

Studies of the Origins of the Kuroshio and Mindanao Currents with EM-APEX Floats and HPIES

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LONG-TERM GOALS

Improving observations and understanding of major oceanographic features and phenomena. We emphasize motionally induced horizontal electric fields (HEF) and bottom pressure and Inverted Echo Sounders (PIES) for measuring ocean velocities from a bottom lander.

OBJECTIVES

The primary objectives of this observational program are to observe the North Equatorial Current (NEC) as it bifurcates into the Kuroshio and Mindanao currents (i.e., KC and MC, respectively) and determine the volume transports of the Kuroshio off NE Luzon Is. The plan was also to reveal interactions between the North Equatorial Current (NEC) and the strong mesoscale eddies. The HEF and PIES provided barotropic and baroclinic velocity components.

APPROACH

The use of bottom-mounted horizontal electric field sensors combined with inverted echo sounder units complements the ADCP moorings in the Kuroshio near the NE tip of Luzon, the Philippines. The new instrument is denoted as HPIES, an abbreviation of Horizontal Electric Field, Pressure and Inverted Echo Sounder. The HEF measures the conductivity-weighted, vertically averaged ocean velocity (Sanford, 1971). This is converted to the barotropic horizontal ocean velocity. The pressure and IES data determine baroclinic velocity when operated in a 2-D horizontal array.

Five HPIES were deployed around Ren-Chieh Lien's upper ocean ADCP moorings. The ADCP is moored at 450-m level and upward looking. The HPIES provides the depth-averaged velocity. Thus, the combination provides both upper-ocean Kuroshio transport and total-water transport. The moorings and the HPIES were installed at NE of Luzon, centered under the Kuroshio.

Nine EM-APEX floats were deployed along 135°E between 20°N and 12.5° N. The floats trajectories not only outlined the drift of the NEC and the eddy influences, but also regularly conduct velocity and CTD profiles.

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WORK COMPLETED

KORDI's R/V *Onnuri* deployed EM-APEX floats in June 2012 (Fig. 1). The deployment started around 20°N, 133°E and ended at 12.5°N, 136°E. Floats drift generally at a 200-m “hold” depth as they move with the westward component of the NEC. Along the way, every ten days they profile to 800 m to acquire velocity and density profiles twice, spaced $\frac{1}{2}$ inertial period apart, which range from 35 h at 20°N to 55 h at 12.5°N.

R/V *Revelle* cruises 1205 in Jun 2012 and 1307 and Jun 2013 were devoted the deployments and recovery of ADCP moorings, HPIES and CTD stations along 18.75°N, NE of Luzon Is., respectively. The field operations went well and all gear was recovered.

Analyses have been conducted to determine data quality and make comparison between HPIES and mooring observations. Results from the HPIES and EM-APEX float observations were presented at the ONR Peer Review in Chicago on 18 September 2013.

RESULTS

The array of EM-APEX floats was successful in revealing the NEC path toward a bifurcation region south of Lamon Bay on Luzon Is. The profiles soon after deployment provide a section of zonal geostrophic velocity (Fig. 2). The banded meridional structure is different from that pictured of the NEC by Qiu and Chen (2012) but now documented in the Solo glider section along 135°E and explained in the theory and modeling of Qiu in OKMC program.

Later, many of these floats were managed with the intention of guiding them to the KC-MC bifurcation zone in October 2012. Only about half the floats directly approached Luzon Is. There is a nice show of floats converging in a jet-like flow, as emphasized in Fig. 3. Other floats were entrained into the Kuroshio and headed toward Taiwan or into the S. China Sea. The floats group into four categories defined in Fig. 4: namely, KC floats, Eddy floats (East of Taiwan), S. China Sea float, and MC float. A single float entered the Mindanao Current and jetted south. One got trapped in the mesoscale eddy SW of Taiwan and provided profiles in the eddy for several months.

