Examination of the Decadal Tropical Mean *ERBS* Nonscanner Radiation Data for the Iris Hypothesis

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ABSTRACT

Recent studies of the *Earth Radiation Budget Satellite* (*ERBS*) nonscanner radiation data indicate decadal changes in tropical cloudiness and unexpected radiative anomalies between the 1980s and 1990s. In this study, the *ERBS* decadal observations are compared with the predictions of the Iris hypothesis using 3.5-box model. To further understand the predictions, the tropical radiative properties observed from recent Clouds and the Earth's Radiant Energy System (CERES) radiation budget experiment [the NASA Langley Research Center (LaRC) parameters] are used to replace the modeled values in the Iris hypothesis. The predicted variations of the radiation fields strongly depend on the relationship ($-22\%\ \mathrm{K}^{-1}$) of tropical high cloud and sea surface temperature (SST) assumed by the Iris hypothesis.

On the decadal time scale, the predicted tropical mean radiative flux anomalies are generally significantly different from those of the *ERBS* measurements, suggesting that the decadal *ERBS* nonscanner radiative energy budget measurements do not support the strong negative feedback of the Iris effect. Poor agreements between the satellite data and model predictions even when the tropical radiative properties from CERES observations (LaRC parameters) are used imply that besides the Iris-modeled tropical radiative properties, the unrealistic variations of tropical high cloud generated from the detrainment of deep convection with SST assumed by the Iris hypothesis are likely to be another major factor for causing the deviation between the predictions and observations.

1. Introduction

It is generally assumed that the variations in the global means of the earth's radiative budget (ERB) at long temporal scales are small. However, recent study based on accurate long-term overlapping multisatellite ERB observations indicates that the observed decadal variations of tropical mean radiation fields are much larger than expected and far beyond the simulated decadal variabilities found in current general circulation models (GCMs; Wielicki et al. 2002a). Specifically the observed large-scale tropical means (20°N–20°S) of outgoing longwave (LW) radiation at top-of-atmosphere (TOA) have increased about 4 W m^{-2} between the late 1980s and the mid-to-late 1990s. This LW radiative anomaly has reached a value as large as 8 W m^{-2} during the 1997/98 El Niño event (Wielicki et al. 2002a). Relative to the late 1980s, this decadal-scale increase in tropical mean LW radiation has been linked to strengthening of the Hadley and Walker circulations in the 1990s (Chen et al. 2002). An intensified tropical general circulation produces stronger sinking motion in the subtropics. Sinking subtropical air dries adiabatically and should cause cloudiness over the tropical regions to decrease. This stronger tropical circulation is also supported by the changes in the tropical cloud distributions found in the Stratospheric Aerosol and Gas Experiment II (SAGE II) observations (Wang et al. 2003). Note that the downward branches of the Hadley and Walker circulation dominate the tropical mean radiation because their area coverage is much larger than the upward branch.

Lindzen and Giannitsis (2002) claim that the observed ERB anomalies are consistent with those suggested by the Iris hypothesis (Lindzen et al. 2001, hereafter LCH). Since global (and tropical) surface temperature was slightly higher during the 1990s compared with the 1980s, the observed intensification of Hadley and Walker cells and the reduction of clouds in the Tropics associated with the rise in TOA LW radiation in the 1990s at first seem to qualitatively support the Iris effect. According to the Iris hypothesis, tropical high clouds would decrease with rising surface temperature due to an increase in precipitation efficiency and a reduction in detrainment of intensified tropical deep convection. The decrease in these high clouds would allow more thermal or LW radiation to emit to space and, therefore, cool the climate system. This negative feedback ($-0.45 \sim -1.1$) would be potentially strong enough to stabilize the climate system and to greatly

