Air-Sea-Aerosol-Cloud Interactions

Djamal Khelif, Carl Friehe
Department of Mechanical and Aerospace Engineering
University of California, Irvine
Irvine, CA 92697-3975
phone: (949) 824-7437   fax: (949) 824-8585   email: dkhelif@uci.edu

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http://wave.eng.uci.edu

LONG-TERM GOALS

The long-terms goals of our research are to understand and parameterize the physics of air-sea interaction and the marine boundary layer over a wide spectrum of surface forcing ocean conditions and cloud coverage.

OBJECTIVES

The main objectives of this effort are to study the air-sea-aerosol-cloud interaction under different wind and cloud coverage conditions. Particular emphasis is on the parameterization of aerosol equilibrium loading. Accurate measurement of the surface latent heat (water vapor), sensible heat and momentum fluxes is a critical part of this effort. In past projects, we have typically made these measurements from research aircraft at the lowest possible flight level of 30 m. Flux-profile assumptions had to be made to extrapolate the measurements down to the 10 m "canonical" reference height to calculate the mean quantities to be used in the parameterization of the air-sea fluxes. The use of the newly developed aircraft-towed Controlled Towed Vehicle at controlled heights as low as 10 m allows true direct measurements of surface turbulent flux without any profile assumption.

APPROACH

During the high wind experiment conducted off Monterey Bay in April 2008, we used the recently-developed "Controlled Towed Vehicle" (CTV) and the CIRPAS Twin Otter with the UCI turbulence instrumentation and the extensive CIRPAS aerosol suite to address important marine meteorological questions. The CTV provided air-sea interaction and meteorological measurements at heights as low as 10 meters above the sea while the tow airplane was making complementary measurements above. This made it possible to obtain turbulence data simultaneously from two levels inside the MABL.

We plan on using the same turbulence instrumentation in the larger VOCALS-REx field experiment to be conducted off the coast of northern Chile in October-November 2008. The focus of this experiment is on stratocumulus clouds and our role will be to obtain surface latent and sensible heat fluxes as well as turbulence measurements in-clouds and near cloud top and base.

WORK COMPLETED

A large amount of our effort in the past year has been dedicated to preparing for and conducting field experiments with the CIRPAS Twin Otter. Part of the effort was focused on improving the turbulence instrumentation of the CIRPAS Twin Otter (shown in Fig. 1) for two field experiments that were

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completed and for an upcoming one in October 2008. A brief description of the main work completed follows.

