Annual Report to
NOAA's Climate Variability and Predictability Program

Investigation of Surface Flux and Cloud/Precipitation Aspects of Air-Sea Interaction in the Tropical Eastern Atlantic

C. W. Fairall, D. Wolfe, L. Bariteau, S. Pezoa
NOAA Earth System Research Laboratory

Period covered by this report: Oct 1, 2006 - Sept 30, 2007
Project Manager: C. W. Fairall, Chief of Weather and Climate Physics Branch.
NOAA Earth System Research Laboratory Physical Sciences Division, 325 Broadway, Boulder, CO 80305
303-497-3253 Chris.Fairall@noaa.gov
Finance Contact: Jo Novosel, 303-497-6588 Jo.Novosel@noaa.gov
Lab Director: William D. Neff

15 January 2008

Investigation of Surface Flux and Cloud/Precipitation Aspects of Air-Sea Interaction in the Tropical Eastern Atlantic

Background

In this project we plan to analyze observations from a ship-based measurement program to obtain statistics on key surface, atmospheric boundary layer, cloud macrophysical and microphysical, and radiative properties relevant to NOAA's CLIVAR Atlantic Program. We plan to place a suite of instruments on NOAA ships deploying and servicing new buoys at 23W. The buoys are part of a joint NOAA AOML/PMEL project funded by NOAA's Office of Climate Observations (OCO).

The principal goal of the study is to examine the role of local air-sea interaction in the annual cycle of the Tropical Atlantic cold tongue and ITCZ complex. A second goal is to investigate modification of surface flux parameterizations in the presence of deep convection. The project will also provide comprehensive detail at a few points within a large array of *in situ* and satellite observations being used to investigate Tropical Atlantic variability.

The basic objectives of the measurements and analysis are to:

*Provide an assessment of the balance of surface fluxes and ABL structure in the TA equatorial cold tongue and ITZCZ complex.

*Advance development of bulk turbulent and radiative flux parameterizations either directly or by linking with LES and CRM research efforts.

*Advance understanding of the role of convective clouds, aerosols, and precipitation in cloud radiative forcing.

*Increase the utility of long time series buoy observations of air-sea fluxes through intercalibration, atmospheric profiles, cloud properties, and spatial context.

*Provide comprehensive information for operational weather forecast model evaluation/development and satellite calibration/validation and algorithm development

2007 Field Program

The PSD air-sea flux and cloud group conducted measurements of fluxes and near-surface bulk meteorology during the field program AMMA at 23 W Longitude from 5 S to 20 N Latitude (see instruments listed in Table 1). The ETL flux system was installed initially at Charleston, SC, in February 2007. The observations were taken from May 2 to June 1 (see Figure 1).

The air-sea flux system consists of six components: (1) A fast turbulence system with ship motion corrections mounted on the jackstaff. The jackstaff sensors are: INUSA Sonic anemometer, LiCor LI-7500 fast CO_2/hygrometer, and a Systron-Donner motion-pak. (2) A mean T/RH sensor in an aspirator on the jackstaff. (3) Solar and IR radiometers (Eppley pyranometers and pyrgeometer) mounted on top of a seatainer on the 02 deck. (4) A near surface sea surface temperature sensor consisting of a floating thermistor deployed off port side with outrigger. (5) A Riegl laser rangefinder wave gauge mounted on the bow tower. (6) An optical rain gauge mounted on the bow tower.

Slow mean data (T/RH, PIR/PSP, etc) are digitized on a Campbell 23x datalogger and transmitted via RS-232 as 1-minute averages. A central data acquisition computer logs all sources of data via RS-232 digital transmission:

1. Sonic Anemometer
2. Licor CO2/H2O
3. Slow means (Campbell 21x)
4. Laser wave sensor
5. not used
6. Systron-Donner Motion-Pak
7. Ship's SCS
8. ETL GPS

The 8 data sources are archived at full time resolution. At sea we run a set of programs each day for preliminary data analysis and quality control. As part of this process, we produce a quick-look ascii file that is a summary of fluxes and means. The data in this file come from three sources: The ETL sonic anemometer (acquired at 10 Hz), the ship's SCS system (acquired at 2 sec intervals), and the ETL mean measurement systems (sampled at 10 sec and averaged to 1 min). The sonic is 5 channels of data; the SCS file is 15 channels, and the ETL mean system is 42 channels. A series of programs are run that read these data files, decode them, and write daily text files at 1 min time resolution. A second set of programs reads the daily 1-min text files, time matches the three data sources, averages them to 5 or 30 minutes, computes fluxes, and writes new daily flux files.

