Surface Radiation Processes in the Tropical Pacific

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This short article is a summary of the results contained in a forthcoming article (Gautier and Frouin, 1989) investigating net surface solar irradiance variability in the central and eastern tropical Pacific from GOES satellite data for the period 1982-1985. This period covers the 1982-1983 El Niño event during which major changes took place in the coupled atmosphere-ocean system. The satellite estimates provide an unprecedented and accurate description of the spatial and temporal variability of the surface solar radiation on a daily (to monthly) basis and a 50 km spatial scale.

The first result of the study was a preliminary assessment (see Fig. 1) of existing climatologies by comparing them with the mean annual satellite estimates (over the October 1983 to September 1985 period), which are expected to be accurate to better than 15 Wm^{-2}. In Fig. 1 the climatological val-

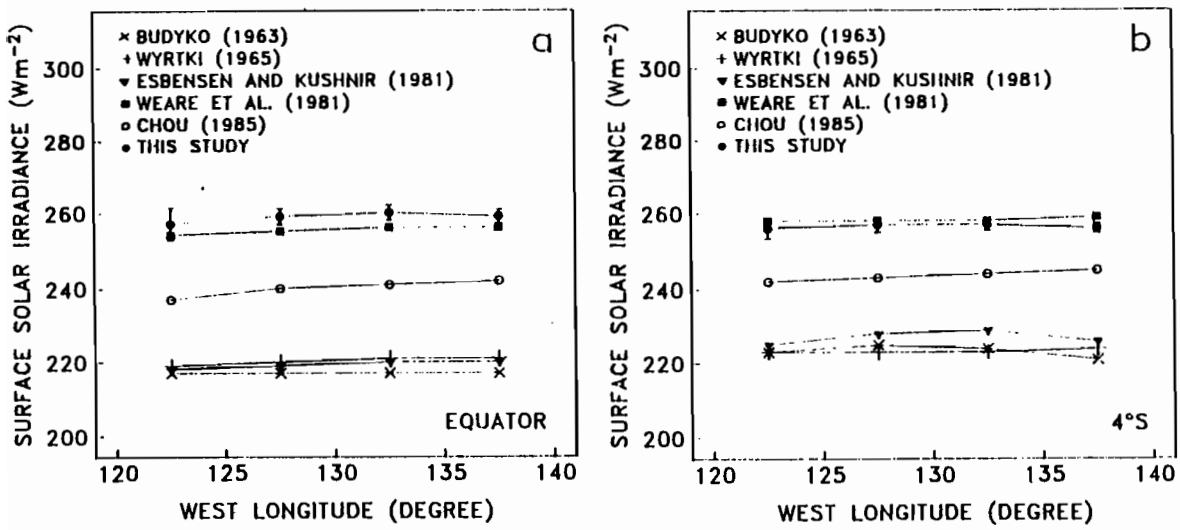

Fig. 1 Comparison of annually-averaged net surface solar irradiance obtained by various authors and computed with the satellite technique of Gautier et al. (1980) in regions centered at the equator (a) and at 4° S(b). Each point corresponds to 4° lat. by 5° lon. averages. The vertical bars (satellite technique only) represent the spatial standard deviation in the 4° lat. by 5° lon. areas.

ues at the equator computed by Budyko (1963), Chou (1985), Esbensen and Kushnir (1981), and Wyrtki (1965) all appear to underestimate solar irradiance

at the surface by about 20 to 40 Wm^{-2}, whereas those computed by Weare et al. (1981) are very close (within 1 to 2 Wm^{-2}) to the satellite estimations. When the annual mean is computed by including the El Niño conditions, the satellite estimations are reduced by only 8 Wm^{-2}, suggesting that most climatologies underestimate solar irradiance at the surface.

