Western Pacific Warm Pool
TASK FORCE

Workshop Report


Attendees:
Alex Sen Gupta        Gary Meyers        Richard Matear
Andreas Schiller     Guomin Wang       Seon Tae Kim
Andrew Lenton        Jaci Brown        Sophie Cravatte
Awnesh Singh         Jo Brown          Tatiana Rykova
Christophe Maes      Chris Evenhuis     Terry O’Kane
Clothilde Langlais   Matt Wheeler       Xuebin Zhang
Felicity Graham      Peter Oke

Workshop supported by the Pacific Australia Climate Change Science and Adaptation Planning Program and the CSIRO Frohlich Fellowship scheme.

Objectives of the workshop:
• Share knowledge from varied disciplines all related to WPWP.
• Discuss definitions/characteristics of the WPWP
• Discuss possibility of submitting special session to Ocean Sciences 2004.
• Outline report for CLIVAR Exchanges or similar

Workshop Program:
Day 1: Characterising the Western Pacific Warm Pool.
Day 2: Decadal Variability and Trends.
Day3: Warm Pool Edge, Barrier Layers and Atmospheric Influences.
      Guest lecture – Mojib Latif – Super El Niños in a warming world.
      El Niño Southern Oscillation and the WPWP.
Day 4: Biogeochemistry and applications.
– Each day was summarised by different ‘reporters’ and detailed below.

Actions:
☐ Aim to write a short workshop report to submit to Clivar Exchanges – Jaci Brown
☐ Decided not to ask for special session at Ocean Sciences, but to incorporate our work into already submitted session that Christophe Maes is convening.
☐ Presentations to be shared on common dropbox.
☐ Figure to be created depicting the WPWP in mean and ENSO phases – Alex Sen Gupta.
☐ Would like to hold another workshop in future, but need to find appropriate funding.
The Western Pacific Warm Pool (WPWP) is a region of intense ocean atmosphere coupling that is an important source of moisture and latent heat to the atmosphere. It is a major energy source for the large-scale zonal and meridional circulations. It constitutes the Pacific portion of the larger Indo-Pacific Warm Pool that is characterised by some of the world’s warmest open ocean temperatures, exceeding 28-29C. The eastern extent of the WPWP undergoes dramatic zonal excursions on interannual timescales that is a defining feature of ENSO. Warm pool processes cover temporal scales from diurnal to multi decadal and spatial scales from 100m to 1000s km. In the Pacific the WP (zonal extent, area and SST) has weak seasonality (although the WP appears to undergo large seasonal meridional migration) and strong inter-annual variability (e.g. warm pool edge and area is strongly coupled with nino34 SST). In the Indian Ocean WP seasonality is much stronger.

East of the WPWP is characterised by consistent easterly equatorial winds that drive a surface divergence and upwelling of cool, salty, high nutrient, high pCO2 water forming the Pacific cold tongue. The winds also drive a strong surface confined flow – the equatorial component of the South Equatorial Current. Water becomes increasingly warm as it flows west, heated by strong insolation. Over the WPWP winds are typically weak, with occasional intense westerly wind bursts (WWB), leading to intermittent zonal jets in the upper ocean. Convergent winds and high temperatures result in deep convection over the WPWP and high levels of precipitation generally exceeding 2-3m/yr. The WPWP is therefore characterised by low salinity. The predominantly westward/eastward flow on the east/west side of the WPWP edge results in a zonal convergence at the edge. This meeting of water masses of very different properties leads to a sharp front in salinity and other properties (e.g. pCO2 and surface Chl-a resulting from the relatively high levels of upwelled micromaco nutrient), although SST exhibits no such front. Subduction of the westward flowing salty eastern Pacific equatorial water below the fresh WPWP water leads to a barrier layer: a vertically isothermal region incorporating a strong salinity gradient that acts to isolate the upper (density) mixed layer from the entrainment of cooler deep water and suppressing the downward flux of surface momentum.

The above characteristics lead to a number of possible ways to define the edge of the warm pool (table 1), based on thermodynamic (e.g. SST), dynamic (e.g. zonal convergence) or biological (e.g. chl-a) criteria. While definitions will approximately co-vary there are often substantial discrepancies particularly during large ENSO events. Certain definitions will diverge considerably with changes in the background state e.g. Global Warming (particularly the most widely used SST threshold definition). While a one-size-fits-all definition of the WP edge might be desirable, it is probably best to choose a metric based on the application considered. Given the dynamical link between the WP edge and ENSO, the edge location could represent a useful metric for describing ENSO.
Within the WPWP the surface heat fluxes are largely balanced by turbulent fluxes at the base of the mixed layer that is strongly related to deep mixing during WWBs.

