

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 electric fields and Inverted Echo Sounders for measuring ocean velocities from a bottom lander.

OBJECTIVES

The primary objectives of this observational program are to quantify the origin of the Kuroshio and Mindanao currents at their origin and determine the volume transports off NE Luzon Is.

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 EF, Pressure and Inverted Echo Sounder. The HEF measures the barotropic horizontal velocity. The pressure and IES data determine baroclinic velocity when operated in a horizontal array. Three complete HPIES exist from the original NSF development support. Two new HPIES are built using existing PIES and new HEF units.

Nine EM-APEX float are deployed along of 135°E between 13° N and 22°N. Floats drift at a parking depth (~200m) that moves with the westward component of North Equatorial Current (NEC) with profiles to 800 m to acquire velocity and density profiles. Two profiles are taken about half an inertial period apart.

Ren-Chieh Lien deployed five HPIES around upper ocean ADCP moorings. The ADCP is moored at 600-m level and upward looking. The HPIES will provide the depth-averaged velocity. Thus, the combination provides both upper-ocean Kuroshio transport and total-water transport. The moorings and the HPIES are installed at NE of Luzon. The HPIES and ADCP array are centered at the Kuroshio stream.

WORK COMPLETED

The KORDI R/V Onnuri deployed nine EM-APEX floats in June 2012 (Fig. 1). The deployments have been delayed after float #4906 was deployed to allow Typhoon *Guchol* to pass. The deployment started

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around 20°N, 133°E and ended at 13°N, 136°E. All the floats are profiling every half inertial period which has ranges from 35 h at 20°N to 53 h at 13°N.

Revelle cruises 1205 in Jun 2012 and 1307 and Jun 2013 were devoted the deployments of ADCP moorings, HPIES and CTD stations along 18.8°N, NE of Luzon Is., respectively. The field operations went well and all gear was recovered.

Data analyses have been conducted to determine data quality and make comparison between HPIES and mooring observations. The HEF (hor. E-field) observations suffered from a failure of the optical interrupter sensor to stop the water switch at the desired “pinched” and “unpinched” positions. However, the default “timeout” did provide adequate pinch/unpinch conditions. As a result was recovered about 80% of the expected 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 shown in Fig. 1 was successful in revealing the NEC flow toward a bifurcation region south of Luzon Bay on Luzon Is. Figure 2 is the trajectories of the floats. There is a nice show of floats converging in a jet-like flow. Float 4911 moved steadily toward Luzon where it stalled. Figure 3 shows the changes in the T/S structure as the float moved west. Float 4437 left the Kuroshio and entered the Luzon Straits and South China Sea, trapped in the mesoscale eddy SW of Taiwan. Floats 4915 and 3763 were entrained into the Mindanao Current Kuroshio and rapidly moved south and headed toward Taiwan or into the S. China Sea, respectively. Figure 4 shows the water properties and along track absolute velocity versus latitude. The bifurcations latitude is clearly around 15°N.

Initially, it appeared that much of HEF (horizontal electric field) system on the HPIES had failed. The evidence was that several of the HEF units exhibited failure to pinch the water switch tubing properly. After analysis, it was found that the default mode of the water switch provided adequate pinching for about 80% of the time. So we have proceeded with analyses of the HEF data.

Much of the past year has been devoted to quality control of the HPIES data and comparisons of HPIES observations with other methods used in the area. Suitable co-located and simultaneous observations include shipboard ADCP, Lien’s ADCP moorings, Lee’s Seagliders and single EM-APEX floats that pass over the array. In this work we have been aided by the advice and analyses of Ren-Chieh Lien, Barry Ma, Vigan Mensah (NTU) and Magdalena Andres (WHOI).

Results from the floats include comparisons of geostrophic vs. MIV velocity profiles, velocity and water mass structures along the tracks of floats that ended up in the Kuroshio and Mindanao Currents and relationships between AVISO surface current and float profiles.

The HPIES provides bottom pressure, IES transmission times (related to heat content of the water column) and vertically averaged velocity from motional induction. They were deployed in association with Lien’s ADCP moorings along 18.8°N, NE of Luzon Is., the Philippines (Figs. 5 and 6). For half the duration of the deployment, Lee deployed Seagliders. The shipboard CTD and Seaglider data provide the information to construct a GEM model for interpreting the IES observations.

