Preliminary Analysis of the Nauru Island Effect Study Data

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Introduction

During the Nauru99 field experiment (held during June and July of 1999); the presence of an island effect on the cloud and radiation measurements recorded from the Atmospheric Radiation Cloud Station (ARCS) site at Nauru was identified. The island cloud effect occurs when moist air is advected over the island and the diurnal heating of the island (relative to the surrounding ocean) induces convection and cloud formation (Nordeen et al. 2001). The ARCS site was located on the leeward side of the island (relative to the prevailing easterly trade winds) due to a limited choice of available sites on Nauru. Although the increased cloudiness due to the island has a relatively small effect on the radiation budget in the region, it may cause the radiation and cloud measurements at the ARCS site to be biased relative to the surrounding ocean.

To determine whether the island cloud effect can be detected and its effect on the measurements at the ARCS site quantified, the Nauru Island Effect Study (NIES) was developed. The NIES consists of two parts: (1) a permanent installation of simple, low maintenance instrumentation at an upwind site to allow the longterm study of the island cloud effect and (2) a temporary installation of more sophisticated instruments to quantify the island effect on cloud amount and surface radiation. A suite of instruments including a ceilometer, met station, LI-COR pyranometer, Eppley pyranometer and pyrheliometer, total sky imager (TSI), and infrared sky thermometer (IRT) were installed near the Menen Hotel (see Figure 1) in early November, 2001. Wind direction and relative variability in downwelling shortwave (SW) measurements at the two sites will be used to identify times when the island cloud effect is occurring; the ceilometer data will be used to confirm the presence of the island cloud effect. Assuming the data are useful in detecting the island effect, the LI-COR pyranometer and met station will be left permanently at the upwind site

Method

We examine 3-hour averages of wind, radiation, and cloud measurements at the two sites. The main requirement for the existence of the island effect is that the wind must consistently blow over the width of the island before reaching the site.

Normally, Nauru lies in the path of the easterly trade winds. However, during El Niño conditions, the easterly trade winds weaken in the tropical western Pacific. Figure 2 shows the effect of an El Niño, which began in mid 2001, on the wind direction measured at the ARCS site. Although the instruments were installed at the NIES site in November of 2001, due to problems with the NIES data logger, little

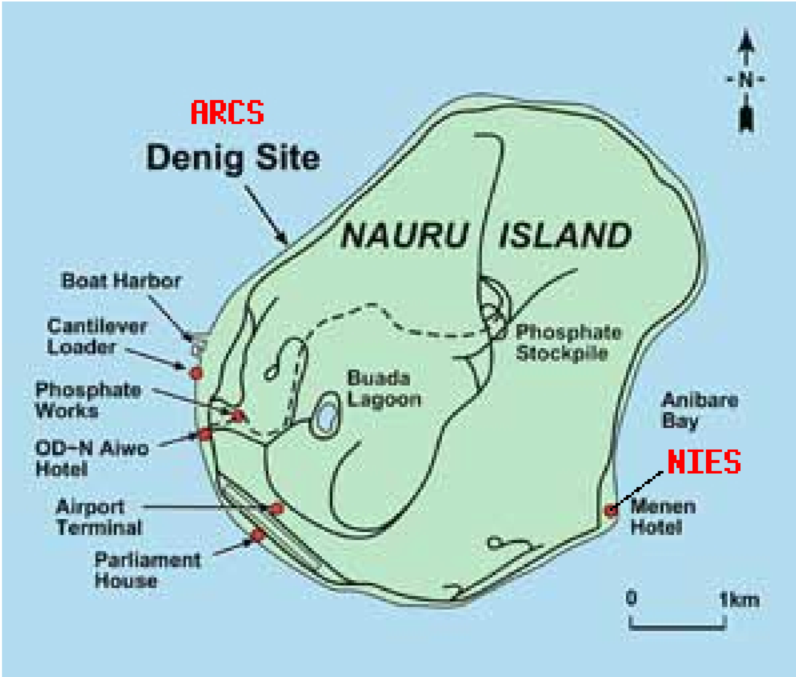

Figure 1. Map of Nauru indicating location of the ARCS and NIES sites.

usable data exists prior to September, 2002. Therefore, we have only 395 periods with good radiation, met station, and ceilometer data at both sites. Of these, only 65 periods have average wind directions from the east or southeast, such that an island cloud effect might exist at the ARCS site. To increase the number of periods available for analysis, we also consider that an island cloud effect might be seen at the NIES site, if the wind is consistently from the west or northwest over the period. An additional 114 periods fit this criteria. We classify the winds at each site as being land-influenced if the average wind direction for the period is $60° < \theta < 200°$ for the ARCS site or $240° < \theta < 350°$ for the NIES site. If the time period is land-influenced, we examine the magnitude and variability of the SW radiation at the two sites to determine if an island cloud effect is likely. We then examine the low cloud amounts determined from the ceilometers at the two sites to assess whether the classifications are correct. For days identified as having an island cloud effect, we attempt to quantify the effect of the island-induced clouds on the daily radiation budget.

