Nauru Island Effect Study

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Introduction

During the Nauru99 field experiment, low-level cloud plumes, which were induced by the island of Nauru and then advected downwind were frequently observed at the site, located on the western side of the island (see Figure 1). This cloud plume forms when warm, moist air is advected over the island and the diurnal heating of the island (relative to the surrounding ocean) induces convection and cloud formation. Although these shallow cumulus clouds have little impact on the total radiation budget of the tropical Pacific region, they may bias the cloud and radiation measurements taken at the site. In an analysis of geostationary meteorological satellite (GMS) 1.25 km visible images from June 1999 through June 2000 by Nordeen et al. (2001), cloud plumes were seen in 50% of the daytime images, with afternoon frequency increasing to 63%.

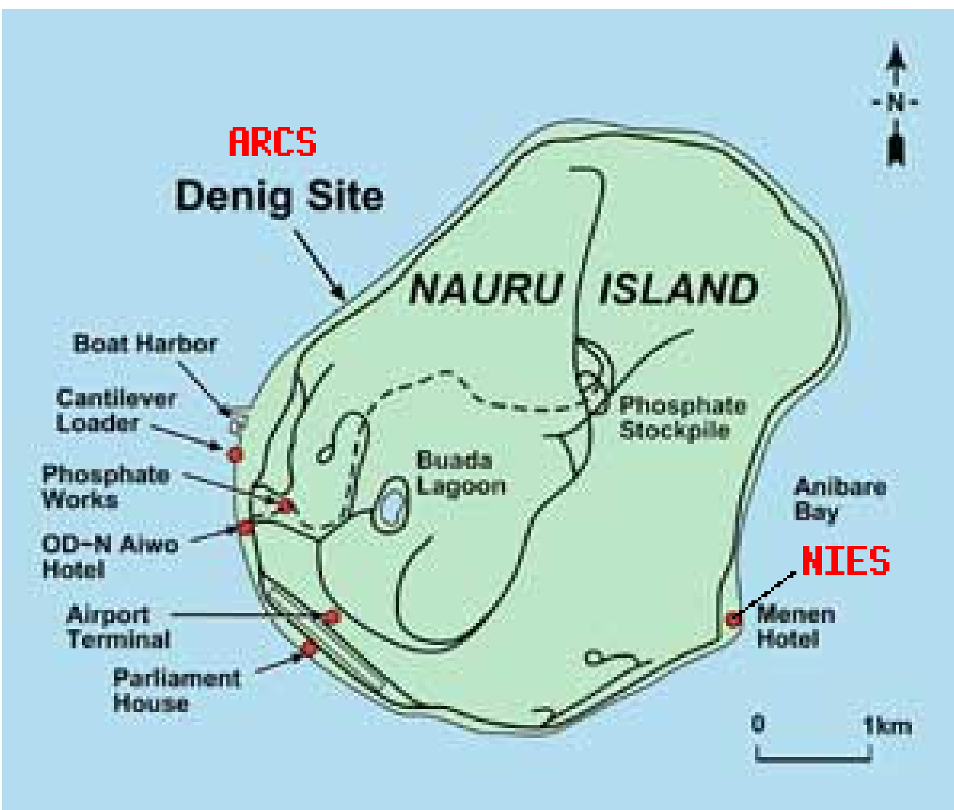

Figure 1. Location of sites.

In order to develop a method to identify times when the island-induced clouds are occurring and to quantify their effect on the measurements at the site, the Nauru Island Effect Study (NIES) was developed. The NIES consists of two parts, the installation of a permanent meteorological station with simple instrumentation (temperature, humidity, wind speed and direction, and total shortwave sensors) at an upwind site, and the temporary installation of a more sophisticated set of instruments (including a ceilometer, multi-filter rotating shadowband radiometer [MFRSR] and suite of Eppley radiometers). The temporary instruments will be used to measure the existence of increased low-level cloudiness and will provide a way of relating the long term basic measurements to the existence of the island-induced cloud plume. The temporary instruments were installed near the Menen Hotel in November 2001 (Widener et al. 2002) and removed in May 2003. Due to several failures of the island's generators and issues with the NIES data logger, data availability from the NIES site prior to September, 2002 is greatly reduced. In this study, only data from September 2002 through May 2003 are analyzed.