Atmospheric aerosols were measured with a Particle Measurement Systems (PMS) Lasair-II aerosol spectrometer. The Lasair-II draws air through an intake and uses scatter of laser light from individual particles to determine the size. Particles are counted in six size bins: 0.1-0.2, 0.2-0.3, 0.3-0.5, 0.5-1, 1-5, and greater than 5.0 μm diameter. The ETL system was mounted in the seatainer on the 02 deck with the intake on the upwind side of the container. The system ran at 1.0 cfm (0.028 m3/min) sample volume flow rate with a count deconcentrator that reduces the counts a factor of 10 (to prevent coincidence errors). The time series of aerosol data is shown in Fig. 2. Notice the high concentrations of larger particles around day 133 (May 13, 2007) associated with Saharan dust (see the satellite image for this day in Fig. 3).

ETL/Flux also operated four remote systems: a Vaisala CT-25K cloud base ceilometer, a 915 MHz Doppler wind profiler, a microwave radiometer systems and the Ronald H Brown's scanning Doppler C-band radar. The ceilometer is a vertically pointing lidar that determines the height of cloud bottoms from time-of-flight of the backscatter return from the cloud. The time resolution is 30 seconds and the vertical resolution is 15 m. The raw backscatter profile and cloud base height information deduced from the instrument's internal algorithm are stored in daily files. One Radiometrics Inc. 'Mailbox' microwave radiometers was deployed, this unit is the same one that has been deployed on numerous TAO/PACS cruises. Measured microwave brightness temperatures are converted to estimates of column integrated vapor and liquid water using model-based retrieval algorithms.

The wind profiler is a Doppler radar that operates at 915 MHz, electronically stabilized. It has five beams, one that points vertically, two points to port side at 90˚ apart with a 45° offset from the bow, and two that points to starboard, these four beams have an elevation of 75°each. The horizontal component of the wind speed and direction is calculated with these five vectorial beams for several kilometers up into the atmosphere. Each beam reflects off of clear air or air turbulence to determine the wind speed and direction at different levels.

Table 1. Instruments and measurements deployed by ESRL for the ship-based cloud/ABL AMMA-06 project.

Item	System	Measurement
1	Motion/navigation package	Motion correction for turbulence
2	Sonic anemometer/thermometer	Direct covariance turbulent fluxes
3	IR fast H_2O/CO_2 sensor	Direct covariance moisture/CO2 fluxes
4	Mean SST, air temperature/RH	Bulk turbulent fluxes
5	Pyranometer/Pyrgeometer	Downward solar and IR radiative flux
6	Ceilometer	Cloud-base height
7	0.92 Doppler radar profiler	Cloud-top height, ABL microturbulence
8	Rawinsonde	ABL wind, temperature, humidity prof.
9	23, 31 GHz :wave radiometer (ARM type - MAILBOX)	Integrated cloud liquid water Integrated total water vapor
10	Riegl Laser wave sensor	Ocean surface wave height/period
11	Lasair-II aerosol spectrometer	Aerosol size spectra
12	*Ronald H. Brown* C-band radar	Precipitation spatial structure

Data Processing

Preliminary processing of all systems was done in the field and a summary CD was distributed to the participants on the ship. An example for cloudbase height from the ceilometer is shown in Fig. 4. A second round of processing (principally editing and quality control) is done at ESRL; this has been completed for most instruments. Data files from 06 and 07 are posted on the ESRL archive: ftp://ftp.etl.noaa.gov/et6/cruises/ and will be made available to the AMMA database.

