Air–Sea Measurements from Moored Surface Buoys During the 2010 Pacific Typhoon Season

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INTRODUCTION

It is recognized that there is a lack of knowledge of the physics of air-sea exchange at wind speeds above gale force. (Black *et al.*, 2007) In order to try and fill this void in our understanding two pairs of buoys were deployed in the Philippine Sea, ~740km east of Southern Taiwan, as part of the *Impact of Typhoons on the Ocean in the Pacific* (ITOP) experiment. Each mooring pair consisted of an Extreme Air-Sea Interaction (EASI) buoy, (Drennan and Williams 2008), and an Air-Sea Interaction Spar (ASIS) buoy, (Graber et al. 2000).

The northern mooring was located at 21.23ºN,126.96ºE in 5608m water depth and the southern mooring was located at 19.63ºN,127.25ºE in 5512m water depth. EASI buoys were anchored to the seabed via ~8000m of line allowing them to move freely upon the surface. ASIS were tethered to their respective EASI with a horizontal separation of ~60m. Distance between moorings was approximately 180km. The north mooring collected data from August 6th to December 1st 2010 (DOY 218-335), while the south mooring collected data from August 4th to November 22nd 2010 (DOY 216-326). ASIS south and north broke loose on October 16th and September 15th , respectively, and were subsequently recovered. Figure 1 shows a typical ASIS-EASI mooring configuration.

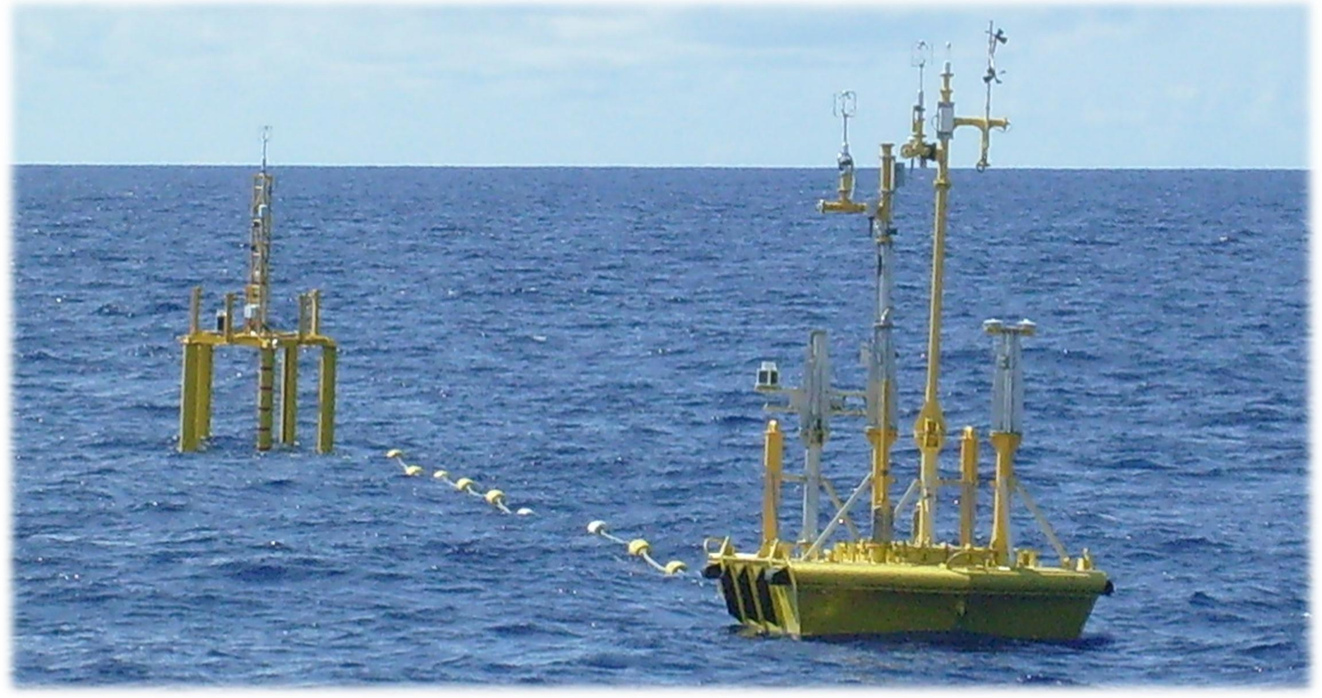

Figure 1: Typical mooring configuration of EASI (foreground) and ASIS (background).

