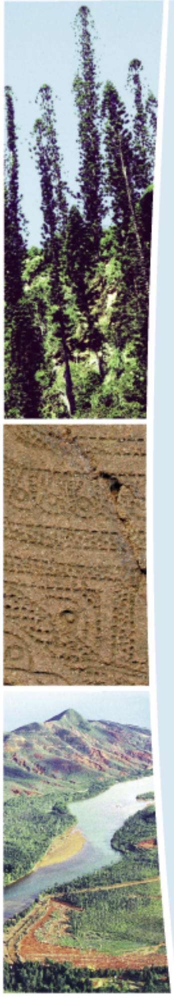

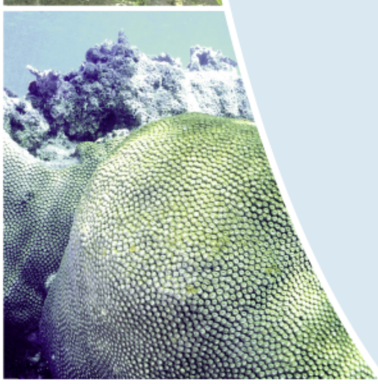

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N° 5

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Cairns, Australia 19th to 21st August 2005

Alexandre GANACHAUD
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Workshop on the Southwest Pacific Ocean Circulation and its relation with climate

Organizing committee: A. Ganachaud, LEGOS/IRD Toulouse/Noumea
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Cairns, Australia
Friday 19 August 2005~Sunday 21 August 2005

1 Introduction

Climate in the South West Pacific region varies due to superimposed effects of El Niño/Southern Oscillation (ENSO) and other signals including seasonal variations, global warming and natural decadal-scale variability. Ocean transport changes, driven by basin-scale winds, are the principal cause of temperature and salinity variability. Theory, numerical simulations and the few existing large-scale observational datasets suggest a complex regional ocean circulation: While surface flow is eastward as far north as 15°S, occurring partly as concentrated filaments emerging from the East Australia Current (EAC) recirculation, at thermocline level and below the South Equatorial Current (SEC) transports more than 30 Sv westward. Encountering the southwest Pacific islands, the SEC divides into strong and narrow zonal jets that cross the Coral Sea and bifurcate at the east coast of Australia, feeding both the EAC and the New Guinea Coastal Current system (Figure below). The latter supplies most of the water of the Equatorial Undercurrent, and emerges finally as the east Pacific cold tongue. Variations of both transport and water properties propagate into the flow of both current systems and their eddies and can influence the modulation of the ENSO cycle, which then reverberates through the climate of the entire basin. ENSO events then influence the winds and water characteristics of South Pacific, closing a large scale 'climate loop' on decadal time scales. Though variability of this circulation has profound consequences for both regional and basin-scale climate, the structure of its currents and the mechanisms that cause its variations remain poorly sampled. The broad-scale observational network (Argo, VOS XBT sampling, and satellite winds and altimetry) is beginning to provide a large-scale picture, but the complex island jets and western boundary currents require dedicated study, and this workshop is a first step in planning such an effort.

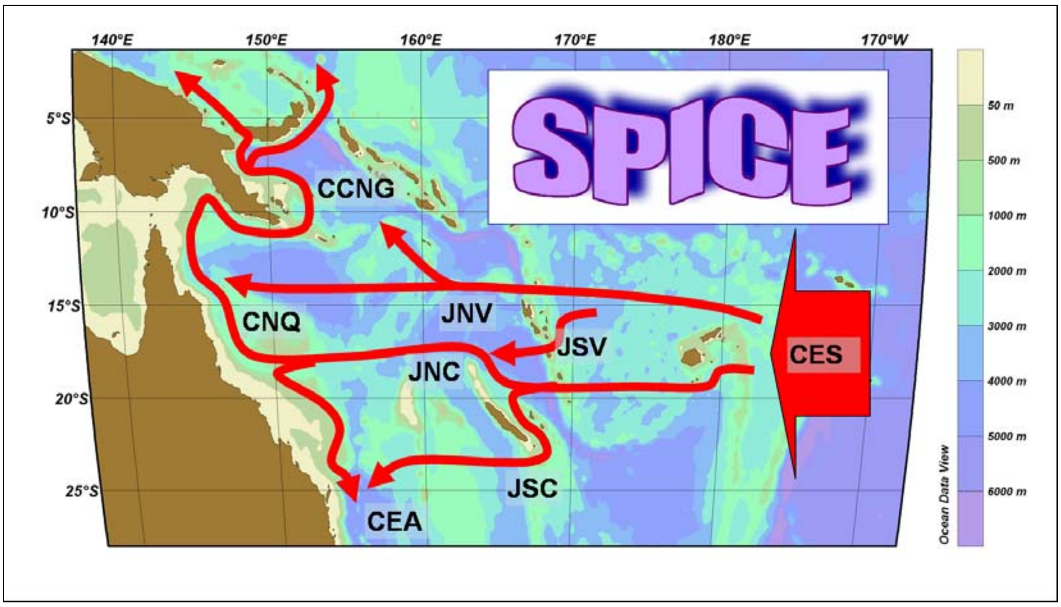
A 3-day workshop with 27 scientists was held to initiate this project. The meeting took place in a resort close to Cairns, Australia, August 19-21, 2005. This workshop preceeded a IAPSO meeting in Cairns. The workshop reviewed ongoing work and identified the possibilities for advancement. Participants to this workshop are presently contributing to the redaction of science plan for a coordinated observational and modelling program under the auspices of the CLIVAR Pacific Panel.

Le Climat dans les îles du Pacifique Sud-Ouest est constitué composantes distinctes. Une grande partie des variations climatiques est associée à l'oscillation climatique « El Nino », et les événements climatiques dans une île ou dans une région donnée sont déterminés par la superposition de la composante « El Nino » et d'autres signaux climatiques (signaux saisonniers, réchauffement global, etc.). Par exemple, la température océanique environnante est un paramètre déterminant. Cette température est contrôlée essentiellement par les courants océaniques.

