# The Impact of the Annual Cycle on Cloudiness at Manus and Nauru

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## Introduction

Convection is ubiquitous throughout the maritime continent region. The frequency of convection is modulated by a variety of phenomena including the diurnal cycle, intra-seasonal waves, and El Niño/Southern Oscillation (ENSO). While much of this region does not experience seasons to the same degree as one finds in mid-latitudes, the annual solar cycle also has a significant impact on convection throughout the maritime continent and the Tropical Western Pacific (TWP). The Atmospheric Radiation Measurement (ARM) Program has three sites in the TWP region. Each of these exhibits a somewhat different annual convection cycle resulting from its location within the region. Darwin experiences a strong annual cycle associated with the Australian monsoon with active convection being prevalent from December through March and suppressed conditions prevailing from May through September. There have been numerous studies of the Australian monsoon (e.g., Drosdowsky 1996; Hendon and Liebmann 1990) so the following will focus on the annual cycle at Manus and Nauru. The seasonal variation is less pronounced at Manus and Nauru but it may be important for interpreting data collected at those sites and it reveals important processes in the TWP region.

The four panels in Figure 1 show distributions of outgoing longwave radiation (OLR) plotted from National Center 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 while high values (in red) represent clear conditions. 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 largely concentrated over the large islands (New Guinea, Borneo, and Sumatra) of the maritime continent. In July, when solar insolation in the TWP is near its minimum, OLR is significantly diminished over the large islands. In July and October, there is an extended region of suppressed convection north of Australia. Finally, low OLR values are most widespread in the TWP in (and near) January.

Thus the distribution of convection is not uniform throughout the maritime convection and the distribution of convection varies throughout the year. In particular, the relative amounts of convection over land and ocean varies significantly with convection over land being prominent near the equinoxes when solar insolation is a maximum while the land-based convection is at a minimum when the solar forcing is weakest. The widespread convection during the Austral summer coincides with the active phase of the

