CLIMATE CHANGE AND BIODIVERSITY IN MELANESIA

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Stephen J. Leisz and J. Burke Burnett

Regional Climate Change Projections for the Southwestern Pacific with a focus on Melanesia

Kelvin Richards and Axel Timmermann
International Pacific Research Center, School of Ocean and Earth Science and Technology, University of Hawaii

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Recent climate change in Melanesia

As thoroughly documented in the 4th Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC 2007), the average global mean surface air temperature has risen by 0.74°C since 1906. There is unequivocal evidence that a large fraction of this warming can be attributed to anthropogenic greenhouse gas emissions. Areas that experienced the largest warming throughout the last century include northern North America, eastern South America and Siberia. The general 20th century surface air temperature warming in the South Pacific region amounts to about 0.05°C/decade, which is slightly less than the global mean value. This warming trend has increased to about 0.3°C/decade during the last 30 years. This surface warming is associated with an increase in sea surface temperatures, upper ocean heat content (Barnett et al. 2001) and sea level height (Figure 1). In particular, in the Melanesian region, a decadal sea level trend of up to 8-10 mm/year has been observed on the east coast of Papua New Guinea (PNG). This rapid sea level rise can be attributed to the slow oceanic response to decadal trends in the tropical Pacific wind forcing. More research has to be conducted to identify the robust regional patterns of future sea level rise in the equatorial and Southwestern Pacific.

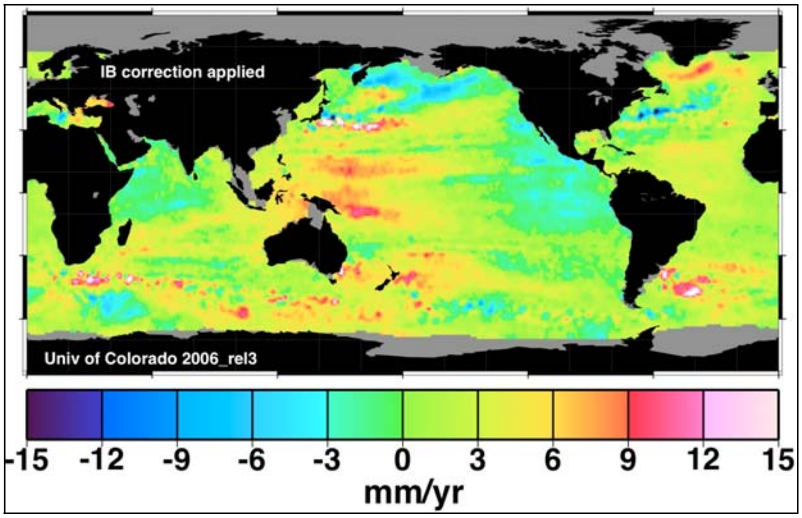

Figure 1**.** Global map of the rate of change sea level height as measured by satellites over the 10 years. The rate of increase in the Melanesia region, at 8-10 mm/year is approximately 3 times the global average.

Climate model projections

Many of the present-day state-of-the art Atmosphere-Ocean General Circulation Models (AOGCM) exhibit severe temperature biases in the Pacific. Most commonly one observes a cold bias in the eastern to central equatorial Pacific and a warm bias in the southeastern tropical Pacific (Figure 2). This bias in the southeastern Pacific is partly due to an under-representation of the stratus cloud deck and partly due to an underestimation of oceanic heat export from this region. This warm bias results in a misrepresentation of the entire southern trade wind regime and presumably also affects the simulated position of the South Pacific Convergence Zone (SPCZ) (Figure 3). Following the migration of warm surface waters and wind-convergence, the SPCZ is a rain band that extends from PNG down to the central South Pacific and merges with the South Pacific storm track. Its seasonal migration is mainly responsible for the seasonal variations of rainfall in large parts of Melanesia.. Many of the climate models used as part of the IPCC AR4, simulate a SPCZ that is positioned either too far to the east (Figure 3) or exhibits a zonally uniform structure. Resolving these modeling biases is essential for improving our projections for the Melanesian region. A recent NOAA-funded program will support modeling studies that will help to reduce these biases.

