Marine Boundary-Layer and Air-Sea Interaction

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LONG-TERM GOALS

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

OBJECTIVES

The main objectives of this effort are to study the air-sea interaction under different conditions: cold air outbreaks in the Japan/East Sea experiment, trade winds off the east coast of Oahu, Hawaii during the Rough Evaporation Duct experiment (RED), stratocumulus marine layer off the central coast of California during the Cloud-Aerosol Research in the Marine Atmosphere I,II & III (CARMA I, CARMA II & CARMA III) and the summertime mostly stable boundary-layer south of Martha's Vineyard, Massachusetts during the Coupled Boundary Layers/Air-Sea Transfer (CBLAST – Low winds)
We are primarily interested in the characterization of boundary-layer structure, the measurement of momentum, heat and water vapor (latent heat) air-sea fluxes, the determination of their spatial variability as well as their parameterization.

APPROACH

The Navy NPS CIRPAS Twin Otter research aircraft (which we instrumented with turbulence instrumentation for a previous ONR project, the Japan/East Sea experiment) was used to measure air-sea fluxes and boundary-layer structure during RED, CARMA I, II, & III in the summers of 2001, 2002 and 2004 and 2005 respectively. Since the primary focus of CARMA was on the interactions between aerosols and clouds, many flux runs were also made in and at top of the stratocumulus cloud layer to quantify vertical transport in and near clouds.

For the summer 2003 CBLAST-Low experiment, we instrumented the CIRPAS Pelican aircraft (a modified Cessna 337 with only the pusher engine) with turbulence instrumentation similar to that described in Khelif et al. (1999). The flight patterns flown in CBLAST-Low mainly consisted of 30-m flux mapping legs, vertical structure profiles, repeated legs across SST fronts and flux divergence legs over the WHOI Air-Sea Interaction Tower (ASIT). We collaborate with Haf Jonsson of NPS/CIRPAS on all of these projects and Dean Hegg on the CARMA studies. Both are cloud physics and aerosol investigators.

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14. ABSTRACT
The long-terms goals of the research are to understand and parameterize the physics of air-sea interaction and the marine boundary layer over a wide spectrum of weather and ocean conditions.

15. SUBJECT TERMS

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WORK COMPLETED

CBLAST-Low: We released in March 2005 a new version of the data for all 19 flights of the CIRPAS Pelican. The data set is available at this URL:http://wave.eng.uci.edu/files/cblast/flights/. The improvements made in the latest release include (i) correction of time delays caused by GPS dropouts of the C-MIGITS II INS/GPS unit on two flights; (ii) removal of spikes (caused by HF radio) from temperature and humidity sensors; (iii) use of moist air thermodynamic properties in the compressible flow equations to calculate true airspeed and other parameters and (iv) recalibration of angles of attack and sideslip of the radome 5-hole wind system. We used the method described in Khelif et al, (1999) to perform these calibrations. The vertical component of the wind has small induced variations during a fast (about 8.4 s oscillations period) pitching maneuver as evidenced in Fig. 1. The ratio of the standard deviation of the vertical wind component to that of the vertical velocity of the aircraft was found to be 6.7% which is well below the 10% customary acceptable level.