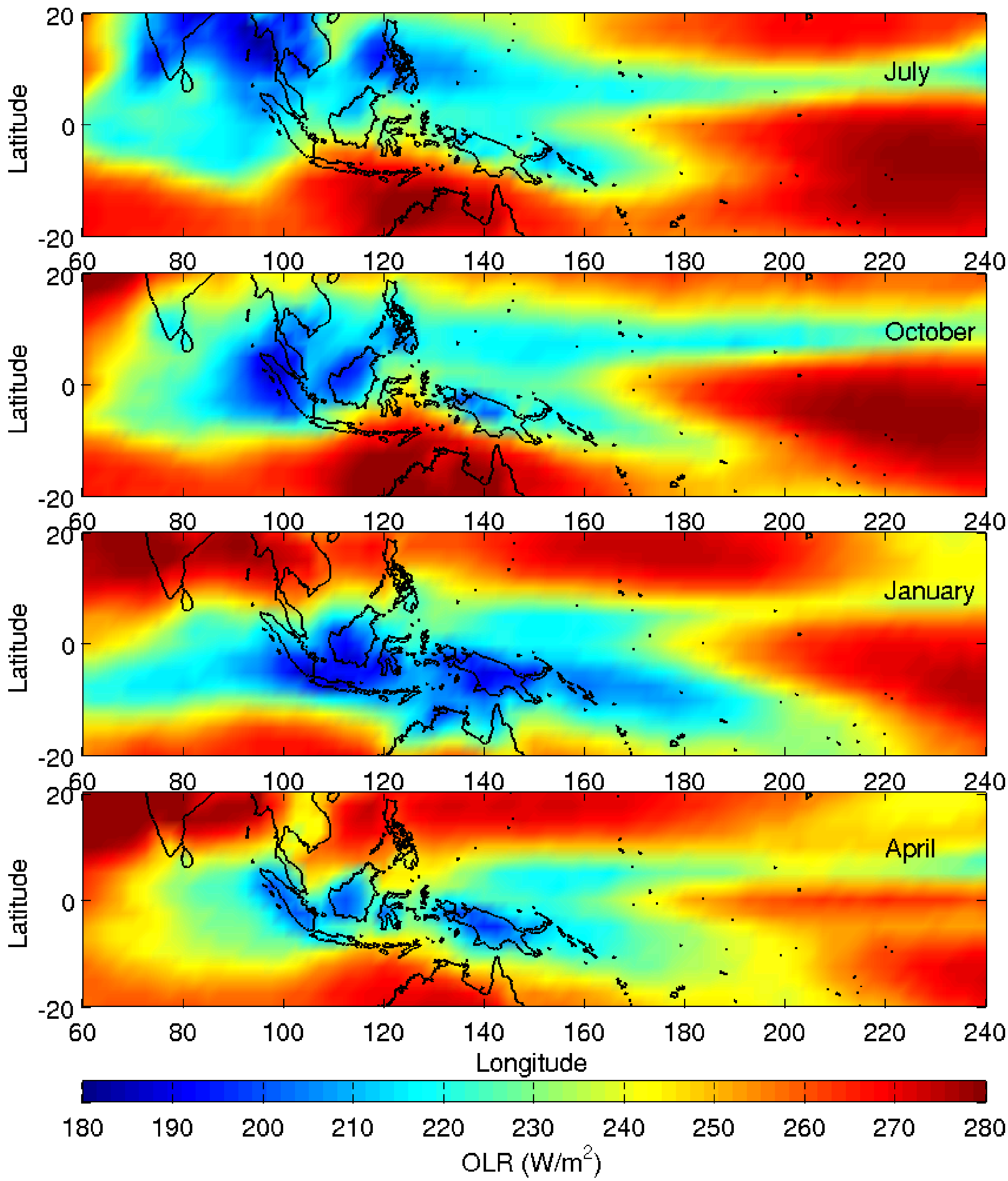


**Figure 1**. Seasonal OLR patterns in the TWP/maritime continent region. Data were obtained from NCEP analysis and were averaged over the period 1975-2002.

Australian monsoon. This pattern should influence cloudiness at Manus, which lies adjacent to the Maritime Continent region.

## Observations of Convective Activity at Manus

The shortwave cloud effect for Manus, defined here as (OBS – CLR)/CLR where OBS is the observed surface shortwave flux and CLR is the calculated clear-sky flux. So a value of –1 corresponds to a measured shortwave flux of zero, while a cloud effect of 0 is associated with clear-sky. These data have been smoothed using Gaussian filters with half-widths of 7 and 20 days (Figure 2).

