Texas Automated Buoy System

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Abstract- **The Texas Automated Buoy System (TABS) began in 1994 when the Texas General Land Office (GLO) funded the Geochemical and Environmental Research Group (GERG) at Texas A&M University to design and purchase five telemetering current meter buoys. Instrumented buoys continuously measure current velocity about six feet below the surface and transmit the data to shore on a regular schedule via satellite telephone. The system has eight buoys funded by the TGLO operating along the Texas Coast – one near Sabine Pass, two off Galveston, one midway between Freeport and Corpus Christi, one off Corpus Christi, and two off Brownsville. The eighth buoy, a three meter discus buoy, was installed off Port Aransas in the summer of 2005 and removed in 2008. Two additional buoys located near the Flower Garden Banks National Marine Sanctuary are funded separately by an oil industry consortium but are operated as part of the TABS program.**

Four different types of TABS buoys are currently used by the program. All the buoys can accommodate single point current sensors. The 2.25 and 3m and TABS II buoys can accommodate acoustic current profiling instruments and meteorological packages which include air temperature and humidity, barometric pressure, as well as wind speed and direction. The larger two buoys have both mechanical and acoustic anemometers as well as accelerometers for measuring waves. The TABS I buoys can be deployed in 10-20m water depth. The TABS II buoys are suitable for deployment in 15m to 45m water depth. The two larger buoys have been deployed in up to 110m water depth.

Computers at Texas A&M University automatically collect data from the buoys every two hours via the satellite data modems and make the observations available to GLO and the general public via the Internet. TABS data are made available to NOAA NDBC via ftp to permit the data to be used by the National Weather Service. TABS sites B, J, K N and V have been given NDBC designators 42043, 42044, 42045, 42046 and 42047 respectively.

In 1998 a modeling component was added to the TABS program with the development and implementation of POM adapted to perform simulations on the Texas shelf. In 2002 the modeling was extended with the implementation of ROMS. Both models are run on a regular basis and output to a web page. Wind data from National Center for Environmental Prediction (NCEP) Eta-12 wind fields are used to drive the model in nowcast and forecast modes.

Hurricanes have affected the buoy system resulting in the loss of several buoys at the deeper offshore locations. The TABS 2.25m buoy was developed in an effort to deploy a buoy that could survive hurricanes. In September, 2008, the eye of Hurricane Ike passed directly over Buoy V located near the Flower Garden Banks. The mechanical anemometer was damaged but the acoustic wind sensor gave a complete record of the storms passage. Wave and atmospheric pressure data were also recorded. Perhaps most interesting is the decrease of measured waves in the eye of the storm.

I. INTRODUCTION

During the first few hours of an oil-spill event, the spill-response management team must make critical decisions about operations and logistics. Effective response requires immediate information about wind and current velocity conditions to quickly evaluate the trajectory, fate, and potential impact of spilled material. In 1991 the Texas legislature passed the Texas counterpart of the federal Oil Pollution Act of 1990 (OPA), the Oil Spill Prevention and Response Act (OSPRA). This act designated the Texas General Land Office (GLO) as the lead state agency for dealing with oil spills in the marine environment. In 1994 the GLO implemented plans for an operational system of instrumented buoys off the Texas coast, to be known as the Texas Automated Buoy System (TABS). The purpose of the buoy system was to protect Texas coastal waters by providing timely, accurate observations of winds and currents for use in spill response operations [1], [2], [3]. The GLO funded, from its Coastal Protection Fee, the Geochemical and Environmental Research Group (GERG) at Texas A&M University to design, build and operate a system of moored, telemetering current meter buoys using off-the-shelf technology. GERG, working with Woods Hole Group (WHG) of East Falmouth, Massachusetts, designed the buoys to measure current velocity at a fixed depth of about two meters below the surface using an electromagnetic current sensor and transmit the data to shore on a regular schedule via the existing offshore cellular telephone network. In early 1995, less than nine months after receiving the contract, GERG deployed the first buoys utilizing this technology. In March 1996 TABS experienced its first major test with the barge *Buffalo 292* oil spill [4]. In its first ten years of operation there were twenty major spills in which NOAA personnel have worked with and consulted the TABS data [3]. A comprehensive description of the history and operation of the Texas Automated Buoys System is given in [5].

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II. EQUIPMENT

Four types of buoys are used by the program. All are solar powered and are moored to the bottom with chain and or Nilspin wire. The buoys are shown in Figure 1 approximately to scale.

