Systematic Bias in the NOAA Outgoing Longwave Radiation Dataset?

SULOCHANA GADGIL, ASHA GURUPRASAD, AND J. SRINIVASAN

Centre for Atmospheric Sciences, Indian Institute of Science, Bangalore, India

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ABSTRACT

The outgoing longwave radiation (OLR) fluxes derived from *NOAA-SR* (1974–78) are found to be consistently higher than those from *NOAA-7* (1982 onward) over a large part of the tropical belt. Analysis of the variation of the mean July–August OLR and the rainfall over the Indian region suggests that the lower values of OLR in the latter period cannot be attributed to more intense convection. Thus, the consistently lower values of OLR in the latter period over a large part of the tropical belt (including the oceanic regions) may be a manifestation of a systematic bias arising from various factors such as changes in instruments, equatorial crossing time, etc. Obviously, if such a bias is present, it has to be removed before the dataset can be used for the study of interannual variations. If the bias is removed by a simple method based on the variation of convection over the entire tropical belt, the OLR variations over the Indian region become consistent with the rainfall variations.

1. Introduction

The outgoing longwave radiation flux (OLR) at the top of the atmosphere, estimated from the radiance measured on board NOAA operational satellites has been archived by NESDIS of NOAA. This is available in a convenient form as 2.5 degree gridded twice-daily values from 1974. Since the beginning of this dataset there have been several changes in satellites, their orbits, and instrumentation, as well as in the procedures used for deriving the OLR. Corrections have been applied for the entire record so as to render the long record as homogeneous as possible (Gruber and Krueger 1984). This dataset has proved to be a valuable source for a large number of studies of tropical convection such as investigation of intraseasonal variation (e.g., Lau and Chan 1983a,b; Weikmann 1983; Murakami and Nakazawa 1985) and interannual variation (e.g., Short and Cahalan 1983; Yoo and Carton 1990; Nitta and Yamada 1989) and the elucidation of the nature of variation in the ENSO phenomenon (Climate Analysis Center 1983, etc.). An atlas of the mean seasonal patterns derived from the OLR data of 1974–83 has been prepared by Janowiak et al. (1985). From an analysis of this OLR dataset, Nitta and Yamada (1989) showed that the mean OLR for the equatorial belt (10°S–10°N) is lower in 1980s than in 1970s and hence concluded that the decade of 1980s experienced enhanced levels of convection as compared to the 1970s.

We have analyzed the daily 2.5-degree OLR–albedo data to study the intraseasonal variation of the intertropical convergence zone (Gadgil and Srinivasan 1990), using an objective method specifically developed for the delineation of the ITCZ from these data (Gadgil and Guruprasad 1990). The method involves imposition of a bispectral threshold and subsequent filtering to retain large-scale convective regions. Daytime OLR rather than the daily-average values are utilized because both OLR and albedo are analyzed. Since rainfall in the tropics is known to be reasonably well correlated to the number of days with highly convective clouds (Kilonsky and Ramage 1976; Lau and Chan 1983a), we expected the interannual variation of the number of days of occurrence of the ITCZ over the Indian region in the summer to be related to the variation of the monsoon rainfall. This was indeed the case for variations between 1974–75 and 1982–83. However, we found that the variation of the convective days between the seasons of 1975 and 1982 is not completely consistent with that of the rainfall (Gadgil and Srinivasan 1990). Therefore, we decided to examine the variation of a more basic variable, namely, the mean OLR, which has been successfully used to estimate rainfall (Arkin 1984; Yoo and Carton 1988, and references therein) and is often used as a proxy for tropical rainfall.

We found that the seasonal mean OLR over the Indian region (derived from either daytime or daily average values) is consistently lower during 1982–85 (derived from *NOAA-7*) as compared with 1974–78 (from *NOAA-SR*). This difference in OLR is not associated with a difference in the rainfall over the Indian region. This suggests the possibility of a systematic bias between the OLR derived from *NOAA-7* relative to that from *NOAA-SR*. In fact, the seasonal mean daytime, as well as daily, average OLR for the period 1982–

Corresponding author address: Sulochana Gadgil, Centre for Atmospheric Sciences, Indian Institute of Science, Bangalore 560 012, India.

85 is consistently lower than that during 1974–78 over much of the tropics, including large parts of the oceans. This coherent variation of the OLR from *NOAA-7* relative to that from *NOAA-SR* persists even if the El Niño–Southern Oscillation (ENSO) events of 1976 and 1982 are omitted in the calculation of the means. Our analysis of the variation of OLR over the Indian region suggests that this difference between the OLR of the two periods over large parts of the tropics could be a manifestation of a systematic bias in the fluxes derived from the different satellites. Gruber et al. (1990) have indicated that the differences in the OLR fluxes from different satellites can arise from nonuniform spatial/temporal/angular sampling and uncertainties in sensor calibration. Another possible cause is the differences in the equatorial crossing times. Irrespective of the underlying causes, it is clear that if such a bias is present in the long dataset, it has to be removed before interannual variation over the entire period can be studied.