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reduce the global warming effects caused by both the increasing atmospheric CO_2 concentration and its associated positive feedbacks (such as sea ice). Analyzing the latest satellite data from the Clouds and the Earth's Radiant Energy System (CERES) over the Tropics and classifying the tropical high clouds in the same way as LCH, Lin et al. (2002) showed that if the areas of tropical high clouds decrease, the extra solar [or shortwave (SW)] radiative energy into the earth–atmosphere system would counterbalance the increased LW radiation to space. This solar heating effect is due mainly to the fact that the observed cloud reflectivity is much larger than that assumed by LCH. As a result, the decreases in these tropical high clouds would cause a weak positive feedback to the climate system, instead of a strong negative feedback suggested by the Iris hypothesis. Fu et al. (2002) also pointed out that the tropical radiative properties of LCH are not consistent with satellite observations, and the high cloud feedback should be small. These findings were further supported by other recent studies on the Iris effect. For example, detailed study of the tropical high clouds in terms of cloud cover, cloud temperature and height, and cloud particle thermodynamical phase (ice/water) using the improved CERES Single Scanner Footprint (SSF) dataset showed similar results to a weak Iris feedback (Chambers et al. 2002, hereafter CLY). Analyzing the same dataset as that of LCH, Hartmann and Michelsen (2002) found no physical evidence for the Iris effect. Since the variation of high clouds around an equatorial area is much smaller than that at higher latitudinal zones of the Tropics, the increase (or decrease) of high clouds at these higher latitudinal zones acts to elevate (or reduce) high cloud amount and to lower (or strengthen) averaged sea surface temperature (SST) below the clouds for the Tropics. Thus, the strong negative relationship between high cloud amount and SST obtained by LCH and assumed by the Iris hypothesis is not supported by the data. The current paper extends the earlier short time-scale Iris hypothesis tests to ask: Do the decadal satellite radiative energy budget data of Wielicki et al. (2002a) support the Iris hypothesis? The dataset and analysis method are discussed in next section. Section 3 shows the results. And finally, the answer to the question asked and summary/conclusions are given in section 4.

2. Data analysis

The decadal satellite radiative budget anomaly data used in this study are from the nonscanner measurements of the *Earth Radiation Budget Satellite* (*ERBS*) during 1985–99 (Wielicki et al. 2002a). The nonscanner measures broadband total and SW radiation. The LW values are obtained from the differences between the two broadband channels. To remove the temporal aliasing effect caused by the slow drift of the *ERBS* orbit (Trenberth 2002), these tropical mean radiative anomalies are calculated based on the full 72-day precession period of *ERBS*. Specifically, the satellite radiation data are first averaged into 72-day means using *ERBS* daily mean data before transforming into radiative anomaly fields. These anomaly fields are referenced to 1985–89 period. There are five 72-day means per calendar year. The last 5–6 days of the satellite measurements in each calendar year are not used in the analysis to avoid local time aliasing. These 72-day averages remove about 2/3 of the semiannual SW variability in the monthly means seen by Wielicki et al. because there was an interaction between the monthly data processing and a slow drift in the phase of the precession by 6 h over the period from 1985–95 (Wielicki et al. 2002b). The decadal variations of LW, SW, and net radiation essentially remain the same as those in Wielicki et al. (2002a) except that these signals are even clearer.

In order to investigate the effects of SST on clouds and radiation fields as suggested by the Iris hypothesis, the SST dataset from National Centers for Environmental Prediction (NCEP) reanalyses for the same period as the *ERBS* nonscanner radiation data is analyzed. The SST values, basically from the Reynolds analysis (Reynolds and Smith 1994), are first averaged in 72-day cycles over the Tropics. The SST anomalies referenced to 1985–89 baseline values are then constructed using the 72-day mean in the same manner as the *ERBS* radiative anomalies. These temporally consistent anomalies of observed TOA radiation and SST fields are used as the benchmarks for examining the Iris hypothesis in this study. Note that the tropical mean *ERBS* anomalies over oceans are very similar to those calculated over all scene types. The averaged differences between all and ocean only data are about 0.01, -0.07, and 0.06 W m^{-2} for LW, SW, and net anomalies, respectively.

The theoretically predicted tropical LW, SW, and net radiative anomalies caused by the Iris effect during the same satellite data period from 1985 to 1999 are calculated using the same 3.5-box greenhouse model as that given in the LCH. The 3.5-box model is essentially a simplified radiative energy balance model, which divides the globe into tropical moist, tropical dry, and extratropical areas. The tropical moist area has higher humidity in the upper troposphere caused by the detrainment of tropical deep convection, and further splits into cloudy-moist (i.e., the deep convective and anvil clouds) and clear-moist (i.e., high cloud free) regions. The model assumes that the temperature gradients between the surface and the emission level within each box do not change with small climate perturbations, and the surface temperatures (T_s) of the Tropics and extratropics are 10 K above and below the global mean surface temperature (currently 288 K), respectively. According to LCH, the key climate feedback factor for the Iris effect is that high cloud area (or cloudy-moist area) decreases with increased T_s at a rate of 22% K^{-1}.