The spatial variability of the annual net solar irradiance depicted from the satellite data is illustrated in Fig. 2a and b for the periods Oct. 1982 – Sept. 1983 and Oct. 1983 – Sept. 1984. Also included in Fig. 2a and b are the corresponding temporal standard deviation fields. During non-El Niño periods (Fig 2b), the annually averaged net solar irradiance field is dominated by very weak zonal gradients (1 to 2 Wm^{-2} over 2000 km) and stronger meridional ones (up to 20 Wm^{-2} over 200 km) in the region of the ITCZ. The standard deviation field also has weak zonal gradients and its maximum values (about 25 Wm^{-2}) are found in the southern part of the study area. During the El Niño period (Fig 2a), the zonal variability becomes as large as the meridional variability, particularly in the central Pacific, where intense convection dominates the atmospheric state. The standard deviation from the annual mean reaches 40 Wm^{-2} in that region, much larger than that observed within the ITCZ region during non-El Niño years. A difference of more than 150 Wm^{-2} in surface solar irradiance takes place in the equatorial region between 140° and 180° W between January 1981 and January 1983, where the largest SST anomaly is observed. The variability of the standard deviation reflects the large changes in surface solar irradiance occurring during the El Niño year. Its maximum values (about 45 Wm^{-2}) are found in the western part of the study area.

A general view of the seasonal and interannual variations of the net surface solar irradiance is obtained by condensing the data into diagrams of latitude (and longitude) versus time. Such diagrams, illustrated in Fig. 3a and b, have been obtained by averaging the data longitudinally (and meridionally) over the entire domain. The latitude versus time diagram (Fig. 3a) shows the meridional extension of low net surface solar irradiance values (less than 160 Wm^{-2}) covering the entire study area starting in November 1982 and retreating in May 1983. These low values are associated in the north with the ITCZ, but their large meridional extent suggests that they are also related to processes other than ITCZ displacements. The longitude versus time diagram (Fig. 3b) supports this statement and shows a large zonal extension of the low net surface solar irradiance values. This extension is associated with the eastward displacement of the main region of convection/precipitation, as mentioned above.