Both moorings were in place and operational during the passage of four major storms: tropical storm Dianmu, typhoon Fanapi, super typhoon Megi, and typhoon Chaba. Corresponding storm tracks were as close as 68 km from the buoy locations according to the Joint Typhoon Warning Center, (Angrove and Falvel, 2010). See figure 2. Significant wave heights over 10m were recorded as were maximum wind speeds exceeding 25 m/s (30 minute average) with instantaneous gusts exceeding 35 m/s.

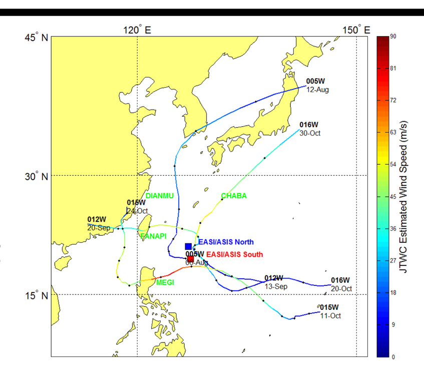

Figure 2: JTWC storm tracks during ITOP

OCEAN TEMPEATURE MEASUREMENTS

Instrumentation and Technique

A combined thirty-seven subsurface temperature sensor/data loggers were connected intermittently to the mooring line in the upper ~150m of the ocean. Sensors sampled at rates from 4 seconds to 8 minutes and were calibrated pre- and post-deployment in a high precision bath.

The sensor arrays included RBR-TDR2050 dual channel temperature, pressure loggers from which depth was determined. Fitting a quadratic to the mean depths of these loggers, as a function of their position on the mooring line, the mean depth of all sensors was determined.

Of the thirty-seven original below surface sensors thirteen failed during the experiment. This was likely due to intense vibration of the near-surface mooring line. The depth of the remaining sensors, as a function of time, for the north (left) and south (right) moorings are shown in figure 3.

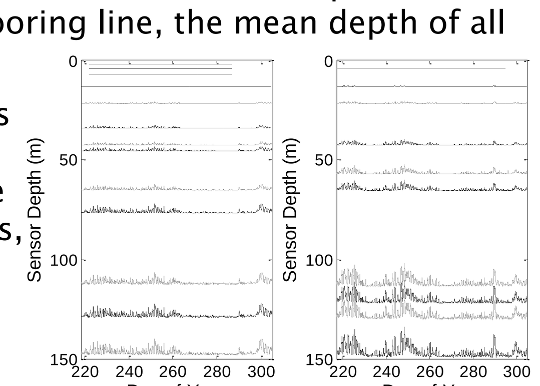

Figure 3: (right)Sensor depths for north (left) and south (right) moorings

Profiles, Sea Surface Temperature, Mixed Layer Depth

- Upper ocean temperature profiles were created by linearly interpolating though the water column between adjacent sensors.
- Sea surface temperature was assumed to be equal to temperature recorded by the shallowest sensor at each mooring (~1m).
- Mixed layer depths (MLD) were estimated to be the depth where temperature is 0.5˚C below SST, following the work of Levitus (1982), amongst others.

Figure 4 show SST, ocean temperature with MLD, and wind speed (for reference) for the north and south moorings. Timing of the named storms are also shown.