Clearly, eddy motions were generally greater than the NEC and controlled the paths of most floats. The interactions between mean current and eddies has been investigated in animations of float trajectories compared with AVISO SSH and surface geostrophic velocity. In most cases, the floats at 200 m followed the AVISO surface flow. However, there are many examples where the 200-m flows are at variance with the surface values.

Float 2411 proceeded directly to the vicinity of southern end of Luzon Is. In doing so, it provided a nice section of the T/S structures and velocity (Fig. 5). This float demonstrates the longitudinal changes in T/S in the NPTW salinity maximum and NPTI water with S minimum.

While the EM-APEX floats were profiling along the trajectories of Fig. 4, there were 5 HPIES making observations along Lien's ADCP mooring line. HPIES is a combination of a horizontal electric field sensor and URI's PIES. The deployments were near latitude 18.75°N, NE of Luzon Is. PI (Fig. 6). From November 2012 until Jun 2013, eight Seaglider transects were obtained to 1000 m over the mooring array. The intended configuration, depicted in Fig. 7, was to place HPIES between ADCP mooring. In reality, the location was adjusted based on the multibeam bathymetry surveys around each

intended location. The bathy surveys in Fig. 8 revealed much bottom topography, both near each deployment and over the entire array.

The PIES subsystem provided bottom pressure (BP) at each site and travel times (TT) at 4 of the 5 locations. (H3 had either a weak transducer or an improper threshold setting from manufacturer) The HEF subsystem, shown in Fig. 9, yielded up to 80% data return, with all channels working for 1 year. However some optical interrupters failed to reliably stop at the points to separate ocean from electrode voltages. Further quality control will determine if any of the observations cannot be used. In the meantime, attention is focused on results at H2.

H2 can be compared with the nearby ADCP moorings M2 and M3. H2 HEF is converted to velocity simply by dividing the observed electric field by the local vertical component of the Earth's magnetic field, F_z . The velocity is the electrical conductivity weighted, vertically averaged ocean velocity. The conductivity weighting is a positive correction of about 10% for the meridional (i.e., N) component. The direct comparison of HEF and ADCP transports per unit width, the vertical integral of horizontal velocity, is shown in the upper two panels of Fig. 10. It appears that HEF is about 50% larger than the ADCP values and differs by 30 degrees. Of course, the vertical integral is over the whole water column for HEF and the upper 600 m for the ADCP. So it is possible that the differences are caused by deeper flows – seeing the deeper flow was a reason for deploying the HPIES. However, there is another consideration – one not anticipated before the deployments. This is galvanic distortion (Chave et al., 2004) due to surface electric charges on the non-conducting seafloor that arises to deflect electric current from entering the much less conducting seafloor. Galvanic distortion is not frequency dependent, allowing a single gain factor to correct the motional electric field. However, the gain factor is not isotropic and will be different in east and north components. An *ad hoc* adjustment is shown in the bottom two panels in Fig. 10. The amplitude of the HEF transport is reduced by 1/3 and the direction rotated 30° CCW. Post cruise analysis will focus on understanding and correction for galvanic distortion.

As the Gravest Empirical Mode model is being developed from CTD, we can see that the travel time differences between HPIES sites is correlated with the major velocity fluctuations. This comparison using TT differences from H1 and H2 vs. adjacent ADCP moorings is shown in Fig. 11.

RELATED PROJECTS

Process Study of Oceanic Responses to Typhoons using Arrays of EM-APEX Floats and Moorings (N00014-08-1-0560) as a part of the ITOP DRI. Fourteen EM-APEX floats were air-deployed into two W. Pacific typhoons. *T. Fanapi* was a category 1 tropical cyclone. Seven floats were deployed about a day in front of *Fanapi* in mid-September 2010. Similarly, 7 floats were deployed in front of Super Typhoon Megi in mid-October. All floats survived the deployment and reported profiles. We are studying the characteristics and dynamics of the oceanic response to and recovery from tropical cyclones in the western Pacific Ocean