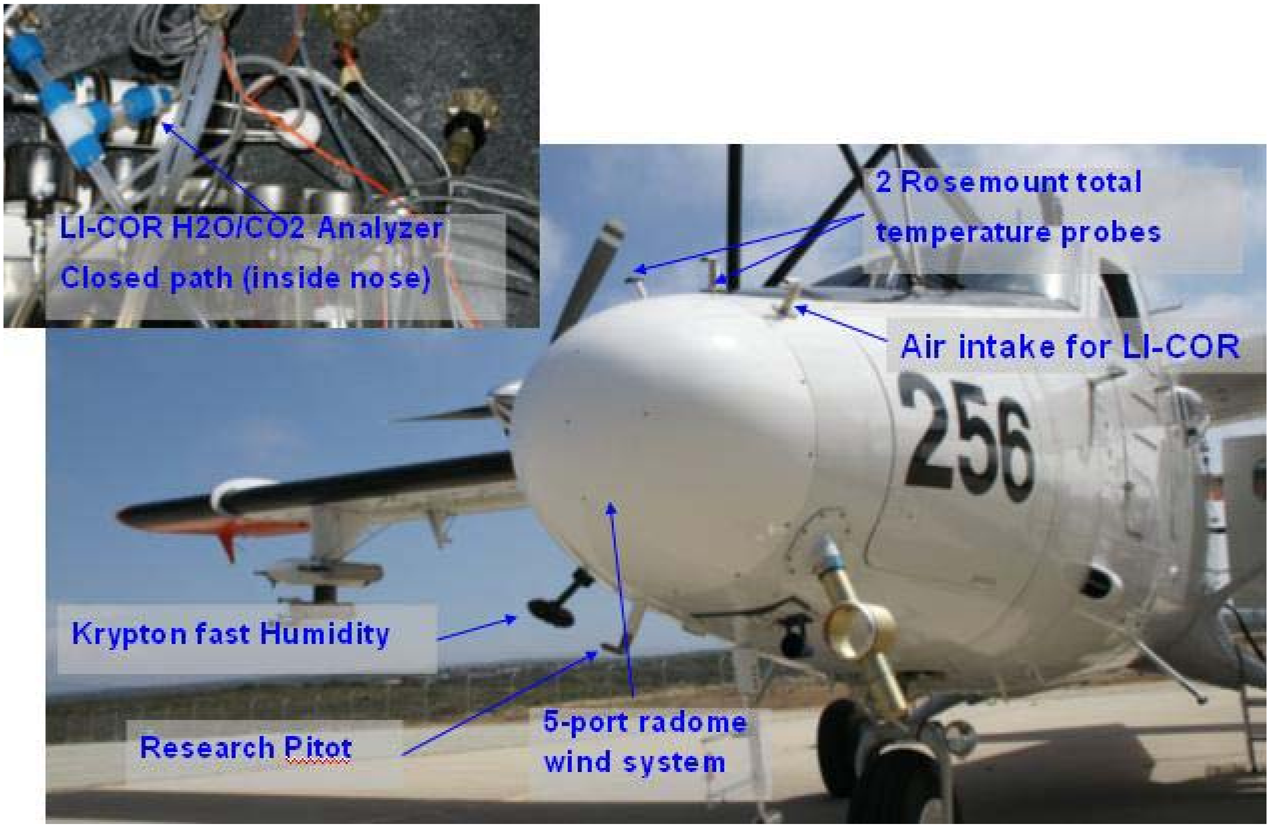

Figure 1: UCI Turbulence instrumentation on the CIRPAS Twin Otter for POST and VOCALS-REx field experiments in 2008.

High-Wind Experiment:

The High-wind experiment was conducted off the coast of Monterey Bay in April 2008. Fourteen flights about 5 hours each were completed by the CIRPAS Twin Otter and its Controllable Towed Vehicle (CTV). Winds varied from ~5 m s^{-1} to ~17 m s^{-1}. Data from the Twin Otter have been processed and shared with Larry Mahrt from NWRA who is collaborating with us to analyze the data from this project. A first processing of CTV data from the 14 flights was completed. Due to the newly developed synchronization technique described below, we plan to implement it to the CTV data and reprocess all its flights.

VOCALS-Rex:

Since a large part of the October-November 2008 VOCALS-REx Twin Otter flight time is expect to be in-clouds, there is a potential problem for the radome wind system pressure line to be obstructed by the ingested cloud liquid water which would make its data useless. After several tests of tubing material, sizes and water trapping methods a new plumbing of the radome has been implemented.