The major inputs for the 3.5-box model are the relative area, SW albedo, and LW flux (or equivalent emission temperature) for tropical dry, clear-moist, and

TABLE 1. The tropical properties of the Iris hypothesis and LaRC parameters.

	LaRC			Iris hypothesis		
	Dry	Clrm	Cldm	Dry	Clrm	Cldm
Coverage	0.5	0.4	0.1	0.5	0.28	0.22
Albedo	0.154	0.258	0.510	0.211	0.211	0.349
SW	338.7	297.1	196.2	315.9	315.9	260.6
LW	287.7	253.9	154.8	303.1	263.1	137.7

Note: Clrm—clear moist; Cldm—cloudy moist. The unit for radiative fluxes is W m^{-2}. The LaRC parameters were observed from CERES measurements (Lin et al. 2002).

cloudy-moist areas. Table 1 lists the major parameters of the Iris hypothesis over tropical regions along with the CERES observed values [Lin et al. 2002; hereafter referred as the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) parameters]. As pointed out by Lin et al., the main differences between the parameters from the Iris hypothesis and the LaRC parameters are area coverage, SW albedo, and LW flux for the cloudy-moist area. For example, the observed values of SW albedo and LW flux for the cloudy-moist area are 0.161 and 17 W m^{-2}, respectively, higher than those assumed by LCH. These differences, along with those for clear-moist and dry regions, in SW albedo and LW flux are large enough to change the strong negative climate feedback in LCH to a weaker positive climate feedback in Lin et al. Fu et al. (2002) also found that the albedo of tropical high clouds should be much higher than that used by LCH, and that the radiative feedback of cloudy moist area is close to zero. Since the LCH and LaRC results are so different from each other, this study will further examine the sensitivity of the predicted radiative anomalies using both types of parameters and compare the predicted anomalies directly with the observed *ERBS* decadal radiative anomalies fields.

The detailed description of the 3.5-box model and the data analysis techniques used in obtaining the parameters in Table 1 can be found in LCH and Lin et al. (2002), respectively. The current study uses the parameters in Table 1 to run the 3.5-box model, and calculates baseline tropical LW, SW, and net radiative fluxes for the model assumed climate (i.e., T_s values of the Tropics and extratropics are 298 and 278 K, respectively). The modeled tropical radiative fluxes during the *ERBS* period are then calculated based on the NCEP SST anomalies and the relationship (i.e., $-22\%\ \mathrm{K}^{-1}$) of high cloud coverage with SST assumed by the Iris hypothesis. As we pointed out in the previous section, this strong negative relationship was obtained by a faulty data analysis. The only purpose for using it here is to test the Iris hypothesis. The model-predicted tropical radiative flux anomalies, the differences between the modeled fluxes during the *ERBS* period from 1985 to 1999 and the calculated baseline radiative values, are compared with the observed *ERBS* anomalies.

There are some spatial mismatches in obtaining the LaRC parameters (within ±30° latitudes) and the tropical mean *ERBS* radiative anomalies (within ±20° latitudes). Its effects on the modeled radiative flux anomalies are very small because the modeled flux anomalies estimated from LaRC parameters represent the values caused by assumed cloud amount variations associated with the tropical SST anomalies. The main driving factor for the 3.5-box model, namely the SST anomalies, is calculated for a ±20° latitude band in the current study, consistent with the method used to constructed *ERBS* tropical mean anomaly data. In addition, studies of Lin et al. (2002) and CLY found that the observed CERES radiative properties for the 3.5-box model are very close to the data from the tropical western Pacific, tropical eastern Pacific, and the whole Tropics. Thus, the basic results for the modeled radiative anomaly (*not* absolute) values should be the same even if a slightly different definition of tropical mean is used. Furthermore, we found that the differences between *ERBS* anomalies within ±20° and those within ±30° latitudes are very small (also c.f. Wielicki et al. 2002a and Chen et al. 2002). For example, the differences in the decadal averaged LW, SW, and net radiative anomalies between these two definitions of the tropical means are only 0.06, -0.05, and -0.05 W m^{-2}, respectively.