Figure 7 is a comparison of the HPIES pressure record and the TPXO numerical tidal model.

Vigan Mensah with help from Magdalena Andres and others developed the GEM model used to compute sections of the hydrographic structure based on the IES array. Figure 8 shows the comparisons with ADCP and Seaglider volume transports per unit width and the results from the IES system on HPIES.

The results in Figure 9 show a period of major discrepancy from the end of July to mid-September 2012, where a maximum difference of nearly 5 Sv exists. This time corresponds to the passage of a small and relatively weak anticyclonic eddy following a NNW course and whose westernmost influence seems to extend towards the east of PIES array.

This rather weak eddy could have a significant influence on the surface layer only. In this case, its influence would not be captured properly by the ADCP, owing to the fact that the velocity in the upper 45m is consider constant from the last good ADCP surface bin (45m) to the surface.

A comparison of the ADCP and PIES velocity profiles during that period tend to confirm this hypothesis, as the PIES derived profiles show a much stronger surface current than the ADCP at M4 and M5. This difference decreases towards the west, which would be consistent with the limited westward extent of the eddy influence.

The influences of the near-surface anomalies of water properties, causing unexpected variations in sound speed and τ is evident in the spatial structure of SST shown in Fig. 10.

The PIES data present the advantage of providing full depth profiles of velocity. It is then possible to obtain valuable information on the current below the core of the Kuroshio. The monthly current velocity sections exhibited in Figure 11 show that a southward flowing undercurrent with a strong temporal and spatial variability is present below $\sim 400\text{m}$. A study about this undercurrent, based on Seaglider sections, is currently in progress (Ma et al., 2014). It is hoped that the PIES derived velocity profiles will come as a complement to the Seaglider data and will provide valuable qualitative information about this undercurrent.

Figure 12 shows that HEF-derived velocities and transports appear larger by 30% and at a slightly different direction compared with the ADCP averaged between M2 and M3, which bracketed H2 (see Fig. 5).

RELATED PROJECTS

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 as 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. Preliminary results were presented at the *Ocean Sciences Meeting* in February 2014.

REFERENCES

Meinen, C. S., D. S. Luther, D. R. Watts, K. L. Tracey, A. D. Chave, and J. Richman (2002), Combining inverted echo sounder and horizontal electric field recorder measurements to obtain absolute velocity profiles, *J Atmos. Oceanic Technol*, **19**(10), 1653-1664.

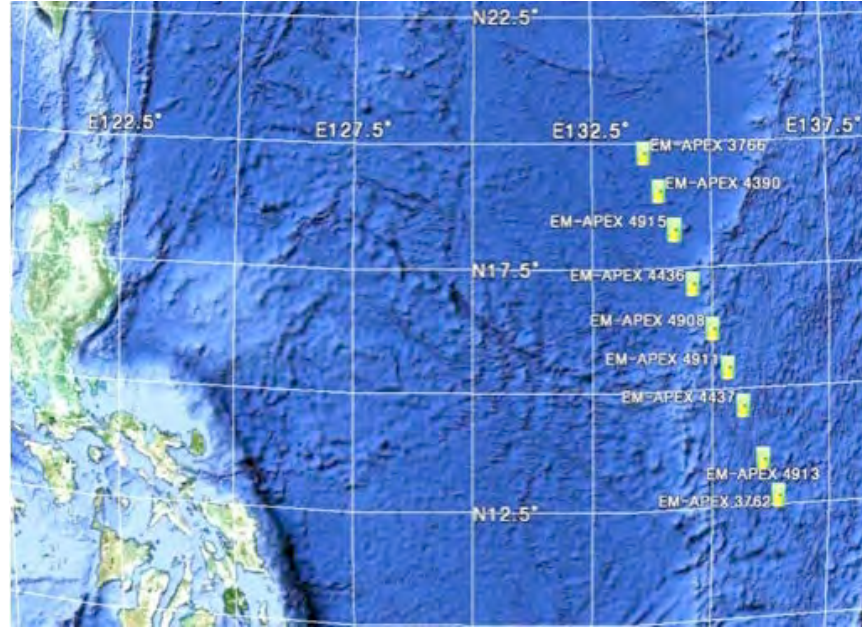


Fig. 1: Deployment positions for the 9 EM-APEX floats deployed by the Korean Ocean Research and Development Institute's R/V Onnuri, in June 2012 between 20°N and 12.5°N along 135°E.