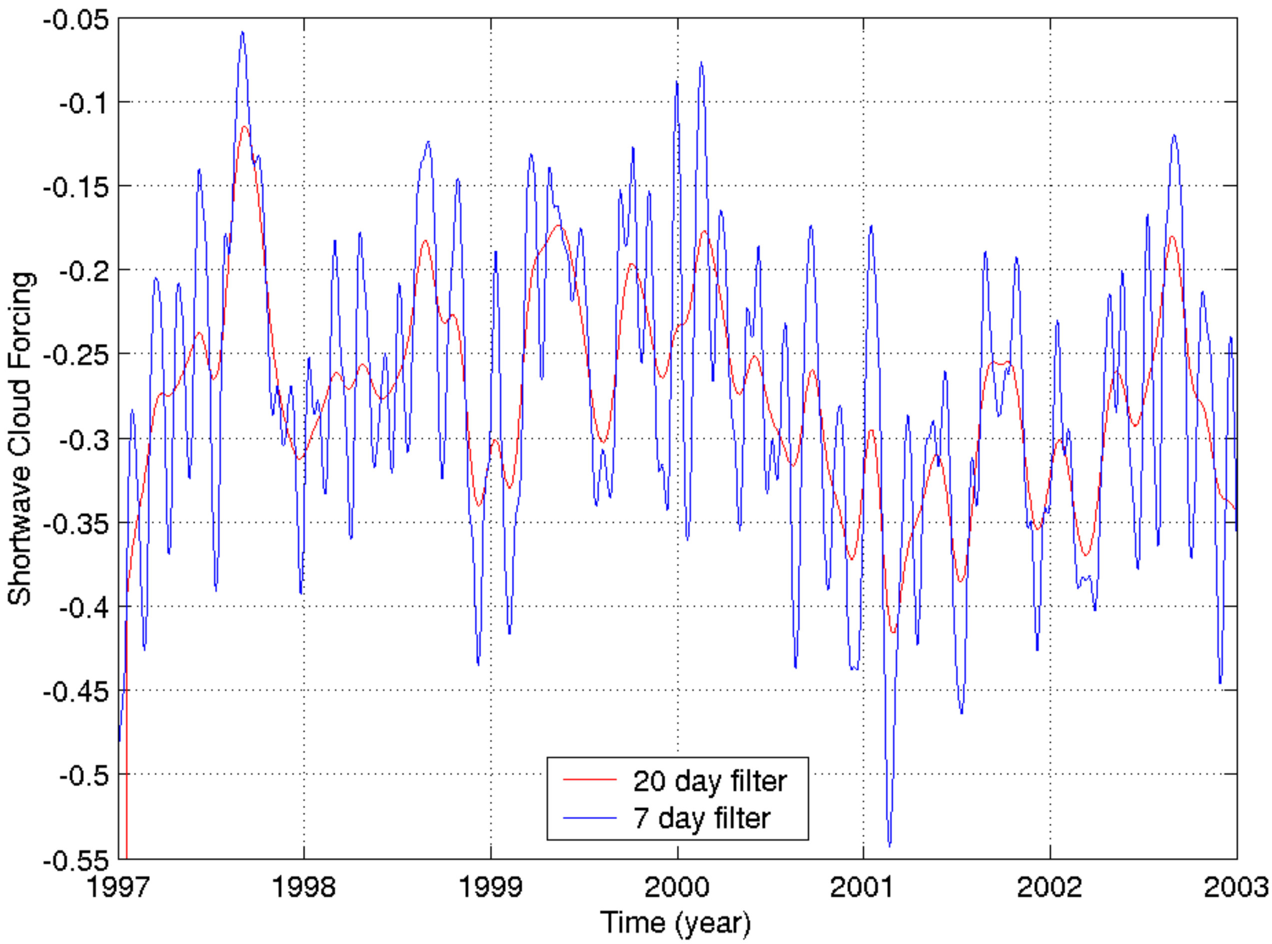


**Figure 2**. Shortwave radiative cloud effect at Manus. The two separate traces have been smoothed with 7-day and 20-day Gaussian filters.

The time series is complex but after careful examination, several interesting features emerge that give clues to the processes affecting convection at Manus. An oscillation resembling the MJO is present throughout the series. In some years (e.g., 1998 and 2000) this intraseasonal feature dominates variability, while in other years (1999 and 2001) a semi-annual cycle is apparent. This semi-annual cycle observed in the shortwave data is consistent with the maritime continent patterns observed in the

OLR data. Further evidence for a seasonal cycle at Manus can be found in the vertical distribution of clouds.

The two primary instruments for detecting clouds over the ARM sites are the millimeter cloud radar (Moran et al. 1998) and the micro-pulse lidar (Spinhirne 1993). Figure 3 shows the frequency with which these instruments observe clouds in a vertical column over Manus as a function of time and altitude for the period September 1999 through November 2000. This period represents the longest period of concurrent lidar and radar data currently available for the Manus site. To produce this plot, the ARM Active Remotely-Sensed Cloud Locations (ARSCL) data product was used. ARSCL combines cloud radar and lidar data to determine the vertical distribution of clouds as a function of time (Clothiaux et al. 2000). One of the features that is most obvious in this figure is the annual cycle of the maximum observed cloud top altitude.

