「The Sea」 Journal of the Korean Society of Oceanography
Vol. 9, No. 3, pp. 130 — 136, August 2004

Performance of Minimet Wind Drifters in Hurricane *Fabian*

PETER NIILER, WILLIAM SCUBA AND DONG-KYU LEE*
Scripps Institution of Oceanography, La Jolla, California 92093, U.S.A.
**Busan National University, Busan 609-735, Korea*

In September 2003 wind-measuring drifters were air-deployed in front of the projected path of Hurricane *Fabian* from an altitude between 300 m and 400 m. Eight drifters transmitted wind, air pressure and SST data through ARGOS and three drifters were within 35 km of the hurricane center. Measurements of the air pressure in the eye of the hurricane by dropsondes, suggested the air pressure at the eye was between 939 hPa and 944 hPa. The lowest pressure measured by a Minimet was 943 hPa at 33 km from the hurricane center. *Fabian* cooled the SST at its center from 28.9℃ to 26.8 ℃. After the passage of *Fabian*, SST warmed to between 27.5℃ and 28.5℃ in 7 days.

Key words: Hurricane, Wind-drifter

Introduction

Since 1996 wind drifters have been deployed in tropical ocean areas where hurricanes tend to develop in strength or approach landfall. Projection of winds from NCEP reanalysis wind data on these drifters has revealed that the 133 wind drifters whose data appeared on the Global Telecommunication System (GTS) in 1999, 2001 and 2002, no wind drifter south of 30N in the Atlantic experienced winds in excess of 27 m/sec. Typically, drifters were deployed in the general hurricane development area at the start of the hurricane season and simply hurricanes missed these drifters. Several other targeted instrument deployments have been done in front of specific hurricanes (Sanford *et al.* 1987; Shay *et al.* 1992; DAsaro, 2003) but these involved profiling or neutrally buoyant floats. We report on the methodology of deployment of surface drifting buoys and the quality of the data transmitted from them. To deploy wind-drifters in front of targeted hurricanes, operational air-deployment packages were developed. These were tested and approved for operational deployments by the "Hurricane Hunter "C-130-J 53rd Air Force Reserve. On September 3, 2003, 11 Minimet drifters (Milliff *et al.*, 2003) were successfully deployed at a distance about 18 hours in front of the projected path of a category-4 hurricane, *Fabian*, in the vicinity of 25N, 65W.

Over the past 30 years the methods for predicting the track of a hurricane have improved, however the ocean/atmosphere processes that determine a hurricanes intensity are not as well understood. One of the reasons for this is that there is a lack of data at and below the sea surface. At the current time, there is no operational method available to reliably deploy drifters in front of the projected path of a hurricane to obtain these data.

This paper describes the air deployment scheme used to drop 8 containers, containing 16 Minimets in the path of hurricane *Fabian*, in the tropical Atlantic Ocean, and displays the data time series received from these drifters. In total 8 Minimet drifters recorded ambient noise (wind speed) and wind direction, SST, atmospheric pressure, and drifter positions throughout the passage of *Fabian* over the drifter array. Based on this unique, but limited data set, recommendations are made for continued research and operational deployments of drifters into hurricanes from operational C-130-J, or other aircraft.

Drifter and Air Deployment Package

The drifters used in the experiment were Digital Minimet drifters manufactured by Pacific Gyre, Inc. (Fig. 1) that included a barometer, thermistor, drogue-on sensor, wind speed sensor (hydrophone/ambient noise sensor) and wind direction sensor (compass and wind vane).

The air deployment package consisted of a 100 cm × 100 cm × 100 cm cardboard container, in which 2 Minimets were stacked one on top of the other. Each Minimet was individually packaged in a cardboard container (Figs. 2 and 3). A third smaller cardboard box encased the drogue. This smaller box had a hole cut in its top to allow room for a protrusion of the tether that attached the drogue to the surface float. An outer cardboard sleeve, or wrap, with 5 sides was used to cover the two Minimet boxes and served to hold them in place on a wooden pallet. A slit was cut down one corner of this outer box to allow for its rapid disintegration once the entire package was in the water. All of the cardboard boxes were held together with water-soluble paper tape, which