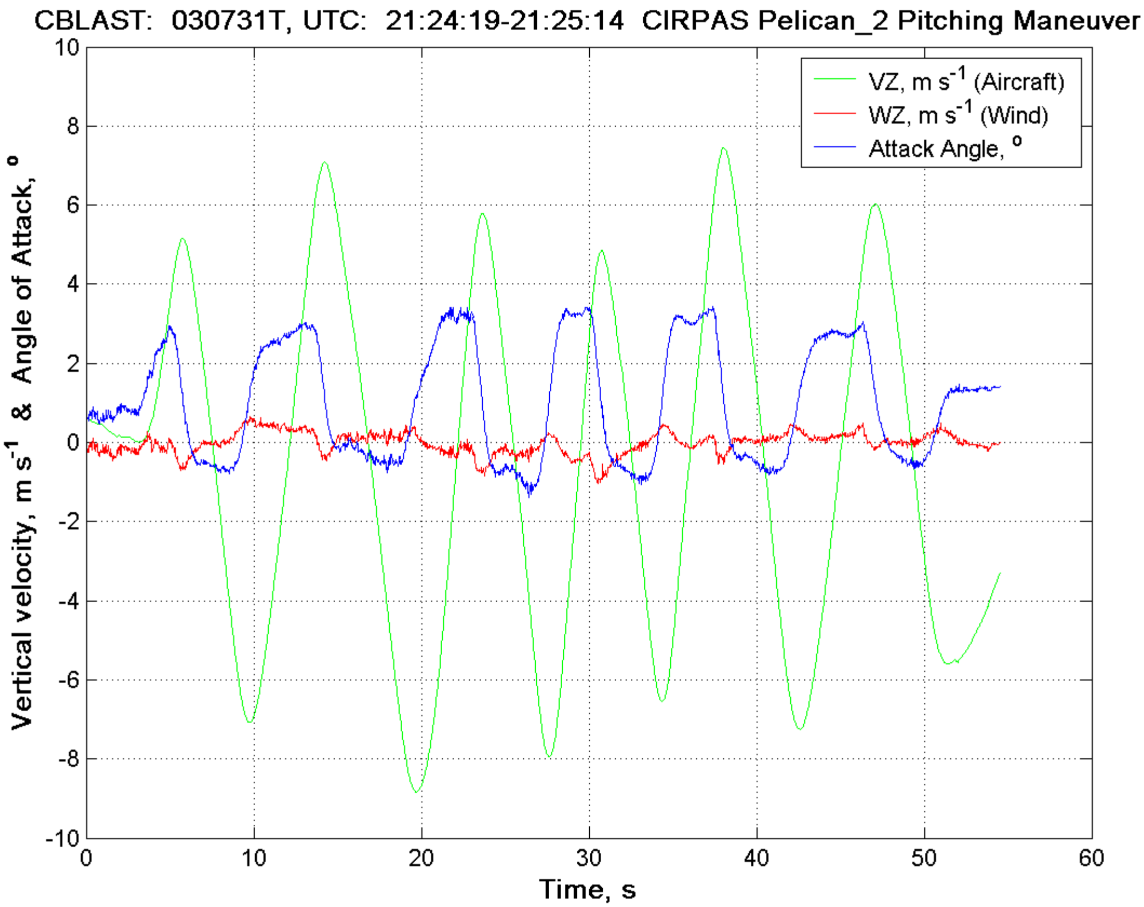

Figure 1 Time series of vertical aircraft velocity (vz, green) angle of attack (blue) and vertical component of the wind vector (wz, red) from a pitching maneuver performed in clear air well above the boundary layer. The ratio of the standard deviation of wz to that of vz was found to be 6.7% which is well below the 10% customary acceptable level. Data are from CIRPAS Pelican 2 aircraft on July 31, 2003 in CBLAST-Low.

