The Southwest Pacific Ocean Circulation and Climate Experiment (SPICE): a new CLIVAR programme

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Abstract

The Southwest Pacific is a region of complex oceanic and atmospheric circulation, with strong currents interacting with islands and the erratic behaviour of the South Pacific Convergence Zone (SPCZ), whose position and intensity modulate the wind field, heat flux and precipitation. To understand the circulation and its influence on local and remote climate, ocean and atmosphere scientists from Australia, France, New Zealand, the United States and Pacific Island countries initiated an international research project, the Southwest Pacific Ocean Circulation and Climate Experiment (SPICE). The project, endorsed by CLIVAR (http://www.clivar.org/organization/pacific/pacific_SPICE.php), reflects a strong sense that substantial progress will be made through collaboration among South Pacific national research groups, coordinated with broader South Pacific projects including VOCALS (VAMOS Ocean-Cloud-Atmosphere-Land Study; VAMOS = Variability of the American Monsoon Systems), NPOCE (Northwestern Pacific Ocean Circulation Experiment), and the developing PACSWIN (PACific Source Water Investigation). SPICE is purposely oriented towards long term monitoring to serve climate prediction, and to foster projects and collaborations with other fields such as ocean and weather forecasts, coral reef and ecosystem monitoring, and climate-related diseases. Here we present the outline of a regionally-coordinated experiment to model, measure, and monitor the ocean circulation and the SPCZ, to validate and improve numerical models, and to integrate with ocean/atmosphere data assimilating systems. Additionally SPICE will actively seek new collaborations with other research groups studying South Pacific climate variability.

1. Introduction

South Pacific thermocline waters are transported in the westward-flowing South Equatorial Current from the subtropical gyre center towards the southwest Pacific Ocean - a major circulation pathway that redistributes water from the subtropics to the equator and to the Southern Ocean (Figure 1). The transit of these thermocline waters in the Coral Sea is potentially important to tropical climate prediction because changes in either the temperature or the amount of water arriving at the equator can modulate the western warm pool and equatorial undercurrent. This has potential influence on the El Niño-Southern Oscillation (ENSO) cycle and subsequent basin-scale climate feedbacks as well as the Indonesian throughflow and the Indian Ocean. The southern pathway of thermocline waters is, comparably, of major influence on Australia and New Zealand's climate as its seasonal and inter-annual evolution influences air-sea heat flux and atmospheric conditions. Substantial changes of this circulation have been observed in recent years: the subtropical gyre has been spinning up with possible consequences for ENSO and for the East Australian Current (EAC) whose influence has moved south, dramatically affecting the climate and biodiversity of Tasmania.

Few observations are available to diagnose the processes and water pathways through the complicated geography of the numerous islands and ridges of the southwest Pacific (Figure 2). The South Pacific Convergence Zone (SPCZ) is poorly documented; access to many areas is difficult for conventional research platforms, and the large temporal variability and strong narrow currents in a region of complex bathymetry pose serious challenges to an observing system. Numerical model results are sensitive to parameter choices and forcing, and the value of such simulations remains uncertain because of the lack of in situ data for validation. The existing observational network (Argo, eXpandable Bathy Thermograph (XBT) sampling from voluntary observing ships, and satellite sea surface temperature, wind and sea surface height) is starting to provide a large-scale picture, but the complex circulation and strong western boundary currents require a thorough, dedicated, study.

