends in the Walker circulation have been hard to characterize from existing observations.

Difficulties arise because sampling is limited in space and time, and changes in observational practices over the years have resulted in seriously biased measurements. One of the gravest biases has been in the marine surface wind measurements, which are important in determining sea surface temperature (SST) and regional sea level changes in the tropics. Direct wind measurements are taken mostly



Schematic of changes in anemometer height on ships.

by ships, and their bias comes from the fact that as ships have increased in height over recent decades, so has the height of the wind-measuring anemometers, resulting in spurious intensification of the prevailing winds (Figure 1a). Central to the debate are also the historical SST data sets in the tropical Pacific; but they, too, are inconsistent, some showing a flattening, others a strengthening of the east-west temperature difference.

To provide a clearer picture of the trends in observations, IPRC Assistant Researcher **Hiroki Tokinaga** spearheaded a team of mostly IPRC scientists, who have analyzed in great detail the in situ observational climate data sets in the tropical Indo-Pacific over the last six decades, bias corrected them as necessary, and then synthesized them to see whether a physically consistent pattern emerges among SST, cloudiness, sea level pressure (SLP), surface wind, and subsurface ocean temperature.

The data sets they analyzed consisted of the following: SLP and total marine cloudiness observations (with biases removed) of the International Comprehensive Ocean-Atmosphere Data Set (ICOADS); Tokinaga's bias-corrected Wave- and Anemometer-based Sea Surface Wind (WASWind; *IPRC Climate*, vol. 10, no. 2); subsurface ocean temperatures from bias corrected expendable bathythermographs (XBT) in the Enhanced Ocean Data Assimilation and Climate Prediction of the Hadley Centre, and land precipitation from rain gauge data of the University of Delaware and the Climatic Atlas Project.

Since the SST pattern affects the Walker circulation so much, they cross-checked the SST trends with five different surface temperature reconstructions: Extended Reconstructed Sea Surface Temperature (ERSST), the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) data sets, bucket-sampled SST from ICOADS, and night-time marine air temperature (NMAT) data sets from ICOADS, and the Met Office Historical Marine Air Temperature (MOHMAT). These observations were compared with the European Centre for Medium Range Weather Forecasting 40-year Reanalysis (ERA40) and the National Centers for Environmental Prediction (NCEP)-National Center for Atmospheric Research (NCAR) reanalysis.

According to the new bias-corrected surface WASWind, the easterly winds over the western tropical Pacific and westerly winds over the tropical Indian Ocean have both weakened (Figure 1b). These changes are consistent with observed changes in SLP, which has been rising over the Maritime Continent and falling over the central equatorial Pacific (Figure 1c). Over the Maritime Continent, the rain gauge data reveal a significant decrease in land precipitation, consistent with ship observations, which show an eastward shift of marine cloudiness from the Maritime Continent to the central equatorial Pacific (Figure 1d). All these changes point to a weakening of the Walker circulation.

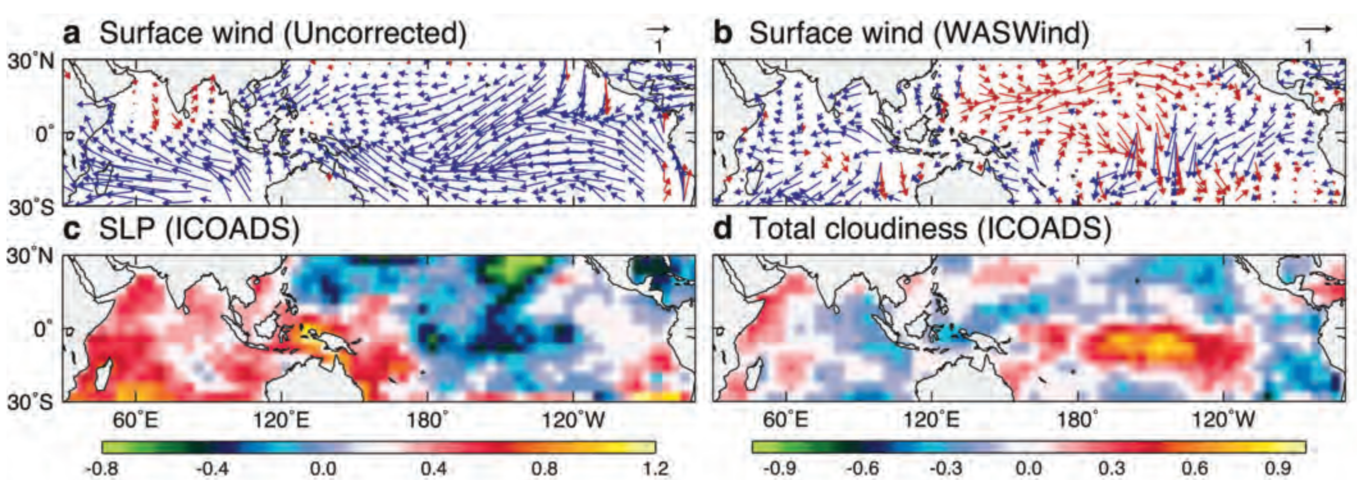


Figure 1. Annual mean trends for 1950–2008. (a) Uncorrected surface wind [m/s over 59 years], (b) bias-corrected surface wind from WASWind [m/s over 59 years], (c) SLP from ICOADS [hPa over 59 years], (d) marine cloudiness from ICOADS [okta over 59 years]. Red (blue) vectors in (a) and (b) indicate westerly (easterly) trends.