In this study, we briefly describe the analysis that suggests the presence of a systematic bias between OLR derived from *NOAA-SR* and *NOAA-7* satellites. Our aim is to initiate a discussion on the possible existence of a systematic bias and perhaps trigger studies involving more detailed analysis of the variation of convection and precipitation that can yield conclusive evidence regarding the presence, or otherwise, of such a bias. The analysis of the anomalies of the OLR vis a vis the rainfall over the Indian region is presented in section 2. The spatial distribution of the differences in the OLR from the two satellites over the tropics is discussed in section 3. In section 4, we show that if the bias is removed by a simple correction formula based on the variation of convection between the two periods for the tropical belt as a whole, the OLR variations over the Indian region become consistent with the rainfall variations.

2. Comparison of the seasonal anomalies of OLR and rainfall over the Indian region

Several studies have shown that there is a negative correlation between the rainfall and OLR on the monthly/seasonal scale (e.g., Arkin 1984; Yoo and Carton 1988; Arkin and Ardanuy 1989, and references therein). The magnitude of the correlation does vary to some extent from region to region. However, given that it is always significantly negative on the monthly/seasonal scales, even if the magnitude of the correlation is not large, we expect a large difference in the rainfall between two different years to be associated with a difference of the opposite sign in the OLR. Whether the observed variations are consistent with this expectation can be checked by a comparison of the OLR variations between two monsoon seasons with large variation in rainfall.

In the period 1974–86 over which the OLR data was available, there was considerable interannual variation in the summer monsoon rainfall over India, with above normal rainfall in the seasons of 1975 and 1983 and deficient rainfall in 1974 and 1982 (Parthasarathy et al. 1987). However, there is little variation on the decadal scale, and the amplitude of the all India average anomalies are comparable between the poor monsoon seasons of 1974 and 1982 (−12% and −13%, respectively) and between the above-normal seasons of 1975 and 1983 (12% and 12%, respectively). We computed the differences in the rainfall in the peak monsoon months of July and August, between the three pairs of years, 1974–75, 1975–82, and 1983–82 for all the meteorological subdivisions of India from the data published by the India Meteorological Department (1974, 1975) and Ramasastry et al. (1983, 1984). A comparison with the differences in the mean July–August daytime OLR for the 2.5-degree grid for these three pairs of years showed that for the first pair, that is, 1975–74 (with OLR derived from *NOAA-SR*) and the second pair 1983–82 (with OLR derived from *NOAA-7;* Fig. 1a), areas with positive (negative) rainfall differences are generally characterized by negative (positive) OLR differences, as expected. However, when the rainfall and OLR differences between 1975 and 1982 (Fig. 1b) are compared, we find that while the rainfall anomalies are positive over large regions, so are the OLR anomalies. Thus, the spatial variations of the OLR seasonal anomalies are consistent with that of the rainfall when the data from within the same satellite period are compared, but not so when the data from different satellite periods are compared. The cumulative frequency distributions of the daytime OLR derived from the daily data of all the 2.5-degree cells in the nonorographic parts of the Indian region from 10° to 25°N during July–August 1974–78 were also compared with those for 1982–85. Although the July–August rainfall over this region is comparable in the poor monsoon years of 1974 and 1982 and smaller than that in the good monsoon years of 1975 and 1983, the OLR frequency distributions for 1974 and 1975 are below those for 1982 and 1983 over almost the entire OLR range (Fig. 2a). Note that there is greater variation between profiles derived from data of different satellites than between seasons with large variation of rainfall. Thus, it appears that there is a bias toward lower values in the daytime fluxes derived from *NOAA-7* relative to those derived from *NOAA-SR*.

One possible cause for the inconsistency between variations of OLR and rainfall could be our use of the daytime OLR data, which is likely to be influenced (over the continental regions) by the changes in the equatorial crossing time (see Table 1). Gruber and Krueger (1984) suggest that daily average OLR data be used, as it is difficult to correct for changes in equatorial crossing time. In fact, most of the analysis of tropical convection is based on the daily average OLR data. We, therefore, examined the variation of daily average OLR and found that, although the magnitude