Exploratory cruises in the Coral Sea occurred mainly from the mid 1950's to the mid 1980's (except for an intensive survey during World War II), however with the increased focus of research on El Niño associated with the TOGA programme, most of the attention (and funding, for almost 20 years) was devoted to the equatorial processes. In 2005, a small workshop was organized in the Queensland Tablelands, Australia, to review the current knowledge in

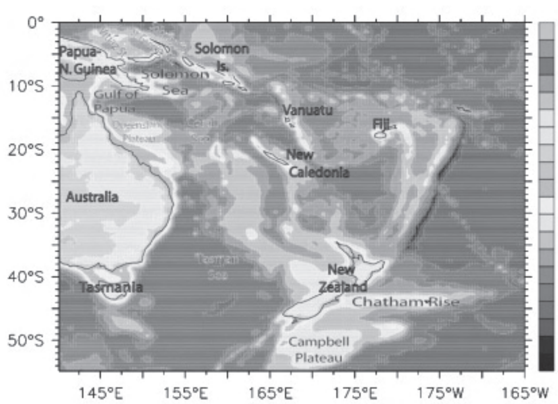

Figure 1: Geography and topography of the southwest Pacific. The incoming, westward flowing South Equatorial Current encounters large topographic obstacles before reaching the western boundaries.

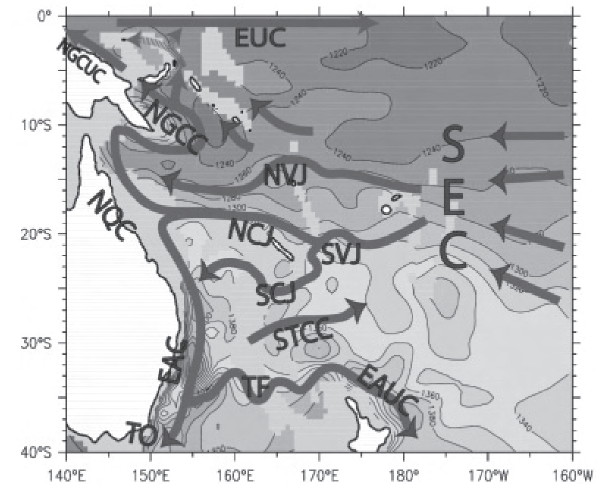

Figure 2: Integral dynamic height between 0 and 2000m (m^3/s^2) from the CSIRO Atlas of Regional Seas (CARS) data. Overlain are the major current systems of the Southwest Pacific. Complex pathways divide the southern part of the South Equatorial Current (SEC) into jets : North/South Vanuatu Jet (NVJ/SVJ), and South/North Caledonian Jet (NCJ/SCJ). Those jets feed the western boundary current system: the North Queensland Current (NQC) and 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) to the south.

the area and envisage further exploration. Twenty-seven scientists met for 3 days and laid down the foundations of an international, regionally-coordinated experiment, the Southwest Pacific Ocean Circulation and Climate Experiment (SPICE).

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. To achieve this, four specific efforts are proposed:

1. Analysis of the role of the southwest Pacific 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. Use of remotely and locally sampled meteorological fields, and ocean model analysis, to determine 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.

2. Organization

SPICE is regionally focused, but integrates basin-scale studies of the ocean-atmosphere system. The large-scale context including the basin-scale South Pacific circulation and its connection with equatorial processes and climate variability is addressed within CLIVAR and related projects. SPICE is organized in the following work areas (Figure 3):

- South Pacific Convergence Zone: formation, variability, air-sea interactions;
- South Equatorial Current inflow: jet formation, bifurcation against Australia, western boundary currents;
- Tasman Sea circulation: EAC/EAUC variability; heat balance and air-sea fluxes in the Tasman Sea;
- Gulf of Papua and Solomon Sea circulation: western boundary current and interior pathways, flow through the Solomon Straits;
- Downscaling and environmental impacts of climate and oceanic environment changes: cyclones; sea level rise; coral reef sustainability; coastal ecosystems.

The proposed approach is collaborative and cost-effective, based on existing manpower and technical resources. It will rely heavily on ocean and atmosphere modeling, combined with process studies to acquire basic knowledge in the north Coral Sea region; but also with monitoring where necessary and regional adaptation of global observing programs.