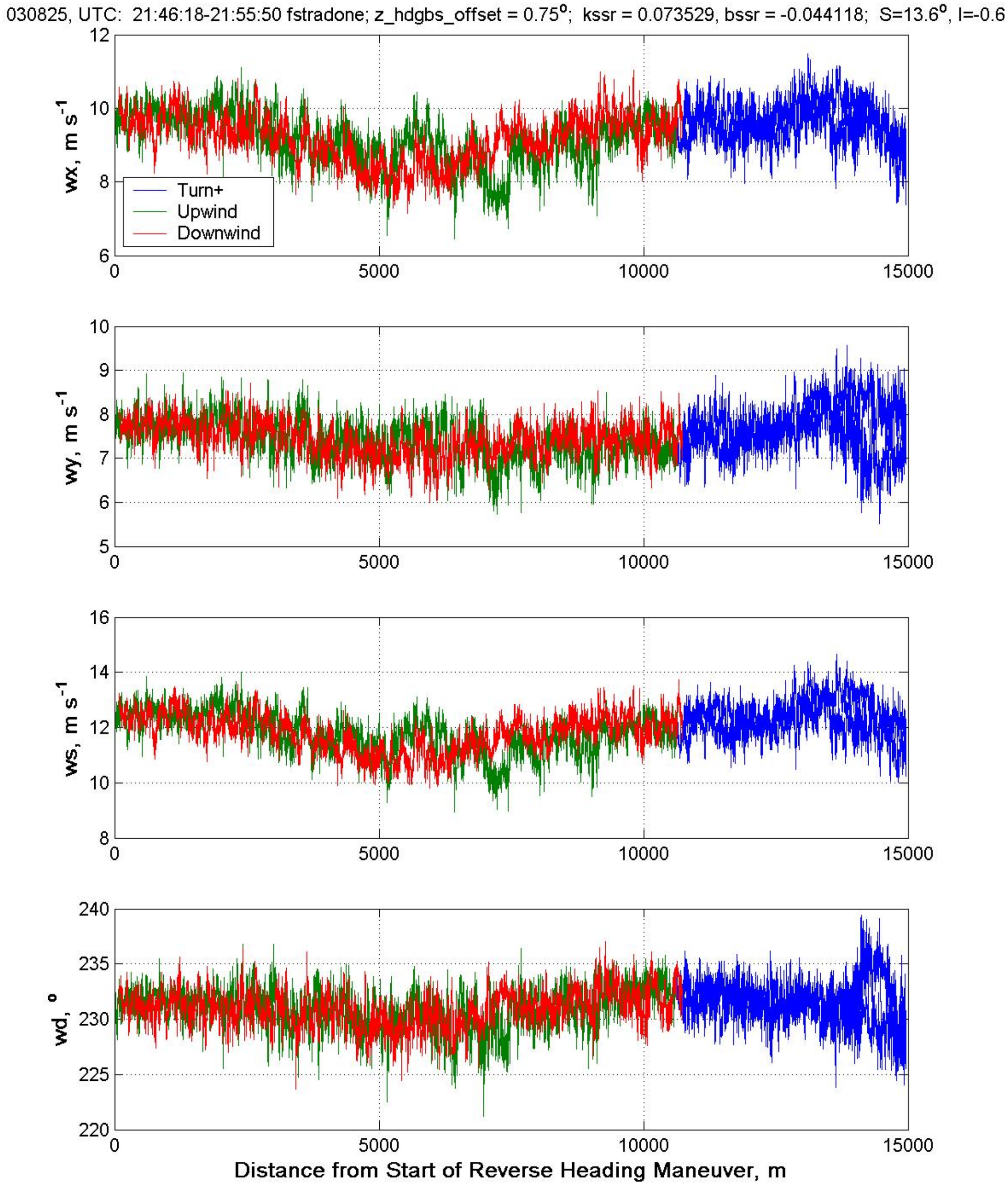

Figure 2 Reverse heading maneuver showing almost identical upwind (green) and downwind (red) traces of (from top to bottom) east, north wind components, wind speed and wind direction. These are plotted versus distance in meters from the location where the maneuver started. The blue section correspond to the 180^o (270^o Right / 90^o Left) turn.

Figure 2 shows the reverse heading "test" on the horizontal wind. If no errors are present in the angle of sideslip and true airspeed measurements the east and north components of the wind (as well as wind speed and wind direction) are conserved after the 180^o about turn of the aircraft. To a reasonable extent this seems to be the case for the data shown.

CARMA: The third field phase of CARMA took place off Monterey Bay in August 2005. A total of 17 research flights were flown. Flight patterns were tailored to mission objectives witch ranged from high winds far offshore to aerosol gradient to rift formation. Figure 3 shows the 2-D tracks for all 17 flights. UCI turbulence instrumentation and data system performed well and there were no failure for the whole duration of the project. Due to the C-MIGITS II problems experienced in last year's CARMA II, we logged data this time from the newer C-MIGITS III (on loan from CIRPAS) which incorporates the state of the art technology of integrated GPS/INS systems. Prior to the experiment, we made substantial modifications and improvements to our LabView-based data acquisition and real time onboard display software to comply with data format of the C-MIGITS III. The 12-channel GPS receiver on the new unit (compared to the 5-channel receiver on its C-MIGITS II predecessor) has significantly improved its performance. The analysis of the turbulence data from previous CARMA flights has focused on runs in and around clouds since understanding cloud processing of aerosol is the main scientific goal of the experiment. Results from the turbulence sensors were part of a co-authored paper with Dean Hegg as the lead author.