<table>
<thead>
<tr>
<th>Warm Pool Edge metric</th>
<th>Advantages</th>
<th>Disadvantages</th>
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| SST threshold (e.g. 28.5, 29°C) | • Important for atmospheric response, e.g. convection, tropical cyclones, WWB (also has sharp upper bound SST).  
• Convenient/lots of available data  
• Continuous boundary | • Definition problems as background SST increases  
• Inconsistent thresholds when comparing models  
• Certain higher SST isotherms (e.g. 20°C) not always present |
| SSS threshold (e.g. 34.8) | • More closely representative of dynamical edge  
• Proxy for high precipitation?  
• Continuous boundary | • Same as above  
• Limited data availability |
| Maximum SSS gradient | • Less affected by background state  
• Representative of dynamical edge  
• Noisy | • Limited data availability |
| Isotherm fit to SSS gradient | • As above, except more continuous boundary  
• Useful for model inter comparison | • Isotherm needs to be revised with background warming |
| Density threshold | • Combines temperature and salinity changes | • Incorporates disadvantages of both temp and salinity. |
| Convergence zone | • Representative of dynamical edge  
• Can use dynamic height as proxy | • Need to compute hypothetical drifters/ time to converge  
• May not converge in models  
• Limited observations/ wide separation of TOGA stations |
| Nitrate/pCO2 | • Closely tracks SSS | • Limited observations |
| Chl-a (e.g. 0.1mg/m3) | • Sharp front | • Limited to satellite record |
| Atmospheric definitions? | • Relevant for impacts  
• More observations? |
A number of challenges exist in the simulation of the WPWP in climate models. This stems from mean state and variability biases in the tropical Pacific e.g. cold tongue bias/associated eastward ENSO bias, large SSS biases, lack of barrier layer, weak thermocline, poor representation of atmospheric processes. This makes it hard to define the simulated WP. The observed increase in SST towards the west with a plateau of maximum SST in the WP core is only simulated by a subset of models, many have double plateaus, no plateau (i.e. the cold tongue essentially extends across the entire basin) or more unusual SST structure. One reasonably successful WP edge definition uses the isotherm that most closely follows the maximum SSS gradient (at the equator).
Xuebin Zhang – Decadal variability in the Western Pacific
Decadal – Interannual timescales
- Spatial patterns (basin versus regional)
- Is ENSO decadal variability independent of and clearly separated from other modes?
- What are the underlying mechanisms to sustain decadal to interdecadal timescales?
- Observations are important but not long enough, continuous or sustained – How good are reanalysis?
- Can we separate anthropogenic Climate change signal from natural variability?
- PDO: ENSO like decadal variability but broader meridional extent – i.e. inter-annual versus interdecadal.
- Schneider & Cornuelle 2005: PDO is a combined forced response: Aleutian low, ENSO and Kuroshio extension region.
- Zhang, Wallace & Battisti: Cannot separate inter-annual and decadal variability.
- PDO Index – to first order sinusoidal over 1900- present.
- Fayos & Mehta: Interdecadal variability of WPWP and ENSO – when WPWP is cooler -> stronger El Nino.

Sea level rise:
- Altimeter sea level trend by simple linear regression 1995-2011 ~ 12mm/year in WPWP region.
- Definition of climate indices using multiple linear regression – Zhang, Battisti & Wallace method.
- Sea level trend – interannual and decadal fingerprints.
- SST trends – aliasing and decadal fingerprints based on Reynolds SST data: do we see Modoki or El Nino fingerprint?
- Decadal fingerprints of SLP, Wind Stress curl for ERA40 data.

Concluding remark: Interdecadal variability needs to be accounted for in climate change studies.

Guomin Wang – Decadal variation of ENSO prediction and its link to Pacific Mean State
- Enhanced skill during 80s & 90s relative to 2000-2010.
- Phase lagging during 80s & 90s leads to better skill i.e. heat content leads NINO3.
- In recent years correlation and lag in heat content is reduced i.e. not much recharge-discharge therefore reduced predictability.
Why did ENSO change?
- Barrier layer thickness in WPWP much less during 80s & 90s (relative to 2000-2010 period).