*Corresponding author: lee@makaha.ucsd.edu

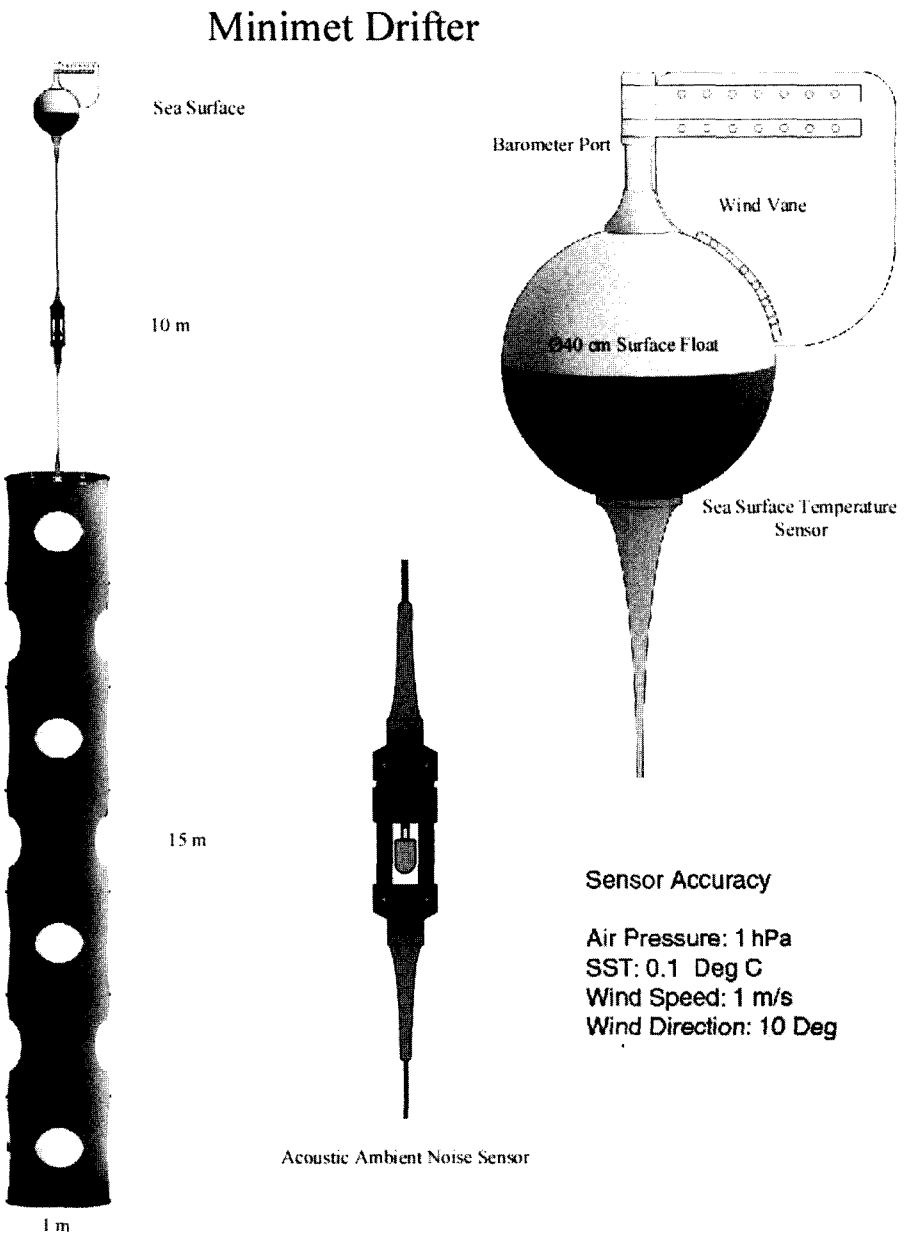

Fig. 1. Schematic of Minimet drifter. The ambient noise sensor is used to measure sea surface wind speed.

quickly dissolved in sea-water. The deployment package of three layers of cardboard was designed so the cardboard wrap came apart first, allowing the two inner boxes that each contained a float and the drogue to separate from each other before these dissolved. To keep the drogues from entangling, the boxes that contained the drogues were the last to dissolve.

The cardboard containers were placed on top of a specially designed wooden pallet. Blocks of wood around the corners of the top of the pallet kept the container laterally secure during the air deployment, as during deployment into the air-stream there can be a large sideways force on the container. These wooden blocks and the straps running up all four sides of the container were designed to keep the container from coming off the pallet during its decent to the ocean.

