

# **UMass Participation in Air-Sea Flux Estimation of High-Wind Boundary Layers**

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## **LONG -TERM GOALS**

Our goals are to contribute to the understanding of the upper ocean and lower atmosphere through the development and application of microwave remote sensing techniques, as well as provide extensive datasets to foster research.

## **OBJECTIVES**

The objective of this work is to measure profiles of 3-D vector winds and precipitation in tropical storm and hurricane boundary layers from the NOAA WP-3D aircraft. These data will help us characterize the atmospheric boundary layer (ABL) and its fluxes in extreme conditions.

## **APPROACH**

The Imaging Wind and Rain Airborne Profiler (IWRAP) is a downward-looking conically-scanning Ku-band and C-band radar which measures profiles at 30 m range resolution. During rain, the aircraft's motion along with the downward-looking conically-scanning geometry allows for the measurement of continuous 3-D wind vectors, as well as the effective reflectivity Z of the rain. Using scatterometry, surface backscatter provides the surface wind vector. The UMass Simultaneous Frequency Microwave Radiometer (USFMR) measures surface wind speed and integrated rain rate which provide provide crucial independent measurements in the extreme conditions found in hurricane boundary layers.

## **WORK COMPLETED**

IWRAP and USFMR were flown aboard the NOAA WP-3D aircraft during the 2003, 2004, and 2005 hurricane seasons. Development of IWRAP was completed prior to the 2003 hurricane season. A new, higher power RF amplifier at Ku-band was integrated for the 2004 hurricane season. The system was also configured to work at two simultaneous incidence angles (approximately 30 and 40 degrees incidence) with a pulse repetition frequency (PRF) of 40 KHz, therefore doubling the standard PRF used in the 2003 hurricane season. For the 2005 hurricane season, the capability of measuring 50 degrees incidence angle was added to increase the sensitivity of IWRAP as a scatterometer and to better match the geometry of the QuikSCAT scatterometer. The PRF was reduced to 20 KHz to enable greater range resolution, thus greater flight altitude. An important addition to the 2005 effort was the development and implementation of raw data acquisition by Drs Paul Chang and Daniel Esteban from NOAA NESDIS. The raw data allows the calculation of Doppler spectra and thereby characterization the lowest few hundred meters of the atmosphere. Collaboration with Drs Chang and Esteban will allow us to reanalyze the data and characterize boundary layer winds much more accurately.

# Report Documentation Page

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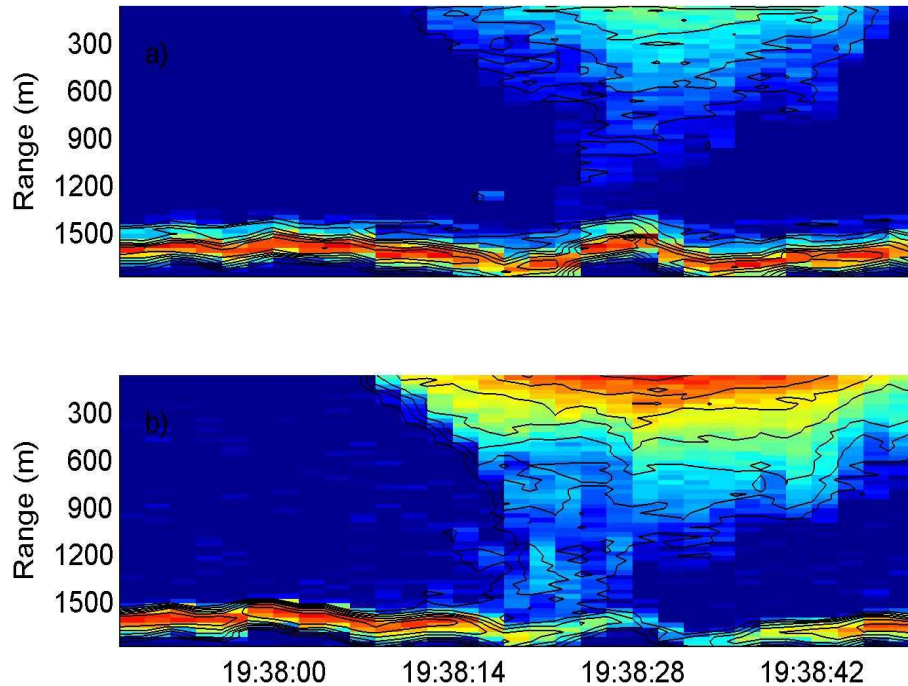
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*Table 1 Description of flights for the 2005 hurricane season. [Hurricane Ophelia was sampled during its evolution from tropical depression to category 1 hurricane. Rita was sampled as a category 4 an 5 hurricane.]*