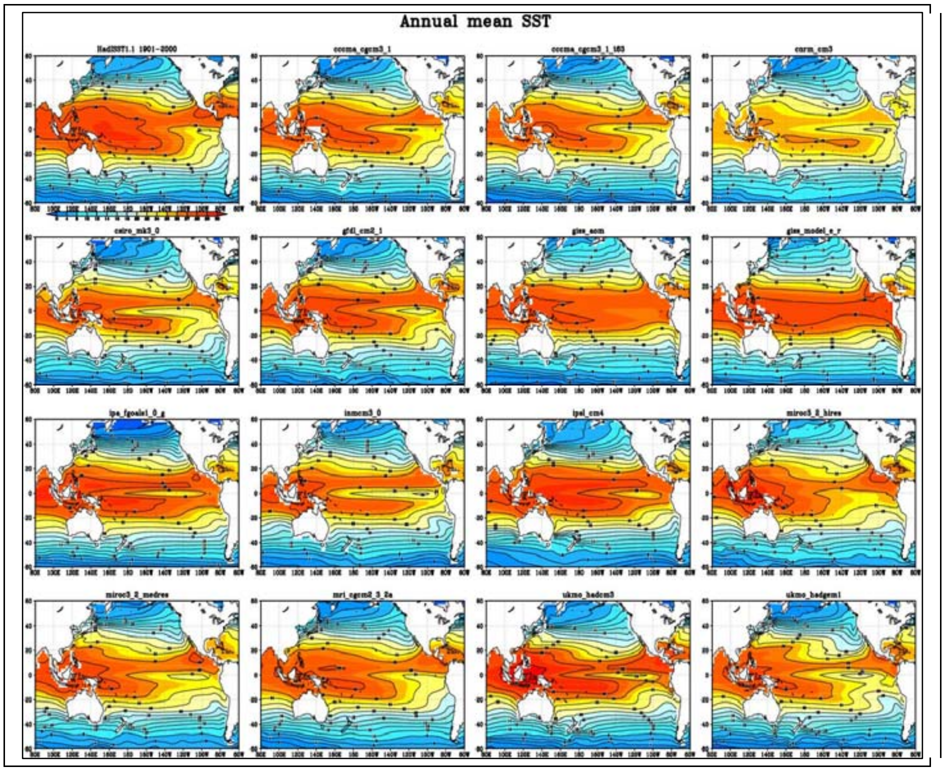

Figure 2. Observed (upper left panel) and simulated annual mean sea surface temperature from fifteen state-of-the art Coupled General Circulation Models run under present-day greenhouse gas concentrations (A. Kitoh, Personal communication).

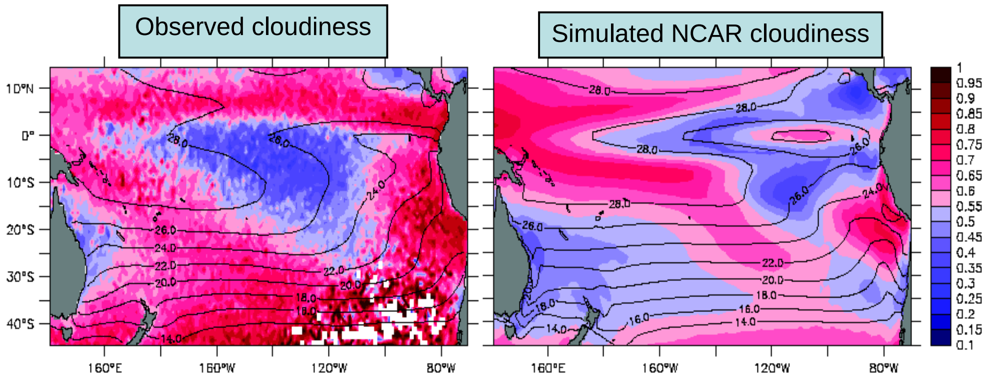

Figure 3. Left: Observed cloudiness (color shading) from NCEP/NCAR reanalysis (Kalnay et al. 1994) and SST (contour) from the HadSST data set (Rayner et al 2006). Right: Same as left but for simulated present-day conditions using the NCAR CCSM3 climate model.