3. Results

Observations of land and ocean surface temperature reveal that the 1990s were slightly warmer than the 1980s. Figure 1 shows the time series of the 72-day averaged tropical mean SST anomalies from the NCEP reanalysis for the *ERBS* data period between 1985 and 1999. The positive and negative SST anomaly peaks during the mid-to-late 1980s clearly indicate the 1987 El Niño and the 1989 La Niña events, respectively. The competitive effects of the surface cooling from the Mount Pinatubo eruption and the surface warming due to the El Niño event make the SST anomalies slightly positive during 1991/92. The strongest El Niño event recorded in the last century created about 0.8 K tropical mean SST warming during its peak time in 1998. Due to lack of realistic high atmospheric aerosol loading, generated by the Mount Pinatubo volcanic eruption, in the NCEP reanalysis, this study will exclude the SST data during the early 1990s and will concentrate ex-

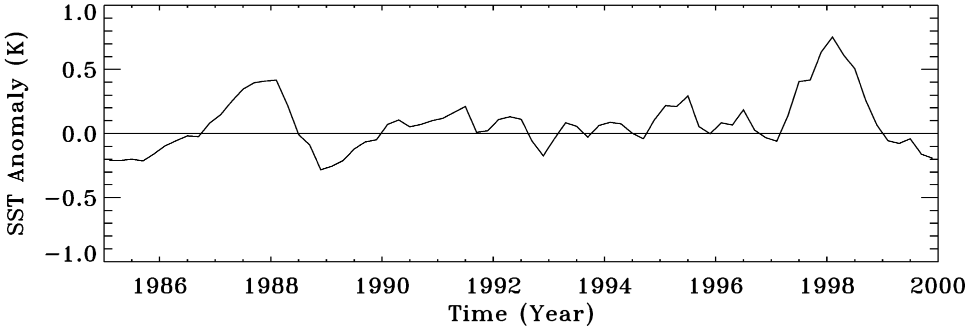

FIG. 1. Time series of tropical mean sea surface temperature (SST) anomalies. The baseline SST values are referenced to the 1985–89 period.

amining the differences between the 1985–89 (hereafter referred to as the 1980s) and the 1994–97 (hereafter referred to as the 1990s) periods. The Pinatubo volcanic aerosols strongly altered the TOA earth radiation budget (LW, SW, and net; see later) by significantly increasing/decreasing the SW reflection/LW emission, respectively, to space. On a decadal time scale, the tropical mean SST during the 1990s was only about 0.144 K larger than its value during the 1980s. There are no statistically significant SST trends during these periods due to the large SST fluctuations.

Figure 2 plotted the time series of LW anomalies from *ERBS* nonscanner observation (red curve), along with the model-calculated anomalies based on the tropical SST anomalies shown in Fig. 1 for the Iris hypothesis or the LaRC parameters. There are some gaps in the *ERBS* LW anomaly time series that are caused by a spacecraft battery system anomaly problem (e.g., 4 months in late 1993). During the SST anomaly peak time of 1997/98 El Niño, LW fluxes observed by CERES also experienced the biggest anomaly, reaching as large as 8 W m^{-2} (Wielicki et al. 2002a). Unfortunately, there were no *ERBS* data for March 1998 due to a data transmission problem, and thus, the 72-day means during the peak period were not available. Compared with the NCEP SST anomaly (Fig. 1), the *ERBS* LW anomalies have very similar seasonal to interannual variations. The two datasets without the values for the Pinatubo eruption period are statistically significantly correlated (correlation coefficient 0.563; note that SW and

