Patterns of Convection in the Tropical Western Pacific

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Introduction

Convection is ubiquitous throughout the maritime continent region. However, the frequency of convection is not uniform. While much of this region does not experience seasons to the same degree as one finds in mid-latitudes, the annual cycle of the sun's passage does have a large impact on convection throughout the maritime continent and the tropical western Pacific. The distribution of islands also affects convection in a variety of ways.

Atmospheric Radiation Measurement (ARM) Program has three sites in the Tropical Western Pacific (TWP) region, illustrated in Figure 1. The sites are located on Manus, Nauru, and at Darwin, Australia. Each of these exhibits a somewhat different annual convection cycle. We will examine how the annual solar cycle affects the annual convection cycle at the Manus and Nauru sites.

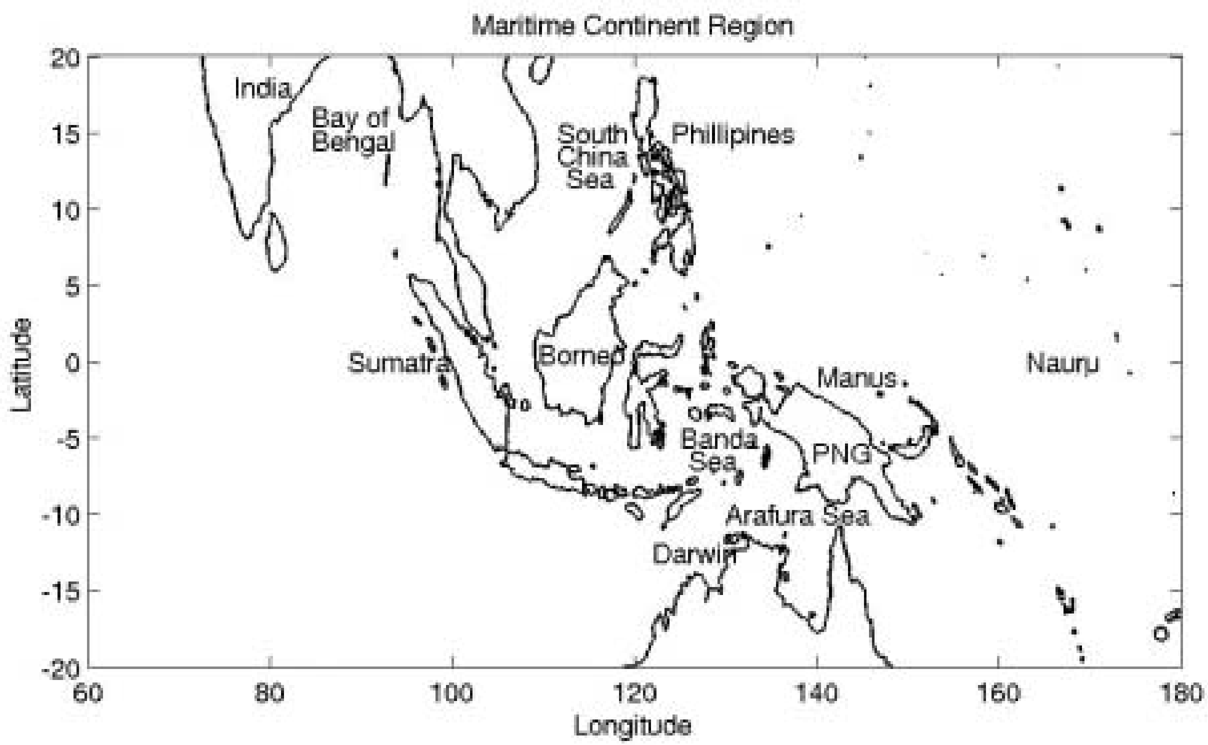

Figure 1. The TWP/maritime continent region.

Repetitive Features in the Manus Shortwave Record

Downwelling shortwave radiation data from Manus is presented in Figure 2 spanning the period from installation in October 1996 through mid-2002. Rather than plot the actual down-welling flux, the shortwave cloud effect is used. This quantity is defined here as (Fobs – Fclr)/Fclr where Fobs is the observed shortwave flux and Fclr is the flux which would be observed under clear-sky, but otherwise equivalent conditions. Displaying this quantity effectively normalizes variations in solar zenith angle with season so that variability is due to cloud variations alone. With this definition, a value of 0 corresponds to clear-sky while a value of -1 corresponds to complete attenuation of the solar flux.