A. Hulls

The TABS I buoys are built from a 15 cm pipe with flanges at both ends covered with a closed cell urethane foam which in turn is covered with a Kevlar jacket. A stainless steel cage protects the current meter and provided an attachment point for the mooring.

TABS II buoys have a fabricated aluminum pressure case which is also covered by urethane foam a with a Kevlar jacket. TABS II buoys have a fabricated aluminum tower that holds the solar panels, met sensors and communication antennae. A stainless steel cage protects the current meter and provides an attachment point for the mooring.

The TABS three meter buoy uses a commercial hull from two different manufacturers as used by the NOAA NDBC and Environment Canada.

The TABS 2.25m buoys have a 2.25m diameter foam hull, aluminum top and bottom plates, an aluminum tower, and a stainless steel underwater bottom frame. We have constructed TABS 2.25m buoys using urethane foam floatation covered with Kevlar and also using a foam hull provided by Gilman.

B. Power Systems

All TABS buoys make use of silicon solar panels and lead-acid batteries.

C. Buoy Electronics and Communications

TABS I buoys use a dedicated microprocessor provided by Woods Hole Instrument Systems and a Qualcomm GSP-1620 Packet Data Modem.

Other buoys use a PC-104 embedded computer running the Linux operating system. These systems provide twelve RS-232 channels, USB, Wi-Fi, and eight A/D channels. The computer can send and receive data using a Qualcomm GSP-1620 Packet Data Modem via the GlobalStar satellite network. An ARGOS PPT serves as a backup data system and as an emergency locator beacon.

D. Current Meters

All buoys can be equipped with Aanderaa Doppler Current Sensor DCS4100R although some of the TABS II buoys use model DCS3900R. The TABS II, TABS 2.25m and TABS three meter buoys can also be equipped with TRDI Workhorse ADCP.

E. Meteorological sensors

TABS II, 2.5m and three meter boys have the following complement of sensors:

- Wind speed and direction – Gill Instruments Wind Observer II Ultrasonic Anemometer Model 1390
- Buoy tilt compensation for winds – Honeywell HMR 3300 Digital Compass or a Shaevitz AccuStar II Dual Axis Clinometer
- Buoy orientation for winds – Either a KVH C100 compass or a Honeywell HMR 3300 digital compass
- Air temperature – Either a Rotronics MP101A or an RM Young 41342VC in a radiation shield
- Relative humidity – Rotronics MP101A
- Air pressure – Vaisala PTB 100A

TABS 2.25 and three meter buoys have an additional R. M Young wind sensor.

F. Wave sensors

TABS 2.25m buoys and TABS three meter buoys use a Crossbow 4400IMU inertial monitoring unit. This instrument provides accelerations in the x, y, z directions and angular acceleration rates around the pitch, role and yaw axes. Data from a Honeywell magnetic compass are combined with this unit to calculate wave height and direction.

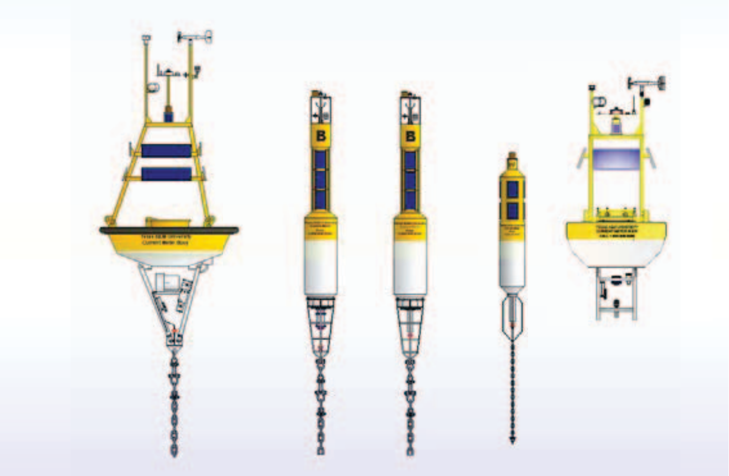

Figure 1. TABS buoys left to right: three meter discus buoy, TABS II buoy with ADCP, TABS II buoy with single point current meter, TABS I buoy, TABS 2.25 meter buoy