Under normal conditions at Nauru, the low-level winds are dominated by the easterly trade wind regime, and the eastern edge of the warm pool experiences suppressed conditions. These were the conditions at Nauru during the Nauru99 field experiment and during the period of the Nordeen et al. (2001) satellite plume analysis. However, during the NIES study period, the tropical western Pacific was experiencing and/or recovering from the El Niño that began in mid-2001. Nauru experienced enhanced convection during this period. Additionally, the easterly trade winds relaxed, and the low-level winds were from all directions. As part of our analysis, we manually examined the visible GMS images (following the method of Nordeen et al. 2001) to determine the plume frequency. During the NIES period, the plume appeared much less frequently. It was seen in only 17% of the visible GMS images and in only 23% of the afternoon images. In addition, the plume heading was seen to be strongly related to the surface wind direction (as seen in Figure 2), and plumes were often seen downwind of both the NIES and the site.

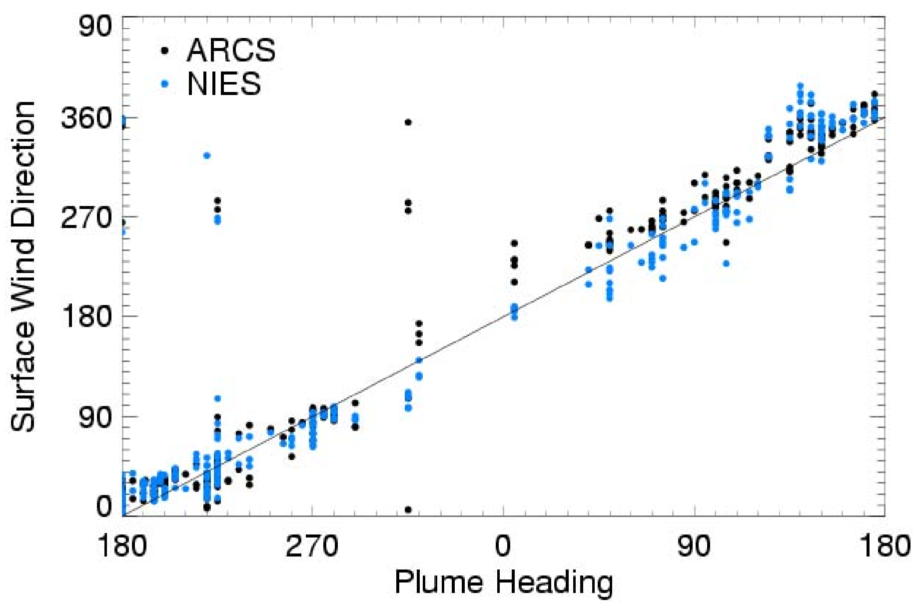

Figure 2. GMS satellite plume headings versus average surface wind direction in 1-hour period centered on satellite observation time.

Identification of Island-Induced Clouds

To identify plume affected periods, the data was broken up into one-hour periods between 0700 and 1700 Local Standard Time (LST). Only periods in which good data existed at both sites were included in the analysis. The average surface wind during the period was used to determine which site was downwind and thus might be affected by the island-induced clouds. Identification of island affected periods was determined by requiring:

- surface temperature at the downwind site to be above a given threshold (as the island has to be warm enough to induce convection)
- low correlation in surface radiation at the two sites during the period (very high values of correlation indicate that the radiation field is dominated by a larger scale system, not a local scale system such as the induced clouds)
- greater variability in the downwelling shortwave radiation measured at the downwind site than at the upwind site.

To assess the cloud plume identification, we examined the frequency of occurrence of low clouds (bases less than 1 km) at each site, as measured by the ceilometer data. Figure 3 shows the distribution of the average low cloud frequency at the site minus the average low cloud frequency at the NIES site. The

