Notes from TWP-ICE Workshop
Thursday January 8, 2004
Talaris Conference Center - Seattle, WA

The Tropical Warm Pool – International Cloud Experiment (TWP-ICE) is an ARM experiment being planned for January 2006. TWP-ICE will be based at the Darwin ARM site and the Darwin International airport. In addition, there will be several boundary sites for measuring fluxes and launching radiosondes. There will also be a ship stationed in the Timor Sea. The science plan for TWP-ICE can be viewed at:

http://engineering.arm.gov/~mather/darwiniop

This planning meeting brought together scientists with diverse backgrounds ranging from those who will operate aircraft or instruments on aircraft to cloud modelers who will use data from the experiment to improve models in the tropics.

Peter May – TWP-ICE Overview

Peter gave an overview of the Darwin experiment. The following text is taken from the science plan introduction.

> The impact of oceanic convection on its environment and the interaction between the characteristics of the convection and the resulting cirrus characteristics is still not understood. An intense airborne measurement campaign combined with the extensive network of ground-based observations is planned near Darwin, Northern Australia during the monsoon period when the convection is largely of oceanic origin to address these questions. This will be the first field program in the tropics that attempts to describe the evolution of tropical convection through its life cycle including the large scale heat, moisture and momentum budgets, detailed cloud observations and measurements of the impact of the cloud on the environment with a special focus on radiative impacts and the cirrus microphysics. A crucial aspect is that the experiment is designed such that a data set suitable for the forcing and testing of cloud resolving models and paramaterizations in GCM's is provided as well as the observational validation data for such simulations. Furthermore an extensive set of in-situ validation data for ARM ground based and NASA space-borne remote sensing systems will be collected. The experiment is a collaboration between the US DOE ARM project, the Bureau of Meteorology, NASA and several US and Australian Universities. There is also possible European involvement.
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> This experiment will be undertaken over a four week period in January-February 2006.
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> The observational network is built around the Darwin Climate research station and the ARM Atmospheric Radiation and Cloud Station (ARCS) site. These provide the detailed radar coverage to document storm and cloud structure out to a range of about 150 km. A dense sounding network is being constructed in an approximate circle

around the Darwin site. This will enable model forcing data sets to be collected and provide the data for NWP systems and budget studies. The core of the experiment will be a several research aircraft including the NASA WB57 and the DOE Proteus, as well as the ARA Egrett, King Air and Dimona. These aircraft carry an extensive suite of in situ sensors for measuring the state variables, radiation, cloud microphysics and chemistry. Several of the aircraft will be carrying remote sensors such as lidar, cloud radar and the Proteus includes an IR interferometer (airborne AERI).

> There has been some interest expressed by European scientists to bring the Geophysica (a stratospheric aircraft similar to the ER-2) and the Falcon (a middle-altitude aircraft). They have funding to come to the tropics but there is a potential timing problem – they may need to come by the end of 2005. This connection is being pursued.

The experiment seeks to build on a number of past experiments. The recent Crystal-FACE and Emerald experiments have focused on deep organized convection systems typical of coastal areas. Darwin 2006 will be undertaken during the monsoon. Despite the experiment also taking place on a coastal location, the convection that occurs over and near Darwin at this time is largely of maritime origin with large fetch over water. Based on previous experiments, the convection appears typical of maritime convection with widespread convection that has complex organization, but is not as deep or as intense as continental or coastal convection.

This is one of the first experiments to focus on clouds per se with modern remote sensing instruments and high flying aircraft equipped with modern microphysical measurement capability in an area well covered by modern (polarimetric and Doppler) radars. Previous experiments such as TOGA-COARE focused largely on the organisation of the deep convection while Nauru 99 sampled little convection. The experiment will be unique in providing both the synoptic setting and forcing of the cloud systems as well as detailed cloud information including the evolution of the convection and the cloud microphysics.

A goal of the project will be to take quantitative microphysical measurements of cloud systems and their nearby (vertically) thermodynamic structure during the monsoon season. The primary target will be the cirrus generated by the deep convection, but it is also planned to take in situ measurements of stratiform rain (and snow) over the wind profiler site. As a part of this detailed observations of the convective clouds, the environment in which they form and their microphysical structure are being collected so that the cirrus measurements can be put into context with regard to the “source” clouds.

The monsoon period has been selected because it represents oceanic convection representative of wide areas of the tropics and will provide a contrast for recent experiments with coastal and continental convection where the convection tends to be both more organized and more intense (at least in terms of the vertical motions within the convection and maximum cloud height) that was sampled during CRYSTAL-FACE and will be addressed in Emerald 2 near Darwin this year.