L'Océan Pacifique Sud-Ouest est relativement peu étudié. Hormis certaines régions telles que la partie sud-est de l'Australie (le grand courant Est Australien), les mesures in situ sont spartiates. Des simulations numériques ont montré que la circulation dans cette région était relativement complexe et unique : le grand Courant Equatorial Sud qui ramène vers l'ouest des eaux salées provenant des régions polynésiennes, entre la surface et 600 mètres de fond, se divise en puissantes veines de courants (« Jets ») en heurtant les archipels d'îles du Pacifique Sud-Ouest. Ces Jets traversent la mer de corail pour atteindre les côtes australiennes où ils bifurquent, une partie importante remontant le long des côtes australienne puis de Papouasie-Nouvelle Guinée vers le Nord pour atteindre l'Equateur et alimenter les courants de subsurface équatoriaux (Figure ci-dessous)*. Ces eaux finissent par remonter à la surface sous l'équateur, où elles déterminent les variations lentes des conditions océaniques à partir lesquelles les événements El Nino prennent naissance.*

Cette circulation fait partie d'une « boucle climatique » susceptible d'influencer l'oscillation El Nino sur des échelles de temps décennales (Luo et Yamagata, 2001). En effet, les caractéristiques d'El Nino sont en grande partie déterminées par les conditions océaniques équatoriales, conditions elles-mêmes influencées par la boucle de circulation décrite ci-dessus. Cette circulation prend ses origines dans les régions polynésiennes du Sud, régions dont le climat est sous l'influence distante des conditions El Nino via l'atmosphère. Le temps mis par l'eau pour parvenir à l'équateur étant d'environ 15 ans, cette circulation provoque un effet rétroactif sur les variations climatiques décennales. La géographie des îles et l'influence des vents océaniques du Pacifique Sud Ouest détermine les cheminements et la distribution des eaux polynésiennes.

Comprendre et prévoir la circulation océanique dans la région du Pacifique Sud-Ouest est donc important d'une part pour comprendre les effets locaux du climat, et d'autre part les variations climatiques sur le long terme dans le contexte du réchauffement global. Une meilleure description des courants autour des îles sert aussi de base nécessaire à la prévision des conditions locales avec des applications aux études biologiques, à l'étude de la montée du niveau de la mer et à l'évaluation des impacts des changements climatiques. Une réunion de travail a été organisée à Cairns, Australie, du 19 au 21 août 2005, pour fédérer les principales forces de recherche de la région du Pacifique sud-ouest autour d'un projet commun de mesure, d'analyse et de prévision de cette circulation sous l'auspice du programme international CLIVAR.



The south-west Pacific thermocline current system: A complex pathways divides the southern part of the South Equatorial Current (CES) into jets: North Vanuatu Jet (JNV), South Vanuatu Jet (JSV), North Caledonian Jet (JNC), South Caledonian Jet (JSC). Those jets feed the eastern Australian current system: (East Australian Current, CEA; North Queensland Current, CNQ; New Guinea Coastal Current, CCNG) before joining equatorial waters through the Solomon straits. *Le système de courants des eaux de thermocline du Pacifique Sud-Ouest:un cheminement complexe divisant le courant équatorial sud (CES) en jets: Jet nord Vanuatu (JNV), jet sud Vanuatu (JSV), jet Nord Calédonien (JNC), jet Sud calédonien (JSC). Ces jets alimentent les systèmes de courant du bord est Australien (Courant Est Australien, CEA; Courant du nord du Queensland, CNQ, Courant Côtier de Nouvelle-Guinée, CCNG), avant de rejoindre les eaux équatoriales par les détroits de la Mer des Salomon.*

2 Objectives

The workshop was organized according to the following objectives:

1. To establish a synthesis of current knowledge and open questions concerning the ocean circulation of the southwest Pacific, and of its direct and indirect influence on the climate and environment;

2. To initiate an international research project under the auspices of CLIVAR. We intend to plan a regionally-coordinated experiment to measure, study and monitor the ocean circulation, and to improve and validate numerical models of the region.

3 Organization and program

The workshop program and organization are archived on
http://www.ird.nc/UR65/SPICE/Malanda/workshopcairns2005.html

4 Acknowledgements

This workshop was essentially supported by the French Government through the Secretariat Permanent pour le Pacifique. The organizing committee wishes to thank all who contributed to the organization, and particularly, Christelle Gourdeau and Catherine Hartmann (IRD-Noumea); John and Suzan Conde (Malanda Lodge Motel). The organizing committee also wishes to thank warmly all participants for their active contribution that made this workshop very stimulating.

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6 Abstract of presentations

6.1 Overviews (convener B. Kessler (NOAA/PMEL); Report: A. Ganachaud (LEGOS/IRD), K. Ridgway (CSIRO))

6.1.1 Observational overview of SW Pacific Circulation: What do we know? What should we know?

Dean Roemmich (Scripps)

The design of an ocean observing system is an iterative process, with the knowledge gained from existing observations and models being combined with advances in technology to define the next step in observations. In the southwest Pacific, the large-scale oceanographic context has been described using mixed-era datasets by Reid (1997) and Ridgway and Dunn (2003), with the strengths and limitations of these "climatological" data discussed by Roemmich and Sutton (1998). A major focus in the southwest Pacific region is the bifurcation of the westward South Equatorial Current (SEC) at the coast of Australia, forming an equatorward low latitude western boundary current (LLWBC) feeding the equatorial region, and a poleward western boundary current (East Australian Current) feeding the subtropical gyre. In the SEC, Davis (2005) showed a surprisingly strong mid-depth flow using WOCE float data. As a further complication, the prevalence of topographically controlled filaments in the SEC was seen by Webb (2000) and illustrated by Stanton et al (1998). Scientific interest in the geographically complex LLWBC centers on its role as a primary source of upwelled waters in the Equatorial Undercurrent. Measurements of the LLWBC are needed to complement interior observations of interannual variability in the shallow meridional overturning circulation (McPhaden and Zhang, 2002, 2004). Interest on the EAC centers on its role in the oceanic heat balance and mid-latitude climate (e.g. Roemmich et al, 2005). The southern subtropical oceans at 40°S have heated by 4 W/m2 since 1993 (Willis et al, 2004), more than four times the globally averaged increase in ocean heat content. Strong decadal warming in the Tasman Sea was described by Sutton et al, 2005. In the subtropical gyre interior, recent observations from altimetric height and Argo floats show a decadal spin-up of the gyre (Roemmich et al, 2006, Qiu and Chen, 2006) in response to strengthening sub-polar westerly winds. The spin-up is seen in downward displacement of isotherms to depths greater than 2000 m, hence accounting for the strong warming. A freshening of intermediate waters has continued, as observed earlier by Johnson and Orsi (1997) and Wong et al (1999). In summary, climate-relevant variability of global significance, on interannual to decadal scales, is seen in both the tropical and mid-latitude southwest Pacific.