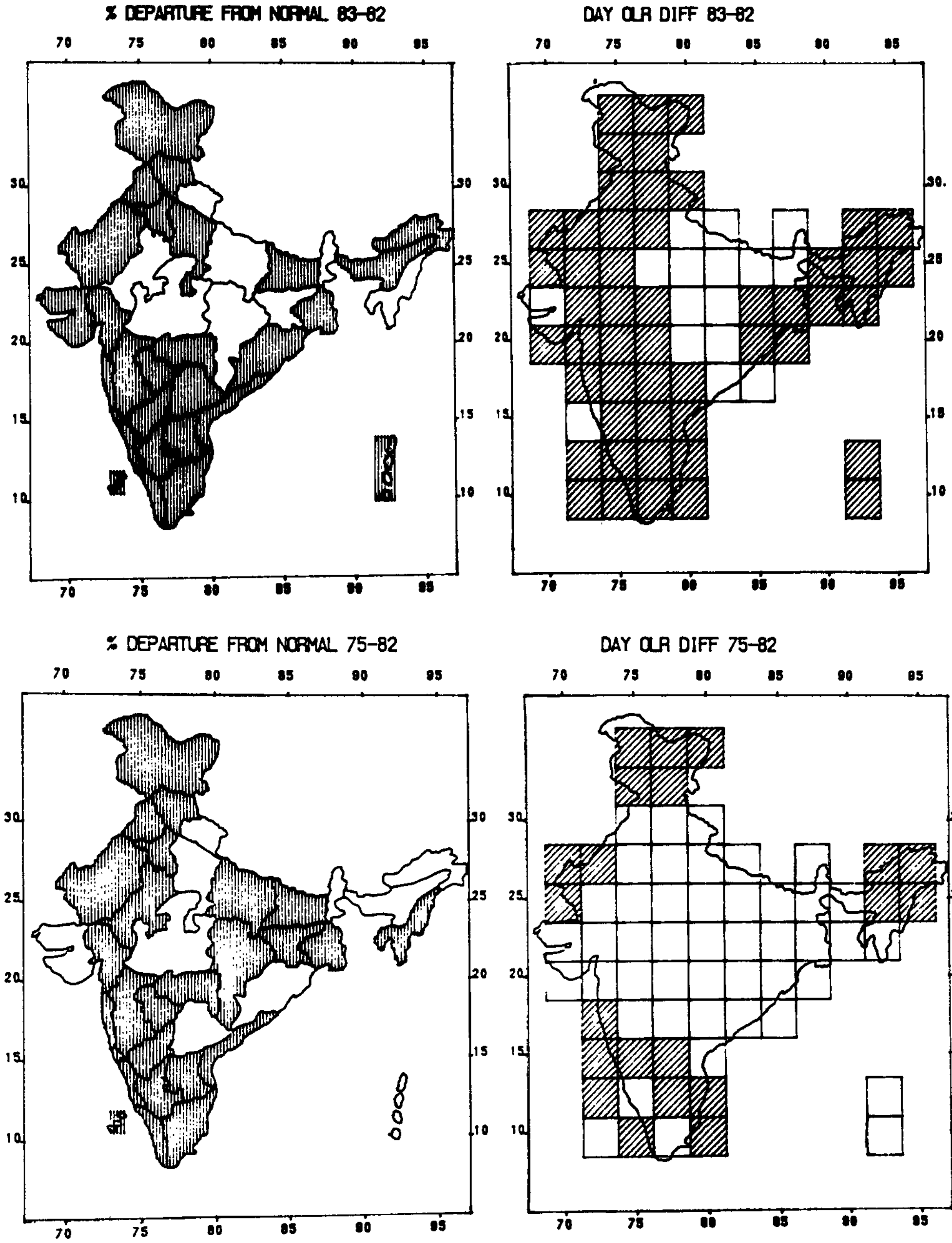

FIG. 1. (a) Difference in the July–August rainfall over the meteorological subdivisions of India (left) and the mean daytime OLR over the 2.5-degree grid (right) for 1983–82. The regions with positive difference in rainfall and negative difference in OLR are shaded. (b) Same as (a) but for 1975–82.

of the differences between satellites is smaller for daily average OLR, the pattern of variation between the satellites is similar to that noted for the daytime data for the low OLR range (Fig. 2b).

In order to test whether the OLR data from the *NOAA-SR* are significantly different from those from the *NOAA-7* satellite, we applied the Kolmogoroff–Smirnov test (Siegel 1956) to the mean July–August cumulative frequency distributions for 1974–77 and 1982–85. While the maximum expected difference in these distributions of the daytime (daily average) OLR from chance alone for the given sample size (about 4100) at the 5% level is 0.029, the actual difference is 0.108 (0.049), much larger than the expected. Thus, the frequency distributions of OLR from the two satellites are found to be distinct, supporting our hypoth-