III. MODELLING

Two numerical ocean models of the Texas shelf are run on a regular basis by R. D. H and S. K B. in the Department of Oceanography at Texas A&M University The original shelf circulation model, developed and maintained by Dr. Joseph Yip from 1998-2002, consists of a 3-D version of the Princeton Ocean Model (POM) adapted to perform simulations on the Texas shelf on a domain extending from 25°N on the Mexican coast to 85°W at the coastline of Florida. The operational POM model is a simplified barotropic version that performs a 24 hour surface current prediction once per day. When R. D. H took over the program in 2002, he led the development of a second-generation shelf circulation model using the Regional Ocean Modeling System (ROMS). The development continues today. The ROMS based circulation model was designed to provide greater maintainability and extensibility than was available with the POM model, as well as to enable greater flexibility and ease of managing and transforming the simulation model input and output fields. Both the computational kernel and the data handling infrastructure were completely revised for these purposes.

ROMS is a free-surface, hydrostatic, primitive equation ocean model that uses stretched, terrain-following coordinates in the vertical and orthogonal curvilinear coordinates in the horizontal. (See [6] and the references therein for background information on both POM and ROMS.) Computationally, ROMS uses advanced numerical algorithms and software technology to facilitate efficient simulations on single and parallel computer architectures. Scientifically, it contains a variety of modular features including high-order advection schemes; accurate pressure gradient algorithms; several subgrid-scale parameterizations; atmospheric, oceanic, and benthic boundary layers; biological modules; radiation boundary conditions; and data assimilation. These scientific and computational features allow for both an easily maintained present operational system, and a flexible upgrade path for the research and development of future, improved versions of the system. The higher order advection scheme and the boundary layer schemes, in terms of mixing, are used; data assimilation is not.

Both models are driven by 12km gridded winds derived from the NCEP NMC WRF model which are downloaded from NCEP by an automated system in the Department of Oceanography.

IV. DATA MANAGEMENT

A. *Communications*

Primary communication with the TABS buoys is via the Globalstar satellite data network. The buoys initiate the communications link once every 0.5 to 2 hours by placing a call to the modems at GERG or at Texas A&M University. The duration of the each call is generally a minute or less, during which current speed and direction, water temperature, meteorological data, and engineering data are transmitted as ASCII strings. One advantage of Globalstar is the ability to conduct two-way communications. Buoys can be instructed to transmit data more frequently in the event of an oil spill or other emergency. After data are received, an automated data collection algorithm checks for data loss. Any gaps in the telemetered data can then be filled at the next successful transmission. If the communication buffer on board the buoy fills up, this is assumed to be an indication that the primary communication link is down and a secondary communication link, ARGOS, is initiated. The message size of System ARGOS is limited to 32 bytes, so we assure that the most recent data in the communication buffer have priority over older data. Each message, or burst, contains four sets of half-hourly currents and battery voltages. During a satellite overpass, up to seven bursts can be uploaded depending on the duration of the pass (a function of the elevation and azimuth) and the quality of the transmission link. The interval between satellite passes varies.

B. *Data analysis*

The analysis of the data proceeds in two steps: Level I quality control and Level II quality control. Level I quality control is automated and begins when the raw data from the TABS buoys are received. Raw data are transferred to a Linux server where the ASCII data are converted to engineering units. Obviously flawed data are removed. The Level I data are immediately used to update the main web page shown in Figure 2. This web page shows in graphical form the latest data and provides links to the underlying data bases. Graphical displays are generated every hour showing time series plots of the currents, water temperature, buoy tilt, and various engineering parameters that indicate the operating status of the buoy.

