LOCATIONS IN MELANESIA MOST VULNERABLE TO CLIMATE CHANGE

Stephen J. Leisz
Colorado State University

May 2009

Introduction

As part of the Bishop Museum's look at climate change impacts on biodiversity in Melanesia, the papers commissioned in our study reviewed the state of knowledge and the projected changes in climate, ocean currents, temperatures, ocean pH / aragonite saturation levels, and $pC0_2$. These fundamental physical changes were used to assess likely impacts of climate change on the main categories of terrestrial and marine biodiversity in Melanesia. To complement these reviews and analysis, this paper reviews the projected climate and ocean acidification data from a spatial viewpoint and attempts to illuminate, based on the best available current data, where and to what extent the projected changes are likely to be most acute over the course of the 21st century. The analysis is based on outputs from the MIROC-HIRES[1] model (Hasumi and Emori 2004) for warming projections; projections for aragonite saturation levels are drawn from Feely et al. (2008). The goal of this paper is to provide a spatial overview of the specific areas in Melanesia that are projected to be most seriously impacted by climate change in the 21st century, and which can therefore serve as a provisional assessment of which areas are at relatively higher risk of biodiversity impacts from climate change.

Climate projection results from global Atmosphere-Ocean Global Coupled Models are usually presented as separate information classes, e.g. projected land surface temperature changes, projected sea-surface temperature changes, projected changes in average rainfall, and project cloud cover changes are each presented separately and discussed separately. This type of presentation and discussion is used in most publications as exemplified by the IPCC AR4 (2007). However, presenting information in this manner does not facilitate easy analysis of how each of those projected changes will interact with each other or even how they will, or will not, coincide with each other over a specific location. To address this limitation, this paper examines the projected changes in land surface temperature, sea-surface temperature, precipitation, cloud cover, and changes in the Degree Heat Weeks (DHW)[2] for Melanesia by geographically registering climate projections to a map base and spatially overlaying them. The projected land surface temperature changes, precipitation changes, and cloud cover changes are then overlaid to determine how the extent or degree of each type of change intersects over land. The projected sea-surface temperature changes, changes in number of degree heat weeks, and projected changes in rainfall are overlaid for ocean areas to determine how the extent and degree of each type of change intersects for these areas. This overlay analysis is based on the hypothesis that:

[1] MIROC-HIRES GCM is the GCM with the smallest spatial resolution (½ degree by ½ degree). The results of this GCM for the Melanesian region reflect the multi-model ensemble that is used by the IPCC, but the spatial scale is finer, making it the most appropriate model for an area with a large number of islands such as Melanesia (personal communication, Dr. Axel Timmermann, International Pacific Research Center, School of Ocean and Earth Science and Technology, University of Hawaii, October 4, 2007.

[2] DHW is defined as the number of weeks in which the sea surface temperature of an area exceeds its average thermal maximum by 1-2^{o} C. DHW has become a key operational metric for reef monitoring and management.

(1) terrestrial areas where flora and fauna will be most vulnerable in each decade are lands that are projected to experience the most change in land surface temperatures, precipitation and cloud cover; and

(2) areas were marine flora and fauna will be most vulnerable in each decade are ocean areas that are projected to experience the most change in sea-surface temperature, number of degree heat weeks, and precipitation.

The following report highlights these areas by decade: 2031-40, 2051-60, and 2071-80.

For ocean areas, this paper also examines projected spatial changes in aragonite saturation levels. These map layers were not included in the previously described analysis since averaged decadal projections were not available (available data was only for the specific years 2040, 2060, 2080). There is strong evidence that when aragonite saturation drops below 3, reefs cannot precipitate the calcium carbonate from ocean water that they need to build their shells. Thus a level of 3 or less is thought to indicate conditions in which corals can no longer build their skeletal structures (Langdon and Atkinson 2005). Also, decreasing levels of aragonite saturation will have very negative impacts on other ocean life (Brewer 2008), so it is important to include the data here in order to best highlight the areas where ocean flora and fauna will be vulnerable during the coming century.

Sea-level rise is not discussed here as it has been discussed for the region by country in other reports (see the Consensus Report for details on sea-level rise).

Decade 2031-40

Based on MIROC-HIRES projections, Figure 1 spatially illustrates the projected average yearly changes from present for the decade 2031-2040 in temperature, cloud cover and rainfall over land, and for the ocean changes in sea-surface temperatures, DHW, and rainfall.

New Guinea and surrounding islands

By the end of the decade Papua New Guinea and the Indonesian Provinces of Papua and West Papua are expected to see overall average land surface temperatures rise between 0.5° and 1° C from present. Rainfall is projected to change little along the north coast, while increasing by 10% to 20% throughout much the rest of the island. The outer islands of Papua New Guinea are projected to have similar temperature increases, with rainfall also projected to increase by 10% to 20%. Cloud cover is not projected to change much from the current average amount during this decade.[3]

[3] It needs to be noted that increases in precipitation do not necessarily imply that there will be corresponding increases in cloud cover. The various AOGCMs indicate that cloud cover may increase or decrease independent of changes in precipitation.

The ocean areas around the island are projected to see an increase in the average sea-surface temperatures of between 0.5° and 1° C by the end of this decade. The number of DHW per year is projected to be between 0 and 5, and rainfall is projected to remain similar to the present yearly averages. Ocean acidification will begin to impact areas around New Guinea (Figure 2). To the east and south of the island aragonite saturation levels will fall below 3, indicating that corals may have trouble producing the calcium carbonate they need to build their skeletons. This will impact the ability of reef structures to have growth rates that exceed natural bioerosion rates. To the north aragonite saturation levels are projected to remain above 3.