One end of each strap was attached to a C-9 military personnel parachute on top of the box and the other end was secured to the pallet using salt blocks. On the salt block end of the straps were loops that passed through slots on all 4 sides of the pallet. A 7.5 cm × 1.75 cm × 1.75 cm salt block, cut with a band saw from horse-lick salt, was inserted through each loop and was then wrapped with water-soluble tape to secure it during deployment. The salt blocks prevent the straps from pulling back through the slots during the parachute decent to the ocean. Upon contact with the sea-water, the salt blocks dissolve, releasing the parachute from the pallet.

This deployment scheme of multiple cardboard containers, attached to a parachute rigging via a pallet, was tested in

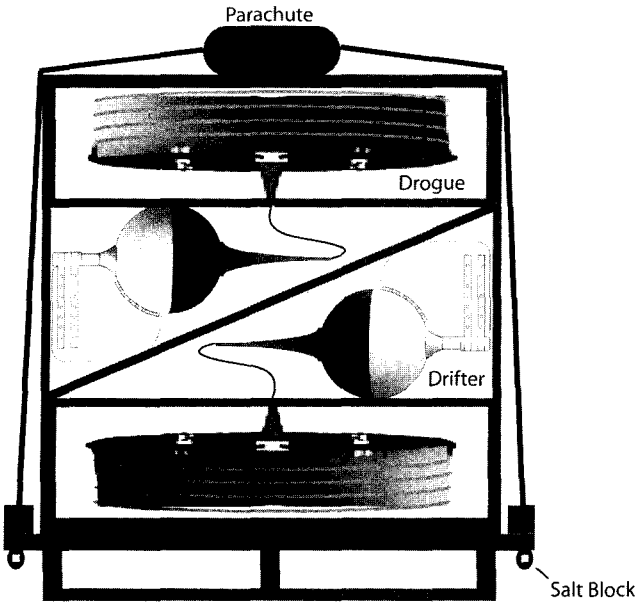

Fig. 2. Schematic drawing of the drifter with attached drogue in the air deployment container.

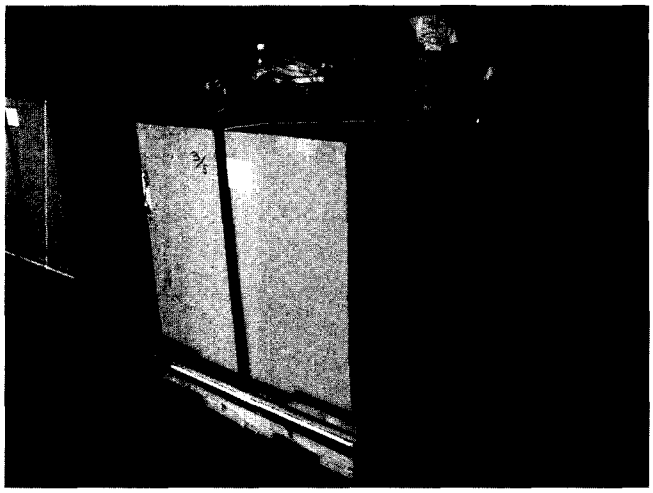

Fig. 3. Box containing two Minimet drifters on top of pallet. Wooden deployment pallet is sitting on top of a shipping pallet that is removed before deployment.

15°C, 1 m high seas off the coast of San Diego with deployment from a small vessel. After the test container with the parachute open was placed into the sea, the salt blocks dissolved in about 20 minutes. The individual drifters deployed successfully in about 40 minutes. More rapid disintegration is expected in higher waves.

The deployment scheme from C-130-J aircraft was tested with 8 separate drops over land during training missions for the crews of the US Air Force Reserve 53rd Weather Reconnaissance Squadron, "Hurricane Hunters", stationed at Keesler Air Force Base, Mississippi. During these tests, two "dummy" drifters were placed into the containers that simulated the weight distributions of the Minimets. During these test flights, 6 of the 8 containers deployed correctly. One parachute inverted during deployment, but the container landed safely. One cardboard container disintegrated during deployment because a weight that was used to simulate a drifter float came loose within the container and broke through the container walls, but the pallet with the parachute attached landed safely.

Hurricane Deployments

In early September, 2003 a Category 4 Hurricane, *Fabian,* was moving rapidly to the west-north west in the Atlantic north and east of Leeward Islands. Eight fully rigged containers with 2 Minimets in each container were loaded aboard a C-130-J at Keesler Air Force Base and the deployment flight commenced. The 8 containers were deployed in a two-line array approximately 18 hours in front of the projected path of *Fabian* at an altitude between 300 m and 400 m and between 20:00 and 24:00 local time (Fig. 4). The ground wind speed at the location of deployment was between 17 ms^{-1} and 22 ms^{-1} and the wave height was approximately 7 m.