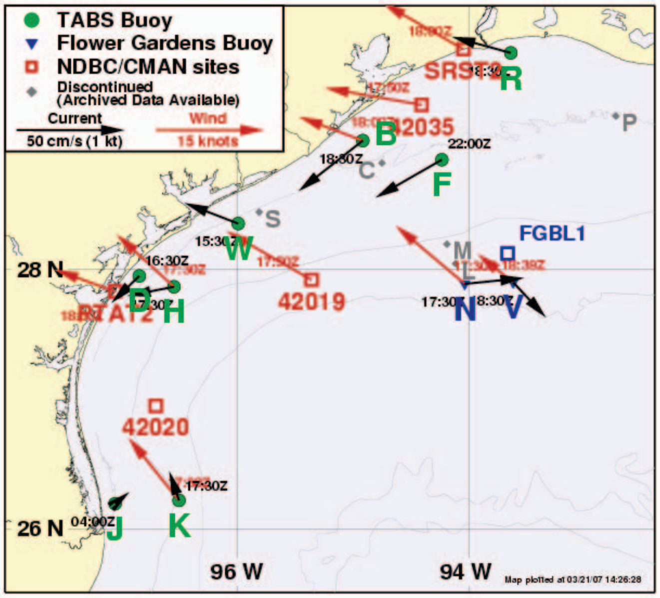

Figure 2. Image from TABS web page showing near real time oceanographic data. The green letters represent TABS buoys. The red letters and numbers represent NDBC buoys and CMAN stations. Surface currents are shown as black vectors. Winds are shown a red vectors but can be displayed at wind barbs at the viewers option

An example of the plot displaying currents and water temperature is shown in Figure 3. Time series plots of the meteorological data, winds, air temperature, and atmospheric pressure are made available for the TABS II buoys. Once a day, the quality of the Level I data is reviewed by an experienced oceanographer, who can then make further corrections to the data when needed. The final quality-controlled Level I data are then inserted into a database for retrieval by users.

C. *Data dissemination*

The Level I quality controlled data are inserted into an archival database designed to facilitate the extraction of user specified subsets. The database is built on mysql, an open source Linux structured query language database, and on simple flat ASCII files. The data have proven useful for model initialization, model skill assessment, research, and operational planning purposes. The GLO has direct access to this database via FTP over the Internet. The public has access through the World Wide Web (WWW) at http://tabs-os.gerg.tamu.edu/tglo/index.php.

Additionally, TABS meteorological data from sites B, J, K, N, and V are branded as NDBC sites 42043, 42044, 42045, 42046, and 42047 and formatted for ingest into the National Data Buoy Center. The TABS web page provides the user with access to a variety of oceanographic and meteorological data products. Using their browser, the user is able to view either the latest data or access the database and view archived data. The user can also download the data for later use. Users can select a TABS buoy location from the map or from text links for those without a graphical web browser. For each TABS station the user can choose to view either a graph of the past 4 days of data or the data in tabular format. The graph consists of a ‘‘stick plot’’ of the currents, cross shelf, and along shelf components of the current and water temperature (see Fig. 3). Data are presented in both English and metric units. Graphs can be downloaded as either a GIF image or a postscript file.

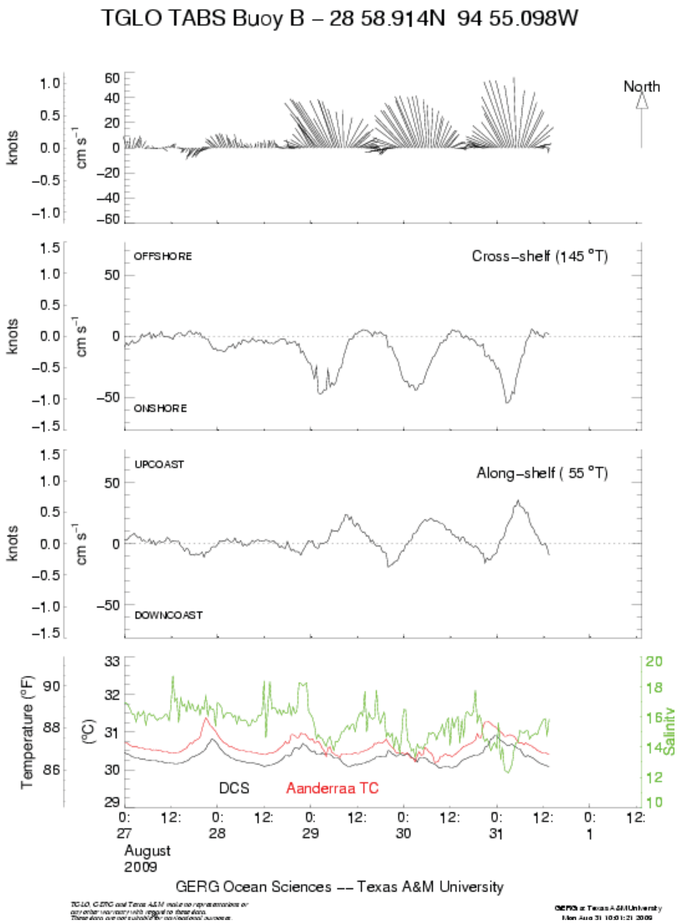

Figure 3. Level I data from TABS Buoy B viewed by clicking on the map Shown in Figure 2. The four day stick plot gives the viewer an immediate indication of data quality. A time series of the along-shelf and cross-shelf components of the currents have been found useful to a wide variety of users. The last panel gives salinity at ~1.7m depth and temperature at ~1.7 and ~2.4 meter depth.

