P1.66 DEVELOPMENT AND INITIAL DEPLOYMENT OF AN OMNIDIRECTIONAL PRESSURE-SPHERE ANEMOMETER FOR OBSERVING WINDS AND TURBULENCE IN TROPICAL CYCLONES

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1. INTRODUCTION

Turbulent exchanges of heat and momentum between the atmosphere and the earth's surface are a primary driving factor in the intensification and decline of tropical cyclones. However, the extreme environment associated with these tropical systems makes it difficult to reliably measure turbulence and surface fluxes with standard ground-based instruments. The NOAA Air Resources Laboratory (ARL) is developing a tower-mounted Extreme Turbulence (ET) probe capable of operating in the high winds and precipitation associated with tropical systems.

The ET probe is based on pressure-sphere anemometry, which has been used for many years to measure turbulence quantities from aircraft (Brown et al. 1983; Crawford and Dobosy 1992). On aircraft, these anemometers are routinely operated at airspeeds of 50–120 m s^{-1}, which correspond to category 3–5 hurricanes on the Saffir-Simpson scale. A ground-based anemometer of this design should therefore have no difficulty operating in hurricane-force winds.

2. INSTRUMENT DESIGN

Pressure-sphere anemometers use a series of differential pressure sensors that are connected to holes distributed over a smooth spherical surface. The magnitude and direction of the incident airflow can be computed from the pressure distribution over the sphere as sensed at these holes. On an aircraft, only a partial sphere pointing forward is required, since the direction of the incident airflow has a limited range. The ET probe must be omnidirectional, so it is designed around a 43 cm diameter sphere made from fiberglass-epoxy composite (Fig. 1). Ten pressure holes are located on the sphere's equator at 36° intervals. Two other rows of holes are located 18° above and below the equator. Additionally, two temperature sensors are located in a small "mushroom" housing on top of the sphere.

Data from the ET probe are collected by a nearby computer. Raw pressure and temperature data are first digitized at 50 Hz. The processing software then uses the pressure data to search for the location of the wind's stagnation point on the sphere. Data from the pressure sensors closest to the stagnation point are used to compute a 50 Hz time series of the ambient wind-vector components (u, v, w).

Figure 1: Photograph from September 2003 showing the ET probe deployed in Beaufort, NC for Hurricane Isabel. The white ET sphere is mounted on an aluminum tripod.

ARL has also developed an ET probe deployment kit that can withstand hurricane winds and keep the electronics dry. The kit must be easily portable and quick to set up. As shown in Fig. 1, the probe is deployed on a 3 m high tripod made from aluminum tubing. The tripod is held in place by a combination of 76 cm screw anchors and heavy ballast located at the tripod legs. The computer and battery power source are located in the enclosure at the base of the tower.

The probe's pressure holes are susceptible to being fouled by rain or spray, so the final probe design must eliminate or at least mitigate this problem. As discussed in Section 5, this problem is still under active investigation.

3. TESTING

Field tests of the ET probe were conducted in 2002 and 2003. Many of the initial tests were conducted with a probe mounted on a vehicle, allowing the probe to be tested at highway speeds up to 30–40 m s^{-1}. A cup

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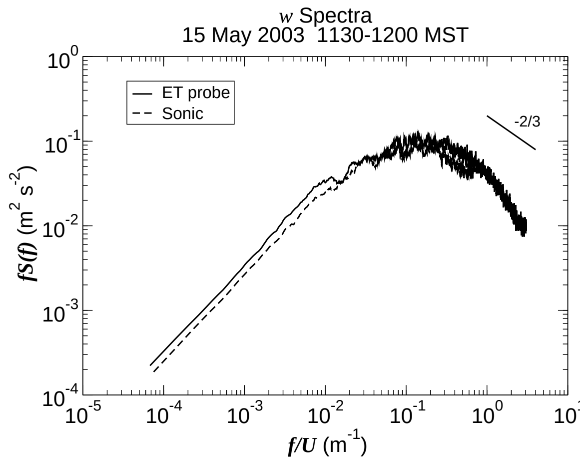

Figure 2: Comparison of ET probe and sonic anemometer power spectra for the vertical velocity component. f is the frequency, $S(f)$ is the spectrum, and U is the mean wind speed.

anemometer was mounted beside the probe for comparisons. The wind speeds from the ET probe matched the cup anemometer closely in the road tests, except in a few cases when crosswinds put the cup anemometer in the wake of the vertical shaft used to mount the ET probe on the vehicle. Pressure spheres do not work properly in light winds, when the dynamic pressure fluctuations become too small to easily detect. The road tests indicated that wind speeds of about 5–10 m s^{-1} are required before the ET probe begins to operate properly.

Plans were also in place to operate an ET probe next to an existing sonic anemometer operated by ARL in Idaho, but the normally reliable springtime windy conditions in Idaho failed to materialize in 2003. One such test was performed on 15 May 2003. The mean winds were 8–15 m s^{-1} during the test, which is marginal for proper operation of the probe. Figure 2 shows an example of power spectra for the vertical velocity component for both the ET probe and the sonic. These spectra were derived from half-hour time series beginning at 1130 LST. The ET probe was higher above the ground than the sonic (3 versus 2 m AGL), which may explain why the probe's spectrum is slightly above the sonic's. At high frequencies the ET spectrum has a slope steeper than the -2/3 slope expected from inertial-subrange theory. This may be related to the wind speeds being only marginally strong enough for operating the ET probe.

4. ISABEL DEPLOYMENT

The first hurricane deployment of an ET probe occurred in 2003 with Hurricane Isabel. On 16 September 2003, a three-person crew from ARL traveled to North Carolina to deploy 2 ET probes near the coast in the path of the hurricane. One of the probes was installed at the airport in Beaufort, NC—near the coast to where the hurricane's eye was expected to make landfall. The second ET probe was significantly damaged during shipment; it could not be repaired in time for deployment. The eye of Isabel made landfall on 18 September just to the north of the ET probe at Beaufort.

The Beaufort probe was retrieved on 19 September with no significant damage. The data acquisition system operated without interruption for over 36 hours, producing about 1.2 Gbytes of 50 Hz data. Overall, the Isabel deployment provided ARL with valuable experience in the logistics of a hurricane deployment, and demonstrated that the instrument and deployment kit could stand up to a category 3 hurricane.

5. ONGOING DEVELOPMENT

A major issue remaining with the ET probe is the development of hardware modifications to eliminate or reduce water fouling of the pressure holes. The original plan was to have the modifications ready for the 2003 hurricane season, but program funding delays forced a postponement. Thus, the probe deployed in Isabel did not have such modifications. Two different approaches are under investigation. The first one is a passive approach that uses gravity to help drain out larger-diameter plastic tubing within the probe. The second is an active approach that uses an air pump to backflush the tubing. Both approaches have their problems, and further testing will be required to determine whether either approach provides satisfactory results.

6. ACKNOWLEDGMENTS

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