3. Modeling strategy

The SPICE program is stimulated by the need to improve climate prediction at both large and regional scales to allow island communities to benefit from climate research. Model experiments will provide the necessary linkage between large scale questions (e.g. how the subtropical gyre waters get to the Equator) and regional issues (e.g. what are the detailed oceanic pathways and impacts in the SW Pacific) through downscaling. Use of a variety of numerical models (Figure 4), validated against observations, will help to improve our understanding of the dynamical aspects that cannot be adequately observed and to identify the observable features thereby providing guidance to the design of the in-situ observing program. Model types range from global, coupled systems to local, high-resolution nested models (Figure 4, middle). Three existing operational oceanography projects are important for the Southwest Pacific (e.g., Bluelink, MERCATOR and SODA). The former two are assimilating systems that offer a nowcast and forecast estimate of the

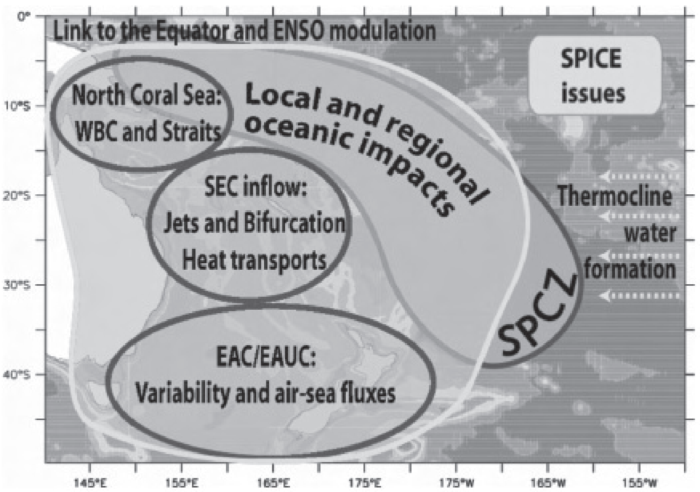

Figure 3: Main issues addressed within SPICE. The programme is regionally focused, but integrates larger scale programmes within CLIVAR (e.g. ENSO modulation). It is organized in four geographical areas with specific approaches, and favors interactions with regional studies specific to the different islands and coasts.

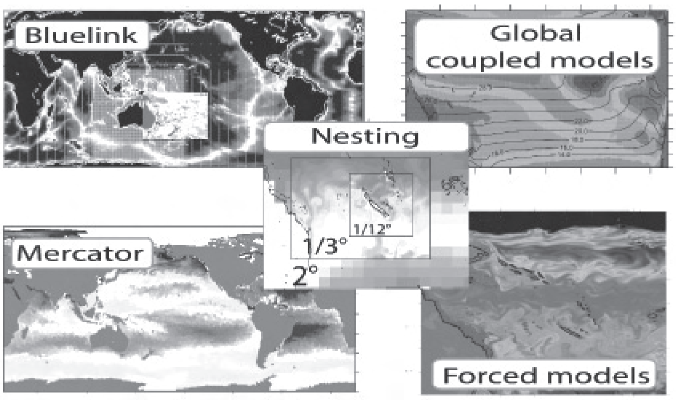

Figure 4: The modeling approach will rely on a range of models from coarse climate models to high-resolution, nested regional models. Upper left : the Bluelink (www.marine.csiro.au/bluelink) operational ocean model grid and southwest Pacific subdomain. Lower left: the Mercator French operational model (www.mercator-ocean.fr). Middle: nesting of the Noumea ROMS model from the 2° MERCATOR grid to 1/12° grid around New Caledonia (www.ird.nc/UR65/ROMS). Upper right: an IPCC-IR4 global coupled model. Lower right: the OFES high resolution ocean model.

true state of oceanic currents, temperatures and salinities which are supported operationally providing information throughout the SPICE experiment.

Modeling experiments will have to address a number of issues, such as understanding the oceanic and atmospheric teleconnections between the southwest Pacific and the basin-scale dynamics; the SPCZ formation process; key aspects of the thermocline water pathways (jet formation; bifurcation against the Australian coast; flow through the Solomon Sea; route to the Equator; variability along the East Australian Current and the Tasman Outflow); local ocean-atmosphere variability and impacts on the oceanic environment over the area.

