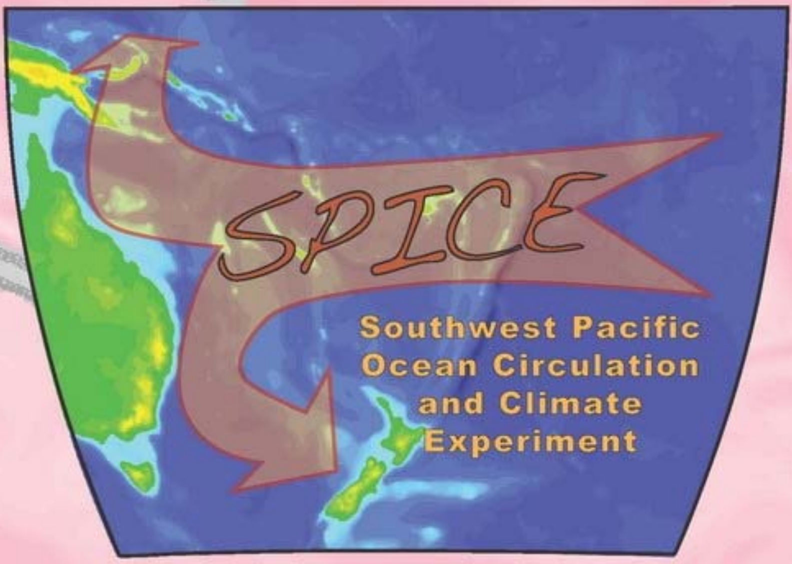
Southwest Pacific Ocean Circulation and Climate Experiment (SPICE)

Part I. Scientific Background

May 2007



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Southwest Pacific Ocean Circulation and Climate Experiment (SPICE)— Part I. Scientific Background

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Contents

1. Rationale

South Pacific thermocline waters are transported in the westward flowing South Equatorial Current from the subtropical gyre center toward the southwestern Pacific Ocean—a major circulation pathway that redistributes water from the subtropics to the equator and to the southern ocean. The transit in the Coral Sea is potentially of great importance to tropical climate prediction because changes in either the temperature or the amount of water arriving at the equator have the capability to modulate the El Niño-Southern Oscillation (ENSO; glossary of acronyms at the end of the document) cycle and thereby produce basin-scale climate feedbacks. The southern fate of thermocline waters is, comparably, of major influence on Australia and New Zealand's climate; its seasonal and interannual evolution influences air-sea heat flux and atmospheric conditions, and it participates in the combined south Indian and Pacific Ocean "supergyre." Substantial changes of this circulation have been observed over the past 50 years, and are continuing in global climate projections. The subtropical gyre has been spinning up in recent years with possible consequences for ENSO modulation and for the East Australian Current (EAC), whose influence has moved south, dramatically affecting the climate and biodiversity of Tasmania.

Despite its apparent importance to the climate system, few observations are available to diagnose the processes and pathways of transport through the complicated geography of the southwest Pacific. The South Pacific Convergence Zone is poorly documented; the region is remote, and the large temporal variability and strong narrow currents in a complex bathymetry pose serious challenges to an observing system. Numerical model results are sensitive to parameter choices and forcing, and the results are uncertain because of the lack of in situ data for validation. The existing observational network (Argo, VOS XBT sampling, and satellite winds and altimetry) is beginning to provide a large-scale picture, but the complex circulation and western boundary currents require further dedicated study. This document lays out the scientific background and identifies the open issues in the southwest Pacific Ocean. Its purpose is to set the basis of a regionally coordinated experiment, the Southwest PacIfic Ocean Circulation and Climate Experiment (SPICE, `http://www.ird.nc/UR65/SPICE`) under the umbrella of the International CLIVAR program (Climate Variability and Prediction, `http://www.clivar.org`). The corresponding implementation plan will be developed in a second report, integrating both observational and modeling analysis to provide a more complete description of the mean and variable circulation and climate in the southwest Pacific Ocean.

2. Objectives

The goal of SPICE is to observe, simulate, and understand the role of the southwest Pacific Ocean circulation in (a) the large-scale, low-frequency modulation of climate from the Tasman Sea to the equator, and (b) the generation of local climate signatures whose diagnosis will aid regional sustainable development. This goal will be realized through four specific efforts, which are discussed in detail in this Scientific Plan:

1. Analysis of the southwest Pacific role in global coupled models;
2. Development of an observational program to survey air-sea fluxes and currents in the Coral, Solomon, and Tasman Seas, and their inflows and outflows, with special attention to the strong boundary currents and jets;
3. Combination of these observations with focused modeling efforts to devise a sustained monitoring program to adequately sample the time-variability of the currents and their heat and mass transports;
4. Using remotely and locally sampled meteorological fields, and the ocean analysis, determination of the air-sea heat and freshwater fluxes and water mass transformations that occur in the region, and their effects on the local and global climate. A focus here may be the design of a process study to observe, model, and understand the South Pacific Convergence Zone.

The simultaneous large-scale and regional approach allows applications ranging from ENSO forecast improvement, to coral bleaching, cyclone trajectory, or projection of local ocean and climate conditions.

3. Scientific Background and Issues

3.1 Introduction: The Southwest Pacific Ocean in the Climate System

The characteristics of the El Niño-Southern Oscillation (ENSO) have been shown to be sensitive to background oceanic conditions (Fedorov and Philander, 2001). Those conditions vary on decadal timescales

(Wang and Ropelewski, 1995), with some hypotheses suggesting an influence of the subtropics. Subtropical-tropical interaction and ENSO modulation has been debated over the past 10 years, some authors suggesting that ENSO decadal variability was related to the thermocline water inflow (McPhaden and Zhang, 2002; Schneider, 2004), others that it was caused by atmospheric variability outside the tropics conveyed via the atmosphere (Pierce *et al.*, 2000), or again by the non-linearities inherent in the coupled equatorial dynamics (Timmermann, 2003). The extra-tropical variability may be transmitted to the Tropics via the ocean (McGregor *et al.*, 2004, 2007) by: (i) changing the temperature of the water that is advected into the Tropics in the meridional overturning circulation (the vT' hypothesis; Gu and Philander, 1997; Zhang *et al.*, 1998); (ii) changing the rate at which water in the meridional overturning circulation is advected into the Tropics (the $v'T$ hypothesis; Kleeman *et al.*, 1999; McPhaden and Zhang, 2002; Nonaka *et al.*, 2002); and (iii) oceanic Rossby waves excited by variations in the extra-tropical wind stress (Lysne *et al.*, 1997; Liu *et al.*, 1999; Capotondi and Alexander, 2001; Capotondi *et al.*, 2003; Wang *et al.*, 2003a,b).

Recent numerical and data analyses suggest that the characteristics of ENSO on decadal timescales mainly originate from the South Pacific (Luo and Yamagata, 2001; Luo *et al.*, 2003; Luo *et al.*, 2005; Moon *et al.*, 2007), a mechanism involving changes in wind stress patterns and thermocline water transports. It is conceivable that all these effects contribute to determine the characteristics of ENSO, and the coupled, non-linear nature of the system may preclude a rigorous deconvolution. Nevertheless, understanding and modeling properly the mechanisms that determine the characteristics of the thermocline waters that emerge within the equatorial cold tongue is of major importance to all these processes.

Thermocline water pathways are little documented in the subtropical South Pacific in comparison with those of the subtropical North Pacific. Both the dynamics and geography are fundamentally different between the hemispheres. To the north, the Inter-Tropical Convergence Zone (ITCZ) inhibits equatorward flow in the ocean interior (Johnson and McPhaden, 1999) and part of the southward western boundary current leaks into the Indonesian Throughflow. To the south, where no ITCZ inhibition occurs and most of the equatorial thermocline waters originates, there is a dilemma between a direct (through the ocean interior) link and an indirect (through western boundary currents) link to the equatorial region, each having a very different impact on equatorial SST (McCreary and Lu, 1994; Luo and Yamagata, 2001; Giese *et al.*, 2002; Lee and Fukomori, 2003; Fukomori *et al.*, 2004). Observations have also suggested that the equatorward thermocline transports in the ocean interior have changed in past decades (McPhaden and Zhang, 2004), but the relative pertinence of interior and boundary transports remains unknown.

Ocean reanalysis suggests that thermocline waters formed near the center of the South Pacific subtropical gyre advect spiciness anomalies (i.e., temperature anomalies on isopycnals) to the equator via complex pathways through the southwest Pacific (Giese *et al.*, 2002). The anomalies, with magnitudes close to 0.5°C, are acquired through mixing processes with the surface oceanic layer (Yeager and Large, 2004) and advect to the equatorial cold tongue in about 10 years (Luo and Yamagata, 2001; Giese *et al.*, 2002). Upon their arrival at the equator, these signals have been identified, in some coupled ocean-atmosphere models, as influential on the amplitude of ENSO (Luo and Yamagata, 2001; Schneider, 2004; Luo *et al.*, 2005). Some global warming simulations show a similar mechanism, with greenhouse warming first altering subtropical thermocline waters which then advect toward the equator, thereby influencing ENSO toward "Niño-like" conditions (Cai and Whetton, 2000). The southern pathway of thermocline waters fuels the East Australia Current (EAC), the predominant dynamical feature south of 18°S (Church, 1987). The EAC transports large quantities of heat energy toward higher latitudes. It separates from the Australian coast in filaments, giving rise to a region of intense eddy activity and air-sea exchanges, with marked influence on climate over Australia and New Zealand (Sprintall *et al.*, 1995; Cai, 2006).