A considerable effort was devoted to intercomparisons activities associated with different research groups making observations on the cruise: ESRL, Ronald H. Brown, U. Miami, and Howard U. systems. Comparisons were done for solar and IR radiative fluxes, air temperature and humidity, and microwave radiometer retrievals of column water vapor. Several problems were found in some instruments (a few were corrected during the cruise).

.

Interesting Results from AMMA06

We have been analyzing data from the 2006 cruise and results have been presented at two international conferences (see below). Ludovic Bariteau has completed processing of direct covariance fluxes for this cruise. Figure 5 shows a comparison of momentum, sensible heat, and latent heat fluxes using the COARE bulk algorithm, inertial-dissipation estimates, and direct covariance computations. The results are high quality but there is a significant difference in the bulk and direct latent heat fluxes. This is probably a hardware issue with the fast hygrometer but we have not verified that yet. We are still resolving issues with these hygrometers (just started using them two years ago).

One important scientific aspect of AMMA is the relative balance of IR and solar radiative heat fluxes at the sea surface. These are important in the oceanic surface heat budget. In the Eastern Pacific, clouds dominate the variability of the radiative fluxes. This is usually expressed as the cloud radiative forcing, CF

$$CF = < R > - R_{clear}$$

which is the difference in the mean observed radiative flux, $<R>$, and the flux that would be observed in the absence of clouds, R_{clear}. This quantity is computed for both IR and solar fluxes. *CF* is positive for IR flux (clouds warm the surface) and negative for solar flux. The clear sky flux is estimated with models that are functions of conditions. For solar flux, we use a model that requires inputs on column water vapor and aerosol optical thickness, *k*. The water vapor is measured with the microwave radiometer and we obtain the optical thickness by tuning *k* until the model agrees with the observed solar flux in periods where the sky is cloud free. In the Eastern Atlantic the aerosol effects are much greater than in the EPac, especially when under the influence of Saharan dust. Similarly to cloud forcing, we can define an aerosol radiative forcing, *AF*

$$AF = R_{clear}(k) - R_{clear}(0)$$

We compute solar *AF* as the difference in the solar clear sky model flux and the flux that would be observed in the absence of aerosols (i.e., by setting k=0 in the model). Results for AMMA06 are shown in Fig. 6. This is, to our knowledge, the first credible observation-based comparisons of cloud and aerosol radiative forcing in the AMMA region. The *CF* results are roughly comparable to the EPac, but the *AF* values are much larger. On average, aerosols cool the ocean about 30 W/m^2 in the AMMA region with Saharan dust events cooling as much as 100 W/m^2. Aerosols also have a small impact on IR flux, but we don't have a clear sky model for that at the moment.

Other Activities

Ludovic Bariteau presented preliminary results from the ESRL observations from the 2006 AMMA cruise on Ronald H. Brown at the AMMA SOP Debriefing and Process Studies Workshop held at Toulouse in November 2006 (see http://amma-international.org/meetings/thematicWorkshops/Nov2006/index.php).

Chris Fairall presented an invited paper 'Observations of Air-sea interaction in the Northeast Tropical Atlantic' at the AGU spring meeting in Acapulco, MX, May 22-May26, 2007.

Chris Fairall presented a paper at the 'Observations of Air-sea interaction in the Northeast Tropical Atlantic' at the 2nd International AMMA Conference in Karlsruhe, Germany, 26-30 November, 2007.

Copies of these presentations can be downloaded from ftp://ftp.etl.noaa.gov/user/cfairall/PNE_AMMA .

Plans for FY2008

The principal activities planned for 2008 are continued analysis of the 2006 and 2007 data and participation in the 2008 AMMA cruise to the same region. The analysis will focus on completing remaining processing and quality control tasks (processing of motion-corrected direct covariance turbulence fluxes for AMMA07 will be completed soon) and the creation of an integrated data file combining many of the basic time series to simplify future analyses. Preliminary scientific issues will focus on flux, cloud, aerosol, and precipitation processes on the N-S cross sections at 23 W longitude. Another round of intercomparison activities is planned, including comparison of ESRL observations with buoy observations.

