2.12 NEW CERES DATA EXAMINED FOR EVIDENCE OF TROPICAL IRIS FEEDBACK

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1. INTRODUCTION

New data products from the Clouds and the Earth's Radiant Energy System (CERES; Wielicki et al., 1996) instrument were recently released. The Single Scanner Footprint (SSF) data product combines radiation budget data from CERES with cloud property retrievals from an imager on the same platform to provide a vastly improved characterization of the state of the atmosphere. In addition, the SSF incorporates new CERES angular distribution models (ADM; Loeb et al., 2002) based on improved scene identification to obtain more accurate top-of-atmosphere fluxes from the satellite-measured radiances. Together these advances allow the study of radiative fluxes for specific cloud types with unprecedented accuracy. SSF data products are now available using the Visible and InfraRed Sensor (VIRS) for the Tropical Rainfall Measuring Mission (TRMM). These data are used here to explore the Iris hypothesis recently proposed by Lindzen et al., 2001 (hereafter LCH).

2. THE CERES INSTRUMENT

The CERES instrument is a bi-axial scanning radiometer (Wielicki et al., 1996). On the TRMM satellite, CERES operated in a quasi-periodic cycle of 2 days in Fixed Azimuth Plane Scan (FAPS) mode and 1 day in Rotating Azimuth Plane Scan (RAPS) mode, with an occasional day of along-track scanning. FAPS mode is basically a cross-track scanning mode and obtains maximum geographic coverage over the orbital swath. RAPS mode scans in azimuth in order to obtain information on the anisotropy of radiation in the full hemisphere. TRMM is a precessing spacecraft with an orbital inclination of about 35^{o}. It samples all local times over a 46 day period.

CERES measures radiative energy in 3 broad channels: the shortwave (SW) channel measures reflected solar radiation, the window (WN) channel measures thermal radiation between 8.10 and 11.79 μm, and the total (TOT) channel measures the total energy leaving the Earth at all wavelengths (0.3 - >100 μm, Priestley et al., 2000). The longwave (LW) radiation is obtained by subtraction: LW=TOT-SW.

CERES is primarily a climate instrument, so great attention has been paid to its calibration. As a result, the radiative fluxes measured by CERES have been both stable and accurate over the lifetime of the instrument. Uncertainties in measured radiances are generally below the 0.5% level (Priestley et al., 2000). The errors in the instantaneous estimated fluxes of SW (13 W/m^2) and LW (4.3 W/m^2) radiation are mainly due to errors in the application of the angular distribution models (Loeb et al., 2002) which result from errors in the scene identification.

3. DATA ANALYSIS

A CERES SSF contains about 130 parameters describing each CERES footprint. These include time, position, and viewing angles, surface information, filtered and unfiltered radiances, radiative fluxes at the surface and top of atmosphere, and a variety of parameters describing the clear and cloudy portions of the footprint. The latter are obtained from imager (VIRS) information and from ancillary inputs such as numerical weather prediction models (http://asd-www.larc.nasa.gov/ATBD/ATBD.html). The nominal 2-km VIRS-pixel derived properties are then convolved using the CERES scanner point spread function to obtain cloud properties for up to two cloud layers within the ~10 km CERES footprint. Currently these layers are distinct, with no overlap properties identified. For this analysis, since radiative fluxes are only available at the CERES footprint scale, the properties of the two layers are area-weighted to obtain footprint-mean cloud properties.

A set of screening criteria are applied to the data to ensure that footprints with problems are not used. This leaves more than half a million regionally distributed footprints per day to be analyzed.

CERES TRMM SSF data are available for the period January 1 to August 31, 1998. This includes the peak and decay of the strong 1997-98

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El Niño. Short periods of data are available after this, but are not included in this study because of the precessing orbit. Along-track days are also not included, due to poor spatial sampling. To prevent temporal sampling biases, the TRMM data are analyzed in 46-day intervals to get radiative properties over the full range of local times. This is necessary to compute a correct insolation-weighted albedo. Details of the averaging method are given in Chambers et al., 2002a. The radiative properties of a particular M-type footprint are found to be very stable from one precession cycle to the next, suggesting that the results are in fact representative of that cloud/atmosphere type; and not responding to a seasonal or El Niño signal.

Three Tropical Ocean regions between 30° S - 30° N latitude are considered: the Tropical West Pacific (TWP, 130° to 190° East Longitude, corresponding to the region studied by LCH); the East Pacific (200° to 280° East Longitude); and the entire Tropical Ocean. When calculating the radiative properties, each region was broken up into 10° latitude zones. Since similar results are obtained for all three regions, only those for the entire Tropical Ocean are given in this paper. For the land mask, SSF footprints are screened by surface scene type for complete coverage by water.