The southwestern Pacific Ocean is therefore the center of major water pathways from the subtropics to the equator and to southern latitudes. Both observational (Tsuchiya, 1981; Tsuchiya *et al.*, 1989) and model tracer studies (Blanke and Raynaud, 1997; Izumo *et al.*, 2002; Fukumori *et al.*, 2004) suggest that a substantial fraction of the water arriving at the equatorial cold tongue can be traced back to the western boundary current system of the South Pacific. Models and observations also suggest that the bulk of the transport feeding the Indonesian Throughflow transits through this region too (Inoue and Welsh, 1993; Blanke *et al.*, 2002; Talley and Sprintall, 2005). Conversely, the southwest Pacific has a strong ENSO imprint on its oceanic variations (Holbrook and Bindoff, 1997; Taft and Kessler, 1991; Sutton and Roemmich, 2001; Gouriou and Delcroix, 2002) as well as on its atmospheric variations (Power *et al.*, 1999).

An overriding issue is how inflow from the subtropical gyre is redistributed meridionally to the equator and to the Tasman Sea as it arrives at the western boundary. Ocean currents in the southwest Pacific Ocean are impacted by its complex topography (Fig. 1). Westward-flowing thermocline waters encounter successively the Fiji plateau; the Vanuatu and New Caledonia Archipelagos; the Solomon Island Chain; the Australian Coast with the Great Barrier Reef and Queensland Plateau; New Zealand to the south, the sharp Papua-New Guinea coastline to the north, and the Solomon Sea with its three narrow north exits: Vitiaz and Solomon Straits and St. Georges Channel. These features cause narrow boundary currents and jets, with structures and dynamics that are not properly modeled or sampled.

While basin-scale climate studies point to the southwest Pacific as a region pivotal to decadal climate variability, neither its oceanic nor atmospheric features have been properly depicted by models or observations, and key aspects of its climate-important components are not well understood. Those components are, specifically, the main atmospheric feature, the South Pacific Convergence Zone (Section 3.2), the thermocline water pathways and variability (Section 3.3–3.5), and the local water mass transformations and environmental impacts (Section 3.6).

3.2 Main Atmospheric Features: SPCZ and Trade Winds

The southeasterly trade winds dominate the atmospheric circulation in the South Pacific. Their direction and strength are associated with the South Pacific Convergence Zone (SPCZ), which is noted as "one of the most expansive and persistent cloud bands" (Fig. 2; see Vincent, 1995, for a review). The SPCZ is a region of high convective activity associated with strong precipitation, wind convergence, and diabatic heating (Zhang, 2001). The trade winds in the central South Pacific are substantially affected by its position (Vincent, 1995). The SPCZ appears to be the dominant convective feature of the Southern hemisphere (Hurell and Vincent, 1987). For Zhang (2001), the Pacific double ITCZ, and henceforth its lower branch that corresponds to SPCZ, is caused by equatorial westward advection of cold air over the cold tongue that splits the ITCZ system. For our purposes the remarkable feature of the SPCZ is its southward bend east of the dateline, causing a diagonal northwest/southeast shape that distinguishes it from its northern counterpart. This shape has to do with both SST distribution and the subtropical atmospheric jets, but its presence is not fully understood (Kiladis *et al.*, 1989; Yoshikane and Kimura, 2003).

The SPCZ position and activity have substantial intraseasonal, seasonal, and interannual variations. Seasonally, it is most marked in January, when maximum precipitation extends from New Guinea to 120°W, 30°S, following closely the lines of sea surface temperature and wind convergence maximum (Kiladis *et al.*, 1989). In July, the SPCZ has a strong zonal portion over the warm pool near New Guinea and a less marked diagonal portion to the southeast. On interannual timescales, a northeastward displacement is associated with El Niño, while a southwest displacement is associated with La Niña. On longer timescales, its position is affected by the Interdecadal Pacific Oscillation, with a recent equatorward shift since 1976 (Salinger *et al.*, 2001; Folland *et al.*, 2002).

Locally, the SPCZ has a strong influence on oceanic conditions. On decadal timescales, changes in precipitation and henceforth in the SPCZ position are measurable in sea surface salinities (Delcroix *et al.*, 2007). The major South Pacific region of decadal ocean heat content anomalies driven by latent heat exchanges is located just north of the SPCZ. Those anomalies would then advect to the northwest before joining the equator (Garreau and Battisti, 1999; Yu and Boer, 2004). The most important decadal changes in thermocline temperature (50–200 m) also occur there, caused by variations in the wind curl (Chang *et al.*, 2001; Luo and Yamagata, 2001; Cibot *et al.*, 2005).

Many coupled climate models do not reproduce properly the SPCZ and its variations. Coupled models exhibit a South Pacific convergence zone that extends zonally all the way to the coast of South America, in quasi-symmetry with the ITCZ north of the equator (e.g., Houghton *et al.*, 2001, p. 480). This results in overestimation of precipitation in the southeast Pacific and underestimation in the central and west South Pacific where the observed SPCZ bends to the south. The model error, though common to almost all coupled general circulation models, is not understood (Li *et al.*, 2004). It may be related to an overestimated equatorial SST gradient and to difficulties in obtaining realistic cloudi-

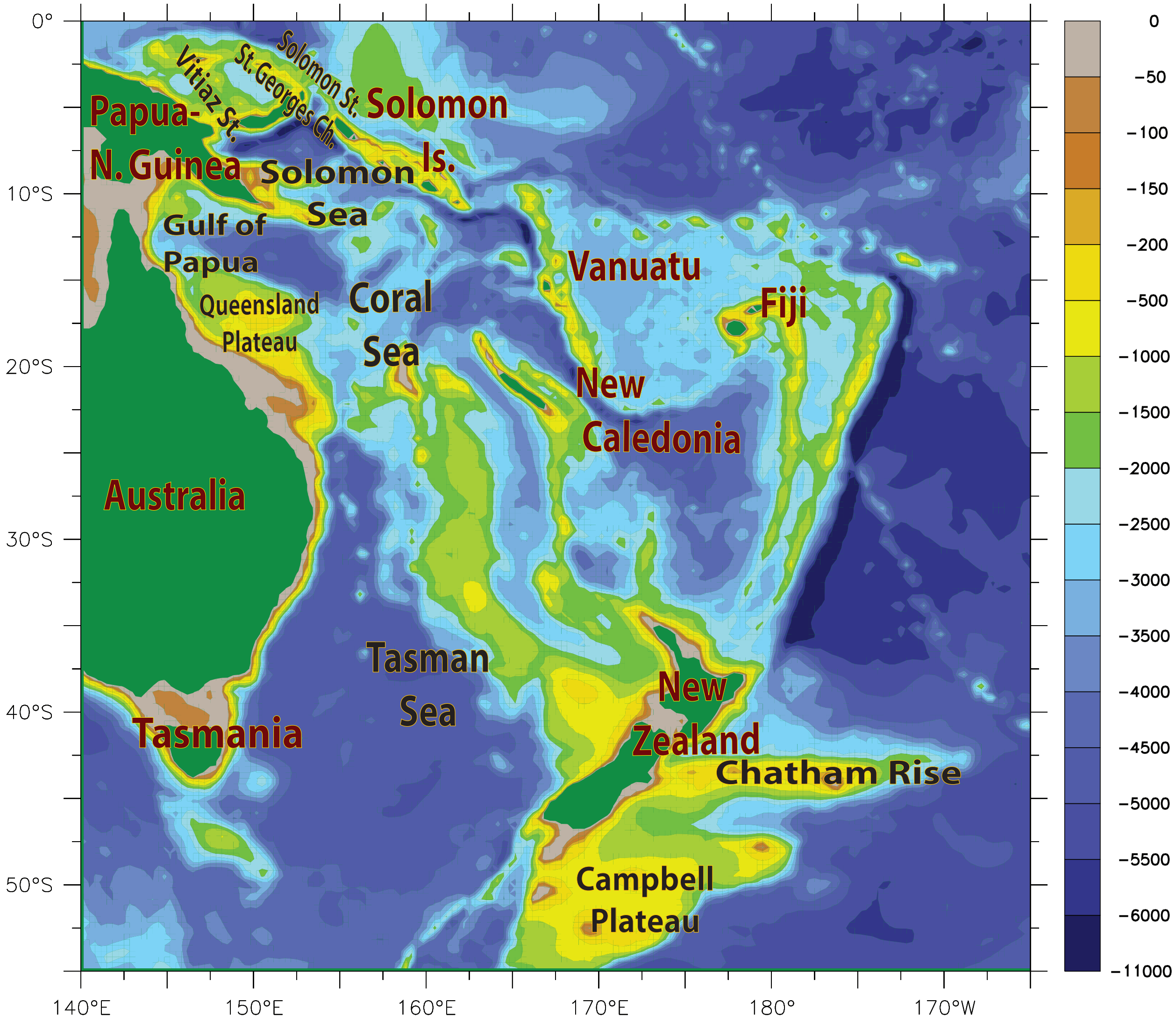

Figure 1: Topography of the southwest Pacific.

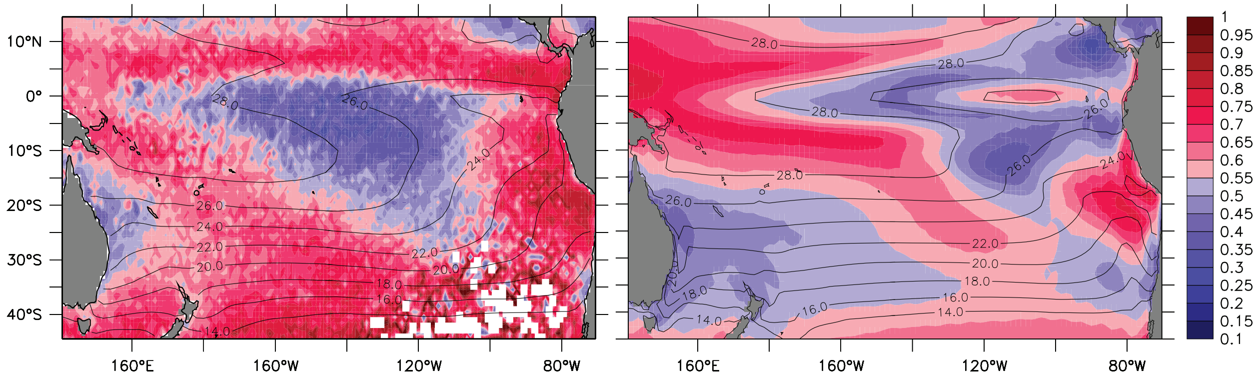

Figure 2: Left: Observed ERSST (contour) [K] averaged over the period 1954–1974, COADS cloudiness (shading) averaged from 1960–1970. Right: Simulated time-averaged present-day SST [K] and cloudiness simulated by a 20th-century climate model simulation.

ness off the coast of South America (Wood *et al.*, 2006). One consequence of the long zonal SPCZ in coupled models is that it does not encompass the kind of interannual variability of longitudinal position that is in fact observed. This has unexplored repercussions on air-sea interaction and atmospheric teleconnections between the mid-latitudes and the tropics.