The IPCC 4th Assessment Report provides only very sparse information on the projected climate change in the Melanesian region: "Since AOGCMs do not have sufficiently fine resolution to see the islands, the projections are given over ocean surfaces rather than over land and very little work has been done in downscaling these projections to individual islands." (IPCC, AR4, 2007, chapter 11). Comparing the climate conditions between 2090-2100 with the present-day conditions, more than 66% of the AR4 (CMIP-3) climate model projections using an A1B scenario (modified "business-as-usual", i.e. rapid growth, convergent world, with more balanced energy sources) show an increase of precipitation in the northern Melanesian region, whereas more than 90% of the model experiments predict a summer drying in the southern areas of Melanesia (Figure 4).

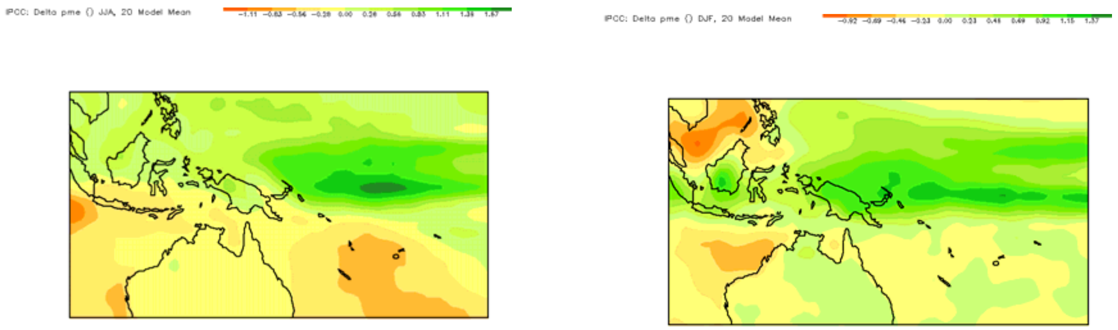

Figure 4. Robust findings on regional climate change for austral summer (right) and winter (left) precipitation minus evaporation. This multi-model mean ensemble assessment is based upon 22 AOGCM simulations, conducted as part of the Coupled Model Intercomparison Project 3 (CMIP3).

These projected precipitation trends are accompanied by a multi-model ensemble mean surface air-temperature increase of about 2^{o}C in the Melanesian region (see Figure 5).

The temperature response is strongest near the equator with potential repercussions for coral bleaching. How such temperature and precipitation regimes will affect marine and terrestrial ecosystems and the societies that depend on them is still an open question. In particular, the fact that most of the state-of-the-art climate models have severe difficulties in simulating the mean present-day rainfall in this region leaves some doubt on the reliability of the multi-model ensemble mean precipitation scenario shown in Figure 4.