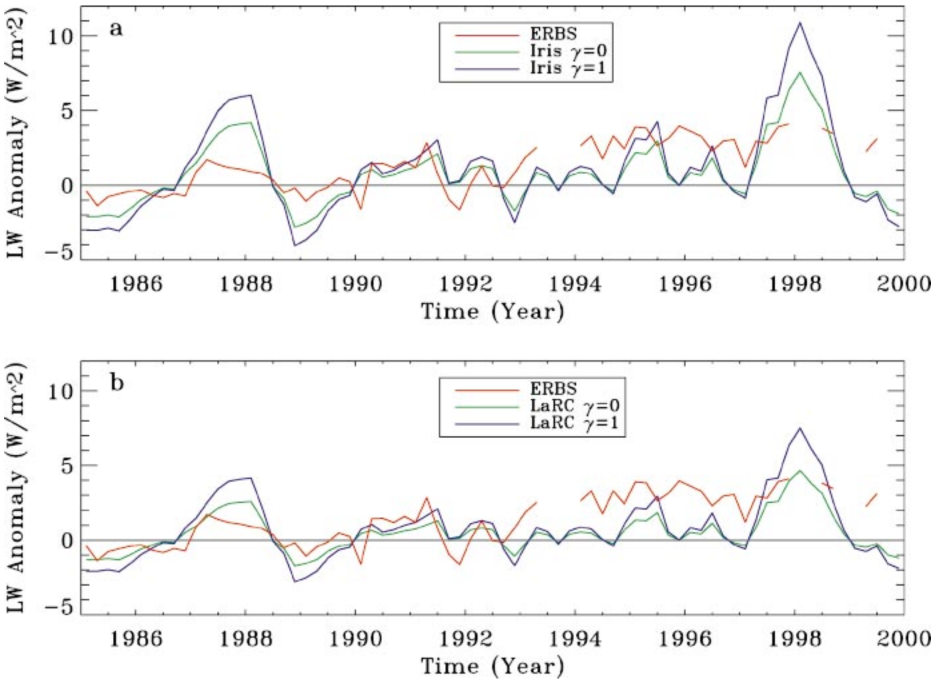

FIG. 2. Time series of outgoing LW radiative anomalies for the *ERBS* measurements, and the predictions from (a) the Iris hypothesis and (b) the LaRC parameters. The γ value is the sensitivity parameter representing the relationship among tropical clear-moist and cloudy-moist, and dry areas (see text).

net are also correlated with SST). The regression slope of LW with SST is about 4.6 W m^{-2} K^{-1}, which is similar to the theoretical increase of LW due to blackbody emission (~4 W m^{-2} K^{-1}), and much larger than the predictions (~2.3 W m^{-2} K^{-1}) from 1D radiative–convective models with fixed relative humidity. Without *ERBS* decadal LW anomalies (see later), the regression slope drops to ~2.1 W m^{-2} K^{-1}, indicating the tropical climate system may be close to the radiative–convective equilibrium in seasonal to interannual time scales.

Unlike the very small SST change during the 1990s compared with the 1980s, the *ERBS* LW radiation increased by about 3 W m^{-2} in the 1990s. This systematic decadal variation in the radiative energy budget is the focus of current study. It is important to point out that the *ERBS* nonscanner offsets before and after the 1993 battery problem were determined from the onboard blackbody and verified by deep space maneuvers and other satellite instruments (Wielicki et al. 2002b). Furthermore, the *ERBS* data showed significant LW rising (early 1993) even before the satellite battery failure (late 1993). In addition to the surface temperature anomalies, three other factors also influence the model-predicted LW anomalies from the Iris hypothesis or the LaRC parameters. The first factor is caused by the assumed area coverage change of the cloudy moist region (or tropical high clouds) as a function of SST. The rate of area coverage change with SST used in this study is −22% K^{-1} as assumed by the Iris hypothesis. This factor would increase outgoing LW radiation with increasing SST because of decreasing high cloud amount. Corresponding to the high cloud variations, clear moist and dry areas may also change, which would introduce additional LW anomalies to the tropical radiation fields due to radiative flux contrast among these areas. This is the cause for the second factor. The parameter γ in Fig. 2 is the sensitivity parameter that represents the relationship among tropical clear moist, cloudy moist, and dry areas. For $\gamma = 1$, the tropical clear moist area increases at the same rate as the increase in tropical cloudy moist area. For $\gamma = 0$, the total tropical moist area (the combination of cloudy moist and clear moist) is fixed at 50% of the Tropics, and is independent of the cloudy moist area. These are the same values of γ used in LCH and Lin et al. (2002). The third factor controlling the model-predicted LW anomalies is related to atmospheric temperature variations introduced by surface temperature anomalies within each tropical box. Since the 3.5-box model does not have an atmospheric temperature profile or lapse-rate feedbacks, the temperature gradient between surface and LW emission level is assumed to be constant in each box. Thus, the LW emission for each tropical box increases with tropical surface temperature. The effect of this factor is small compared with the other two because of the small magnitude of the SST anomaly.

The LW flux anomaly time series estimated from the Iris hypothesis (Fig. 2a) and the LaRC parameters (Fig. 2b) track the *ERBS* observations very well. This is to be expected because the modeled anomalies are not only directly calculated from, but also almost linearly dependent on the NCEP SST anomaly values. The Iris estimates for El Niño and La Niña events are significantly exaggerated even for the decoupled case of moist and dry areas ($\gamma = 0$), which is understandable because the Iris hypothesis assumed much higher LW contrast between cloudy- and clear-moist regions compared to CERES observations (Table 1). The predictions with LaRC parameters for these interannual variations are closer to the measurements than the Iris estimates. For the decadal time scale, both the Iris and LaRC estimates are considerably smaller than the *ERBS* anomalies during the 1990s. Table 2 lists the averaged radiative flux anomalies for the 1990s. It can be seen that the Iris hypothesis predicts about 1/2 to 2/3 of the observed decadal LW variability, while the magnitude from LaRC parameters is even smaller.