The ultimate aim of the experiment is to gain a complete picture of oceanic convective storm evolution, the role of the large scale environment on its evolution, and its impact on the environment. The specific goals of the project are

1. Document the evolution of oceanic convective clouds from the early convection phase through to the remnant cirrus with particular emphasis on their microphysics.
2. Make detailed measurements of the cirrus microphysics and how they relate to storm intensity and proximity (spatial and temporal) to the parent convection
3. Measure the dynamical and radiative impacts of the cloud systems.
4. Characterize the environment in which the cloud systems occur.
5. Document the evolution of the convective boundary layer throughout the diurnal cycle and through the lifecycle of convective systems
6. Provide data sets for forcing cloud resolving and single column models that will attempt to simulate the observed characteristics and impacts.
7. Verification of remotely sensed microphysical measurements.

These goals are clearly inter-related, but provide the basis for a comprehensive field program. In order to achieve these goals an extensive network of ground based and airborne sensors will be put in place. Use will be made of the outstanding infrastructure around Darwin with its radar network, ARCS station and operational soundings. Additional soundings will be made at a ring of sites around Darwin. These sites will include radiation observations. An ARCS like platform will be deployed on the Australian research ship RV Southern Surveyor. Two high flying aircraft with extensive remote sensing and in-situ measurement capability will be flown along with a mid-altitude aircraft with airborne radar and lidar and a lower flying aircraft for flux and boundary layer measurements.

Paul Newman – NASA's Role in TWP-ICE

Paul gave an overview NASA's participation in TWP-ICE. NASA will participate primarily by providing the WB-57 (or possibly the ER-2) equipped with instruments aimed at measuring chemistry and microphysical parameters.

NASA also expects to support the launch of ozone sondes and special water vapor sondes (equipped with TDL-based measurements) and may provide funds to support chemical measurements on a boundary layer aircraft.

The primary support for the NASA's involvement is through AURA validation. Consequently, the focus of their interest is more on chemistry of the upper troposphere and lower stratosphere than on the radiative effects of clouds. Despite this, because of the close ties between upper tropospheric water, stratospheric chemistry and cirrus, there is a great deal of overlap between the science goals as seen by ARM and by NASA.

Andy Heymsfield – Tropical Ice Cloud Studies

There have been several experiments that provided in situ observations of tropical cirrus (Heymsfield et al., 2002). Measurements in thin cirrus at -80C showed 10 micrometer triagonal crystals and 50 micrometer columns. Observations in cirrostratus between 6-12 km showed a strong dependence of size on altitude/temperature with larger particles found near the bottom of the clouds and smaller particles at the top. This distribution indicates that settling of the larger particles is occurring.

Andy noted that microphysical probes are poorly designed to characterize small particles ("small here" roughly referring to particles with diameters of 1-50 micrometers) – particularly in the presence of large particles.

The largest particles (diameters > 1 millimeter) have only recently been observable. Observations using equipment capable of observing these very large particles were made in 1999 over Kwajalein during a three hour spiral. Andy showed some data from this flight. The particle size distributions were fit to gamma distributions. Gamma distribution parameters exhibited a strong temperature dependence.

Close to convection, the mixture of habits was very complex.

The largest particles observed were up to 1 centimeter.

There was some discussion regarding whether small particles or large particles dominated the ice content. Results from CRYSTAL-FACE seemed to suggest that small particles played the dominant role. But discussion during this session – part of which was based on a presentation made by Eric Jensen at the December 2003 AGU meeting – suggested that it was actually the large particles that dominated the ice water content.

There were also questions raised about the degree to which tropical cirrus layers were supersaturated. There is considerable uncertainty/controversy about the CRYSTAL-FACE results. This underscores the need to have the best possible water vapor observations in the high-flying in situ aircraft (e.g. the Proteus).

Jay Mace – Cirrus microphysical properties

Important sciences issues/goals for TWP-ICE include:

Determine role of cirrus for maintaining upper troposphere humidity
Capturing the transition from anvil to self-maintaining cirrus properties
Determine the impact of large scale vertical motion on cirrus maintenance
Document the vertical distribution of ice particle habits
Develop IWC/habit database for various stages of anvil development

Showed results of on-going study to describe the dependence of cloud properties as a function of age as observed over Nauru. Satellite images were used to track clouds observed over Nauru back to the convection that produced the cloud (using a technique developed by Brian Soden). This analysis allowed an age to be assigned to clouds observed at Nauru. The dependence of cloud parameters on age were assessed.