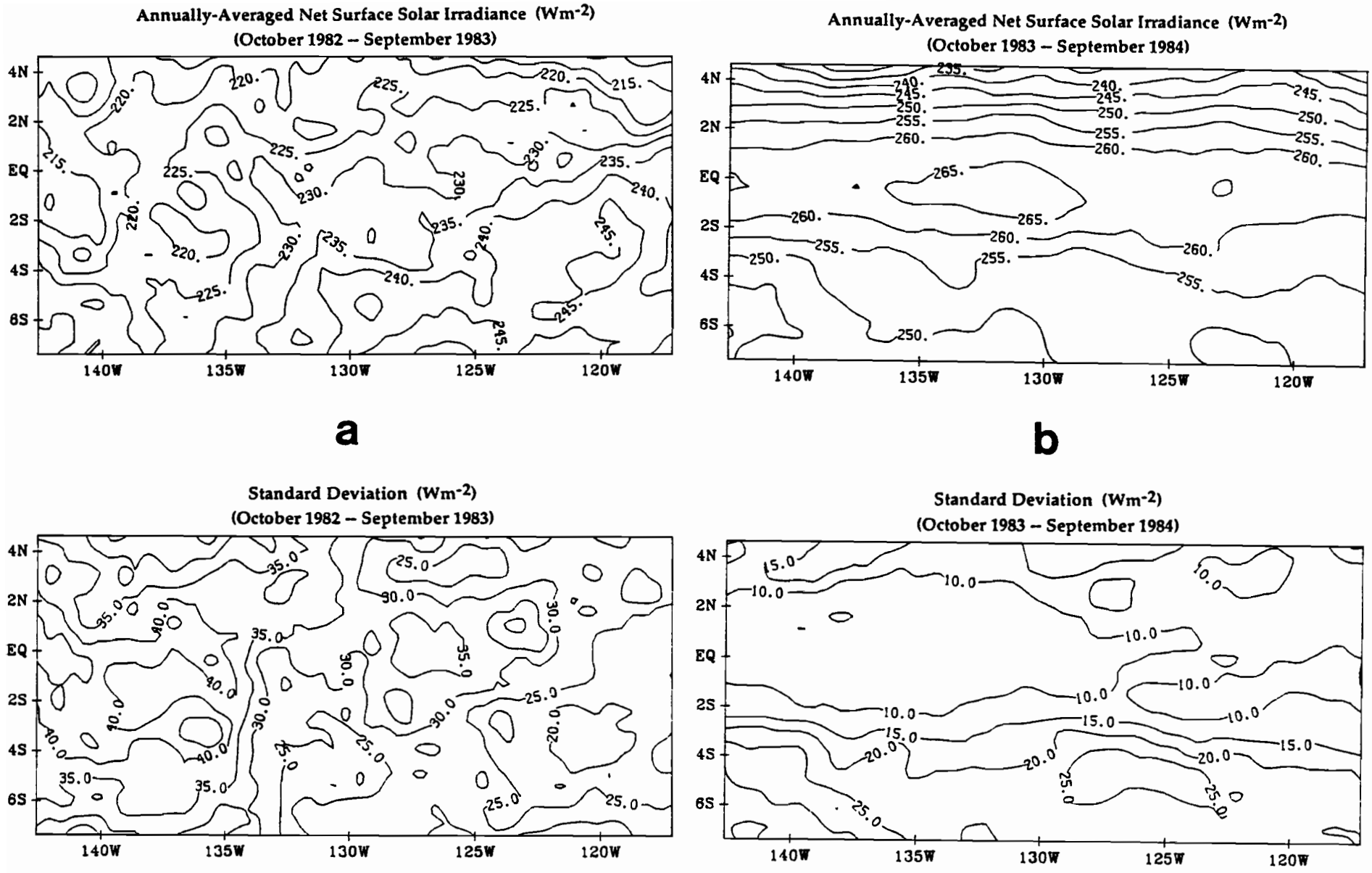

Fig. 2 Spatial distribution of annually-averaged net surface solar irradiance (computed with the satellite technique of Gautier et al., 1980) for the periods October 1982—September 1983 (a) and October 1983—September 1984 (b). The corresponding temporal standard deviation fields are also shown below.