Several additional features of the TABS website assist in the utilization of the TABS data. A summary plot provides a stick plot for each buoy using a common time axis.

A status table lists buoy latitude, longitude, lease block, and water depth. The status table also indicates which of the buoys have successfully transmitted their data during the past 12 hr and contains other information regarding the operational status of each buoy. Each buoy page also contains a link that allows the user to search the TABS database and retrieve data from a buoy for a user-selectable time period. The user can access up to two months of data at a time. The results of each database search can be viewed in both graphical and tabular format.

V. REAL TIME ANALYSIS

The Real Time Analysis feature provides the user with multiple views of the quality controlled oceanographic, meteorological and engineering data for the past 30 days. The oceanographic data is presented for each buoy as a series of graphical products showing the vector stick plots of the currents, the decomposition of the current into its mean, periodic, and autoregressive components, the rotary spectra, a short-term stochastic forecast, the probability of a flow reversal, the tides, a scatter plot, a current rose, and the water temperature. The current vectors, the current decomposition and the current rose are provided in 1-, 2-, 4-, 7-, 14-, and 30-day slices to accommodate the needs of oil spill managers. An example of a 7-day current decomposition plot is shown in Figure 4 for buoy D.

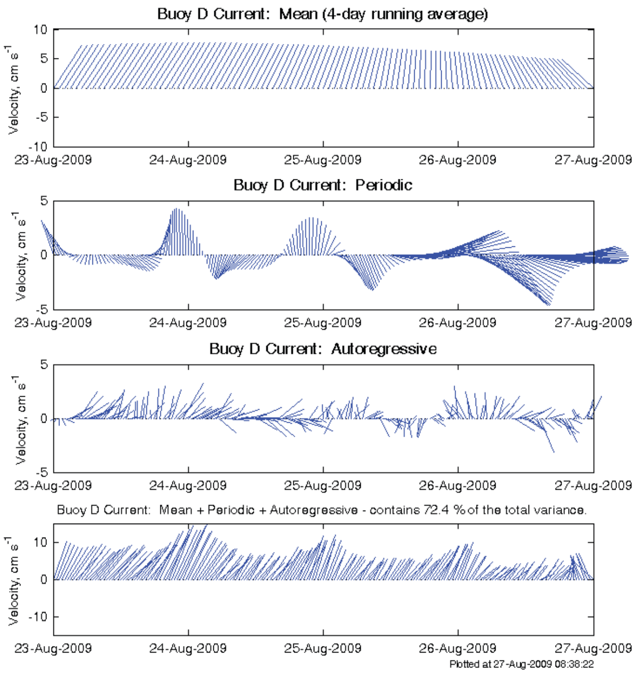

Figure 4. An example of the RTA product showing the 7-day decomposition of the current into its mean, periodic and autoregressive components. The sum of the three individual components accounts for 72.4% of the variance.

During the summer the flow at this site is weak and variable. The combination of the three individual components, mean, periodic and autoregressive, accounts for 72.4% of the variance. This provides a sound statistical framework for making a short-term stochastic forecast. Figure 5 shows the forecast for the next 48 hours in the top panel. In the middle panel the forecast that was made the day before is compared to the actual currents, along with statistics for speed and direction. The bottom panel shows the 48-hour old forecast and compares it with the actual currents. We note that this is a particularly good example of the forecast model. For those buoys equipped with a meteorological package, the wind data is presented as vector stick plots, a time series of the speed of the 10-minute mean and the maximum gust, the scatter plot, a wind rose, the air temperature, the barometric pressure, and the relative humidity. The winds are presented as 1-, 2-, 4-, 7-, 14-, and 30-day stick plots. Also plotted are the latent heat flux, the sensible heat flux, the wind stress magnitude, and the air-sea temperature difference. All of the oceanographic and meteorological data can be easily downloaded by the user.

