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The Arctic Lower Troposphere Observed Structure (ALTOS) Campaign

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ARM CLIMATE RESEARCH FACILITY

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Summary

The ALTOS campaign focuses on operating a tethered observing system for routine in situ sampling of low-level (< 2 km) Arctic clouds. It has been a long-term hope to fly tethered systems at Barrow, Alaska, but it is clear that the Federal Aviation Administration (FAA) will not permit in-cloud tether systems at Barrow, even if unmanned aerial vehicle (UAV) operations are allowed in the future. We have provided the scientific rationale for long-term, routine in situ measurements of cloud and aerosol properties in the Arctic. The existing restricted air space at Oliktok offers an opportunity to do so.

Tethered observing systems have been flown successfully in the Arctic, but only under limited conditions for short periods. An example of one such system is the Stratton Park Engineering Company (SPEC) system, which includes a microphysical package that features a low-power, lightweight cloud particle imager especially designed for application on tethered balloons, operated in conjunction with a cloud droplet probe. In addition to these cloud probes, the package measures pressure, temperature, humidity, wind speed and direction, GPS position, and actinic radiation using a 4-π radiometer. However, sustained operations with such tethered cloud physics instruments have not been tried under adverse conditions such as may be expected under year-round operations.

The Arctic was selected for a permanent ARM Climate Research Facility (ARM) site because climate models suggest that it is particularly sensitive to climate change. Indeed, near-surface warming across the Arctic has been observed at approximately twice the global average since the late 1960s. Inter-model scatter in projected Arctic temperatures is also an order of magnitude larger in the Arctic than in mid-latitudes. Current climate models do not capture the full set of physical processes/feedbacks that determine the state of the Arctic climate. One reason for this may be that climate model parameterizations of atmospheric physical processes rely mostly on our understanding of mid-latitude processes; yet important feedbacks in the Arctic appears to be exclusive to the Arctic. While climate models agree in their projection that these trends will continue through this century, there is no consensus regarding the underlying reasons for this enhanced climate sensitivity in the Arctic.

The ice and snow in higher latitudes have an important contribution to climate trends through the ice-albedo feedback. The magnitude of this feedback remains uncertain because this feedback is strongly coupled to Arctic cloud processes and ocean heat transport, the complete physics of which remain poorly understood. Perennial sea ice in Arctic has declined by more than 20% since the mid-1970s, raising concerns that a threshold in the positive ice-albedo feedback may have been crossed. Recent studies suggest that sea-ice retreats, as depicted by the summer ice edge, are correlated closely to an upward trend in the downwelling, longwave radiative flux in the Arctic springtime. Increasing downwelling longwave flux appears to be driven mostly by increases in clouds and precipitable water vapor, thus establishing the need to better understand the contribution of clouds to this important feedback process.

Low-level boundary-layer clouds tend to dominate in the Arctic with very high temporal frequencies in all seasons. A particularly important feature is that these clouds are often mixed-phase even at quite low temperatures, consisting of liquid-water tops that precipitate ice, or even multiple liquid-water layers

embedded within precipitating ice. To understand the surface cloud radiative forcing, it is necessary to understand the factors that regulate the cloud microphysical processes, in particular the liquid-water phase.

By contributing to our understanding of Arctic cloud processes and radiative transfer through the Arctic cloudy atmosphere, ARM can reduce one of the great uncertainties in climate models, thereby improving climate prediction capabilities. Detailed cloud-resolving model studies have suggested that modest increases in ice nuclei concentrations in Arctic mixed-phase clouds can transform a largely liquid stratus deck of wide aerial coverage into a broken, optically thin cloud system. Based on observations from the Mixed-Phase Arctic Cloud Experiment (M-PACE) conducted at the North Slope of Alaska (October 2004), it was concluded that observed concentrations of ice nuclei are insufficient by several orders of magnitude to explain observed ice, and that other mechanisms have to be invoked to explain ice formation in mixed-phase clouds. Aerosol variations also appear to have a direct impact on the surface cloud radiative forcing through the liquid phase. In addition to these aerosol effects, cloud liquid-water content depends on cloud-scale dynamics, sea ice coverage and thickness, and large-scale atmospheric circulation patterns, all of which have strong seasonal dependence.

Contents

1.0 ALTOS Science Objectives

1. What is the distribution of microphysical properties of low-level Arctic clouds, and how do these vary with environmental conditions?
2. What is the horizontal variability in microphysical properties in layered clouds, and what are the factors that determine this horizontal variability?
3. How do gravity waves interact with and impact cloud layers?
4. What is the relationship between microscopic and macroscopic cloud properties and the thermodynamic environment in which they occur?
5. How well do ARM microphysical retrievals capture the statistical distributions of cloud properties?
6. Can we make a definitive conclusion about ice shattering effects on microphysical measurements from the low-aspiration balloon measurements?

2.0 ALTOS Measurements

Tethered balloon. A 100-cubic meter balloon containing a cloud physics instrument payload will record data at the instrument package and also transmit to the ground using a radio link. The tethered balloon system will be provided by Paul Lawson and colleagues from SPEC (http://www.specinc.com). The tethered balloon is designed to fly to an altitude of up to 2 km above ground level. Its altitude is controlled by a winch that will be housed in a dedicated shelter. In addition to controlling the balloon altitude, the tether also carries a cable that connects the balloon-borne instruments to infrastructure on the ground, which will be housed in a shelter adjacent to the winch house. Instruments and equipment on the balloon will include:

- low-power, lightweight cloud particle imager (CPI)
- forward scattering spectrometer probe (FSSP)
- compact cloud condensation nuclei (CCN) counter
- cryogenic frost point hygrometer
- ice nucleus filters
- weather package including measurements of temperature, pressure, wind speed, and direction
- GPS position
- actinic flux radiometer.