Fabian first reached hurricane strength on 0000 UTC 30 August over the east-central tropical Atlantic. *Fabian* reached its estimated peak intensity of 65 m/s at 1800 UTC 1 September when it was centered about 490 km east-northeast of the northern Leeward Islands. It maintained Category 3 or Category 4 intensity on the Saffir-Simpson Hurricane Scale for almost a week.

Five Minimets did not transmit any data after the air deployments. Three more stopped transmitting data before the complete passage of the hurricane (~36 hours). The remaining eight drifters provided data through *Fabian* passage (Figs. 5 and 6). Three drifters came within 35 km of the hurricane center.

There are several explanations for the failure of the Minimets. Firstly, in the high winds (20 m/s) and waves (7 m), significant horizontal forces on the deployment can result as the container hits the water. During high winds the deployment container is moving horizontally at a large speed, as are waves that are breaking. The deceleration caused by the drifter package contacting the water can cause the two drifters to be forced into each other or into the wooden pallet with sufficient force to damage the electronics or their floats. Secondly, 4 containers were damaged during shipment to Keesler Air Force Base by being stacked on top of each other. These containers were repaired, but they still might not have had sufficient integrity to survive insertion from the C-130-J into the air stream. In the damaged containers, 3 out of the 8 Minimets survived the hurricane. In the undamaged

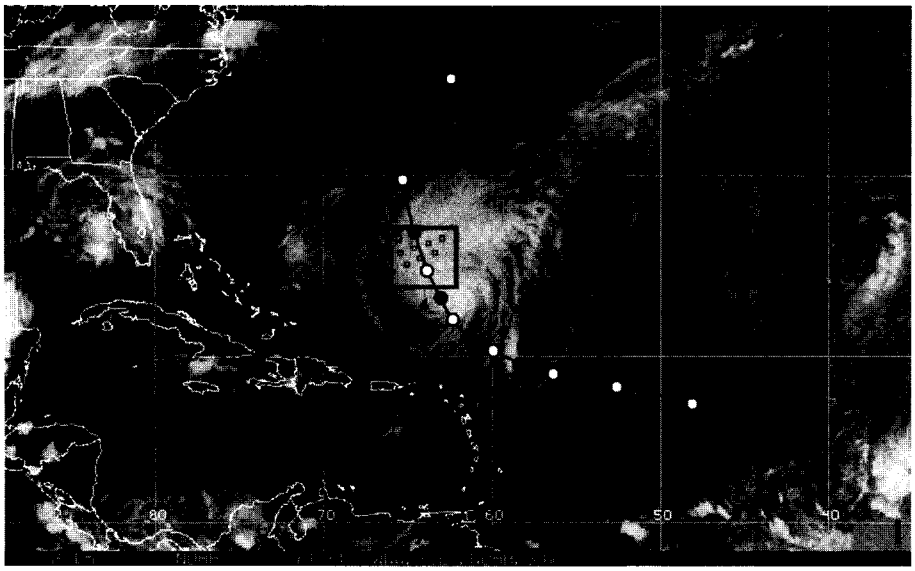

Fig. 4. Initial location of the 8 containers and the center track of *Fabian*. The numbers on the hurricane track indicate the calendar day *Fabian* was at the location starting on August 30 and ending on September 7. The containers were deployed on September 4th.

