Meteorology 6150
Exercise 1: Cloud Radiative Forcing
Due: February 1, 2005

We will use observational estimates of the longwave (infrared) and shortwave (solar) radiative fluxes at the surface and at 100 mb within a 5 by 5 degree region of the Tropical Western Pacific Ocean centered at 155°E, 2°S, for the 4-month period from Nov 1992 to Feb 1993. This region is labeled the IFA, for Intensive Flux Array, on the map at <http://atmgcm.msrc.sunysb.edu/ coare/togamap.gif>.

The purpose of the exercise is to quantify the radiative effects of the clouds in this region and for this time period on the surface, the troposphere, and the earth-troposphere system.

Cloud radiative forcing, or *CRF,* is the difference between the actual, all-sky, radiative heating rate and the corresponding clear-sky radiative heating rate. The radiative heating rates may apply to the earth's surface, the atmosphere, or the earth-atmosphere system, for example. For the earth's surface and for the earth-atmosphere system, the radiative heating is determined by the radiative fluxes at the surface and the TOA (top-of-atmosphere), respectively, while for the atmosphere, the radiative heating rate is determined by both the surface and TOA fluxes.

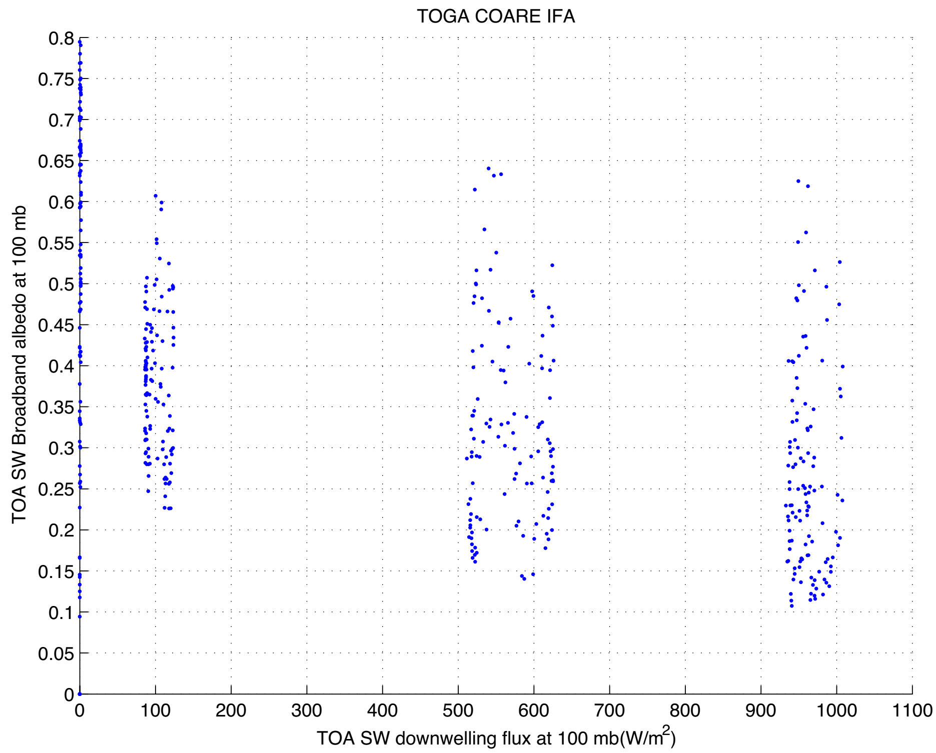
1. We need the *clear-sky* radiative fluxes in order to calculate the cloud radiative effects. There are basically two definitions of the clear-sky flux. One definition is the flux that *is actually measured when the sky is clear.* We will use this definition. Another definition is the flux that *would be measured if the radiative effects of any clouds present could be eliminated.* This clear-sky flux cannot be measured, but it can be calculated.

   The following all-sky radiative fluxes, averaged over 6-hour intervals, are available from <http://atmgcm.msrc.sunysb.edu/coare/main.html2>, in text files of the same name with .txt appended:

   srf_sW_Up
   srf_SW_Dn
   srf_lw_up
   srf_lw_dn
   100mb_sw_up
   100mb_Sw_dn
   100mb_lw_up
   100mb_lw_dn

   We will determine the clear-sky value for each flux, for each 6-hour period of the day. The clear-sky SW fluxes obviously vary according to the time of day; the clear-sky LW fluxes may also, despite the maritime location of the region.

   (a) The following plot illustrates one method to determine the clear-sky fluxes for 100mb_sw_up. The plot was produced by the Matlab program **read_100mb_sw_up_dn.m**, which is available at ∼skrueger/6150/, where ∼skrueger/ = <http://www.met.utah.edu/ skrueger/>, or /web/skrueger/ (department file system).



The *broadband albedo*, SW_up/SW_dn, is plotted versus SW_dn at 100 mb for all 478 6-hourly intervals. The SW_dn depends only on the time of day and the day of the year, whereas the albedo depends on the surface and cloud properties. When the sky is clear, the albedo is smallest (because the ocean's albedo is less than that of clouds) and depends primarily on the solar zenith angle. The clear-sky albedo, α_{clr}, for each time period is easily determined by inspection of the plot.

The clear-sky SW_up for each time period is then simply $\alpha_{\mathrm{clr}}\overline{\mathrm{SW\_dn}}$, where $\overline{\mathrm{SW\_dn}}$ is the average SW_dn for each time of day (and is calculated in **read_100mb_sw_up_dn.m**).

(b) The method to determine the clear-sky fluxes for 100mb_lw_up is the same, but simpler because the diurnal variation of 100mb_lw_up is much less than that of 100mb_sw_up. See the Matlab program **read_100mb_lw_up_sw_dn.m**.

When the sky is clear, is the LW_up smallest, or largest? Whichever it is, it is easily determined by inspection of the plot.

(c) The method to determine the clear-sky fluxes for 100mb_lw_dn is the same as for 100mb_lw_up. At the true TOA, 100mb_lw_dn = 0, but at 100 mb, 100mb_lw_dn > 0 because of emission from the stratosphere above. Also, SW_dn at 100 mb < SW_dn at the true TOA because of absorption in the stratosphere (mainly by ozone).

(d) To determine the clear-sky fluxes for srf_SW_Dn and srf_lw_dn, use the same methods as for the TOA (100 mb) fluxes, except that for srf_SW_Dn, plot the transmittance, t = srf_SW_Dn / 100mb_Sw_dn, instead of albedo, versus vs 100mb_Sw_dn.

(e) To determine the clear-sky fluxes for srf_sW_Up, it is useful to recognize that

$$\text{srf\_sW\_Up} = \text{srf\_SW\_Dn} \times \ \alpha_s = \text{100mb\_Sw\_dn} \times \ t \times \ \alpha_s,$$

where $\alpha_s \equiv$ srf_sW_Up / srf_SW_Dn.

(f) How to determine the clear-sky fluxes for srf_lw_up, which is almost entirely determined by the sea surface temperature, is not obvious. We will make the simplest reasonable assumption: that there is no cloud effect on srf_lw_up, so that the clear-sky flux is the same as the actual flux at all times.

(g) Tabulate the clear-sky fluxes for each time of day for all fluxes except srf_lw_up. Include the clear-sky albedoes and transmittances for the SW fluxes. Submit your plots.

2. (You will use your clear-sky fluxes to calculate the cloud radiative effects. Details forthcoming.)