Identifying the Island Cloud Effect

We assume that either site can experience the cloud effect if the average wind direction at the site over a 3-hour period indicates that the wind consistently blew across the width of the island before reaching the site. Figures 3 and 4 illustrate that the island cloud effect can be seen at either the NIES or ARCS sites, depending on the cloud direction. The top panel in each plot shows time series of downwelling global shortwave (GSW) radiation at the two sites, while the 2nd panel shows the variability in the normalized downwelling GSW at the ARCS site minus that at the NIES site, the 3rd panel shows the ceilometer cloud bases at the two sites, and the bottom two panels show histograms of the wind direction at each

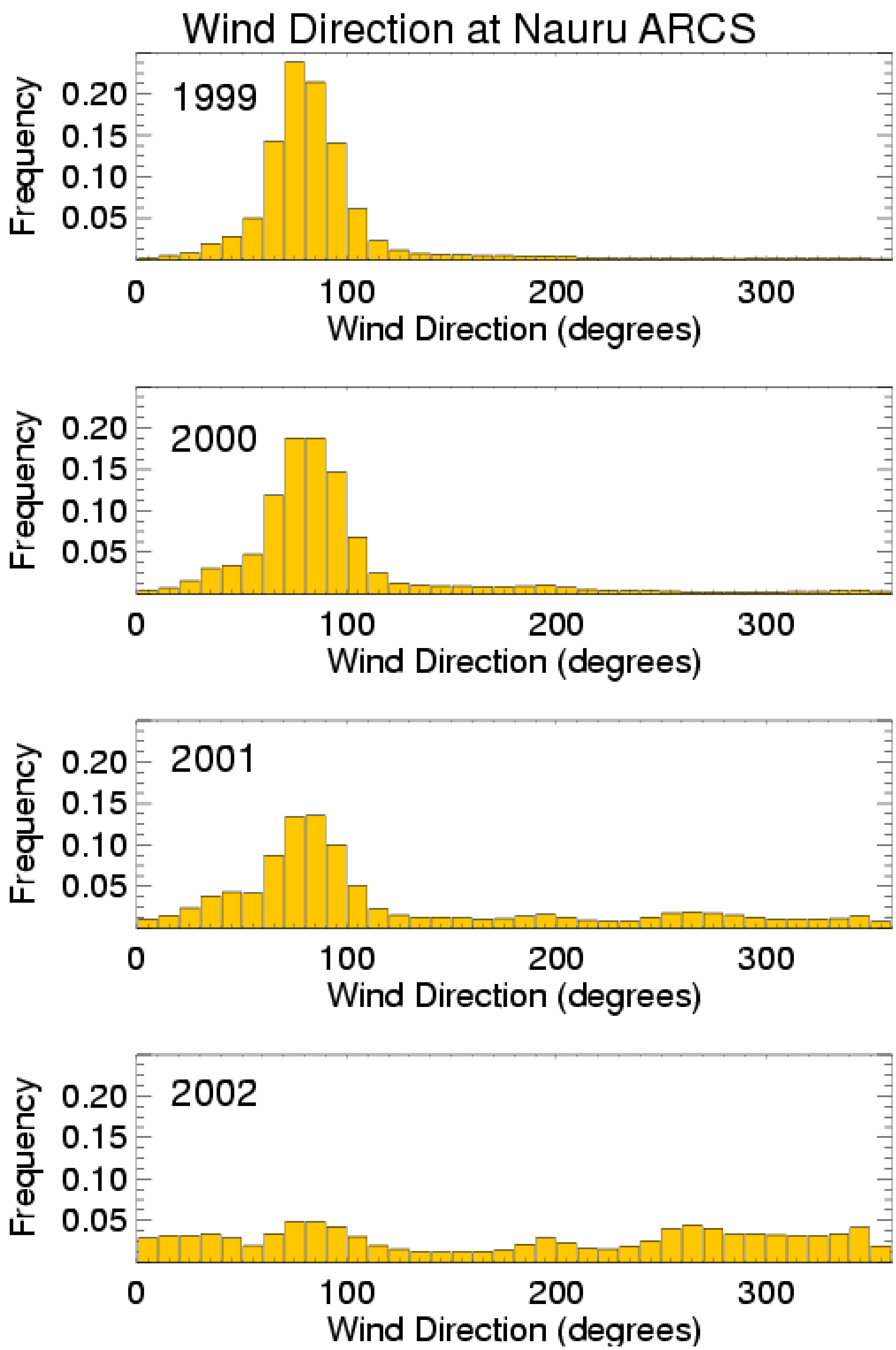

Figure 2. Histogram of the wind direction at the Nauru ARCS site for the years 1999-2002. The effect of the El Niño that began in mid-2001 on the wind direction can clearly be seen.

site. In Figure 3, an island cloud effect at the ARCS site is illustrated. The wind direction at both sites is primarily from the east and the ARCS site shows less downwelling shortwave radiation at the surface, more variability in the normalized downwelling shortwave, and higher low cloud amounts than the NIES site. In Figure 4, an island cloud effect at the NIES site is illustrated, with the winds coming from the west and more cloud amount and variability in downwelling shortwave at the NIES site than the ARCS site.