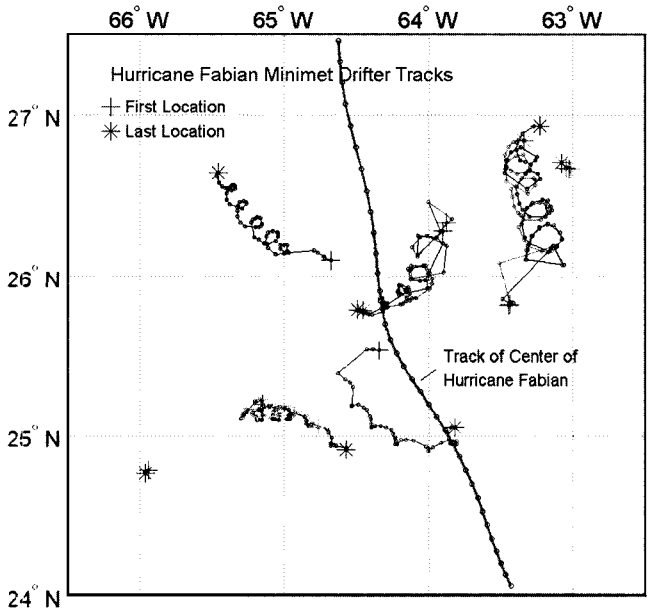

Fig. 5. Position of drifters from September 4, 2003 to September 10, 2004. Hurricane *Fabian* passed over on September 4 and 5. The track of *Fabian* runs northward through the image with large dot placed at 30 minute intervals. The hurricane path is interpolated from 6 hour interval data from NOAA.

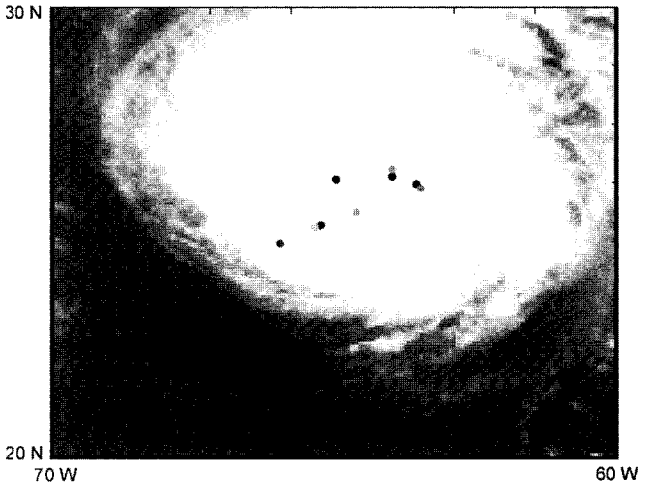

Fig. 6. Locations of the drifters at their closest position to the center of hurricane *Fabian*. The image was taken on September 4th, 19:15 UTC.

containers, 5 out of the 8 Minimets survived the hurricane. Thirdly, one failed Minimet was recovered and two pin-holes were discovered in the epoxy that was used to seal the upper half of the drifter float to the lower half. Sufficient water had leaked into the float to short out the electronics but not sink the float.

Preliminary Findings

Analysis of the drifter wind direction data during the ~36 hours of the passage of *Fabian* revealed the expected cyclonic motion of the hurricane winds (Fig. 7). The speed of motion of the hurricane was fast as compared to that of the drifters so the wind direction data was obtained in lines, one per drifter, along the direction of motion of the hurricane.

The radially averaged wind direction relative to the distance from the center of the hurricane (Fig. 8) shows that from 35 km to 70 km from the center of the hurricane, the wind direction shifts from a slight outward slant to a slight inward slant. Between 70 and 300 km there is a relatively steady slightly inward slant. The inward slant of the wind direction then begins to increase again moving from 300 km to 500 km from the center of the hurricane. These multiple surface wind sensor observations through a hurricane passage are novel.