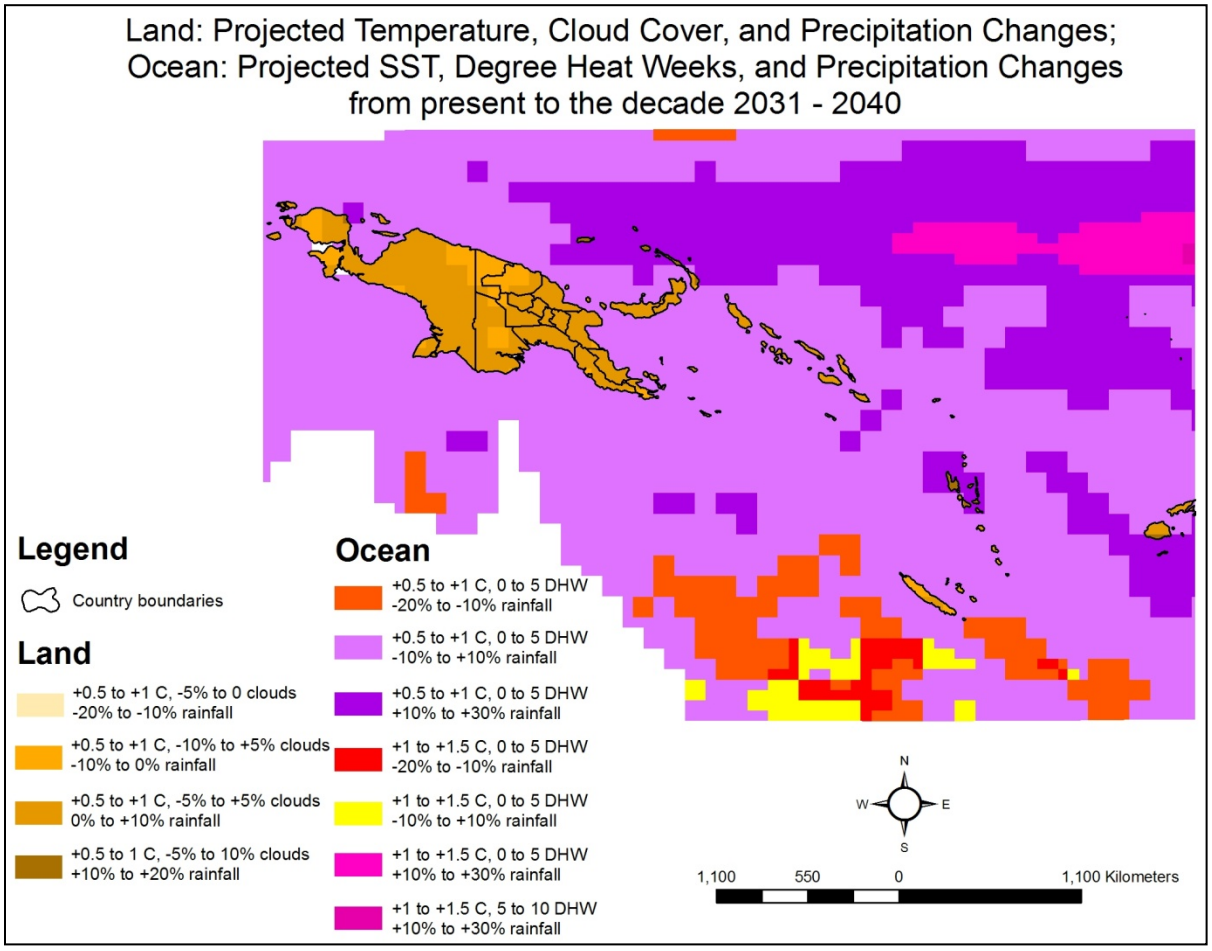

Figure 1. Projected changes from the present decade to 2031-2040.

Solomon Islands

By the end of the decade land areas of these islands are projected to have overall average land surface temperatures rise between 0.5° and 1 ° C from present. Rainfall is projected to vary from present by between 0% and 10%. Cloud cover is not projected to change much from the current average amount.

The oceans areas around the islands are projected to see an increase in the average sea-surface temperatures of between 0.5° and 1° C. DHW per year are projected to be between 0 and 5, and rainfall over the ocean areas is projected to remain similar to the present yearly averages. Ocean acidification will start to be seen in the areas around the islands (Figure 2). To the south of the islands aragonite saturation levels will fall to just below 3, indicating that corals may have trouble producing the calcium carbonate they need to build their skeletons. To the north of the islands aragonite saturation levels are projected to remain at or slightly above 3.

Vanuatu

By the end of the decade the islands of Vanuatu are projected to see overall average land surface temperatures rise between 0.5° and 1° C from present. Rainfall in the northern islands is projected to increase by 10% to 20% from present. The southern