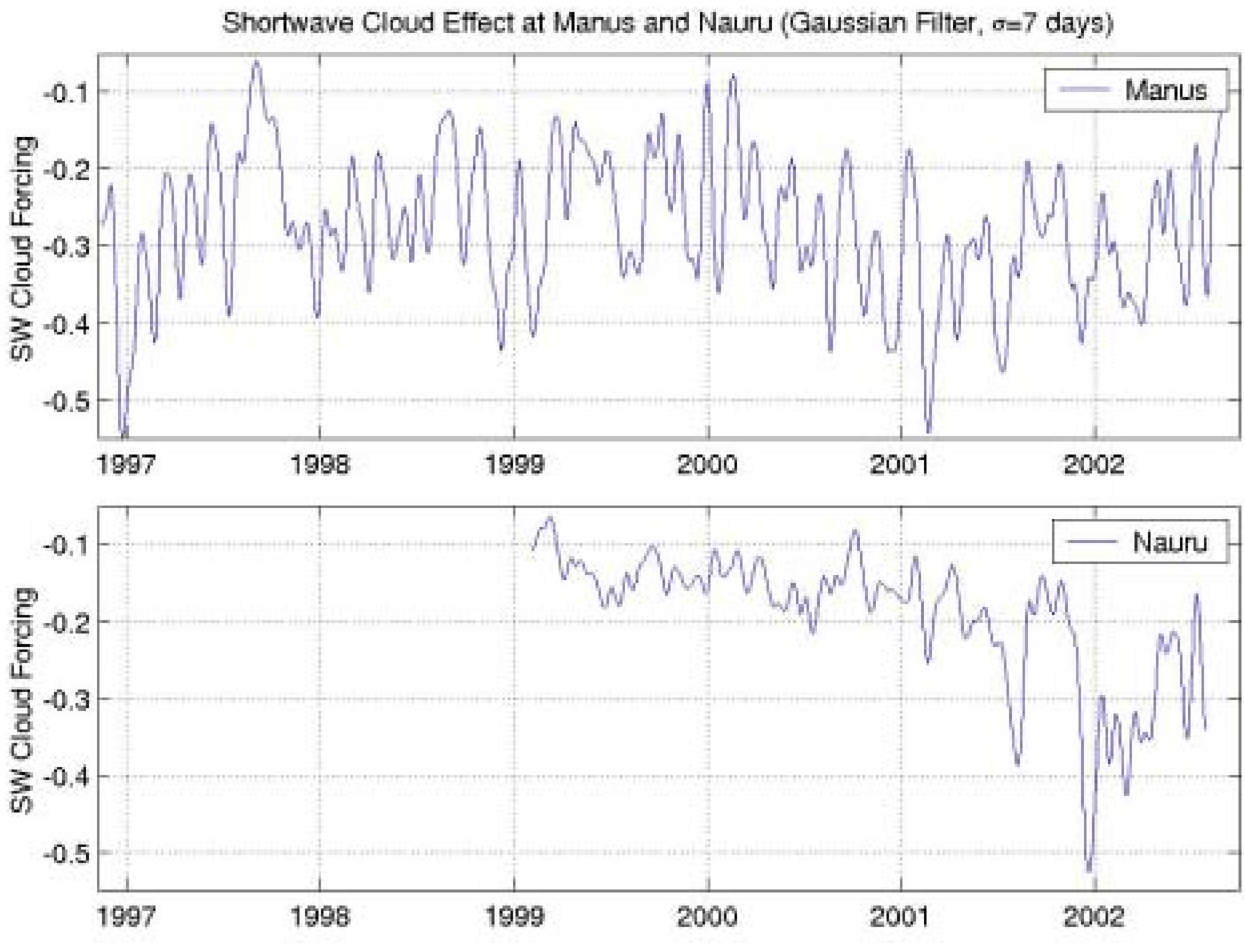

Figure 2. Shortwave observations at Manus and zonal wind observations from Darwin, Australia.