As a first step in identifying the island cloud effect, we classify each period as having no land influence, being land-influenced at the ARCS site, or being land-influenced at the NIES site. We then examine the low cloud frequency of occurrence measured by the ceilometer at each site. Figure 5 shows histograms of the ARCS low cloud frequency of occurrence minus the NIES low cloud frequency for all data periods, and for periods identified as land-influenced at each site. The boxed values give the percentage of periods for which the ARCS frequency of occurrence is larger. For the entire set of data, the ARCS low cloud frequency of occurrence is larger 39% of the time; however, for periods we identified as land-influenced at the ARCS site the ARCS low cloud frequency of occurrence is larger 67.7% of the time and for periods identified as land-influenced at the NIES site the ARCS low cloud frequency is greater only 21.1% of the time. These results indicate that the primary indicator of the island cloud effect is wind direction, as expected.

A secondary indicator of the island effect is variability in the normalized GSW. An island cloud effect is more likely if the variability in the normalized GSW is greater at the land-influenced site than at the other site, and if the magnitude of the variability is above a certain value. The top two panels of Figure 6 show the low cloud amount at both sites for ARCS land-influenced periods. Boxed values indicate the percentage of periods for which the ARCS low cloud frequency of occurrence is greater than the NIES low cloud frequency of occurrence. The bottom two panels show similar results for the NIES land-influenced periods. For periods that are classified as land-influenced at the ARCS site and for which the variability in normalized GSW at the ARCS site is greater than 0.12 and is greater than the variability at the NIES site, over 76% of the periods have a larger frequency of occurrence of low clouds at the ARCS site. For the same conditions at the NIES site, only 95.1% of the periods have a larger frequency of occurrence of low clouds at the NIES site.

Analysis of other variables, such as the magnitude and variability of the IRT measurements, wind speed, direct and diffuse flux, surface temperature, pressure, and relative humidity, resulted in no significant improvement in identifying the occurrence of the island cloud effect.

Influence of the Island Cloud Effect on Daily Radiation and Cloud Measurements

The previous results have shown that we can identify time periods when the island effect is occurring based on wind direction and variability in the GSW. We also want to determine if we can quantify the effect on the daily radiation and cloud measurements. Once the intensive observation period is over in May 2003, the more sophisticated instrumentation will be removed from the NIES site, and only the LI-COR pyranometer and surface met station will remain to identify and quantify the island cloud effect.