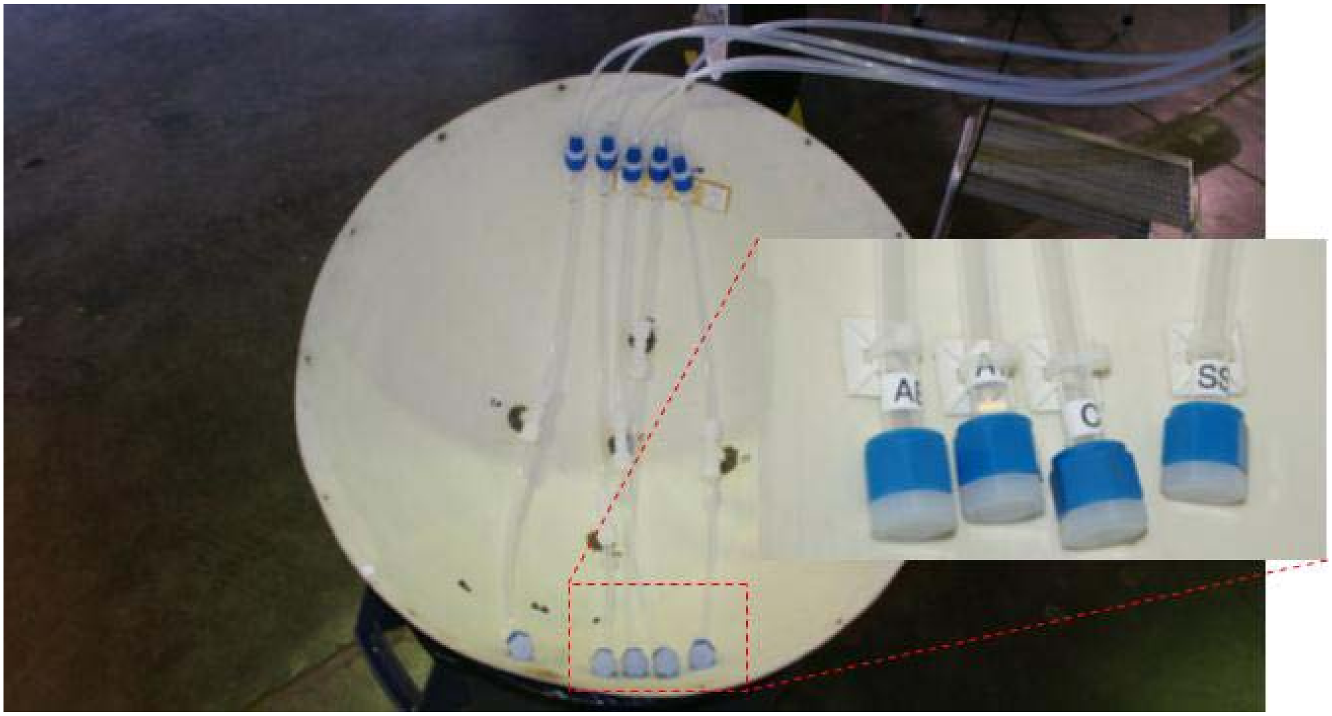

Figure 2: Radome wind system new plumbing uses special tubing with water traps that prevents the water ingested during in-clouds (or through rain) flights from obstructing the pressure lines.

Special hydrophobic tubing with an inner diameter wide enough to allow the water ingested at the radome pressure holes during in-clouds flights to bead and “slide” on the tubing inner walls (without bridging) to ultimately collect at the bottom of the water reservoirs. A photograph of the inner side of the radome system with the new plumbing is shown in Fig. 2. The detail insert shows the water collected after 7 flights (~5hours each) conducted mostly in-clouds during the Physics of the Stratocumulus Top (POST) experiment in July-August of this year. After 17 flights in POST no wind data were lost due to water ingestion. The new system proved to be virtually maintenance free and does not require removal of the collected water between flights resulting in a much more efficient operation.

We have been relying on AIR Lyman-alpha for fast humidity measurements. The source and detector tubes of our three probes and there is no replacement for them in the market. We modified the Campbell Scientific KH2O absorption krypton hygrometer by mounting its source and detector tubes inside the Lyman-alpha housing. We tested it during POST this summer and it worked well even during in-cloud runs. We also made a modification to the LI-COR H2O/CO2 gas analyzer so that it can be used in a closed path mode inside the nose section to avoid exposing its source and detector windows to liquid water from clouds. In this mode, as expected, a loss of bandwidth was experienced (the signal power spectrum density dropped just above 1-Hz) but values of the latent heat flux were comparable to those of the fast-responding modified-KH2O.