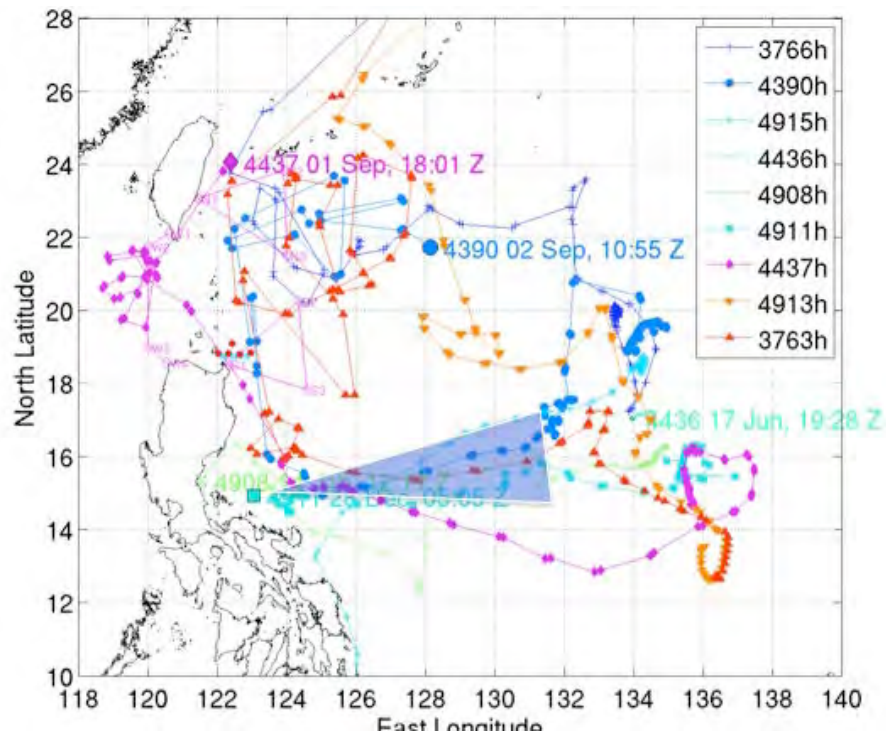


Fig. 2: Float trajectories from deployment along 135°E. Some floats went directly toward Luzon Is. Others tended to go NW toward Taiwan. Floats that neared Luzon, went mostly N.

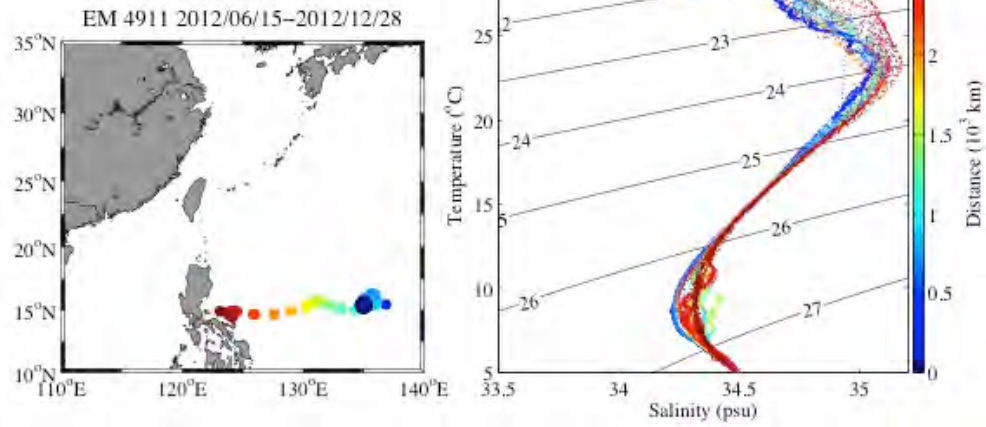


Fig. 3: Float 4911 went straight toward Luzon. On the way, the T/S relation changed, especially in the regions of the salinity maximum and minimum.