Quantify Lateral Dispersion and Turbulent Mixing by Spatial Array of χ -EM-APEX Floats (N00014-09-1-0193) as part of the LatMix DRI. A suite of twenty-one EM-APEX floats, 10 with Chi turbulence sensors, was used in three experiments SE of Cape Hatteras, NC in June 2011. This was the first time a number of EM-APEX has been choreographed to profile simultaneously. For most of the time, the RMS differences on arrival at the surface were less than 1 minute. Only a single float was lost during the experiment, a result that partly was achieved by the development and use of a situation

awareness system developed at APL for this experiment. Assets in the water were displayed on a dedicated screen on the bridge of each of the three research vessels. More than 8,000 CTD and velocity profiles were obtained in the three experiments. The data are being processed for distribution by 1 January 2012.

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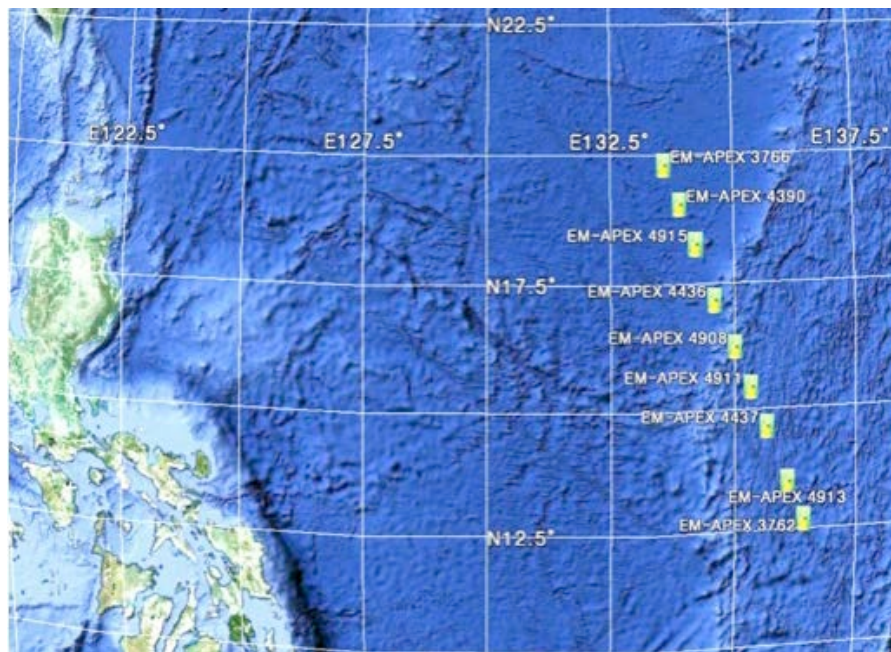


Fig. 1: Deployment positions for the 9 EM-APEX floats deployed by the Korean Ocean Research and Development Institute's R/V Onnuri, in June 2012 between 20°N and 12.5°N along 135°E.