The wind vector is computed as the difference between the air stream velocity vector with respect to the aircraft and the aircraft velocity vector with respect to earth. The air stream velocity vector is obtained from the analog signals of the five-pressure-port radome systems while the aircraft velocity and attitude angles are obtained from the digital serial data output of the INS/GPS C-MIGITS unit. It is very critical that the two types of data are well synchronized throughout the flight to be able to resolve the full frequency range of the wind components fluctuations and hence turbulent fluxes.

We recently developed a new technique to synchronize the analog data from the radome wind system, temperatures, humidity sensors etc and the aircraft INS serial data from the C-MIGITS. The analog output of an independent Systron Donner pitch rate sensor is recorded. Its measurements are then compared to the C-MIGITS pitching rate data. Any time shift between the analog and digital data is thus easily and systematically detected and corrected during the post-flight processing.

RESULTS

In order to evaluate the quality of the wind data from the newly plumbed radome and the new synchronization method, plots from a slow pitching and fast pitching maneuvers performed in the quiescent free atmosphere air above the boundary layer are shown in Fig. 3. Pitching maneuvers, especially fast oscillating ones, amplify any time shifts between variables used in the calculation of vertical wind. As a general rule of thumb the ratio of the standard deviation of the pitching induced variations of the vertical wind component to that of the aircraft vertical velocity should be less than 10%. We found this ratio to be 4% and 5% for the slow and fast pitching maneuvers respectively which attests of the good quality of the data from the newly configured radome and data system.

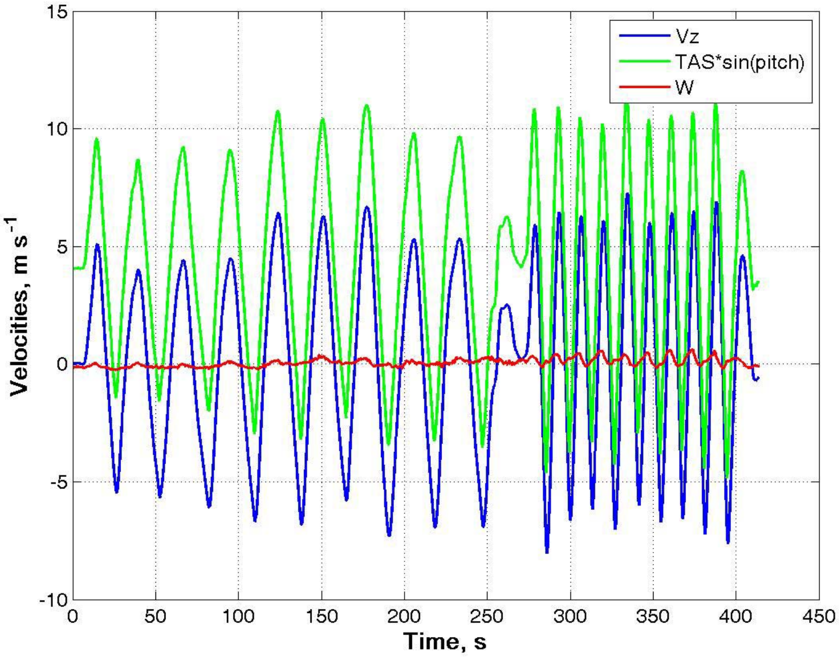

Figure 3: Twin Otter vertical velocity (blue), true airspeed times sin(pitch angle) (green) and vertical wind component. (red) from a back-to-back slow and fast pitching maneuvers flown in the free undisturbed atmosphere well above the MABL. Note that only little variations in the vertical component of the wind are induced by the pitching oscillation. The ratio of the standard deviation of the vertical wind component to that of the aircraft vertical velocity was 4% and 5% for the slow and fast pitching maneuvers, respectively.