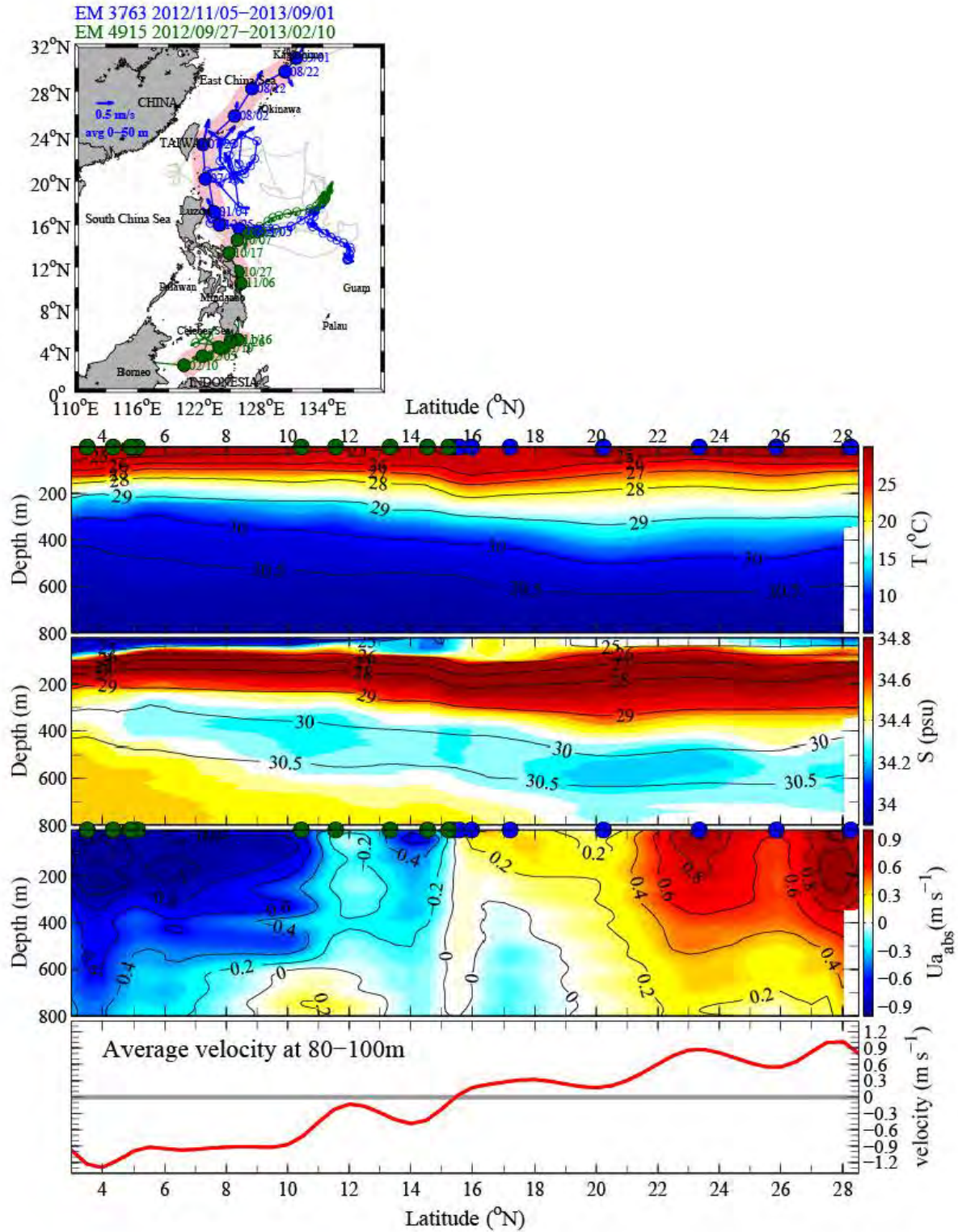


Fig. 4. Two EM-APEX floats went into the bifurcation site at 15°N. One flowed north (blue dots: float 3763) joining the Kuroshio Current, and one flowed south (green dots: float 4915) joining the Mindanao Current. Along these tracks temperature, salinity, absolute velocity and average velocity at 80–100 m are shown as a function of latitude.