Balloon operation as well as data collection and processing will be handled by SPEC, with the exception of the CCN counter. Greg Roberts of the University of California, San Diego will manage data processing for the CCN counter.

Surface Instrumentation. Measurements from a subset of instruments on the ground will be used to constrain the profiles obtained by the tethered balloon system. Kim Nitschke will provide the Self-

Kontained Instrument Platform (SKIP) system to support the bulk of the ground-based instruments. This system includes a custom shipping container and, for ALTOS, the following instruments:

- 95-GHz cloud radar (W-Band)
- micropulse lidar (MPL)
- ceilometer
- microwave radiometer (MWR)
- longwave and shortwave radiometer package including up- and down-looking precision infrared radiometers (PIR) and precision spectral pyranometers (PSP), normal incident pyrheliometer (NIP), and multifilter rotating shadowband radiometer (MFRSR)
- surface meteorological (SMET) package on a tripod.

These instruments, with exception of the 95-GHz radar, were previously deployed with SKIP as part of the second Radiative Heading in Underexplored Bands Campaign (RHUBC-II) in Chile in the fall of 2009 and are still with the system. SKIP also includes a basic data system with a collector computer but does not provide for on-site data processing.

The 95 GHz vertically pointing cloud radar will be provided by Ken Sassen of the University of Alaska Fairbanks (UAF). Dr. Sassen will be assisted by Dr. Verlinde from Penn State for the operation of the radar during the operational period. Dr. Sassen will be responsible for data processing and delivery.

3.0 Site Operations

The ALTOS experiment includes four on-site phases: Setup 1, Setup 2, Primary Observations, and Pack-up. The planned dates for these phases are given below. They provide for a core 30-day operations period.

Setup Phase I, October 13–19: Set up containers, electricity, infrastructure

- Sandia National Laboratories (Sandia) Technologist
- Los Alamos National Laboratory (LANL) Technologist
- Sandia Prime

Setup Phase II, October 20–26: Set up tether balloon system

- Penn State Project Leader
- SPEC: Four people
- Sandia Prime

Project, October 27–November 25: Primary observational period

- Penn State Project Leader
- SPEC: Four people first two weeks, reducing to three after that

- Greg Roberts (two weeks)
- Sandia Prime
- UAF: One person (one week)

Pack-up, November 26–30: Pack-up instrumentation

- Sandia Technologist
- LANL Technologist
- Sandia Prime
- SPEC: Three people
- Penn State helper
- UAF: One person

Within this schedule, Sandia will work with LANL to do the initial site setup, with LANL primarily responsible for the SKIP system and Sandia for the remaining infrastructure. In the second week, SPEC and the UAF personnel will arrive to set up the tethered balloon and radar respectively. At the end of this period, Greg Roberts will arrive to complete integration of the CCN counter onto the tethered balloon. During the experiment operations period, Sandia will be the lead for logistics and Penn State for science guidance, including identification of suitable conditions for flying.

Collected data from the SKIP instruments will be transferred to the Data Management Facility on a daily basis. SPEC will transfer all data from the balloon instrument package to the SPEC headquarters in Boulder for quality assessment and preliminary analyses. The radar data will be transferred to UAF and Penn State for analyses. All raw data will be transferred to the ARM Data Archive within six weeks after the completion of the experiment.

4.0 Science Operations

Flight operations will be conducted according to the approved Aviation Safety Review document. Sandia will monitor compliance and will act as the intermediary to the FAA and other parties that need to be informed about ALTOS operations.

The FAA must be notified with a **26-hour lead-time** when the restricted air space will be activated. There will be a daily meeting with the project steering committee, consisting of the Penn State project leader, the SPEC project leader, and the Sandia representative, determine the feasibility of a flight for the following day. Penn State will provide the weather forecast for six-hour window blocks in the 12–48 hour range. The steering committee will determine the need to activate the restricted air space and decide on the operational plan for the next day. The Sandia representative will communicate flight decisions to the FAA.

On declared operational days, the steering committee will meet prior to commencement of operations. An updated weather forecast for the flight period will be provided by Penn State. If the forecasted favorable weather does not materialize, operations will be canceled or postponed, and the Sandia representative will communicate the decision to the FAA.

Balloon operations will consist of a basic set of sampling strategies to address different science goals. The steering committee will decide which sequence of patterns will be conducted and for how long operations will continue

The tethered balloon maximum spooling rate is about 100 m per minute. A profile through the full 2-km depth can thus be accomplished in approximately 30 minutes, using a conservative estimate. Alternatively, a 400-m thick cloud could be profiled at 5-minute intervals. With these numbers in mind, we identified three basic sampling strategies:

1. *Lower tropospheric profiling*: Continuous profiling through the maximum extent of the tether, documenting the full structure of the lower troposphere.
2. *Cloud layer profiling*: Rapid (at maximum spooling rate) ascent/descent through a single cloud layer to document the cloud microstructure and its variability.
3. *Constant altitude flights*: Document horizontal structure below, in, and above the liquid cloud layer.

Full profiles are necessary to characterize the full thermodynamic structure in which the clouds are formed and the impact the thermodynamic structure has on the microstructure of the clouds. The rapid sampling of single cloud layers is necessary to develop the statistical descriptions to constrain numerical model simulations of the cloud microphysical processes. Constant altitude flights are necessary to document the horizontal structure in the environment/cloud that impact cloud microstructure, including gravity wave activity and aerosol variability below, in, and above the cloud.

Flights will be terminated when cloud conditions change, or when any of the steering committee representatives deem that safe operations are no longer possible.

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