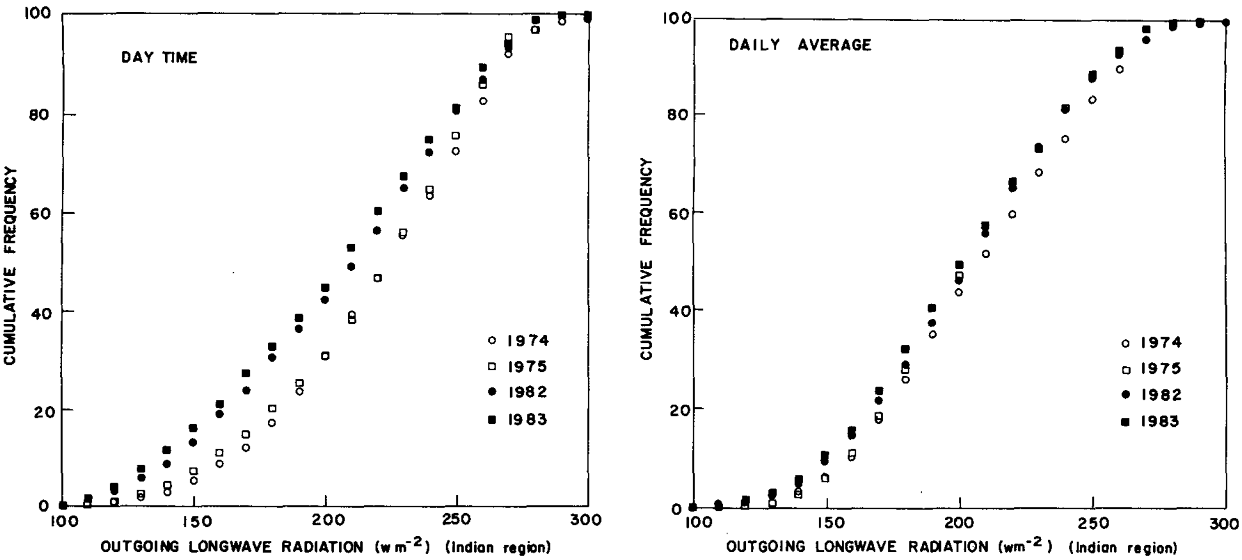

FIG. 2. (a) Cumulative frequency distribution of daytime OLR derived from the daily data of all the 2.5-degree cells in the nonorographic part of the Indian region between 12.5° and 25°N for 1974, 1975, 1982, and 1983. (b) Cumulative frequency distribution of the daily average OLR derived from the daily data of all the 2.5-degree cells in the nonorographic part of the Indian region between 12.5° and 25°N for 1974, 1975, 1982, and 1983.

esis of the existence of a bias between the OLR derived from the two satellites.

3. Global variation

The difference between the mean July–August daytime OLR for the period 1974–77 (*NOAA-SR*) and 1982–85 (*NOAA-7*) over the region 30°N–20°S is shown in Fig. 3a. It is seen that the OLR of *NOAA-7* is less than that of *NOAA-SR* over a large part of the tropics, including oceanic regions. Since the differences in the equatorial crossing time were not corrected for [Gruber and Krueger (1984)], one possible factor leading to systematic differences in the daytime fluxes is the diurnal variation. However, the diurnal variation is known to be small over oceanic regions (Saunders and Hunt 1980). Gruber and Chen (1988) have shown that diurnal variation of daytime OLR over oceanic regions seldom exceeds 5 W m^{-2}. Thus, the large difference in the mean OLR of the two satellites in Fig. 3a (higher than 10 W m^{-2} over large parts of the tropical oceans and even exceeds 20 W m^{-2} over parts of the west Pacific and the Indian Ocean) cannot be completely explained by the changes in equatorial crossing time. Not surprisingly, the spatial variation of the difference in the mean OLR derived from the daily average values (Fig. 3b) is similar to that derived from the daytime values (Fig. 3a). We found that the spatial variation of the difference between the means computed after omitting the data of the El Niño seasons for the two satellites (i.e., for 1974, 1975, 1977 and 1984, 1985, 1986) is similar to that in Figs. 3a,b.

It is seen from Fig. 3 that while the OLR during 1974–77 is higher than that in 1982–86 over most of the tropics, over some parts such as 15°S–25°N, 10°W–10°E, the OLR in the former period is lower than that in the latter period. Hence, the magnitude of the difference between the tropical/global average OLR is not as large as that for regional averages. For example, although the values of the July–August average OLR are consistently higher for years in the former period relative to those in the latter period (e.g., 253.7 W m^{-2} and 254.8 W m^{-2} for 1974–75 and 249.9 W m^{-2} and 250.2 W m^{-2} for 1982–83, respectively), the differences are generally less than 5 W m^{-2}. Note that the tropical average value of the July–August OLR for 1982 (characterized by a strong El Niño) is rather close to that for 1983 (characterized by a La Niña). This clearly shows that the interannual variation primarily involves spatial shifts of zones of convection rather than an increase or decrease of convection of the tropical belt as a whole. Thus, even the differences of the order of 5 W m^{-2} for the tropical average OLR

TABLE 1.

Satellite	Equator crossing time	Period of record
NOAA-SR series (NOAA 2, 3, 4, 5)	0900 LST–2100 LST	June 1974–February 1978
TIROS-N	0330 LST–1530 LST	January 1979–January 1980
NOAA-6	0730 LST–1930 LST	February 1980–August 1981
NOAA-7	0230 LST–1430 LST	September 1981–February 1985