3.2.1 SPCZ summary and issues

The SPCZ is of major influence on the ocean circulation, on the regional climate, and on global climate. Yet, many aspects are not well understood, such as:

- The formation of the SPCZ;
- Its annual and interannual variability, and the possibility of ocean-atmosphere feedback controls;
- The southward veering of the SPCZ east of the dateline, versus the near-zonality of the ITCZ;
- Why global climate models fail to properly reproduce its southward veering (double ITCZ); and what are the consequences on ENSO forecast.

3.3 Thermocline Water Inflow: Jets and Bifurcation

We now turn to the main water mass that transits through the southwest Pacific region: the “thermocline” water. Thermocline waters originate from “South Pacific Eastern Subtropical Mode Water” (SPESMW, Hanawa and Talley, 2001) that forms in the dry and windy center of the southeast Pacific gyre (high salinity patch on Fig. 3). In this region, water acquires its high salinity and salinity anomalies through diapycnal mixing due to winter erosion of a strong vertical salinity gradient, rather than direct subduction (Yeager and Large, 2004; Johnson, 2006). SPESMW is then advected to the west, forming the core of the South Equatorial Current (SEC, Gouriou and Toole, 1993; Donguy, 1994; Donguy and Meyers, 1996) with salinities in excess of 36 practical salinity units (PSU). The SEC carries thermocline waters to the Coral Sea (Fig. 4). Upon its encounter with the island ridges of Fiji (Stanton *et al.*, 2001), New Caledonia, and Vanuatu, it divides into three main jets: the South Caledonian Jet (SCJ, 24°S), the North Caledonian Jet (NCJ, 18°S), and the North Vanuatu Jet (NVJ) at 13°S (Webb, 2000). The NCJ bifurcates on the east coast of Australia, feeding both the EAC and the New Guinea Coastal Current (NGCC) system. The NGCC supplies the Equatorial Undercurrent; its properties can be traced to the east Pacific cold tongue (Tsuchiya *et al.*, 1989). To the south, the EAC flows southward along the eastern coast of Australia from 18° to 35°S. Its circulation is complicated by the numerous reefs, deep basins, and ridges that form a complex topography. The main portion of the EAC separates from the coast at ~32°S, much of which either recirculates northward or flows eastward across the Tasman Sea (as the

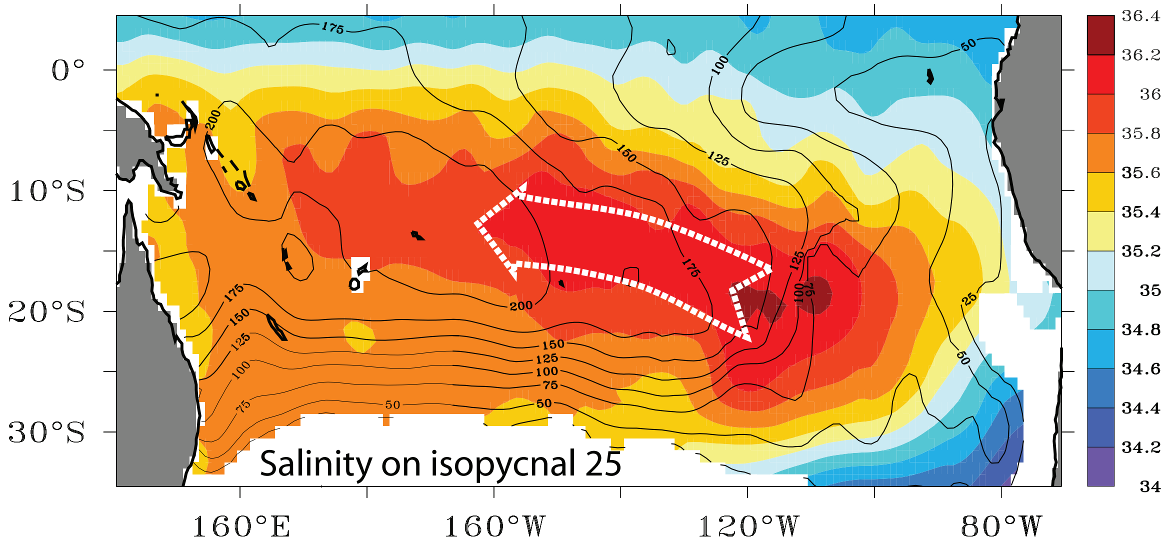

Figure 3: Salinity on isopycnal $\sigma_\theta = 25$ (color) and isopycnal depth (contours) from the Levitus climatology. $\sigma_\theta = 25$ corresponds to the core of the Equatorial Undercurrent (EUC). The white dashed arrow indicates the main propagation direction of high-salinity waters.

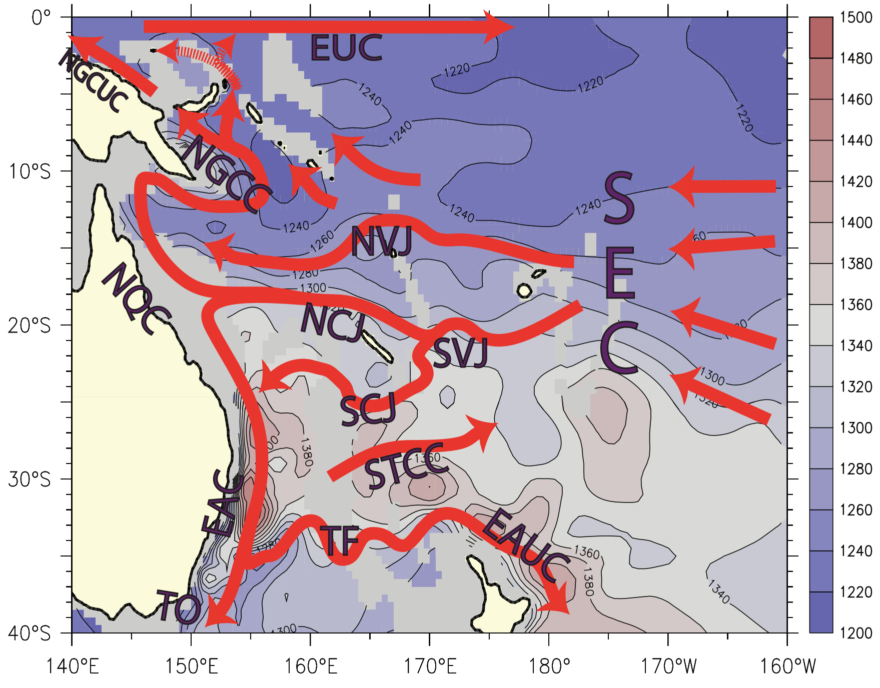

Figure 4: Integral dynamic height between 0 and 2000 m (m^3/s^2) from the CARS data. Overlain are the major current systems of the southwest Pacific. Complex pathways divide the southern part of the South Equatorial Current (SEC) into jets: North/South Vanuatu Jet (NVJ/SVJ), and South/North Caledonian Jet (NCJ/SCJ). Those jets feed the western boundary current system: the North Queensland Current (NQC), New Guinea Coastal (Under) Current (NGCC/NGCUC), and, to the south, the East Australian Current (EAC). The northern fate of the water is the Equatorial Undercurrent (EUC) through the Solomon Straits. The southern fate is the Subtropical Countercurrent (STCC), the Tasman Front (TF) and the East Auckland Current (EAUC), and the Tasman Outflow (TO).

Tasman Front). A portion of the Tasman Front reattaches to the northern coast of New Zealand, forming the East Auckland Current and a sequence of permanent eddies (Ridgway and Dunn, 2003). North of the Tasman Front, a broad, shallow northeastward flow forms, the Subtropical Countercurrent (STCC). A remainder of the EAC transport continues southward along the Australian coast as far as Tasmania and then turns westward into the eastern Indian Ocean as the Tasman Outflow (Tilburg *et al.*, 2001; Speich *et al.*, 2002).

This circulation is highly variable on a wide range of timescales. At high frequencies, Qiu and Chen (2004, Fig. 5) identify four regions of high sea surface height variability (equivalent to thermocline displacements): (1) the South Equatorial Countercurrent, SECC; (2) the EAC; (3) the STCC; and (4) the Antarctic Circumpolar Current (ACC). The observed eddy signals tend to migrate westward as Rossby waves (Maharaj *et al.*, 2005, 2007), accumulating ultimately along the western boundary of the basin, likely impacting the regional circulation changes in the west on intraseasonal timescales, as well as on longer timescales through eddy-mean flow interaction. On seasonal timescales, upper ocean observations suggest an important role of local wind curl and remotely forced Rossby waves between 10°S and 30°S (Holbrook and Bindoff, 1999, 2000a,b). From a numerical model, Kessler and Gourdeau (2007) found that the western subtropical gyre responds as a whole to wind changes, spinning up and down. Increased SEC transport in the second half of the year feeds both the EAC and the NGCC. On interannual timescales, XBT observations suggest a dominant ENSO influence (Ridgway *et al.*, 1993; Holbrook and Bindoff, 1997) with variations in the Solomon Sea leading ENSO. However, the mechanism of these variations remains to be understood. In the North Coral Sea, variations of the main oceanic features, and the island climate, are dominated by ENSO (Delcroix and Hénin, 1989; Delcroix, 1998), but the main mechanisms by which those variations are transmitted to the boundary currents and the equator/Tasman Sea remain unresolved. On longer timescales, important changes are underway: Roemmich *et al.* (2005) found a strengthening of the subtropical gyre over the last decade, related to an upward trend of the Southern Annular Mode (SAM) (Cai *et al.*, 2003), which has been attributed to Antarctic ozone depletion (Cai, 2006).