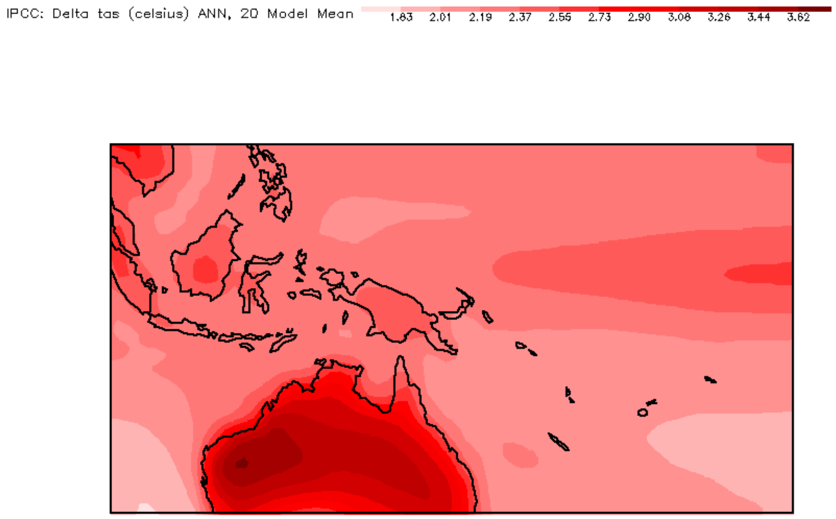

Figure 5. Robust findings on regional climate change for annual mean surface temperature [C]. This multi-model mean ensemble assessment is based upon 22 AOGCM simulations, conducted as part of the Coupled Model Intercomparison Project 3 (CMIP3).

On interannual timescales, the El Niño-Southern Oscillation (ENSO) exerts a strong influence on the climate in Melanesia. During El Niño events large-scale shifts of the seasonal rainfall patterns occur as a result of central and eastern equatorial Pacific warming. Furthermore, the westward expansion of the warm pool during an El Niño event significantly increases the probability of occurrence of large westerly wind bursts along the equator. These westerly wind-bursts often occur in association with twin typhoons, such as the one shown in Figure 6.

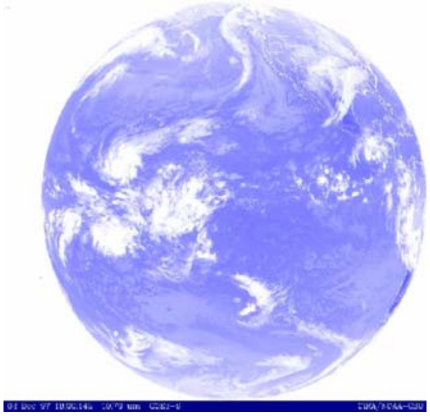

Figure 6. Satellite picture (NOAA-CSU) from 2nd December, 1997. The joint occurrence of typhoons north and south of the equator leads to very high westerly wind stress forcing on the equator, accelerating the development of an El Niño event.

There is evidence from climate change projections (Jin et al. 2007) that the amplitude of this type of intraseasonal variability might increase under greenhouse warming conditions. This will have an important impact on the occurrence of extreme weather patterns in Melanesia. Furthermore, it is important to understand whether the ENSO phenomenon is subject to any greenhouse-warming induced changes. Oldenborgh et al. (2005) analyzed the changes in the variability of ENSO in 17 state-of-the art CGCM simulations, forced under business as usual greenhouse gas concentrations. This modeling study suggests that by year 2100, several models simulate an intensification of ENSO variability (Figure 7), while other models show a weakening or little change. Given the importance of ENSO variability on the Melanesian region, the current uncertainty makes it difficult to develop reliable and robust regional forecasts for the Melanesian region.

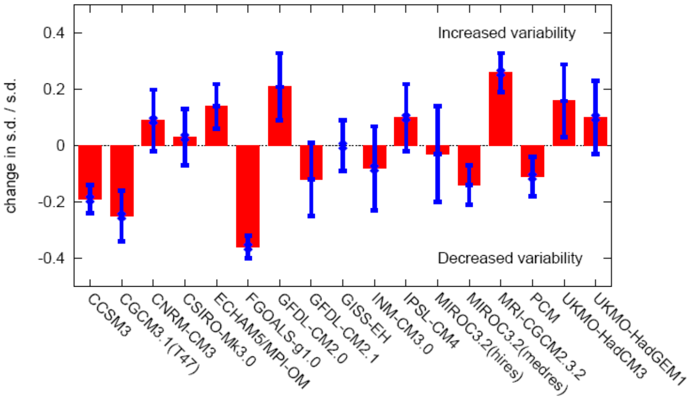

Figure 7. Simulated changes of Niño 3.4 SSTA (area-averaged eastern equatorial Pacific SST) under present-day climate conditions for 17 state-of the art A1B scenario climate change simulations (acronym of model name on x-axis) (from Oldenborgh et al 2005).

