Radiative Fluxes and Heating Rates During TOGA COARE Over the Intensive Flux Array

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Introduction

We have used the surface radiation measurements taken at five sites in the Intensive Flux Array (IFA) during the Tropical Ocean Global Atmosphere (TOGA) Coupled Ocean Atmosphere Response Experiment (COARE) and satellite-derived top-of-atmosphere (TOA) fluxes to estimate the 3-hourly time series of the atmospheric solar and infrared (IR) radiative heating rate in the IFA. This information will be useful for evaluating cloud and radiation models and for constraining analyses of the IFA enthalpy budget.

We used a simple average of the surface IR downwelling flux measured at five surface sites to estimate the IFA-averaged surface IR downwelling flux. We determined the relationship between the solar transmission and the collocated satellite-derived albedo and used this relationship to estimate the IFA-averaged surface solar downwelling flux from the satellite-derived albedos.

We compiled three estimates of TOA IR and solar broadband radiative fluxes over the IFA during TOGA COARE. While the outgoing IR estimates are quite similar, there is a significant range in the estimated global albedos averaged over the 4 months of COARE: 0.23, 0.28, and 0.29.

IFA-Averaged Surface Radiative Fluxes

We used measurements of downwelling IR and solar radiative fluxes made at five sites in the IFA during TOGA COARE. These sites included two islands (Kavieng and Kapingamarangi), two ships (Kexue and Shiyan), and the Woods Hole Oceanographic Institution (WHOI) buoy. The island and ship sites were located on the perimeter of the IFA, while the WHOI buoy was located in the interior of the IFA.

The IFA-averaged surface downwelling IR fluxes were assumed to be well represented by a simple average of the measurements at the five surface sites because these fluxes are only weakly affected by clouds. The surface upwelling IR fluxes were calculated from the sea surface temperature (assumed uniform over the IFA but varying in time) and the surface downwelling IR fluxes using an emissivity of 0.97 following Weller and Anderson (1996).

Based on the Barnett et al. (1998) study of the correlation between point and area-averaged measurements of the downwelling solar radiative flux averaged over various time intervals, we concluded that the measurements of downwelling solar flux from the five IFA surface sites were not likely to be representative of the entire IFA when averaged over 3-hour time intervals (although they would be when averaged over longer time intervals, such as a month).

Many investigators have developed methods that use the area-averaged TOA upwelling solar flux to estimate the corresponding area-averaged surface downwelling solar radiative flux. We developed such a method for use over the IFA during TOGA COARE.

We first determined the relationship between the area-averaged solar transmission $\overline{\tau}$ and the collocated satellite-derived area-averaged albedo $\overline{\alpha}$. Then we used this relationship to estimate the time series of IFA-averaged surface solar transmission from the satellite-derived IFA-averaged albedos.

Barnett et al. found that the correlation between a point measurement and an area-averaged measurement of surface downwelling solar radiative flux increases with the averaging time and decreases with the averaging radius (or area). In order to develop a reliable relationship between the area-averaged solar transmission and the area-averaged TOA albedo, we used TOA albedo estimates averaged over areas that ranged in size from 1 square degree to 4 square degrees. Each area was centered on one of the five surface sites.

Figure 1 is a scatterplot of 3-hour averages (centered at 00Z) of surface transmission versus area-averaged TOA albedo for all five surface sites. The correlation between the area-averaged albedos and the point measurements of surface transmission that are included in this plot is 0.75. This level of correlation corresponds to what Barnett et al. found using a 75-km averaging radius and a 3-hour averaging time for sunny days during the summer in Oklahoma.

The plot indicates that for a specific value of the area-averaged albedo, any one out of a wide range of point transmission values may occur. The area-averaged transmission may be estimated as the average of the point measurements for a single value (or a small range of values) of the area-averaged albedo. In practice, the resulting dependence of $\overline{\tau}$ on $\overline{\alpha}$ is nearly the same as the corresponding linear regression fit of τ to $\overline{\alpha}$.

Figure 2 shows the resulting linear regression fits for four times of the day: 00Z, 03Z, 06Z, and 21Z. These correspond to late morning, early afternoon, late afternoon, and early morning, respectively. The fits fall into two groups: 00Z and 03Z (the two upper lines), and 06Z and 21Z (the two lower lines) that correspond to relatively small and large solar zenith angles, respectively. We applied the linear regression fits to the IFA-averaged TOA albedos to estimate the IFA-averaged surface transmissions and downwelling solar fluxes for the entire intensive observation period (IOP).