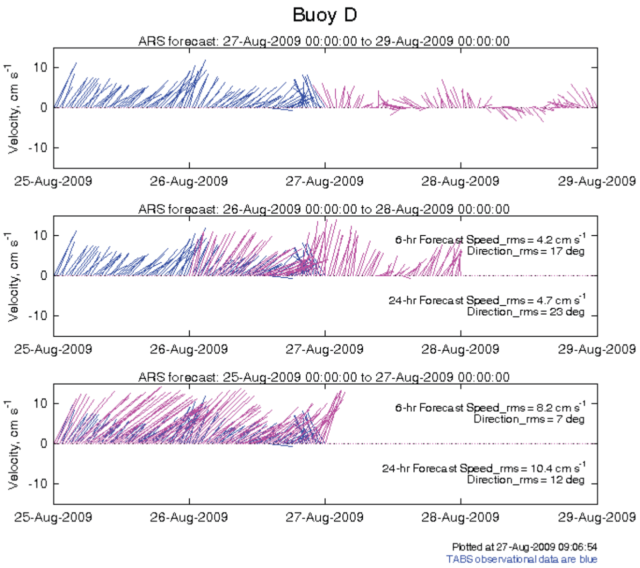

Figure 5. This is an example of the RTA product showing the short-term statistical forecast of the currents. The recorded currents are shown in blue, the forecast currents in magenta.

Figure 6 shows another real-time analysis product namely a current rose for Buoy K for the month of August 2009.

VI. WAVE MEASUREMENTS

The new 2.25-m TABS buoys are outfitted with two instruments for measuring buoy motions, a six degree of freedom accelerometer and a high quality aviation grade 3-axis magnetometer. The significant wave heights, peak and mean periods and directional spectra are computed from this data. The accelerometer is a Crossbow IMU440 solid state MEMS device designed to measure the linear acceleration along three orthogonal axes and the rotation rates around the same three orthogonal axes. The unit is not gimbaled, but is mounted (strapped-down) inside the buoy's system controller housing approximately at the waterline with the z-axis aligned perpendicular to the buoy deck. The magnetometer is a Honeywell HMR 3300 digital compass that uses an internal two-axis accelerometer to allow accurate heading even when the unit is tilted at 60 deg. On board the buoy during real-time operations the x, y and z channels of the accelerometer data are first processed to remove outliers. In order to compensate for the buoy's pitch and roll, the magnitude of the three axes accelerations is taken to be the earth-referenced vertical acceleration, or heave [7]. The acceleration spectrum is then computed with a smoothed auto-spectral estimate based on the auto-covariance estimate described by [8]. The major advantage of auto-covariance spectra is the frequency bins can be specified a priori, allowing one to concentrate the frequency resolution in the region where wave energy resides and eliminating bins at very low frequencies where no wave energy is expected to be present. The benefits of using a covariance spectra rather than an FFT outweigh any minor speed advantage gained from the FFT. A modified frequency domain filter similar to that of [9] is applied to the acceleration spectrum to remove any low frequency noise. The acceleration spectra is then converted to the 1D displacement spectra, from which the significant wave height, peak period and mean period are computed. Figure 7 shows an example of the resulting 1D displacement spectra.

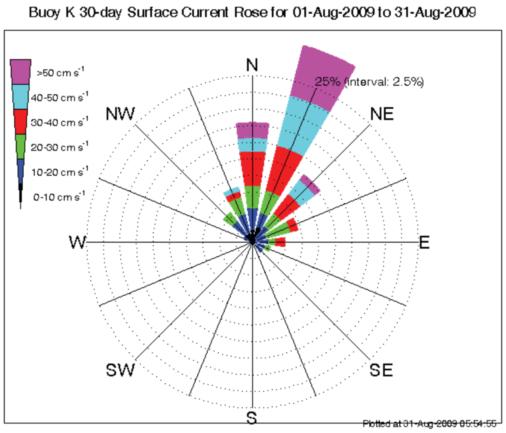

Figure 6. This is another example of a real-time analysis product showing a current rose for the month of August 2009 for Buoy K.