The shortwave data have been smoothed using a Gaussian filter with a half-width of 7 days. The time series is complex but after careful examination, several interesting features emerge that give clues to processes affecting convection at Manus. First, an oscillation resembling the Madden-Julian Oscillation (MJO) is present throughout the series. Second, in some years (e.g., 1998, 2000) the MJO seems to dominate variability while in other years (1999, 2001) a semi-annual cycle is apparent. This semi-annual cycle is characterized by weak solar forcing at the equinoxes and stronger forcing at the solstices.

In almost all years, typically active conditions near the austral summer solstice are interrupted for a brief period near the new year.

The lower panel in Figure 2 shows the 1000 mb to 500 mb pressure weighted zonal wind from radiosondes launched at Darwin, Australia. This deep layer mean zonal wind has been used to identify active periods of the Australian monsoon (Drosdowsky 1996). The coincidence of suppressed conditions at Manus with the onset of the Australia monsoon suggests a dynamical link between these sites.

Spatial Patterns in TWP Convection Throughout the Year

The four panels in Figure 3 show distributions of outgoing longwave radiation (OLR) plotted from National Centers for Environmental Prediction (NCEP) analyses of National Oceanic and Atmospheric Administration (NOAA) polar orbiter data averaged over the period 1975 – 2002 for 4 months: July, October, January, and April (Chelliah and Arkin 1992).

Low values of OLR (in blue) represent high, cold clouds which may be interpreted as regions of active convection. High OLR values (in red) represent regions of suppressed convection. These data illustrate the migration of a region of active convection, north and south between Asia and Australia, along the maritime continent. In addition to this north-south oscillation, several features are noteworthy:

In October and April, convection is concentrated over the large islands (Papua New Guinea [PNG], Borneo, and Sumatra) of the maritime continent. In July, when solar insolation in the TWP is near its minimum, OLR is significantly diminished over these islands. Meanwhile, OLR over the most of the maritime regions of the TWP shows little annual cycle although low OLR values are most widespread throughout the TWP during the northern hemisphere winter. North of Australia, there is an extended region of suppressed convection during the northern hemisphere summer and fall. This suppression is associated with decreased sea surface temperatures. The decreased sea surface temperatures seem to result from Australia’s northern coast, driven by the dry monsoon season circulation.

Cirrus Observations at Manus

The suite of instruments at Manus includes the millimeter cloud radar and micropulse lidar, which together provide vertical distributions of clouds. Cloud occurrence statistics derived from these data for parts of 1999 and 2000 are plotted in Figure 4.

High level clouds are common through the year though not with uniform frequency. Less common are months with high frequencies of cloud occurrence throughout the column. Such months are indicative of local deep convection. Months with high clouds without underlying clouds are indicative of cirrus advected from another location. The highest cirrus frequencies occur during months when there is little local convection (e.g., October-November 1999, February-March 2000). These clouds were likely formed by convection over PNG, New Britain or within the Inter-tropical Convergence Zone (ITCZ).