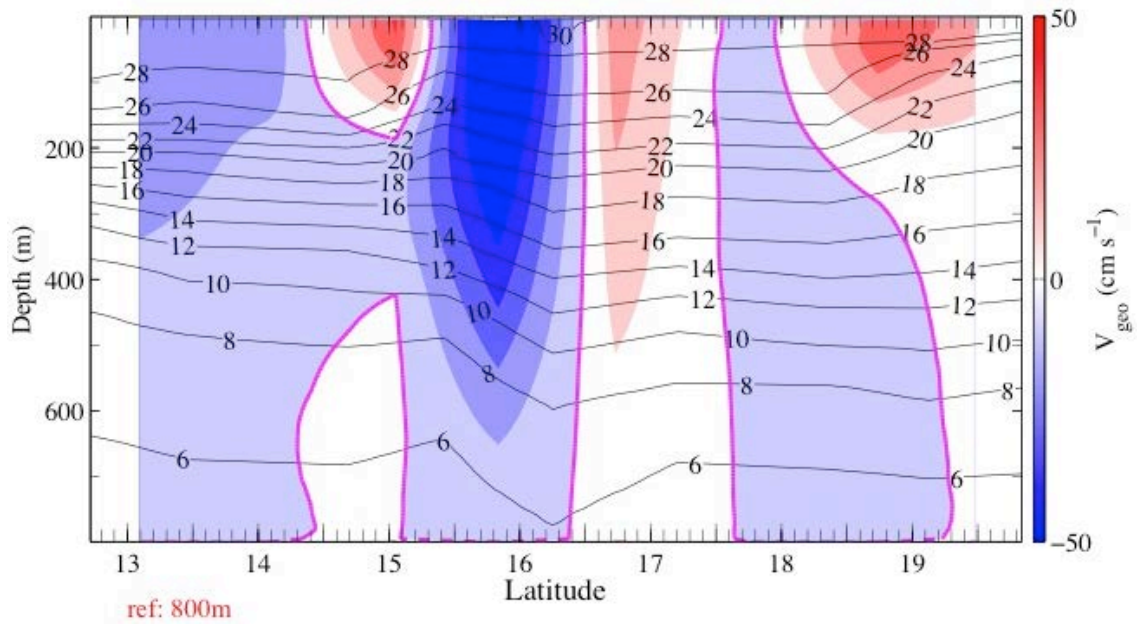


Fig. 2: Zonal geostrophic velocity (ref. 800 m) from the CTD profiles on the EM-APEX floats averaged over the first 19 profiles.

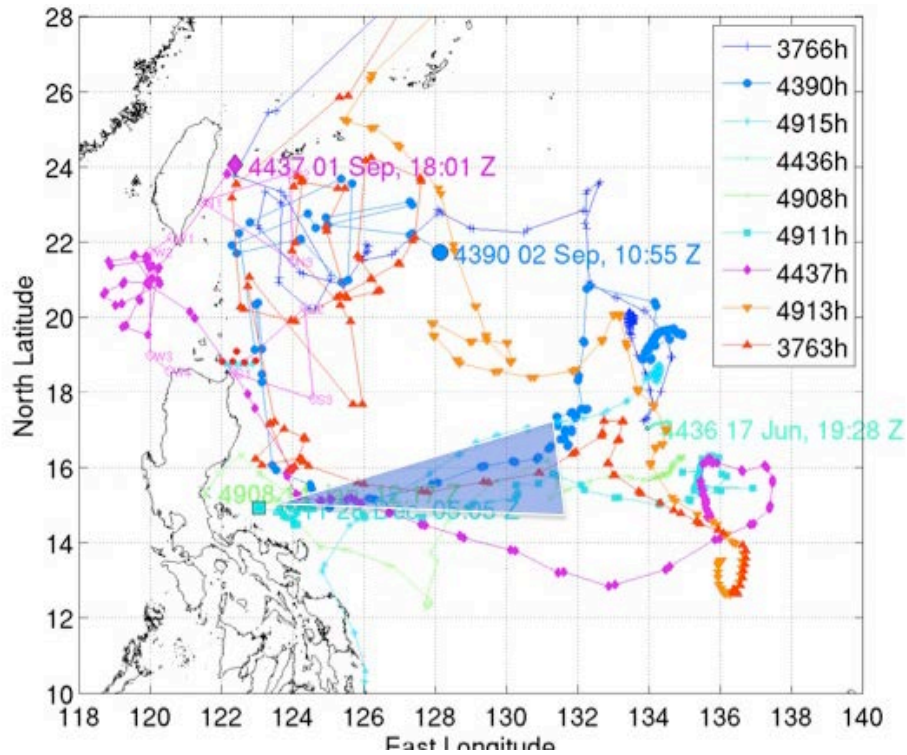


Fig. 3: Float trajectories from deployment along 135°E. Some floats went directly toward Luzon Is. Others tended to go NW toward Taiwan. Floats that neared Luzon, went mostly N.