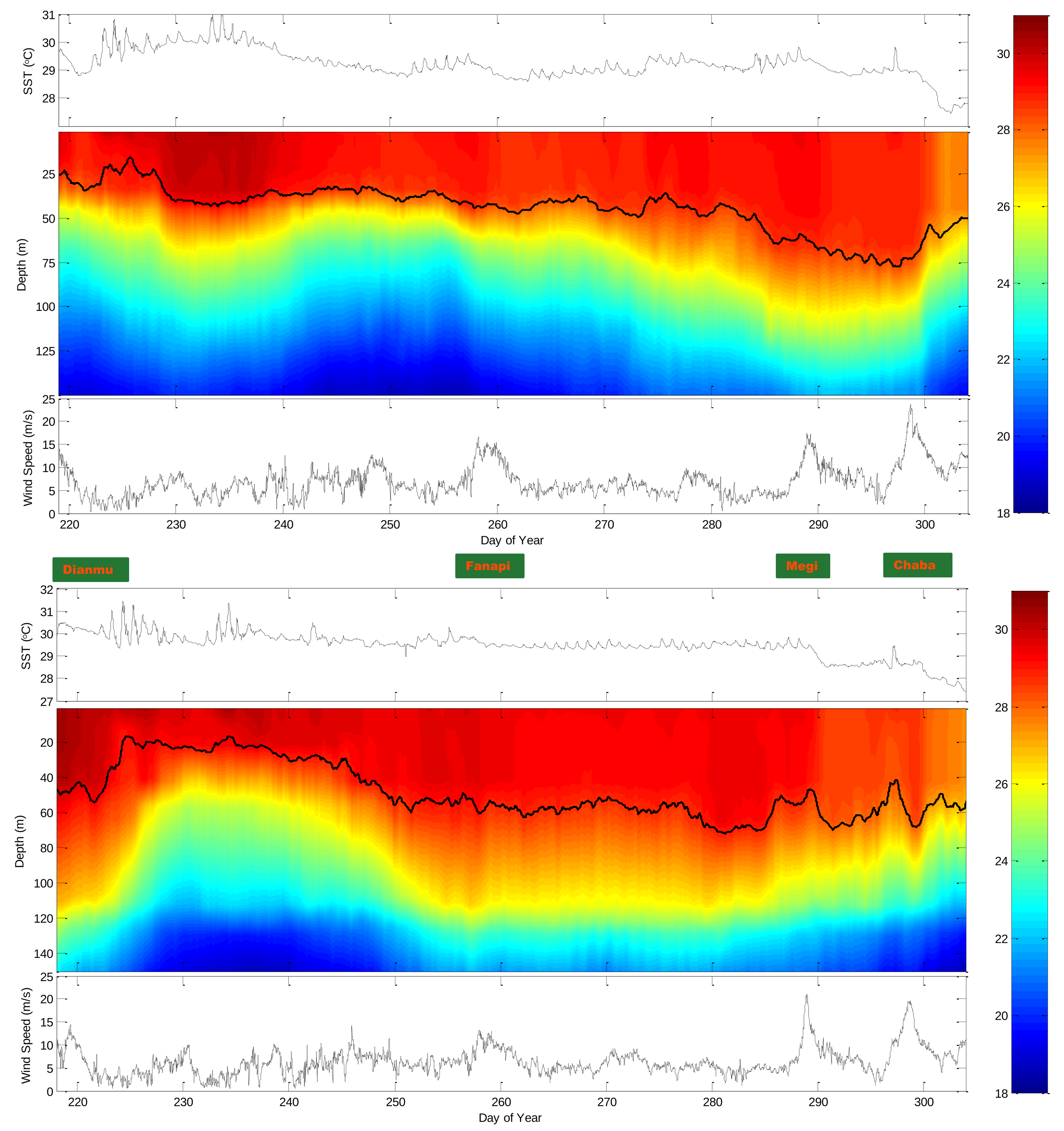

Figure 4: SST (top), ocean temperature (ºC) with MLD (middle), wind speed (bottom) for the north (above) and south (below) moorings

METEOROLOGICAL MEASUREMENTS

The mooring pairs were equipped with an array of above-water sensors collecting meteorological parameters. These included:

- **Wind speed** – sonic- and K-Gill- anemometers.
- **CO_2 H_2O gas** – LICOR LI7500, LI7200 gas analyzers
- **Sea Spray aerosol** – CLASP aerosol spectrometer
- **Humidity and temperature** – Rotronic MP101A
- **Atmospheric pressure** – Setra 278 barometer.
- **Radiation** – Eppley PSP and PIR radiometers

Each buoy was also equipped with **compass**, **accelerometers**, and **rate gyros** so that measurements could be motion corrected and adjusted to a fixed reference frame.