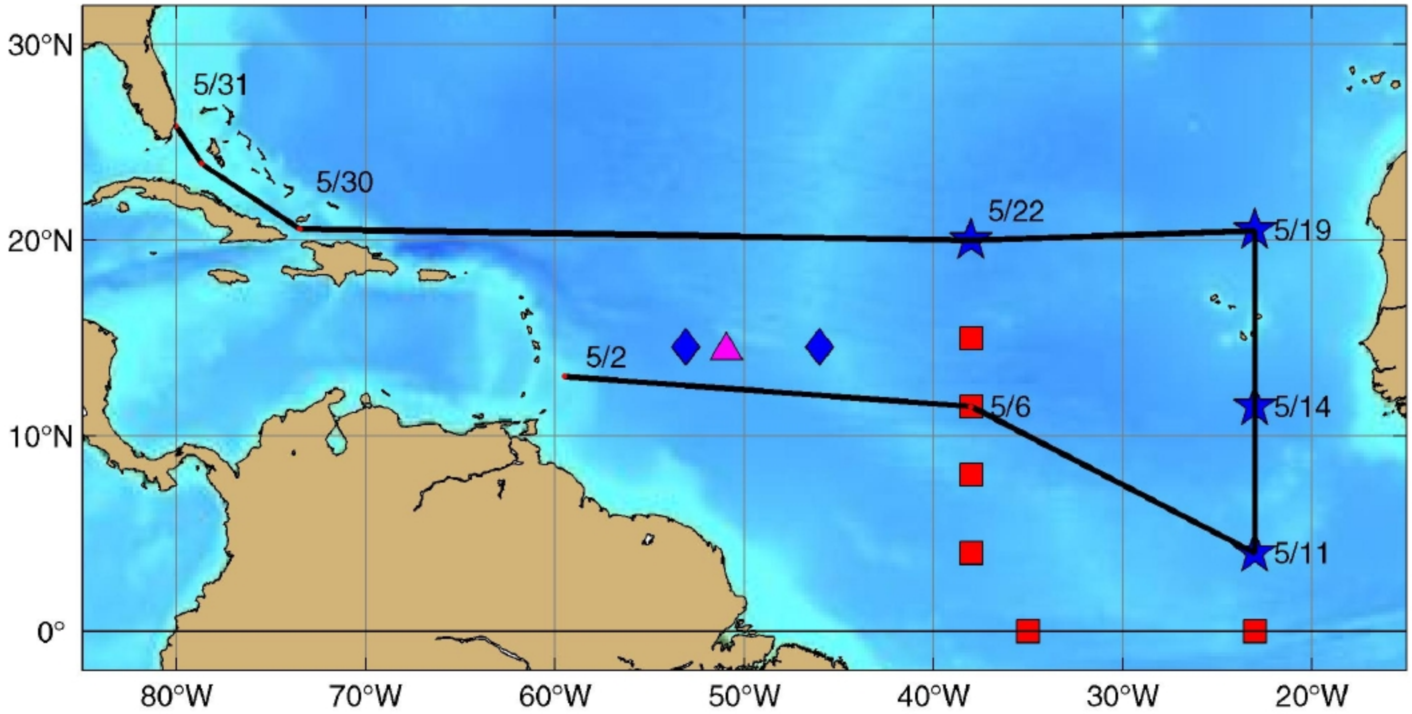

Figure 1. Map showing the ship track for ESRL measurements from R/V *Ronald H. Brown* during the AMMA 2007 field program.