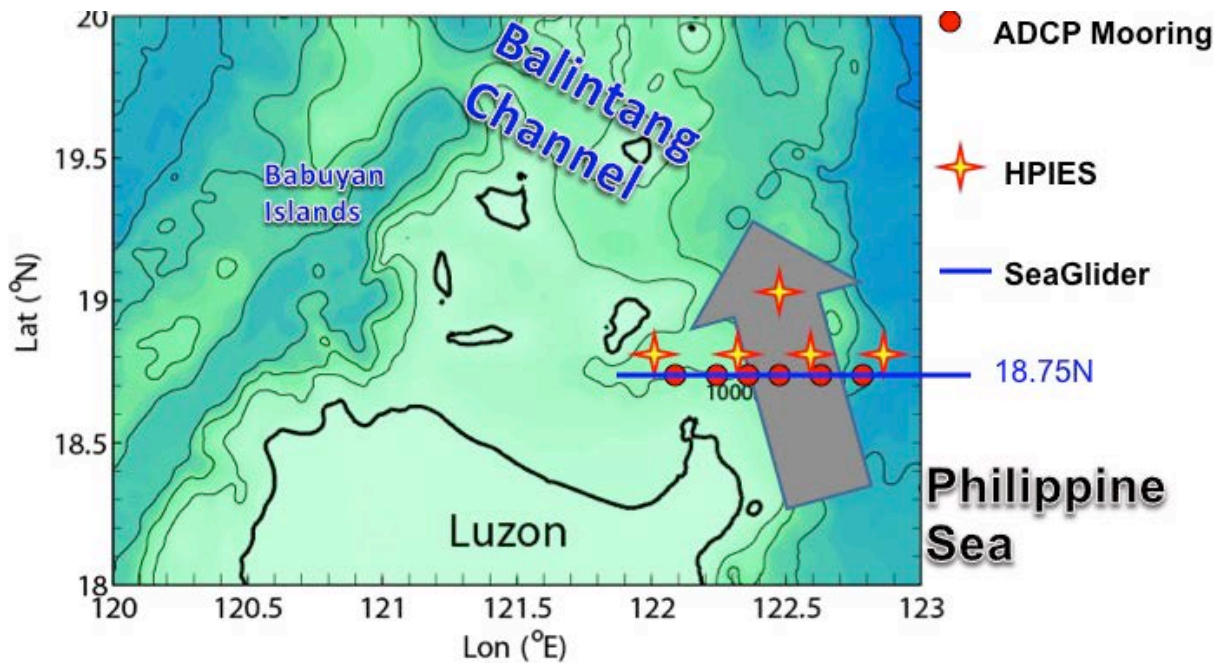


Fig. 6: Locations of the ADCP moorings and HPIES NE of Luzon Is. June 2012-June 2013.



Fig. 7: Illustration of HPIES (right panel) deployed in relation to R-C Lien's ADCP mooring array (left panel). The HPIES consists of the URI CPIES on top. This unit measures travel time of acoustic pulses to and back from the surface and bottom pressure. The HEF unit is in the yellow hard hat with electrode arms and water switches on the white plastic platform.