The recent observations and analyses highlight a strong need for a systematic and sustained observing system in the southwest Pacific to provide the following:

(a) The time mean circulation for a fixed period, with realistic error bars, including both mesoscale and large-scale features.

(b) Direct measurements of the mid-depth flow in addition to geostrophic shear, for understanding the total transport in relation to wind forcing (i.e. Sverdrup balance).

(c) Time-varying circulation with realistic error bars, on periods of a season and longer, including the boundary currents and large-scale interior flows.

(d) Closed heat and freshwater budgets - including storage, air-sea flux, oceanic flux convergence - with errors 5 W/m2 or less on spatial scales of ~1000 km and time scales of a year and longer.

6.1.2 Overviews of the circulation in the SW Pacific and the problems to attack Modelling perspective

Wenju Cai (CSIRO)

This talk focuses on two areas:

1.the capability of coupled climate models in simulating the seasonal cycle and the regional flow structures;

2.the global context of the variability and change of the South Pacific circulation.

Most contemporary climate models are NOT able to produce several major features including

- a stronger flow through the Tasman Sea in summer than in winter;
- a clearer, better-defined separation in winter;
- zonal jets and the interactions with islands.

This is despite the fact that these features appear to be present in the observations (Ridgway and Dunn, 2003) and are implied in the circulation derived using model outputs of winds.

Climate models however are able to produce the gross flow patterns of the annual mean state, its linkage and inter-basin exchanges with flow outside the South Pacific. This feature can be used to examine the dynamics of warming in the Tasman Sea over the past decades with a warming rate that is three times as large as that of the global ocean average, and is simulated to be the greatest of the Southern Hemisphere. The large observed warming rate is consistent with observations over the past decades (Roemmich et al. 2006, Qiu and Chen, 2006). Using observed surface wind changes to force Godfrey's Island Rule (Godfrey 1989) model reveals that the observed large warming is consistent with a southward shift of the EAC and a spin-up of the entire southern hemispheric circulation forced by wind stress curl associated with an upward trend of the Southern Annual Mode (SAM), which is primarily induced by ozone depletion since the 1970s (Cai 2006). Climate models forced by the Intergovernmental Panel on Climate Change scenarios project a continuing upward trend of the SAM into the future (Fyfe et al., 1999; Kushner et al., 2001; Cai et al., 2003). In response, the EAC moves southward by up to 8 degree latitudes by year 2070 (Cai et al. 2005). The southward shift is a part of annular-scale circulation changes that involve all subtropical gyres of the Southern Hemisphere.

The model relationship between wind forcing and air-sea thermal interactions in the model shows that there is a strong correspondence between the change pattern of wind stress curl and that of the heat flux. In areas where there is an increase in positive curl, the ocean gains southeast orientated strips in the subtropical southern Indian Ocean, as well as in the Tasman Sea, where the strong heat loss is associated with a decrease in the wind stress curl. The correspondence suggests that the change in wind stress curl in fact reflects a series of air-sea couplings in terms of not only the momentum exchange but also the thermal interactions. The effect of this process in the interannual and decadal variations of the South pacific needs to be explored.

6.2 Interior circulation of the South West Pacific (Convener: A. Schiller (CSIRO); Report: T. Qu (IPRC))

6.2.1 Dynamics of circulations in the Southwest Pacific Ocean

Jay McCreary (IPRC) and Billy Kessler (NOAA/PMEL)

Solutions to a hierarchy of models are discussed. The models are 1) a linear continuously stratified (LCS) model, 2) a nonlinear layer model, and 3) several oceanic general circulation models (OGCMs). The LCS model is a linear version of an OGCM, in which solutions are represented as expansions in the vertical normal (barotropic and baroclinic) modes of the system. A key process in the nonlinear layer model is that higher-order (n > 1) Rossby waves propagate along "characteristics," rather than due westward; as a result, these modes can become isolated from the overall wind-driven response, and hence be observable separately; in addition, arrested fronts (shocks) form where characteristics overlap. Solutions to the LCS model are able to reproduce realistic equatorial flows (EUC, equatorial upwelling and "rolls," etc.), but their extra-equatorial flows tend to have unrealistic aspects. Furthermore, a serious problem is that steady-state, inviscid, wind-driven solutions consist of a Sverdrup flow located within the surface layer, inconsistent with observed mean flows. Solutions to the nonlinear layer model nicely illustrate the dynamics of Subtropical Cells (STCs); in these solutions, the n- mode bends equatorward along characteristics to separate from the wind-driven subtropical gyre, thereby providing the subsurface branch of the STCs that carries cool thermocline water to the equator. Similar STC structures are present in solutions to OGCMs. Solutions to nonlinear layer models also provide an explanation for the Pacific Tsuchiya Jets, which are narrow, subsurface currents on either side of the, and somewhat deeper than, the EUC. In these solutions, the TJs are arrested fronts, generated by the propagation of n > 1 Rossby waves from off-equatorial upwelling regions (Peru and the Costa Rica dome). Again, similar features are present in solutions to OGCMs. Finally, the layer model provides a possible explanation for the existence of the Subtropical Countercurrents (STCCs) present in the North and South Pacific, the model STCCs being associated with an n = 2 mode separated from the main gyre along equatorward-bending characteristics.

