Aerosols, Clouds, Precipitation and Climate: Barbados Field Study

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ABSTRACT

What controls the distribution and vertical structure of clouds and precipitation in the trade-winds? To help answer this question the Max-Planck-Institut für Meteorologie is leading an initiative to develop a aerosol-cloud-precipitation observatory on the Caribbean island of Barbados. The facility will employ state of the art instrumentation capable of monitoring the state of clouds, the aerosol and the ambient meteorology; and it will anchor a new IGBP/WCRP initiative on Aerosol, Clouds, Precipitation and Climate. The proposed site's exposure to the undisturbed trades provides a unique opportunity to make measurements necessary to help answer longstanding questions related to the interplay of clouds, precipitation, meteorology and the ambient aerosol. Regular airborne measurements, employing complementary suites of remote sensing instrumentation deployed from the new Germany research aircraft HALO, will connect local point measurements at the site with the broader meteorological context and the developing satellite record. The impetus for this initiative, by a leading climate modeling institute, will advance the use of the data as a climate reference, although we also anticipate that the measurements will be useful for evaluation of data products from the next generation of satellites employing active remote sensing.

1. SCIENTIFIC CONTEXT

1.1. Motivating Question

The observatory is being developed to provide the measurements necessary to answer one crucial question:

> What controls the distribution and vertical structure of clouds and precipitation in the undisturbed trades?

The specific point of focus, trade-wind convection, is motivated by a number of studies ([1], [3], [4]) which show that differences in model representation of cloudiness in the trade-wind regimes is the single largest contributor to model based estimates of climate change. Climate science hinges on our understanding of clouds; getting them right means the difference between very strong, or rather more tepid responses of globally averaged temperatures to increasing concentrations of CO_2. Additionally, rain in the trades is not necessary; the water budget can be balanced simply by enhanced transport of dry-air to the surface. Hence questions pertaining to the role of the aerosol in modulating rain and cloud amount tend to focus on trade-wind cloud regimes. So understanding the role of the aerosol in modulating trade-wind cloudiness is also imperative.

1.2. Subsidiary (or Related) Issues

In addition to the above issues, long-term observations of the distribution of clouds in an environment whose meteorological and aerosol properties are well characterized offers the opportunity to address a number of subsidiary issues. These include:

- The evolution of mineral dust and the air-mass that transport it, and their effects on marine convection.
- The interplay of the aerosol and maritime deep convection along the ITCZ margin, and the specific nature and role of ice-microphysical processes.
- The climate of the inter-American seas (this being a region of the world with surprisingly little observations) a situation that a new international initiative (IASCLIP) is attempting to address.
- Ground validation of a new generation of active, satellite borne, remote sensing instruments (such as will be flown aboard EarthCARE).

2. THE BARBADOS ADVANTAGE

Barbados provides an ideal site for the proposed measurements both for logistical and meteorological regions. Its location in the west Atlantic, well upwind (to the East) of the main Caribbean archipelago that separates the Caribbean sea from the Atlantic ocean. Its location, good infrastructure, and relative modest topographic relief have long made this location a favorite for the study of tropical convection in general, and trade-wind convection in particular [2], [5].

Additional advantages of locating the observatory on Barbados include:

1. The opportunity to make use of a pre-existing observational site. This site has been developed and maintained for the last forty years by the University of Miami, and occupies a windward promontory (bluff) that is perfectly positioned for sampling the onshore trades.
2. The expertise and cooperation of the Caribbean Institute for Meteorology and Hydrology (CIMH). Infrastructure maintained by, or accessible

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through, the CIMH include a state-of-the-art precipitation radar, a surface meteorological network, and daily soundings from the international airport.

3. Past experiences in the region, including a recent period of intensive field measurements centered on the nearby islands of Barbuda and Antigua [7], [6].

These advantages make Barbados a singularly attractive location for observing the interplay of the aerosol, clouds and precipitation in the trade-winds.