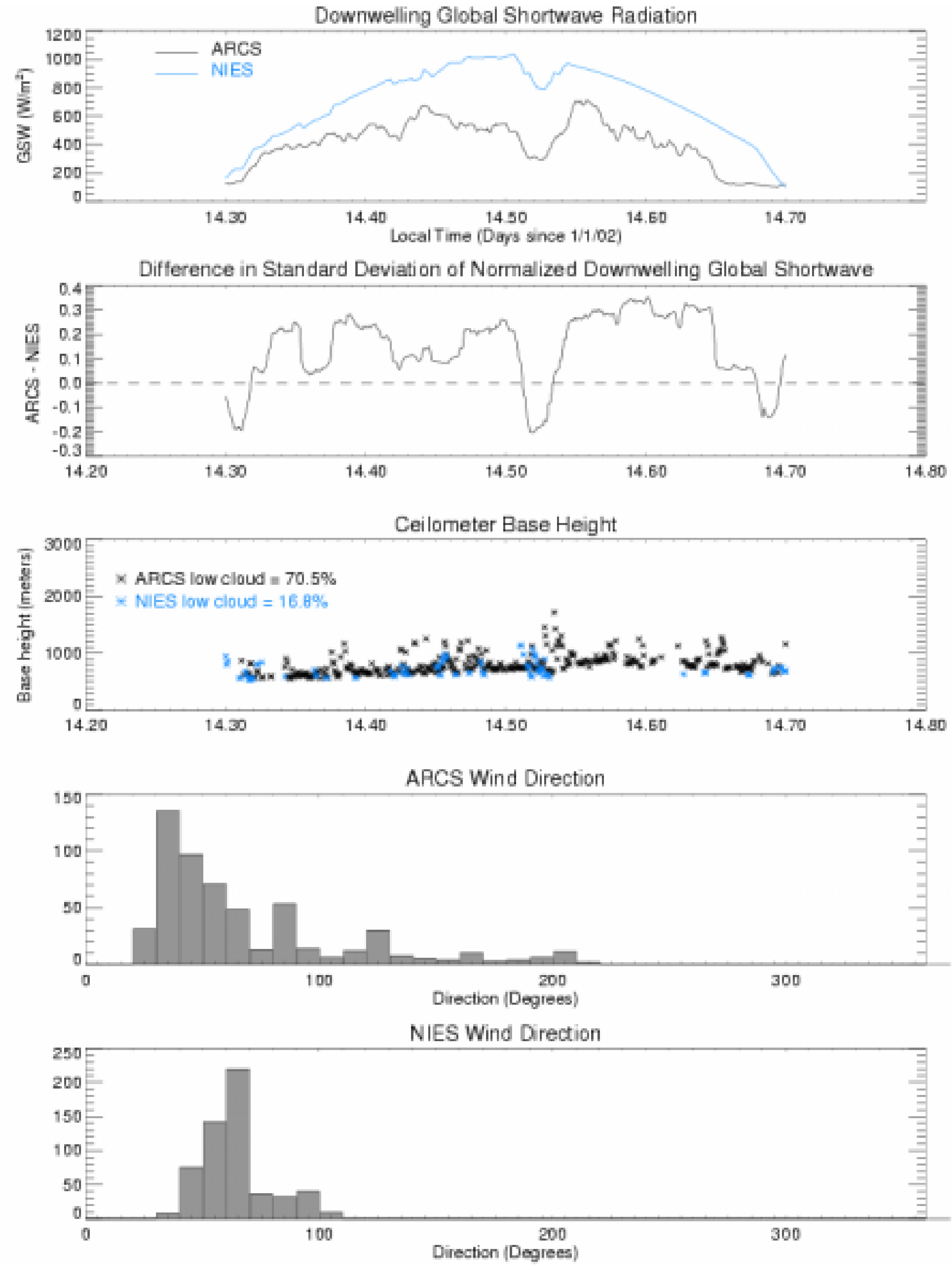

Figure 3. Example of the island cloud effect at the ARCS site illustrated by the high variability in normalized GSW relative to the NIES site and the increased low cloud amount.

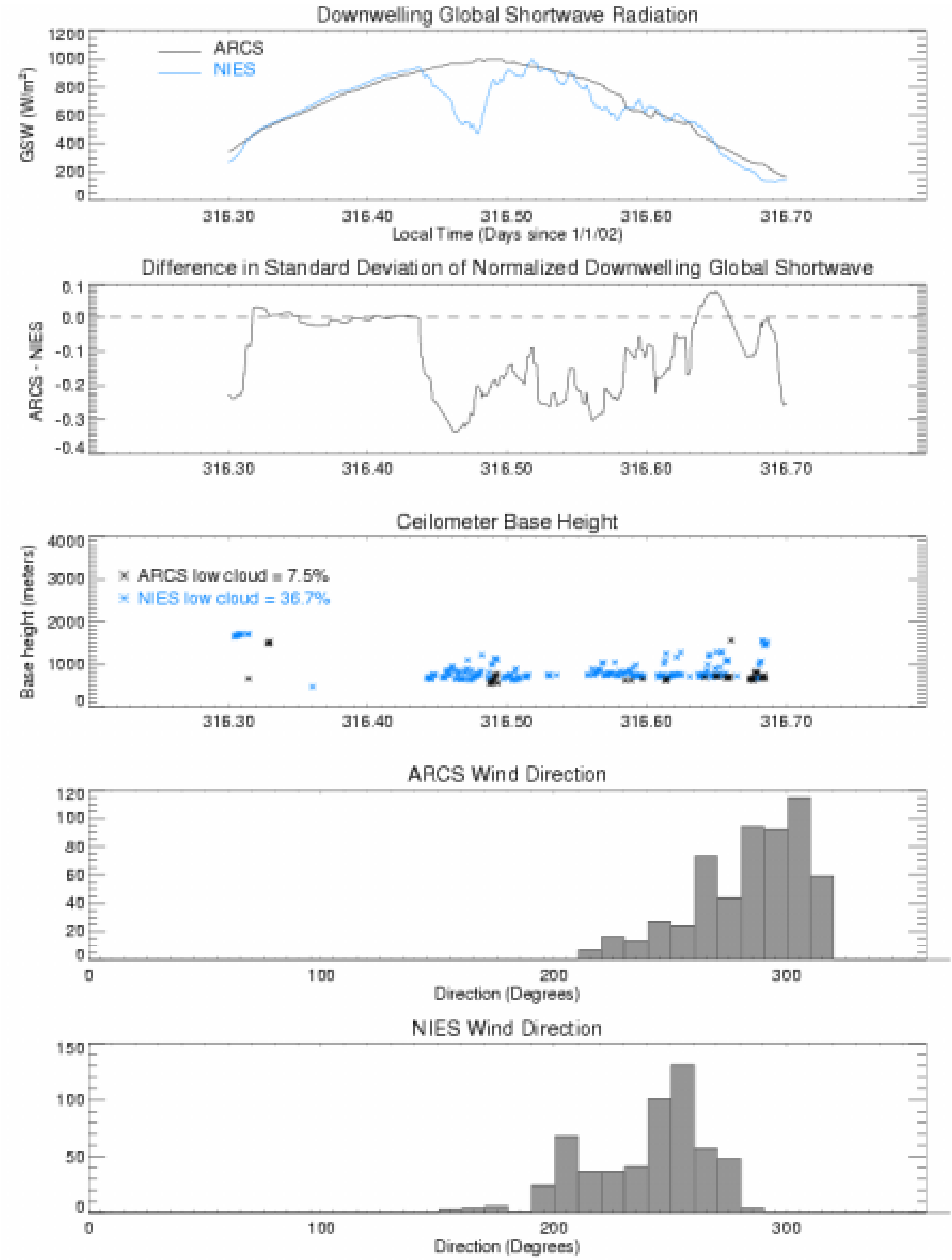

Figure 4. Example of the island cloud effect at the NIES site.