Observations demonstrate the effects of the higher-order mode influence on the South Pacific gyre. The gyre structure is tilted poleward with depth, as upper isotherms successively peel off the top of the thermocline and produce eastward shear above the westward South Equatorial Current (SEC). One result is that surface geostrophic flow is eastward everywhere south of about 15°S (the STCC). This vertical shear provides the necessary condition for baroclinic instability, most strongly in the 20°-30°S band, which is confirmed by altimetric height variance (Qiu and Chen, 2004). Deeper structures that might be part of the extended southern TJ are tilted as well. The tilt of the gyre probably also results in the tilt of the western boundary current bifurcation at the coast of Australia, as suggested by the nonlinear layer model solutions, but the full dynamics of the boundary response to the gyre shape needs further investigation. The response of the South Pacific STCs to ENSO wind anomalies might be a crucial piece of the ENSO-modulation puzzle. In general one might expect El Niño wind anomalies to weaken the STCs, but this may not be the case in the South Pacific. A composite of ENSO winds suggests that off-equatorial wind and curl anomalies are a prominent feature of these events in the central South Pacific, unlike the northern hemisphere where off-equatorial wind anomalies are modest. At the height of El Niño, relatively strong easterlies are observed at 15°-25°S, with a dipole of downwelling curl near 25°S and upwelling near 15°S. The resulting pattern of Ekman divergence suggests an enhanced sheared STC-like meridional transport pattern, that might have a strong influence on variability of inflow to the equator and the reverberations of one El Niño event on the subsequent evolution of the ENSO cycle. Understanding and diagnosing these phenomenon will require time series of subsurface properties to document the varying shear field, as well as continued modeling efforts.

6.2.2 Zonal currents of the SW tropical Pacific

Billy Kesser (NOAA/PPMEL) and Lionel Gourdeau (LEGOS/IRD)

1. Relation of jets to features in the winds needs exploration (atmos analysis and model experiments).
2. Flows into Solomon Sea need explication from models and observations (western boundary influence on Equator is crucial, and we don't know where it originates).
3. Relation of sources of subducted water to west Pacific thermocline remains unknown. Are the characteristics of the subducted water a major influence, or do wind-driven dynamics dominate?
4. Modal structure of S Pacific thermocline is crucial but remains speculative (theory, models and observations).
5. Glider

6.2.3 Observations of the Mesoscale Eddy Field in the Western South Pacific Ocean

Bo Qiu (U. Hawaii)

High mesoscale eddy variability in the western South Pacific Ocean is concentrated in three zonal bands. The 1st band is along the South Tropical Countercurrent (STCC) centered on 25°S, the 2nd band is along the South Equatorial Countercurrent (SECC) centered on 8°S, and the 3rd band is along the South Equatorial Current (SEC) inside the Western Fiji Basin and the Coral Sea. While the eddy variability in the STCC and SECC bands has been extensively investigated, much less has been explored with regard to the eddy signals in the 2nd band. A preliminary analysis of satellite altimetry data reveals that the regional variability in the Western Fiji Basin and Coral Sea is dominated by westward propagating mesoscale eddy signals with a period of 70-80 days. The strength of these eddy signals have a well-defined annual cycle with a maximum (minimum) in austral summer (winter). At present, causes for these observed 70-80-day oscillations remain unclear. Potential candidates include barotropical instability of the SEC, intraseasonal wind forcing in the region, natural oscillations in the semi-enclosed basins, and the influence of island topography. Clarifying the underlying dynamics of the mesoscale eddy variability is important as these eddies not only affect the general ocean circulation and biology within the Western Fiji Basin and the Coral Sea, they can also impact the SEC's bifurcation along the Australian coast and influence potentially the downstream western boundary currents in the region.

6.2.4 A Cautionary Note on Evaluating Pathways of Circulation & Property Budgets

Ichiro Fukumori (JPL)

Eulerian time-mean descriptions do not necessarily describe pathways of circulation. Possible differences between an Eulerian mean and a Lagrangian mean are illustrated for the Pacific Subtropical Cell using a numerical ocean circulation model with a passive tracer and its adjoint. Temporal evolution of passive tracers describe where tracer-tagged water goes, whereas that of adjoint tracers quantify where the water comes from. Due to stirring caused by the ocean's temporal variability, the time-mean tracer-derived Lagrangian description identifies a broad interior subtropical-tropical pathway that is absent in Eulerian mean circulation pathways. Due to such short-circuiting of flow between Eulerian streamlines, the Subtropical Cell is not a closed circulation pathway. A common practice of comparing volume-integrated advective tendencies between different directions is subject to local redistribution processes and may not represent effects of large-scale advection from different directions. Instead, relative effects from different directions can be quantified by referencing properties (e.g., temperature) to the subject domain's volume average and integrating individual directional fluxes along the region's bounding surface. Studies of circulation pathways and property budgets should take into consideration such Lagrangian pathway and method of property flux evaluation, especially in regions with strong temporal and/or spatial variability.

6.3 Western Boundary Current systems and outflows (Convener: G. Meyers (CSIRO); Report: B. Qiu (U.Hawaii))

6.3.1 Bifurcation Dynamics

Lionel Gourdeau (LEGOS/IRD) and Billy Kessler (NOAA/PMEL)

The broad westward flow associated with the South Equatorial Current (SEC) interacts with the complex bathymetry of the South West Pacific. Encountering the islands of Fidji, Vanuatu and New Caledonia, the SEC divides into strong and narrow zonal jets that cross the Coral Sea. The North Vanuatu Jet (NVJ), and the North and South New Caledonia jets (respectively NCJ and SCJ) are clearly identifiable, and are centered respectively at 14°S, 18°S and 24°S. These jets have a 2° latitudinal extension, and the cores are found deeper with latitude. Therefore a major part of the jets flow at depth. Each jet has mean transport of about 14 Sv, and they are separated by a region of null transport at 16°S. The SEC bifurcates at the Australian coast to feed the Western Boundary currents (WBCs), namely the southward Eastern Australian Current (EAC), and the northward North Queensland Current (NQC). The strength of the WBCs depends critically on the intensity of the SEC reaching the Australian coast, and on the latitudes where the SEC bifurcates at the western boundary. According to Sverdrup theory, the bifurcation latitude is determined by the zero zonally-integrated wind stress curl line. This simple steady-state, depth averaged theory, however is not sufficient to describe the actual flow field, which is highly variable in time and space, and conditioned by the topography. For example, the Queensland plateau forces the NCJ northward (from 18°S to 15°S at 500 m depth). The mean latitude of the bifurcation varies greatly with depth from 15°S at 100m depth to 19°S at 500 m. This latitude range corresponds principally to the latitude of the NCJ which appears to be of prime importance to feed both the EAC and the NQC.