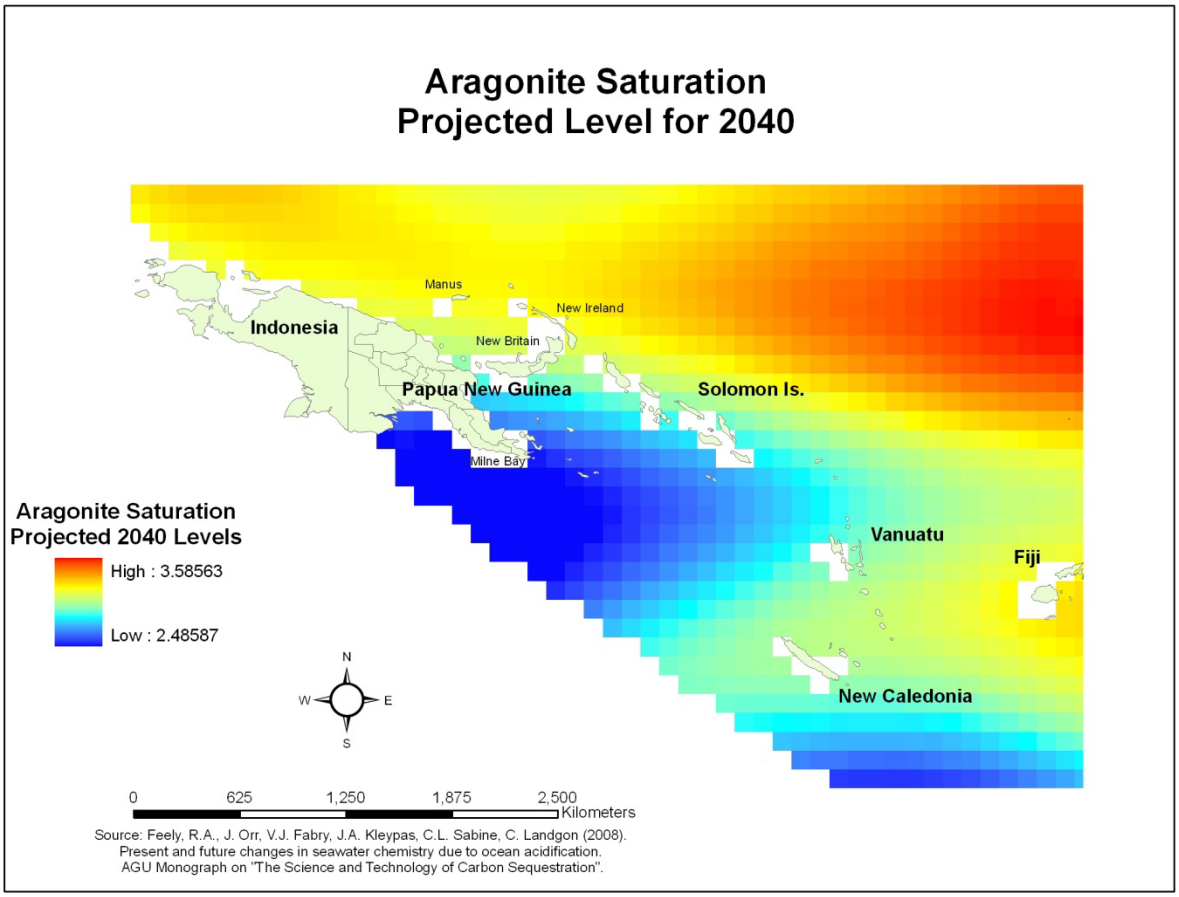

Figure 2. Projected aragonite saturation levels for 2040.

islands will have little change to their average rainfall from present. Cloud cover is not projected to change much from the current average amount during this decade.

The ocean areas around the island are projected to see an increase in the average sea-surface temperatures of between 0.5° and 1° C by the end of the decade. The number

of DHW per year is projected to be between 0 and 5, and rainfall is projected to increase 10% to 20% in the north and be similar to the present yearly averages in the south. Aragonite saturation levels around the northern islands will fall to just below 3 (Figure 2), indicating that corals may have trouble producing the calcium carbonate they need to build their skeletons. Around the southern islands the aragonite saturation levels are projected to remain at or slightly above 3.

New Caledonia

By the end of the decade New Caledonia is projected to see overall average land surface temperatures rise between 0.5° and 1° C from present. Rainfall is projected to change little throughout the area, around +/-10% from the present average amount. During this decade cloud cover is not projected to change much from the current average.

The ocean areas around New Caledonia are projected to see an increase in the average sea-surface temperatures of between 0.5° and 1° C. The number of DHW per year is projected to be between 0 and 5, and rainfall is projected to remain similar to the present yearly averages (+/- 10%). Aragonite saturation levels are projected to remain above 3 (Figure 2).

Fiji

By the end of the decade Fiji is projected to see overall average land surface temperatures rise between 0.5° and 1° C from present. Rainfall is projected to change little throughout the country varying from present by +/- 10%. Cloud cover is not projected to change much from the current average amount.

The ocean areas around the islands are projected to see an increase in the average sea-surface temperatures of between 0.5° and 1° C. The number of DHW per year is projected to be between 0 and 5, and rainfall is projected to remain similar to the present yearly averages around the main islands and to the north. To the south of the main islands, rainfall is projected to increase from present by +10% to +20%. Ocean acidification will be least felt in this area as aragonite saturation levels are projected to remain well above 3.

Decade 2051-60

Based on MIROC-HIRES projections, Figure 3 spatially illustrates the projected average yearly changes from present for the decade 2051-2060 in land surface temperature, cloud cover and rainfall over land, and for the ocean changes in sea-surface temperatures, degree heat weeks, and rainfall.

New Guinea and surrounding islands

By the end of the decade central and southern parts of Papua New Guinea and the Indonesian Provinces of Papua and West Papua are projected to see overall average land surface temperatures rise between 1.5° and 2° C from present. The northeastern part of Papua New Guinea and the outer islands of the country are projected to have increases in land surface temperatures of between 1° and 1.5 ° C. Rainfall is projected to change little for the central and southern parts of Papua New Guinea and the Indonesian Provinces of Papua and West Papua. However, the northern part of Papua New Guinea and the outer islands are projected to have a decrease in rainfall of between -10% and -20%, while Eastern New Britain and new Ireland are projected to have increases of +10% to +20%. Cloud cover is not projected to change much from the current average amount during this decade.

The ocean areas around the island are projected to see an increase in the average sea-surface temperatures of between +1° and +1.5° C. The number of DHW per year is projected to be between 0 and 5, and rainfall is projected to increase by up to 30% in the north, while decreasing up to 30% in the south. The ocean near New Ireland is projected to have increased sea-surface temperatures of +1° to +1.5° C, have DHW per year of between 5 and 10, and increase yearly rainfall of up to 30%. Aragonite saturation will drop to less than 2.5 for the ocean east and south of the island and to less than 3 for the areas north of New Guinea and around Papua New Guinea's outer islands (Figure 4). This projected level of aragonite saturation suggests that coral reefs to the south and east will be severely vulnerable to actual dissolution of the reef and that reefs to the north and around the outer islands will have trouble producing the calcium carbonate they need to build their skeletons. This will impact the ability of reef structures to have growth rates that exceed natural bioerosion rates.