TABLE 2. Averaged tropical mean radiative flux anomalies (W m^{-2}) during the 1994–97 period from the *ERBS* observations, the Iris hypothesis, and the LaRC parameters.

		Iris		LaRC	
	ERBS	$\gamma = 0$	$\gamma = 1$	$\gamma = 0$	$\gamma = 1$
LW	3.05	1.434	2.066	0.887	1.424
SW	2.40	0.382	0.382	0.319	0.976
Net	−0.651	−1.052	−1.684	−0.568	−0.448

The modeled SW and net incoming radiative anomalies, along with *ERBS* measurements, are plotted in panels a and b, respectively, of Figs. 3 and 4. Figure 3 is the results from the Iris hypothesis, while Fig. 4 is for the LaRC parameters. The major contribution to the modeled incoming SW values is from the high cloud amount change caused by the SST anomaly and its associated area coverage variations of clear moist and dry regions. Generally, the SW anomalies from the Iris hypothesis are small because the hypothesis assumed a low albedo for tropical high clouds (Table 1). The low albedo and a high value for low clouds contribute significantly to the negative feedback of the Iris hypothesis (Fu et al. 2002). The Iris-predicted SW values (blue curve of Fig. 3a) are much smaller than those of *ERBS* observations (red curve) even without consideration of the Mount Pinatubo volcanic eruption period (hereafter all discussions based on the data without the volcanic event). Because SW fluxes are constant in clear-moist and dry areas (Table 1) in the Iris hypothesis, different coverage relationships of moist and dry regions (i.e., different γ values) degenerate into one condition, as shown in the blue curve in Fig. 3a. The SW estimates from the LaRC parameters (Fig. 4a) have a better match with the observations than those from the Iris hypothesis, especially during the 1990s. The absolute modeled SW values of decadal variability from the Iris hypothesis are only 16% of the *ERBS* observations (Table 2). The SW values for the LaRC parameters are also small

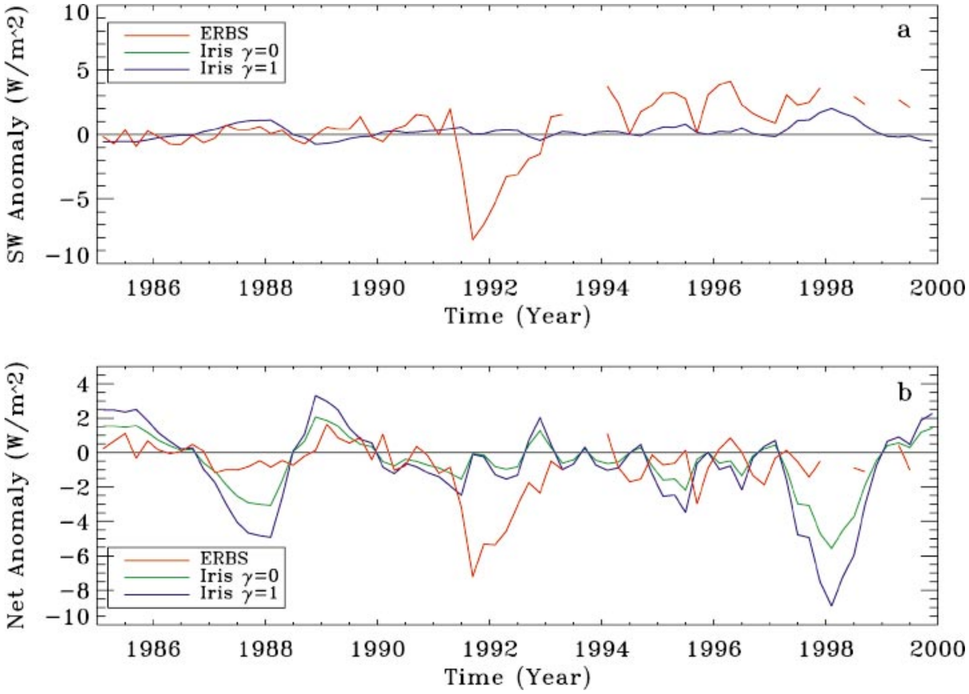

FIG. 3. Same as in Fig. 2 except for (a) incoming SW and (b) net incoming radiative anomalies from both the *ERBS* measurements and the Iris predictions.

and vary from 13% ~ 40% of the *ERBS* observations (Table 2).