At seasonal cycle, the bifurcation shifts southward about 5° at all depths during austral winter, over a range from 13°S to 23°S. The annual cycle of the bifurcation latitude is greatly modulated at interannual time scales. At 100 m depth, the latitude of the bifurcation shifts from 12°S in October 1997 to 16°S in October 1999. At depth (800 m), the latitude of the bifurcation shifts from 18°S in July 1998 to 24°S in July 1999. While the annual cycle of the bifurcation is in phase at all depths, there appears to be an irregular phase relation at interannual timescales.The WBCs are integrated in depth between 0-1000m. The EAC is usually fully developed south of 26°S (17 Sv), and the NQC north of 14°S (13 Sv), therefore the transports of both currents are estimated at these latitudes. The minus sign of the WBCs means outflow from the Australian coast, and negative value of zonal transports, estimated at 161°E, represents westward flow. The EAC and

NQC exhibits a well marked seasonal cycle in phase opposition that is well correlated with the bifurcation. The EAC is stronger and the NQC weaker during austral summer when the bifurcation is furthest north. As the seasonal cycle of the SEC is nearly nonexistent, the bifurcation latitude shift appears to explain this seasonal variability.

At interannual time scales, the total coastal outflow (sum of the NQC and EAC) is strongly correlated with the NCJ, but poorly correlated with the NVJ. In fact, the two inflow jets are themselves uncorrelated, and the WBCs are mostly related to the NCJ variability. Unlike the strong seasonal anticorrelation, at interannual timescales there is no clear relationship between the NQC and EAC variability. One explanation could be the disconnection of the bifurcation between the upper and the deeper layers. In fact, the NQC is particularly well related to the bifurcation in the upper layers, while the EAC is more closely related to the bifurcation in the deeper layers.

6.3.2 The East Australian Current: a review

Ken Ridgway (CSIRO)

The EAC system is defined as the western termination of the South Pacific Gyre within the Tasman/Coral Sea basin. The circulation of the EAC system is complicated by the complex topography at the southwest Pacific Ocean boundary. The Tasman Basin region is bounded by the Australian continent in the west, New Zealand in the south-east corner and the island archipelago of New Caledonia, Vanuatu and Fiji in the north-east. The bathymetry is dominated by several ridges which radiate northward from the New Zealand continental land mass. The EAC is the predominant dynamical feature in the region. The long-term average picture of the EAC develops following the bifurcation of the westward flow of the South Equatorial Current (SEC) and is observed along the eastern coast of Australia from 18^o to 35^o S. The northern component of this bifurcation ultimately feeds into the Indonesian Throughflow. The main portion of the EAC separates from the coast at ~32°S, and either recirculates northwards or flow eastward across the Tasman Sea. A portion of this eastward flow reattaches to the northern coast of New Zealand, forming the East Auckland Current and a sequence of permanent eddies. The residue of the EAC transport continues southward along the Australian coast as far as Tasmania and then turns westward into the eastern Indian Ocean.

The general features of the regional circulation are captured within fairly simple linear, wind-driven models. However, the flow is strongly attenuated by the complex topography. Results from a GCM and confirmed by observations, show that the westward inflow to the region, is not simply a uniform stream, but interacts with the complex island bathymetry to form a series of individual zonal jets. Model results confirm that gradients in wind stress curl control the current separation locations, non-linear dynamics induce the southward loop of the EAC as it separates from the coast and that the eastward meandering flow and quasi-permanent eddies are associated with upper ocean-topographic coupling.

The variability of the EAC dominates the mean flow. The boundary of an abyssal cul-de-sac adjacent to the western boundary is shown to enclose the peak variability. Much of this variability arises from the production and propagation of mesoscale eddies (rings). The timing and frequency of the eddies are controlled by remotely forced Rossby waves from the eastern Pacific. The eddy trajectories follow complex patterns which resonate within the deep basin at periods of 100 and 150 days. The EAC also demonstrates strong seasonal cycle with maximum alongshore flow in summer. Evidence of further interannual and decadal signals is present in the altimeter and in-situ datasets.

6.3.3 North Queensland/New Guinea Coastal Current system: the connection to the equator

Tangdong Qu (IPRC) and Billy Kessler (NOAA/PMEL)

This presentation provides a brief overview of the recent progress in understanding the North Queensland/New Guinea Coastal Current system. Existing observational and model studies have shown that the northward-flowing Great Barrier Reef Undercurrent starts at 20° -22°S in the western Coral Sea. The current intensifies northward underlying the surface East Australian Current, and merges with the North Queensland Current at about 15°S. It then turns eastward along the south coast of Papua New Guinea, and enters the Solomon Sea through the Lousiade archipelago to feed the New Guinea Coastal Undercurrent. The current system has been identified to be an important pathway for the South Pacific waters. Evidence exists to suggest that both the thermostad low-thermocline water and the Antarctic Intermediate Water reach the western equatorial Pacific via this pathway. However, due to the lack of sufficient observations, the variability of the current system and its relation to the formation of water masses and the equatorial thermocline remain unknown. Further field and model experiments will be needed to further address these issues.

6.3.4 The South-West Tropical Pacific: some impacts of ENSO, and importance for ENSO modulation

Sophie Cravatte (LEGOS/IRD) and Billy Kessler (NOAA/PMEL)

1. Some impacts of ENSO
   At interannual timescales, the ENSO cycle modifies the oceanic and atmospheric conditions in the South-West Pacific region. During an El Nino, different studies have shown: 1) anomalous northward wind, negative curl; 2) less precipitations; 3) colder, saltier in surface; 4) a shoaling of the thermocline during the course of El Nino; 5) an increase of the SEC transport. Several questions remain: Is the shoaling of thermocline driven by a local forcing or remote forcing (probably both)? The SEC transport increases, but where does the additional water of the SEC go? How does the bifurcation change? What about the WBCs? What about the EAC? Is the shoaling of the thermocline and the increase of the SEC important for the subsequent El Nino? Does it matter for the discharge or the recharge of the equatorial band? Is it important for the subtropical gyre?

2. Importance for decadal Modulation of ENSO:

   (a) Theories relying on the south west pacific: To our knowledge, there is no theory yet to explain decadal variability of the Pacific relying on an specific air-sea interaction in the South-West Pacific. It means that there is no theory in which the South-West Pacific alone could generate decadal variability. Instead, several theories have been proposed, in which the South-West Pacific Ocean is either a "passive" region downstream of a subduction region, or an "active" region in which anomalies are generated.