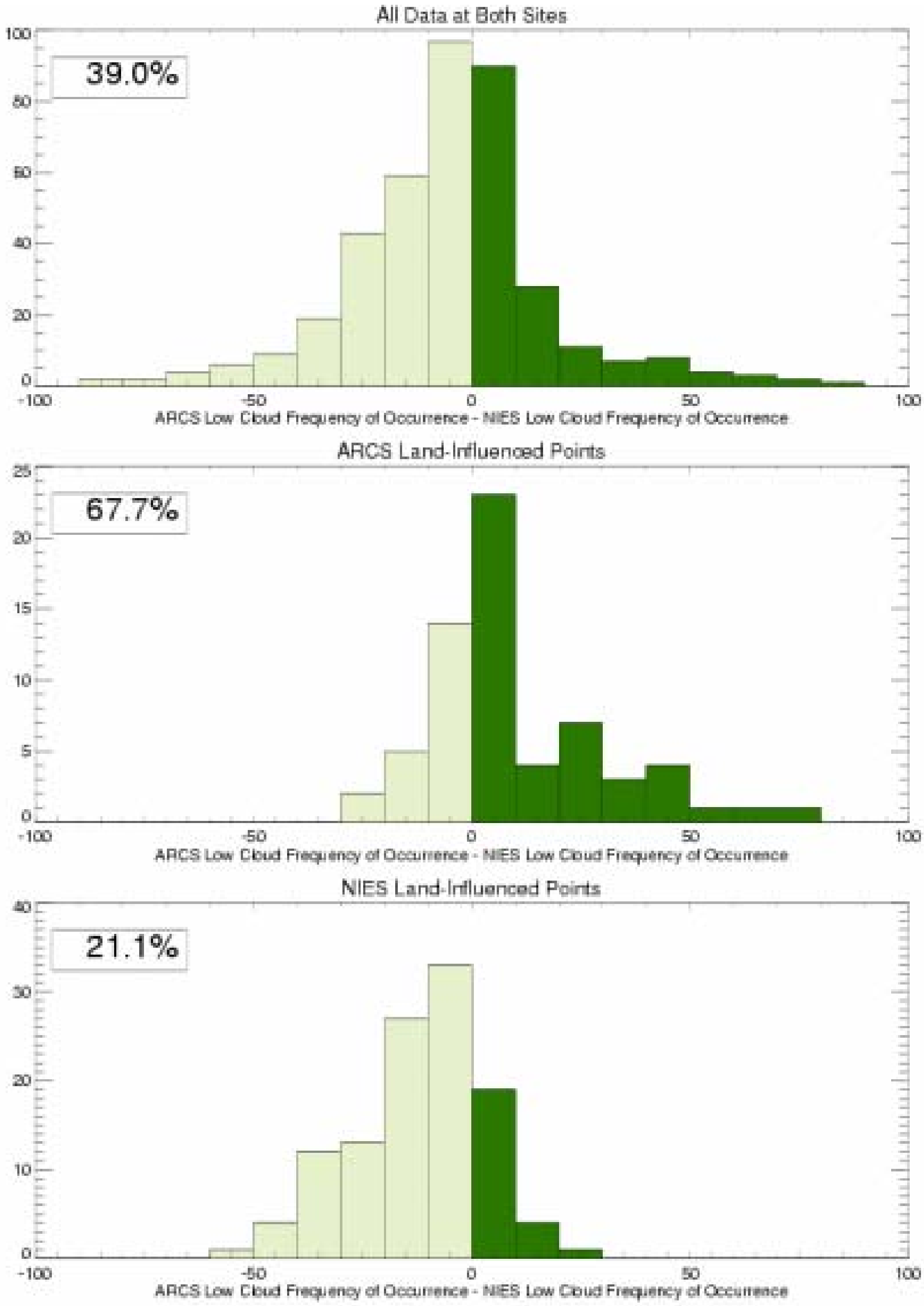

Figure 5. Histograms of the ARCS low cloud frequency of occurrence minus the NIES low cloud frequency for all data and periods classified as land-influenced at the two sites. The boxed values give the percentage of periods for which the ARCS frequency of occurrence is larger.