3. OVERVIEW OF PROPOSED MEASUREMENTS

3.1. Barbados Observatory

Field work will be centered around observations to be collected on a pair of promontories (Ragged and Deebles Points) on the island of Barbados. The measurement sites on peninsulas on the eastern coast of the island are ideally suited to sample a variety of cloud regimes, not least the downstream regime of the winter trades. In early 2010 we plan to install and remotely operate:

- A highly sensitive dual-axis scanning K-band polarized Doppler cloud radar.
- A DIAL water vapor Lidar.
- An advanced five-channel Raman Lidar.
- A JENOPTIK CHM 15K Ceilometer
- A Micro-rain Radar to measure drop size distribution, liquid water and drop fall speed distributions.
- An all sky imager.
- Time-lapse photography (perhaps stereo).

We will endeavor to maintaining the instruments in continuous operation on this site for at least two years, thereby spanning two seasons. After two years the observational facility will be re-evaluated in consultation with our hosts and partners. In addition to the instruments listed above additional measurements will be made by partner institutes. These include:(i) CCN measurements by the MPI for chemistry in Mainz (pending); (i) aerosol measurements by the University of Miami; (ii) the AGAGE site, which measures 40 trace gases; (iii) daily soundings from the international airport; (iv) S-Band radar measurements made continuously by the Caribbean Meteorological Organization; (v) surface meteorological measurements across the island. In addition we hope to augment our measurements with the help of a second, portable, cloud radar, periods of more intensive *in situ* sampling, and perhaps more advanced surface radiative and microwave measurements through the participation of other institutes as discussed below.

3.2. Airborne remote sensing

The long-term measurements will be complemented by *in situ* sampling and airborne remote sensing designed to relate the point measurements on Barbados to the broader trade-wind region and the developing satellite record. The principal platform for these measurements will be the HALO aircraft, operated by the DLR. In the second year of the project we plan to fly two to four HALO missions. Each mission shall consist of 20-30 hours of flight time distributed over three legs. It is planned for missions to be flown as part of the NARVAL and (possibly) the ACRIDICON demonstration projects. HALO will fly above the north-east trades and measure their evolution with modern remote sensing as they move across the Atlantic ocean. The flight strategy for each HALO mission is illustrated by Fig. 1. An outbound leg, will begin at the HALO home base in Oberpfaffenhofen, near Munich, and end at the Grantley Adams airport on Barbados. HALO will fly, at cruising altitude, along an air-mass trajectory that intersects an A-Train orbit three days upwind of Barbados. At the point (marked “1” in Fig. 1) where the air-mass, HALO, and the A-Train coincide HALO will descend to the near surface and commence a period of *in situ* measurements so as to characterize the air-mass, surface fluxes and cloud properties. HALO will then proceed at altitude to Barbados where, before landing, it will again characterize air-mass and cloud properties just upwind of the measurement site. The following day, time permitting, a short (2-3 hr) mission will be flown in the air-mass upwind of the Island, as marked by the figure. On the third day HALO will reverse its outbound journey, this time attempting to intercept the originally sampled air-mass, where it again is intercepted by an A-train overpass, as indicated by the point marked “3” on the figure.

In addition to the Hamburg Microwave Package (HAMP, which contains many twins of the instruments to be deployed on the Barbados ground site) important instrumentation anticipated for the HALO include: dropsondes; microphysical sensors mounted from PMS canisters on wing-pods; aerosol measurements similar to what is being requested for ACRIDICON; as well as standard instrumentation for measuring basic state parameters, including turbulence measurements with the gust-probe and fast temperature and humidity sensors. In addition we also intend to fly the DLR-DIAL system so as to measure the profile of water vapor along the flight path, as measurements are crucial to understanding the behavior of clouds and would further complement those being made at the ground site.

4. PARTNER INSTITUTES

In its totality the ACPC Barbados field study will be a joint effort involving many partners. Those who have expressed interest in participating, or who are already contributing to the project in key ways, are discussed in turn below.