   (b) The SW Pacific is downstream of a subduction region: Both spiciness anomalies (VT' process) or transport anomalies (V'T process) could affect the equator through a pathway inside the South-West Pacific Ocean (Giese et al., 2002; Bratcher et al., 2002; Schneider et al., 2000; Yeager and Large, 2004; McPhaden et Zhang, 2002, 2004. . . .)

3. Open questions:
   Are the spiciness anomalies generated in the South-Eastern Pacific really propagating to the western boundary, and then along the equator, without being mixed or damped? Are there decadal variations of the WBCs transport? The SW Pacific could be a region of forcing anomalies at decadal timescales: By Ekman pumping anomalies (Garreaud and Battisti, 1999; Chang et al., 2001, Luo and Yamagata, Luo et al., Cibot et al., 2005, Capotondi et al., 2003) or by heat flux anomalies (Yu and Boer, 2004) What are the main processes? (dynamics, fluxes...) How does the signal propagate equatorward and eastward?

6.4 Climate impacts of Pacific ocean Circulation (Convener: J. Salinger (NIWA); Report: G. Alory (CSIRO))

6.4.1 Regional climate variability in the South West Pacific

Jim Salinger (NIWA)

The climate of the southwest Pacific is part of the general circulation of the atmosphere. The South Pacific it is set between the equatorial trough where the climate circulation of the northern and southern hemispheres meet, and the anticyclones of the subtropical high pressure belt towards the poles. In the South Pacific key climate zones are the intertropical convergence zones, tropical easterlies, south east trade wind belt, the South Pacific Convergence Zone (SPCZ) and the subtropical high pressure belts. The annual modulation of these features of the climate circulation gives the seasonal cycle in South Pacific climates. The climate of the Southwest Pacific is unique in that there are climate drivers on seasonal to interannual and decadal time scales that modulate the climate system: the well known El Nino/Southern Oscillation, and the recently described Interdecadal Pacific Oscillation (IPO). In the former the easterly trade winds weaken during El Nino episodes, and strengthen in La Nina events. The IPO operates on decadal time scales and causes shifts in climate throughout the region. In the last change to the positive phase of the IPO 1976/77 air pressures generally increased west of the Date Line, and decreased to the east, giving the Southwest Pacific a more El Nino like climate, with drying in the subtropics, and precipitation increases in the northeast. Underneath the seasonal to decadal variability increasing greenhouse gases are causing a warming of South Pacific climates. Southwest of the SPCZ warming has occurred throughout the 20th century and amounts to 0.7°C, whilst to the northeast warming commenced in the 1970s and amounts to 0.5°C.

6.4.2 Regional Climate Variability: An Australian perspective

Bertrand Timbal (BMRC)

There is a number of oceanic (or coupled ocean-atmosphere) climate variability evident on a range of scales. These have an impact on Australian climate and society: Rainfall, Temperature, Tropical Cyclones, crop yields, river discharge ... There is a predictable part in these signals: The Australian Bureau of Meteorology is exploiting this using empirical-based prediction scheme. It appears that coupled climate models are not yet a clear winner and that raises couple of issue for the future:

- How do we deal with Climate Change and empirical linkages ?
- How can we make our direct model predictions more useful to beat statistical schemes?

Data assimilation in climate prediction models is a key issue

- We need to investigate local SSTs versus ENSO index: (which appears to have a strong impact but maybe a small predictability?)
- Monitoring of the SW Pacific is important for us (a critical area)
- We have more work to do to understand our system:
  - ENSO on-set: the role of intra-seasonal stochastic forcing
  - ENSO decay: what are the mechanisms?
  - Relationship between ENSO & Indian Ocean Variability

6.4.3 Southward shift of the East Australian Current over the past decades

Wenju Cai (CSIRO)

The response of the Southern Hemisphere ocean circulation to climate change is not as well studied as the Northern Hemisphere counterpart. Observational studies have revealed an upward trend of the Southern Annular Mode (SAM) over the past few decades, although the relative importance of greenhouse, ozone depletion and natural variability in forcing the trend is not fully conclusive. Here we demonstrate, via the Sverdrup relationship, that the associated change in wind stress curl causes a southward shift of the Southern Hemisphere subtropical gyre, particularly the Eastern Australian Current (EAC), leading to an intensification of the southern part of the gyre circulation. Climate models forced by the Intergovernmental Panel for Climate Change scenarios project a continuing upward trend of the SAM into the future. In response, the EAC moves southward by up to 8° by year 2070. The intensified EAC generates a warming rate in the Tasman Sea that is greatest in the Southern Hemisphere (SH) with significant implications for sea level rise. The southward shift is a part of annular-scale circulation changes that involve all subtropical gyres of the Southern Hemisphere. The changes significantly alter the boundaries of bio-diversity and generate accelerated warming and sea-level rises in regions where the southward flowing current intensifies. Although the circulation change can primarily be attributable to changes in wind stress curl, it is found that the pattern of curl changes actually reflects the pattern of heat flux changes, indicating the coupling between momentum and heat fluxes. The detailed thermal and dynamical coupling process awaits a thorough examination.

6.5 Coastal and island oceanography: coastal circulation, upwelling and mixing (Convener: E. Wolanski; Report: J. Aucan (U.Hawaii) and E. Martinez (UPF))

6.5.1 The Tasman Front and flows around northern New Zealand

Mike Williams (NIWA)

The western boundary current in the South Pacific Ocean is unique, in that it separates from Australia's east coast, crosses the Tasman Sea, and reattaches to New Zealand's North Island. This current crosses the Tasman Sea as the Tasman Front, where it was initially identified and studied in the 1970's and 1980's, and again become a subject of interest in recent years. Most observational studies focussed on the Tasman Fronts transport, which was estimated to be ~15 Sv (about half the transport of the East Australian Current); and spatial variability, where meanders in the front are of the order of 300-400 km. Along the east coast of the North Island lies the East Auckland Current, and the associated recirculating North Cape and East Cape eddies. In the 1990's it was found the East Auckland Current had significant biological importance due to shoaling of tracer properties near the coast, a process that is also reinforced by the prevailing upwelling favourable winds. Southward transports in the East Auckland Current were found to range between 5 and 20 Sv. Off the North Island's west coast the West Auckland Current has relatively weak flow, when compared with the East Auckland Current. Here geostrophic calculations from data collected in the 1970's suggest a weak southwards flow, while current meter data from 2003-4 shows the flow is highly variable with maximum along shore velocities of up to 5 cms-1 in both directions and a mean velocity close to zero.