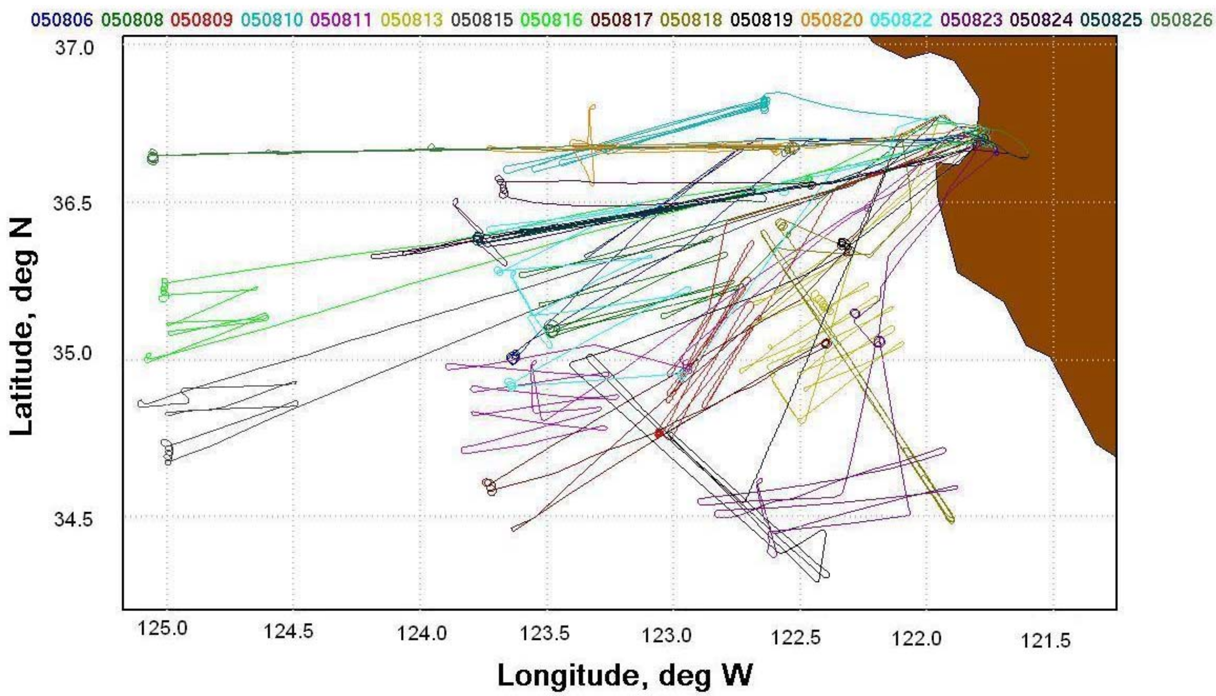

Figure 3 CARMA III tracks from all 17 research flights in August 2005

RESULTS

CBLAST-Low

Results of CBLAST-Low 2003 air-sea interaction measurements from a newly instrumented small aircraft seem to capture unique features of the study area. One of the findings is the highly non-homogeneous SST which exhibited gradients of up to 6 ^{o}C at edges of cool water bands causing a reversal in the stability. These gradients are expected to affect the air-sea fluxes (Friehe et al. 1991).

An example of SST variability is given in Fig 4 where a 3 ^{o}C east-west gradient was observed on August 26, 2005. Because of the bathymetry and the ocean circulation in the research area just south of Martha's Vineyard, the variability patterns of SST do not linger in general more than a day. Farrar et al. (2004) attributed the small scale (10-500 m) variability in SST signals observed under low winds are to oceanic internal waves.

On some of the days when the Pelican flew twice it was possible to detect significant differences in the SST variability between morning and afternoon.