Graeme Stephens – A-Train Validation

Cloud-Sat is scheduled for launch in late 2004. The radar has a vertical resolution of 500 meters and is nadir-pointing. The sensitivity of the radar is -29 dBZ. Graeme distinguished between verification (a pre-launch activity) and validation (a post-launch activity). TWP-ICE would serve as a validation activity.

Goals from the Cloud-sat perspective include assessing radar performance (for example by testing radar calibration) and by quantifying errors.

Radar performance tests include looking at ocean targets and matching airborne observations. For the latter – it would be highly desirable to put an upward looking cloud radar on an aircraft under-flying the in situ aircraft and the cloud-sat radar. Because of the desire to match cloud volumes, it would be preferable to put the radar on an aircraft (like the King Air) that could closely match the air speed of the in situ aircraft (Proteus, WB-57, and Egrett) rather than a boundary layer twin engine prop plane (like a Twin Otter).

Jim Holton – The Tropical Tropopause Layer

Introductory comment - between 20-22 km, stratospheric water has been increasing by approximately 1%/year. One would expect that a warming of the tropopause would accompany such a change but no such accompanying trend has been observed. This is a mystery.

The tropical tropopause layer (TTL) is a topic of significant interest currently due to its role in controlling trop/strat exchange, its impact on cirrus clouds and other issues. The lower boundary of the TTL is approximately 12 km. At this altitude, tropical soundings begin to depart from moist adiabatic. Also at this altitude, the frequency of convective towers drops rapidly. Very few towers penetrate the cold point.

Note – the altitude (and temperature) of the cold point (minimum in the vertical temperature profile) exhibits a distinct annual cycle with the coldest temperatures occurring in January.

The cold point also exhibits spatial variability through the tropics. In the maritime continent region, a minimum during the monsoon period can be found east of Darwin. In this region, water vapor concentrations dip to approximately 3 ppm above the cold point.

See recent ref on tropopause height by Seidel et al., JGR, 2001.

An important set of issues are the roles of overshooting convection, cirrus anvils, quasi-horizontal advection, and large scale forced ascent in affecting the properties of the TTL.

NASA's TC4 program involves a number of field experiments – including TWP-ICE (primarily through the contribution of the WB-57) to explore these issues. In addition to the high altitude aircraft documenting water vapor, cloud properties, and chemical tracers of trop/strat exchange other important componts of TC4 will include ozone sondes and low altitude aircraft. Documenting profiles of ozone in the TTL helps to determine the degree to which exchange is occurring across the tropopause over time.

The boundary layer aircraft would be used to characterize the chemical composition of the lower atmosphere.

To actually get at the large scale ascent part of TTL processes, it is necessary to measure net heating rates to a precision of approximately 0.5 K/day. Measuring vertical velocities would be preferable but that is likely impossible. Even measuring heating rates to this precision is going to be very difficult. Reaching this precision will likely require a strategy combining observations of fluxes with model simulations.

Ed Zipser – Tropical Convection

Began with strong support for the currently proposed configuration of five sonde sites around the central Darwin facility with balloons launched at 3-hourly intervals at all site. With this recommendation came the caution that adequate staff must be scheduled so that sleep deprivation does not become a problem as this will significantly impact data quality. Part of the sleep issue is to minimize the number of meetings – especially on non-flight days!

Mesoscale convective systems (MCS) tend to peak several hours after smaller, isolated cumulo nimbus (CB). MCS tend to peak at night.

Satellite infrared products provide very poor estimates of convective strength. A better (albeit still imperfect) indicator is the 20dBZ contour from radar. This product will be available for TWP-ICE because of the pair of cm radars in the Darwin vicinity.

Showed maps of results from TRMM that indicate the diurnal cycle of large and small convective systems over ocean and over land.

Christian Jakob – Cloud Modeling

Outlined the ARM framework for using various models to ultimately improve parameterizations in GCMs. Much of the parameterization development is done in single column models (SCMs – a single column of a GCM with forcing provided via observations, NWP analyses or another model) and cloud resolving models (CRMs – high resolution models that explicitly resolve cloud systems while still parameterizing microphysics).

ARM has been working with SCMs and CRMs for a number of years with some success but feeding back to GCMs is trickier. Christian offers some suggestions for this process in an article that appeared in BAMS (October 2003).