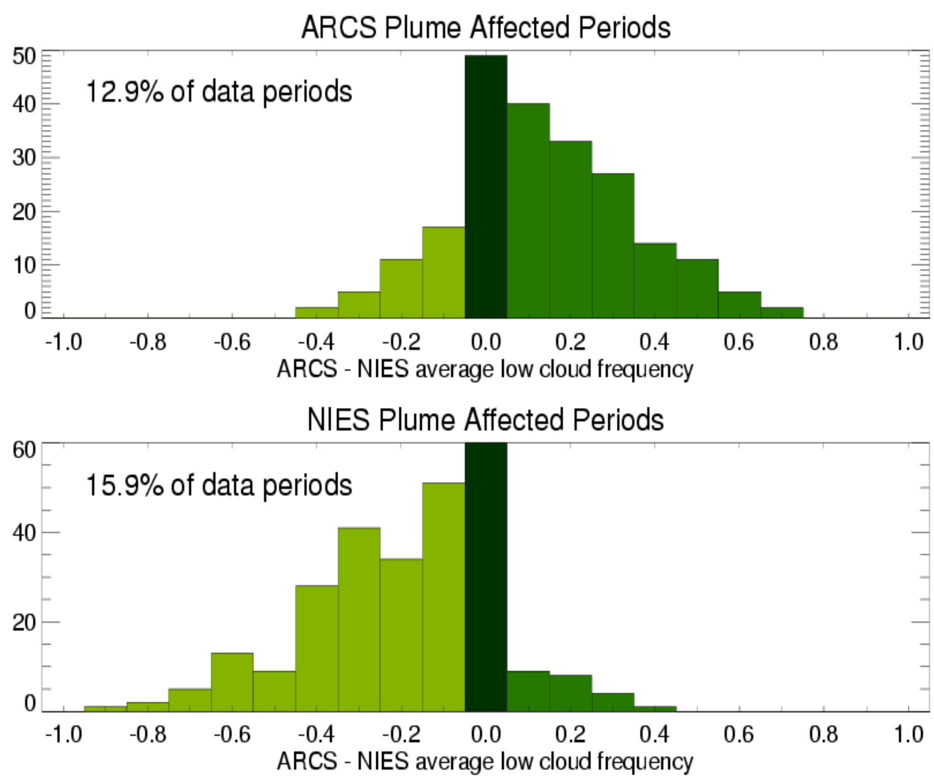

Figure 3. Difference in ceilometer hourly low cloud frequency at the two sites.

darkest bar indicates periods where the absolute difference in the average low cloud frequency at the two sites is less than 5%. The top panel indicates periods identified as affected by the cloud plume at the site. The cloud frequency at the site is greater than or equal to that at the NIES site for 77% of these periods. The bottom panel represents the periods where the NIES site has been identified as affected by the island-induced clouds. In 76% of these periods, the low cloud frequency at the NIES site is greater than or equal to that at the site. Some periods identified as plume affected may have less cloud at the downwind site than the upwind site because during the morning and late afternoon the clouds tend to form slightly downwind of the island rather than directly overhead as they do near noon (Matthews 2003). These clouds might still affect the radiation measurements, but would not be seen by the zenith-pointing ceilometer.

Impact of Island-induced Clouds on the Cloud and Radiation Measurements

To quantify the affect of the plume on the cloud frequency, we looked at the average plume frequency of occurrence for periods that were plume affected and not plume affected at each site (see Figure 4). The average low cloud frequency at the site was 17% for non plume affected periods and 31% for plume affected periods. At the NIES site, the average low cloud frequency was 21% during non plume affected periods and 32% during plume affected periods. Thus, the island-induced clouds are seen to increase the average low cloud frequency from roughly 20% to 30% during the NIES period.