6.5.2 Oceanic Circulation in French Polynesia

Elodie Martinez (UPF)

French Polynesia ([5-35°S]/[200-230°E]), is situated in the middle of the South Pacific Ocean. This area has been poorly studied and one of the difficulty in this region is its lack of in situ data. Surface circulation has been determined using satellite data and seasonnal and interannual variations have identified. Satellite data also have been used to initiate the study of strong phytoplankton blooms around Marquesas islands. For the last 15 years, four CTD transects, 3 TAO buoys and XBT samples mostly along merchant cruises transect (Noumea-Tahiti, Tahiti-Panama and Tahiti-Hawaii) are available, with a limited possibility to study spatial or temporal variations. A regional oceanic model (ROMS) has been implemented at the university of French Polynesia. The circulation features that were presented included: the east extention of the South Equatorial Counter-Current (SECC) and its influence on tropical cyclone formation, the formation area of the South Tropical Water (STW) in a region of high evaporation (and consequently its impact on climate), the obstacles formed by the Tuamotu archipelago and, in the south, a meso scale eddies area with a strong thermal and haline front. Some repeat transects along 150°W and 120°W (to study the SECC and the STW), XBT sampling along merchant sails as well gliders along the STW could strongly improve our knowledges.

6.5.3 Regional modeling application to New Caledonia upwelling system

Andres Vega (LEGOS/IRD)

The New Caledonian reef is a 700 km-long barrier oriented parallel to dominant trade winds. As a result, wind-driven upwelling events regularly appear on the west side of the reef. Satellite images and in situ sensors are used to describe these events that occur essentially during the austral summer. This upwelling has very unique features: it occurs in a very oligotrophic region; it lowers the temperatures by up to 6°C and it is very energetic. A regional ocean model (ROMS) was used to understand its mechanisms. The high resolution model (1/20°) is nested in a global, low resolution ocean model and forced with ECMWF fields at the surface. The simulation reveals a very good agreement with the few in situ temperature sensors. The spatial extent of the events are comparable with satellite observations. The influence of the larger scale ocean circulation on the temperature patterns is also shown, with the cold South Tropical Countercurrent and the warm South Equatorial Current intersecting near New Caledonia. Some future applications are considered, such as island effect on large scale circulation, biochemical dynamics, tracer transport, and cyclone trajectories. The next step is to implement a Regional Atmospheric Model System (WRF) to forecast the New Caledonia upwelling system.

6.6 Internal waves and mixing :Local effects of larger scale variability

J. Aucan (U.Hawaii)

1. New Caledonia and New Zealand are very energetic barotropic conversion site, radiating significant amount of internal tidal energy.
2. Southern Oceans storms likely generate significant amounts of equatorward propagating near-inertial waves.
3. Stratification changes affect local distribution of mixing, and vice-versa.
4. This can mean uneven geographical distribution of inertial and tidal dissipation, with implication for point source pollution.
5. Air/sea fluxes long term Observational systems (moorings) are also ideal platforms for observations of episodic mixing events if instrumented accordingly.

6.7 Coastal impacts: ocean influences on ecosystems and populations

6.7.1 Water circulation around oceanic islands: lessons from Raine Island, Ribbon Reefs, Mururoa, Tahiti, Scott Reef, Guam, and Palau

Eric Wolanski (AIMS)

Field and model studies of the water circulation around these oceanic islands reveal that oceanic currents generate island-generated internal waves up to 270 m peak-to-trough.

1. These waves occur even if there are no eddies in the lee of the island.
2. These waves radiate away and contribute to the oceanic variability.
3. These waves upwell nutrients; an upwelling also results from flow through reef passages.
4. The upwelled nutrients can reach the surface through the spur-and-grooves of coral reefs.
5. This upwelling helps maintain coral reefs.
6. Large upwelling favours the alga Halimeda.
7. Excessive upwelling generates a thermal shock that results in depauperate coral reefs at depths.
8. Coral Sea inflow helps control outer shelf GBR health.

6.7.2 Oceanographic Monitoring for Sustainable Development in the South Pacific

Sarah Grimes (PI-GOOS/SOPAC)

Marine science, oceanographic and associated climate monitoring has wide-reaching implications for sustainable development, environmental health and improved mitigation of impacts of natural hazards in the South Pacific. Despite this, the region is still developing a capacity for ocean science and its application to coastal and marine management, and sustainable development planning. Currently, most coastal, marine and risk management efforts are uncoordinated, duplication is common and planning gaps exist, with little access to timely and reliable scientific data (especially oceanographic) to support appropriate decision-making. This is attributed to poor communication links, insufficient human resources and knowledge in the region. Most South Pacific-focused marine and related atmospheric science qualifications, research and industry practice have been conducted elsewhere, especially Australia, USA and Europe. After completion of international research and industry projects, Pacific Island Countries (PICs) often have difficulty acquiring the information that has been taken offshore. At present, there are only six known physical oceanographers practising within the region, none of which are Pacific Islanders. This absence of information and local expertise can impair management of island resources, activities and development within PICs. As such, there is a critical need to improve knowledge, monitoring, data collection, cataloguing, analysis and dissemination of ocean science products in order to assist and improve research, capacity building, environmental planning, decision-making and self-reliance.

The Pacific Island Global Ocean Observing System (PI-GOOS) has been set-up by the Intergovernmental Oceanographic Commission in response to this need, and recently has been improved and strengthened. The presentation outlined key milestones in the past year, including development of the first South Pacific Ocean web-portal. This has been developed to encourage networks between PICs and international scientists operating in the region, as well as being relevant to disaster risk management and understanding the ENSO phenomena and its influence on regional fisheries and tourism industries.

The discussion outcomes included:

1. Consideration of the social implications of oceanographic monitoring in the region and how to transfer information into products for use by PICs; and

2. Identifying PICs where oceanographic research results can be immediately developed into pilot products useful for coastal and marine management and planning.