An important modeling activity will be to study the representation of the Australian monsoon in selected climate models. This should be done before and after the experiment. The same should be done with GCMs run in CAPT mode. CAPT (the CCPP-ARM Parameterization Testbed) is a project in which GCMs are run in numerical weather prediction mode. That is, the models are initialized with observations and run forward – giving predicted atmospheric states – as a weather model would be.

> Paul Newman advocated that a pre-experiment exercise should be done in which experiment participants are given access to weather products similar to those that will be provided during the experiment. This should be done sometime during the 2004/2005 monsoon season. A similar exercise was done at Penn State in preparation for CRYSTAL-FACE.
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> Minqua Zhang provided support for the 3-hourly soundings. He and the cloud parameterization working group considered the network of 5 sounding stations to be a minimum requirement. The 3-hourly launches were chosen in part to match the spatial separation of the launch sites (order 100 km). This time resolution is also important to capture the diurnal cycle which has a strong influence on convection.

Christian concluding by summarizing the operational models used by the Australian BOM. These are run at a broad range of spatial scales from GCMs (order several hundred km) down to regional mesoscale models (order 5 km). By 2006 it is likely that non-hydrostatic CRM model will be ready to run within the BOM model framework.

Paul Newman – WB-57

The WB-57 has a ceiling of approximately 16-17 km early in a flight (fully loaded with fuel) but can reach altitudes up to 19 km near the end of a flight.

Many instruments are bolted onto palettes. These palettes can be preloaded, shipped with the instruments, and bolted onto the frame at the experiment site.

Instruments of particular interest to ARM that are being planned for the Darwin deployment include:

CAPS and VIPS

Frost point hygrometer
An aerosol lidar
An FTIR (e.g. the scanning HIS)
Microwave Temperature Profiler
1 Total water instrument

It was argued by Jay Mace that more than one total water instrument is required due to the uncertainties associated with these instruments.

Tim Tooman – Proteus

Preferred speed is Mach 0.6. The Proteus can go slower but the fuel consumption increases.

Instruments include:

In Situ State Parameters
Solar Spectral Flux Radiometer (SSFR)
Spectral Radiance Package (SRP)
Broadband Hemispheric Radiometers

Cloud, Aerosol, and Precipitation Spectrometer (CAPS)
Cloud Integrating Nephelometer (CIN)
Video Ice Particle Sampler (VIPS)
Nevzorov Probe

Cloud Detection Lidar (CDL)
Compact Millimeter Wave Radar (CMR)
Diffuse Field Camera (DFC)
Scanning High-Resolution Interferometer Sounder (S-HIS)

Additional instruments being considered include:

The JPL Tuned Diode Laser for water vapor (5ppm)

A second Cloud Detection Lidar – looking up. The Proteus will not be able to get above all the cirrus. There will be a dead-zone of several hundred meters above (and below) the aircraft.

May fly the COSSIR – a 12 channel scanning radiometer

Looking into the BAT (Best Aircraft Turbulence) probe

Probably will not have a CPI

Jim Mather asked whether a Microwave Temperature Profiler would be a useful asset. In subsequent discussion, it was determined that the MTP package is rather small but requires a forward looking port. It provides temperature profiles +/- 5 km from the flight altitude. This needs to be posed to the larger ARM community.

Addressing questions about the Proteus' sensitivity to turbulence and charged particles – Tim indicated that while the Proteus would not fly near convective cores, it was not sensitive to moderate turbulence. It was not clear how seriously it might be affected by the advection of charged particles.

The Proteus includes an Iridium communications link.

Jorg Hacker – Airborne Research Australia (Egrett, King Air, boundary layer)

The ARA King Air has been sold but an agreement makes it available to the experiment in 2006. We do need to decide within the next few months, however, if the King Air will be used.

Some stats for the Egret – its initial ceiling is 13.5 km but can reach 14.5 km near the end of a flight.

For the Egret to be a useful platform, it must include the following observations:

Extinction (e.g. with CIN – Garrett)
Total water (e.g. CVI)
Particle sizes (CAPS)
Habits (CPI)

Also need good water vapor (e.g. TDL – Randy May)

The Egret comes with turbulence (the BAT probe), state parameters

Emerald-2 instruments also included CPI, FSSP and, TDL (source of these instruments?)

In addition, Jim Whiteway is interested in supplying his lidar and plans to seek funding for support of the lidar deployment and for partial support of the Egret.

Discussed two potential boundary layer aircraft, the Diamona and a Cessna. The Diamona is less expensive and can be fitted with the Eco chemistry package which would satisfy most of NASA's requirements.