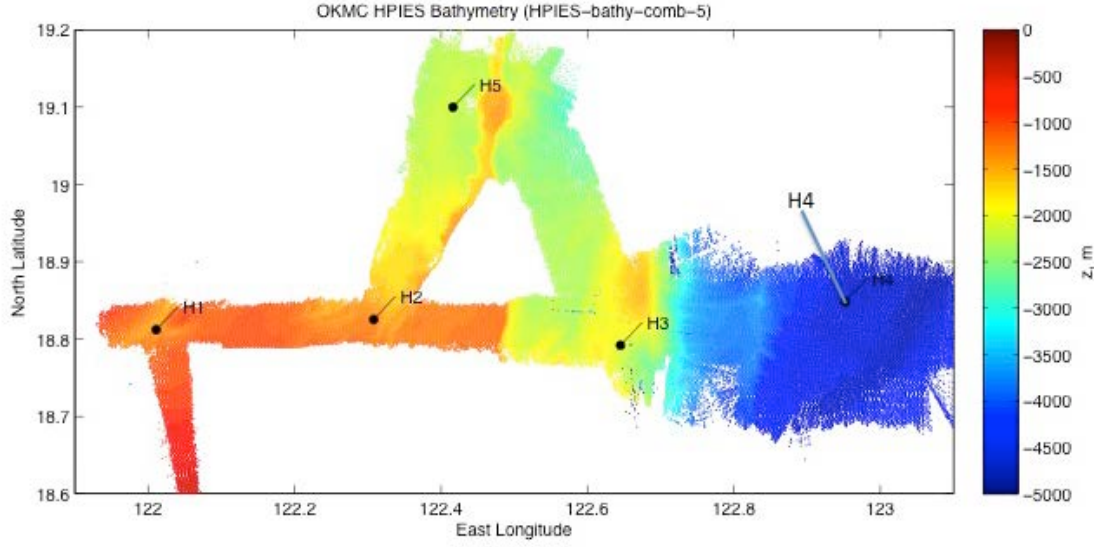


Fig. 8: Bottom topography along the line of HPIES deployments. The appearance is of irregular lava flows with nearby topography of hundreds of meters. The overall trend is from about 1 km at H1 to over 4 km at H4.

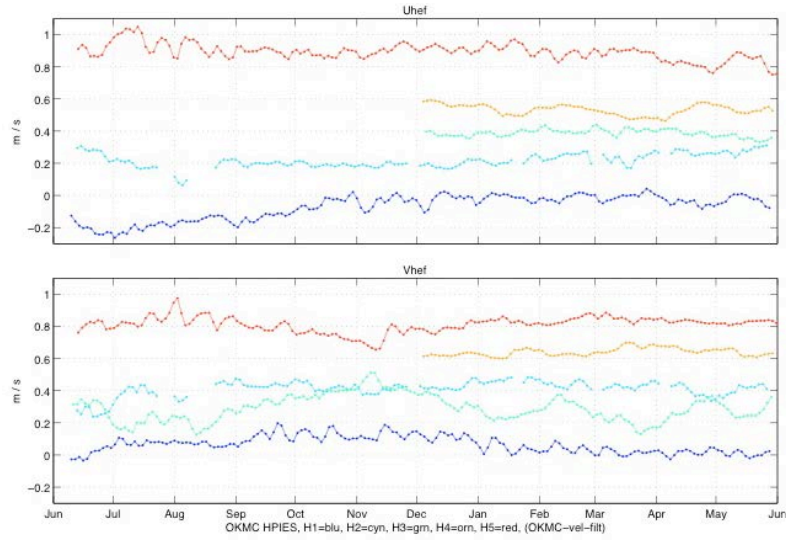


Fig. 9: Time series of vertically averaged U and V components from the HEF observations. The code is H1 (westernmost) blue, H4 (easternmost) brown and H5 (northern unit) red with each offset by 0.2 m s^{-1} .