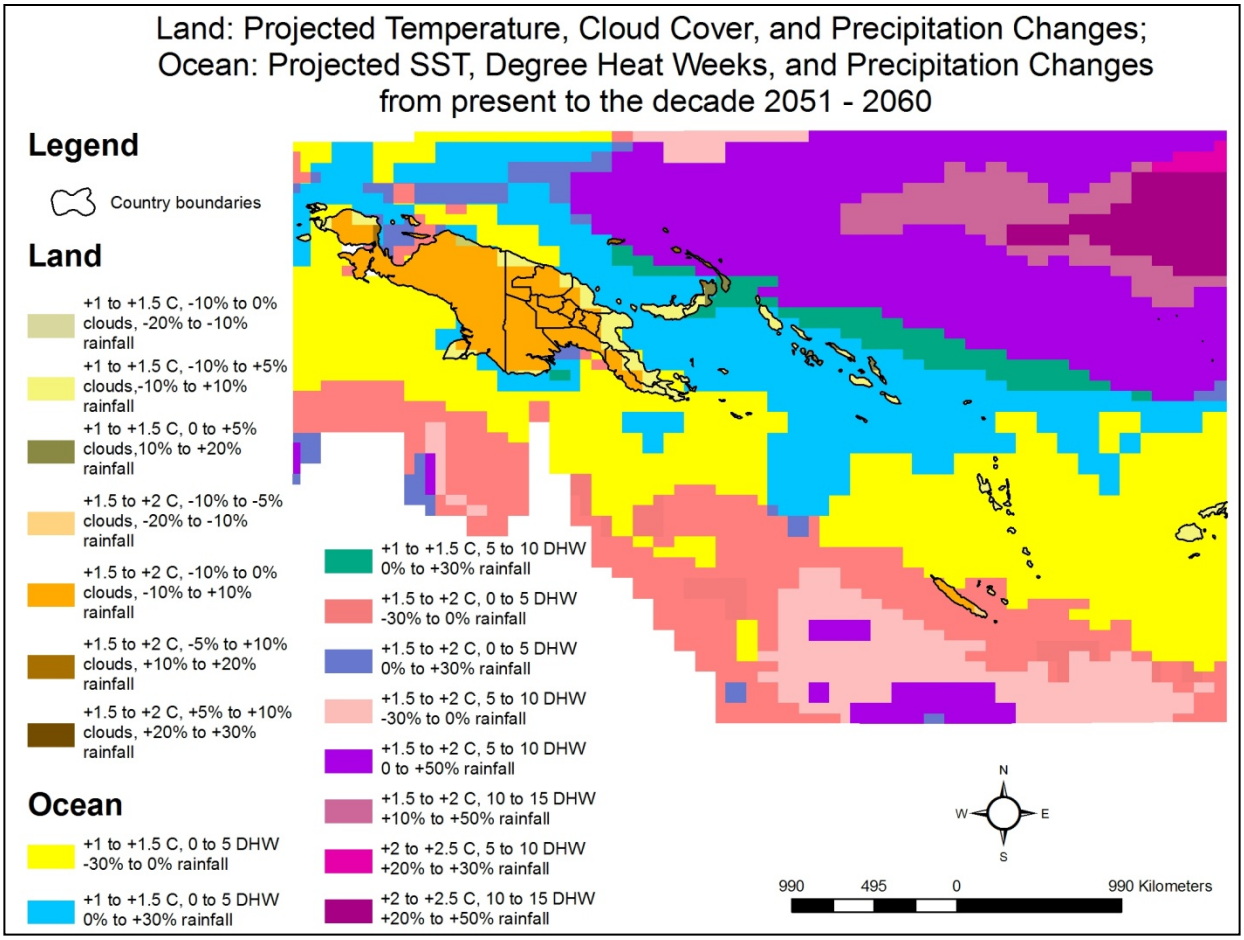

Figure 3. Projected changes from the present decade to 2051-2060

Solomon Islands

By the end of the decade, land areas of these islands are projected to have overall average surface temperatures rise between 1° and 1.5° C from present. Rainfall is projected to vary from present by between -10% to +20% depending upon the island. Cloud cover is not projected to change much from the current average.

The ocean areas around the islands are projected to see an increase in the average sea-surface temperatures of between 1° and 1.5° C. DHW per year are projected to be between 0 and 5 to the south and north of the islands, and rainfall over the ocean areas is projected to increase by up to 30%. Aragonite saturation levels will drop to less than 3 for the ocean around all of the islands (Figure 4). This projected level of aragonite saturation suggests that coral reefs will be vulnerable to actual dissolution as they will have trouble producing the calcium carbonate needed to build their skeletons. This will impact the ability of the reef structures to have growth rates that exceed natural bioerosion rates.