At the time – Jorg indicated that the Diamona would be restricted to flying near shore. He has indicated in subsequent conversation that the Diamona could do ocean flux surveys between Darwin and the ship. He has also indicated that the Cessna is not an ideal platform for measuring fluxes – because of its higher operating cost and because it does not provide data of the same quality as the smaller Diamona.

The Eco chemistry package is European and this poses a problem to NASA who would likely provide the support for the package. They cannot support non-US investigators. This seemed to point to a requirement to use the Cessna – but that is not ideal for fluxes and is more expensive. So – this issue – the choice of a boundary layer aircraft was left without resolution. Decisions about NASA funding for AURA validation (which will be important in this thought process) will come out in Fall of 2004.

Jorg provided revised cost estimates for each aircraft.

Chris Fairall – Ship-based flux measurements

Goals of the ship platform:

Ocean-based radiosonde launch site
Radiation impacts
Air-sea interactions
    Monsoonal – evolution of SST
    Diurnal – land/sea interaction
    Convective structure

Significant advances were made in some air-sea interaction issues during TOGA-COARE (e.g. work by Moncrieff et al or George Young).

Measurements should include:

Surface fluxes: Turbulent, radiation, precipitation
Near surface bulk meteorology
Radiosonde
Ceilometer
Microwave Radiometer
S-band radar (this is something we have discussed but have not planned for as yet)
Oceanographic instruments including CTD

Chris commented on the use of bulk vs. eddy correlation flux techniques.

First – what drives the accuracy requirement for surface fluxes?

Time scale of processes
Variability (temporal and spatial)
Model limitations

At TOGA-COARE – to meet goals – needed to acquire net surface fluxes to an accuracy of +/-10 W/m^2. This implies a need to measure flux components to an accuracy of +/- 5 W/m^2.

This goal was achieved during TOGA-COARE (with considerable work).

The assumptions used in applying bulk flux techniques fail under the following conditions:

Short fetch – offshore flow
Shallow water (this could be a problem)
Rapidly changing conditions
Large swell

A lot of work is required to do either the bulk fluxes (for calibration) or the eddy correlation fluxes properly but the latter are more expensive by roughly an order of magnitude.

In the balance, Chris did not feel that the eddy correlation fluxes were required unless the application was to study the detailed relationship between the two techniques (for example to improve bulk relationships).

Jim Mather – Ship-based remote sensing measurements

In addition to the instruments described by Chris, we could put a cloud radar and lidar on the ship. This would provide a second ground site for obtaining cloud properties (in addition to the ARM site at Darwin). This provides a second target for aircraft seeking to observe clouds over a ground-based site. The ocean site would also have the advantage of not being adjacent to an airport which could reduce flying restrictions over the site. There is also interest in putting remote sensing instruments on the ship because it may be that clouds over the ocean environment are different than over Darwin. It would be useful to know how representative Darwin is of the ocean environment during the monsoon.

A potential source of the cloud radar and lidar is the PNNL Atmospheric Remote Sensing Laboratory (PARSL). PARSL also includes some of the other instruments on Chris' list including the microwave radiometer, ceilometer, sounding system, and bulk meteorology.

Jim Mather - Budget and closing discussion

Current commitments to fund the Darwin IOP currently cover approximately $800,000 (USD). While estimates for the experiment cost are closer to $1,300,000.

An overview of this budget sparked a number of comments and suggestions.

Jorg will get a revised version of the aircraft cost. He thought it would be cheaper/plane to field three planes than to field a single plane due to overlap in costs (e.g. ground crew).

Jim will get a revised estimate for PARSL.

Both Jorg and Jim have subsequently provided revised estimates that reduce the total cost by approximately $200 K (USD)

It was also pointed out that there will be additional costs that have not yet been accounted for. For example, costs associated with a pre-experiment forecasting exercise (would be held during the 2004/05 monsoon season. These additional costs are likely to erode much of the savings from the aircraft and PARSL.

When the question was posed regarding what platforms could be cut to reduce costs – Graeme Stephens suggested that we were approaching the problem the wrong way. He said we should, instead, carefully go through the science goals and define precisely what resources were needed to accomplish those goals – matching platforms and instruments with science questions. Then go after funding to support that budget. He suggested that we should use the members of the ARM STEC to help us go after that funding – both from ARM and from external agencies.

Several groups suggested potential support – these included the Cloud-SAT program and the UK Met office – these are potential avenues to pursue.