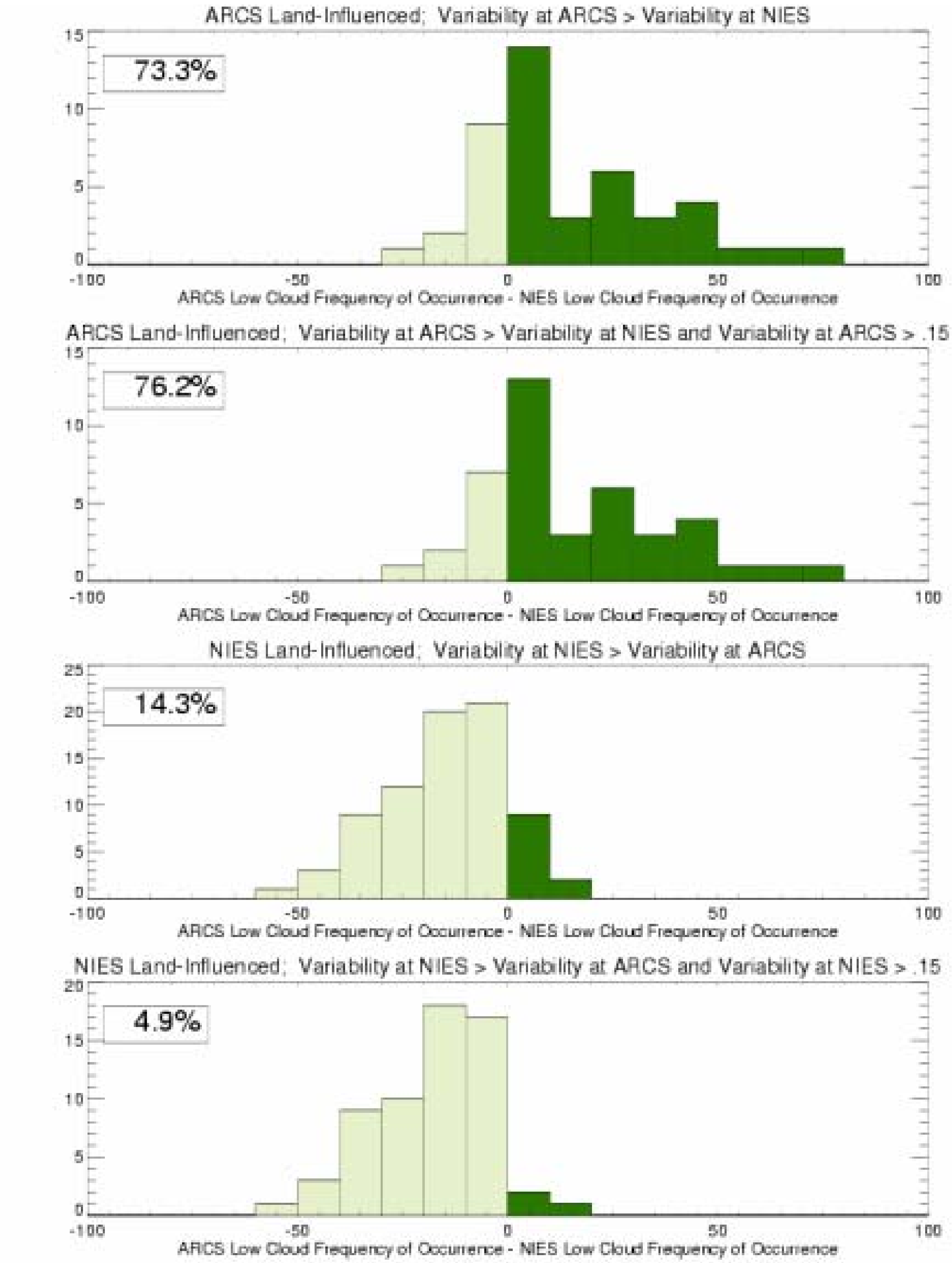

Figure 6. Histograms of the ARCS low cloud frequency of occurrence minus the NIES low cloud frequency of occurrence. The boxed values give the percentage of periods for which the ARCS frequency of occurrence is larger.

Figure 7 shows the daily average GSW calculated from the NIES LI-COR pyranometer and the ARCS Eppley pyranometer for each day with at least one good 3-hour period. Each day is classified as having no island effect, an ARCS island effect, or a NIES island effect based on the analysis discussed above. For days with no island effect, the daily average GSW from the two sites agree fairly well, while days with an ARCS island effect tend to show lower values of daily GSW measured at the ARCS relative to the NIES site, and days with a NIES island effect tend to have higher values of daily GSW at the ARCS site.