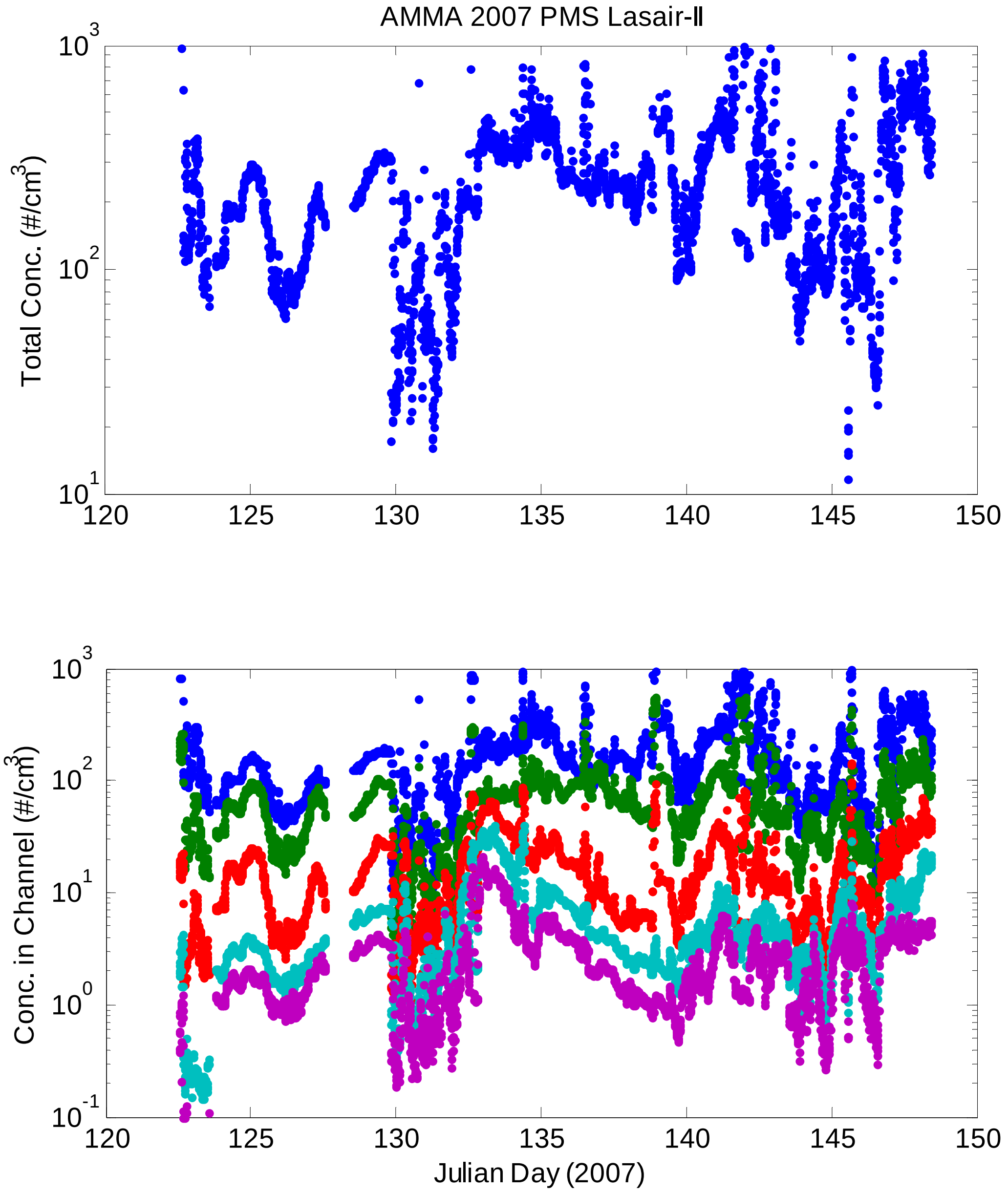

Figure 2. Aerosol concentrations from Lasair-II spectrometer for AMMA 2007. Upper panel: total number concentration for aerosols larger than 0.1 micron diameter. Lower panel: aerosol concentrations for 0.1-0.2 (blue), 0.2-0.3 (green), 0.3-0.5 (red), 0.5-1.0 (cyan), and 1.0-5.0 (magenta). Spikes are caused by the ship's exhaust.