| <b>Flight</b> | <b>Date</b> | <b>Description</b>      | <b>Program</b> | <b>Conditions</b>   |
|---------------|-------------|-------------------------|----------------|---------------------|
| 1             | 08/30/05    | Test/calibration flight | Ocean Winds    |                     |
| 2             | 09/06/05    | TD 16                   | Ocean Winds    | Tropical depression |
| 3             | 09/07/05    | Ophelia                 | Ocean Winds    | Tropical storm      |
| 4             | 09/08/05    | Ophelia                 | Ocean Winds    | Category 1          |
| 5             | 09/11/05    | Ophelia                 | Ocean Winds    | Category 1          |
| 6             | 09/12/05    | Ophelia                 | Ocean Winds    | Tropical Storm      |
| 7             | 09/22/05    | Rita                    | Ocean Winds    | Category 5          |
| 8             | 09/23/05    | Rita                    | Ocean Winds    | Category 4          |
| 9             | 09/28/05    | Test/calibration flight | Ocean Winds    |                     |

During 2005, missions through tropical storm/hurricane Ophelia and hurricane Rita were flown (Table 1). Ophelia evolved into a category 1 hurricane and provided data suitable for the investigation of a high-wind boundary layer. Hurricane Rita was a category 4 and 5 storm that provided copious data at extreme wind speeds. Figure 1 shows uncalibrated power profiles for an incidence angle of 30° at a) C-band and b) Ku-band as the aircraft transected a rain band in hurricane Rita. These data were measured one week ago. The areas of high return at about 1600 meters are backscatter from the ocean surface at a cross-track azimuth angle. The undulations in the range of surface backscatter are the result of the aircrafts motion changing the instantaneous incidence angle and distance from the surface. It is evident in the figure that Ku-band backscatter is heavily attenuated by rain while C-band is not. This difference at Ku-and C-band will be used to accurately profile rain in the atmosphere. As was done with the 2003 data, 2004 and 2005 data will be processed to give profiles of vector winds and the effective reflectivity factor Z. Special attention being paid to the correction of attenuation.

Hurricane Rita, Sept. 22 2005

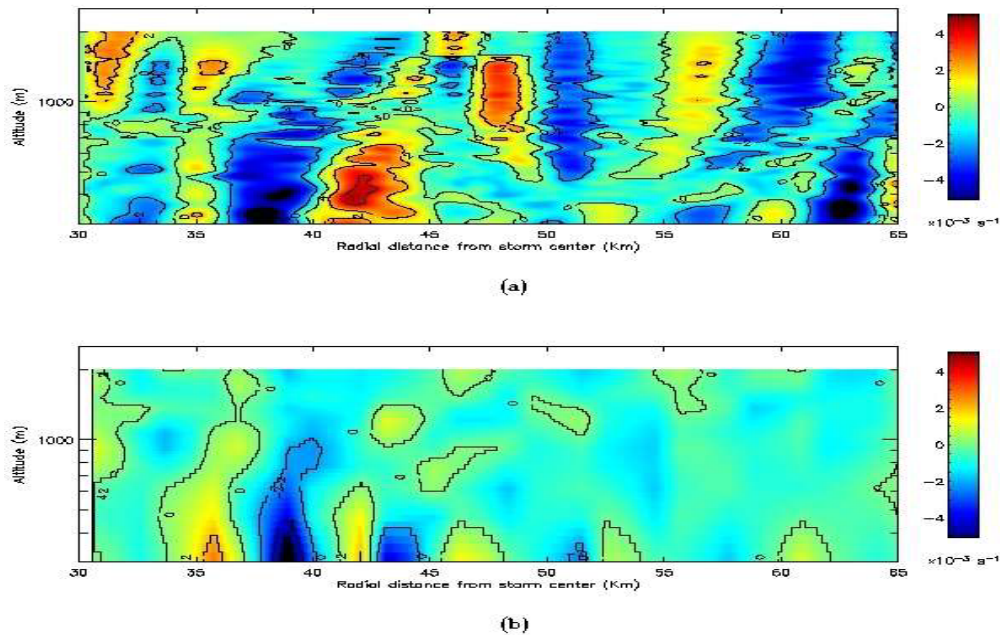


*Figure 1a) C-band and b) Ku-band uncalibrated power during a transects through Hurricane Rita. [Ku-band is sensitive to rain but also attenuated. C-band samples rain but is attenuated little.]*