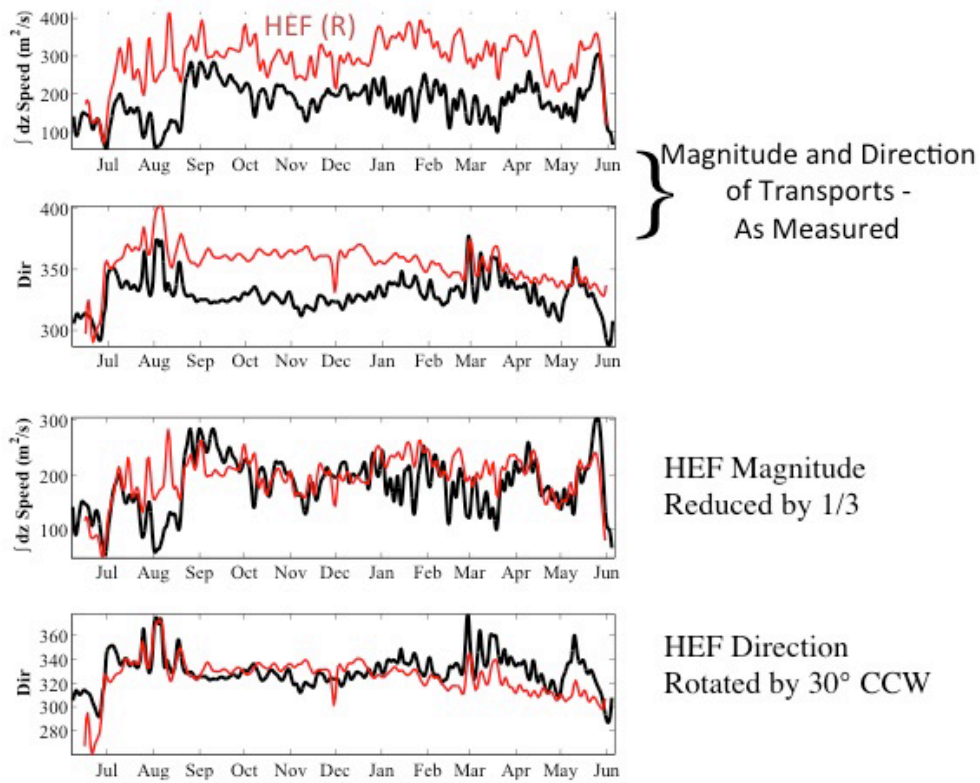


Fig. 10: Example of H2 time series from June 2012 to June 2013. The top two panels show volume transport per unit width (vertical integral of horizontal velocity) as observed by the HEF (red) and ADCP (black). The ADCP is averaged over upper 600 m. The HEF is over the 1343 m of the water depth. The differences between the two measurements appear to be caused by galvanic distortion (Chave et al. 2004). An ad hoc correction to the observations makes the two observations much more similar, assuming little mean flow below 600 m.

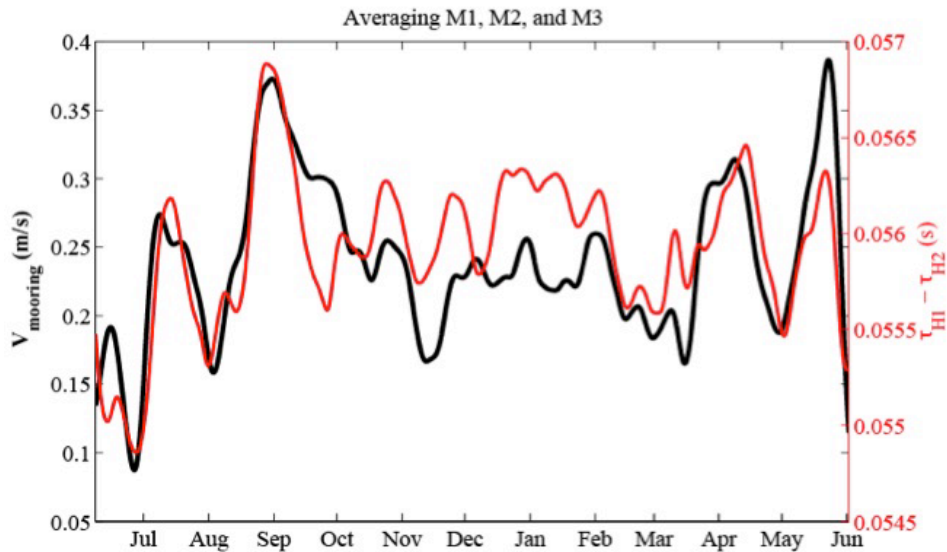


Fig. 11: Comparison of travel time differences between H1 and H2 and vertically averaged velocity on adjacent ADCP moorings.