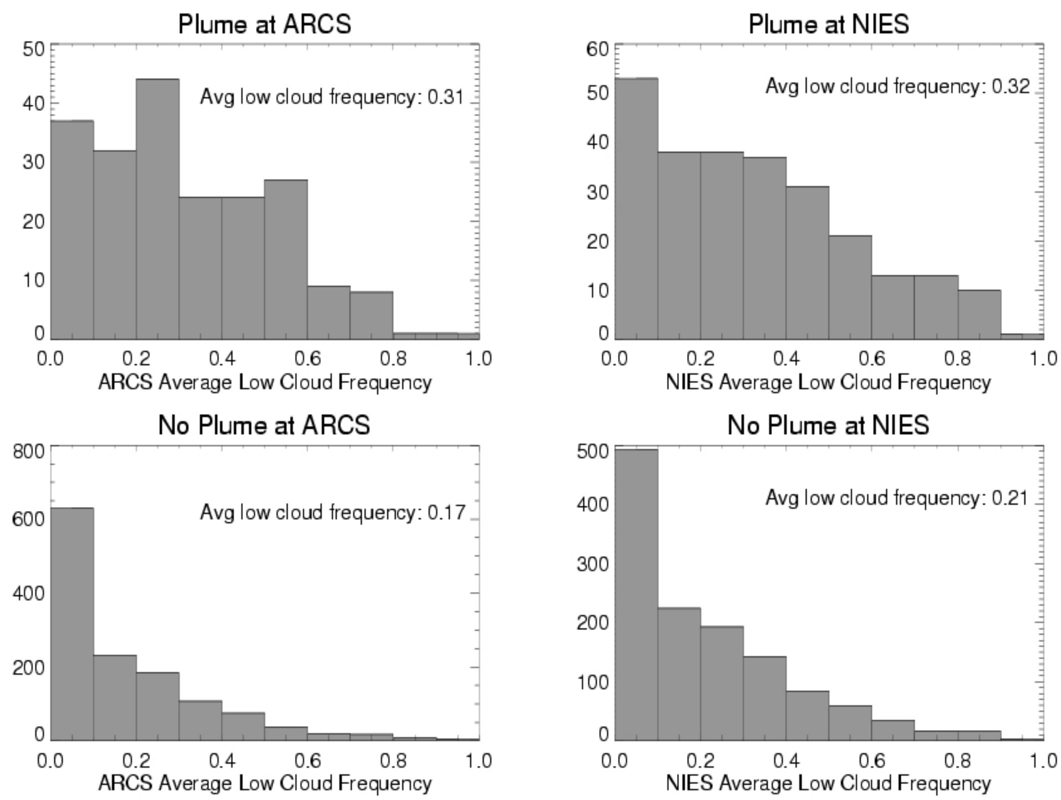

Figure 4. Distribution of hourly average low cloud frequency.

The increase in cloud amount also affects the downwelling shortwave radiation measured at the plume affected site. Figure 5 shows the hourly averaged global shortwave (GSW) radiation measured at each site. Over the entire dataset, the average GSW measured at the two sites is roughly the same. During periods where the site is affected by the cloud plume, the downwelling GSW at the site is notably less than that at the NIES site. Similarly, during periods that the NIES site is affected by the cloud plume, the GSW at that site is less. The site that is not affected by the cloud plume receives an average of 50 to 65 W/m^2 more downwelling GSW than the plume-affected site between 0800 and 1600 LST.