4. RADIATIVE PROPERTIES

4.1 The original 3.5 box Iris model

The Iris hypothesis of LCH relied on examination of the variation of cirrus cloud coverage with cloud-weighted Sea Surface Temperature (SST) over a large area. This was done using the 11 and 12 μm split window channels on Japan's Geostationary Meteorological Satellite, GMS-5. LCH used these observations to develop a 3.5 box climate model consisting of the extratropics and the dry and moist Tropics, the latter further divided into a cloudy-moist region containing upper-level cirrus cloud and a clear-moist region without this high cirrus. The GMS instrument provides only limited information on the cloud properties. Thus, LCH used the brightness temperature at 11 μm, $T_{11} < 260$ K, as an indicator of the cloudy moist region. Further, LCH used a fairly subjective approach to select the radiative properties of each box in the climate model, subject to the constraint of matching Earth Radiation Budget Experiment (ERBE, Barkstrom et al., 1989) global and Tropical mean values. Previous studies (Fu et al., 2002 and Lin et al., 2002) suggest that the LCH LW flux and SW albedo for the cloudy moist portion of the model are too low, while the corresponding properties of the dry portion are too high. Hartmann and Michelsen (2002) have called into question the interpretation of the observed cloud cover versus SST relation.

From the SSF, radiative properties are obtained for the dry region, which LCH assume covers half the Tropics, from those footprints having the highest 50% of outgoing LW flux. This corresponds to emission from the lowest levels of the atmosphere, as occurs with very low upper troposphere humidity. Properties for the moist region are obtained from the remaining pixels. These are compared to the 3.5 box properties of LCH in Table 1. The final row combines the LCH Cloudy and Clear Moist values for comparison. Note the near-constant net flux measured by CERES, as opposed to the large range of net flux in the LCH values.

Table 1: Radiative Properties for the Tropics

Region	Area Coverage	SW Albedo	OLR, W/m^2	Net Flux, W/m^2
CERES Fluxes for Highest and Lowest 50% of LW				
Dry	50%	0.14	292	51.4
Moist	50%	0.32	231	42.4
LCH Values				
Dry	50%	0.21	303	12.8
Cloudy Moist	22%	0.35	138	123.
Clear Moist	28%	0.21	263	52.8
Moist (Cldm+ Clrm)	50%	0.27	208	84.3

4.2 Improved Cloudy Moist Definitions

The use of a brightness temperature threshold to identify upper level cirrus cloud is problematic. When the brightness temperature threshold is set very low, to remove all water clouds, it will also miss thinner cirrus clouds. When the threshold is too high, water clouds will be selected along with the cirrus clouds. Chou et al. (2002) indicated that $T_{11} < 260$K was merely an index for the variation of the cloudy moist region, and LCH actually used an area fraction about twice that of the T_{11} < 260K region for the cloudy moist box. The CERES SSF contains vastly improved information on cloud properties, including cloud temperature and cloud particle condensation phase (i.e., water or ice), using associated VIRS imager data. As a result, retrieved cloud properties themselves can be examined to obtain a better identification of cirrus cloud. Two basic approaches are considered here: 1) T_c tests find CERES footprints where the retrieved cloud temperature (accounting for the emissivity of thin clouds) is suggestive of ice clouds; 2) cloud water/ice phase tests find CERES footprints in which the cloud is mostly or predominantly ice.

Initial validation studies of the CERES SSF cloud properties suggest that the T_c retrieval places single layer cirrus clouds within 1 km of their actual height; while the phase retrieval is excellent for single layer clouds (Minnis, 2002, personal communication). Comparison to ground truth results shows no evidence that the CERES algorithm is missing anything more than isolated thin cirrus (0-5% cloud fraction; Chambers et al., 2002b). For cirrus over low water cloud, the retrieval is not so well understood. Some high cirrus over low cloud may be missed or mis-classified in this analysis. However, given the lack of sensitivity in the results below, it does not appear that this could be a major issue.

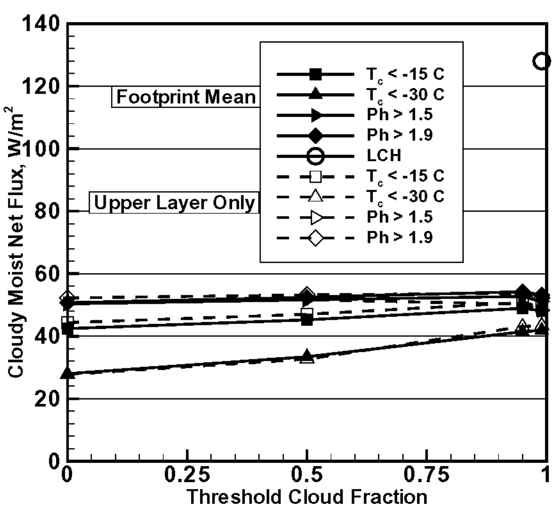

Fig. 1 Net flux computed for a variety of definitions of the cloudy moist region. Solid symbols for results from footprint-mean cloud properties. Open symbols for results from upper layer properties.