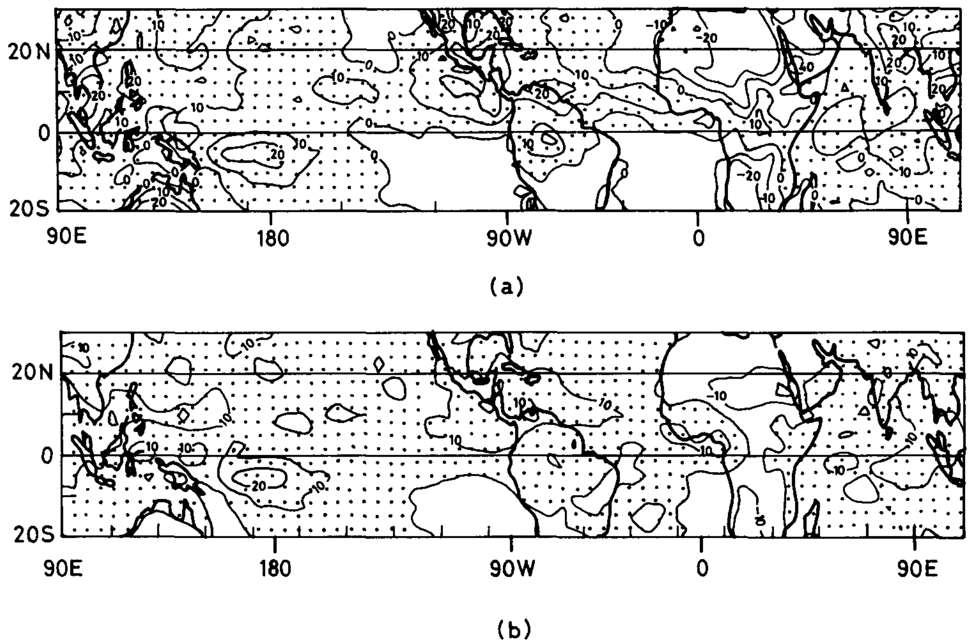

FIG. 3. (a) The mean daytime OLR for July–August (1974–77) minus July–August (1982–1985) for the region 20°S–30°N. Region with positive difference has been shaded and contours of differences of ±10, ±20 W m^{-2} are marked. (b) Same as (a) but for daily average OLR data.

between two satellite periods could be a manifestation of a bias.

Nitta and Yamada (1989) also found that the anomaly of the average OLR for the region 10°N–10°S is negative throughout the period 1982–85 and positive throughout the period 1974–78. The variation of the OLR anomaly between these two periods is almost like a step function with values around 3 W m^{-2} in 1974–78 and around −2 W m^{-2} in 1982–85. This difference in the OLR of the two periods (which is larger than the interannual variation within one satellite period) could arise from a difference in the intensity of convection as suggested by them. Alternatively, it could be the result of a bias in the fluxes derived from the different satellites (due to the changes in equatorial crossing time, instruments, windows, algorithms used in the derivation, etc.). Our analysis of the variation over the Indian region supports the latter hypothesis. The important phenomena in the tropics such as El Niño or monsoon failures involve coherent changes in convection over large-scale subregions of the tropics with scales of a few thousand kilometers. Hence, if there is a bias in the derived OLR over such regions, it has to be corrected before the entire dataset can be used for the study of interannual variations.

Perhaps a better measure of the systematic differences/bias between the OLR derived from the two satellites than the global/tropical averages is the frequency distribution of the differences of the mean OLR for the two periods (1982–85 and 1974–77) computed from all the 2.5-degree cells over the tropical belt. We find that the distribution derived from the differences between the OLR of 1982–83 (within the same satellite period) is almost symmetric about the mode at zero, with 37% of the cells on the positive and 38% on the negative side of the mode. However, it is seen from Figs. 4a and 5a for the daytime and daily average OLR, respectively, that the distributions of the cellwise difference between the mean OLR of 1974–77 relative to that of 1982–85 are markedly skewed toward the positive side. This is because the OLR derived from *NOAA-7* during 1982–85 is lower than that from *NOAA-SR* during 1974–78 for a large fraction of the 2.5-degree cells. The analysis of the Indian region (section 2) suggests that this arises from a bias in OLR fluxes rather than variation of the convection between the two periods. Chang and Kousky's (1987) empirical orthogonal function (EOF) analysis also indicated that the second OLR mode was associated with differences in the satellites. Next, a simple method for correcting the bias is considered.

4. Correction of the bias

A method for correction of a bias between the OLR of the two periods can be developed once the factors leading to it are identified and the impact on the OLR is analyzed in detail. However, in the meanwhile, for the large user community, it would be useful to ascertain whether the OLR and rainfall variations become consistent if the bias is removed in some manner. We attempt this here by using a very simple method for