The directional spectrum is computed in the manner of [and, because it requires pitch, roll and heading data, involves synchronizing the compass data to the acceleration data. The co-spectra and quad spectra of the

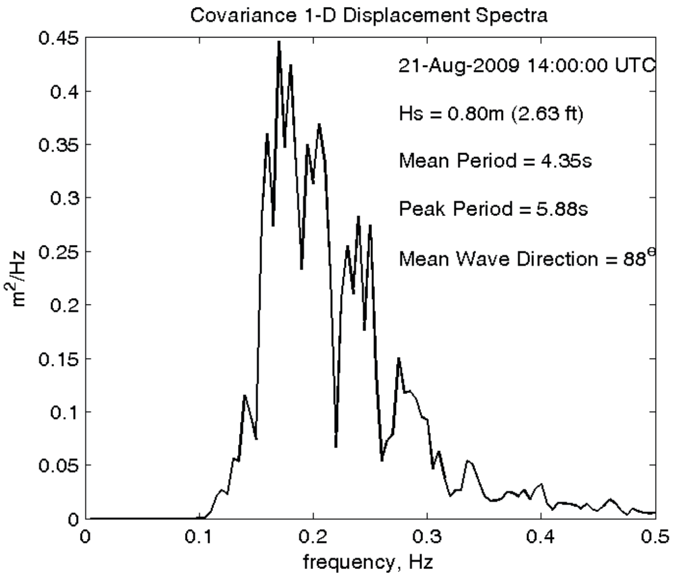

Figure 7. The 1D displacement spectra measured at buoy N.

combinations of heave, pitch and roll are computed on board the buoy computed with a smoothed auto-spectral estimate based on the auto-covariance estimate described by [8]. Each of these spectra are sent to shore on an hourly basis, where the College Station computers compute the directional spectra. Figure 8 shows an example of the time series of wave heights, periods and mean wave direction recorded at buoy N. The mean wave direction is defined at the direction the waves at the peak period are coming from, measured clockwise from the north.

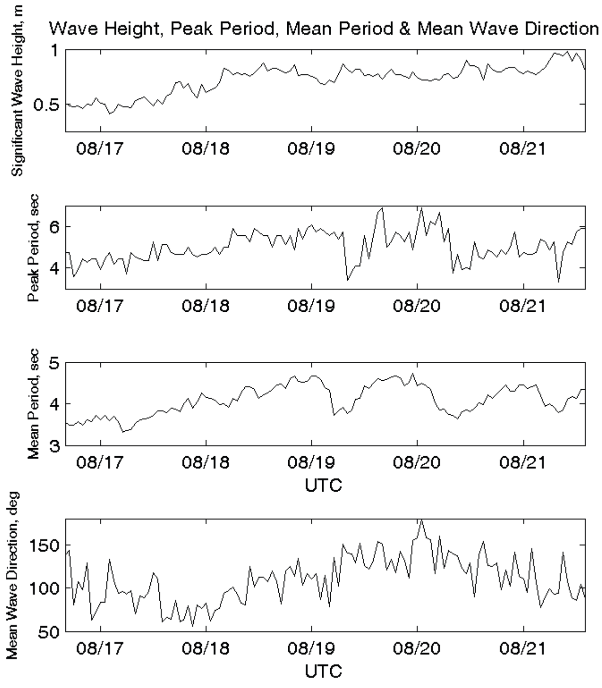

Figure 8. Sample of wave information from a five day period.

VII. HURRICANE IKE

In its passage across the Texas continental shelf before going ashore at Galveston, Texas around 2 am on September 13, 2008, Hurricane Ike passed within 20 nautical miles of buoys "B", "F" and "N" and went over the top of "V". The hurricane track and buoy locations are shown in Figure 9.

Some data transmissions from buoys B, F and N were never received, though the data was retrieved from B and F when the buoys were recovered. Buoy "B" experienced peak wind gusts of 17 m s^{-1} before the data stopped reaching College Station, buoy "N" experienced peak wind gusts of 25 m s^{-1} before the superstructure was swept away, and buoy "V" experienced peak wind gusts of 33 m s^{-1}, first when the leading edge of the eyewall passed over the buoy and then again as the trailing edge went over. Buoy "V" experienced a peak current speed of 101 cm s^{-1}, buoy "F" was 108 cm s^{-1}, buoy "R" was 109 cm s^{-1}, buoy "B" was 111 cm s^{-1}, buoy "W" was 122 cm s^{-1}, buoy "N" was 127 cm s^{-1}, and the highest peak current speed was recorded at buoy "D", 128 cm s^{-1}. Internally-recorded data from buoy N could not be recovered for post-processing. The wave and meteorological data from buoy V transmitted in near-real-time provide a fascinating record as the eye of Ike passed directly over the buoy (Figure 10).