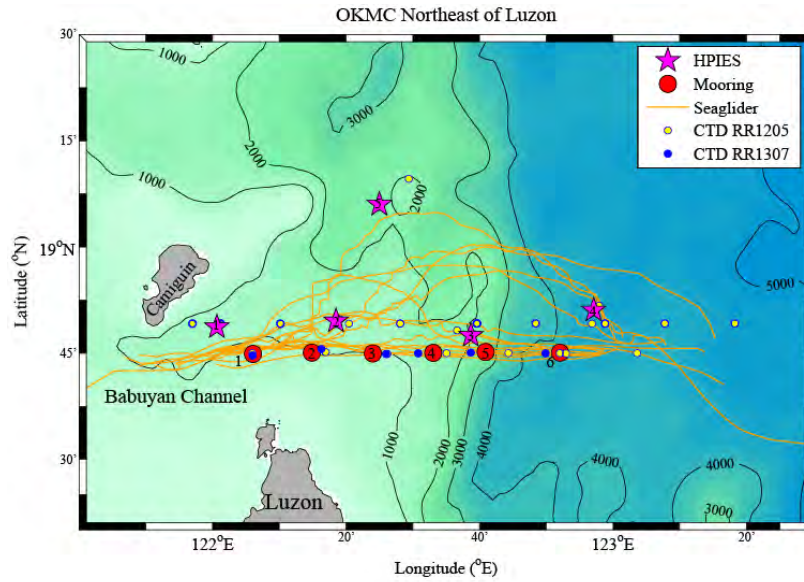


Fig. 5: Locations of the ADCP moorings, HPIES and Seaglider tracks NE of Luzon Is. June 2012-June 2013.

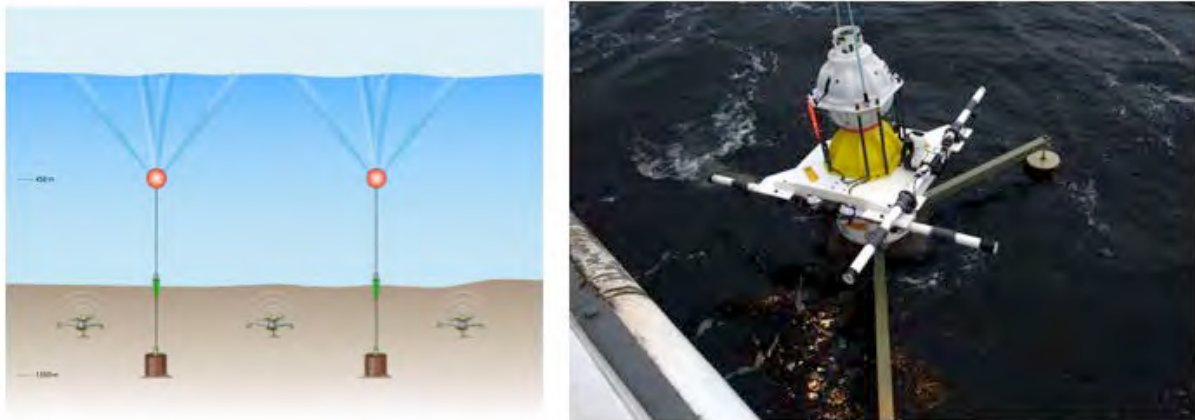


Fig. 6: Illustration of HPIES (right panel) deployed in relation to R-C Lien's ADCP mooring array (left panel). The HPIES consists of the URI CPIES on top. This unit measures travel time of acoustic pulses to and back from the surface and bottom pressure. The HEF unit is in the yellow hard hat with electrode arms and water switches on the white plastic platform.