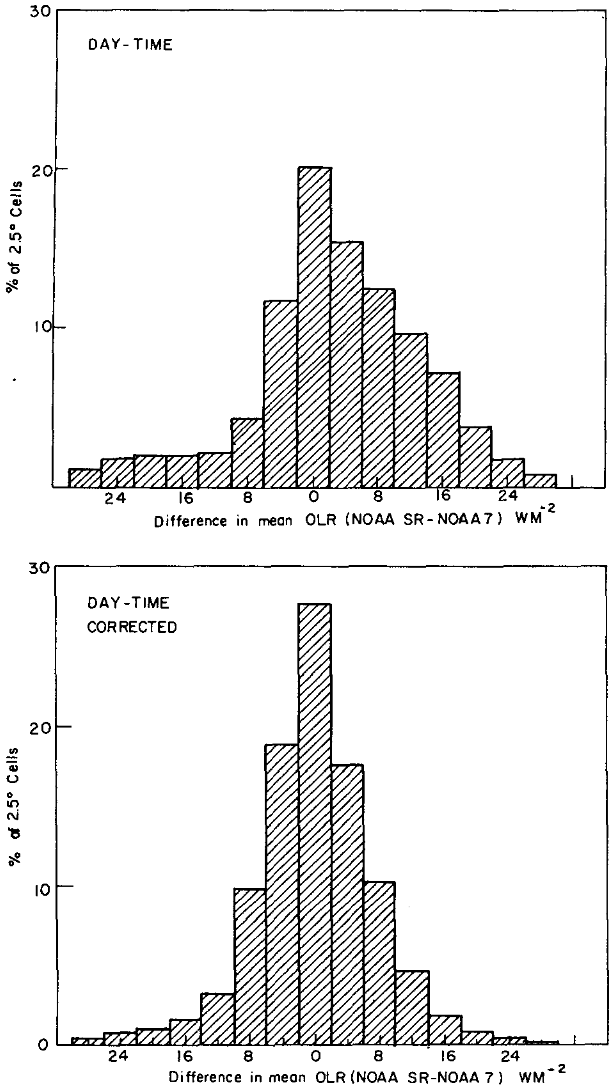

FIG. 4. (a) Frequency distribution of the difference between the mean daytime OLR during July–August 1974–77 and July–August 1982–85 derived from the 2.5-degree cells in 20°S–30°N. Note the asymmetry in the profile with about 54% (26%) of the cells on the positive (negative) side of the mode. (b) Same as (a) but for OLR data corrected as discussed in section 4. The profile is almost symmetric with 36% on the positive and negative sides of the mode.

removing the bias. Obviously the method should not be specific to a particular region of the tropics. Our method is based on the variation of the convection over the tropical belt as a whole. In the last section, it was noted that the interannual variation of the average tropical convection between the El Niño year 1982 and La Niña year 1983 is very small and the distribution of the differences between the OLR of these two years derived from all the 2.5-degree cells in the tropical belt is almost symmetric about zero. Hence, we expect the distribution of the differences between the two periods corresponding to *NOAA-SR* and *NOAA-7* to be also symmetric. The basic assumption in our method is that this distribution is actually symmetric.

A comparison of Fig. 3 with the mean summer OLR distribution in Janowiak et al. (1985) shows that regions where the mean OLR of *NOAA-7* is much lower (higher) than that of *NOAA-SR* are regions of low (high) values of the mean OLR. Thus, even the simplest correction formula must involve a dependence on

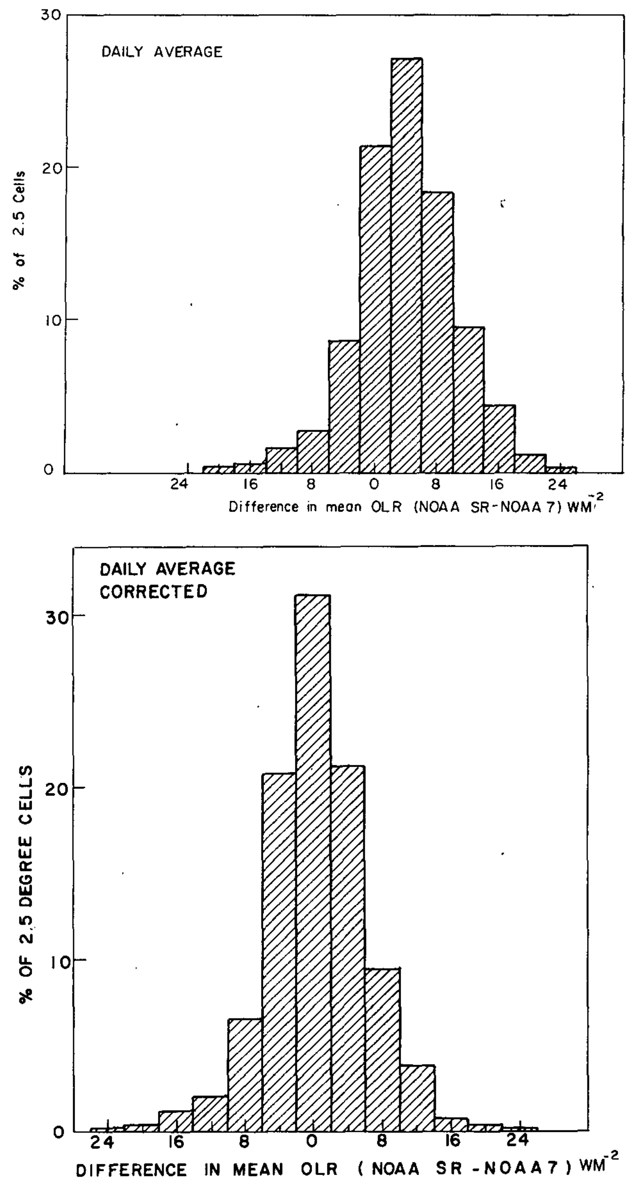

FIG. 5. (a) Frequency distribution of the difference between the mean daily average OLR during July–August 1974–77 and July–August 1982–85 derived from the 2.5-degree cells in 20°S–30°N. Note the asymmetry in the profile with the mode on the positive side and 64% (14%) of the cells with the difference larger (smaller) than 2 (−2) W m^{-2}. (b) Same as (a) but for OLR data corrected as discussed in section 4. The profile is almost symmetric with 36% (31%) on the positive (negative) side of the mode.