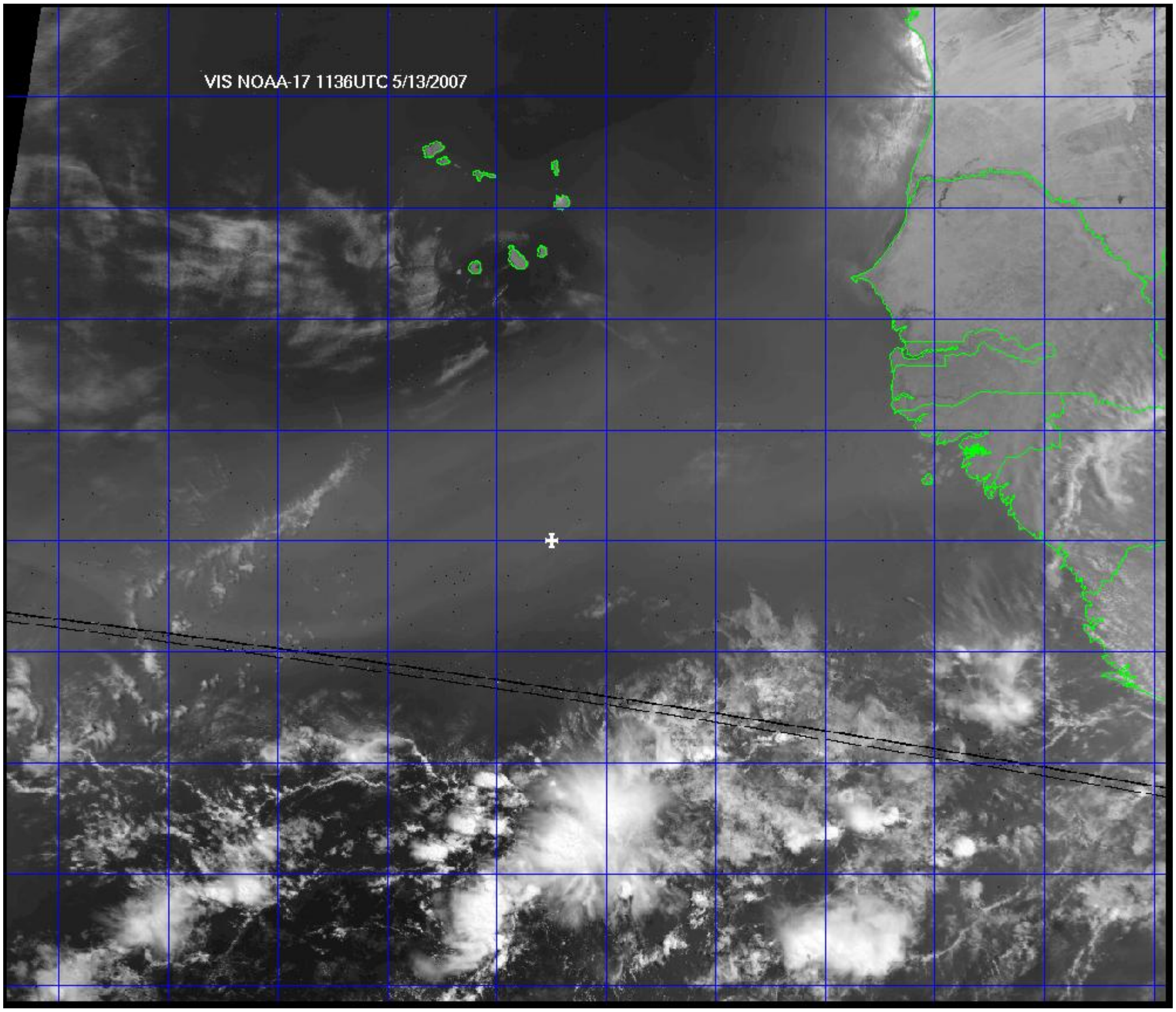

Figure 3. Satellite image for May 13, 2007 (JD 133) showing Saharan dust plume. The *Ronald H. Brown* is in the center of the image (cross symbol).