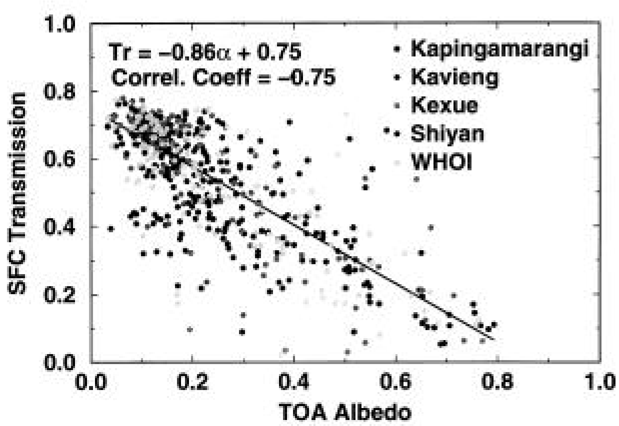

Figure 1. Scatterplot of 3-hour averages (centered at 00Z) of surface transmission versus area-averaged TOA albedo for five surface sites: Kapingamarangi, Kavieng, Kexue, Shiyan, and Woods Hole buoy. The black line indicates linear regression fit for all five sites. The resulting equation and correlation coefficient are also given.

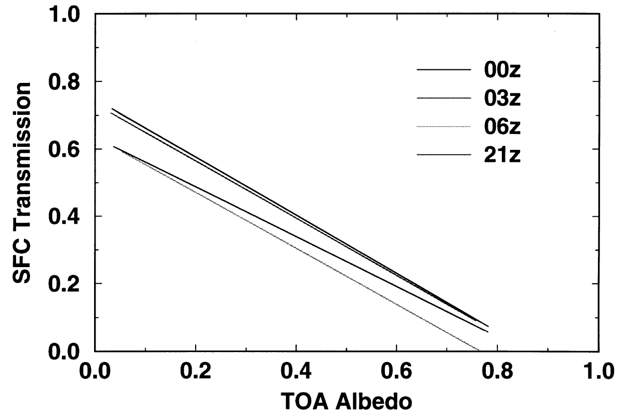

Figure 2. Linear regression fits of point surface transmission measurements to area-averaged TOA albedos for four times of the day: 00Z, 03Z, 06Z, and 21Z.

The surface upwelling solar fluxes were calculated from the surface downwelling solar fluxes using a constant ocean albedo of 0.055 following Weller and Anderson (1996).

IFA-Averaged TOA Radiative Fluxes

We define IFA-averaged fluxes as averages over the 5° by 5° region centered at longitude 155° E latitude 2.5° S. Three TOA radiative flux datasets were used to estimate the IFA-averaged TOA radiative fluxes.

Zhang et al. (1995) and Rossow and Zhang (1995) produced the ISCCP Flux Cloud (FC) dataset for TOGA COARE. They used a radiative transfer code and the International Satellite Cloud Climatology Program (ISCCP) cloud properties to derive radiative flux profiles at 3-hourly intervals. An early version of the dataset can be obtained from http://daac.gsfc.nasa.gov/WORKINPROGRESS/TOGA/isccp-flx.html. Paul Ciesielski of Colorado State University (CSU) provided the FC TOA and surface radiative fluxes to us, already averaged over the IFA.

Pat Minnis and co-workers estimated TOA broadband fluxes for TOGA COARE from geostationary meteorological satellite (GMS) narrowband radiances. They recalibrated the hourly radiances and converted them to broadband fluxes. The resulting TOA fluxes agree with the Earth Radiation Budget Satellite (ERBS) wide-field-of-view (WFOV) Shape Factor 10° data. The narrowband to broadband relationship was derived from the December

1986 GMS and ERBS scanner 2.5° data. We obtained the Minnis TOGA COARE dataset from http://vikranth.larc.nasa.gov/larc-toga-twp.html. We first interpolated both spatially and temporally to estimate missing values. Then we averaged spatially and temporally to obtain 3-hourly IFA averages.

Collins et al. (1997) also estimated the TOA broadband fluxes for TOGA COARE from the GMS narrowband radiances. Their narrowband to broadband relationship is based upon collocated observations from the National Aeronautics and Space Administration (NASA) ER-2 aircraft. Collins provided us with a set of mostly hourly IFA-averaged TOA fluxes. Unfortunately, this dataset is not as complete at the Minnis dataset.

IOP averages were estimated for the Minnis and Collins datasets by using the FC dataset as a reference. The resulting IOP- and IFA-averaged TOA upwelling IR fluxes and albedos are listed in Table 2.

Table 1. IOP- and IFA-averaged surface downwelling IR and solar fluxes.

Dataset	LW↓ (W m^{-2})	SW↓ (W m^{-2})
5-site average	417	208
satellite-derived	417	208
FC	442	249

Table 2. IOP- and IFA-averaged TOA upwelling IR fluxes and albedos.