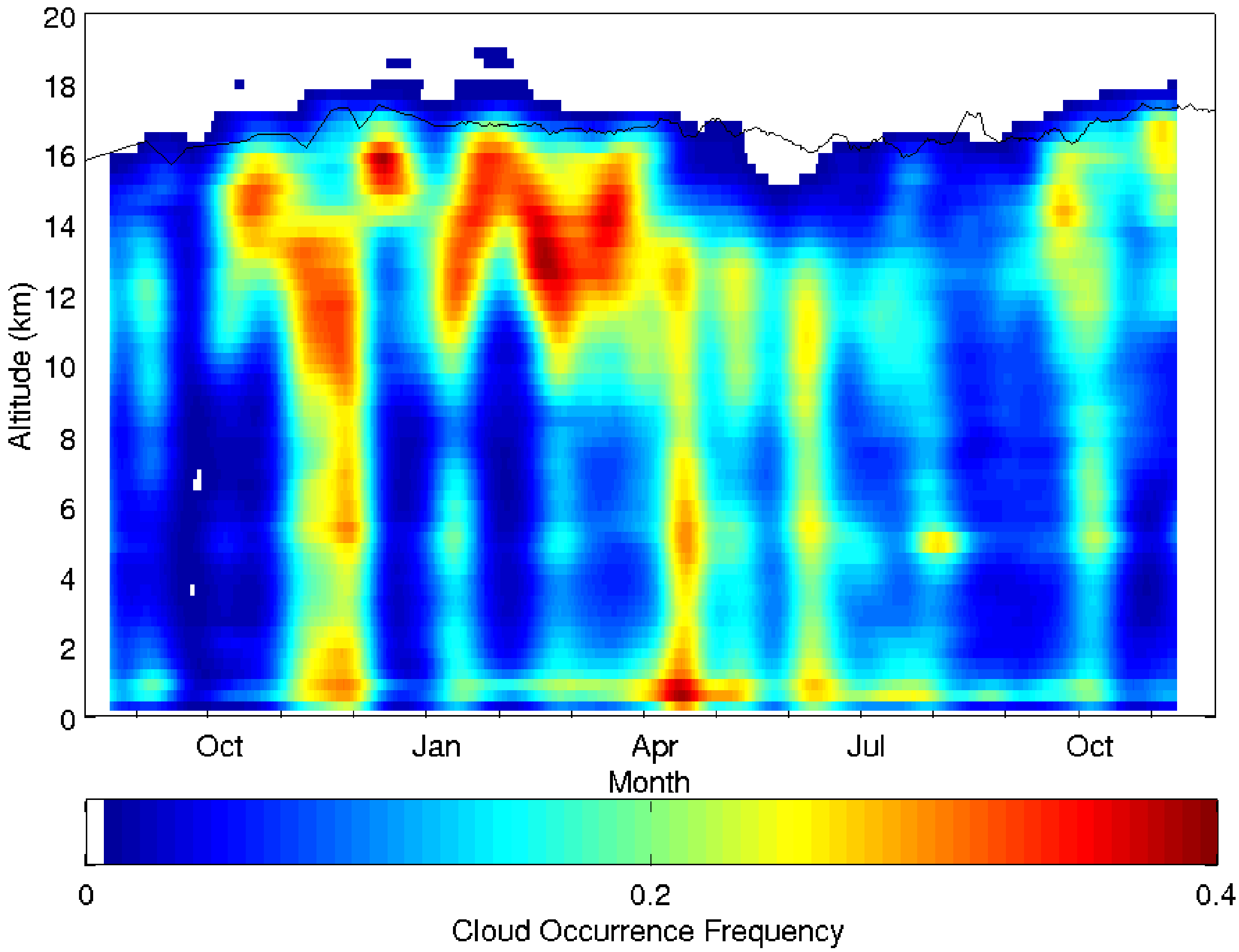


**Figure 3**. Cloud occurrence frequency data from ARSCL data derived from radar and lidar data obtained at Manus. The line plotted adjacent to the cloud top is the cold point temperature derived from Manus radiosonde data.