In the CARS climatology (Ridgway and Dunn, 2003), the mean westward geostrophic transport relative to 2000 m of the jets feeding the Coral Sea totals about 35 Sv between New Caledonia and the southern tip of the Solomon Islands (Fig. 6). At 165°E, the jets have subsurface maxima from 100 m in the north to 250 m in the south, with eastward shear above (Reid, 1997; Qu and Lindstrom, 2002). This structure is a consequence of the general tilt with depth of the subtropical gyre center (defined as the location where isothermals reach their deepest point) whose latitude at 160°W ranges from 14°S (24°C, 160 m) to 32°S (6°C, 800 m) depth (Fig. 6). Eastward shear weakens or reverses the westward SEC above the local depth of the gyre center. In the vertical integral, the gyre center in the western Pacific is near 30°S, but the tilt implies that some of the eastward recirculation of the gyre occurs as shallow flows north of 30°S (Roemmich *et al.*, 2005; Fig. 6). Known as the South Subtropical Countercurrent (STCC, Fig. 6) this eastward surface flow extends to about 15°S, broken into filaments by the islands and jets.

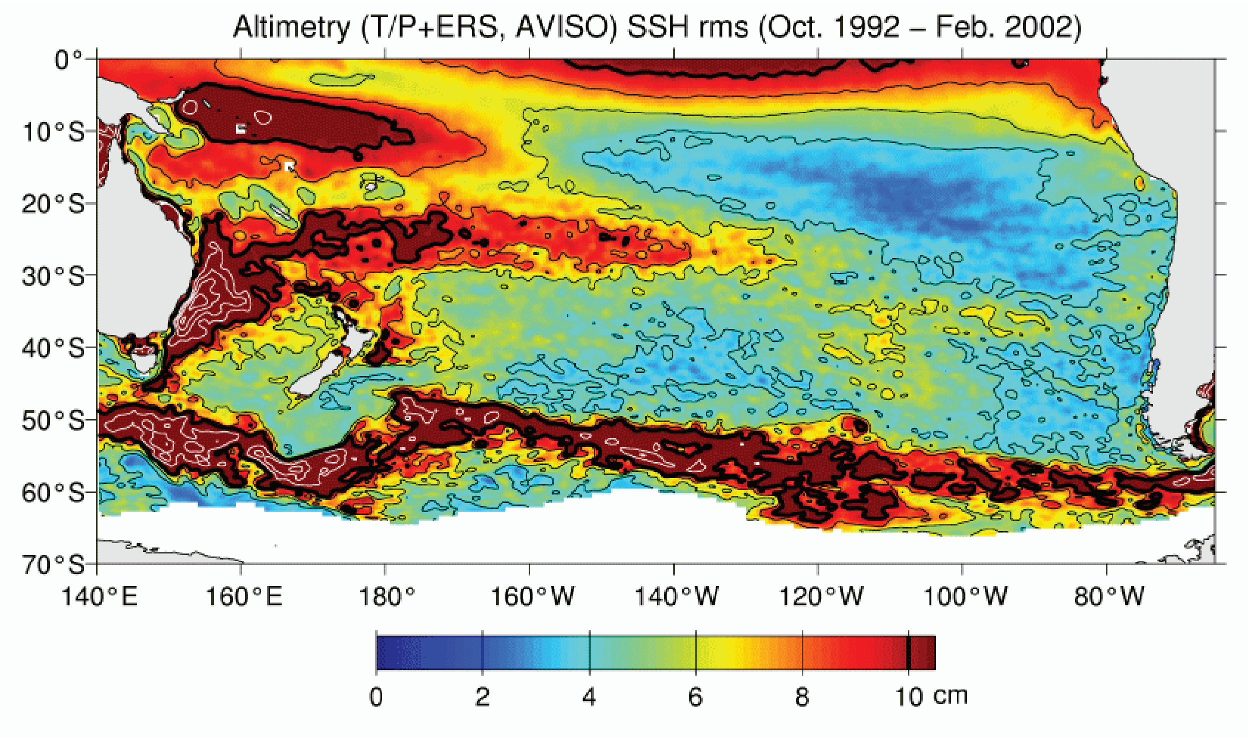

Figure 5: Map of the rms sea surface height variability in the South Pacific Ocean. Based on the combined T/P and ERS1/2 altimetric data from October 1992 to February 2002. Thick solid lines denote the 0.1-m contour. In regions above 0.1 m, thin white lines denote contours at a 0.05-m interval (after Qiu and Chen, 2004).

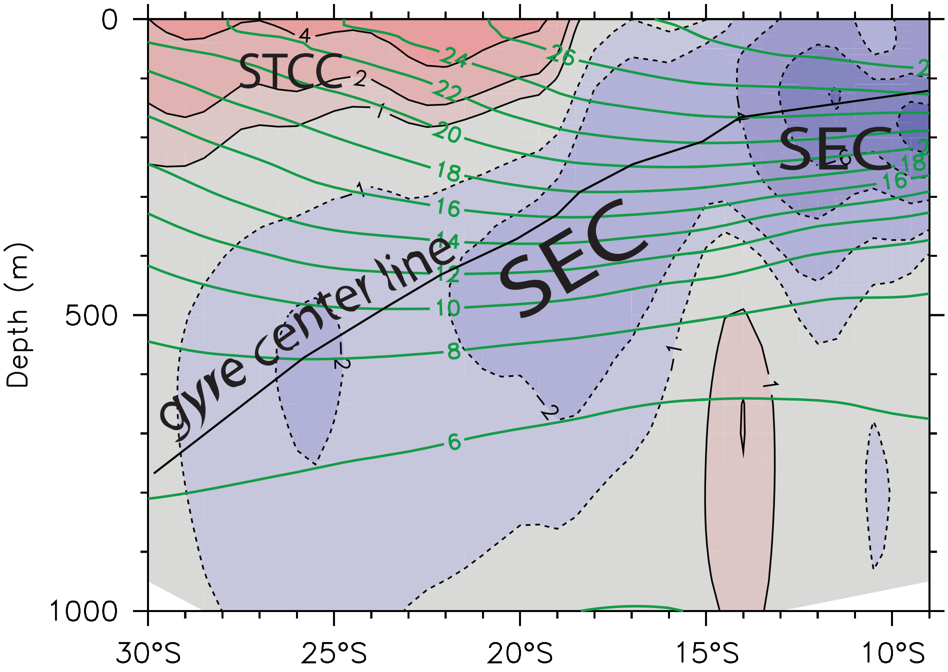

Figure 6: Zonal transport at 160°W from the CARS climatology. The indicated gyre center line marks the bowl of the gyre at each isotherm.

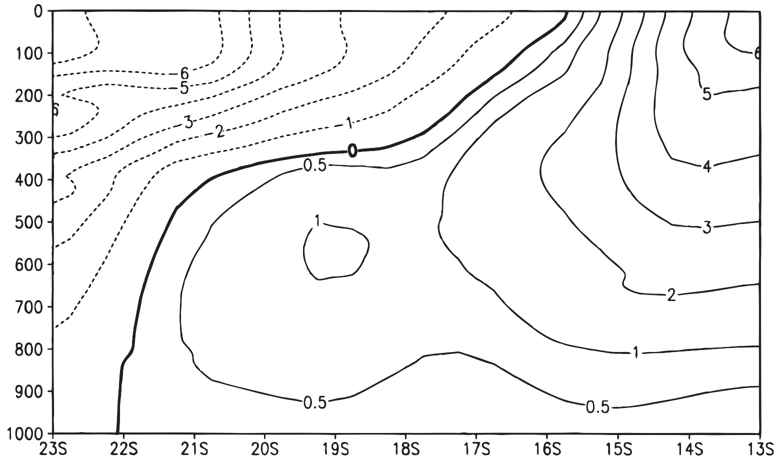

Figure 7: Alongshore velocity (cm/s) averaged within 2° from the coast. Positive values are nortwestward, and the contour of zero velocity indicates the bifurcation of the SEC (after Qu and Lindstom, 2002).

The division of the SEC into jets is principally due to the island arcs (Godfrey's 1989 island rule), though Kessler and Gourdeau (2006) showed that part of the jetlike structure is due to the wind itself. The interaction with islands is assumed to stabilize and enhance jets (Nakano and Hasumi, 2005). The bifurcation of the SEC, roughly at 18°S along the coast of Australia, separates water that flows into the equatorial current system from that which recirculates in the subtropical gyre (Godfrey, 1989; Qu and Lindstrom, 2002; Blanke *et al.*, 2002). The South Pacific bifurcation is little documented compared with its North Pacific equivalent, and our present understanding is essentially a climatological description (Qu and Lindstrom, 2002). According to Sverdrup theory, the bifurcation latitude is determined by the zero zonally integrated wind stress curl line as modified by the Godfrey (1989) "Island Rule" (that shifts its latitude 1°–2° to the south). However, this simple steady-state, depth-averaged theory is not sufficient to describe the strong spatial and temporal variations in the location of the bifurcation indicated by models, nor its vertical structure and dependence on topography. Just as the subtropical gyre circulation varies substantially with depth, so does the latitude of the bifurcation which is found at 15°S near the surface and at 22°S at 800 m (Fig. 7). The vertical structure is complicated by the presence of the Queensland plateau at 17°S, 150°E (Church and Boland, 1983; Fig. 1). The latitude of the bifurcation also varies substantially with time, in relation to boundary current and outflow strengths. At the surface, the seasonal variations from a numerical model range range 15°S to 19°S (Kessler and Gourdeau, 2007), showing that on such timescales bifurcation position variations resulted from a basin-scale response of the boundary currents to regional wind changes.