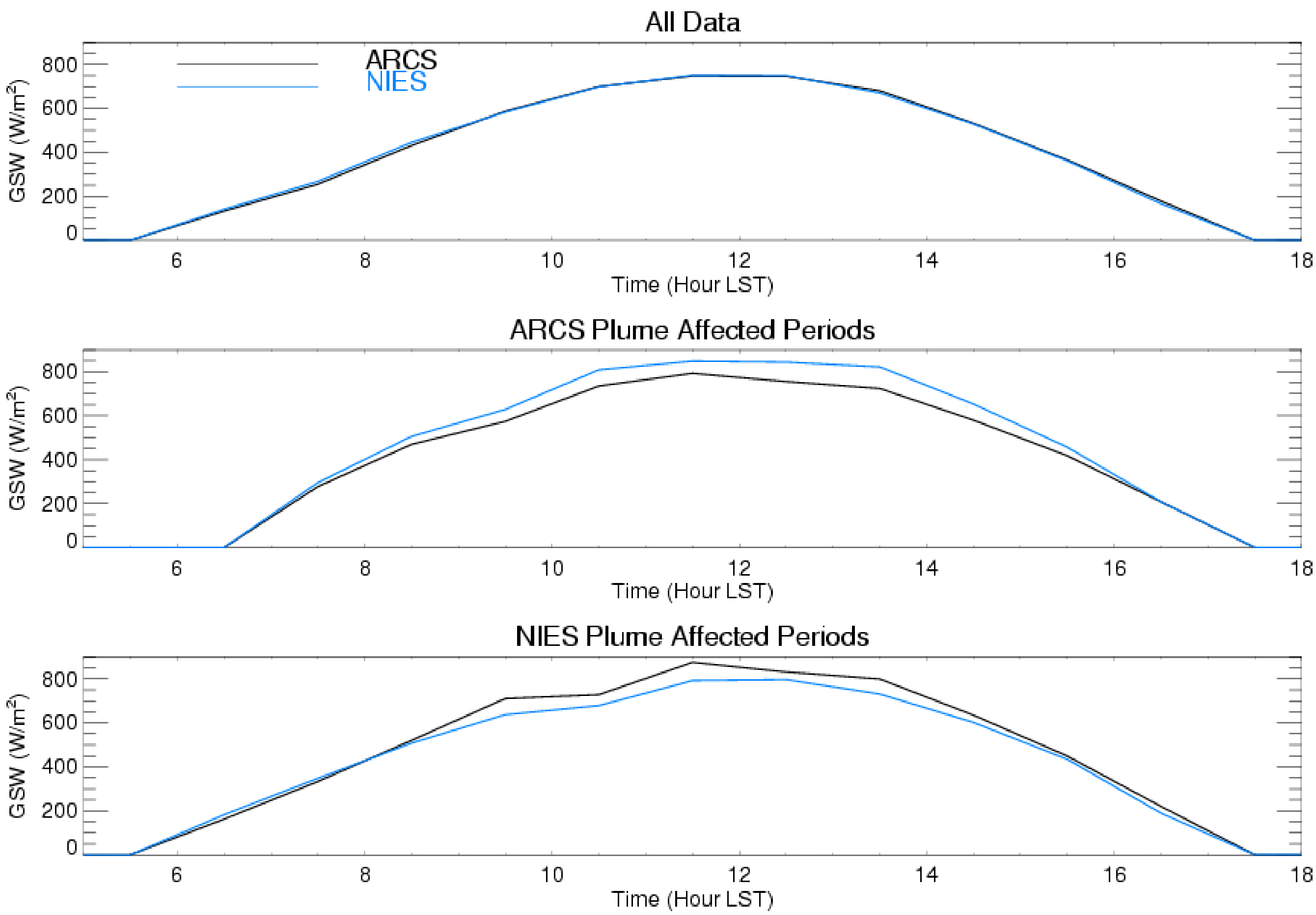

Figure 5. Hourly averaged downwelling GSW at the two sites.

The average ratio of the downwelling GSW at the site to that at the NIES site is shown in Figure 6. For the entire dataset, the ratio is relatively constant, with an average value of 1.02. For the periods where the site is affected by the plume, the ratio is fairly constant in the morning, then decreases in the afternoon. The average value is 0.92. The impact of the cloud plume on the downwelling shortwave radiation at the site is greatest in the afternoon because that is when the plume frequency is the highest and it is also when the plume, which is advecting downwind of the site (i.e., to the west) , blocks the direct solar beam. The ratio at the NIES site is much more variable. It has an average value of 1.08 and is largest in the morning. Although the plume frequency is less in the morning, that is when the plume downwind of the NIES site blocks the direct beam.