Figure 1 shows net radiative fluxes for a variety of ways of defining the cloudy moist region. These include cloud temperature thresholds, Tc < -15 C and Tc < -30 C and phase thresholds of Phase > 1.5 (more than half of cloud in footprint is ice) and Phase > 1.9 (cloud in footprint is predominantly ice). Since cirrus over cumulus is expected to occur often in the Tropics, a second set of tests is also performed using only the properties of the upper cloud layer, if that layer covers more than half the CERES footprint. This captures any occurrence of extensive and identifiable high cirrus cloud in the same footprint with identifiable low cloud. The net flux is quite insensitive to the definition used, including restriction of the results by footprint cloud fraction. About 85% of the cloudy moist pixels are 99% or more cloud covered, confirming that cirrus cloud tends to be spatially extensive.

5. CLOUD FEEDBACK CALCULATIONS

The radiative properties and area fractions from the CERES SSF analysis can be inserted in the simple climate model used by LCH. As in their study, the tropical cloudy moist area is varied +/- 30%, as $A_{cldm}=A_{cldm0}(1+\mu)$, where μ=-0.3 to 0.3. The clear moist area, $A_{cm}=A_{cm0}(1+\gamma\mu)$, may vary through a range of dynamics, from following the change in the cloudy moist area (γ=1) to remaining constant (γ=0).

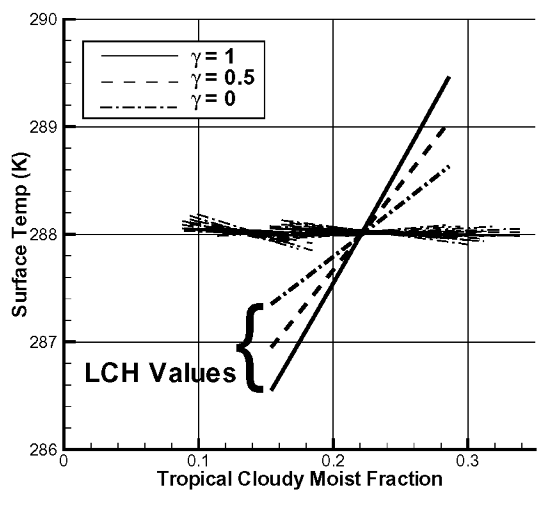

Fig. 2 Surface temperature response in 3.5 box model using various means of defining radiative properties.

The global surface temperature response from a change in the cloudy moist area fraction is shown in Fig. 2. The strong negative feedback found by LCH is reduced to a much weaker feedback. This feedback may be either slightly positive or slightly negative depending on which definition is used for the cloudy moist region, but in all cases is much smaller than that found by LCH.

In contrast to the results of LCH, this study finds the largest effect when γ=0 and the smallest effect when γ=1. This is a result of the very different properties of the dry region in the two approaches. LCH assumed a very small net flux input in the dry region, so decreasing either cloudy moist or clear moist area coverage resulted in a very strong negative feedback. In contrast, the properties of the dry region as obtained from CERES measurements (Table 1) result in a net flux which is nearly the same as that in the cloudy and clear moist regions. As a result, increasing the amount of dry area has little effect.

6. CONCLUSIONS

New data products are available from the CERES instrument, a part of the NASA Earth Observing System. The SSF product combines radiative fluxes with extensive information on the cloud conditions in the footprint, which are retrieved using the co-orbiting imager instrument. These data have been analyzed to more accurately define the radiative properties for the various regions of the recently-proposed adaptive infrared Iris (Lindzen et al., 2001). A variety of ways of defining the cloudy moist region were examined. According to CERES, the net radiative flux for the cloudy moist region ranges between 28 and 54 W/m^2 depending on the specific definition used. This is in contrast to the value of 123 W/m^2 which was somewhat subjectively assigned by LCH.

This simple model may miss many feedbacks in the climate system, but it should provide a rough range of the climate variations if the physics of the Iris is correct. There is some question whether the change in cloudy moist area with cloud-weighted SST actually represents a useful quantity (Hartmann and Michelsen, 2002), and whether extrapolating it from a regional variation to a global response to warmer climate is appropriate. Regardless, the current results show that the proposed Iris feedback is very much weaker when objectively-determined radiative properties are used in the model.

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