OLR. Note that the original fluxes F_o from *NOAA-SR* were corrected by using the formula

$$F_N = 0.7920F_0 + 6.357 \times 10^{-4} \times (\mathrm{m^2\,W^{-1}})\,F_o^2, \quad (1)$$

whereas those from *NOAA-7* were corrected using

$$F_N = 0.8532F_0 + 3.887 \times 10^{-4} \times (\mathrm{m^2\,W^{-1}})\,F_o^2 \quad (2)$$

[Eqs. (5) and (7) from Gruber and Krueger (1984)]. These equations imply an enhancement (reduction) of the *NOAA-7* fluxes vis a vis the *NOAA-SR* fluxes for low (high) values of OLR. Thus, a change in the same direction, that is, enhancement (reduction) of the *NOAA-7* OLR in regions of low (high) OLR should decrease the differences in Fig. 3.

A formula similar to that of Gruber and Krueger (1984) is used for further correction to only one dataset, namely, the *NOAA-7* OLR data,

$$F_C = (1 + A)F_N - B \times 10^{-4}\,(\mathrm{m^2\,W^{-1}})\,F_N^2. \quad (3)$$

The coefficients A, B were determined so as to render the distribution of the differences in Figs. 4a and 5a symmetric (Figs. 4b and 5b);

$A = 0.274$, $B = 10$ for daytime OLR

$A = 0.0854$, $B = 2.8$ for daily average OLR.

Obviously, a similar correction formula could have been applied to the other or to both of the OLR sets so as to render the frequency distribution symmetric.

Although the formula (3) is derived from the pooled data of the entire tropical belt, its application to the data over the Indian region had a significant impact. The nature of the anomaly field between the summers of 1975 and 1982 of the corrected OLR appears to be consistent with that of the rainfall (Fig. 6), with no descrepancies of the type noted in section 2 (Fig. 1) for the original dataset. There is also a marked change in the frequency distributions of the OLR for the Indian region. For the original data on daytime OLR, the distributions for the summers of the two satellites (1974 and 1975, 1982 and 1983) formed distinct clusters. On the other hand, with the distributions for 1982–83 derived from the data corrected as above, the curve for the poor monsoon season of 1982 is below that for the good monsoon season of 1975 (Fig. 7a). The interannual variation of the distributions for the daily average OLR for 1974, 1975, 1982, and 1983 also become consistent with the rainfall variation over the Indian region for all OLR including the low OLR range (Fig. 7b), with the frequency distributions of the corrected OLR for the poor monsoon seasons being distinct from that of the good monsoon seasons. Thus, the interannual variation of the OLR is intimately related to the variations in convection/rainfall once the OLR variation between the satellites has been removed. Obviously, the method we have used here to remove the bias is by no means the only possible method. The aim was merely to demonstrate that if the bias is removed, the variation in OLR and rainfall becomes consistent between the satellites.

5. Conclusions

The July–August mean OLR during 1982–85 (derived from *NOAA-7*) is found to be consistently lower