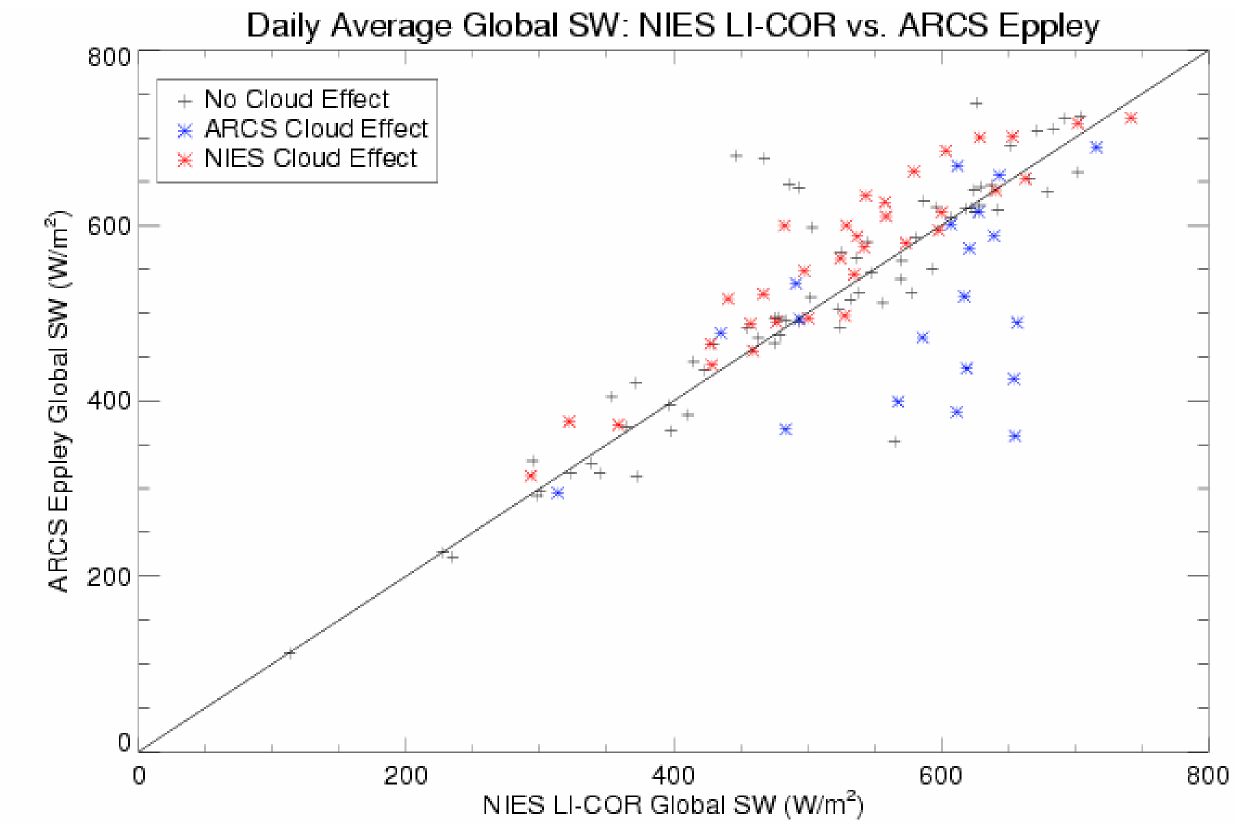

Figure 7. Daily average GSW measured by the NIES LI-COR and ARCS Eppley pyranometers.

Table 1 gives the average values of the daily ratios of the NIES LI-COR pyranometer to the ARCS Eppley pyranometer. On days identified as having no island effect, the average ratio of the NIES LI-COR to the ARCS Eppley pyranometer is 0.99, indicating fairly good agreement between the two instruments. For days with an island effect at the ARCS site, the average bias in the ARCS measurements (relative to the NIES site) of GSW is 20%, and on days with an island effect at the NIES site, the average bias in measurements of GSW is 7% relative to the ARCS site. Although the average ratio for the entire dataset is 1.01, this does not indicate that the island cloud effect does not have a significant impact on the measured radiation. For this time period, due to the El Niño conditions, the island cloud effect can occur at either site and effects on the radiation measurements tend to average out over the entire dataset. However, during periods where El Niño does not affect the tropical Pacific, the island cloud effect will be seen primarily at the ARCS site and it is expected that the ARCS site will show a significant decrease in measured GSW relative to the NIES site.

Table 1. Average of the ratios of the daily GSW measured by the NIES LI-COR pyranometer to that measured by the ARCS Eppley pyranometer.

	Average ratio of NIES LI-COR to ARCS Eppley
All Data	1.01
No Cloud Effect	0.99
ARCS Cloud Effect	1.20
NIES Cloud Effect	0.93

Figure 8 shows histograms of the daily ARCS low cloud frequency of occurrence minus the NIES low cloud frequency for days classified as no island effect, ARCS island effect, and NIES island effect. Boxed values indicate percentage of days where the ARCS low cloud frequency of occurrence is larger. Comparing the average low cloud amount measured by the ceilometer at the two sites indicates that the island cloud effect tends to increase the low cloud frequency of occurrence at the affected site by 15 to 19% relative to the unaffected site

Conclusions and Future Work

The data collected during the Nauru Island Effect Study allows us to begin identifying and quantifying the influence of the island cloud effect on the radiation and cloud measurements at the ARCS site. Due to the El Niño conditions during the study period, the island cloud effect was seen at both the ARCS and NIES sites, depending on the wind direction, although it is expected that the island effect will be seen primarily at the ARCS site when the tropical Pacific is not influenced by El Niño.