Because of the exaggerated and dominant LW effect in the Iris hypothesis, the predicted net incoming anomaly, that is, SW anomaly—LW anomaly, from the hypothesis (Fig. 3b) has absolute values that are quantitatively 60% ~ 160% larger than the observed *ERBS* measurements during the 1990s (Table 2). During the

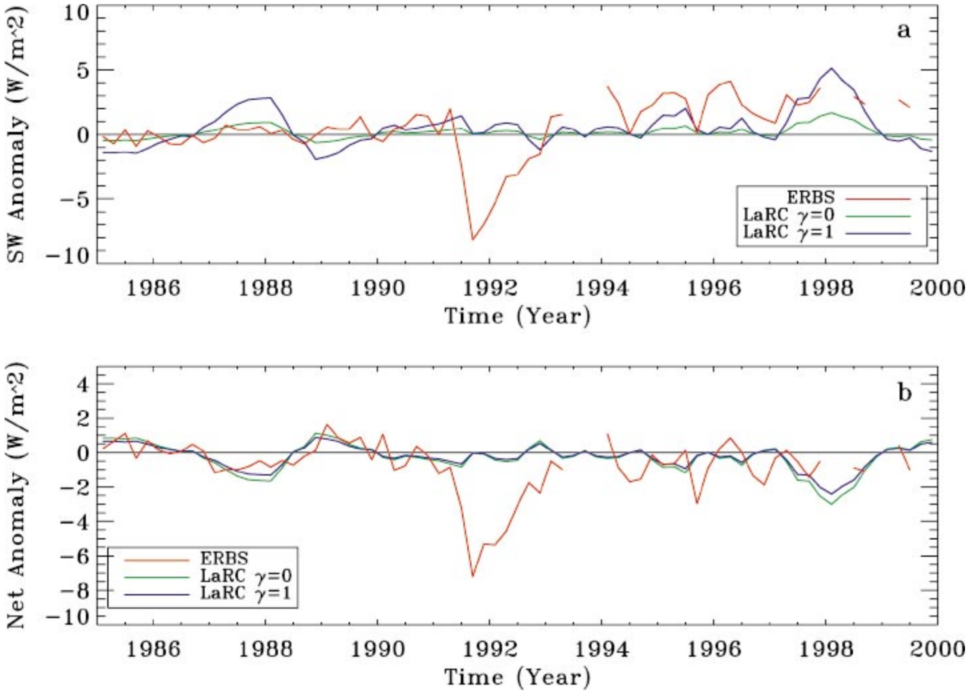

FIG. 4. Same as in Fig. 2 except for the LaRC parameters.

1980s, the variation of the Iris net anomalies are about a factor of 2 larger than the satellite observations. Combining the effects of both SW warming and LW cooling, the net anomaly estimates from the LaRC parameters (Fig. 4b) have a tighter relation with *ERBS* observations during the 1980s. During the 1990s, the averaged net flux anomalies from the LaRC parameters are quantitatively consistent with *ERBS* measurements with differences about 0.1 ∼ 0.2 W m^{-2} (Table 2), and have a much better agreement with observations than those from the Iris hypothesis. These results represent the near balance of the radiative energy over the Tropics during the decades observed by *ERBS* and the weak feedback physics of the relatively small net radiation differences among cloudy-moist (high clouds), clear-moist, and dry regions as observed by CERES (Lin et al. 2002; CLY).

4. Discussions and conclusions

The satellite observations of TOA tropical mean radiative energy budget anomalies during the last two decades are examined for evidences of the Iris hypothesis. The predicted tropical mean LW, SW, and net radiative flux anomalies are calculated from the 3.5-box radiative energy balance model based on the NCEP tropical SST anomalies. The Iris-modeled radiative properties for all tropical boxes (i.e., cloudy-moist, clear-moist, and dry areas) are used in the 3.5-box model simulations. To further understand the sensitivity of the predicted radiative anomalies, the tropical radiative properties, namely the LaRC parameters, from CERES observations (Lin et al. 2002) are also injected into the 3.5-box model to replace the Iris-modeled values and to obtain the second set of predictions in the same way as those simulated for the Iris hypothesis.