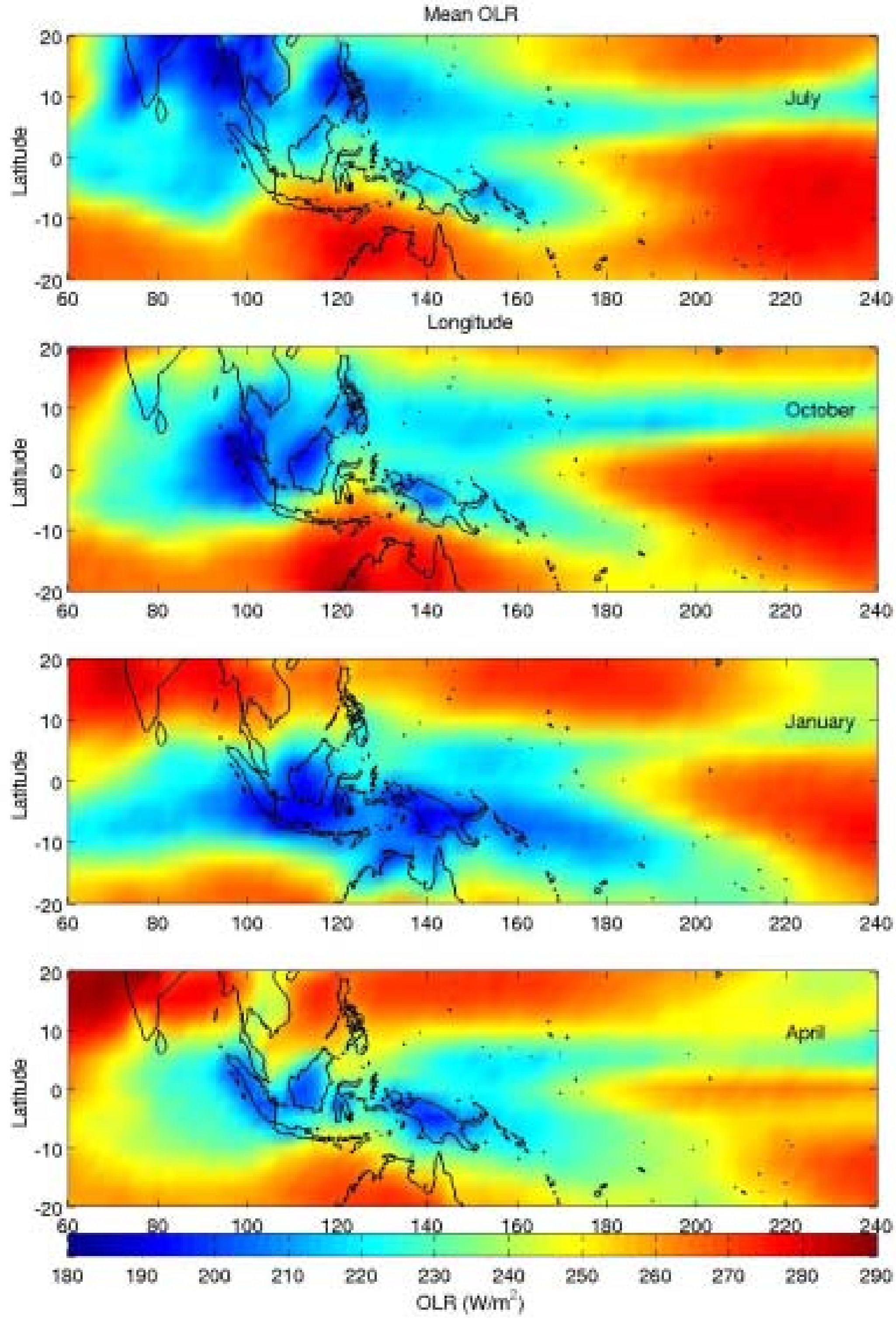

Figure 3. Seasonal OLR patterns in TWP/maritime continent. Data averaged over the 1975-2002 period.