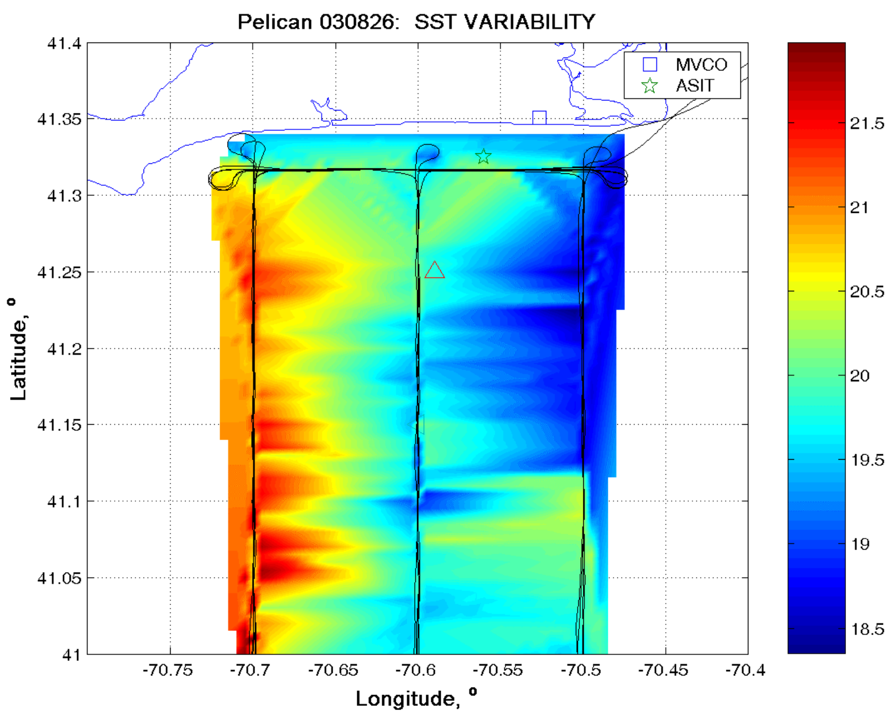

Figure 4 Variability of radiometric SST obtained by CIRPAS Pelican 2 aircraft in CBLAST-Low on August 26, 2003.

Estimates of the sensible heat fluxes along the 30-m flight tracks were interpolated to "map" the variability of the sensible heat flux. Such a map is shown in Fig. 5 corresponding to the same flight of August 26, 2005. In general, the pattern observed on the SST map is similar to that of the sensible heat flux.

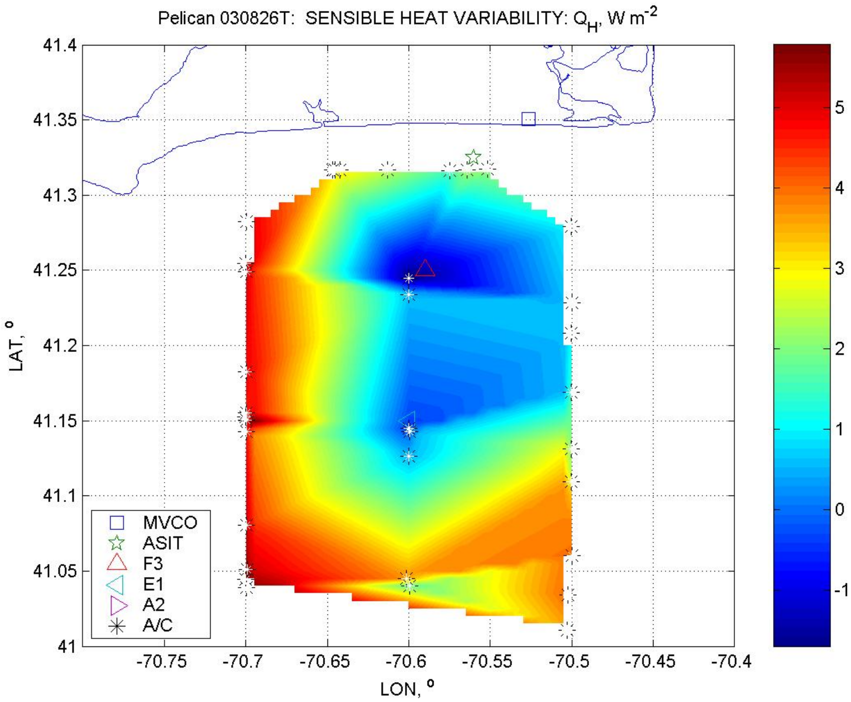

Figure 5 Sensible heat flux (W m^{-2}) obtained by CIRPAS Pelican 2 aircraft in CBLAST-Low on August 26, 2003. **CARMA**