6.8 Status of current programs (Convener: D. Roemmich (Scripps); Report: K. Ridgway (CSIRO) and S. Grimes (PI-GOOS/SOPAC))

6.8.1 Present Obervational Efforts for the Southwest Pacific ocean : a brief overview

T. Delcroix (LEGOS/IRD)

The present in situ oceanic observations in the SW Pacific are either parts of the sustained Global Ocean Observing System (GOOS) or parts of short-term measurements carried out for specific process studies. The components of the in situ observing system mainly include : a) fixed point time series, b) surface drifting buoys, c) ARGO profiling floats, d) tide gauge networks, e) ship of opportunity networks, d) moored buoy networks, and e) repeated oceanographic cruises. Information about the status of these components was presented, focusing on their relative strength and weakness. Given the objectives of the workshop, it was noted for the SW Pacific region: a) the potential need for a dedicated observatory (HOT-type station), b) the weak number of regional surface drifting buoys and derived SST and velocity data, c) the lack of ARGO floats in the Coral Sea, and the absence of planed deployment so far, d) the lack of VOS-derived SSS data in the subduction area of the SE Pacific, e) the lack of moored buoys south of 8°S, e) the non-secure yet long-lasted 165°E repeated oceanographic sections. Workshop participants strongly supported the present in situ observing system, and discussed the need for enhanced and/or dedicated in situ observations with regards to the SPICE project (see the Workshop conclusions).

6.8.2 Operational Oceanography (Mercator and BLUElink)

Andreas Schiller (CSIRO), Andres Vega (LEGOS/IRD), Jerome Lefevre (LEGOS/IRD) and Alexandre Ganachaud (LEGOS/IRD)

In 2003, the Australian Government, through the Bureau of Meteorology (BoM), Royal Australian Navy and CSIRO, initiated BLUElink - Ocean Forecasting Australia, a project to deliver operational short-range ocean forecasts for the Asian-Australian region by 2006. The BLUElink system will provide information on coastal and open-ocean currents and eddies, surface and subsurface ocean properties, products that impact and are linked to maritime and commercial operations, defence applications, safety-at-sea, marine environmental sustainability, and regional and global climate. Global advances in technologies necessary to observe and simulate the oceans have provided scientists at CSIRO and the Bureau of Meteorology with the tools to deliver near real-time information on ocean behaviour. The aim of the project is to generate ocean charts for marine users similar to weather forecast charts available to the rest of the community. The BLUElink initiative centres on ocean prediction and analysis, and forecasting of day-to-day variations in ocean currents, ocean eddies and temperatures around Australia. Central to BLUElink is the development of a global prediction system with a focus on the Asian- Australian region. Operational Oceanography: Benefits and Issues for the SW Pacific Benefits (cf. GSOP):

- Operational Oceanography provides high temporal and eddy-resolving model solutions in close agreement with obs. (cf. coarse resolution climate change climate variability models; ECCO)
- Reanalyses are an important component of operational oceanography Growing number of globally eddy-resolving models (Earth Simulator, MERCATOR, NRL,...)
- Regional groups (IRD, BlueLink, NIWA) can provide "local" knowledge
- Issues:
  - Focus predominantly on upper ocean
  - Mostly uncoupled ocean-only models (due to high computational costs): accuracy of surface forcing
  - Limitations wrt integration times (~1992 onwards, "sparse" data cover prior to 1992)

7 Discussions and working groups

Each session was followed by a discussion on the corresponding topic, lead by the conveners. Two 2-hour general discussions followed on the last day. The main items that were discussed are listed here, and are used as a bases to elaborate the first SPICE structural document, that will be available on www.ird.nc/UR65/SPICE in early 2006. The draft discussion reports may be found on www.ird.nc/UR65/SPICE/Malanda/malandadiscussionsummaries.pdf.

7.1 Interior circulation of the South West Pacific (Convener: A. Schiller; Report: T. Qu)

1. "Think globally, act regionally"
2. How water is fed to the equator
3. Theory of thermocline circulation patterns
4. Variability of thermocline circulation, ENSO influence

7.2 Western Boundary Current systems and outflows (Convener: G. Meyers; Report: B. Qiu)

1. Boundaries of the region of interest
2. East Australian Current and regional climate: decadal variability and global warming effects
3. How to observe the East Australian Current, the inflows, the outflows

7.3 Climate impacts of Pacific ocean Circulation (Convener: J. Salinger; Report: G. Alory)

1. The South Pacific Convergence Zone and its variability
2. Importance of the Interdecadal Pacific Oscillation, Madden-Julian Oscillation and oceanic features for regional climate
3. Recent climate changes and EAC
4. Importance of downscaling from regional oceanography to coastal island circulation

7.4 Status of current programs (Convener: D. Roemmich; Report: K. Ridgway and S. Grimes)

1. Strength and weakness of existing programs for the regional objectives
2. Different approach for global versus regional observationnal programs
3. Different approach for one-time versus sustained observations
4. CLIVAR

7.5 Towards an observational and modeling program for the South-West Pacific

7.5.1 Designing a feasible observational program for the South-West Pacific Ocean (Conveners: A. Ganachaud; J. Sprintall; Report: W. Kessler; L. Gourdeau; S. Grimes)

1. Existing regional infrastructures
2. Monitoring: EAC, bifurcation, outflows
   (a) Enhancing specific XBT lines; adding new lines
   (b) Adapting regionally ARGO program (e.g. in the North Coral Sea)
   (c) Testing and using gliders for monitoring strong currents
3. Interests for mooring deployement (EAC and Tasman Current; straits; bifurcation region)
4. future CTD lines

7.5.2 Modeling opportunities (Convener: K. Richards; Report W. Cai, C. Maes)

1. Jets in high-resolution numerical models
2. Identifying key features that need to be properly reproduced in models (define a metrics)
3. Model comparisons and sensitivity experiments

7.6 Working groups

The discussion was followed by four working groups organized by areas of interest:

1. Jets and Bifurcation (L. Gourdeau / A. Ganachaud)
2. East Australian Current (K. Ridgway)
3. North Coral Sea (B. Kessler)
4. Impacts and outreach (S. Grimes)

each working group addressed the following questions:

1. What are the main scientific questions
2. What observations would be needed to answer those questions
3. What model experiments would answer those questions

The product of those discussion is a document for a coordinated regional experiment, named SPICE. This document is currently being established by a writting committee (A. Ganachaud, S. Cravatte, L. Gourdeau, K. Ridgway, W. Cai, W. Kessler, B. Qiu, D. Roemmich, J. Sprintall, M. Williams).

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