Regional Processes

The complex topography of the Melanesian region and changes to the atmospheric forcing have a large impact on the circulation and pathways of water movement, which in turn influences the local properties of water, the marine ecosystem and the transport of larvae. Appreciation of the complexity of the flow has come about from analysis of satellite derived data and results from high resolution ocean models. To illustrate this complexity, Figure 8 shows a typical ocean circulation pattern derived from the results of a high resolution global numerical model of the ocean. The westward flow at mid-latitudes is blocked by the many islands producing numerous jets in their lee (c.f. Webb et al. 2000, Hughes 2002).

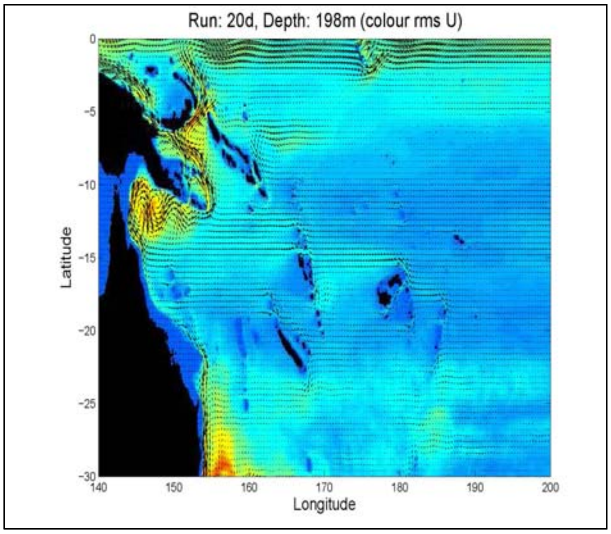

Figure 8. Time mean currents (arrows) and the variability of the flow (color) at 198m depth. The presence of the many islands in the South Western Pacific impacts greatly on the pattern of the flow throughout the full depth of the ocean. The flow is concentrated into jets in the lee of individual islands. Results from a high resolution numerical ocean model (POP).

Small changes in the wind field can produce shifts in the relative strengths of these jets and the paths water takes approaching the western coast of Australia. For instance there has been a shift in the flow around New Caledonia between the 1980’s and the 1990’s to present day. In the 1980’s the flow was concentrated in a jet emanating from the southern tip of the island. Over the last decade the flow has been dominated by a jet from the northern tip (Couvelard et al, 2007).

Even larger changes are brought about by changes in the state of the tropical Pacific under El Niño and La Niña conditions. Figure 9 compares the surface flow patterns under the two conditions (again from the results of a high resolution global ocean model). The changes are large across the region. Here we point out the strong New Guinea Coastal Current along the northern coast of New Guinea during El Niño conditions which is virtually absent during La Niña. In contrast, during La Niña the South Equatorial Current (close to the equator) and South Equatorial Counter Current along 5^o S are particularly strong. The details of the flow along the coasts of individual islands can vary between El Niño and La Niña conditions. For instance, using sea level and *in situ* temperature measurements, Ridgway and Godfrey (1993) infer large unprecedented changes to the flow through Vitiaz Strait and along the coasts of New Ireland and New Britain during the 1982/83 El Niño event. Similar changes are found in the results from high resolution ocean models. Associated with the change in currents there are large changes in sea level height, surface temperature and precipitation. Satellite measurements show changes in sea level height on the order of -/+ 20 cm. between El Niño and La Niña conditions with changes in surface temperature of 1 to 2 degrees Celsius. Ridgway and Godfrey (1993) report variations of 45 cm in sea level height during the 1982/83 El Niño from tide gauge data on the New Ireland coast. During El Niño the region of strong atmospheric convection over the far western tropical Pacific moves eastward taking with it the strong precipitation. The drier pattern further to the west created favorable conditions for the much-publicized fires in Indonesia.