Caribbean Institute for Meteorology and Hydrology (CIMH): The proposed measurements will only be possible through the continuing cooperation and support of the CIMH. In preparation for the measurement phase, scientists and technicians from the CIMH

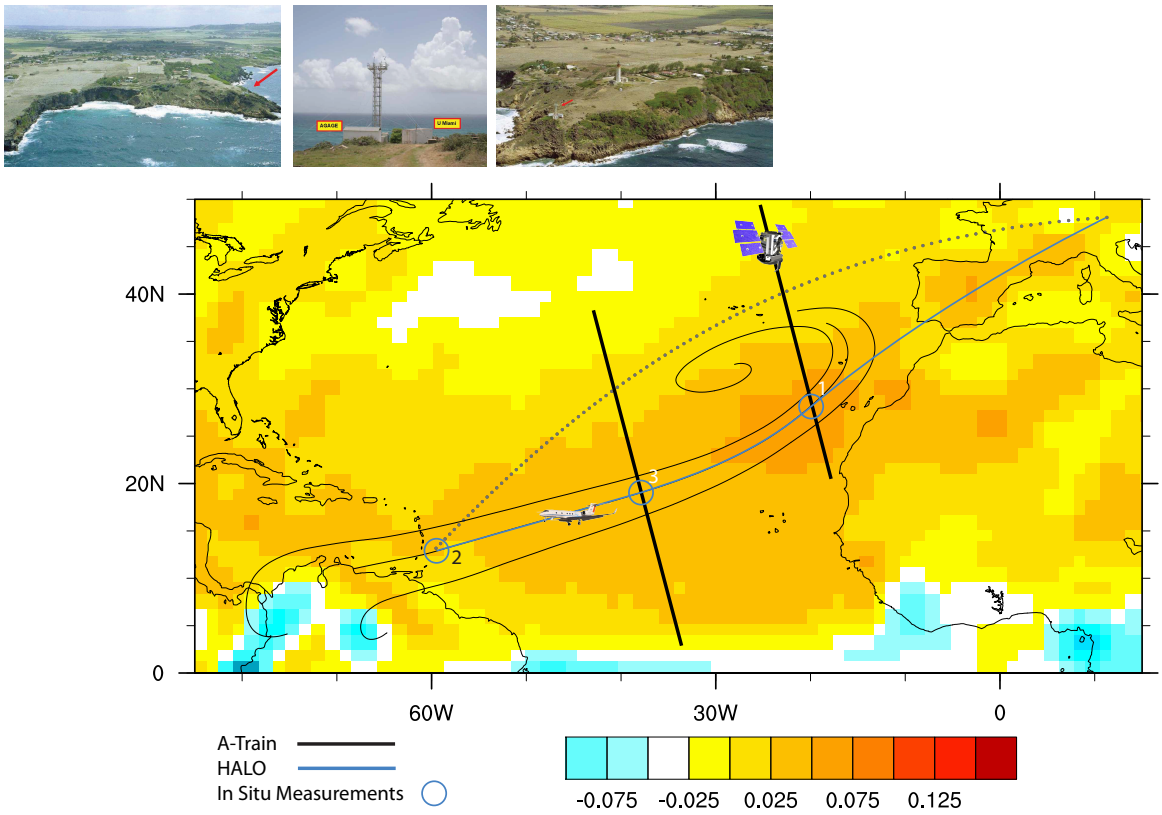

Figure 1. Sketch of proposed flight strategy, showing mean streamlines of the winter trades from ECMWF superimposed on large-scale vertical velocity. A-train orbits are shown by straight solid lines, and the dotted lines indicates a great circle between Oberpfaffenhofen and Barbados. The enumerated circles reflect in situ *sampling stations at positions upwind of Barbados.*

are being brought to Hamburg to receive training on how to operate and maintain advanced instrumentation. CIMH also provides access to meteorological data collected on the island, including the precipitation radar. In the future we anticipate that CIMH scientists will visit our institute to pursue further research and training, and MPI scientists will visit the CIMH to offer seminars and pursue research. The principle contact within the CIMH is its director Dr. David Farrell.