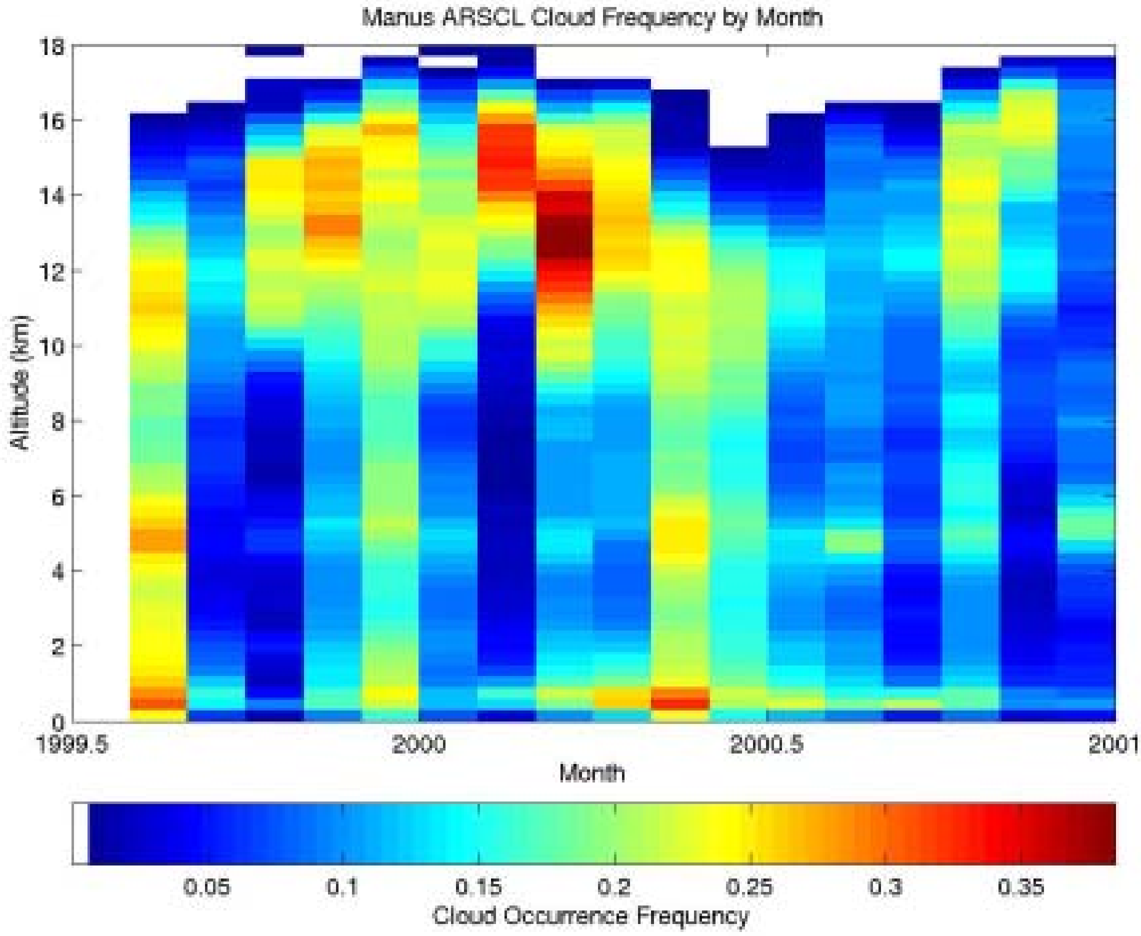

Figure 4. Cloud occurrence frequency data from active remote sensing cloud layer (ARSCL) data derived from radar and lidar data obtained at Manus, PNG.

Local deep convection was common during May-June 2000. As noted previously, near the austral winter solstice, large island convection is suppressed. This creates a situation more favorable for convection over the oceans surrounding these islands. The deep convection in December 1999 may be a result of large-scale dynamical convergence throughout the TWP in response to deep convection over the large maritime continent islands.

The Diurnal Cycle over PNG

As further evidence of the dependence of island convection on time of year, Figure 5 displays one-degree resolution, 10-micron brightness temperature data from the GMS-5 satellite (Nordeen et al. 2001). The data have been plotted for two times of day, evening (09-12Z) and morning (12-24Z). At Manus, local noon occurs at approximately 02Z.

These images illustrate several important points. First, the diurnal cycle over New Guinea is much stronger in January/February than in July/August. This seasonal dependence is consistent with