The central coast of California boundary layer is characterized in the summertime by persistent marine stratocumulus deck few hundred meters thick with often well-defined strong inversions. The analysis of turbulence data from runs near and in clouds combined with data, our collaborator in this effort, Dean Hegg of the University of Washington, has shown that aerosol light-scattering efficiency of detraining air is significantly greater than that of non-detraining air. This suggests that cloud processing increases the aerosol light-scattering efficiency as hypothesized by Lelieveld and Heintzenberg (1992). Dean Hegg is the lead author on a Tellus paper (Hegg et al. 2004) detailing this important CARMA-I finding.

As mentioned above we used the newest integrated GPS/INS unit C-MIGITS III from Systron Donner in CARMA III this summer. Because of the greater number of satellites this unit can track, there were no GPS dropouts and the accuracy was significantly improved. A summary of the performance of the unit is shown in Fig. 6 for the flight on August 26, 2005. The expected errors in vertical and horizontal position and velocity were roughly 0.5 m and 0.2 m s^{-1} respectively. These errors are roughly 20 and 4 times less for position and velocity respectively compared to the errors of the older C-MIGITS II unit we used in previous projects. This should improve further the quality of the wind measurements.

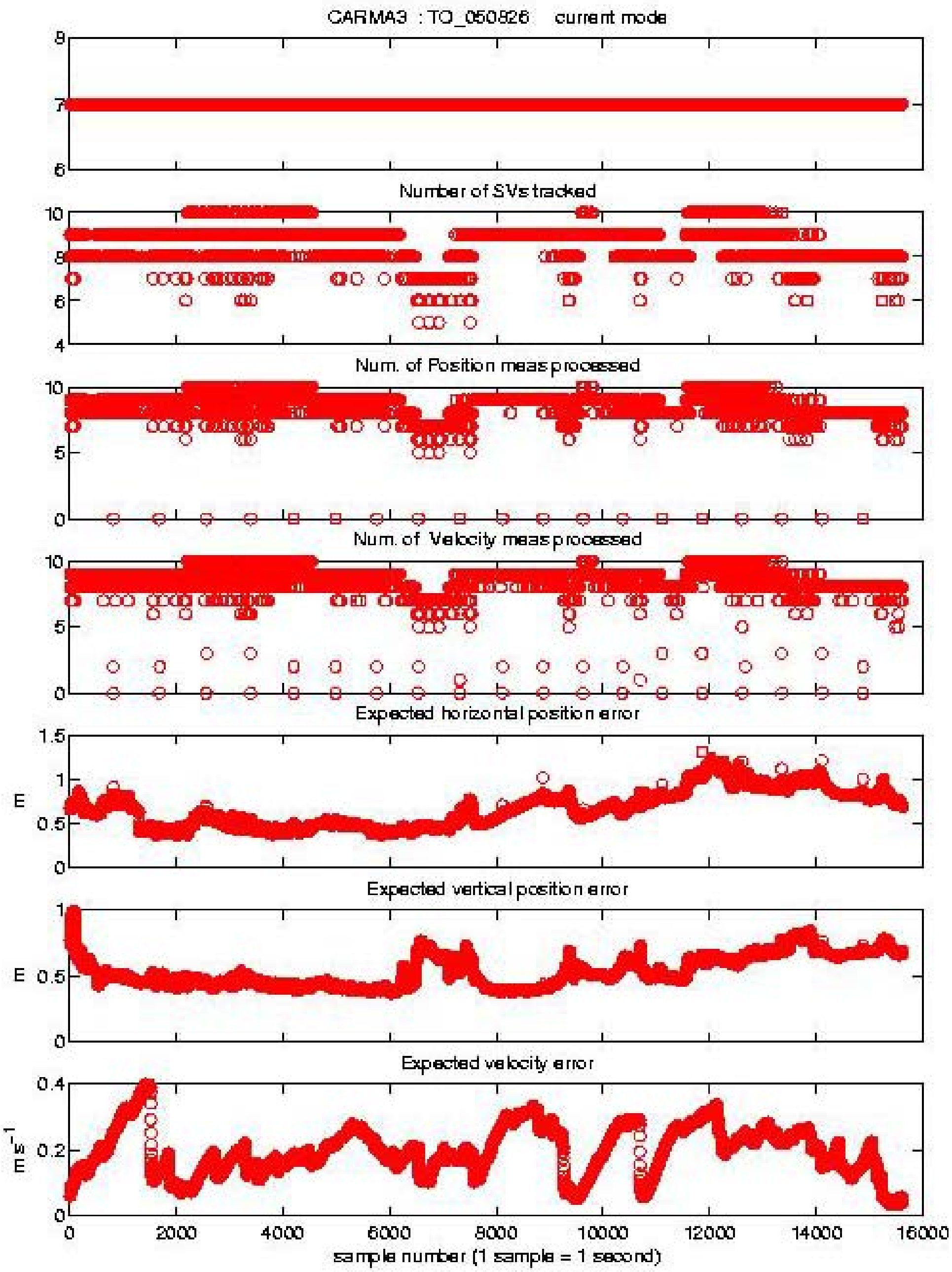

Figure 6. C-MIGITS III performance. From bottom to top: expected velocity, horizontal and vertical position errors, number of velocity and position measurements used, number of satellites tracks and the value 7 on the top plot indicate air navigation mode.

The CIRPAS Twin Otter has a new 5-hole radome system with nylon fittings so that the weather radar (which is required now for safe operation of the aircraft) can function properly. After careful inspection, we determined that the position of the 5 pressure holes on the new radome is slightly different from the configuration on the older radome we installed on this aircraft for our Japan/East Sea project in the winter of 2000. Because of these differences it is required the radome system be calibrated. Special pitching, yawing and reverse heading calibration maneuvers were flown for this purpose during CARMA III. We are in the process of performing these calibrations using data from these maneuvers as well as data from many level runs as described in Khelif et al ., 1999.