Feedback terms:
- $\frac{-w}{\epsilon z}$ thermocline feedback stronger during 80s & 90s
- $-\frac{\partial \tau}{\partial x}$ zonal advective feedback reduced in 80s & 90s but more favorable for CP El Ninos in recent period
- Also more CP – Modoki El Ninos during recent period.
- Duong 2010 Figs 24 & 29: changes in wind stress and current
- Deep barrier layer -> strong correlation with zonal wind stress -> strong ocean current response
- Large barrier layer response in latest 10 years due to **changed mean states of temp and salinity**.
- Larger SSTA and precip anomalies to windstress forcing in WP implies stronger cooling coupling between oceans and the atmosphere over recent period.
- Mixed mixed layer change small – but barrier layer change large

Summary:
- Recharge-discharge mechanism has weakened over the recent decade
- Ocean-atmosphere coupling is stronger in recent period.
- Barrier layer depth change is consistent with stronger zonal advective feedback through more effective ocean-atmosphere coupling
- Change is primarily due to form of decadal variability

**Sophie Cravatte - WPWP changes over the last 50 years**
- Talk based on Cravatte et al 2009: observed freshening and warming of the WPWP

**Period 1950-2003**
- Warming, freshening and increase in size of WPWP
- Uses SSS and SST obs and reconstruction
- Decreasing SSS confirmed bu Durack & Wijffels 2010.
- Increased variability of Eq. Pacific WP edge post 1978 -> strong correlation with PDO
- No consensus about whether the WPWP is warming faster than climate change signal in rest of Eq. Pacific
- No consistency among reconstructions
- Volume and depth of WPWP – SODA and insitu data compared to HadSST, T>28°C -> trend toward larger, deeper wider WP
- Surface density is decreased as warmer/fresher
- Changes in stratification -> mixed layer depth increases (137°E, decreases 165°E)

Is freshening due to anthropogenic CC?
• Response to warming – Clausius Clapyeron: wet get wetter, warm get warmer
\[
\Delta S = \int_{\Delta T} \frac{\Delta(h - P)}{h} \, ds
\]
– freshening WPWP due to global enhancement of hydrological cycle

Conclusions:
• warming and freshening up to 10STD 2.5°C/1.5psu per century
• decrease of surface density
• increase in barrier layer thickness

Causes:
• weakening of Walker circulation postulated by Vecchi & Soden 2008
• more CP El Nino event – Lee & McPhaden 2010

Jo Brown - WPWP and Precipitation
• changes to precip input to WPWP (links to monsoon, ENSO, SPCZ etc)
• projections – large scale rainfall
• observed trends in precip CMAP & GPCP disagree quite significantly (79-2008)
• trends in station data dominated by shift in SPCZ mean position driven by IPO (Salinger 2001, Folland 2002)
• CMIP5 multi-model mean shows no clear trends in annual rainfall
• SPCZ and monsoon: DJF season – western portion sits on WP but no trend in either over 30yr period

CMIP5 projections:
• Little difference between CMIP3 & CMIP5 in mean DJF precip and SPCZ position for period 1980-1999
• 3-4°C warming in central Eq. Pacific in CMIP5 projections
• ~2mm/day change in precip in Eq. Pacific WP
• DJF decreases in rainfall at eastern edge of SPCZ
• Models disagree on average SPCZ changes – no signal in multi-model mean
• Enhanced divergence (increased trade winds) at eastern edge of SPCZ

Decomposition of rainfall:
• Change in precip = dynamic + thermodynamic + covariation
• Dynamic – warming at equator, reduced/increased convergence
• Thermodynamic – response to increase in moisture
• Covariation – increase in trade winds
• Walker circulation weakened in WP? – no understanding of consistency inof Walker circulation changes across CMIP5 models

Changes as a function of SST trend in CMIP5 and AMIP under warming:
• Small warming – dynamic
• Large warming – thermodynamic
• Windlansky et al 2012: changes in SPCZ
• Windlasky et al 2012
• Xie et al 2010: uniform warming versus spatial pattern warming
• Johnson & Xie (2010): change in convection threshold with warming
• Cai et al 2012: ENSO impact on SPCZ (zonal SPCZ events)
Christophe Maes - Barrier Layer and ENSO

Summary points:
- Barrier layer (BL) is the region where salinity stratification dominates, cutting off entrainment to the mixed layer
- Sensitivity studies (e.g. remove BL in model and then integrate forward) indicate that BL thickness impacts on MLD, although no impact on SST, contrary to expectations
- BL may play an important role in the build-up period of ENSO, and it therefore may be a useful tool for ENSO predictability

Discussion points:
- BL thickness importance in destabilisation above thermocline, heat budget and amount of incoming solar radiation
- Important to recognise atmospheric feedbacks as well as oceanic feedbacks during ENSO; as important ocean-atmosphere interactions take place in the warm pool, reasonable to assume the ENSO dynamics involve contributions from both ocean and atmosphere – not purely oceanic.