Plots of the power spectra of the 3 wind components versus frequency clearly exhibit the -5/3 inertial subrange as shown in Fig. 4. The ogive of the along-wind stress shows a nice asymptote to the stress value of -0.225 Pa (Fig. 4 top right). The bottom plot of Fig. 4 shows the latent heat flux ogives obtained from the UCI-modified Krypton hygrometer and the LI-COR 7500 used in a closed path configuration inside the nose section (to avoid wetting of the source and detector windows during clouds penetration). Although the response of the latter is considerably slowed down in the closed path

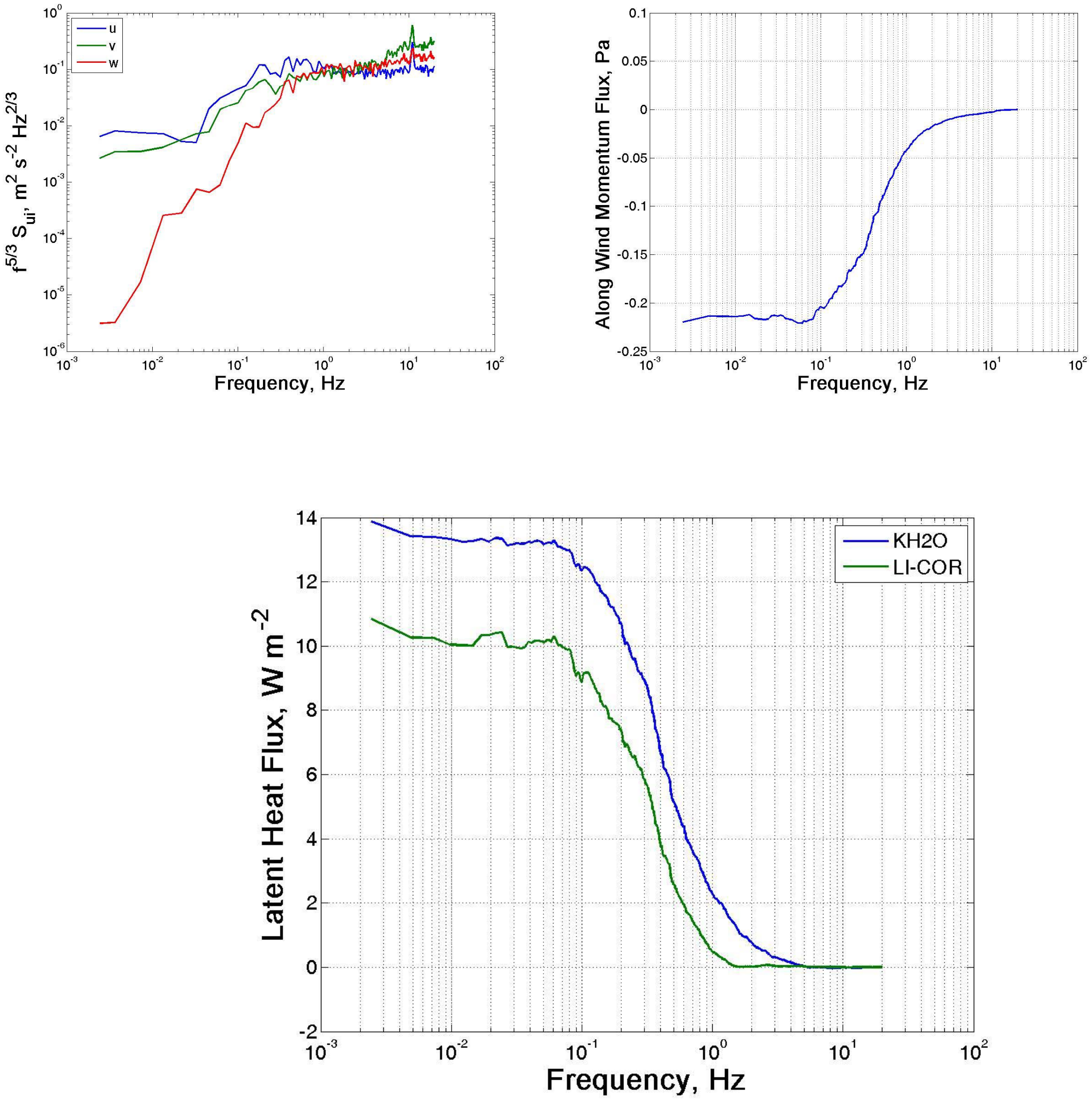

Figure 4: Top-left: Power spectra (multiplied by the frequency to the power 5/3 so that the inertial subrange shows as horizontal line) of the along-wind (blue), cross-wind (green), and vertical (red) wind components. Top-right: Ogive of the along-wind momentum flux. Bottom: Ogives of the latent heat flux from the UCI modified Krypton hygrometer (blue) and the LI-COR 7500 used in closed path mode (green). The data are from the 2008 POST experiment.

configuration (as evidenced by the “flat” part of the ogive on the high-frequencies side, its flux value is only 30% less than that of the faster open-path Krypton. The LI-COR “misses” ~ 2 W m^{-2} of latent heat flux on the high frequencies side. If this was corrected for, the difference between the flux estimates from the two instruments becomes less than 13%.

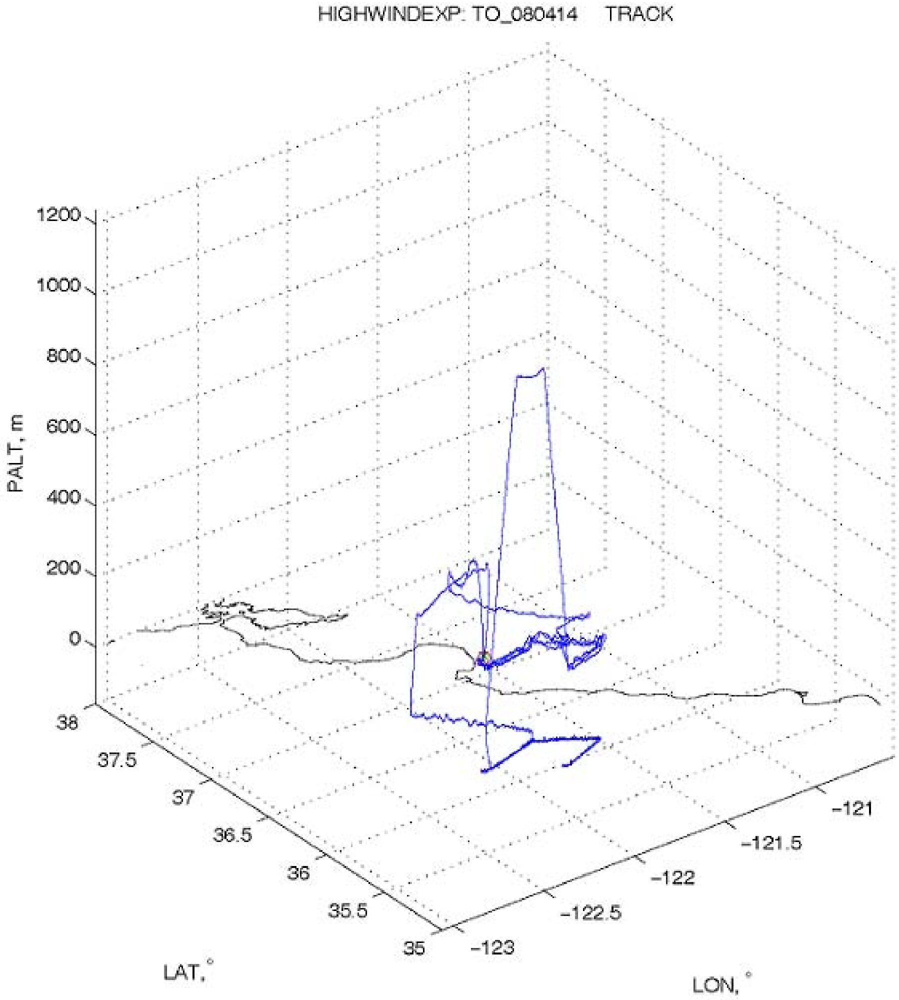

Figure 5: Typical Twin Otter flight pattern during the April 2008 high wind experiment off the coast of Monterey Bay.