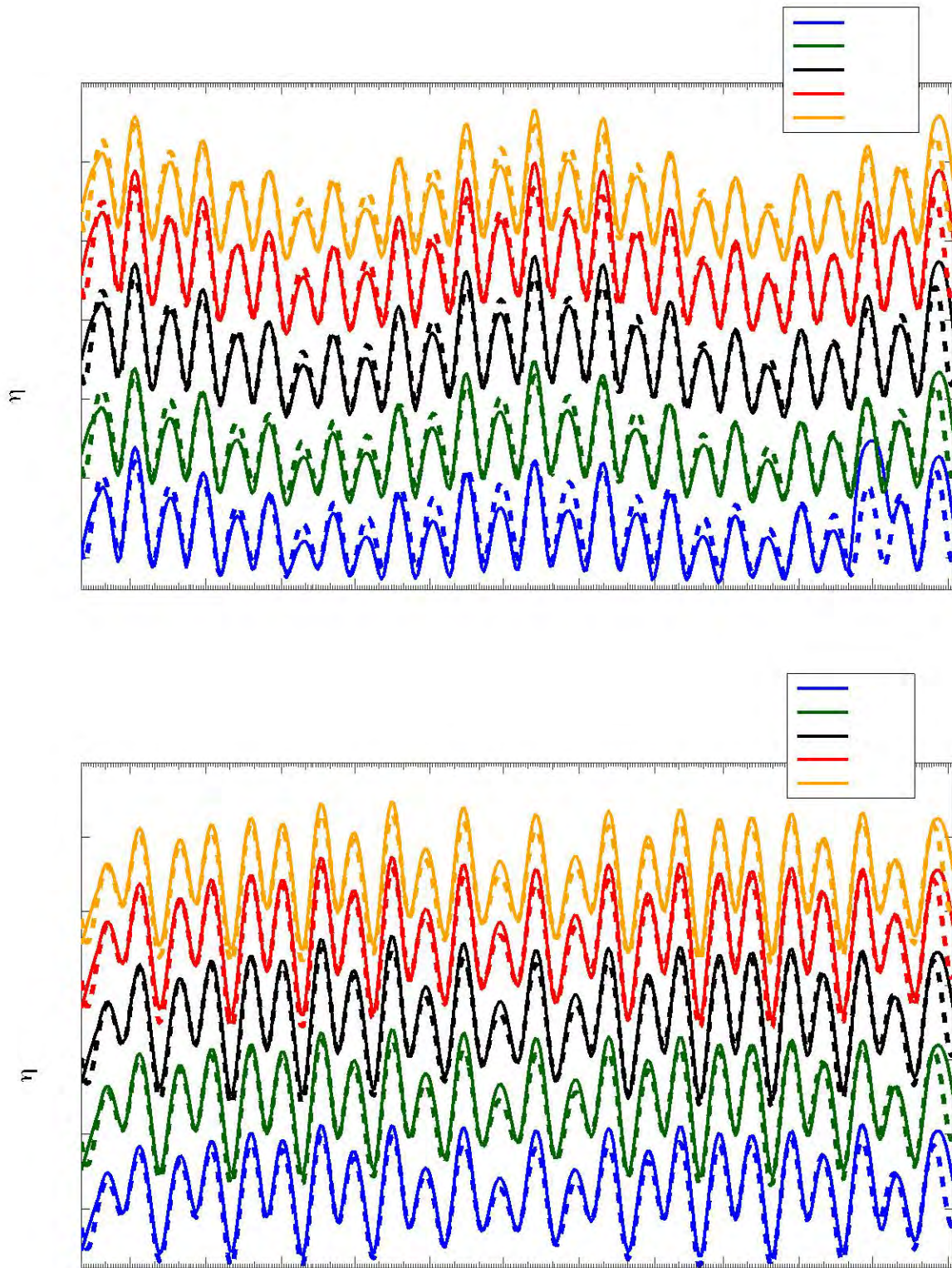


Fig. 7: Comparison o HPIES pressure (P) and TPXO sea surface height (η) timeseries for diurnal (upper panel) and semi-diurnal (lower panel) tides.