In Figure 4, the occurrence of clouds above 14 km is compared to OLR over the large island of New Guinea. These data show a strong correlation between convection over New Guinea with high cirrus over Manus. It seems, therefore, that a likely source for the high level clouds over Manus is convection over the larger islands of Papua New Guinea: New Guinea, New Ireland, and New Britain. New Guinea lies approximately 300 km to the south of Manus, while New Ireland and New Britain lie approximately 250 - 500 km to the southeast.

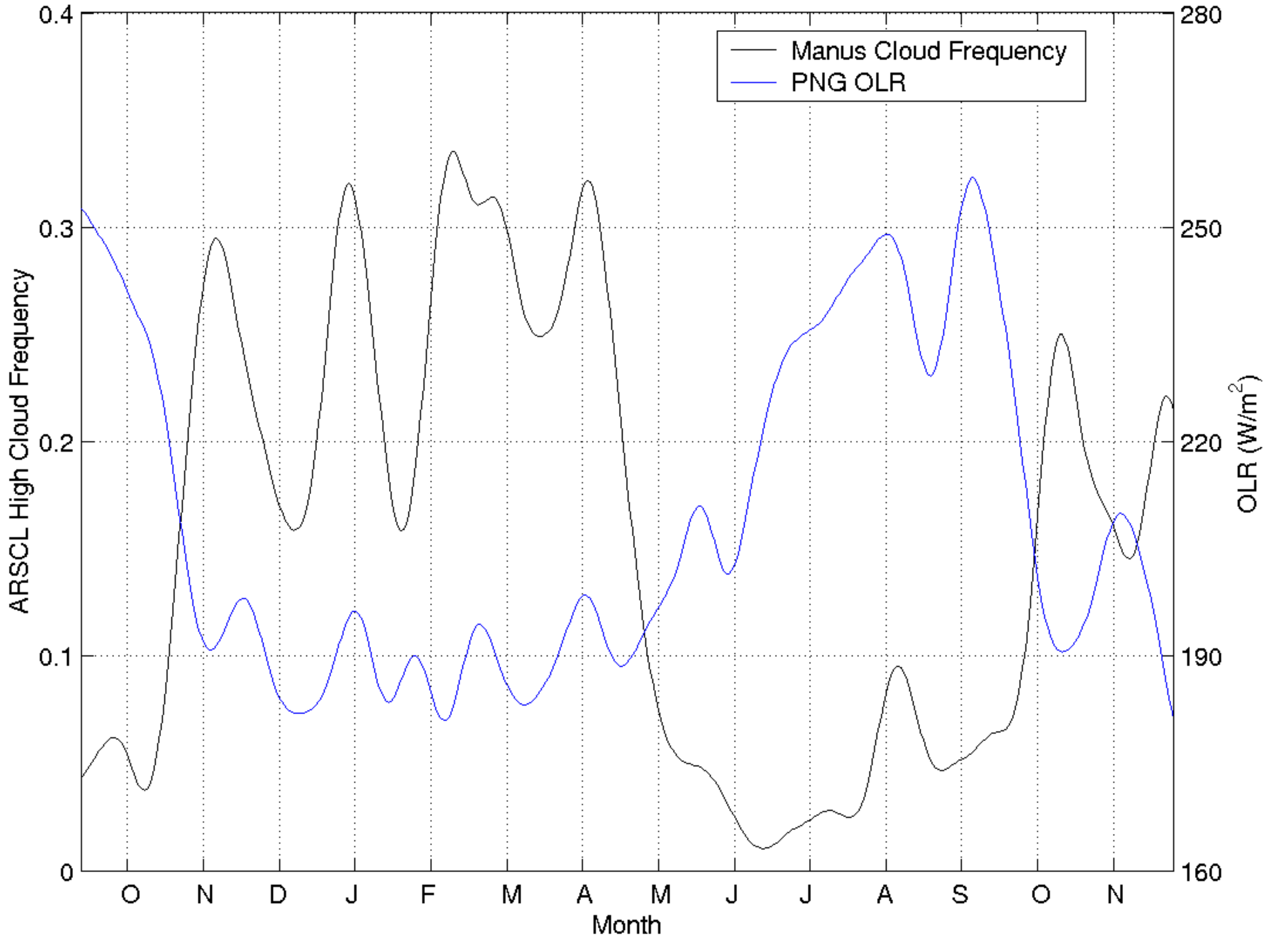


**Figure 4**. Time series of high cloud occurrence frequency over Manus from ARSCL data (solid line) and NCEP OLR (dashed line) over Manus for the period September 1999 through November 2000. High cloud frequency was calculated for the altitude range 14 to 16 km. Both the ARSCL and OLR time series were smoothed using a 7-day half-width filter.

## Observations at Nauru

Beginning in mid-2001, the TWP region began to shift into an El Niño. With this shift, convection became much more prevalent within the central Pacific. The following discussion of Nauru will focus on the preceding two years (1999 - 2000) which reflect neutral or La Nina conditions where convection is concentrated within the maritime Continent and the western Pacific and solar cloud forcing at Nauru is much less pronounced than at Manus.

During this two year period, a strong annual cycle is observed in the surface wind and sea surface temperature (Reynolds and Smith 1995). There is a strong correlation between the wind speed and the sea surface temperature (SST) due in large part to the east-west gradient of SST in the Pacific with cooler water to the East (Figure 5). Strong easterly surface winds advect cooler water into the region and enhance evaporative cooling from the surface. The relatively cool SSTs during northern hemisphere winter would tend to inhibit convection in the region. The strongest solar cloud forcing (period of most active convection) occurs with the highest rainfall amounts near the austral winter solstice. The anti-correlation between convection at Nauru and in the Maritime continent suggests that widespread convection over the maritime continent may also play a role in suppressing convection at Nauru.