University of Miami (Rosenstiel School): This group (led by Professor Joseph Prospero) has been instrumental in developing the Ragged Point measurement site. In addition to providing (along with the CIMH) logistical support the Miami group has been monitoring the aerosol (in particular mineral dust) from the Ragged Point site for about forty years. They are deeply familiar with the meteorology of the region and also make routine surface meteorological observations from their Ragged Point site. In addition we anticipate further cooperation with the boundary layer meteorology group of Professor Bruce Albrecht. Dr. Albrecht is a pioneer in the study of trade-wind convection and is exploring the possibility of making airborne measurements just upwind of the experimental site.

Institute for Tropospheric Research (IfT) and the University of Leipzig: The IfT has great expertise in *in situ* measurements, airborne, ground based and within the laboratory. They are proposing to make episodic ground based measurements to characterize the aerosol in greater detail, and to make airborne measurements to more closely explore cloud microphysical processes. The airborne measurements will be made from unique observational platform, called ACTOS. ACTOS is a helicopter borne sled which enables airborne measurements of the aerosol, cloud microphysical structure and turbulence at very fine scales. Additionally the University of Leipzig have a developing capacity for advanced radiation measurements which may be added to the proposed cloud observatory. Contacts at these institutes include Professor Andreas Macke (its new director), Professor Manfred Wendisch, as well as Drs. Holger Siebert and Frank Stratmann (both senior scientists).

Max-Planck-Institut für Chemistry– Mainz: We have been working with the MPI-Mainz group to de-

velop, or deploy, a facility for making long-term ground-based measurements of CCN, and perhaps other characteristics of the aerosol. Contacts include the director of the Institute (Professor M.O. Andreae) and Dr. Ulrich Pöschl (as senior scientist). Additional opportunities for collaborating with this group in the area of ice microphsyics (Professor Stephan Bormann) and atmospheric chemistry (Professor Jos Lelieveld) are being explored.

The University of Köln (Integrated Remote Sensing Group): Professor Susanne Crewell of the University of Köln is interested in possibly deploying a suite of microwave remote sensors (the HATPRO suite of instruments) for further characterizing the vertical structure and humidity above the measurement site. The Köln group are world leaders in integrated remote sensing, particularly in the microwave region of the spectrum.

The University of Hamburg: The development of the microwave surface and airborne remote sensing instrumentation has been joint with Dr. Gerhard Peters of the University of Hamburg. Use of HALO, and in particular the NARVAL missions in support of this field study are also being jointly planned with investigators from the University.

Deutsches Zentrum für Luft- und Raumfahrt (DLR): The Institute for Atmospheric Physics of the DLR, is led by Professor Ulrich Schumann. It provides logistical support for HALO, and collaborates on the development of the HAMP. They are interested in flying their one-of-a-kind airborne DIAL Lidar system on HALO flights, to complement the ground based DIAL measurements to made on Barbados by the MPI-M group.

Karlsruhe Institute for Technology (KIT): The KIT group, lead by Professor Klaus Beheng (an expert in cloud microphysical processes) has expressed interest in joining the field study and making measurements with a second scanning cloud-radar. Their radar, which can be deployed to different sites on the Island is essentially identical to that which will be deployed on the main measurement site and would provide the opportunity to look at cloud evolution as a result of meteorological and aerosol influences (including biomass burning) from the Island itself.

Finally, additional collaborations with a number of individual investigators, including Dr. Graham Feingold at NOAA, Professor Raymond Shaw at the Michigan Institute of Technology and Professor Patrick Chuang at the University of California Santa Cruz will help ensure that the measurements are at the center of a vibrant international research community.

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