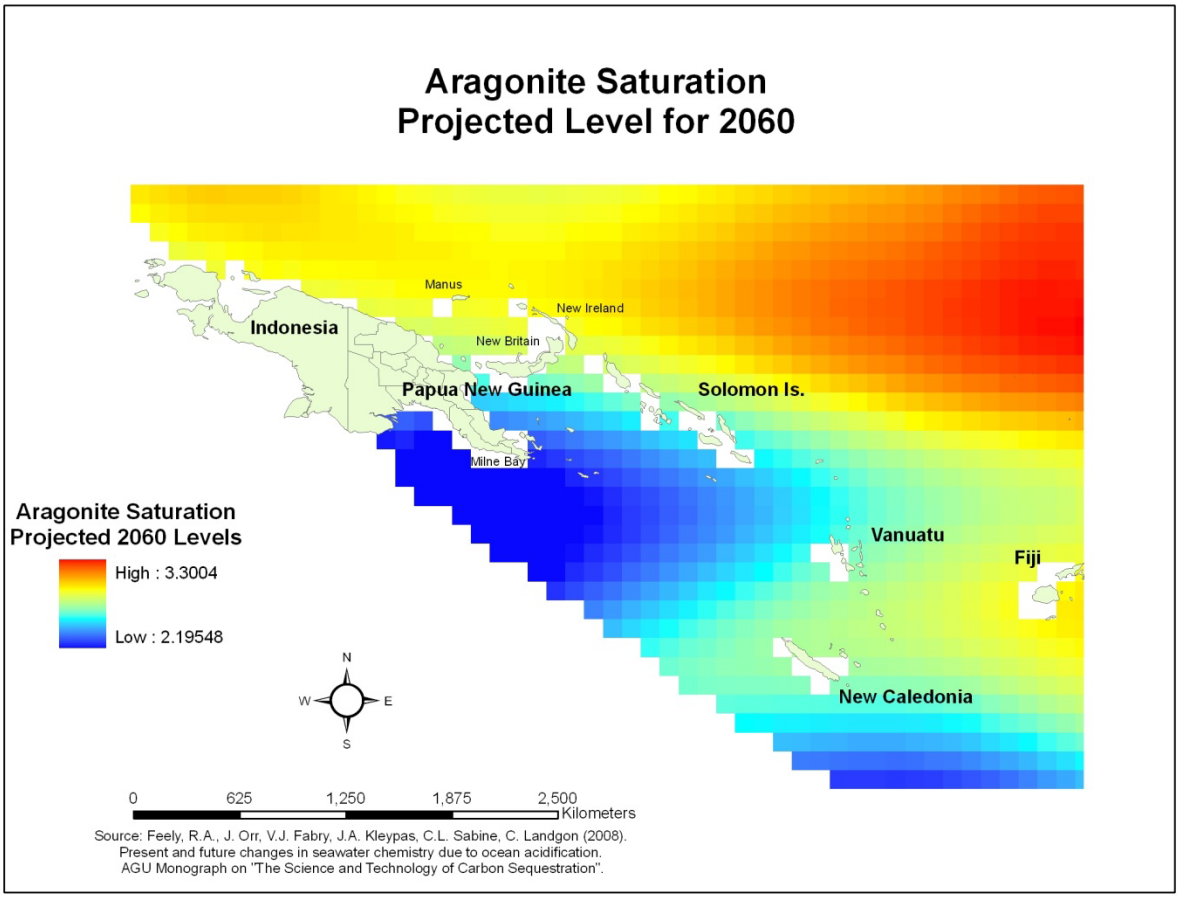

Figure 4. Projected aragonite saturation levels for 2060.

Vanuatu

By the end of the decade, the islands of Vanuatu are projected to see overall average land surface temperatures rise between 1° and 1.5° C. Rainfall is projected to be similar to present levels or decrease by about 10%. There is projected to be little change from present in the amount of cloud cover.

The ocean areas around the island are projected to see an increase in the average sea-surface temperatures of between 1° and 1.5° C. The number of DHW per year is projected to be between 0 and 5, and rainfall is projected to decrease by up to 30%. Aragonite saturation will drop to less than 3 for the ocean around all of the islands (Figure 4). This level of aragonite saturation suggests that coral reefs will be vulnerable to actual dissolution as they will have trouble producing the calcium carbonate needed to build their skeletons. This will impact the ability of reef structures to have growth rates that exceed natural bioerosion.

New Caledonia

By the end of the decade, New Caledonia is projected to see overall average land surface temperatures rise between 1.5° and 2° C from present. Rainfall is projected to

change little or decrease by 10% throughout the area and cloud cover is also projected to decrease by up to 10% as compared to the current average.

The ocean areas around New Caledonia are projected to see an increase in the average sea-surface temperatures of between 1.5° and 2° C. The number of DHW per year is projected to be between 0 and 5, and rainfall is projected to decrease by up to 30%. Aragonite saturation will drop to less than 3 (Figure 4). This projected level of aragonite saturation indicates that coral reefs will be vulnerable to actual dissolution as they will have trouble producing the calcium carbonate they need to build their skeletons. This will impact the ability of reef structures to have growth rates that exceed natural bioerosion rates.

Fiji

By the end of this decade Fiji is projected to see overall average land surface temperatures rise between 1° and 1.5° C. Rainfall is projected to be similar to present levels or decrease by about 10%. There is projected to be little change from present in the amount of cloud cover.

The ocean areas around the islands are projected to see an increase in the average sea-surface temperatures of between 1° and 1.5° C. The number of DHW per year is projected to be between 0 and 5, and rainfall is projected to decrease by up to 30%. To the south of the main islands aragonite saturation levels will be above 3, while to the north the aragonite saturation levels will be just above or below 3 (Figure 4).

Decade 2071-80

Based on MIROC-HIRES projections, Figure 5 spatially illustrates the projected average yearly changes from present for the decade 2071-2080 in land surface temperature, cloud cover and rainfall over land, and for the ocean changes in sea-surface temperatures, DHW, and rainfall.

New Guinea and surrounding islands

By the end of this decade the central parts of Papua New Guinea and the Indonesian Provinces of Papua and West Papua, the parts of the island that correspond to the central mountain range running east – west on the island, are projected to see overall average land surface temperatures rise between 2.5° and 3° C from present. The southern part of the island, the northern coastal shore, the eastern Milne Bay areas, and the outer islands are projected to see increases in land surface temperatures of between 2° and 2.5° C. Rainfall is projected to increase by up to 20% for the central, mountainous, parts of Papua New Guinea and the Indonesian Provinces, increase slightly, up to 10% in the southern and north coastal parts of the island, and on the outer islands, and decrease by around 10% in the eastern Milne Bay area of Papua New Guinea. Cloud cover is not projected to change much from the current average amount.