During the Northern Hemisphere (NH) summer, conditions are most favorable for convection at Nauru. Convection is weaker to the east, surface winds are correspondingly lighter, and the sea surface temperature is in its warm phase. Together, these factors contribute to the increased frequency of convection that is observed at Nauru during NH summer.

## Conclusions

The goal of this work has been to understand better the regional dynamical phenomena that influence convection at the Manus and Nauru ARM sites. Examination of radiation, cloudiness, and meteorological parameters indicate a seasonal cycle related to the Asia/Australia monsoon.

Convection throughout the Maritime Continent/TWP region is most prevalent in the austral summer during the active phase of the Australia Monsoon. Manus typically lies within the convergence region associated with the monsoon while Nauru does not. Thus, the Manus region experiences large amounts of cirrus during this season.

Near the equinoxes, when solar insolation over the maritime continent is a maximum, convection is preferred over the large islands in that region. At these times, much of the cirrus observed at Manus appears to be advected from convection over the large islands of Papua New Guinea.

Finally, during the austral winter, convection is suppressed over the islands of the maritime continent thus the balance of maritime vs. continental convection in this region is significantly shifted toward maritime convection. The balance between maritime and continental convection is important because the source of cirrus over Manus (Maritime or continental convection) is likely to influence cloud properties. Similarly, the balance of Maritime and continental convection is likely to influence the cloud properties throughout the maritime continent/TWP region.

Nauru lies considerably further from the Maritime Continent than Manus and thus is unlikely to experience anvil outflow from any of the large islands in this region. However, convection at Nauru does appear to be modulated by the annual cycle of convection within the Maritime continent.