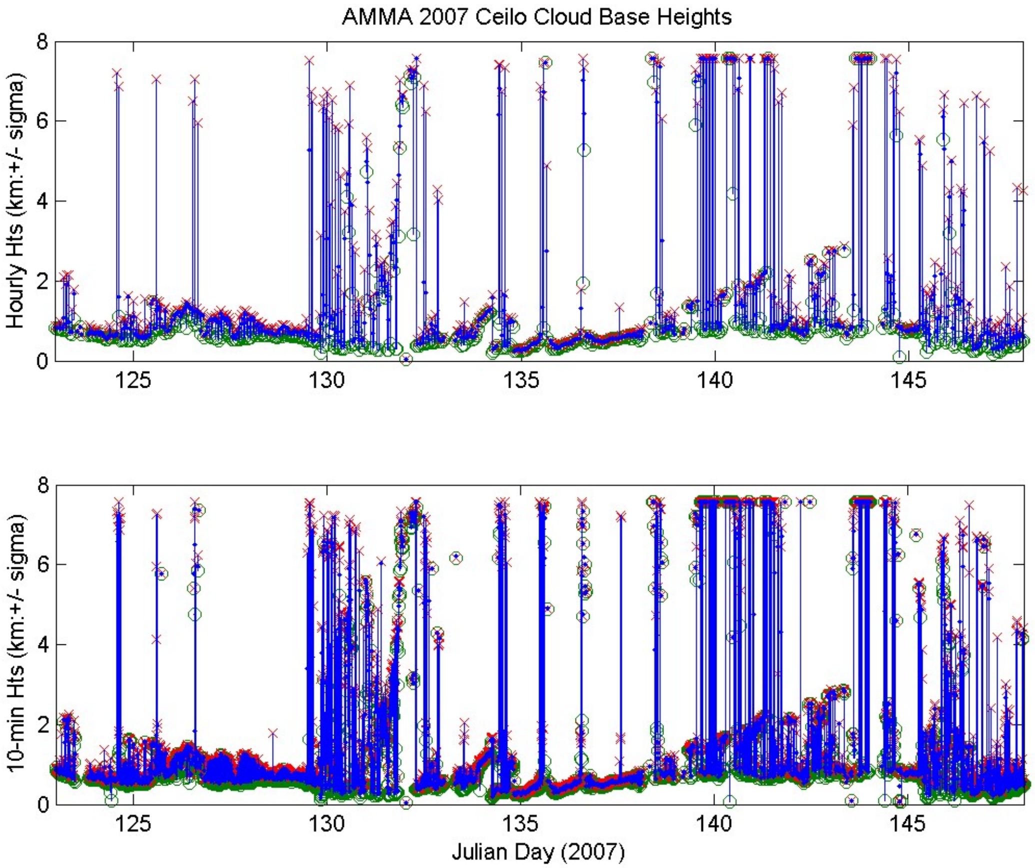

Figure 4. Time-height cross section data from cloud ceilometer for May 2 to May 31, 2007: upper panel, hourly cloud base heights; lower panel, 10-min cloud base heights. The symbols are as follows: green circle, 15% cumulative distribution height; blue dots, 50% cumulative distribution height (median); red x's, 85% cumulative distribution height.