The ocean areas are projected to see an increase in the average sea-surface temperatures of between 2° and 2.5° C. The number of DHW per year is projected to be between 5 and 10 during this decade, and rainfall is projected to be similar to the current average yearly precipitation (+/-10% each year). The ocean areas near the outer islands are projected to have increased sea-surface temperatures of +2° to +2.5° C. They are also projected to have an increase in DHW per year of between 10 and 15. Precipitation is projected to increase up to +20% from present averages. Similar sea-surface temperature, DHW, and precipitation projections are also made for just north of the bird's head part of the island of New Guinea. Aragonite saturation will drop to close to 2 for the ocean east and south of the island and to between 2.6 and 2.7 for the areas north of New Guinea and around Papua New Guinea's outer islands (Figure 6). This projected level of aragonite saturation suggests that coral reefs near the island of New Guinea and Papua New Guinea's outer islands will be severely vulnerable to their actual dissolution.

Solomon Islands

By the end of this decade the land areas of these islands are projected to have overall average land surface temperatures rise between 2° and 2.5° C from present. Rainfall is projected to vary from present by 0% to +10% depending upon the island. Cloud cover is not projected to change much from the current average amount.

The oceans areas around the islands are projected to see an increase in the average sea-surface temperatures of between 2° and 2.5° C, but the middle of the island chain is only projected to have a temperature increase of between 1.5° and 2° C. DHW per year are projected to be between 5 and 10 in the surrounding ocean areas and rainfall over the ocean areas is projected to increase by up to 20%. Aragonite saturation to the south of the islands will be less than 2.5 and between 2.5 and 2.7 to the north (Figure 6). This projected level of aragonite saturation suggests that coral reefs near the Solomon Islands will be severely vulnerable to their actual dissolution.

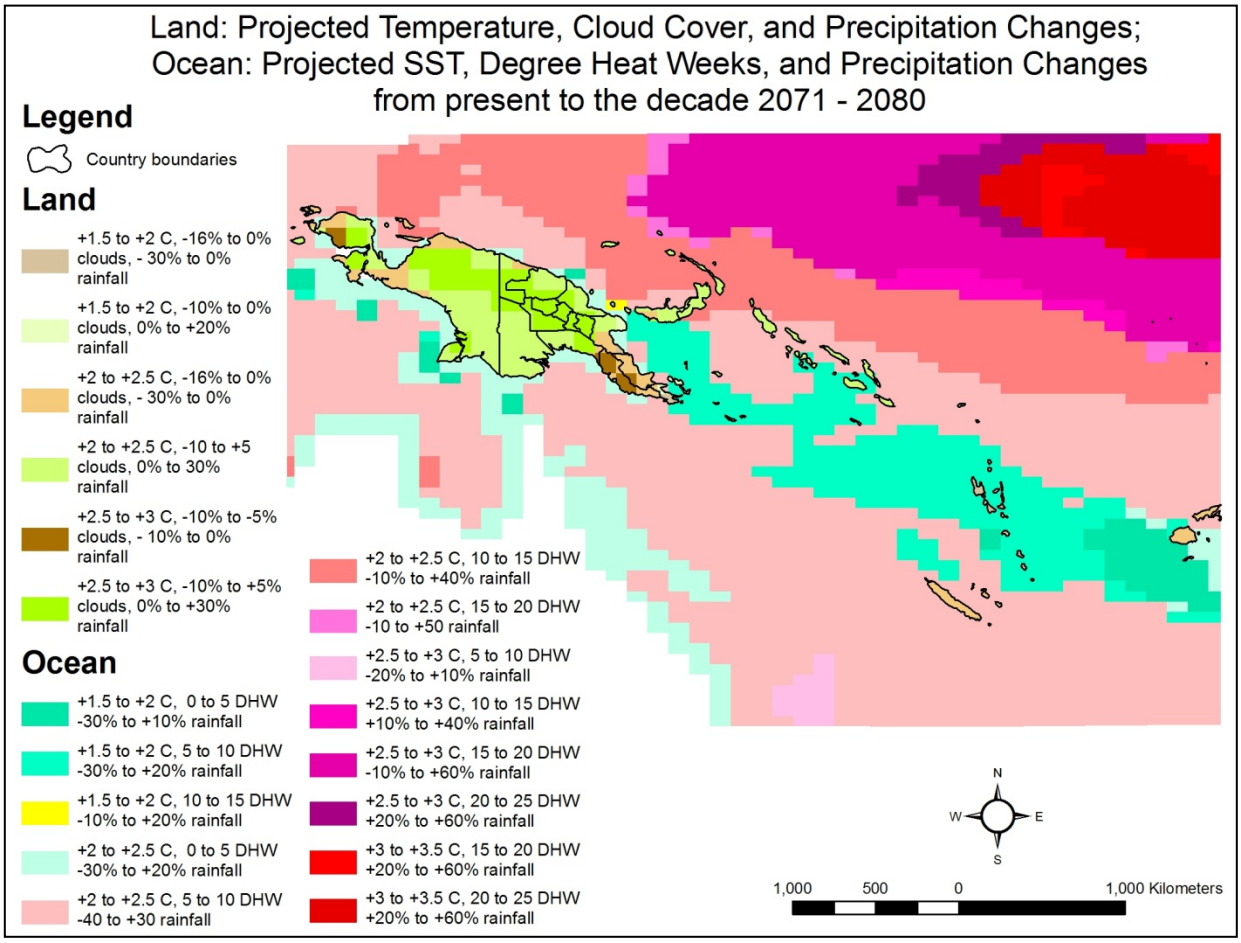

Figure 5. Projected changes from the present decade to 2071-2080.