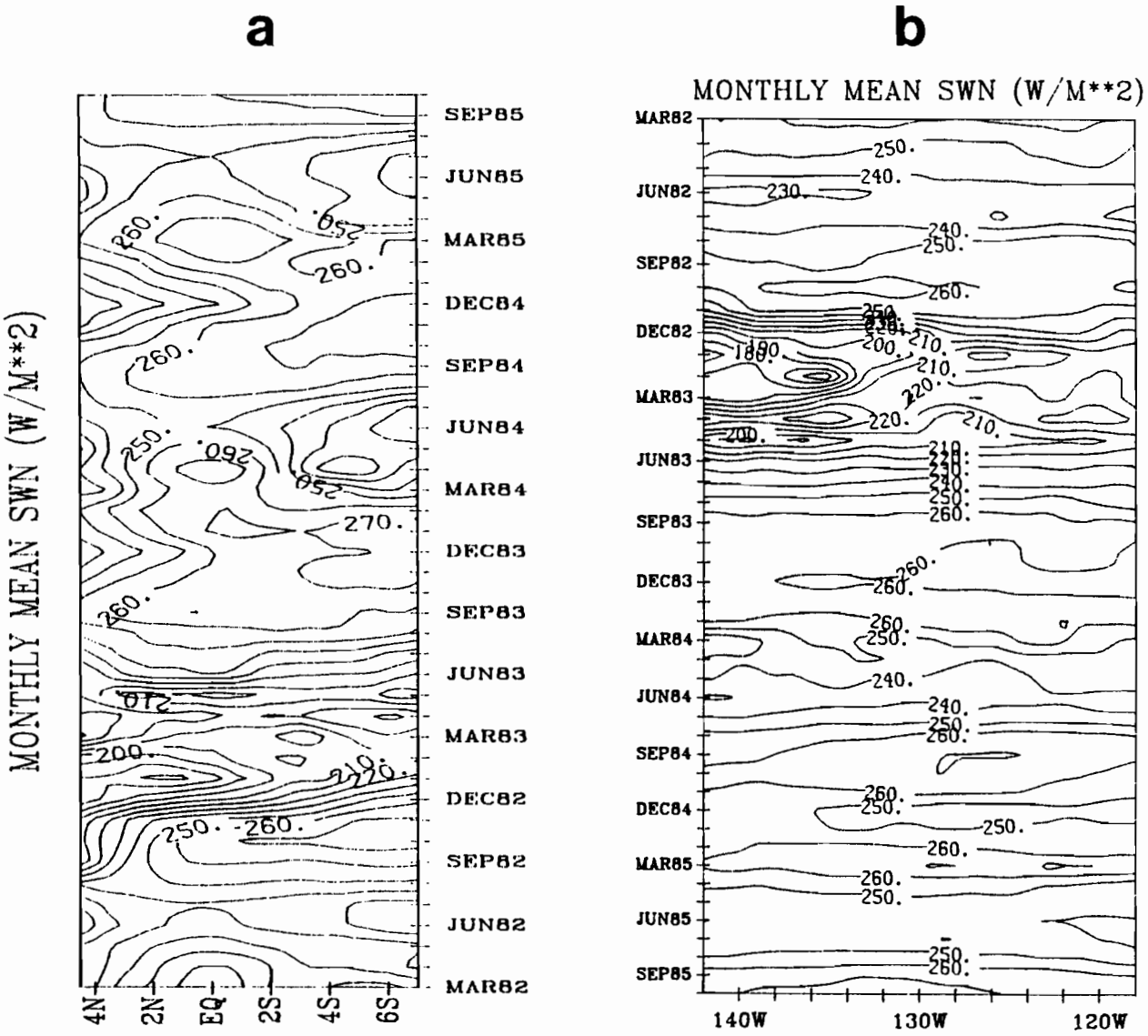

Fig. 3 Diagrams of time vs latitude (a) and time vs longitude (b)

The spatial and temporal variability of the net solar irradiance fields can be further quantified using empirical orthogonal function (EOF) analysis. An EOF analysis has been applied to two types of fields including and excluding the seasonal cycle: (1) difference fields from an annual mean (October 1984 to September 1985) and (2) difference fields from the monthly mean for each month of that same year. The annual mean removed from the first data set is shown in Fig. 4a and the square root of the variance (standard deviation) analyzed is illustrated Fig. 4b. The standard deviation field exhibits values ranging from 15 Wm^{-2} to 32 Wm^{-2} and a very high spatial variability (no direction is privileged).