In most published numerical experiments, the mean position of the bifurcation latitude is too far to the north (e.g., Luo *et al.*, 2005) because of its high sensitivity to key parameters such as the Indonesian Throughflow (Hirst and

Godfrey, 1993) and possibly the flow through the Solomon Straits. The longitudinal distribution of western boundary current transport to the equator is sensitive to the details of the bathymetry of the narrow straits that bound the northern Solomon Sea, and properly representing these features in models is an ongoing subject of research.

3.3.1 Thermocline water inflow summary and issues

The dynamics of the jets and bifurcation need further understanding. We propose here to address the following issues in the SPICE context:

- The jet formation, variability, and characteristics;
- The transit in the Coral Sea and the dynamics of the bifurcation, especially on timescales longer than seasonal;
- Variability sources such as ENSO teleconnections, Rossby waves, forced by basin-wide winds and circulation around Australia;
- The role of the NCJ in the north-south distribution of SEC waters versus the role of the bathymetry in the vicinity of the Queensland Plateau;
- The relationship of the bifurcation latitude and vertical structure with the inflow and the outflow streams of the Coral Sea.

3.4 Tasman Sea

The EAC provides both the western boundary of the South Pacific Gyre and the linking element between the Pacific and Indian Ocean gyres. Climatology shows that the current is accelerated southward along the coastal boundary and then separates into northeastward (STCC), eastward (Tasman Front) and residual southward (Tasman Outflow) components (Fig. 8). Between 18°S and 35°S the southward transport in the EAC ranges from 25 to 37 Sv, the latter value including a significant recirculation feature. A western boundary current forms along the northeastern coast of New Zealand and consists of the East Auckland Current (EAUC), the East Cape Current, and a series of persistent eddies (Fig. 8). Southward transport in the EAUC is highly variable, with a mean of about 9 Sv (Stanton and Sutton, 2003). In the interior of the Tasman Sea, south of the Tasman Front, flow is generally westward and weak (Chiswell and Rickard, 2006). The subtropical front crosses the south edge of the Tasman Sea and is found close to the southern and southwestern coasts of New Zealand before turning east over Chatham Rise (Sutton, 2001; Chiswell, 2005). On the western side of the Tasman Sea, the residual Tasman Outflow turns west south of Tasmania, and joins the South Indian subtropical gyre, thereby playing a significant role in the global thermohaline circulation (Speich *et al.*, 2002).

Surprisingly few modeling studies have focused on the dynamics of the EAC and EAUC. Tilburg *et al.* (2001, 2002) suggested, from a numerical model, that gradients in wind stress curl control the separation locations while non-linear

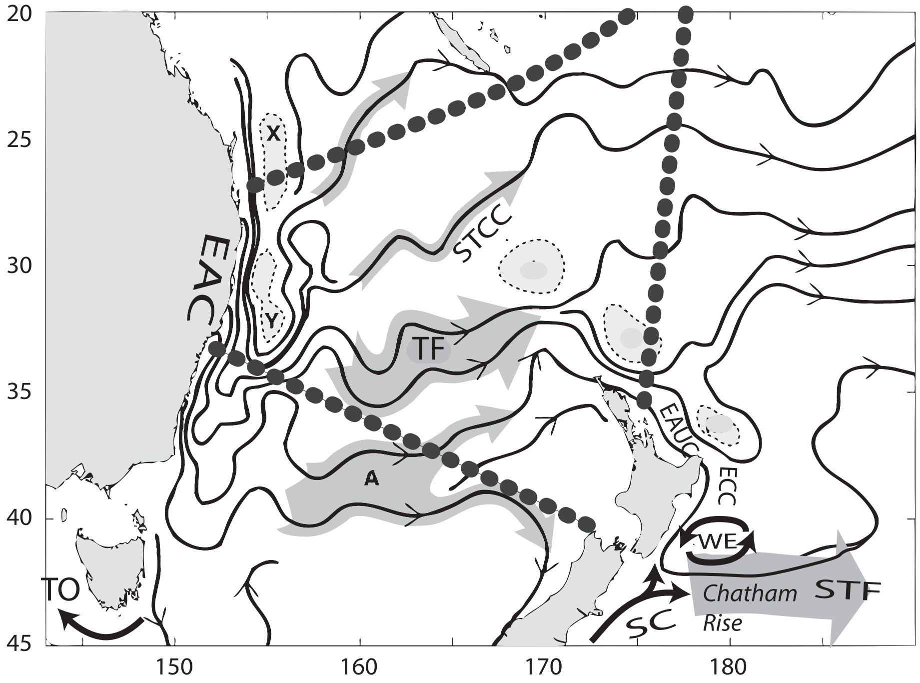

Figure 8: A schematic summary of the EAC and its outflows in the Tasman Sea (adapted from Ridgway and Dunn, 2003). STCC stands for South Tropical Countercurrent, TF for Tasman Front, EAUC for East Auckland Current, ECC for East Cape Current, WE for Wairarapa Eddy, STF for SubTropical Front, and TO for Tasman Outflow. The thick dotted lines delineate the "Tasman box" high resolution XBT lines.

dynamics induce the meanders. The quasi-permanent character of the baroclinic eddies would be associated with a "topographic coupling" between the upper and abyssal ocean. However, in the Tilburg *et al.* model, the EAC variability and the southward outflows were far from realistic. The EAC demonstrates a strong seasonal cycle with maximum alongshore flow in the summer (Ridgway and Godfrey, 1997), and the origin of this seasonality is not well understood. The variability is indeed as large as the mean flow, with a 30 Sv-rms variability for a 22 Sv mean transport at 30°S (Mata *et al.*, 2000). The region of highest surface variability lies above an abyssal cul-de-sac basin adjacent to the western boundary. Much of this variability arises from the production and propagation of mesoscale eddies whose trajectories follow complex patterns that resonate within the deep basin at periods of 100 and 150 days. The origins of the eddies is not clearly understood, those being either generated by strong local instability or controlled by remotely forced Rossby waves from the eastern Pacific (Bowen *et al.*, 2005; Ridgway, 2006).

At the Tasman Sea basin scale, there is considerable interannual variability of the upper ocean temperature field, including ENSO timescale variations (Holbrook and Bindoff, 1997; Holbrook *et al.*, 2005). Such variations are also observed in mode water formation rates (Holbrook and Maharaj, 2007) and in integral heat content (Roemmich *et al.*, 2005). Cai (2006) shows that an observed poleward displacement of the westerly wind maximum has increased the strength of the subtropical gyre and produced an increase in the southward flow of the EAC into the Tasman Sea. The consequence of this shift is an increase in the EAC flow into the Tasman Sea (Cai, 2006), affecting the heat balance. This spin-up of the gyre has been observed on the eastern side of New Zealand (Roemmich *et al.*, 2007), but the present EAC monitoring does not allow us to fully understand the associated changes in the Tasman Sea and their relation with heat balance variability, especially on interannual timescales.

3.4.1 Tasman Sea summary and issues

- The circulation and water mass transports through the Tasman Sea need to be established by determining robust estimates of the mean and seasonal cycle of each inflow and outflow component and identifying the source, strength, property variability, and pathways of the major water masses. The mechanisms associated with features such as current separation and reattachment, location of semi-permanent eddies, retroflection, and the partitioning of the flow needs a comprehensive, quantitative description. The EAC is highly variable and dominated by eddies, but the formation mechanism needs to be understood. Are eddies generated by local forcing or are they entering the region from the east? How do eddies interact with the mean flow and topography? An appropriate theory needs to be developed.
- From a large-scale perspective, the partition of the western boundary flow between the Pacific and Indian Ocean gyres is of major interest. Understanding this partition requires determining the mean and time-varying components of the EAC, the Tasman Front, STCC, and the Tasman Outflow, their variations on interannual to decadal timescales, and the effects of anthropogenic change. How are climate-change-related variations in gyre transport and density structure communicated through the western boundary via the EAC?
- The Tasman Sea heat balance also requires specific studies. As Kelly (2004) shows for the North Pacific, the western, poleward area of the subtropical gyre is one of important transit of heat from the tropics and to the mid-latitude atmosphere. While recent studies in the Tasman Sea have indicated that ocean advection processes are important for the region (Roemmich *et al.*, 2005), the relative contributions of advection and heat storage compared to the surface heat flux are poorly understood, especially on interannual to decadal timescales. We need an improved understanding of the heat flux components, particularly their variability and how heat is partitioned between the atmospheric fluxes and recirculated within the gyre.

3.5 Gulf of Papua and Solomon Sea

The Solomon Sea is both a choke point and the location of intense and interleaved boundary currents that foster mixing of the thermocline waters that feed the EUC and, eventually, the equatorial cold tongue. The partition of these water masses among the three straits determines the thermocline water route to the equator (the longitude at which it joins the EUC), with potential consequences for the equatorial response to changes in the South Pacific winds and circulation.