EASI buoys were the primary platforms for meteorological measurements, the arrangement of sensors can be seen in Figure 6.

Figure 5 displays mean -30 minute averaged – measurements of pressure (a), 10m wind speed (b), wind direction (c), air- and sea surface temperature (d), and relative humidity (e). The approximate time of the named storms are also shown.

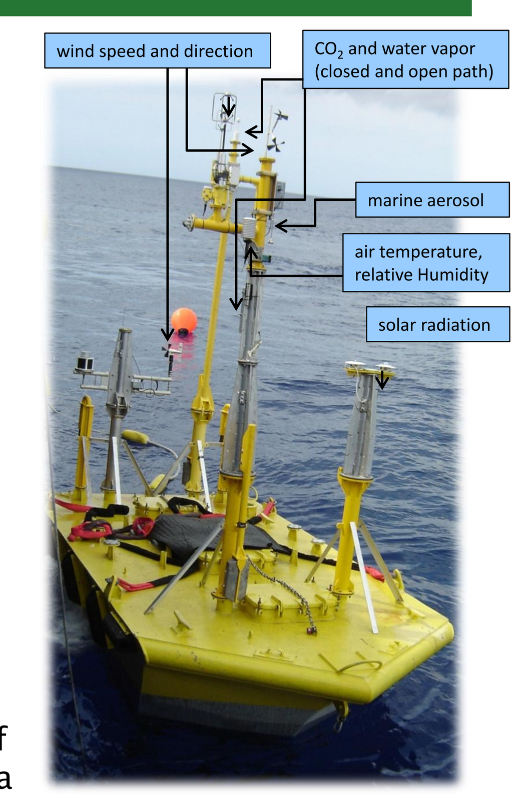

Figure 5: EASI meteorological sensors arrangement

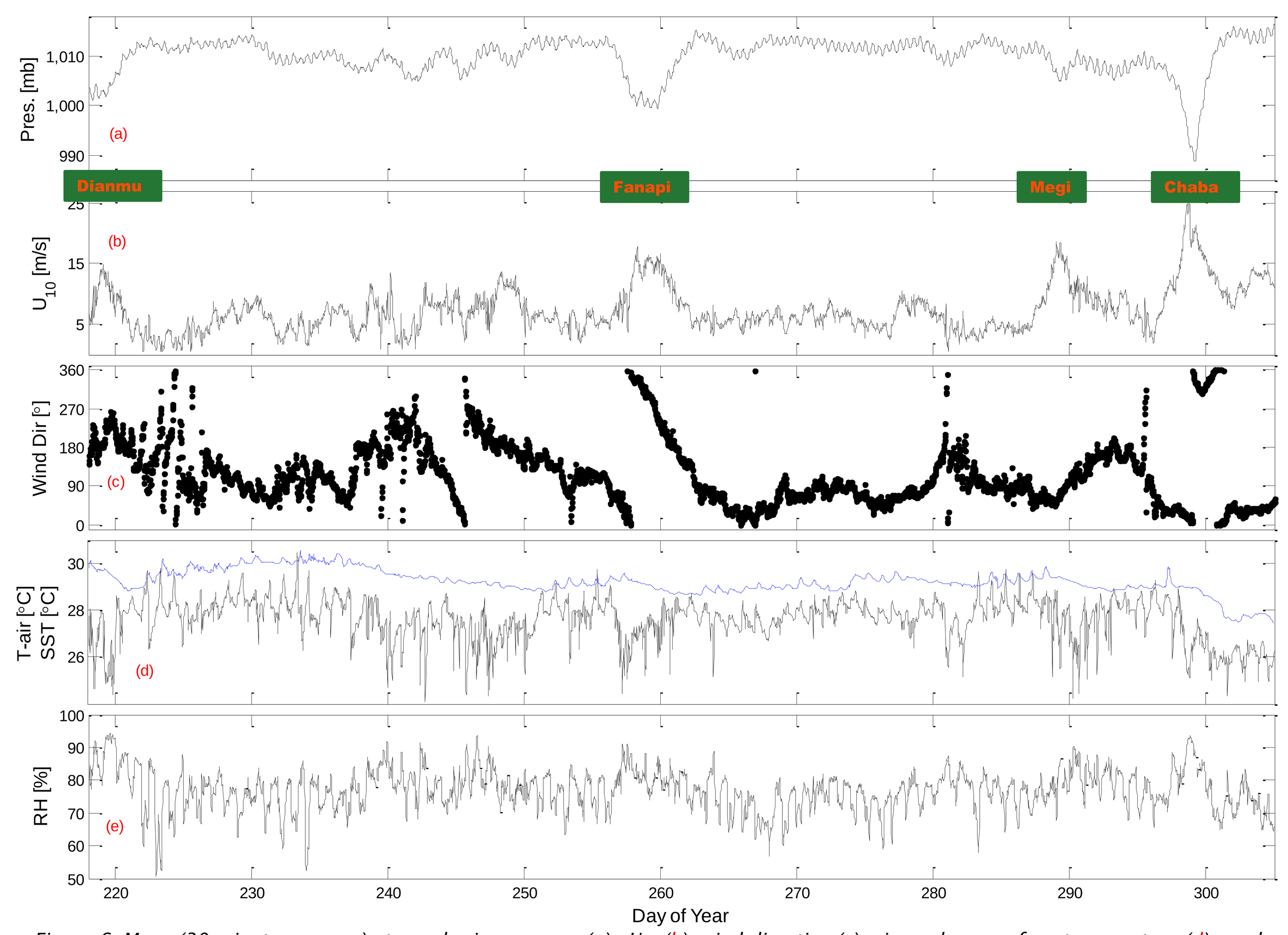

Figure 6: Mean (30 minute average) atmospheric pressure (a) , U_{10} (b), wind direction (c), air- and sea surface temperature (d) , and relative humidity (e), recorded during ITOP at the north mooring.

WAVE MEASUREMENTS

Operating Principles

ASIS buoys heave with waves of period ~>8s and remain relatively stable for waves of period ~<8s. These shorter waves are measured using an array of capacitance wave wires which sense the surface elevation. These are transformed to earth-reference sea surface elations by adjusting for the buoy's motion (Anctil *et al.*, 1993) using the onboard motion sensing system. EASI is a surface follower, all 6 degrees of freedom are recorded (local buoy reference frame) along with compass heading. The heave is tilt corrected and double integrated to produce sea-surface elevation. The compass heading is used to transform pitch and roll to an Earth-fixed coordinate frame and integrated to produce sea-surface slopes.

Measurements

Figure 7 displays some of the parameters that can be determined from EASI wave measurements. These include wave frequency spectrum (a), inverse wave age with fully developed sea reference line (b), significant wave height (c), peak period (d), and direction at the peak period (e).