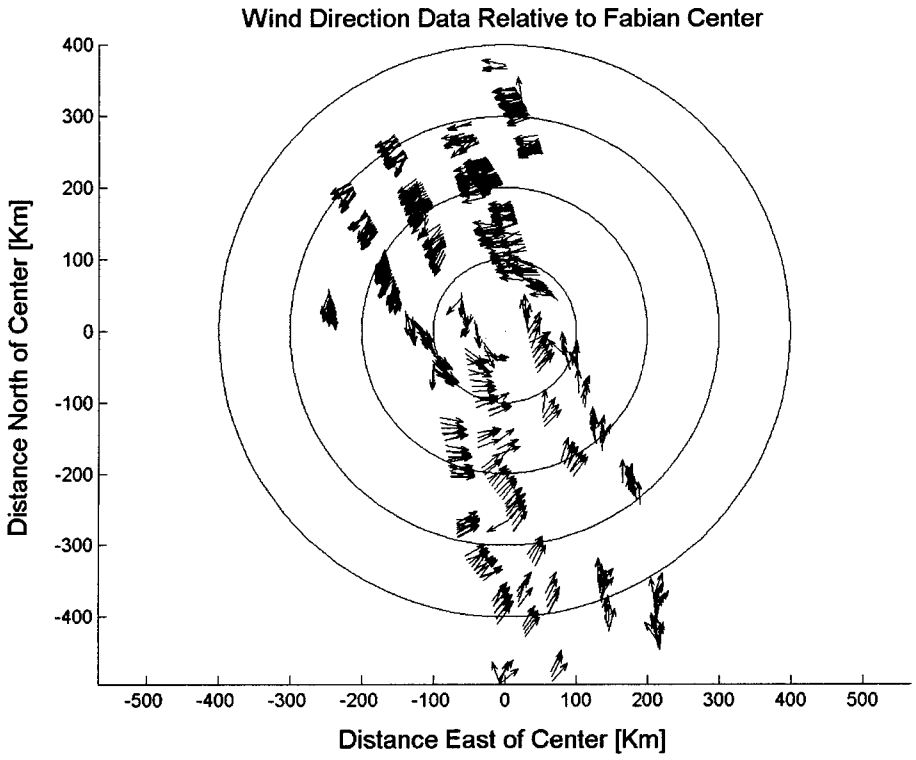

Fig. 7. Wind direction relative to the center of *Fabian* obtained from the deployed Minimet drifters. A circle is drawn every 100 km from the center. Arrows are an indication of wind direction only.

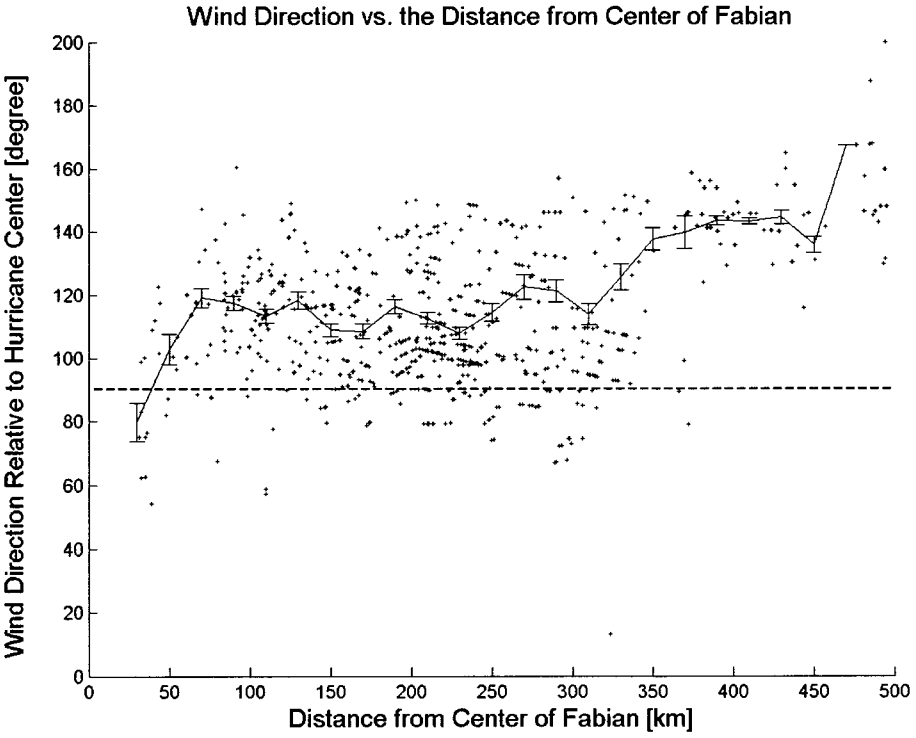

Fig. 8. Wind direction relative to the center of hurricane *Fabian*. An angle of 0 degrees corresponds to wind blowing directly away from the hurricane center with increasing angle in the counterclockwise direction. The dashed line corresponds to the 90 degree angle.

The most notable property of the motion of the drifters is the inertial circles (Fig. 5). Drifters on the right side of the hurricane display larger radius circles than on the left which indicates faster currents on the right side. This effect was observed in other hurricanes (Price, 1981) and is due to the counterclockwise cyclonic motion of the hurricane combining with the forward motion of the hurricane that produces a cyclonic rotation of the wind and a larger, more resonant generation of inertial currents there.