A U-shaped track was flown at 30 m and 305 m and repeated at both elevations 2 to 3 times to obtain more robust turbulence and flux statistics. While the Twin Otter was at 305 m, the CTV was flown at elevations varying between 10 m and 30 m. The upstream and downstream branches of the “U” were oriented in the cross-wind direction and were separated by about 33 km. The idea is to compare turbulence measurements and particle concentrations upstream and down-stream at the surface and just below the inversion.

Concentrations of particles larger than 10, 100, and 600 nm in diameter (measured by the CAPS, PCASP and CN counter probes, respectively) are plotted as a function of latitude to segregate the data into upstream (north) and downstream (south) in Fig. 7 at both 30 m and 305 m elevation. Besides the greater variability in the smallest particles concentration in the downstream leg that might be due to ship tracks of various ages, the concentrations of the larger particles are basically the same down stream and upstream and at both elevations This may suggest that sea salt particles are in equilibrium since no changes between upstream and downstream legs are observed. In the example shown from the flight of April 14, 2008, the mean wind speed was roughly 16 m s^{-1} and mean direction was 325 ^{o}. Given the wide range of wind speeds on the days of the Twin Otter flights, it might be possible to get a relationship between equilibrium particle concentrations (of the three segregated sizes) as a function of surface (30 m) wind speed. We will be collaboration with Dr. Haflidi Jonsson of NPS to analyze the rest of data and try to determine such a relationship.

IMPACT/APPLICATIONS

The modification of the Twin Otter radome wind system to prevent ingested water during cloud flights from obstructing the pressure lines between the pressure port and the sensing transducer was successful. This technique can be implemented on other research aircraft especially if the research projects focuses on cloud work or heavy rain bands such as the ones encountered in tropical storms and hurricanes.

The modified Krypton hygrometer is a good alternative to the obsolete AIR Lyman-alpha for fast-response humidity measurements from research aircraft.

RELATED PROJECT

POST: The Physics of the Stratocumulus Top experiment (funded by NSF and ONR) was conducted off the cost of Monterey, CA from July 16 through August 15, 2008. We completed 17 flights with Sc coverage varying from thick and very compact to thin and broken. Roughly 70% of the flight time was spent in the clouds. It was necessary to redesign the radome wind gust system (for both POST and VOCALS-REx) to avoid liquid water ingestion into the pressure lines. The new system worked well and no wind data were lost due to obstruction of the pressure lines. The proven new system will be used for our immediately following ONR-funded project VOCALS-REx to be conducted off the coast of northern Chile from October 15 to November 15, 2008. We expect a large part of the flight time to be dedicated to Stratocumulus probing.

CTV: The controlled Towed vehicle has been developed in collaboration with Zivko Aeronautics Inc. and CIRPAS. The reasonable meteorological and eddy correlation fluxes results obtained from the CTV from the April 2007 data and from the preliminary data of April 2008 indicate that the concept works. The CTV is a unique platform for the measurement of air-sea fluxes and other variables at low heights over the ocean. Recent operational problems attributed to sea salt contamination in low-flying hurricane research aircraft engines in hurricanes will most likely limit low-level boundary-layer flights. UAS (Unmanned Aerial Systems, previously denoted UAV) and drop sondes are alternates for measurements near the ocean surface. Drop sondes have limited sensor capability, and most present UAS vehicles do not have the payload and power capacity similar to the CTV. The CTV therefore, fills a needed gap between the drop sonde, in situ aircraft, and UAS. Other sensors, such as aerosol, chemical, radiation, etc., could be accommodated in the CTV.

