Deep-Sea Research II 113 (2015) 47–58

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Projected sea surface temperature changes in the equatorial Pacific relative to the Warm Pool edge

Jaclyn N. Brown [a,*], Clothilde Langlais [a], Alex Sen Gupta [b]

[a] Centre for Australian Weather and Climate Research, CSIRO, GPO Box 1538, Hobart 7000, Tasmania, Australia
[b] Climate Change Research Centre and ARC Centre of Excellence for Climate Systems Science, University of New South Wales, Sydney, Australia

ARTICLE INFO

Available online 11 November 2014

Keywords:
Climatic changes
Models
Surface temperature
Equator
El Nino phenomena
Tropical oceanography
Cold tongue bias

ABSTRACT

Projections of equatorial sea surface temperature from CMIP5 climate models are important for understanding possible future changes in marine habitats, local rainfall and climate processes such as El Niño Southern Oscillation. Interpreting the projected changes in the tropical Pacific is complicated by the systematic cold tongue bias and overly westward location of the Warm Pool edge at the equator in coupled models. Here an index based on the maximum zonal salinity gradient is used to differentiate the Warm Pool from the cold tongue in each of 19 CMIP5 models. Warming is then calculated relative to the dynamic edge of the Warm Pool between the second halves of the 20th and 21st Centuries from the RCP8.5 scenario to provide a bias adjusted SST projection.

Based on this definition of the edge, while the Warm Pool edge is projected to warm, it is likely to remain within 10° of its present longitude. This is in stark contrast to the large projected eastward displacements of the isotherms that are usually used to define the edge. Adjusting for the edge, warming within the Warm Pool is projected to be fairly uniform with surface water freshening. Projected warming is enhanced over the cold tongue with the net effect of reducing the zonal SST gradient. In contrast, if the warming is calculated without correcting for the edge of the Warm Pool, the warming signature is dominated by the poorer performing models with an overly westward Warm Pool, resulting in enhanced warming across the equatorial Pacific. Bias adjusting realigns the warming signature and reduces the model spread of projected warming. The biased warming signature also introduces spurious meridional and zonal SST gradients. This will potentially alter the behaviour of the atmospheric convergence zones and the dynamics of ENSO which is influenced by the extent of the Warm Pool and zonal SST gradients.

1. Introduction

Physical, chemical and biological characteristics on the eastern and western sides of the equatorial Pacific differ considerably (Fig. 1; Picaut et al., 2001; Brown et al., 2013b). In the west, waters of the Western Pacific Warm Pool (WPWP) are warm and fresh lying beneath strong atmospheric convection; the temperature is relatively uniform; and a deep thermally mixed layer exists with a barrier layer often forming that inhibits mixing between the warm surface water and cooler thermocline water below. Waters tend to be oligotrophic and contain low levels of pCO_2. In contrast, in the eastern equatorial Pacific, there is strong equatorial upwelling that acts to cool sea surface temperatures (SST); the thermocline shoals and SST decreases towards the east. Surface waters are saltier than in the west, with higher pCO_2 and nutrient concentrations. The boundary between these two very distinct regions is characterised by strong gradients in salinity, pCO_2 and chlorophyll (Maes et al., 2004, 2006) and marks the equatorial edge of the WPWP. This edge has previously been characterised by a surface convergence in the zonal direction: 'hypothetical drifters' (advected only by zonal surface currents) converge at a location that aligns with the more conventionally defined edge as it evolves over time in some datasets (Picaut et al., 1996). The edge, as defined by these various properties may diverge at certain times e.g. during large ENSO events. As such, finding a metric to define the edge is problematic and often dependent upon the application (Brown et al., 2013b).

Observational studies suggest a net warming and freshening of the western Pacific in recent decades (Cravatte et al., 2009; Durack et al., 2012). However different observational products and studies do not agree on how the zonal SST gradient has changed over the 20th Century (Vecchi et al., 2008). Moreover, the tropical Pacific is subject to large decadal variations that can distort the identification of forced trends on multi-decadal timescales. This makes it difficult

* Corresponding author. Tel.: +61 3 6232 5113.
E-mail address: Jaci.Brown@csiro.au (J.N. Brown).