The pioneering WEPOCS cruises of 1985–1986 (Lindstrom *et al.*, 1987) provided important snapshots of the tropical end of the South Pacific western boundary current system, but observations in the Coral Sea consist of scattered surveys that only sketch the large-scale mean flows. The CARS climatology suggests that SEC waters use two pathways to reach the Solomon and Vitiaz Straits (Fig. 9): one coming from the NCJ, bifurcating against the Australian coast near 18°S to form the North Queensland Current (NQC); another more direct pathway flowing between the northern Vanuatu region (10°S–15°S) and the center of the Solomon Sea. The NQC first accomplishes a 200° cyclonic turn in the Gulf of Papua to reach the eastern tip of the Louisiades Archipelago; it then steers north to cross the Solomon Sea, presumably against the western boundary—implying a U-turn on the Louisiades Archipelago tip (as suggested by available shipboard ADCP data), to reach the three northern outflows which are Vitiaz Strait, St. Georges Channel, and Solomon Strait. Observations suggest northward transports in Vitiaz Strait (8 to 14 Sv) and St. Georges Channel (4 to 7 Sv), with currents of order 1 m/s (Lindstrom *et al.*, 1990) and large interannual variations (Ridgway *et al.*, 1993). North of the straits, about half the thermocline water ($\sigma = 24.5$ to $\sigma = 26.5$) flows in the NGCU and the other half in the New Ireland Coastal Undercurrent (Butt and Lindstrom, 1994). Both currents eventually join the EUC, each one using a different pathway (Butt and Lindstrom, 1994). South of the WEPOCS area (9°S), the only existing full-depth, synoptic meridional section across the Coral and Tasman Seas was the WOCE P11 line along 154°E–156°E from the tip of New Guinea, south to 43°S during June–July 1993 (Sokolov and Rintoul, 2000). Taking geostrophic velocities relative to the bottom, they estimated the transport of the SEC across this section to be 55 Sv, balanced almost equally by flow northward into the Solomon Sea via the NGCC (26 Sv) and southward into the EAC (28 Sv). These single-realization transports are about 30% larger than those indicated by climatology.

Neither the thermocline water inflow nor the outflow through the straits are well documented, nor is the circulation within the Solomon Sea. Long-term observations in the region are sparse, and the Argo float array does not sample this enclosed area well because of the fast flow around the numerous small islands and passages. Climatologies are hampered by the very low data coverage, and most of the present knowledge comes from WEPOCS that covered the northern part of the Solomon Sea and the Straits. Because the straits are narrow (Vitiaz Strait and St. Georges Channel are narrower than 50 km at 500 m depth), published numerical models do not properly resolve flow, constraining the thermocline water to exit the Solomon Sea to the east with unknown conse-

Figure 9: Climatological circulation at 200 m depth (CARS climatology).

quences on the total transport and timing between the bifurcation region and the EUC formation region. The presence of highly energetic boundary currents and their encounter with the broader SEC from the east makes the Solomon Sea a potential region of high mixing and water mass transformation.

3.5.1 Gulf of Papua and Solomon Sea summary and issues

The whole region is very poorly described. In the SPICE context, there is an urgent need to better understand:

- The characteristics and transports of waters transiting through the Solomon Sea. Specifically, the partitioning between the Vitiaz Strait/Solomon Strait/St. Georges Channel transport over seasonal-to-interannual timescales;
- The respective contribution of the western boundary current and of the direct flow from the SEC to the east Solomon Sea, as indicated by climatology (Fig. 9);
- Potentially important details of the circulation, including the permanent eddies suggested by numerical modeling, and possible flows through topographic gaps between islands;

- Local versus remote influences on the western boundary current structure (wind-driven surface currents; basin-scale undercurrents);
- Water mass transformations.

3.6 Downscaling and Environmental Impacts

Downscaling is here defined as the transition from large scales to small scales, including island scales and coastal circulation scales. Southwest Pacific countries are particularly sensitive to climate variability and the oceanic environment. Freshwater resources are a critical issue for Australia and vary substantially in relation with ENSO and decadal variability (Power *et al.*, 1999). The Island Nations of the southwest Pacific Ocean are often isolated, low-lying, and densely populated, and highly dependent on their oceanic environment. As direct consequences of global warming, the projected sea level rise, as well as the predicted changes in the occurrence and magnitude of extreme events, could have devastating social and economic consequences (e.g., `http://www.islandvulnerability.org`). However, global climate models have relatively coarse atmospheric and oceanic grids so that climate changes in small-scale ecosystems are not very well understood. The ocean locally has an important influence on the climate and environment by its ability to transport large amounts of heat, controlling the temperature and air-sea fluxes, tropical cyclone intensity and trajectories, and transports of fish larvae. The following sections give a synopsis of the different aspects of ocean and climate impacts in the southwest Pacific.

3.6.1 SST and climate

A base of knowledge on ocean heat transports and exchanges in the Tasman Sea has been gained by monitoring the inflows and outflows along commercial shipping routes. In the southwest Tasman Sea a warming of 0.015°C yr^{-1} between 1955 and 1988 has been observed in the upper 100 m, representing a contribution to sea level rise, through thermal expansion, of about 0.3 mm yr^{-1} (Holbrook and Bindoff, 1997; Pittock *et al.*, 2001). In the “Tasman Box,” as defined in Fig. 8, the regularly repeated measurements over 12 years suggest that the advective ocean heat transport convergence was driving air-sea fluxes (Roemmich *et al.*, 2007). Sprintall *et al.* (1995) identified those fluctuations as the cause of the 1992 New Zealand coldest winter on record. More recently, heat content in the Tasman Sea rose markedly in 1998 before falling several years later (Willis *et al.*, 2004; Sutton *et al.*, 2005). The increased ocean temperatures may have led to an increase in New Zealand’s land temperatures (Sutton *et al.*, 2005; see also Basher and Thompson, 1996).

Along the Australian east coast between southern Queensland and Tasmania, intense low pressure systems known as the “east coast lows” develop (Holland *et al.*, 1987; Hopkins and Holland, 1997). With destructive potential close to that of tropical cyclones, they can blossom in a day or so, drawing moisture from the warm waters of the Tasman Sea and producing intense, flooding rains, wind damage, storm surges, beach erosion, and marine accidents. The observed Tasman Sea warming (Holbrook and Bindoff, 1997; Cai, 2006), which is expected to continue under greenhouse conditions (Cai *et al.*, 2005), is conducive to the genesis of east coast lows. A detailed assessment of how their intensity and frequency will change in response to the Tasman Sea warming is needed.

To the north, climate in the Pacific Island Nations (PINs) is dominated by the position of the SPCZ, which is itself modulated by ENSO and decadal variability (Salinger *et al.*, 2001; Griffiths *et al.*, 2003). The ocean component may be, as for the Tasman Sea, an important contributor to regional climate (see Section 3.2), the local oceanic conditions influencing cloudiness and winds (e.g., cold upwelling water modifying land-sea temperature gradients). Understanding the present and future climate in PINs will require detailed knowledge of the ocean and atmosphere on small scales, making use of regional, high-resolution climate models embedded in global climate projections.

PINs are among the most vulnerable countries to tropical cyclones (Pelling and Uitto, 2001). Tropical cyclones develop on a regular basis in the southwest Pacific Summer. The upper ocean heat content and background atmospheric conditions are of major influence on their incidence, trajectories, and impacts (Basher and Zheng, 1995; McDonnell and Holbrook, 2004a,b). The destructiveness of tropical cyclones has been increasing over the past 30 years, and there is a debated possibility of continued increase associated with global warming (Emanuel, 2005; Webster *et al.*, 2005). The upper ocean is part of a tropical cyclone system. To predict tropical cyclone trajectories and intensity, not only the SST and upper ocean heat content need to be determined on fine scales, but because there are dynamical and thermodynamical feedbacks between the ocean and the atmosphere, a coupled model approach is also necessary.

3.6.2 Sea level

IPCC reports a projected mean sea level rise up to 5 mm/yr (McCarty *et al.*, 2001, p. 845). This is subject to debate and new estimates modify this value (e.g., Overpeck *et al.*, 2006). At a given location, the effective sea level can undergo much larger variations from ocean circulation changes, either naturally or anthropogenically induced. Besides tides, the main component is the thermosteric one, induced by changes in upper-ocean temperature. Over the past 10 years (1993–2003), Willis *et al.* (2004) found substantial changes in the thermosteric component from shifts in the gyre circulation (Roemmich *et al.*, 2005; Qiu and Chen, 2006), with strong spatial variations which, in the southwest Pacific, imply a sea level fall (from 25°S to 32°S) or rise (north and south of this latitude band) of order 10 cm, a result that is related to the large-scale spin up of the South Pacific Gyre reported by Roemmich *et al.* (2005). Lyman *et al.* (2006) noticed, since 2003, and in our region of interest, a thermosteric sea level fall of about 10 cm between 15°S and 30°S as well as along the EAC path, and warming elsewhere with up to 10 cm rise in the Tasman Sea. Those fluctuations need to be better understood, as they can temporarily obstruct longer-term signals.

On shorter timescales of a few weeks, oceanic eddies dominate the sea level signal. A warm eddy with a radius ranging from 20 km (at 40°S) to 100 km (at 10°S; Chelton *et al.*, 1998) can raise the sea level by order 10 cm (Fig. 5), while a cold eddy would lower it by the same amount. Constructive addition of the large-scale changes, an oceanic eddy with high tide, and a storm surge can have disastrous consequences. Understanding and, if possible, predicting those components may moderate the impact, and requires a detailed knowledge of the ocean circulation at fine scales.

3.6.3 Coral reefs

Coral reefs, which constitute the most important natural resource as well as a natural shield against storm surges in many islands, are under serious threat. The IPCC reports that "the combination of anthropogenic pressure, ocean acidification and increased temperature maxima severely affect the reef's ability to keep pace with sea level rise" (McCarty *et al.*, 2001, 17.2.4). Some reef-building species have narrow temperature tolerances and live near their limits. Major bleaching events occur for temperatures exceeding their average summer maximum by 1°C—a limit that will be overreached for about 60% of the world reefs over the next two decades (McCarty *et al.*, 2001, 17.2.4). The 1997–1998 ENSO event caused 90% bleaching in some regions, providing an estimate of the potential effect of future warming (McCarty *et al.*, 2001, 6.4.5). Coral reef health is studied and monitored within specific programs (e.g., UNESCO-funded Coral Reef Initiative in the South Pacific program, `http://www.crisponline.net`; Great Barrier Reef management at AIMS, `http://www.aims.gov.au`). Those programs will benefit from an improved knowledge of temperature and sea level changes associated with changes in the ocean circulation, from the basin scale to the island scale and on monthly to decadal timescales.