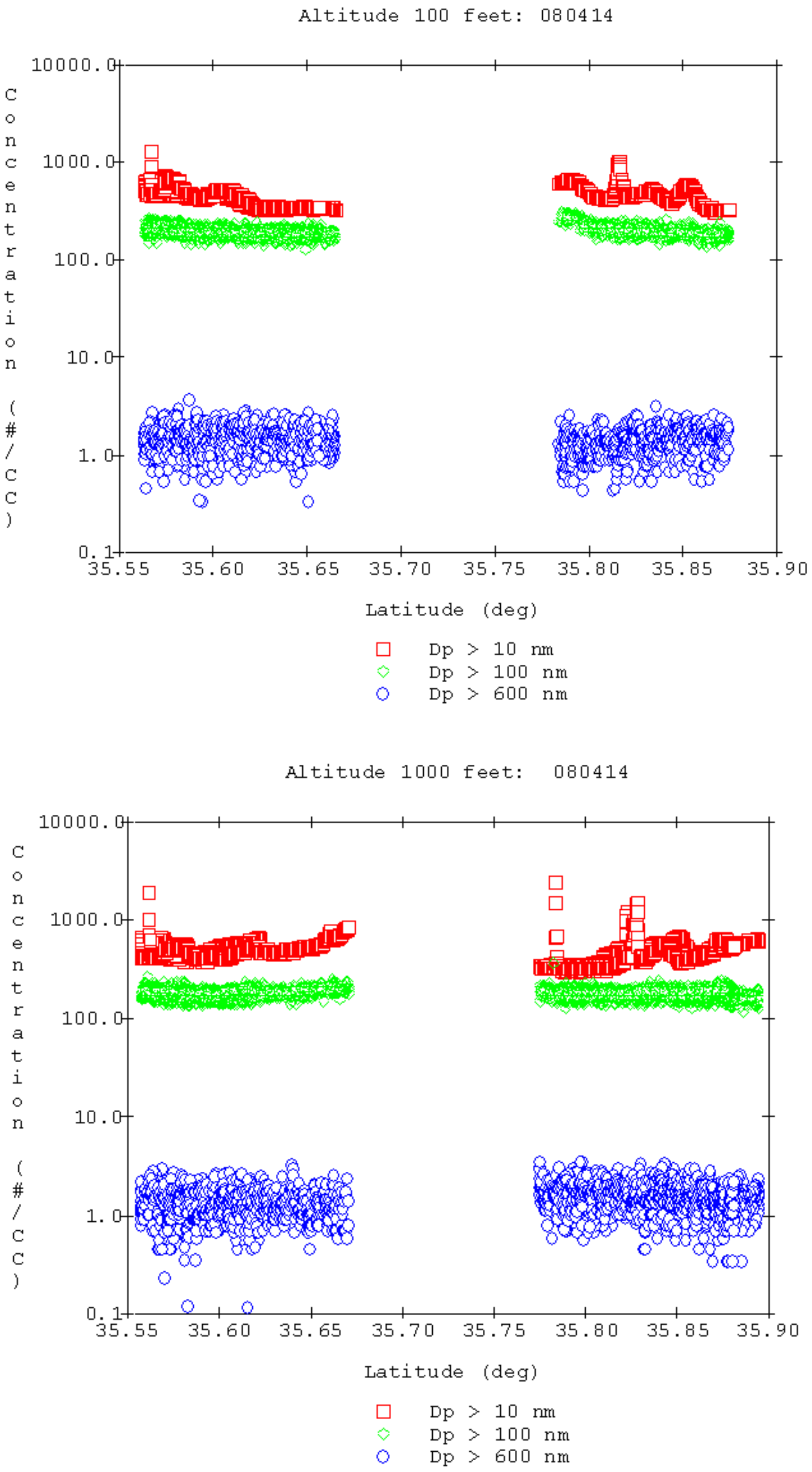

Figure 7: Concentrations of particles larger than 10 nm (red squares), 100 nm (green diamonds), and 600 nm (blue circles) versus latitude at ~30 m or 100 ft (top) and ~305m or 1000 ft (bottom) .

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