CHARACTERIZING OCEANIC CONVECTIVE CLOUD SYSTEMS

The Tropical Warm Pool International Cloud Experiment

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The Tropical Warm Pool International Cloud Experiment (TWP-ICE) that took place over and around Darwin, Northern Australia, in early 2006 collected a comprehensive dataset describing tropical cloud systems and their environment. The experiment examined convective cloud systems from their initial stages through to the decay of the generated cirrus to measure their impact on the environment. It was the first field program in the tropics that attempted to describe the evolution of tropical convection, including the large-scale heat, moisture, and momentum budgets at 3-hourly time resolution, while at the same time obtaining detailed observations of cloud properties and the impact of the clouds on the environment. A major focus of the cloud component was on cirrus. Cirrus clouds are ubiquitous in the tropics and have a large impact on their environment; but the properties of these clouds are poorly understood.

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The experiment design included an unprecedented network of ground-based observations (soundings, active and passive remote sensors) combined with a large range of low-, mid-, and high-altitude aircraft for in situ and remote-sensing measurements. The timing of the experiment was such that both oceanic convection and coastal/continental-type convection were sampled. A crucial outcome of the experiment was the generation of a dataset suitable to provide the forcing and evaluation information required by cloud-resolving and single-column models as well as global climate models (GCMs), with the aim to contribute to parameterization development. This dataset will provide the necessary link between the observed cloud properties and the models that are attempting to simulate them.

TWP-ICE was a large, multiagency experiment that included substantial contributions from the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) program; the Unmanned Aerial Vehicle program within ARM (i.e., ARM-UAV); NASA; the UK Natural Environment Research Council (NERC); the Australian Bureau of Meteorology; Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO); EU programs; and many universities.

INSTRUMENTATION. The ground-based observational network for TWP-ICE included the permanent ARM facility in Darwin and the CSIRO research vessel *Southern Surveyor,* each equipped

The ground-based and in situ observations acquired during TWP-ICE can be used to address a range of important scientific questions related to tropical clouds. Specific goals of the experiment were as follows:

1) Collect detailed measurements of the cirrus microphysics and relate them to storm intensity and proximity (spatial and temporal) to the parent convection.
2) Verify retrievals of microphysical properties from satellites and the ground.
3) Provide datasets for forcing cloud-resolving and single-column models that will attempt to simulate the observed characteristics and impacts.
4) Document the evolution of oceanic convective clouds from the early convection phase to the remnant cirrus, with particular emphasis on their microphysics.
5) Measure the dynamical and radiative impacts of the cloud systems.
6) Measure chemical species generated within the convection that are important for both the radiation budget and ozone chemistry.
7) Characterize the environment in which the cloud systems occur.
8) Document the evolution of the convective boundary layer throughout the diurnal cycle and through the life cycle of convective systems.
9) Observe the characteristics of convectively generated gravity waves.

with cloud radar, lidar, and radiometry; profiler sites; several surface flux sites, including the ship; 3-hourly radiosondes launched from five sites, and 6-hourly radiosondes from a sixth site within a 250-km diameter circle centered on Darwin; Doppler weather radar, and a 5-cm wavelength polarimetric weather radar. The *Southern Surveyor* was stationed in the Timor Sea to the northwest of Darwin and served as a mobile cloud and radiation measurement site, as one of the flux sites, and as one of the radiosonde sites; it also made oceanographic observations. This dataset at a tropical location will allow us to address such fundamental questions as what controls the diurnal cycle of convection over the open ocean.

To fully describe cirrus cloud properties, both in situ and remote sensing airborne observations are required. The aircraft involved in TWP-ICE and their principle payloads are listed in Table 1. These included an extensive set of in situ cloud microphysical observations, detailed radiometry, and aerosol and chemistry measurements, as well as remote sensing with airborne radar, lidar, and an IR interferometer. The observations together with ground-based and airborne radar/lidar systems will be used to test and develop algorithms for satellites such as *Cloudsat* and *Calipso*.

Finally, satellites were important for characterizing the upper boundary of the experiment region. Geostationary satellite and CERES (Clouds and the Earth's Radiant Energy System) observations provided top-of-the-atmosphere radiative fluxes and cloud properties over the entire domain, while more specialized satellite products were collected both as additional sources of information for understanding cloud processes as well as to test satellite remote-sensing retrievals in much the same way that surface-based retrievals will be tested.

COMPLEMENTARY STUDY. TWP-ICE was preceded in November/December 2005 by a highly complementary European aircraft campaign involving the EU Stratospheric-Climate Links with Emphasis on the Upper Troposphere and Lower Stratosphere project (SCOUT-O3) and the UK NERC Aerosol and Chemical Transport in Tropical Convection (ACTIVE) project. These experiments used the permanent facilities in the Darwin observ-

Table 1. TWP-ICE aircraft and their principal roles.

Aircraft	Primary role/instruments
DOE Proteus	Active/passive remote sensing of clouds and in situ microphysical measurements of cirrus
ARA Egrett	In situ measurements of microphysics, aerosols, and chemistry in cirrus and the background atmosphere
NERC Dornier	In situ measurement of aerosols and chemistry in the boundary layer and lower troposphere
Twin Otter International	Cloud radar and lidar observations of clouds
ARA Dimona	In situ state measurements and fluxes in the boundary layer

ing network together with a number of research aircraft. The ACTIVE aircraft were also deployed during TWP-ICE. Key science questions to be answered with this component of the summer's activities include:

- What is and what controls the chemical composition of the Tropical Tropopause Layer (TTL)?
- How fast are short-lived chemical species (e.g., bromine compounds) transported into and through the TTL, and what is their likely impact on the ozone budget?
- How do tropical cirrus clouds affect the water and radiation budgets?
- How does deep convection transport aerosols and chemical species into the TTL?
- What is the relative importance of deep convection and large-scale advection in determining the composition of the TTL?

CONCLUDING REMARKS. Detailed atmospheric measurements were made in the Darwin area through the whole Austral summer of 2005, giving unprecedented coverage of convective clouds through the premonsoon and monsoon periods. There was clearly great synergy between the pre-TWP-ICE and TWP-ICE activities. Together, these datasets are expected to address the relative roles and impacts of intense continental-type storms and the more widespread but weaker oceanic storms, with TWP-ICE collecting one of the most comprehensive datasets ever on tropical convection. Much of the data is already available to the community through the ARM Web site (www.archive.arm.gov) as an Intensive Observation Period (IOP) dataset, while data from the ACTIVE experiment will be available from the British Atmospheric Data Centre (http://badc.nerc.ac.uk/home/index.html) in early 2008.

More details about the experiment are available at:
- http://www.bom.gov.au/bmrc/wefor/research/twpice.htm
- http://science.arm.gov/twpice
- http://personalpages.manchester.ac.uk/staff/geraint.Vaughan
- http://www.ozone-sec.ch.cam.ac.uk/scout_o3