The air pressure at sea level decreases with distance to the center of the hurricane (Fig. 9). There were two air deployed dropsondes which measured the sea surface pressure in the

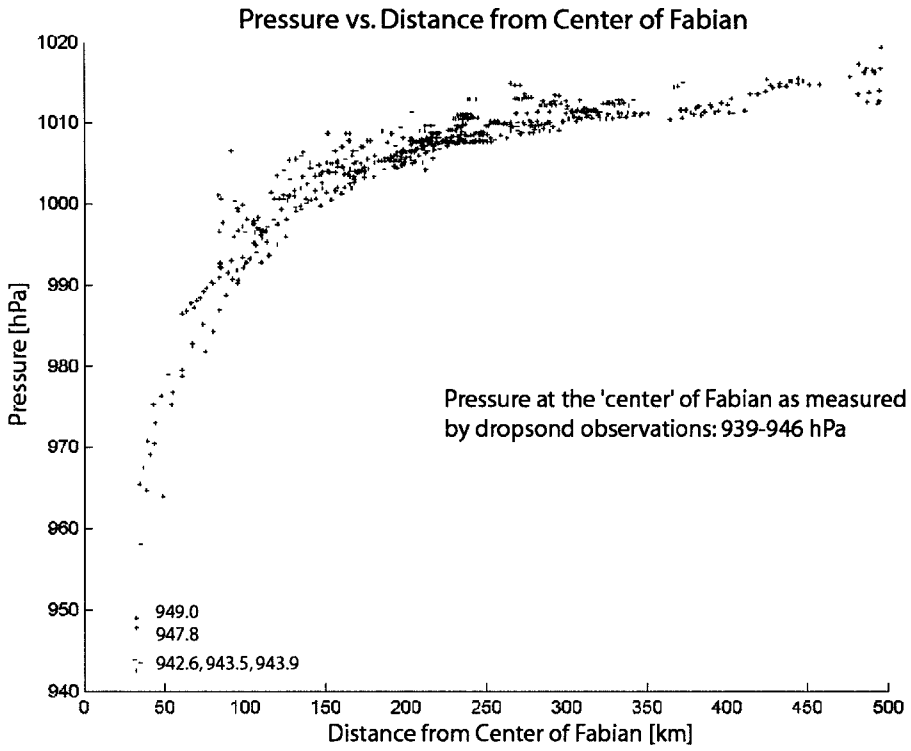

Fig. 9. Atmospheric pressure relative to the distance from the center of hurricane *Fabian*. The values of the lowest five data points are listed on the plot.

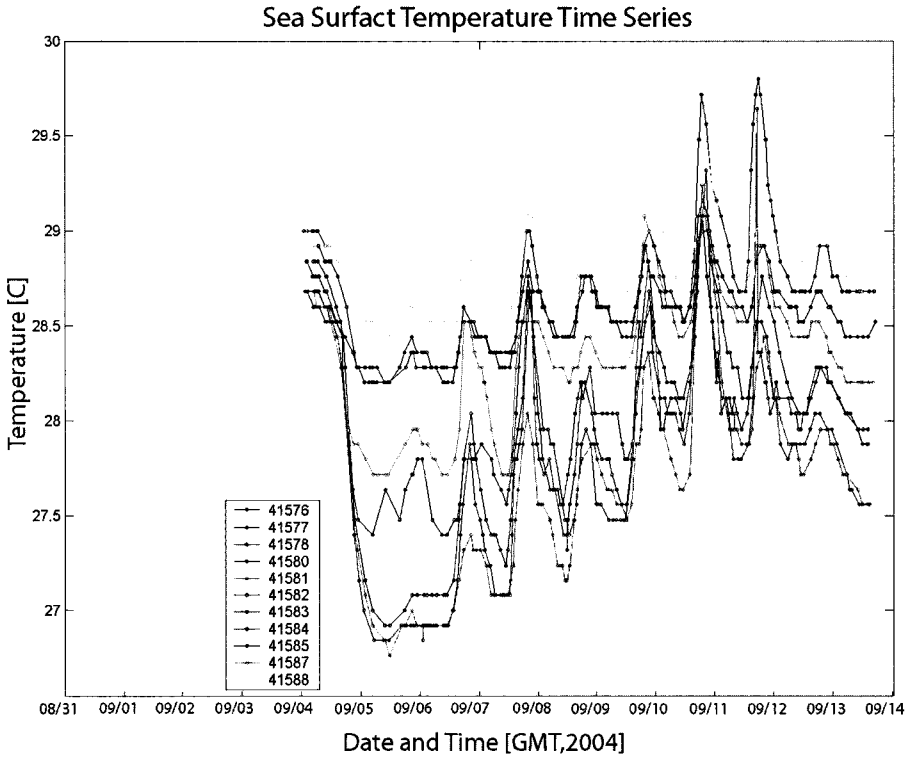

Fig. 10. Sea surface temperature for the 10 day period starting from when the drifters were first deployed. Hurricane *Fabian* passed over on September 4th and 5th. Colors on plot correspond to colors on plot of drifter tracks.

