**Overview**

Characterizing clouds and their larger-scale earth system influences is central to accurately modeling many processes spanning from small-scale precipitation to global albedo affects. A more thorough understanding is required despite many years of focused work and rapid advances in computing and in-situ probe capacities. Improved cloud, weather, and climate models require a more thorough understanding of cloud microphysical processes and how they influence adiabatically-predicted deviations (Boucher 1995). Investigations are complicated by fine temporal and spacial scales, complex process interactions, and incomplete instrument limitation characterization.

Cloud droplet size distributions (DSDs) are nearly ubiquitous in microphysical studies because they provide insight into formation, precipitation, and dynamical processes (Lamb and Verlinde 2011). Characteristic distributions are related to specific cloud important traits and processes. DSDs under 100 um diameter are especially essential for droplet activation and primary precipitation formation studies. Because vapor diffusion growth rate is inversely proportional to droplet diameter, clouds made of newly-activated droplets rapidly progress to a near-monodisperse small diameter distribution. Growth to precipitation-sized droplets by vapor diffusion alone would require timescales far longer than are observed, implying the importance of primary precipitation processes. One such process, droplet collection and coalescence, alters new cloud droplet distributions to a bi-modal shape at the expense of newly-activated droplet concentrations (Lamb and Verlinde 2011). Droplet fall speed is proportionally related to size suggesting small droplet growth by collection is a key precipitation formation precursor. Further complications are introduced by extra-tropical clouds’ mixed-phase (liquid water and ice) composition.

**Significance**

The Droplet Measurement Technologies Cloud Droplet Probe (CDP) is a backscatter spectrometer commonly flown during cloud microphysical studies. The probe retrieves sub-precipitation sized cloud droplets (up to 50 um diameter) size distributions and derived LWC values (Droplet Measurement Tech. 2014). Manufacturer specifications state the CDP is capable of retrieving concentrations up to 2,000 particles cm-3 but studies have shown sample area size uncertainty, inhomogeneous instrument response, and coincidence error (error caused by simultaneous detection of multiple droplets) significantly impacts retrieval capabilities at concentrations as low as 200 cm-3 (Lance 2012). The afore-mentioned uncertainty sources contribute to systematic deviations from truthful DSDs and can significantly skew results.

CDP calibration is traditionally performed using glass beads or polystyrene spheres; both of which introduce complexities due to differential (with respect to water) refractive index effects, spacial imprecision, and volume control difficulty. A handful of institutions and instrument manufactures have developed water droplet generators to mitigate calibration challenges. Droplet generators are capable of creating pure liquid water particles of repeatable size, velocity, and placement; attributes which will allow for calibration and uncertainty investigations free of the refractive index and spacial uncertainty complications of typical calibration methods. Most designs are based on previous work by Lance et. al. (2010) where a piezoelectric print head (typically used for circuit printing or biomedical applications) dispenses droplets into a sheath airflow. Droplets are accelerated by the flow, focused through a nozzle, and passed through an instrument sample area. High speed cameras and imaging software independently verify droplet size, velocity, and trajectory while precision micro-stages alter injection location at micron-scale precision.

The Nevzorov hotwire probe is another extensively used UWKA device capable of measuring LWC. The Nevzorov can derive bulk liquid and total water content using energy balance principles and monitoring heated coil power consumption.

**Objectives**

The proposed work will improve King Air in-situ droplet distribution and LWC retrieval capabilities utilizing algorithm development, laboratory development, and UWKA data analysis. Multi-faceted methodology, focused on both data analysis and laboratory-based experiments, will enhance departmental observational study abilities through improved in-situ probe limitation characterization and calibration abilities. Proposed equipment

Laboratory droplet generator setup and testing will expand departmental Cloud Droplet Probe (CDP) and 2D-S calibration and characterization capabilities. Laboratory efforts will be focused on incremental system development, equipment assembly and testing, and procedure development. --Modifying the point at which droplets enter the airflow systematically affects droplet velocity and size (through evaporation). Theoretically, the UW droplet generator will produce droplet traveling approximately 50 m s-1 at diameters ranging from 10–35 um at concentrations up to 250 drops sec-1 (Need to reference plans).

New Nevzorov IDL data processing algorithms will correct for instrument bias, quantify uncertainty, output diagnostic and experimental products, and streamline processing workflow. Algorithm truthfulness and robustness are to be tested against independent COPEMED 13 Nevzorov calculations and spring/fall 2016 UWKA flight data.

Nevzorov algorithms will allow for in-depth assessment of both characterized and less explored uncertainty sources including particle collection efficiency, latent heat of water temperature dependence, sensor saturation, pressure and temperature variations, airspeed fluctuations, and aircraft orientation effects.

A combination of Nevzorov/CDP derived LWC, refined Nevzorov uncertainty characterization, and in-situ flight data will allow detailed in-situ instrument uncertainty study.

**Background**

Lance et. al. (2012) have shown the CDP is subject to response inhomogeneity and coincidence effects contributing to as great as 27% undercounting and 30% oversizing bias at concentrations as few as 500 cm-3. A simple pinhole mask modification substantially reduced coincidence error but the effect remains significant for droplet size distribution retrieval. Bias is present especially for droplet concentrations greater than 500 cm-3 or small diameter droplets (~ 2-20 μm).

The Nevzorov has several advantages over similar hotwire designs including phase discrimination capability and paired collector/reference coil architecture. The latter simplifies calculations, significantly reduces baseline noise, and increases retrieval confidence in low water content situations (Korolev 1997). Sulskis (2016) has demonstrated CDP and Nevzorov LWC values are generally in good agreement despite the fact the Nevzorov measures bulk LWC using energy balance and thermodynamic relationships (as opposed to the CDP’s more complex optical principles). Many Nevzorov uncertainty sources have been previously characterized and found to behave quite predictably. Bias sources include convective dry air heat losses (Korolev 1997), collection efficiency effects for particle volume-weighted mean diameter (VMD) less than 5 μm or greater than 25 μm (Korolev 1997, Schwarzenboeck 2009), and sensor saturation effects for particle volume median diameter (MVD) 50 μm (Strapp 2003) or LWC 1.3 g m-3 and greater (Sulskis 2016).

Nevzorov data processing software has been developed and tested against well-established COPE-MED 2013 calculations provided by Alexi Korolev, a principle Nevzorov developer. Summer/Autumn 2016 research flight data will provide further validation of calculation truthfulness and robustness. Algorithms include dry air heat loss airspeed and temperature corrections; one of the most significant bias sources.

Several potential uncertainty sources including aircraft orientation, environmental parameter sources, and non-unity collection efficiency, have been examined and deemed negligible. The Nevzorov flown during COPEMED 13 featured an experimental “deep cone” total water content sensor designed to reduce crystal “bouncing and splattering”. It was found the modified sensor, when compared to standard designs, is at least as effective at collecting liquid particles.

In-situ CDP, Nevzorov, LWC-100, and PVM-100A cross-analysis preformed by Sulskis (2016) investigated inter-probe LWC agreement. The Nevzorov was found to be in the best agreement with CDP LWC with percent differences often an order of magnitude less compared to the LWC-100 or PVM-100A. Furthermore, CDP and Nevzorov LWC were the most similar across all concentration and droplet diameter ranges. Very little Nevzorov LWC bias was found for LWC values less then 1.3 g m-3.