Numerical simulations will be designed in order to improve the realism of the Southwest Pacific area in large-scale models. In particular the models will be used to improve our understanding of Southwest Pacific variability and its relation with basin-scale climate; to help design optimal observations; to simulate the small spatial scale features associated with boundary currents, islands and straits; to understand ocean-atmosphere interactions at island and coastal scales and to adapt, or downscale, global climate projections into results that are useful to island communities. Models will also be developed based on low-cost infrastructure so that participating countries can create or use their own modeling capacities.

The backbone of the SPICE modeling activities is the availability of regional expertise and computing facilities in four research centers (Melbourne, Wellington, Noumea and Hawaii), as well as SPCZ-modeling expertise at the University of California, Los Angeles. We propose to address the aforementioned issues using a variety of models and interlaced approaches. Six types of model will be used: 1) basin-scale general circulation models (GCMs) with a typical horizontal resolution ranging from 20 km - 200 km; 2) coupled GCMs; ocean data-assimilating: 3) ocean re-analyses and 4) operational GCMs; 5) regional (nested) models with a typical resolution of 2 km - 20 km and 6) process, or simplified, models. This approach will not only help to test and improve the IPCC projections in the Southwest Pacific, but will also help responding to a high demand for climate change forecasts from Pacific Island Countries which are the most vulnerable to changes in oceanic and atmospheric conditions. Overall, regional models are expected to help identify large scale model deficiencies and prompt their correction. Such improvement may be implemented through "upscaling", by embedding a regional model in a large scale model during integration or by improved parameterizations.

4. In situ observations

Analogous to high resolution models nested in global circulation models, the detailed regional SPICE measurements will complement large-scale observational programs, focusing on local aspects which are either un-resolved or under-resolved. Satellite ocean observations are mostly inadequate to observe the small scale variability and/or subsurface flows of interest. The Argo array provides temperature and salinity profiles over the top 2 km of the water column; however the Coral and Tasman seas are still little sampled by Argo. As a result, most of our knowledge of the hydrography and circulation in the Coral Sea comes from numerical models and climatologies based on sparse data. The observational database in the Tasman Sea is larger, however the high regional variability calls for targeted process experiments and monitoring. While investigations and further analysis of large-scale climatologies will be necessary, a substantial observational effort is needed in the Coral, Tasman and Solomon seas. A major SPCZ-focused field programme has also been envisaged during the design of SPICE, but given the present state of knowledge, it was decided to give priority to numerical model and analytical approaches complemented with analysis of remote sensing data and reanalysis products, without precluding a future SPCZ field experiment (AGU session - OS41B-0537 - SPICE: South PacIfic Circulation and Climate Experiment; December 2007).

The goal of the SPICE field program is to measure and monitor key, climate-relevant quantities. The proposed observations will include large-scale surveys of the Coral, Solomon and Tasman Sea inflows and outflows with special attention to the western boundary currents. A main focus of the observational program will be to test and apply large-scale, in-situ, and remote monitoring of key climate quantities, of which air-sea fluxes, SEC inflow, Solomon and Tasman Sea inflows and outflows are deemed critical. One of the major aims of the project is to close the regional mass, heat and freshwater budgets and to address local site-specific variations.

The field programme includes a variety of observations utilizing the most recent technological developments (e.g. use of gliders) and long-established XBT lines (Figure 5). The observational strategy was designed to address the issues of air-sea fluxes; SEC inflow/mass and heat transports entering the Coral Sea; jet characteristics; transports entering and exiting the Solomon Sea and a basic description of the circulation within the Solomon Sea; Tasman Sea inflows and outflows; and East Australian Current variability. These measurements will benefit studies of regional features and ocean environmental impacts (coastal circulation; water properties and coral reef health), and in some cases stimulate specific, simultaneous local observations based on common platforms.