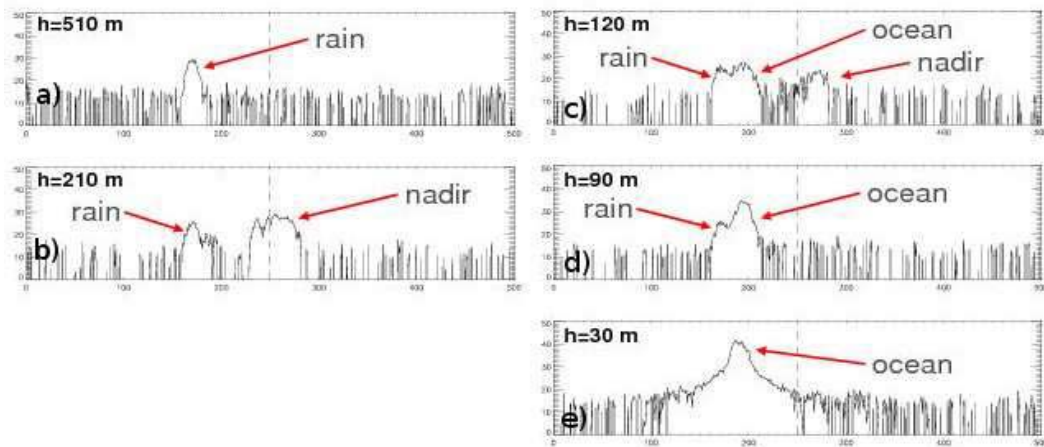
## RESULTS

For the past three hurricane seasons IWRAP has operated very well and provided high resolution profiles of the ABL in extreme conditions. For the 2003 hurricane season, vector winds were computed and from these vertical vorticity and divergence. Figure 2 shows the vorticity from an inbound leg into Hurricane Isabel. Here the vorticity computed from a) IWRAP is compared to that from the b) WP-3D's tail radar. It is evident in the figure that kilometer scale variability ubiquitous in hurricane boundary layers and IWRAP is able to resolve structures in the ABL very effectively.

Collaboration with Drs Chang and Esteban has produced, for the first time, profiles of complete Doppler spectra. The power of this technique lies in its ability to separate relative contributions to scattering when there are scatterers moving at fundamentally different velocities. Figure 3 illustrates this. As can be seen from the figure, the relative contribution to the total backscatter changes with altitude, as does the Doppler shift of the scatterers. This has typically provided an obstacle to interpreting radar data which consist of only the first two or three Doppler moments of the spectra.



**Figure 2** Vertical vorticity calculated from a) IWRAP and b) the NOAA WP 3D tail radar. (from Esteban et al. 2005) [IWRAP resolves high spatial variability in the vorticity.]



**Figure 3** Doppler Spectra of an IWRAP profile at individual range gates. [Backscatter from rain and the ocean surface are visible in multiple range gates]

## IMPACT/APPLICATIONS

Data from the 2003 hurricane season have shown extremely high winds to be common in major hurricanes and provided the basis for development of new geophysical model functions to interpret QuikSCAT measurements.

The multi-year IWRAP dataset provides an unprecedented look at the ABL during tropical storms and hurricanes. UMass will work with its CBLAST partners to use these data to further the understanding of the ABL and its air-sea transfer under very strong wind forcing.

## TRANSITIONS

## RELATED PROJECTS

## PUBLICATIONS

Esteban Fernandez, D., Kerr, E., Castells, A., Frasier, S., Carswell, J., Chang, P., Black, P., Marks, F., IWRAP: the Imaging Wind and Rain Airborne Profiler for Remote Sensing of the Ocean and the Atmospheric Boundary Layer within Tropical Cyclones", *IEEE Trans. Geosci. & Rem. Sensing* [in press].

Esteban Fernandez, D., Frasier, S., Carswell, J., Chang, P., Black, P., Marks, F., Dual-polarized C-and Ku-band Ocean Backscatter Response to Hurricane Force Winds", *J. Geophys. Res.* [submitted]

Esteban, D., Zhang, X., Castells, A., Carswell, J. et al., The Imaging Wind and Rain Airborne Profiler - A Dual Frequency Dual Polarized Conically Scanning Airborne Profiling Radar", *Proc. IEEE Geosci. & Rem. Sensing Symposium (IGARSS 2003)*, Toulouse, France, July 21-25.

Esteban, D., Zhang, X., Castells, A., Carswell, J. et al., Hurricane Wind and Rain MEasurements Using a Dual Polarized C/Ku-band Airborne Radar Profiler, *Proc. IEEE Geosci. & Rem. Sensing Symposium (IGARSS 2003)*, Toulouse, France, July 21-25.