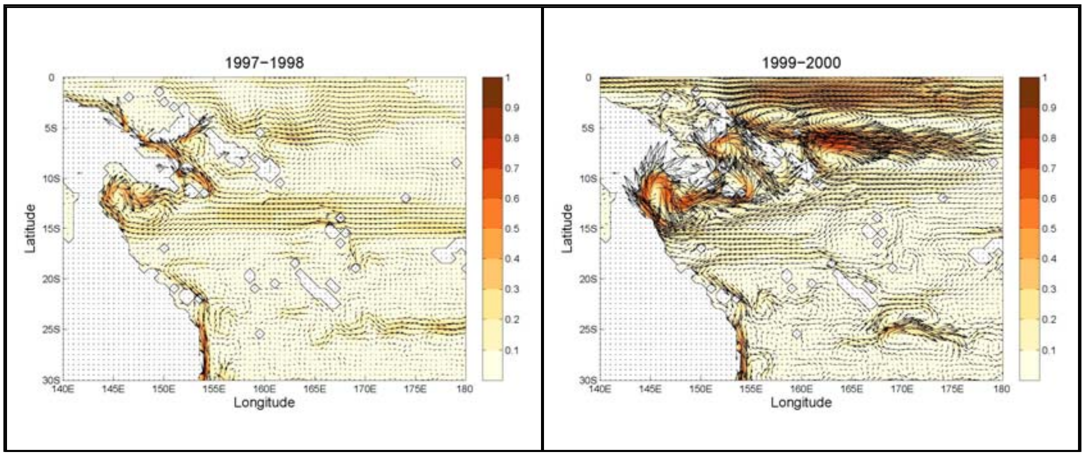

Figure 9. Surface circulation under (a) El Niño and (b) La Nina conditions. Note the large changes in the circulation around New Guinea and the Solomon Islands. Results from a high resolution numerical model (OFES) forced with winds from the NCEP reanalysis.

Direct measurements of ocean currents in the region are limited and usually restricted to single sections (for the flow off New Ireland see Butt and Lindstrom, 1994, Pierre Dutrieux *pers comm.* 2006) An exception is the monitoring of the New Guinea Coastal Current undertaken in the 1990's (Ueki et al. 2003). New technologies, such as the autonomous sea glider, will allow more extensive monitoring to take place (see Couvelard et al., 2007). As part of the international field program SPICE, such plans are presently being pursued by the IRD in Noumea, New Caledonia. Initial glider casts have been conducted in the Soloman Sea,and there are plans for a longer term monitoring of the region using gliders and moorings (Ganachaud, *pers. comm.* 2007).

Much of the variability shown in Figure 8 comes from so-called mesoscale eddies (the ocean equivalent of weather systems in the atmosphere) that have horizontal scales on the order of 100km. These eddies have surface and sub-surface temperature and sea level signals that can persist for a few days to weeks at a single location. A particularly impressive cold water eddy event occurred in March 2007 off the coast of Australia, in which the sea level dropped by 70cm. More typical values are up to +/- 10 cm in sea level height and +/-1 to 2 degrees Celsius in sea surface temperature. The sea level rise associated with the passage of warm core eddies can be enough to temporarily inundate coastal regions and low lying islands.

The conditions at individual locations are influenced by numerous physical processes. As well as the changes to ocean conditions described above there are a number of processes that are of relativity small scale that introduce significant spatial variability in such properties as ocean temperature, salinity and turbidity. These local processes are controlled by the local topography and coastline, the exchange of waters off-shore or at depth, and the local atmospheric forcing such as winds, heating and precipitation. We will describe two examples. The first is mixing by tides. Tidal streams can be enhanced by flowing over submarine ridges or through narrow passages. The swifter currents increase the amount of mixing of waters which can have the effect of bringing colder water to the surface and producing significant reductions in the near surface temperature. Tides can also produce large (100m) uplifts of deeper waters (c.f. Wolanski et al 2004) which can flush coastal lagoons with cold water. To the extent these phenomena are operative, the reductions in temperature may tend to ameliorate the impact of the larger ocean surface warming. The second local process we consider is the impact of the presence of steep mountains on islands. The airflow over and around these topographic features is highly distorted and can be channeled through narrow gaps producing strong wind jets. These wind jets can produce upwelling of cold water or the production of eddies in the lee of islands which in turn affect primary production in the ocean (Xie et al 2001, Calil et al 2007).