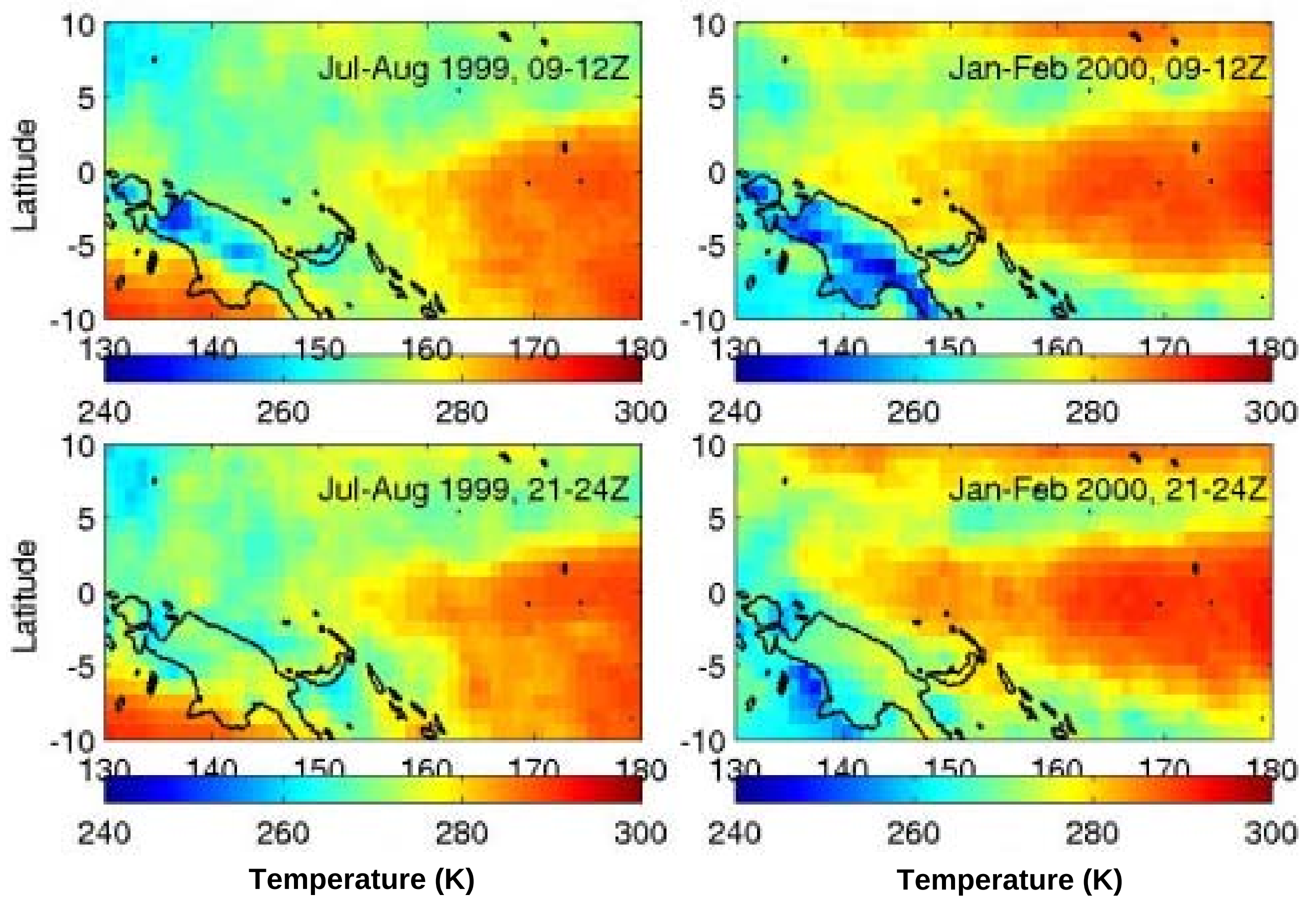

Figure 5. One-degree IR scene temperatures from GMS-5 (provided by Pat Minnis at NASA Langley Research Center).

conclusions drawn from the OLR data. Those data showed the most vigorous convection to occur during the northern hemisphere winter. These brightness temperature data further illustrate that the island convection has a strong diurnal component. Meanwhile, the scene temperature data show that unlike the large island of New Guinea, the diurnal cycle at Manus is weak throughout the year. There is a band of convection around New Guinea associated with the land breeze. This convection is out of phase with the island convection but it appears that Manus is too far from the large island to experience a large impact from this land breeze. There is also a seasonal dependence to this land-breeze convection. Maritime land-breeze convection near the PNG coast occurs primarily to the north of New Guinea in July/August and to the south of New Guinea in January/February. This shift seems to be associated with the general migration of convection north and south of the equator with the monsoon. Finally, the maritime region near Manus is somewhat colder (more convective) during July/August than in January/February.

Observations at Nauru

We have so far concentrated primarily on Manus and the Maritime continent region but a seasonal cycle is also evident at Nauru. During non El Nino years (1999-2000), solar forcing at Nauru is much less pronounced than at Manus. But there is still a seasonal oscillation with the strongest solar forcing occurring during the northern hemisphere summer. A strong annual cycle is observed in the surface wind and sea surface temperature (Figure 6). Strong winds and low temperatures are found near the austral summer solstice. These strong surface winds feed convection in the maritime continent to the west.

The strongest solar forcing occurs with the highest rainfall amounts during the northern hemisphere summer. As with Manus, and other maritime regions in the TWP, convection at this time is more likely as a result of relatively suppressed large island convection. It should be noted that these conditions reflect neutral or cool ENSO (El Nino/Southern Oscillation) conditions. With the onset of an El Nino, tropical convection shifts toward the central Pacific. As a result, much more active convection was observed during the 2002 El Nino than had been observed during the previous three years.