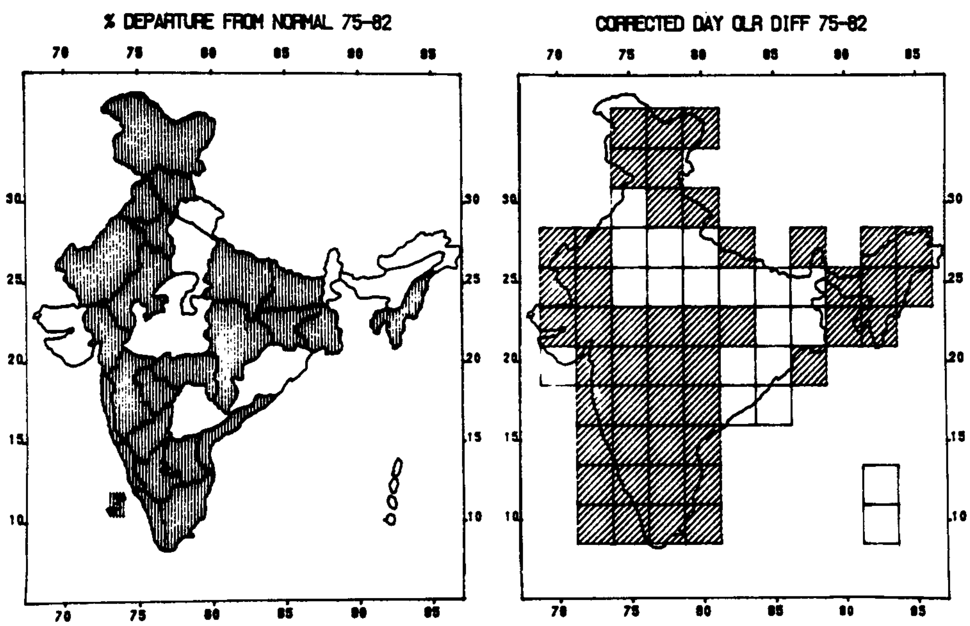

FIG. 6. Same as Fig. 1b but for corrected daytime OLR data for 1982.

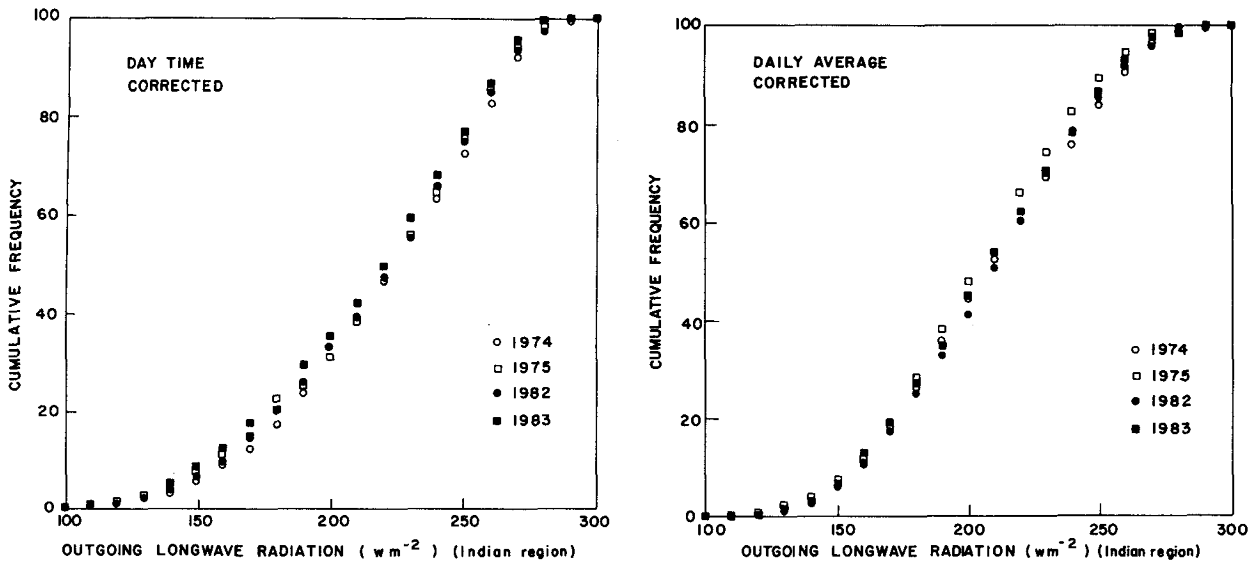

FIG. 7. (a) Cumulative frequency distribution of the corrected daytime OLR derived from the daily data of all the 2.5° cells in the nonorographic part of the Indian region between 12.5° and 25°N for 1974, 1975, 1982, and 1983. (b) Cumulative frequency distribution of the corrected daily average OLR derived from the daily data of all the 2.5° cells in the nonorographic part of the Indian region between 12.5° and 25°N for 1974, 1975, 1982, and 1983.

than that during 1974–77 (derived from *NOAA-SR*) over a large part of the tropics. This is consistent with Nitta and Yamada's (1989) result of the mean seasonal OLR over the equatorial belt in the 1980s being lower relative to that of the 1970s. It is also supported by Motell and Weare's (1987) analysis of the variation of the OLR over the Pacific, which clearly showed that both daytime and nighttime OLR derived from the *NOAA-7* data after 1982 are consistently lower than those from the *NOAA-SR* during 1974–78.

Our analysis of the seasonal OLR and precipitation anomalies over the Indian region suggests that the lower OLR in the 1980s relative to that of the 1970s cannot be attributed to variation in the intensity of convection. There appears to be a systematic bias toward low values in the OLR derived from *NOAA-7* in the 1980s vis a vis that from *NOAA-SR* in the 1970s. We believe that the decrease in OLR in the 1980s relative to that in the 1970s over the equatorial tropics pointed out by Nitta and Yamada (1989), which they have attributed to an increase in convection, is a manifestation of this bias. Chelliah and Arkin's (1990) study also did not support Nitta and Yamada's (1989) hypothesis of interdecadal change in convection.

If the entire dataset is to be used for the study of interannual variation, this bias must be corrected. We show that if the bias is corrected using a simple formula based on the variation of the convection over the tropical belt as a whole, the interannual variations in OLR during the period 1974–85 become consistent with interannual variation of precipitation in the Indian region.

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