Downscaling

As noted above, the AR4 provides little information on the projected climate change for the Melanesian region and most of the AOGCMs do not have high enough resolution to see small islands. This information gap highlights the need to downscale the results of the AOGCMs to the regional level by making use of a combination of dynamic statistical downscaling techniques and regional models with finer resolution that are nested within the AOGCMs.

Several climate change downscaling techniques have been developed in recent years (c.f. Wilby and Wigley, 1997, Schmidli et al. 2006). Statistical downscaling methods exploit existing statistical relationships between large-scale climate processes and their regional manifestations. These relationships are typically derived from present-day observations and it is assumed that these relationships remain stationary in time. The same relationships that are derived from present-day observations are assumed to be valid under greenhouse warming conditions. This assumption is very difficult to test.

Therefore statistical downscaling should be complimented by dynamical-physical downscaling efforts. Dynamical downscaling methods include high resolution ocean or atmospheric models that are configured for the domain of interest. These high-resolution models are forced along their domain boundaries with coarse-resolution climate change projection data, as obtained from the IPCC AR4/CMIP-3 model database and other sources. The dynamical model combines the coarse-scale boundary forcing with internal dynamics in a physically consistent way. This is not guaranteed for the statistical downscaling techniques.

Recently, coupled regional atmosphere-ocean models have been developed, such as the IPRC regional atmosphere-ocean model (IROAM) (Xie et al. 2007). Coarse-resolution boundary forcing is applied both to the atmosphere and ocean components. While regional coupled climate models are becoming more and more realistic under present-day climate conditions, little has been done to apply them in climate change downscaling tasks. Regional coupled models, such as IROAM, can provide an excellent tool to downscale climate change scenarios to different tropical regions around the world.

Recommendation

In order to derive robust regional climate change projections, a series of downscaling experiments have to be performed using both statistical and dynamical downscaling techniques.

Because of the Melanesia region's biogeophysical complexity, the climate projections currently available from IPCC AR4 studies are of limited value in assessing the impact of climate change on the specific ecosystems of Melanesia. The range of spatial and temporal scales considered must be increased and enhanced in order to be able to make useful projections. Of most immediate benefit would be a downscaling of present climate projects to scales that matter to ecosystems. The utility of such an approach has already been demonstrated for other regions and is technically straightforward. We therefore would like to make the following recommendation for further work that is necessary to shed light on the implications of climate change for biodiversity in Melanesia:

A climate projection downscaling project focusing on Melanesia should be initiated. The product would conduct a fine-scale assessment of projected climate change at specific locations in Melanesia that are considered ecologically sensitive or high conservation priorities, such as Kimbe Bay, Raja Ampat, and other sites. The robustness of results and an assessment of the uncertainties will be determined by comparison of the results using a number of AR4 model scenarios and statistical downscaling methods.

The task would be to setup a regional ocean model at high horizontal resolution (high enough to capture the impact of local topography) which is forced

- by climate model forecasts and reanalysis data corresponding to upcoming El Niño and La Niña events; and

- by the climate states of different scenarios (A1, B2, etc.) from a range of models used in the IPCC AR4.

The results of the first task will be compared with existing satellite data and *in situ* data that is being collected in Kimbe Bay during El Niño and La Niña events. The results of the second task will be compared with existing statistical downscaling results for Kimbe Bay in order to obtain robust estimates of the projected climate changes.

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