On the decadal time scale, the simulated radiative anomalies based on both the Iris and LaRC parameters are generally significantly different from those of *ERBS* measurements. While the LW and SW radiative anomalies are much smaller for the Iris and LaRC calculations than observations, the net flux anomalies from the Iris hypothesis are 60% ∼ 160% larger than *ERBS* measurements. The net radiative anomalies obtained from the LaRC parameters match the satellite data better due primarily to the near-balanced nature of the net radiation in both *ERBS* and CERES observations (Lin et al. 2002; CLY). The poor prediction of tropical radiative flux anomalies from the Iris hypothesis for the decadal radiative variability is not surprising: the unrealistic tropical radiative properties and relationship between high cloud and SST assumed by the Iris hypothesis can not provide good predictions. The Iris hypothesis suggests a strong increase of LW with warmer SST, while the *ERBS* nonscanner data show significant increases in both LW and SW, which cannot be explained by thin cirrus changes. Although both the *ERBS* measurements and the Iris hypothesis suggested decreases of cloud amount over the Tropics (Wielicki et al. 2002a; LCH), there are significant differences between the two in terms of spatial distributions and cloud types for the changes in cloudiness. For example, the observations and the hypothesis suggested noticeably different cloud changes over equatorial uplifting and subtropical subsidence regions. As the surface temperature warms, the Iris hypothesis suggested that the tropical high clouds associated with deep convection will decrease and the clouds in clear moist and dry subsidence regions may not change significantly. This set of events is inconsistent with the observations of Wielicki et al. and Chen et al. (2002). In contrast, Chen et al. found from the observations that the Hadley and Walker cells have strengthened over the last decade causing an increase in the high clouds over the areas associated with the rising branch of the Hadley–Walker cell circulations (i.e., increase in high clouds) and a decrease in the lower-level clouds over the subtropics and the areas associated with the sinking branch of the equatorial Walker cell (cf. Fig. 4 of Chen et al.). Since the area coverage of the subsidence regions is larger than the area coverage of the uplifting regions in the Tropics, the net effect was to produce a decrease in the observed tropical mean total cloudiness. Using data collected from the Tropical Rainfall Measuring Mission (TRMM), Del Genio and Kovari (2002) found that although precipitation efficiency of tropical precipitating convection increases faster with increasing SST than cloud efficiency, it is only in a relative sense that these tropical storms convert more of their available potential water into rainwater than into cloud water at a higher SST. In an absolute sense the actual amount of cloud ice/water in the tropical storms is greater and the area coverage of these storms is also larger at higher SST because the absolute value of available water vapor is greater. The significant differences in the current physical understanding of the generation of high clouds from the detrainment of tropical deep convection between the Iris effect and the observational results are one of the key factors for causing the deviations between the model-predicted radiative flux anomalies (i.e., both the Iris hypothesis and the LaRC parameters) and the *ERBS* measurements. Other key factors that contributed to the differences of observed versus predicted flux anomalies include the lack of theoretical explanations for the decadal variability in tropical cloudiness and radiative energy balance, and the incomplete physical knowledge of cloud dynamics, thermodynamics, and radiation interaction. The simplification of the 3.5-box model may also contribute to the differences between predicted values and observations.

Unlike the seasonal to interannual variability, the *ERBS*-observed decadal LW anomaly (3.05 W m^{-2}) is much larger than the calculated changes in blackbody emission (∼0.58 W m^{-2}) resulted from the small decadal variations of tropical mean SST (0.144 K). Furthermore, these observed LW changes are also larger than those predicted by radiative–convective equilibrium models with fixed relative humidity (~0.33 W m^{-2}). However, most of the LW anomaly is balanced by SW radiation (2.4 W m^{-2}), the net outgoing radiation (0.65 W m^{-2}), then, is closer to those theoretical values.

Finally, our analysis shows that there are significant differences between *ERBS* data and the Iris simulated results. Poor agreements between the satellite data and model predictions even when the tropical radiative properties from CERES observations (LaRC parameters) are used imply that besides the Iris-modeled tropical radiative properties, the unrealistic variations of tropical high cloud generated from the detrainment of deep convection with SST assumed by the Iris hypothesis are likely to be another major factor for causing the deviation between the predictions and observations. Thus, there is no observational evidence in the decadal satellite radiative energy budget measurement record supporting the strong negative climate feedback of the Iris hypothesis.

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