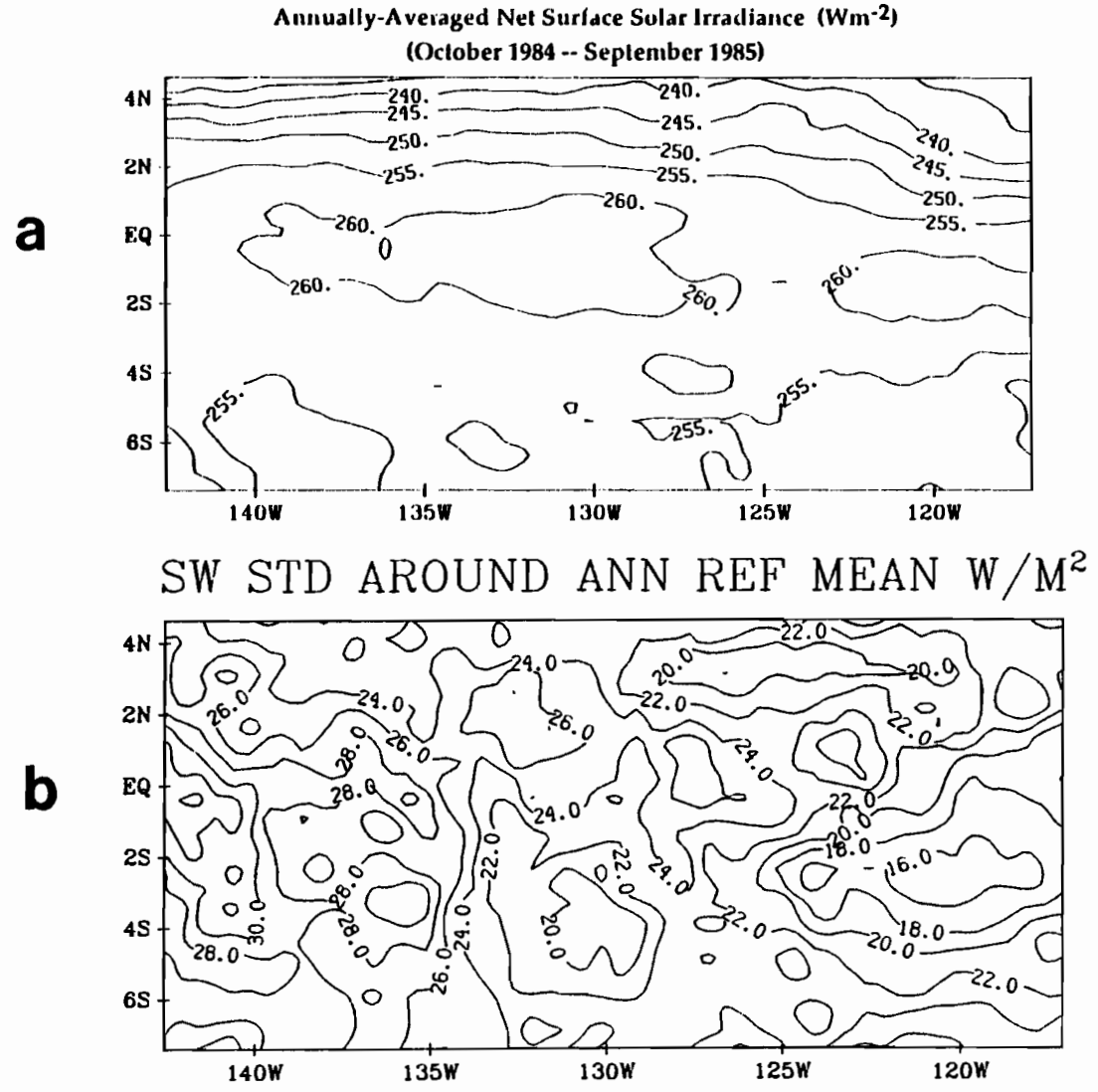

Fig. 4 Annually averaged net surface solar irradiance used for computing the anomalies (a) and the standard deviation around this mean of data used in the EOF analysis (b).

The EOF analysis of the first data set provides us with mostly the seasonal signals: semi-annual and annual. The first two EOFs explain 62.2 and 16.1 % of the variance (78.3 % cumulative), respectively, whereas the two subsequent EOFs each explain less than 5 % of the variance. The remaining EOFs each account for less than 2% of the variance. The first eigenfunction is presented together with its corresponding time varying amplitude coefficient in Fig. 5a. The values of this eigenfunction are small (3×10^{-2}) and negative everywhere; the spatial variability is small and a weak maximum exists in the equatorial region, centered around 2.5° S. The time variability of the amplitude coefficient is dominated by a semi-annual signal (cf. clear net surface solar irradiance plotted on the same graph with scaled amplitude). The semi-annual cycle is strongly perturbed by the El Niño event. The secondary maximum of December is strongly enhanced and delayed by a month whereas the primary maximum of June occurs earlier, after a much reduced minimum. These effects obviously result from cloud variations which counteract the normal sun variation effects and perturb the