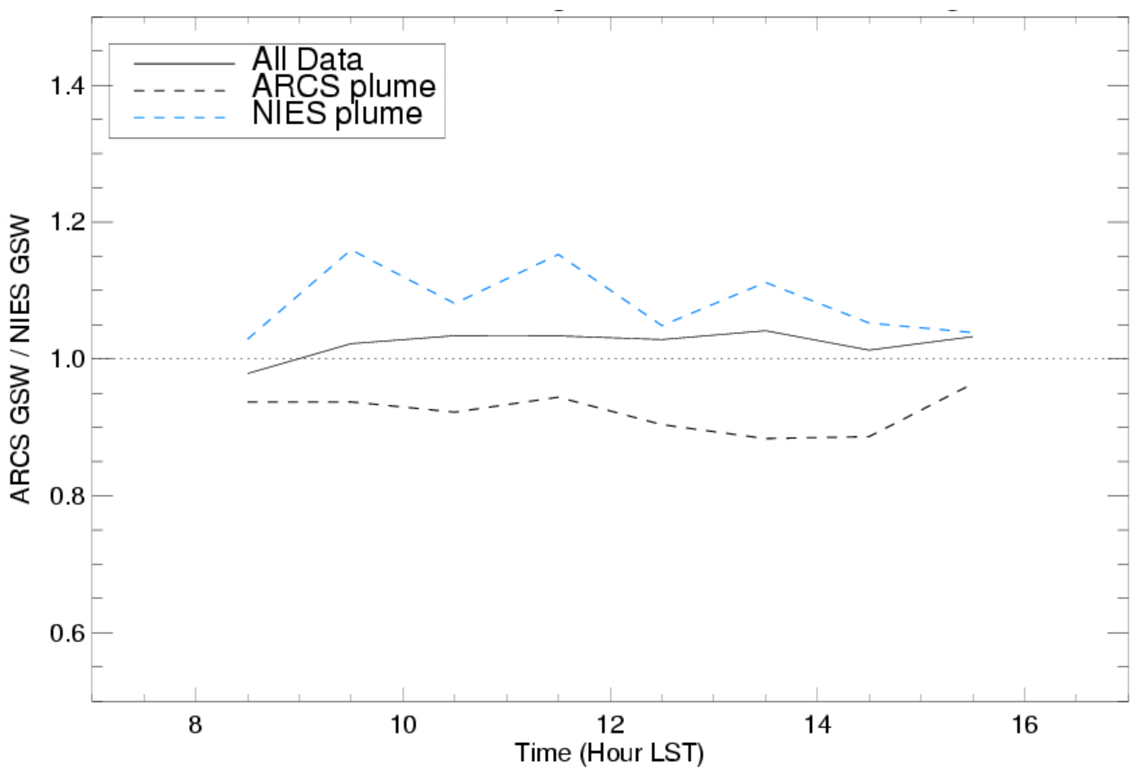

Figure 6. Ratio of downwelling GSW at the site to GSW at NIES site.

Aerosol

A MFRSR was also installed at the NIES site. Differences in aerosol optical thickness and Angstrom coefficient between the NIES and the site were examined as a function of wind direction. In general, during the limited dataset available for comparison, the aerosol optical depths from the MFRSR track well at the two sites (see Figure 7). The differences in optical depth are within the typical uncertainty of 0.02 of the MFRSR.

Cloud Plume Impact During Nauru99

During the NIES period, the winds were more variable and there was enhanced convection (relative to normal conditions at Nauru), making it more difficult to identify the cloud plume and separate its effect on the surface measurements from natural variability. During the Nauru99 period (June 15 to July 15, 1999), the wind was primarily from the east, making the variability in the surface radiation the most important factor in determining the cloud plume existence. We applied the plume identification techniques developed from the NIES study to data from the Nauru99 experiment. During this experiment, two simple meteorological stations with pyranometers were established at upwind sites in the interior of the island. As the results are similar for both stations, we simply show the results from one of these stations, referred to as Topside1.