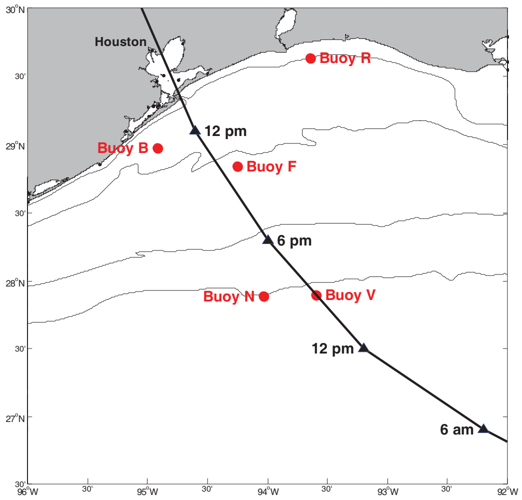

Figure 9. The track of Hurricane Ike on from 5 am September 12 to 5 pm September 13, 2008 and the location of TABS buoys. Times are in CDT.

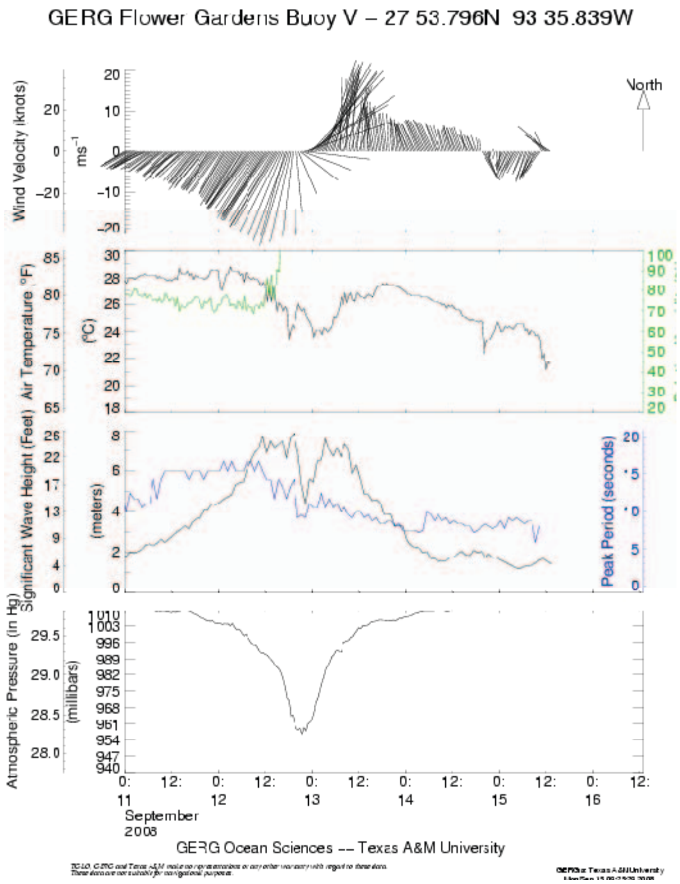

Figure 10. Buoy V recording the passage of Hurricane Ike as seen in near real time on the TABS web site. The top panel shows the wind velocity as a stick plot. The third panel shows the significant wave height. The fourth panel show the atmospheric pressure recorded at the buoy. As the eye of the storm passed over the buoy, the wave height decreased from about 8m to about 5m inside the eye of the hurricane.

The barometer shows a minimum atmospheric pressure of 957 mb as the eye passes overhead; the winds shift from northerly to southerly. The air temperature decreases as the leading edge of the eye wall approaches, and then as the eye passes over it increases to a local maximum and then decreases. As the eye moves away the temperature increases. Swell waves, seen as peak periods greater than 10 seconds begin to arrive at V nearly 48 hours before the hurricane does. In the eye the wave heights decrease from nearly 8 m to less than 5 m.

VIII. CONCLUSIONS

The Texas Automated Buoy System is now in its 14th year of operation. Starting with five buoys in 1995, it has expanded to nine buoys in 2009. We have watched the buoys evolve from small simple buoys like the TABS I suitable for measuring currents in nearshore waters to the more capable TABS II buoys. Hurricanes have taught us that our spar buoy designs may not been the most robust. As a result we developed more capable buoys with more reserve buoyancy have survived hurricanes and provided valuable data during hurricanes. Our experiments with advanced sensors such as sonic anemometers and six axis accelerometers has led to what we believe are improvements in the quality of buoy data. That this has been done in a university environment at reasonably low cost we attribute to the dedication of our staff.

ACKNOWLEDGMENTS

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