Matt Wheeler - MJO

Summary points:
- MJO defined through two techniques: (1) wavenumber-frequency filtering and (2) real-time multivariate MJO (RMM) index
- MJO has large impact on SSTA in warm pool – implications for ocean-atmosphere feedbacks
- Global RMM: variance of global MJO not significantly correlated with ENSO, but shifts in MJO longitude as result of shifts in warm SSTs
- MJO in western Pacific explains similar variance in Niño-3.4 SST as does WWV in period 1980-2004. In particular, strong MJO activity over the western Pacific in boreal spring tends to lead warm ENSO events.

Discussion points:
- Impact of decadal variability on MJO?
- Does correlation between MJO and SST in TOGA-COARE period depend on mean state/ENSO flavour? For example, strong correlation of WWV and SST in TOGA-COARE period might be due to the dominance of “canonical” ENSOs during this period, and hence depends on the background ocean state/atmospheric conditions.

Mojib Latif - Super El Ninos in a warming world
Summary points:
- Super El Niño – defined when SST 3 standard deviations from mean detected in climate change simulation (compared with results from 1000yr control)
- Zonal gradient of SST less robust predictor in super El Niño
- Mechanisms: competition between vertical and zonal advection, thermocline feedback predicted to increase by about 10%

Discussion points:
- Agreement of these predictions with other CGCMs?

Awnesh Singh - ENSO flavours and related trends in PO

Summary points:
- Central Pacific ENSO enhances long-term freshening in warm pool, reduces freshening in SPCZ region
- Central Pacific ENSO does not contribute to eastwards expansion of fresh pool
- Chlorophyll signatures differ between east Pacific and central Pacific events – mainly governed by thermocline feedback and zonal advective feedbacks, which differ between events

Discussion points:
- Sensitivity of trends to averaging periods

Felicity Graham – ENSO mechanisms

Summary points:
- Zonal advective feedback and thermocline feedback important for ENSO growth and termination
- Zonal advective feedback characterised by short ENSO period; thermocline feedback characterised by long ENSO period
- Mean state (e.g. thermocline depth, magnitude of wind stress, background currents, stratification) important in determining dominance of one feedback mechanism over the other
- Regime shift in late 70s coincided with transition from zonal advective feedback to thermocline feedback

Jaci Brown – ENSO and WPWP edge in CMIP5

Summary points:
- Zonal displacement of warm pool edge differs between CMIP5 models
- Variability of warm pool edge not always correct if mean position of warm pool edge correctly modelled
- High correlation between zonal advective feedback variability and Niño-3.4 variability
- Future changes to warm pool edge uncertain; zonal gradient of SST influences zonal advective feedback

Discussion points:
- Does correlation of variability imply causation? Does zonal advective feedback lead warm pool edge variability, or vice versa?

Wednesday discussions:
- Caution needed with interpreting results: many different ENSO flavours (see Wittenberg, GRL, 2009), only 50yrs of reliable observations impacts on our ability to reliably characterise ENSO
- What is important for ENSO – BL, warm pool edge, warm pool area/volume, clouds/convection? Coupled ocean-atmosphere system, so not likely one key mechanism
Richard Matear – Important BGC in WPWP
1. There is low seasonal variability in chlorophyll – why?
2. Nitrate (nutrients, iron) concentration is high in the upwelling regions
3. Phosphate/nitrates are important for phytoplankton growth
4. Ocean is phosphate limited because phytoplankton take in the dissolved nitrogen from the atmosphere (nitrogen fixation – 1% only)
5. Most nitrogen comes from the deep ocean
6. Nitrates are limited in the WPWP – subsurface has phytoplankton because nitrate concentration is there at 200 m depth in WPWP
7. Smaller mixed layer depth allows more light so increase in phytoplankton growth

Andrew Lenton and Chris Evenhuis - Acidification
1. Increase carbon dioxide concentration causes increase in ocean acidification (decrease in pH)
2. Awesome slide on ocean acification! (Can we paste a copy in here?) It basically shows how increased concentration of carbon dioxide in the atmosphere results in a increase in hydrogen ion concentrations in sea water making it more acidic. In addition, there is a reduction in aragonite/calcification/coral reef growth due to lower amounts of calcium carbonate being produced

Clothilde Langlais – Coral Bleaching
1. Coral bleaching has a maximum similar to ENSO pattern
2. Corals obtain the majority of their energy and nutrients from zooxanthellae, which in-turn receive inorganic nutrients from the corals