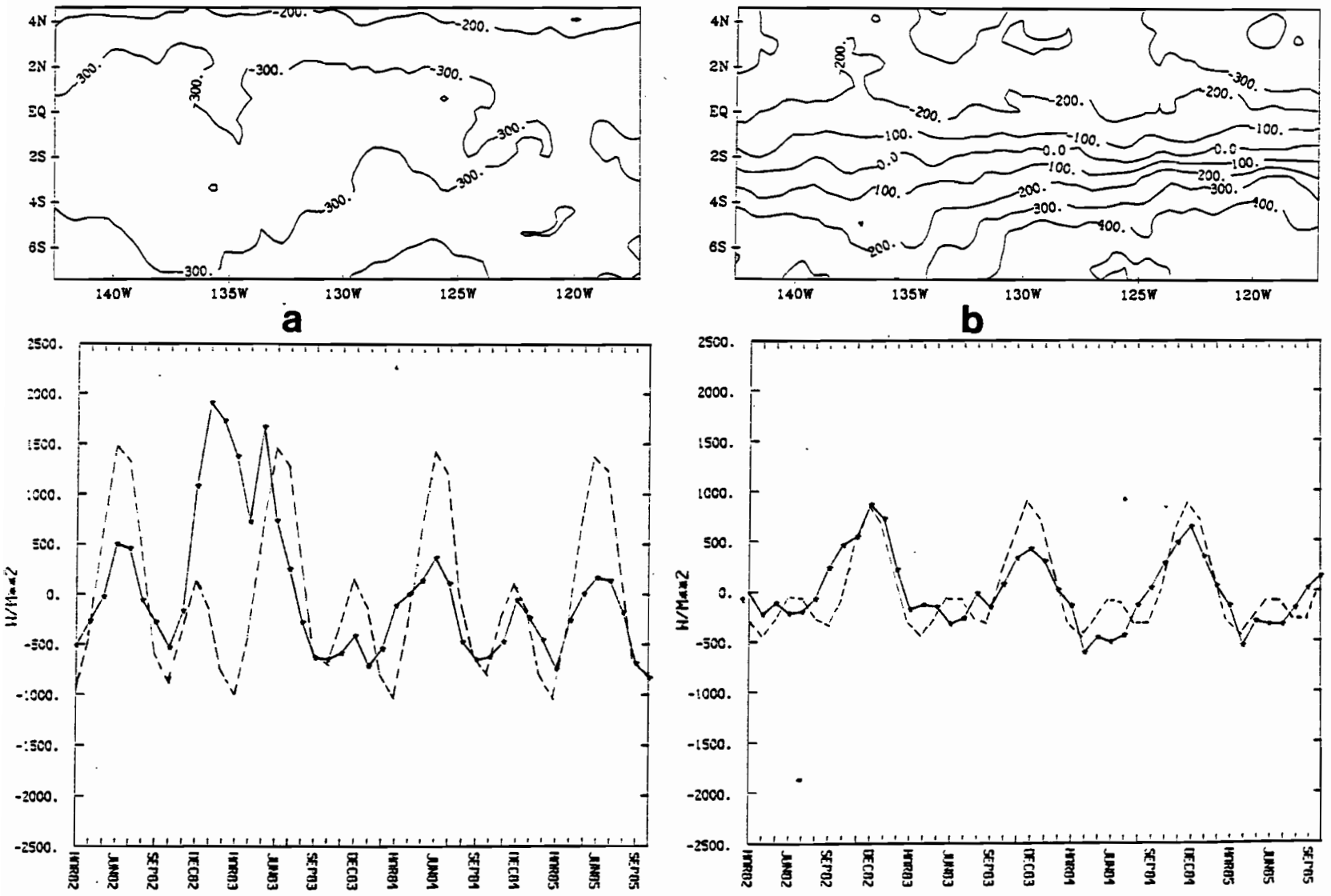

Fig. 5. The first (a) and second (b) empirical orthogonal functions (EOFs) of the seasonal data set. The top figures represent the eigenfunctions, and the bottom figures depict the time variations of associated amplitude coefficient (continuous line) and equivalent coefficient for clear-sky conditions (dashed line).

semi-annual cycle. The amplitude of the semi-annual signal for the area studied is about 30 Wm^{-2} during the years preceding and following El Niño.