http://dx.doi.org/10.1016/j.dsr2.2014.10.022

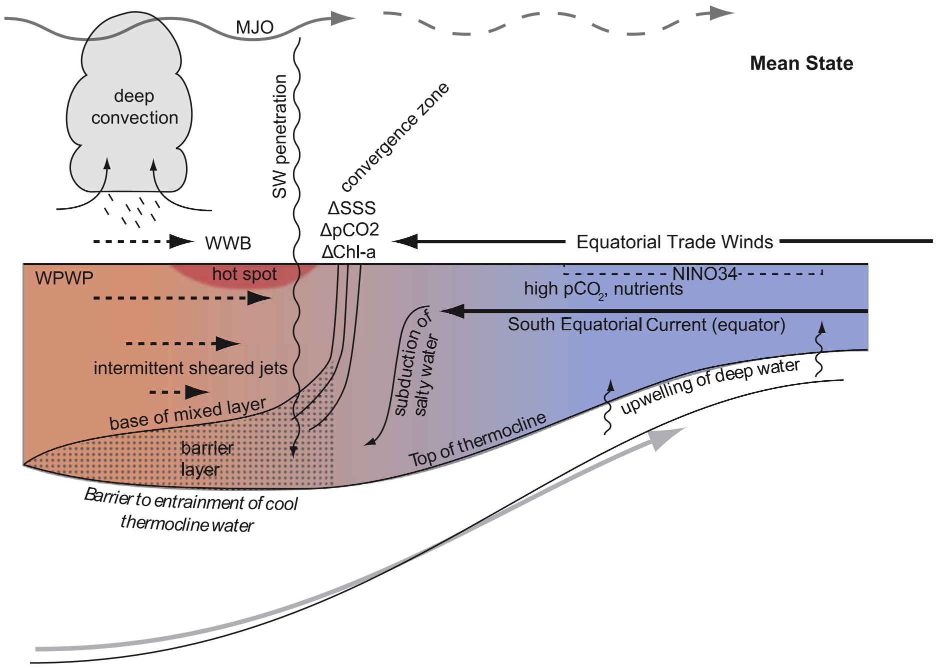

Fig. 1. Schematic of the equatorial Pacific showing characteristics of the ocean and atmosphere in the eastern and western equatorial Pacific and at the edge of the Warm Pool. The western Pacific is characterised by warmer, fresher water than the east, with deep atmospheric convection. The Madden Julian Oscillation (MJO) is stronger over the west Pacific than the east, with westerly wind bursts impacting the ocean surface. The mixed layer and thermocline are also deeper in the west. In the Warm Pool, barrier layers can form beneath the mixed layer, often due to the subduction of salty water to the east. At the edge of the Warm Pool there are strong zonal gradients in salinity, pCO_2 and Chl-a.

to extrapolate potential future warming patterns from past behaviour or to validate climate models against observational trends.

Climate model projections, with increasing greenhouse gases, project regionally enhanced warming along the equatorial Pacific (Meehl et al., 2007; Clement et al., 2010; Xie et al., 2010) that is stronger in the east than the west in most models. The processes involved in warming the western and eastern halves of the basin will likely occur for different reasons. For example, DiNezio et al. (2009) found that changes in cloud cover feedbacks, evaporative cooling and radiative heating is important in the Warm Pool, while changes in vertical ocean heat transport and radiative heating is important in the cold tongue.

Regional details of SST warming are important for their local effects on marine ecosystems. Coral reefs in the western Pacific exist close to their bleaching threshold and future warming information may provide important information on how to better manage and protect the reefs (Bell et al., 2011). Tuna are the most important oceanic fishery in the tropical Pacific (Bell et al., 2013), and catch data suggests an east–west migration of skipjack tuna populations in relation to the expansion and contraction of the Warm Pool (Lehodey et al., 1997; Bell et al., 2013). It is not clear whether the tuna are moving due to shifts in the location of their preferred thermal habitat, or changes to other physical or biogeochemical properties on either side of the edge. Projected changes to at the Warm Pool edge may therefore have large implications for biological systems and associated fisheries.

Changes to the meridional and zonal SST gradients in the tropical Pacific can have important consequences for the local climate and beyond. The strength and location of the tropical convective zones – the Intertropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ) – are a function of the underlying SST and the equatorial meridional SST gradients (Chadwick et al., 2012). Small spatial differences in SST warming can therefore have a large impact on winds and hence rainfall strength and distribution in the future. These details are particularly important when constructing regional projections at the scale of the Pacific Islands (Brown et al., 2013a).

Similarly, El Niño Southern Oscillation (ENSO) behaviour is sensitive to the position of the Western Pacific Warm Pool edge and the mean structure of SST. A key dynamical component in the evolution and decay of ENSO is the longitudinal movement of the edge of the Warm Pool (e.g. Clarke et al., 2000). A change to the location of the Warm Pool edge will alter feedbacks involved in both the growth and decay of ENSO events. The zonal SST gradients across the basin also features in the Bjerknes feedback linking the SST to the strength of the trade winds (Neelin et al., 1998).

For these and many other reasons it is important to understand changes to equatorial Pacific SST. However, reliably projecting SST change is hindered by the systematic cold tongue bias that continues to appear in the latest coupled climate model runs (Brown et al., in press, 2013c). In almost all coupled climate models the mean state temperatures along the equator are cooler than observed (compare Fig. 2A and B). Given that the dynamics to the east and west of the Warm Pool edge are markedly different and the processes that determine future SST distribution (Fig. 2C) are likely to depend upon the mean state of the ocean (Dinezio et al., 2009), projections need to be interpreted cautiously in the context of the biased SST distribution.

Previous work by Brown et al. (in preparation), evaluated the fidelity of the WPWP in the climate models taking part in the World Climate Research Program's (WCRP) Coupled Model Intercomparison Project Phase 5 (CMIP5). They defined a 'Dynamic Warm Pool Edge' (DWPE) by the isotherm that most closely aligns with the zonally varying position of the maxima of the zonal salinity gradient. As a result of the systematic cold tongue bias, this isotherm was nearly always cooler in the coupled models than the corresponding isotherm in observations (29.2 °C). The mean position of the DWPE in models was much closer to observations than if the 29.2 °C isotherm was used to define the edge in the models. Brown et al. (in preparation) also found that many of the models had a very poor representation of salinity, with the maximum sea surface salinity (SSS) gradient being trapped too far west near the