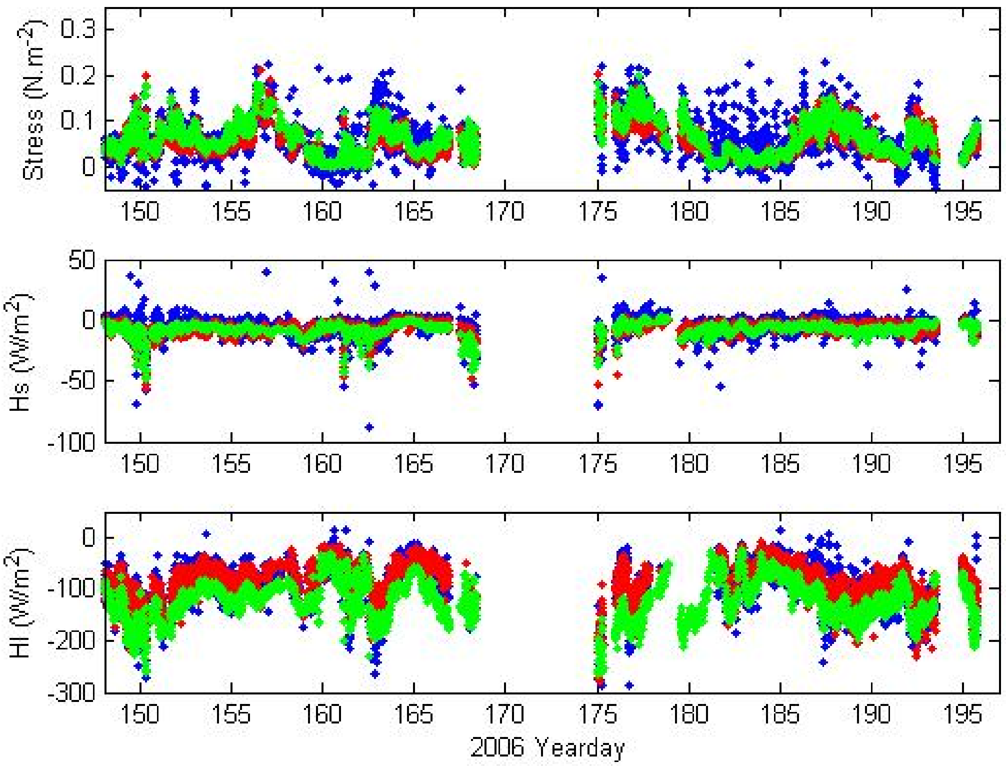

Figure 5. Turbulent fluxes during AMMA06. From the top, the panels show the momentum, the sensible heat and the latent heat fluxes. Positive flux is heat transfer into the ocean. Covariance measurements are represented in blue, the inertial dissipation in red and the bulk in green.

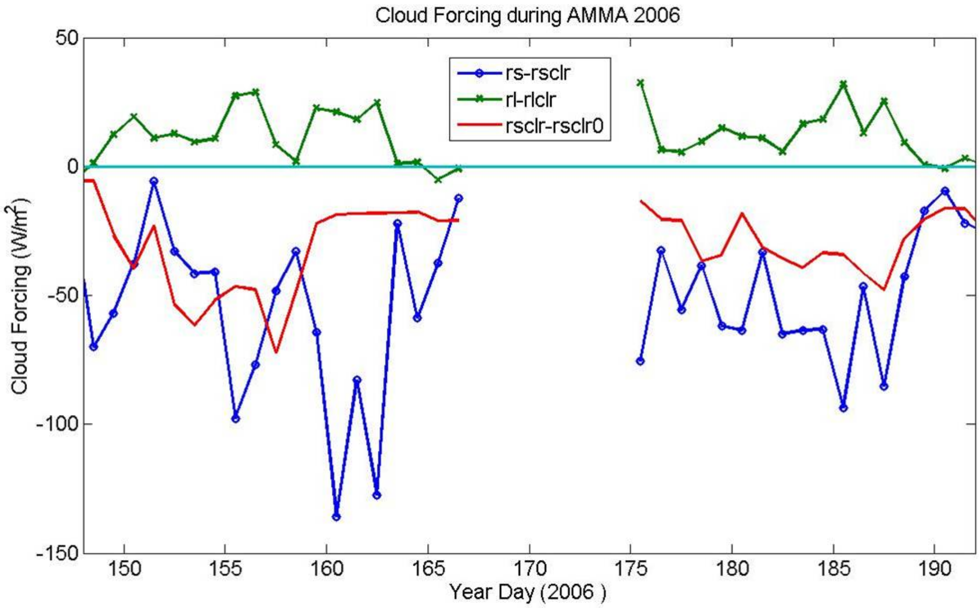

Figure 6. Time series of 24-hr **radiative heat flux forcing** components for AMMA2006: cloud solar flux – blue circles; aerosol solar flux – red line; cloud IR flux green x's.