Results of changes in the zonal SST gradient, though, are inconclusive in the widely used SST products: one product shows a significant strengthening of the zonal SST gradient in the tropical Indo-Pacific (Figure 2d), while another shows no significant change (Figure 2c). However, the bias corrected XBT observations indicate the ocean mixed layer temperature has warmed more in the eastern than in the western equatorial Pacific Ocean (Figure 2a). The bucket-sampled SST and NMAT are consistent with the XBT pattern (Figure 2b,e,f). In other words, both surface and subsurface observations suggest the zonal thermal contrast across the Indo-Pacific has decreased. These analyses are therefore also consistent with the slowdown of the Walker circulation.

To what degree this long-term weakening trend in the Walker circulation resulted from anthropogenic forcing or natural climate variability is still unknown. In climate model simulations with anthropogenic forcing, the

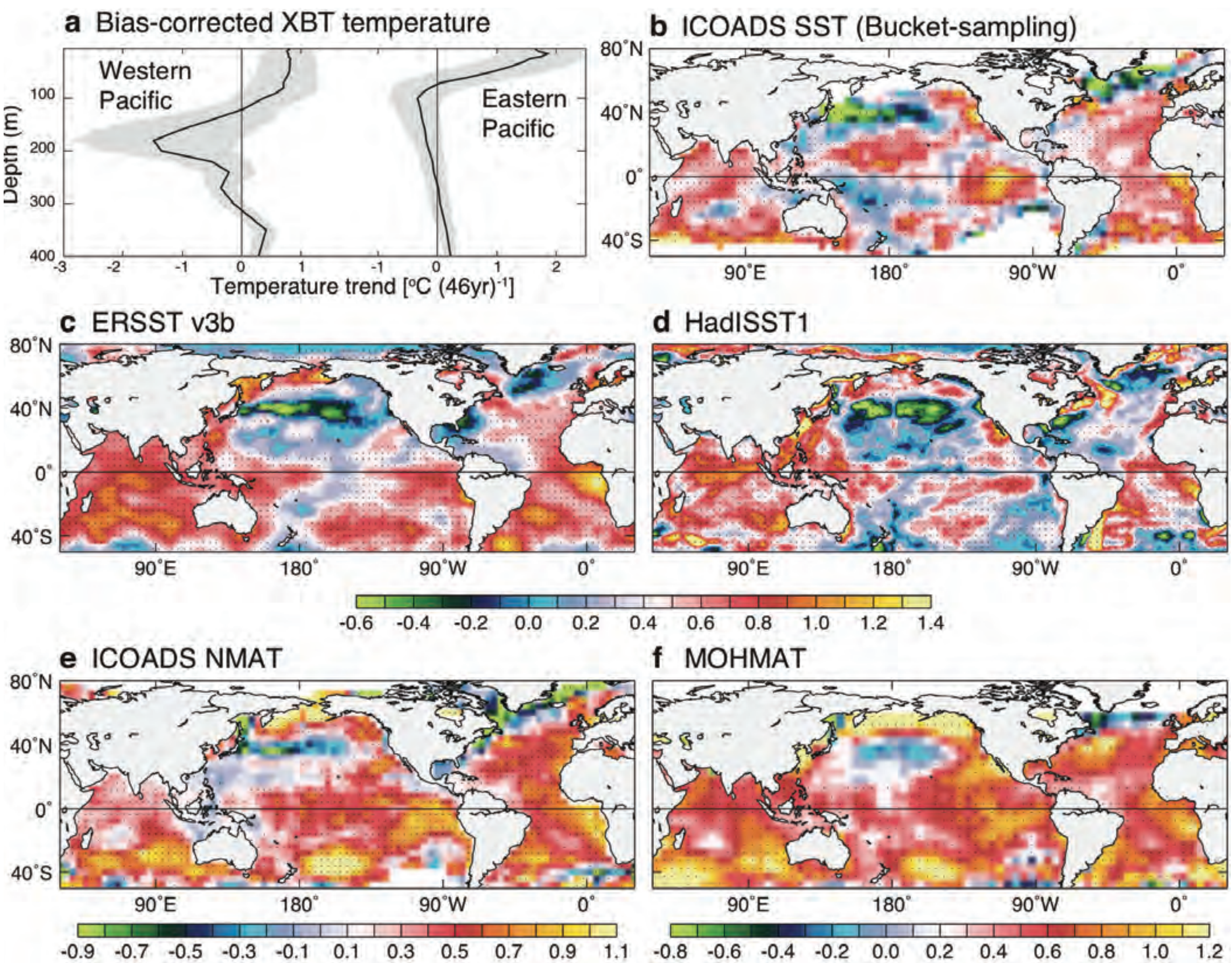


Figure 2. (a) Annual-mean subsurface temperature change [°C over 46 years] averaged in the western and eastern equatorial Pacific for 1963– 2008. (b–f) The surface temperature trends [°C over 59 years] for 1950–2008. (b) Bucket SST from ICOADS, (c) ERSST v3b, (d) HadISST1, and NMAT from (e) ICOADS and (f) MOHMAT.

Sir Gilbert Walker.

Walker circulation also weakened during the twentieth century, but much less than in the above observed changes. Since the mid-1990s, the Walker circulation weakening appears to have been reversing, perhaps due to significant variations on interdecadal timescales. Understanding and projecting the variations in the Walker circulation and its associated ocean temperature and sea level effects thus remain an important challenge for climate science.