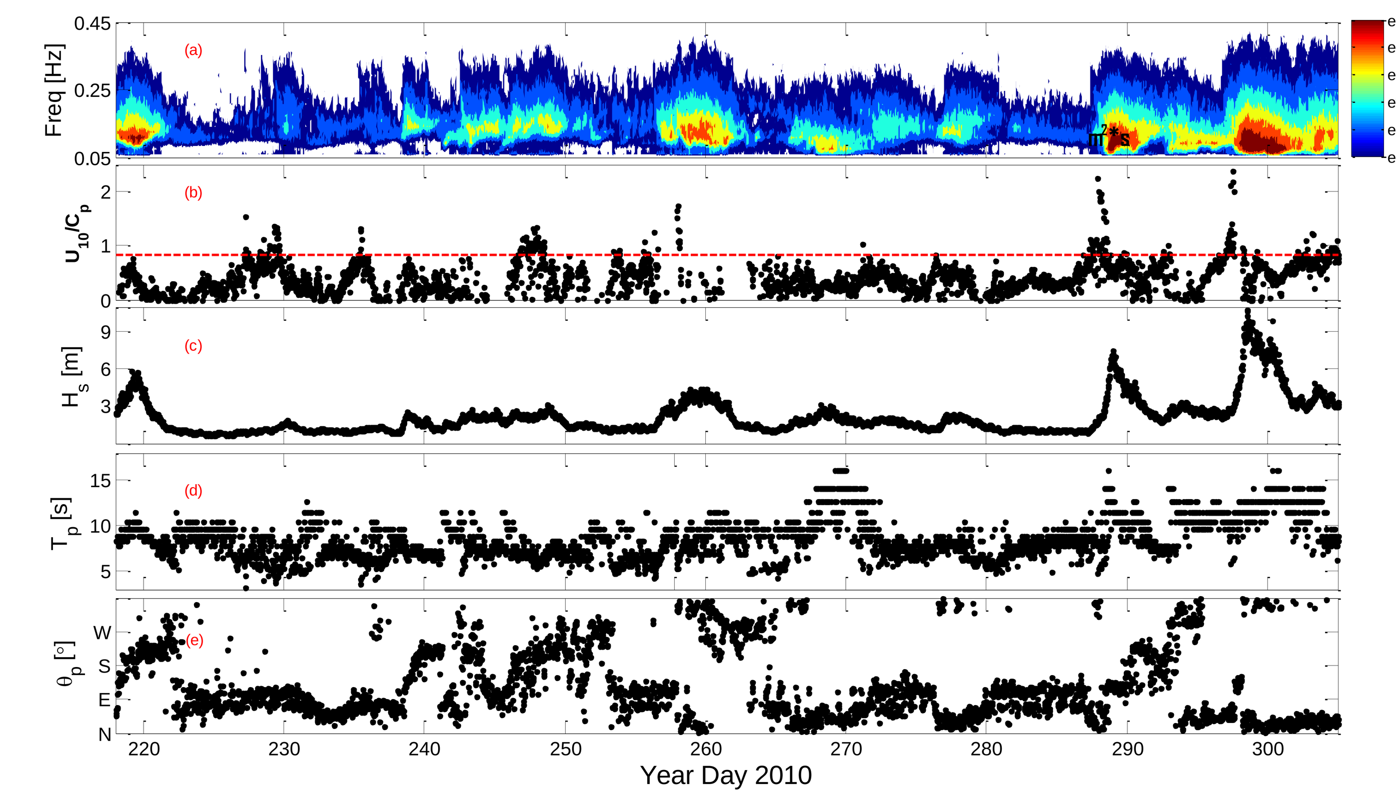

Figure 7: Wave frequency spectrum (a), inverse wave age (b), significant wave height (c), peak period (d), direction at the peak period (e) from EASI north

TYPHOONS MEGI AND CHABA

Typhoons Megi and Chaba had maximum sustained wind speeds of 82m/s and 59m/s, 19km and 28km radius of maximum winds, and passed 284km and 94km from the north mooring, respectively. Figure 8 shows atmospheric pressure (a) , U_{10} (b), wind direction (c), air- and sea surface temperature (d) , wave spectra with peak frequency (e), and significant wave height (f) at the north mooring during these storms.