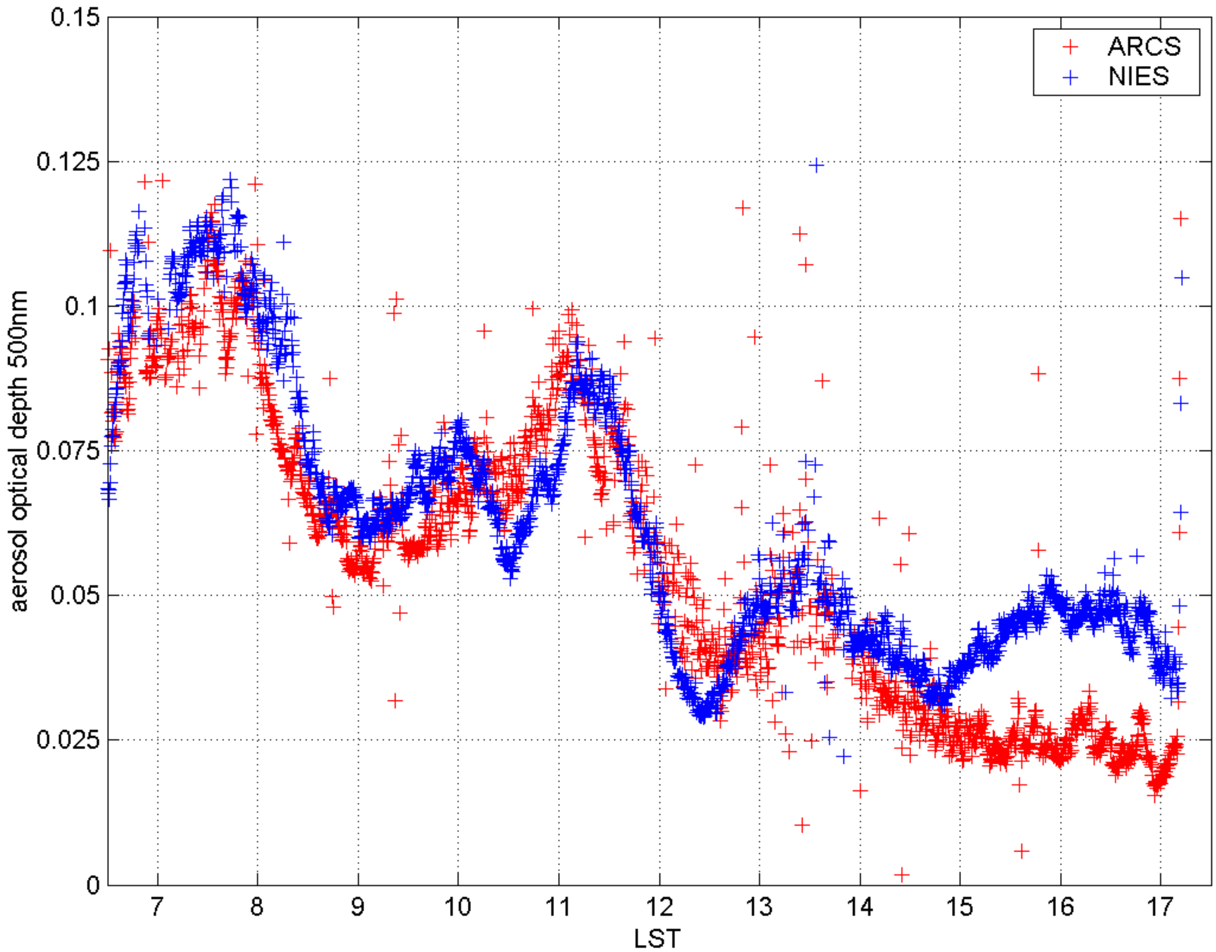

Figure 7. Aerosol optical depths from the MFRSRs at the two sites on May 5, 2003.

Figure 8 shows the average ceilometer low cloud frequency at the site for periods classified as plume affected and non-plume affected (there were no ceilometers at the Topside stations). During no plume periods, the average low cloud frequency was 26%, while during plume affected periods, the average frequency was 44%. Thus, during suppressed conditions, the island-induced clouds increase the low cloud frequency by roughly 18%, a larger impact than that seen during the NIES study. Figure 9 shows the ratio of the site downwelling GSW to that from Topside1 station. Due to the prevalence of cloud plumes during the Nauru99 period (as well as the much shortened data collection time), it was impossible to determine the GSW ratio for periods that were not affected by the plume. However, as for the NIES period, the radiative impact of the cloud plume at the site is seen to be greatest in the afternoon. The average GSW ratio is 0.93, similar to that seen during the plume-affected periods in the NIES experiment.