'eye' of the hurricane. A drop at 22:20 on September 2nd measured 944 hPa and a drop at 22:45 UTC on September 3rd measured 939 hPa (http://www.aoml.noaa.gov/hrd/Storm_pages/fabian2003/sonde.html). The lowest pressure measured by a Minimet was 942.6 hPa at 33 km from the hurricane center at 20:39 UTC on September 4th. From these data it appears that the eye of *Fabian* crossed over at least one of the Minimets.

Fabian cooled the SST at its 'center' from 28.9 °C to 26.8 °C (Fig. 10). After the passage of *Fabian*, there was a 1.5 °C–0.7 °C diurnal variation signal of the cooled area and SST warmed

to between 27.5 ℃ and 28.5 ℃ in 7 days. It is interesting to note that the area that was most highly cooled with the passage of *Fabian* was also the area that had the largest diurnal signal of SST and the largest 7 day warming after the passage of *Fabian*.

Conclusions

Measurements of hurricane wind direction, wind speed, SST, atmospheric pressure and surface currents were obtained by deploying 16 Minimet drifting buoys in front of hurricane *Fabian*. Eight of the 16 drifters transmitted data throughout the entire time they were in the hurricane. The data show that:

1. The atmospheric pressure decreases from ~1018 hPa on the outside of the *Fabian* to ~943 hPa within 35 km of the center.

2. The largest SST decreases was 2.1℃ in the right side of the hurricane. After *Fabian* passage the cold wake recovers quickly with large diurnal variations of SST.

3. The expected cyclonic motion of the hurricane winds is measured well by the Minimets. At distances from 50 km to 500 km there is a component of the wind direction pointing toward the center of *Fabian*.

4. The drifter motions exhibited inertial circles with larger radius circles - which indicate larger current velocities on the right side of the hurricane (when looking in the direction of motion of the hurricane). This is an expected result due to hurricane wind forcing of the oceans.

This experiment demonstrates that by using the operational Hurricane Hunters and a carefully designed air deployment package, an array of drifting buoys can be successfully deployed in the projected path of a hurricane. Further, the air deployment of Minimet drifters in front of hurricanes provide excellent means of obtaining meteorological and oceanographic data that can be used to assess the joint ocean-atmosphere interaction. It is recommended that at least 4 containers, with 8 Minimets be deployed in front of hurricanes when such data are needed. In the 2004 hurricane season, an array of 38 drifters that will return data also from below ocean surface will be deployed in an Atlantic hurricane with the methodology that was developed in this study.

To increase survivability of the instruments, the drifters should be deployed in wind condition of less than 13 ms^{-1} and further steps should be taken to assure the containers are not damaged during shipment. Further care should be exercised in the manufacture of the drifter floats.

Acknowledgements

We acknowledge and thank Luca Centurioni, Euna Lee, Andy Sybrandy and Chris Martin for their help in putting together the Minimet drifters and packaging them. Luca Centurioni and Andy Sybrandy are further acknowledged for their insightful suggestions on presenting the data.

References

D'Asaro, E. 2003. The ocean boundary layer below Hurricane Dennis. *J. Phys. Oceanogr.*, **33**: 561–579.

Milliff, R.F., P.P. Niiler, J. Morzel, A.E. Sybrandy, D. Nychka, W.G. Large. 2003. Mesoscale correlation length scales from NSCAT and Minimet surface wind retrievals in the Labrador Sea. Journal of Atmospheric & Oceanic Technology **20**(4): 513–533.

Price, J. F.. 1981. Upper Ocean Response to a Hurricane. *J. Phys. Oceanogr.*, **11**: 153–175.

Sanford, T., P. Black, J. Haustein, J. Feeney, G. Forristal, and J. F. Price. 1987. Ocean response to hurricane. Part 1: Observations. *J. Phys. Oceanogr.*, **17**: 2065–2083.

Shay, L. K., P. G. Black, A. J. Mariano, J. D. Hawkins, and R. L. Elsberry. 1992. Upper ocean response to Hurricane Gilbert. *J. Geophys. Res.*, **97**: 20 227–20 248.

2004년 1월 13일 원고접수
2004년 6월 17일 수정본 채택
담당편집위원: 이재학