Vanuatu

By the end of the decade the islands of Vanuatu are projected to see overall average land surface temperatures rise between 1.5° and 2° C. Rainfall is projected to decrease by up to 30% depending upon the island. There is projected to be little change from present in the amount of cloud cover.

The ocean areas around the island are projected to see an increase in the average sea-surface temperatures of between 1.5° and 2° C. The number of DHW per year is projected to be between 5 and 10, and rainfall is projected to increase by up to 30%. Aragonite saturation will drop to less than 2.5 for the ocean around the northern islands and to between 2.5 and 2.6 for the other ocean areas of Vanuatu (Figure 6). This projected level of aragonite saturation suggests that coral reefs near Vanuatu will be severely vulnerable to their actual dissolution.

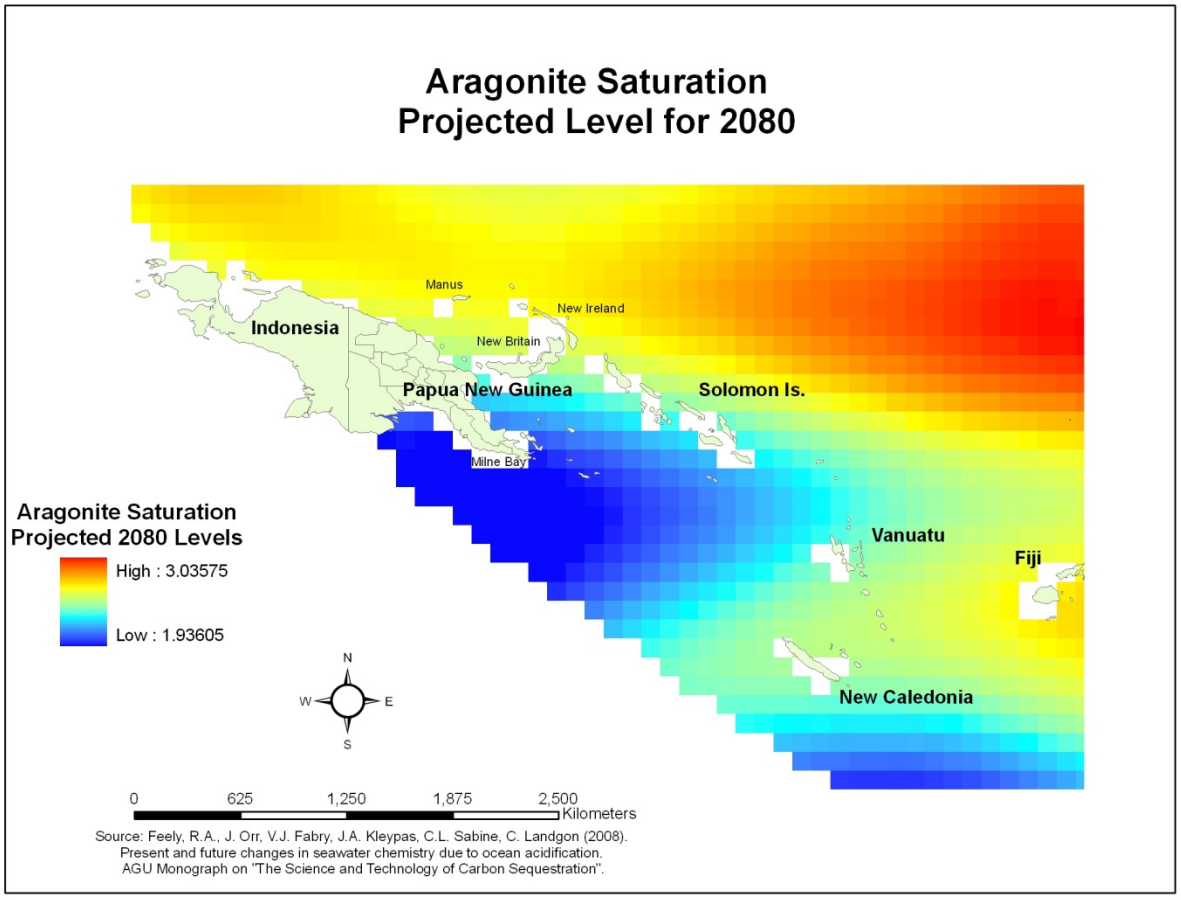

Figure 6. Projected aragonite saturation levels for 2080.

New Caledonia

By the end of the decade New Caledonia is projected to see overall average land surface temperatures rise between 2° and 2.5° C from present. Rainfall is projected to decrease by up to 30% throughout the area and cloud cover is projected to decrease by up to 16% as compared to the current average.

The ocean to the west, east, and south of New Caledonia are projected to see an increase in the average sea-surface temperatures of between 2° and 2.5° C, and an increase to the north of 1.5° to 2° C. The number of DHW per year is projected to be between 5 and10, and rainfall is projected to decrease by up to 30%. Aragonite saturation will be near 2.5 for the ocean near New Caledonia (Figure 6). This projected level of aragonite saturation suggests that coral reefs near New Caledonia will be severely vulnerable to their actual dissolution.

Fiji

By the end of the decade the more southern islands of Fiji are projected to see overall average temperatures rise between 1° and 1.5° C, while the northern islands are

projected to have an increase of 2 to 2.5° C. Rainfall is projected to decrease up to 20% and cloud cover is projected to decrease by up to 10%.

The ocean areas to the south and west of the islands are projected to see an increase in the average sea-surface temperatures of between 1.5° and 2° C. The number of DHW per year to the south, west and east of the island is projected to be between 0 and 5, while to the north it is projected to be between 5 and 10. Rainfall is projected to be within +/-10% of the current averages. The ocean areas around Fiji are projected to have aragonite saturation levels of between 2.5 and 2.7 by 2080 (Figure 6). This projected level of aragonite saturation suggests that coral reefs near Fiji will be severely vulnerable to their actual dissolution.