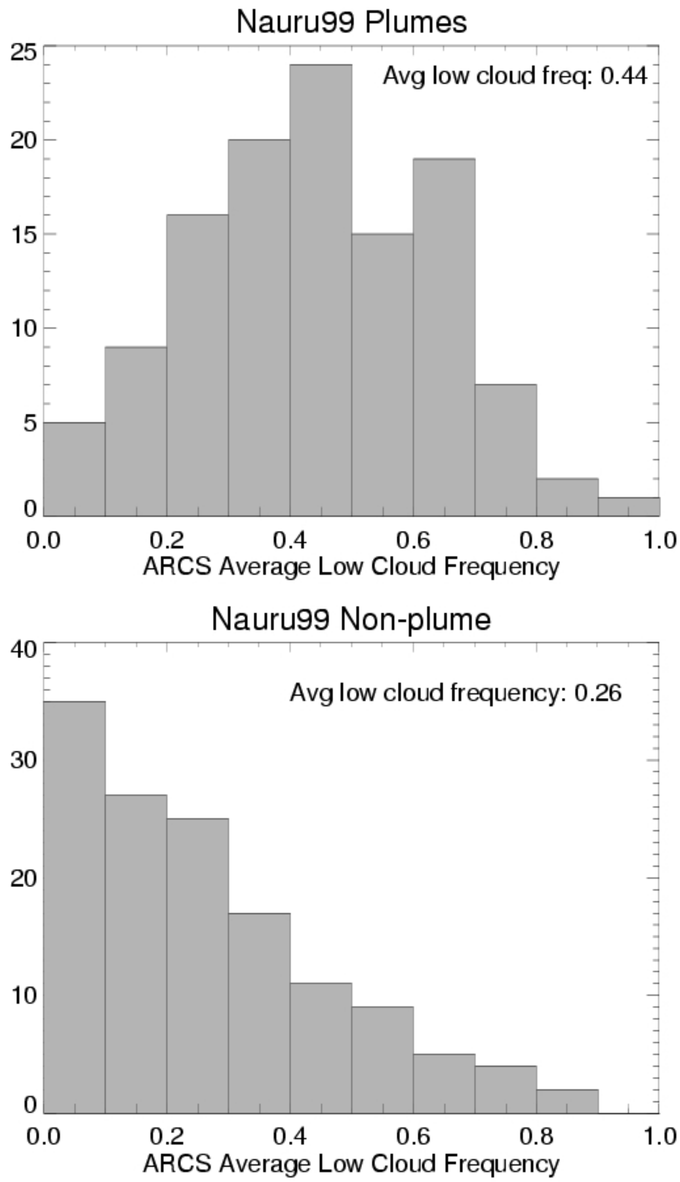

Figure 8. Distribution of hourly average ceilometer low cloud frequency at the site during Nauru99 period.

Summary and Conclusions

We have developed a method of identifying periods when the surface measurements at the site may be affected by the island-induced clouds. During identified periods, the cloud frequency at the downwind site was greater than or equal to that at the upwind site over 75% of the time. Based on the results from the NIES study, the absolute increase in low cloud frequency of occurrence at the affected site is 10% and the average decrease in downwelling GSW at the affected site is 50 to 65 W/m^2. No island effect was seen in the aerosol measurements at the two sites. During the NIES experiment, Nauru was

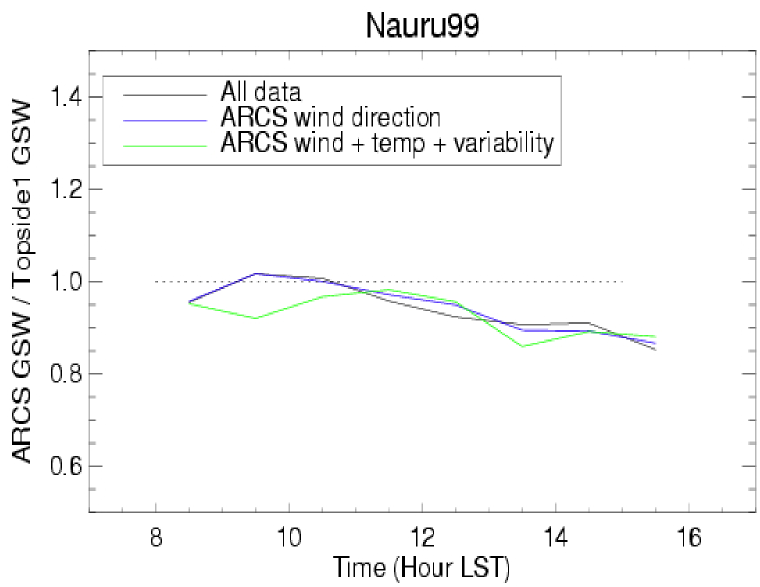

Figure 9. Ratio of downwelling GSW at the site to downwelling GSW at Topside1.

experiencing El Niño conditions, which made the identification of the cloud plume and the quantification of its effect on the surface measurements more difficult. The analysis was also applied to the Nauru99 data, when Nauru was experiencing normal, suppressed conditions. During the Nauru99 experiment, the cloud plume was found to increase the absolute frequency of occurrence of low clouds by 18%, although the effect on the GSW was found to be similar. While the simple, permanent instrumentation is not sophisticated enough to unequivocally identify times when the cloud plume is occurring, it can be used to identify times when the plume is most likely to be affecting the surface measurements. Additionally, by having a measurement of downwelling radiation at a second site, the effect of the cloud plume on the measured radiation field at the site can be quantified on a long term basis.

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