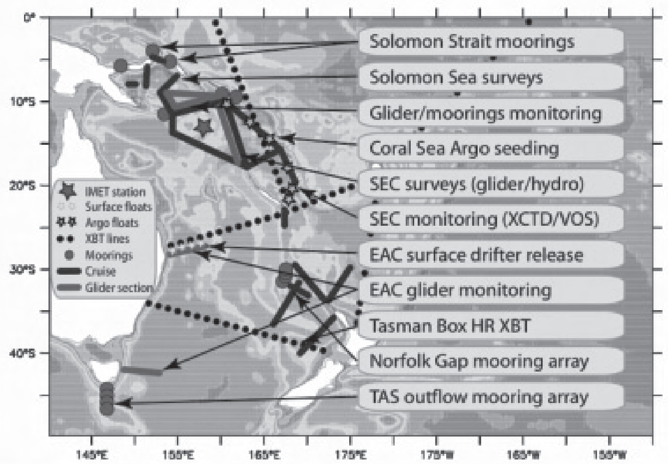

Figure 5: SPICE field experiment. Simultaneous measurements in different parts of the basin will allow analysis and monitoring of the mass/heat budget within the area. Exploratory surveys, some of which have already taken place, are followed by experimental monitoring, with a possible long term monitoring outcome. The different components are either planned, submitted, funded or completed. Fieldwork activities, excluding long term monitoring, are expected to last until 2012.

Although many aspects of the observational plan will be determined by targeted, regional projects, the broad outline is clear. It will rely on extensive regional collaboration, on the existing infrastructures and teams, and on regionally-focused adaptation of global observation programs. An important aspect will be the requirement for quasi-simultaneous observations in different parts of the basin. Exploratory surveys will be needed to identify key quantities that require monitoring (e.g. influx into the Solomon Sea). Experimental monitoring will be followed with the design of a long-term monitoring system at key locations. This in-situ observation plan will be completed with remote observations (e.g. sea surface temperature, height and salinity), calibrated and adapted regionally.

5. Data management and policy

Through the CLIVAR data policy (http://www.clivar.org/data/data_policy.php), measurements and model outputs pertaining to SPICE should be made publicly available through appropriate data servers. Relevant training will help building capacity in local communities to use southwest Pacific data and forecasts in pertinent response to societal demand.

6. Applications and training

The bridge between the large scale ocean and atmosphere circulation and their local impacts on environment and eventually societal sustainability will be established in collaboration with regional agencies and universities. On basin and global scales, the ultimate purpose of SPICE and follow-up projects is to improve climate prediction. Such improvement will be of direct benefit to Pacific Island Countries (PICs) whose climate is strongly influenced by ENSO. In addition, a major SPICE objective is to improve knowledge and prediction of the ocean conditions in the southwest Pacific, over a wide range of time scales and from basin to island space scales. Tools will be developed (e.g. database access; model simulation diagnostics), as well as self-contained projects that are specific to a location or process. This development, along with easy public data access, should align with appropriate training to serve local interests and respond to the demand from Pacific Island countries to improve their appreciation of vulnerability to changes in the oceanic and atmospheric environment as well as their capacity to respond to such changes.

SPICE in collaboration with the Pacific Islands Global Ocean Observing System (PI-GOOS, hosted by SOPAC, the Pacific Islands Applied Geoscience Commission, based in Suva, Fiji), will endorse training initiatives. Training can cover a wide range of topics, some of which are already mentioned in this document (e.g. sea level rise; oceanic conditions and coral reef health; tropical cyclones). Specific research or application projects are also encouraged with the potential for classes on database usage and the opportunity to develop regional expertise on operational oceanography

7. SPICE legacy

The efficacy and reliability of the proposed measurements on climate prediction will be assessed through the modeling efforts. This will pinpoint to the key quantities that may lead to the development of a long term South Pacific monitoring system and to deliver data for initialization and calibration of climate forecasts. Regionally, SPICE will lead to improved understanding of the ocean circulation and ocean forecasts, with direct applications to Pacific Island countries.

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