Dataset	LW↑ (W m^{-2})	Albedo
Collins	218	0.228
Minnis	220	0.277
FC	215	0.285

IFA-Averaged Atmospheric Radiative Heating Rates

The atmospheric radiative heating (ARH) is given by the net radiative flux into the atmosphere. For studies of convection, the average tropospheric radiative heating rate [Q_R] is generally more useful. To obtain [Q_R] from ARH, we used the following empirical relation derived from a 6-day simulation of convection in the IFA during COARE using a cloud-resolving model that includes an interactive radiative transfer code:

$$[Q_R] = -0.06 + 0.01\text{ARH},$$

where [Q_R] has units of K day^{-1} and ARH has units of W m^{-2}.

Figure 3 shows the time series of the IFA-average of [Q_R] averaged over 5-day periods for the entire 4-month period of TOGA COARE calculated using the FC dataset, the Minnis TOA plus the five-station-average (IR) and satellite-derived (solar) surface datasets, and Collins TOA plus the five-station- average (IR) and satellite-derived (solar) surface datasets. The time coordinate is days since December 31, 1991. The differences between the three time series are

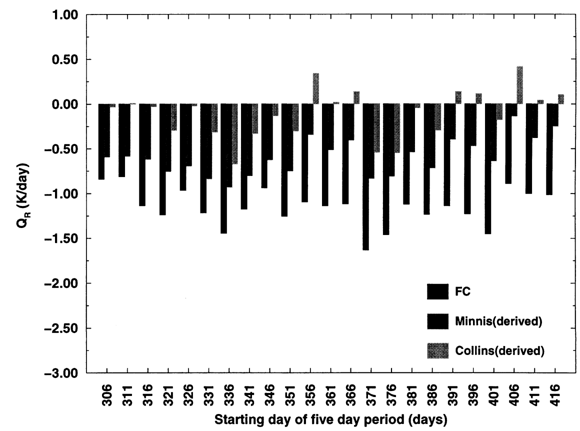

Figure 3. Time series of the IFA-average of [Q_R] averaged over 5-day periods for the entire 4-month period of TOGA COARE calculated using the FC dataset, the Minnis TOA plus the five-station-average (IR) and satellite-derived (solar) surface datasets, and Collins TOA plus the five-station-average (IR) and satellite-derived (solar) surface datasets.

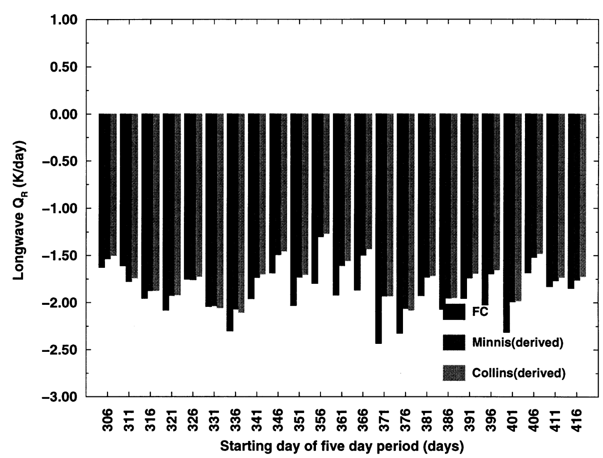

Figure 4. Time series of the IFA-average of the IR component of [Q_R] averaged over 5-day periods for the entire 4-month period of TOGA COARE calculated using the FC dataset, the Minnis TOA plus the five-station-average surface datasets, and Collins TOA plus the five-station-average surface datasets.

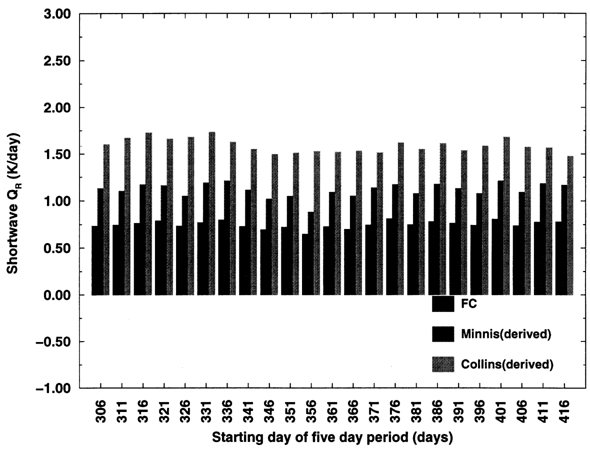

Figure 5. Time series of the IFA-average of the solar component of [Q_R] averaged over 5-day periods for the entire 4-month period of TOGA COARE calculated using the FC dataset, the Minnis TOA plus the satellite-derived surface datasets, and Collins TOA plus the satellite-derived surface datasets.

greater than the variations of each time series during the IOP. Figures 4 and 5 show the IR and solar components of [Q_R], respectively.

Acknowledgments

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