A preliminary analysis of the data collected so far indicates that the primary indicator of the island effect is wind direction while the secondary indicator is increased variability in the downwelling SW radiation at the island effect site. Other meteorological variables add little additional information to the identification. Relative to the Eppley pyranometer, the NIES LI-COR tends to underestimate the GSW at higher values and slightly overestimate the variability in normalized GSW at high values. By examining how the ratio of the daily average GSW measured by the LICOR to that measured by the ARCS Eppley changes over time for days with no cloud effect, we can assess the relative calibration of the LI-COR. The island cloud effect causes biases of 7 to 20% in the daily average measurements of GSW and 15 to 19% in low cloud frequency of occurrence at the affected site relative to the other site.

Future work will include further analysis of the island cloud effect on the daily average radiation and cloud occurrence statistics, using other data sources such as the TSI and satellite data to assess whether the cloud effect is occurring, and examining the island effect on aerosol optical depth measurements.

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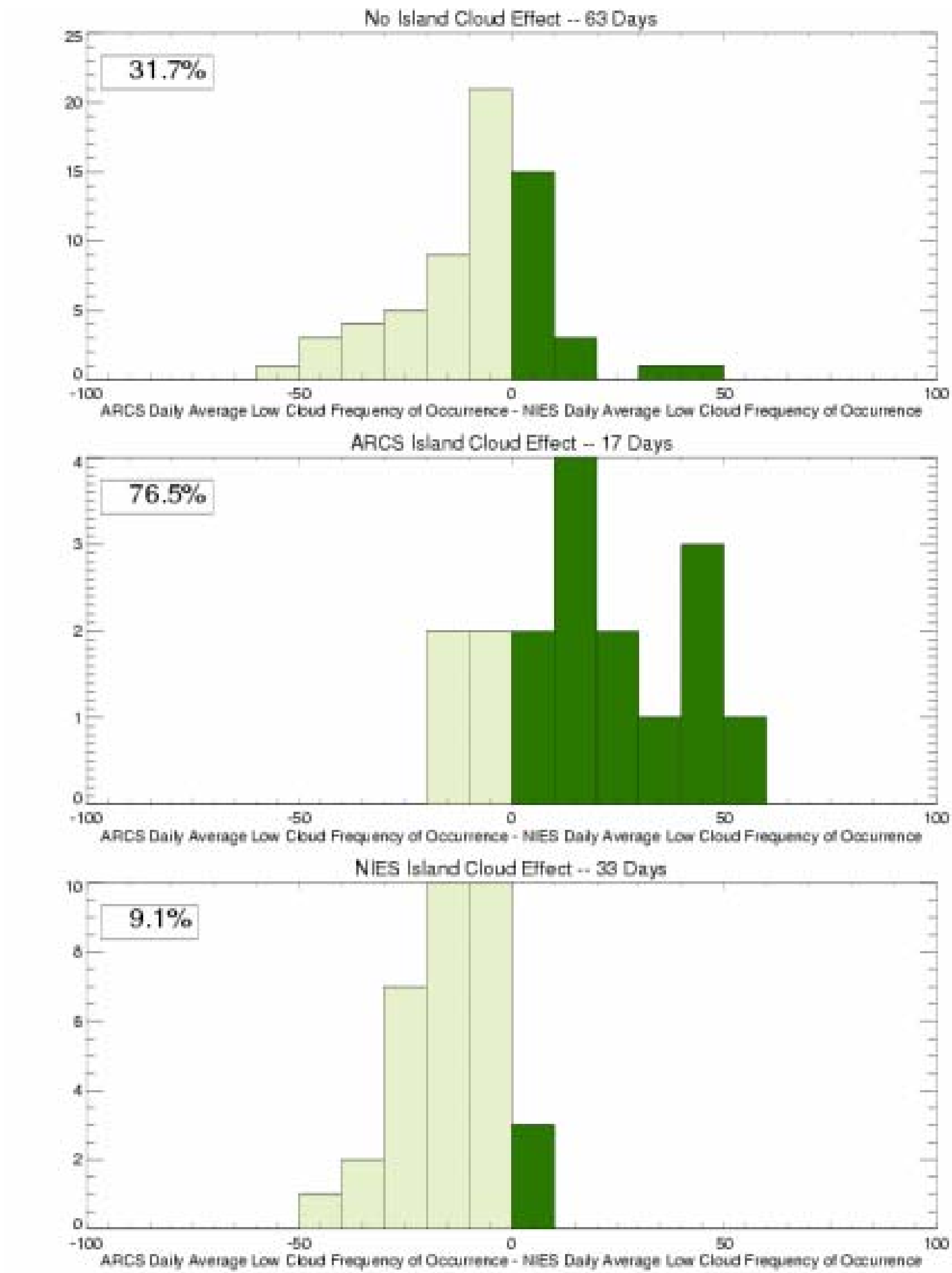

Figure 8. Histograms of daily ARCS low cloud frequency of occurrence minus NIES low cloud frequency for days classified as having no island effect, ARCS island effect, and NIES island effect. Boxed values indicate percentage of days where the ARCS low cloud frequency of occurrence is larger.

Reference

Nordeen, M. L., P. Minnis, D. R. Doelling, D. Pethick, and L. Nguyen, 2001: Satellite observations of cloud plumes generated by Nauru. *J. Geophys. Res.*, **28,** 631-634.