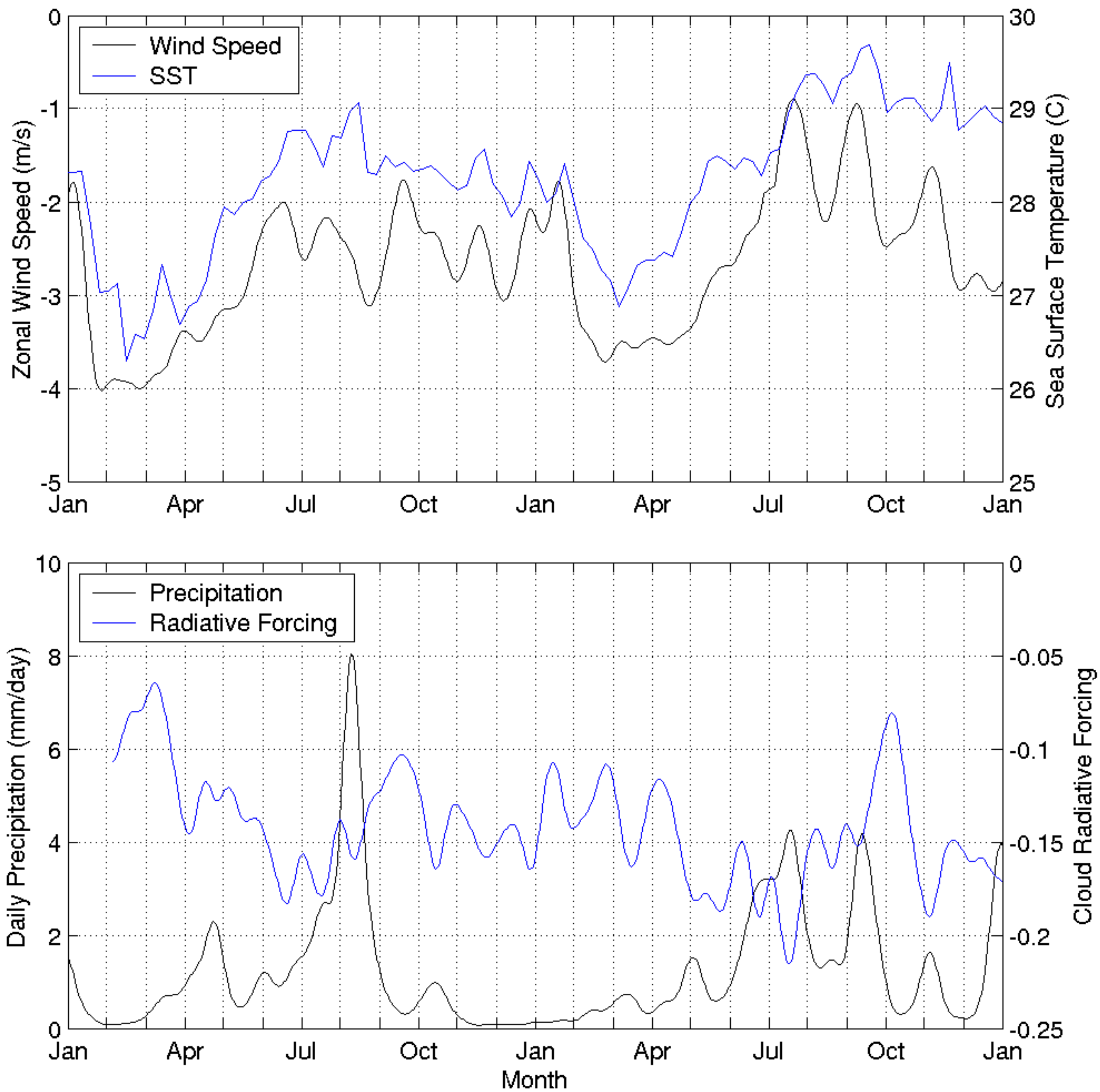


**Figure 5**. Time series of Nauru surface winds, sea surface temperature, precipitation, and cloud radiative forcing for the period January 1999 - December 2000. Wind, precipitation, and radiation data are from the Nauru ARM site while the SST data is from Reynolds analysis (provided by the NOAA-CIRES Climate Diagnostics Center). Taking precipitation to be a proxy for local convection, these data indicate a peak in convective activity during NH summer for the 1999-2001 period.

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