Discussion

2031 to 2040

No countries in Melanesia are projected to experience especially high average increases in either land or sea-surface temperatures, with average increases from the present ranging between 0.5° and 1° C for both land or sea-surface temperatures. Rainfall is projected to increase by up to 20% in parts of New Guinea, Vanuatu, and Fiji, but it is unclear how much impact increasing precipitation will have on the regions flora and fauna. For ocean areas, besides the sea-surface temperature increases, DHW will be between 0 and 5 per year, not of a level to cause severe stress in the coral reefs. The most vulnerable areas in the region during this decade will be the oceans to the south and east of Papua New Guinea, to the south of the Solomon Islands, and in northern Vanuatu, where aragonite saturation levels will drop below 3. In these areas coral reefs, and some other sea life, may be vulnerable.

2051 to 2060

During this decade it is projected that average temperatures will be much higher than present throughout much of Melanesia. The island of New Guinea is projected to experience an average increase in land surface temperature of between 1.5° and 2° C over much of the island and the same is true for New Caledonia. In other parts of Melanesia it is projected that land surface temperatures will increase from present by between 1° and 1.5° C. Rainfall will change the most along the northern coast of Papua New Guinea, where it is projected to decrease by up to 20%; on the outer islands of Papua New Guinea where it is projected to increase by up to 20%; and on the Solomon Islands where it is projected to increase by up to 20%. Based on these projections, land areas where flora and fauna may be most vulnerable during this decade will probably be found on the island of New Guinea.

Ocean areas near New Caledonia are projected to experience increased sea-surface temperatures from present by an average of 1.5° to 2° C, while in other areas of Melanesia the increase is projected to be between 1° and 1.5° C. DHW per year throughout Melanesia will mostly be between 0 and 5, except for areas near New

Ireland where the number of DHW per year are projected to be between 5 and 10, a condition that can stress coral reefs. Projected aragonite levels in the oceans near New Guinea, the Solomon Islands, Vanuatu, and New Caledonia will all drop to less than 3; only Fiji will still have ocean areas with levels higher than 3. Based on these projections coral and other sea life throughout much of Melanesia are projected to be stressed by changing ocean conditions and vulnerable during this decade.

2071 to 2080

The central mountainous area of the island of New Guinea is projected to have the highest increase in land surface temperature from present during this decade for Melanesia with an average projected increase of between 2.5° and 3° C. The Solomon Islands and New Caledonia are projected to have the next highest with land surface temperatures increasing between 2° and 2.5° C. Other land surface areas' projected increases are between 1° and 2° C. Rainfall for New Guinea's central mountain area is projected to increase from present by up to 20% and for New Caledonia and Vanuatu the projection is an increase of 30%. Based on the confluence of projected changes for this decade the areas of Melanesia where land flora and fauna may be most vulnerable are the central mountainous areas of New Guinea (both Papua New Guinea and the Indonesian part of the island) and New Caledonia, followed by the Solomon Islands and the islands of Vanuatu.

Ocean areas near New Guinea, the Solomon Islands, and New Caledonia are projected to have increases from present of between 2° and 2.5° C. Other areas are projected to have increases of between 1.5° and 2° C. DHW are expected to increase to between 10 and 15 per year around the outer islands of Papua New Guinea. In other parts of Melanesia they are projected to vary between 5 and 10 per year. Aragonite saturation levels throughout the oceans of Melanesia are projected to be less than 3. Based on the spatial intersection of these conditions, the most vulnerable ocean area during this decade will be in the outer islands of Papua New Guinea. There aragonite saturation levels will be lower than 3 making it difficult for corals to produce the calcium carbonate they need to build their skeletons and the DHW projected per year would indicate that coral bleaching each year will lead to mortality. In other areas the projected DHW per year indicate that corals may be stressed and bleach, but they may not die. However, in these other areas some ocean life will still be vulnerable due to the low aragonite saturation levels.

Conclusion

This paper has used spatial overlay analysis of MIROC-HIRES climate projection data to identify how change projections for different climate variables overlap for three different decades of the 21st century. The results indicate that given the projected climate changes by the end of the decade the most vulnerable area of Melanesia for land flora and fauna to climate change will be the central mountain chain of the island of New Guinea, were projected temperature increase is the greatest and projected precipitation change is also high; and the most vulnerable area for coral reef systems

and ocean life will be the outer islands of Papua New Guinea, as these areas will be facing stresses from high occurrences of DHW per year and aragonite saturation levels of less than 3.

The results and conclusions presented here are limited in nature by the data available. If more spatial data were available, such as land cover, land use, and downscaled climate projections, more nuanced and detailed, and potentially more accurate, spatial projections of the vulnerability of land and ocean flora and fauna could be made.

References

Brewer, Peter 2008. Climate Changeand Biodiversity in Melanesia: Biophysical science – ocean acidification. [Leisz, S., and J.B. Burnett (eds.) Climate Change and Biodiversity in Melanesia,, Bishop Museum Technical Report 42 (2008-2009)]. The Bishop Museum, Honolulu, Hawaii, 161 pp.

Feely, R.A., J. Orr, V.J. Fabry, J.A. Kleypas, C.L. Sabine, and C. Landgon 2008. Present and future changes in seawater chemistry due to ocean acidification. AGU Monograph on "The Science and Technology of Carbon Sequestration".

Hasumi, Hiroyasu, and Seita Emori 2004. K-1 Coupled GCM (MIROC) Description, Center for Climate System Research (CCSR), University of Tokyo; National Institute for Environmental Studies (NIES); Frontier Research Center for Global Change (FRCGC) http://www.ccsr.u-tokyo.ac.jp/kyosei/hasumi/MIROC/tech-repo.pdf (Accessed October 9, 2007).

IPCC 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Langdon C. and M. J. Atkinson 2005. Effect of elevated pCO2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment, Journal of Geophysical Research, 110 (C09S07).