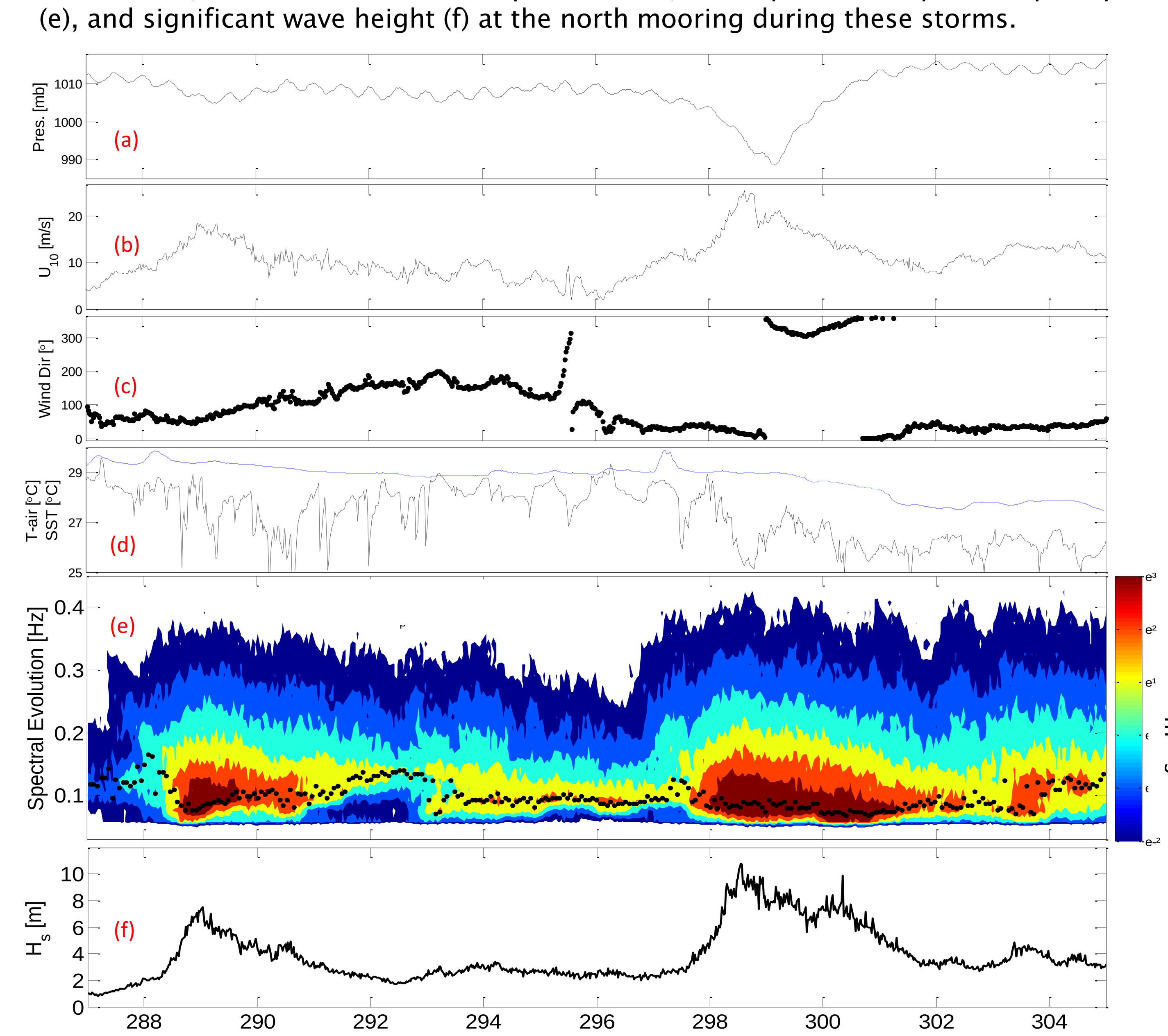

Figure 8: Mean (30 minute average) atmospheric pressure (a) , U_{10} (b), wind direction (c), air- and sea surface temperature (d) , wave spectra (e), and significant wave height (f) recorded during typhoons Megi and Chaba at the north mooring.

CONCLUSION

The deployment of EASI and ASIS in the Philippine Sea during the 2010 typhoon season resulted in a unique and varied data set which reflects the interaction between the ocean and atmosphere at high wind speeds. Further investigation will focus on fluxes of heat and momentum, the evolution of the wave field, and aerosol component analysis, amongst other work. These will help us develop a clearer understanding of air-sea interaction at high wind speeds and improve forecasting of tropical storms.

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