The detection of anthropogenic climate change in the midst of natural variability and a conclusive attribution will have to wait for longer observations and a longer response period to a rise in global temperature. Whatever the outcome, the physical consistency among the many different independent ocean-atmosphere observations indicate that ocean-atmosphere coupling is important in the changes that have taken, and are taking place in the Walker circulation.

On a final note, the findings here call for a judicious use of reanalysis products for climate change research. The reanalysis products that show the Walker circulation has strengthened over the last six decades (Figure 3) have often been treated as observations both to drive GCMs and to validate the model simulations. They prove useful for studying weather and even interannual variability. For long-term trends, however, these products should be used with great care as they can include spurious trends stemming from changes in measurement technique and assimilated data sources. Sustained efforts are needed to develop homogeneous data reconstructions that will yield better descriptions and understanding of regional and global climate changes.

Anemometer.

This story is based on

Tokinaga, H., S.-P. Xie, A. Timmermann, S. McGregor, T. Ogata, H. Kubota, and Y.M. Okumura, 2012: Regional patterns of tropical Indo-Pacific climate change: Evidence of the Walker Circulation weakening. *J. Climate*, **25**, 1689–1710. IPRC-814.

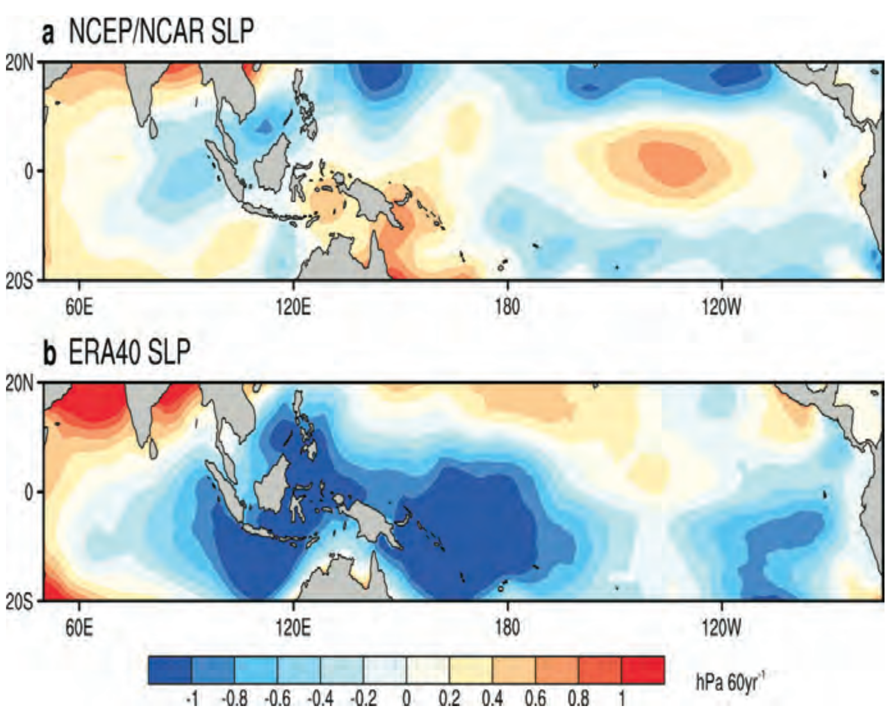


Figure 3. Annual mean SLP trends in reanalysis products [hPa over 60 years]. (a) NCEP/NCAR reanalysis for 1950–2009, and (b) ERA-40 for 1958–2001. ERA40 SLP trends are scaled to the 60-year change.