3.6.4 Coastal circulation and biodiversity

The ocean currents along coastlines, barriers, and islands have various impacts on the oceanic ecosystem, besides the special case of coral discussed above. The growth rate of many organisms is sensitive to changes in temperature, while the reproduction cycle often involves ocean transports of fish larvae. The southwest Pacific currents result from complex interactions between large-scale currents and the numerous islands and ridges. Ocean impacts on ecosystems fall in two main categories: island effects and boundary-current variations.

Island effects. Southwest Pacific islands are mostly surrounded by steep ocean bottom slopes that locally modify the large-scale physical and chemical ocean properties, depending on their configuration with respect to the main ocean currents and atmospheric winds. Island effects are disparate (e.g., `http://www.islandoceanography.org`): in Palau (Micronesia), internal tides produce upwelling (Wolanski *et al.*, 2004); while west of Hawaii, an eastward flow is generated against the main current (Qiu and Durland, 2002). In the Marquesas Islands (south central Pacific), the modification of the SEC flow triggers phytoplankton blooms (Martinez and Maamaatuaiahutapu, 2004). In New Caledonia, the shelf is "felt" by the large-scale ocean dynamics like a 750-km line obstacle oriented SE-NW, as are the dominant trade winds. This configuration leads to the formation of boundary currents on the eastern side, and to an omnipresent upwelling on the western side (Fig. 10). This upwelling lowers the average ocean temperature on the west coast by about 2° (Alory *et al.*, 2006), with an unevaluated influence on the lagoon ecosystem and tropical cyclone trajectories. The consequences of island effects and associated biogeochemistry can be substantial, and southwest Pacific islands are very little documented.

Islands, because of their topography and/or albedo, also have a strong local influence on large-scale winds and cloud cover. This combines with the local SST to modulate land-sea temperature contrasts and associated winds. Conversely, modified coastal winds alter the ocean circulation (e.g., the intensity of an upwelling). A full understanding of the ocean-atmosphere variations, therefore, requires a coupled ocean-atmosphere approach.

Boundary-current impacts. Changes in boundary currents such as the EAC and EAUC (Fig. 8) are dynamically different from the island effects discussed above. The increase in temperatures in the EAC system associated with the subtropical gyre spin-up has modified the Tasmanian ecosystem with the appearance of twenty new species (Cai *et al.*, 2005, and references therein). This same increase is suspected to have reduced the food supply for juvenile fish in the Tasman Sea (Bradford-Grieve *et al.*, 2005). The EAC has a major impact on the shelf circulation and ecosystem south of 20°S, with its seasonal cycle producing strong currents (Huyer *et al.*, 1988; Ridgway and Godfrey, 1997). Interaction of the EAC and its eddies with local topography and wind forcing also contribute to upwelling processes (Rochford, 1975; Gibbs *et al.*, 1998; Oke and Middleton, 2001). East of New Zealand, the EAUC variability is spread over a wide range of frequencies (Stanton and Sutton, 2003) and its fluctuations contribute to harmful algal blooms (Sharples, 1997) and may also induce localized upwelling along the coast (Sharples and Greig, 1998). The EAUC is part of the lobster reproduction cycles, with its semi-permanent eddies along the east coast of the North Island retaining the larvae near the coast during their planktonic stage (Chiswell and Booth, 1999). In the North Coral Sea, including the Gulf of Papua and Solomon Sea, a substantial oceanic influence is foreseeable, given the strong boundary currents and their variations (Lindstrom *et al.*, 1990). Nevertheless, this is a region where a basic knowledge of the structure and dynamics of the currents needs to be established, as discussed in Section 3.5.

3.6.5 Environmental impacts summary and issues

The ocean circulation and biogeochemical properties are poorly known near most Pacific Island nations. How does the large-scale ocean circulation interact with regional climate and circulation near the Pacific Islands? How does the ocean circulation and its variations affect ecosystems and populations? How will climate change influence these systems? These three questions are of major concern to all southwest Pacific nations. The coastal waters of eastern Australia and New Zealand are better understood for having been studied for several decades, but many aspects still remain unexplored. Climate change and projected ocean circulation changes will have a strong, potentially dramatic impact on the southwest Pacific countries. Societal and environmental aspects of this impact are addressed within specific programs, and we propose within SPICE to tackle their oceanic and atmospheric components. We identified a number of sensitive issues, including:

1. Downscaling of projected global climate change;
2. Coral reef sustainability: variations of SST and SSH on timescales from weeks (SST, SSH) to decades (SSH);
3. Small-scale oceanic circulation around islands: the effect on ecosystem, local climate, and cyclones;
4. Impact of cyclone surge: background SSH variations over weekly timescales;
5. Large-scale gyre spin-up: effect on New Zealand and southeast Australian climate and ecosystems.

4. Toward a SPICE Implementation Plan

THIS FIRST OF TWO REPORTS formulates the main issues of the southwest Pacific Ocean and its relation to local and remote climate. The second report will propose a coordinated study of the circulation of the southwest Pacific to address these in a collaborative and cost-effective approach based on existing human and technical resources.

SPICE is regionally focused, but designed within the basin-scale ocean-atmosphere system. The large-scale context, including the basin-scale South Pacific circulation and its connection with equatorial processes and climate variability, are addressed within other CLIVAR experiments. The priorities that are specific to SPICE are summarized in Fig. 11.

The following institutions have expressed interest in contributing to specific aspects of SPICE, given funding opportunities:

1. LEGOS-Toulouse (`http://www.legos.obs-mip.fr`, and its New Caledonia branch at IRD (`http://www.ird.nc`), Noumea; numerical modeling and seagoing facilities; 28-m Research Vessel (RV) and possibilities for using French National Fleet RVs (`http://www.ifremer.fr/flotte/navires`); XBT and thermosalinograph network management).

2. NOAA/PMEL (`http://www.pmel.noaa.gov`, Seattle, WA, USA, theoretical, glider data analysis, and XBT expertise).

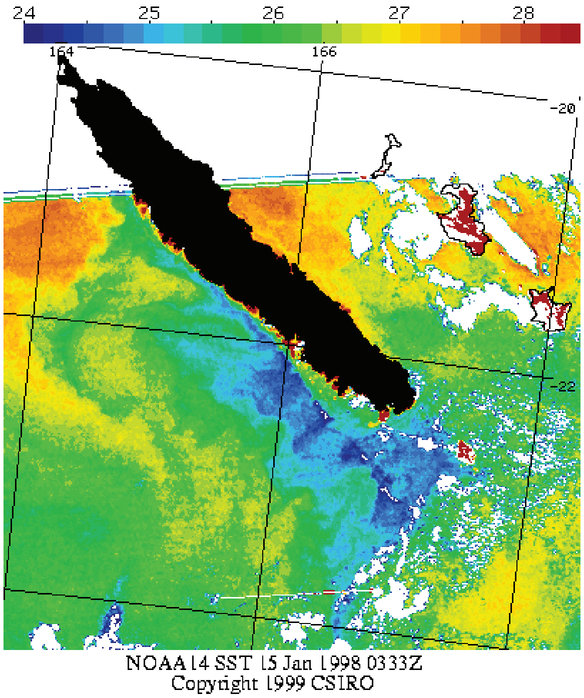

Figure 10: SST image of the southern part of New Caledonia during an upwelling event (A. Vega, P. Marchesiello, J. Lefèvre, and A. Ganachaud, Coastal upwelling modulated by island wake effect off New Caledonia, personal communication, 2007).

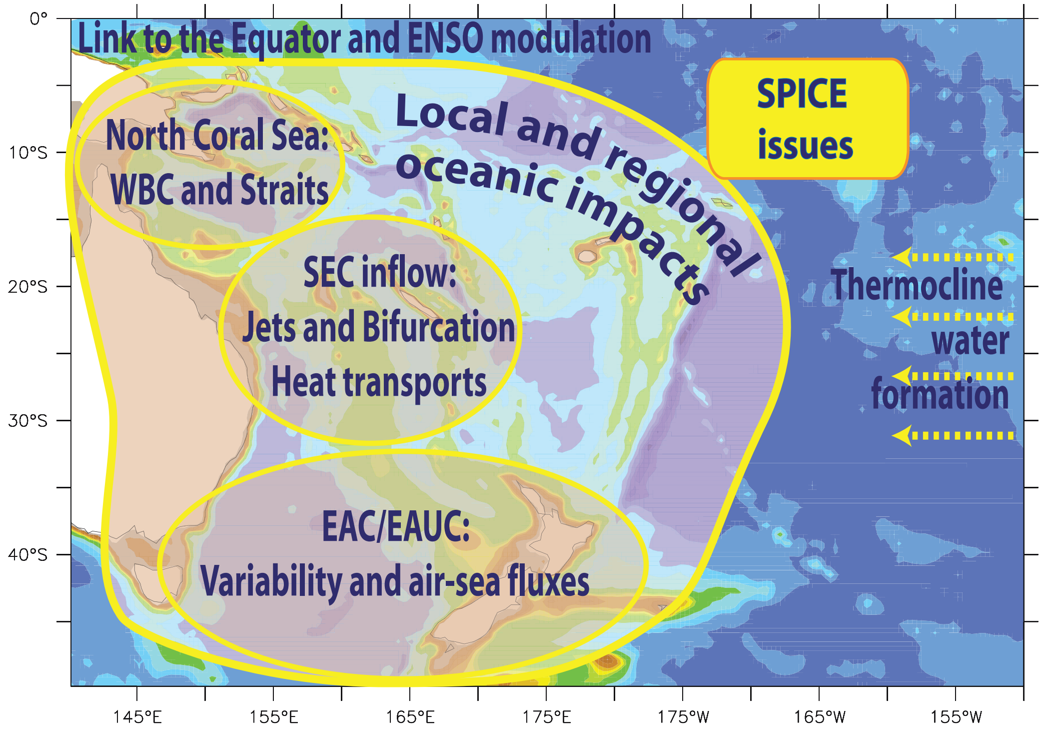

Figure 11: Main issues addressed within SPICE, in addition to the SPCZ caveat. Thermocline water formation and junction to the Equator are addressed within larger-scale programs.