Conclusions

These observations of patterns in fields related to convective activity in the TWP suggest several conclusions. Near the equinoxes, when solar insolation over the maritime continent is a maximum, convection is preferred over the large islands in that region. Maritime convection in the TWP is most common during the northern hemisphere summer when solar heating of land is a minimum and island convection is suppressed. Wide spread convection throughout the Maritime continent during periods of the northern hemisphere winter may be due to large scale convergence initiated by convection over the large islands in October/November. Manus typically lies within this convergence region while Nauru does not (except during El Nino years).

Acknowledgements

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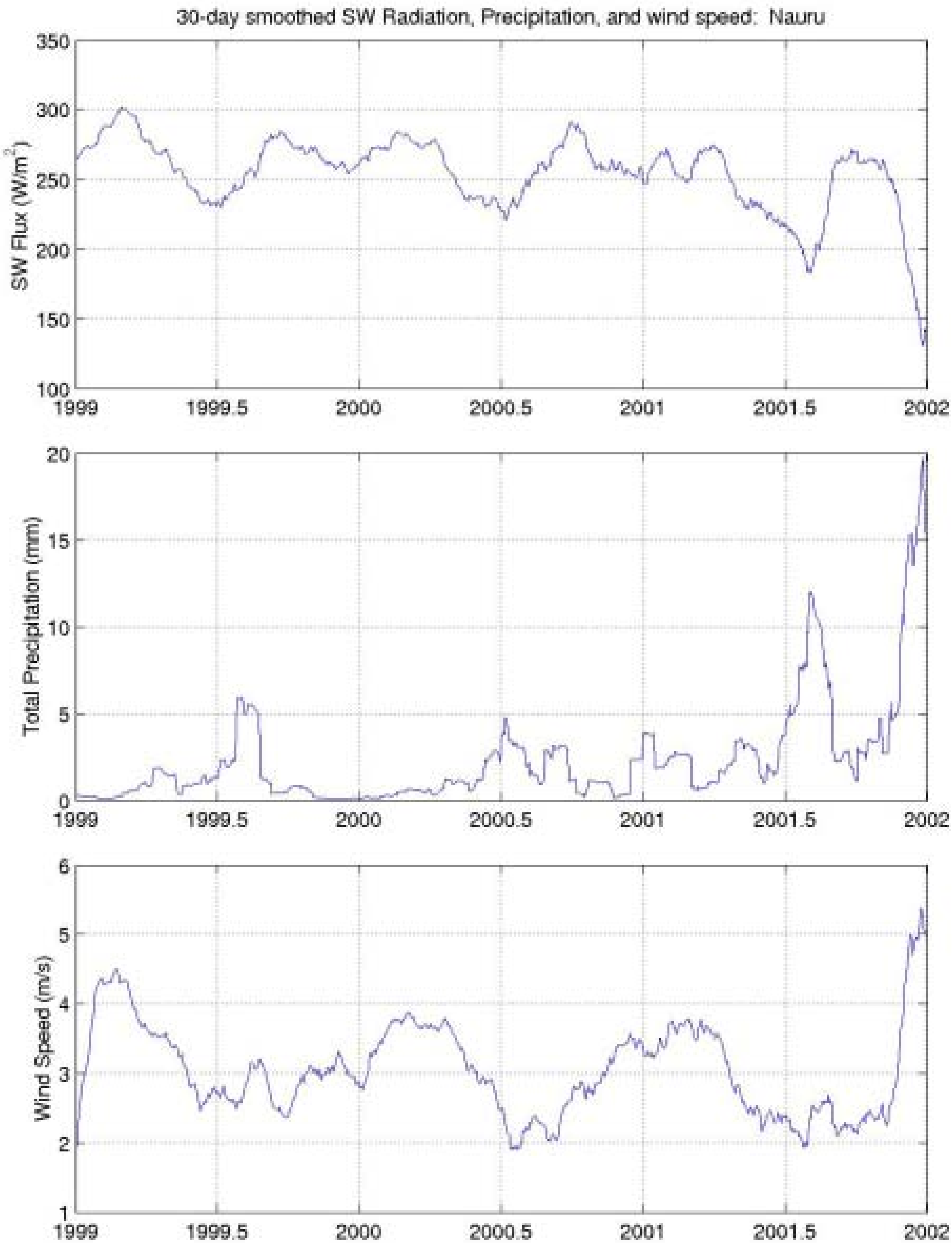

Figure 6. Surface meteorology observations at Nauru.

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