IMPACT/APPLICATIONS

The combination of aircraft state of the art aerosol and turbulence instruments in CARMA-I and II is giving us new insight in the role of cloud processing on aerosol light-scattering efficiency. The high-quality turbulence and meteorological aircraft data obtained during CBLAST-Low provided good spatial (both horizontal and vertical) coverage of the CBLAST research area and captured many unique events such as the switch from stable to instable conditions across SST fronts. Their analysis is helping us improve our understanding of the air-sea interaction mechanisms especially the complex case of stable boundary layer over very variable SST filed. The data will also be very useful for mesoscale models such as COAMPS (collaboration with Prof. Qing Wang of NPS) and LES models (collaboration with Peter Sullivan, NCAR).

TRANSITIONS

The CIRPAS Pelican aircraft has a new capability with the turbulence instrumentation package we installed for CBLAST-Low. The operation of this single engine, single pilot aircraft is significantly more cost effective compared to a lager aircraft and still it can fly for over 5 hours on a research flight.

The LI-COR 7500 fast humidity sensor is proving to be a good candidate to replace the obsolete Lyman alphas. We hope to work in the near future on the design of a special housing that will prevent its windows from getting wet when probing through clouds or precipitation.

CIRPAS has been using our calibration equations for the Twin Otter radome system. We expect CIRPAS to do the same once we determine the equations for the new radome system.

RELATED PROJECT

The summer 2001 data from the CIRPAS Twin Otter are part of Rough Evaporation Duct (RED) experiment (http://sunspot.spawar.navy.mil/red/). The summer 2003 Pelican data are part of CBLAST-Low (http://www.whoi.edu/science/AOPE/dept/CBLAST/lowwind.html).

We are involved in the Gulf Of Tehuantepec Experiment (GOTEX) where we used the NCAR C130 to study the air-sea interaction under strong gap winds conditions. We are in the process of comparing our findings from our ONR-funded JES cold air outbreaks experiment to those of GOTEX. The URL for GOTEX is http://raf.atd.ucar.edu/Projects/GOTEX/docsum.html)

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