3. CSIRO-Hobart (`http://www.cmar.csiro.au`, Hobart: numerical modeling and seagoing facilities; 66 m RV *Southern Surveyor*; state-of-the-art ocean reanalysis system with a domain that includes the whole of the Indo-Pacific; XBT, and Argo data analysis center).

4. CSIRO-Melbourne (`http://www.cmar.csiro.au`, Melbourne: advanced global climate model; Regional Atmospheric Models).

5. NIWA (`http://www.niwascience.co.nz/ncco`, Wellington, New Zealand: numerical modeling and sea going facilities; 70 m RV *Tangaroa*, 28 m RV *Kaharoa*; XBT and Argo support; regional modeling using ROMS, MOMA, Gerris, RiCom).

6. University of Hawaii (`http://www.soest.hawaii.edu/oceanography/`, Honolulu: analysis and interpretations of satellite altimetrically derived sea surface height data in conjunction with in situ observational data and numerical model output).

7. SIO (`http://sio.ucsd.edu`, San Diego, CA: expertise in using floats, gliders, hydrography, moorings, and data assimilating models).

8. Macquarie University (`http://www.mq.edu.au/`, Sydney, Australia: analysis and interpretation of satellite altimeter sea surface height data; in situ ocean data analysis; reduced-gravity ocean modeling and continuously stratified (multi-mode) ocean modeling; climate analysis and climate modeling).

9. Bureau of Meteorology (`http://www.bom.gov.au/bmrc/ocean/index.htm`, Melbourne, Australia: Ocean and marine forecasting, research, and operational data assimilation, seasonal prediction, real-time networks (weather stations, including buoys, VOS SST observations, tide gauges)).

10. SOPAC (`www.sopac.org.fj`), the South Pacific Applied Geoscience Commission, is an inter-governmental regional organization "dedicated to providing services to promote sustainable development in the countries it serves." Research, development, and management of the oceanic environment is one of SOPAC's key programs. A component of this program is the Pacific Islands Global Ocean Observing System, PI-GOOS (`http://www.sopac.org.fj/tiki/tiki-index.php?page= PIGOOS`), aimed at developing capacity in operational oceanography in the Pacific region.

5. Programmatic Context

5.1 CLIVAR

CLIVAR (`http://www.clivar.org`) is the World Climate Research Programme (`http://wrcp.wmo.int`) project that addresses climate variability and predictability. CLIVAR is focused on the role of ocean-atmosphere interactions in climate. It aims at developing our understanding of the physical processes responsible for climate modulation on seasonal, interannual, decadal, and centennial timescales. This objective requires monitoring ongoing changes in our climate system. The work points toward an extension of the range and accuracy of predictions to provide useful information so that governments can make informed decisions about societal impacts.

SPICE has been built to contribute to the CLIVAR objectives, with a large-scale approach targeted toward decadal climate prediction through a better understanding and modeling of the equatorial and southwest Pacific Ocean circulation, and an embedded smaller-scale objective targeted toward coastal and island climate processes and prediction. There is a particular focus here on western boundary currents, which are recognized as a key issue by CLIVAR because they accomplish a large and rapid meridional transport of mass and heat. Though the southwest Pacific boundary currents are less studied than in other parts of the world, they are of special interest for climate because they provide an efficient communication from the subtropical gyre to the equator.

In SPICE we take the first steps toward implementing the observations necessary to interpret the southwest Pacific circulation and its effects on local and remote climate, and to build a regional observing system that will allow ongoing monitoring of its variability. This effort follows the philosophy of the US-CLIVAR Pacific Basin Extended Climate Study (PBECS; Kessler *et al.*, 2001; Davis *et al.*, 2000; Lukas *et al.*, 1998) which was an early effort to frame the problem of observing and interpreting the climate of the Pacific basin. The PBECS view was that the basin-scale observing network (Argo, satellite observations, TAO moorings, ship-of-opportunity cruises) could adequately resolve the broad interior flows, but that special attention would be needed to sample the boundaries (including the surface layer and the equatorial current system and its intimate interaction with the atmosphere).

5.2 Regional Programs

- The PACific Source Water Investigation (PACSWIN) is currently being designed as a follow-up of the International Nusantara Stratification and Transport (INSTANT) program (`http://www.esr.org/instant_index.`

`html`) on the Indonesian Throughflow. The PACSWIN plan is to extend the INSTANT region of interest, including the Coral Sea, to better resolve origins and fates of water masses crossing the Indonesian Seas (P.I.J. You, University of Sydney, Institute of Marine Science).

SPICE will establish the link between large-scale ocean currents and coastal/island circulation in collaboration with the following programs that concern the Pacific Island Countries:

- SOPAC, see Section 4.
- PRIDE (`http://apdrc.soest.hawaii.edu/PRIDE`), Pacific Region Integrated Data Enterprise; aims at providing regional needs for ocean, climate, and ecosystem information to protect lives and property, support economic development, and enhance the resilience of Pacific Island communities in the face of changing environmental conditions.
- SPREP (`http://www.sprep.org`), Pacific Regional Environment Programme; focus on sustainable planning, protection, management, and use of Pacific Island environment.
- START-Oceania (`http://www.usp.ac.fj/start`), capacity building in the domain of impacts of climate change research.

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8. Glossary of Acronyms

AAIW	Antarctic Intermediate Water
ACC	Antarctic Circumpolar Current
ADCP	Acoustic Doppler Current Profiler
AIMS	Australian Institute of Marine Science
ANR	Agence Nationale de la Recherche (Funding agency, France)
CARS	CSIRO Atlas of Regional Seas
CLIVAR	Climate Variability and Predictability
CMAR	CSIRO Marine and Atmospheric Research
COADS	Comprehensive Ocean-Atmosphere Data Set
CSIRO	Commonwealth Scientific and Industrial Research Organization
EAC	East Australia Current
EAUC	East Auckland Current
ECC	East Cape Current
ENSO	El Niño-Southern Oscillation
ERS1/2	European Remote-Sensing Satellites1/2
ERSST	Extended Reconstructed Sea Surface Temperature
EUC	Equatorial Undercurrent
GBRUC	Great Barrier Reef Undercurrent
IMET	Improved Meteorology system for marine meteorological observations
INSTANT	International Nusantara Stratification and Transport
IPCC	Intergovernmental Panel on Climate Change
IPRC	International Pacific Research Center
IRD	Institut de Recherche pour le Développement
ITCZ	Intertropical Convergence Zone
LEFE	Les Enveloppes Fluides de l'Environement (Funding agency, France)
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
MOMA	Modular Ocean Model—Array processor version
NCJ	North Caledonian Jet
NGCC	New Guinea Coastal Current
NGCUC	New Guinea Coastal Under Current
NIWA	National Institute of Water and Atmospheric Research
NQC	North Queensland Current
NOAA	National Oceanic and Atmospheric Administration

NTIS	National Technical Information Service
NVJ	North Vanuatu Jet
OAR	Oceanic and Atmospheric Research [NOAA]
PACSWIN	PACific Source Water Investigation
PBECS	Pacific Basin Extended Climate Study
PI-GOOS	Pacific Islands Global Ocean Observing System
PINs	Pacific Island Nations
PMEL	Pacific Marine Environmental Laboratory [NOAA]
PRIDE	Pacific Region Integrated Data Enterprise
PSU	practical salinity units
REMO	Max-Planck Institut für Meteorologie Regional climate Model
RiCom	River, Coast and ocean model
ROMS	Regional Ocean Modeling System
RV	Research Vessel
SAM	South Annular Mode
SAMW	SubAntarctic Mode Water
SCJ	South Caledonian Jet
SEC	South Equatorial Current
SECC	South Equatorial Countercurrent
SIO	Scripps Institution of Oceanography
SLW	Subtropical Lower Water
SOEST	School of Ocean and Earth Science and Technology
SOPAC	South Pacific Applied Geoscience Commission
SPCZ	South Pacific Convergence Zone
SPESMW	South Pacific Eastern Subtropical Mode Water
SPICE	Southwest Pacific Ocean Circulation and Climate Experiment
SPMW	South Pacific Mode Water
SPREP	Pacific Regional Environment Programme
SSH	Sea Surface Height
SST	Sea Surface Temperature
START	Global Change System for Analysis, Research, and Training
STCC	Subtropical Countercurrent
STF	Subtropical Front
STMW	Subtropical Mode Water
SVJ	South Vanuatu Jet
T/P	TOPEX/Poseidon
TAO	Tropical Atmosphere Ocean
TF	Tasman Front
TO	Tasman Outflow
UNESCO	United Nations Educational, Scientific and Cultural Organization
USP	University of South Pacific
VOS	Voluntary Observing Ship

WBC	Western Boundary Current
WE	Wairarapa Eddy
WEPOCS	Western Equatorial Pacific Ocean Circulation Study
WOCE	World Ocean Circulation Experiment
XBT	eXpandable Bathy Thermograph
ZONECO	Zone Economique Exclusive de Nouvelle Calédonie (Applied oceanic and shore research, New Caledonia)