The second eigenfunction and its corresponding time varying coefficient are presented in Fig 5b. The function field is very zonal and composed of negative values north of about 2.5° S and positive values south of 2.5 °S. Because of the non-symmetry of the studied area, the zero isoline is located at about 2.5° S, instead of the equator, where it should be since this function represents the annual variations of the field. The amplitude coefficient has a strong annual signal with a marked maximum in November–December and a flat minimum around April–July, indicating that the north-south gradient changes sign annually. The El Niño appears to only slightly modify the annual signal (plotted on the same graph) by broadening the period of minimum from March to September 1983 and reducing the maximum. The amplitude of this annual signal varies with latitude; at about 5°S, it is about 30 Wm^{-2} and very similar to the semi-annual signal.

The first EOF of the non-seasonal data set is presented in Fig. 6a. It represents 67% of the total variance, while all the remaining EOFs represent less than 5 %. The spatial variability of the field is very similar to that of the first eigenfunction of the seasonal data set, with the largest value of the coefficients in the western equatorial region. The corresponding amplitude is presented in Fig 6b. It clearly shows the El Niño effect from December 1982 to June 1983. The maximum variation of net solar irradiance during that period was about -75 Wm^{-2} for about 3 months and less than -50 Wm^{-2} for another three months in the western equatorial region. An important aspect to note is the negative values of the amplitude coefficient (corresponding to 10 to 40 Wm^{-2} depending on the region) for most of the time after June 1983, suggesting anomalously clear sky conditions. These conditions were indeed noticed in our analysis of the anomaly fields not presented here.

The results presented above clearly indicate the strong effect the 1982-83 El Niño had on the net solar irradiance of the central equatorial Pacific. The western part of the area studied was in an anomalous state from September 1982 to August 1983. The reduction of net solar irradiance was more than 50 Wm^{-2} for several months. Such a large reduction of net solar irradiance over such a long time period suggests a possible feedback mechanism on the anomalously warm sea surface temperature then existing in the central equatorial Pacific. Whereas the warm sea surface temperature appears to precede the reduction of net solar irradiance, it can be expected that the lasting low values of net solar irradiance might induce a reduction of the warm anomaly during the subsequent months.

A study of the entire tropical Pacific solar irradiance has been recently initiated using data from two geostationary satellites to cover the entire width of the basin. The GMS satellite data have been used to complement the GOES data and compute solar irradiance in the eastern Pacific. The region of the warm pool is found to be dominated by deep convection of a similar nature to that observed in the central Pacific during El Niño.

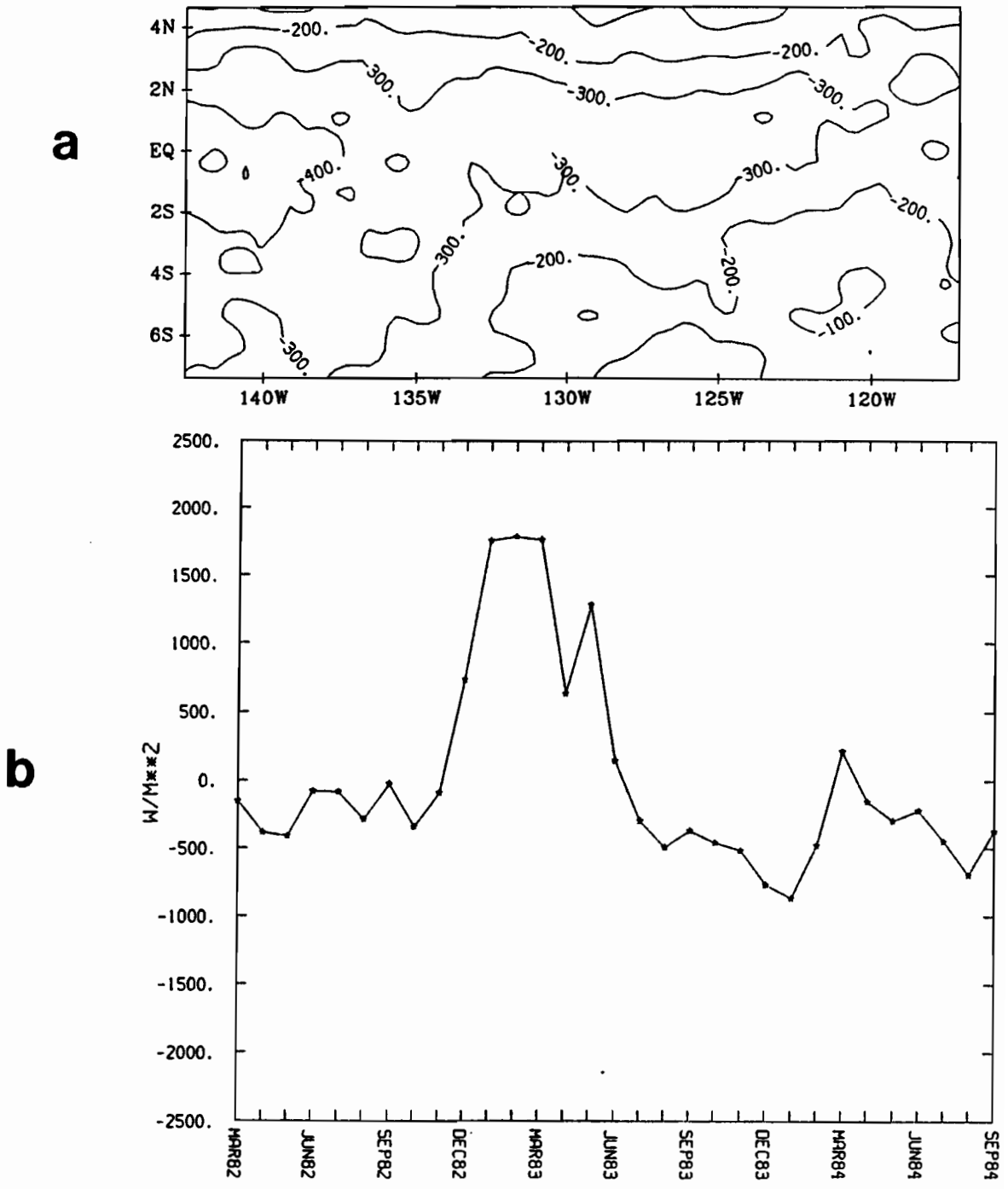

Fig. 6 First empirical orthogonal function of the non-seasonal data set (a) and time variations of associated amplitude coefficient (b).

Acknowledgments

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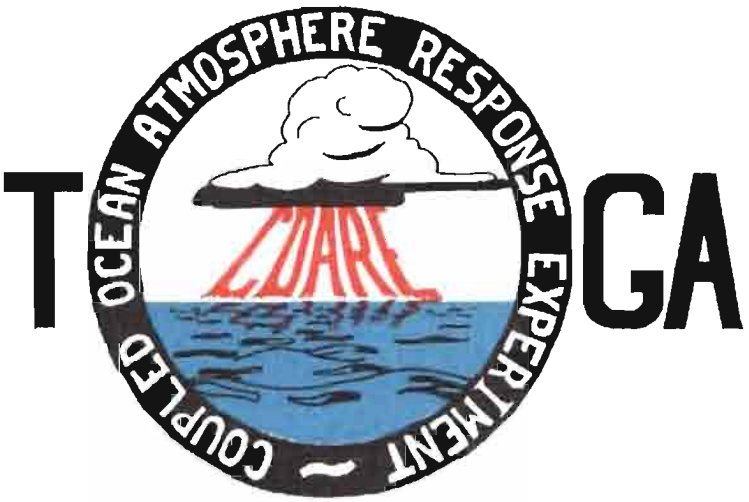

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