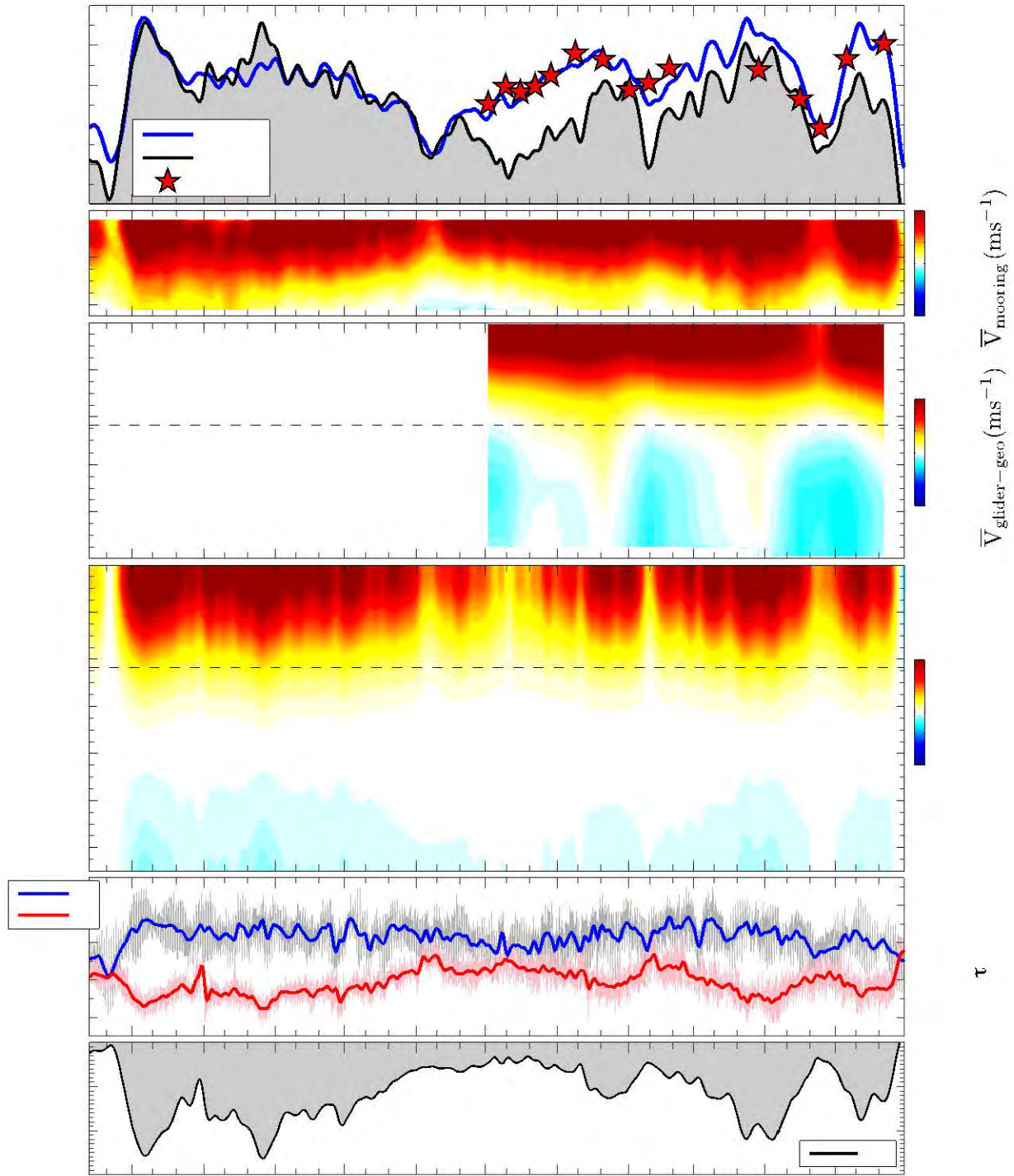


Fig. 8: Comparisons of IES, Moorings and Seaglider timeseries of northward velocity. IES values are averages over the upper 1200 m; Moorings are averages over 400 m and Seaglider estimates are averages over the upper 1000 m. Although IES departs from Mooring and Seaglider results, IES is full water column. Note Fig. 9 shows the comparisons for transport.

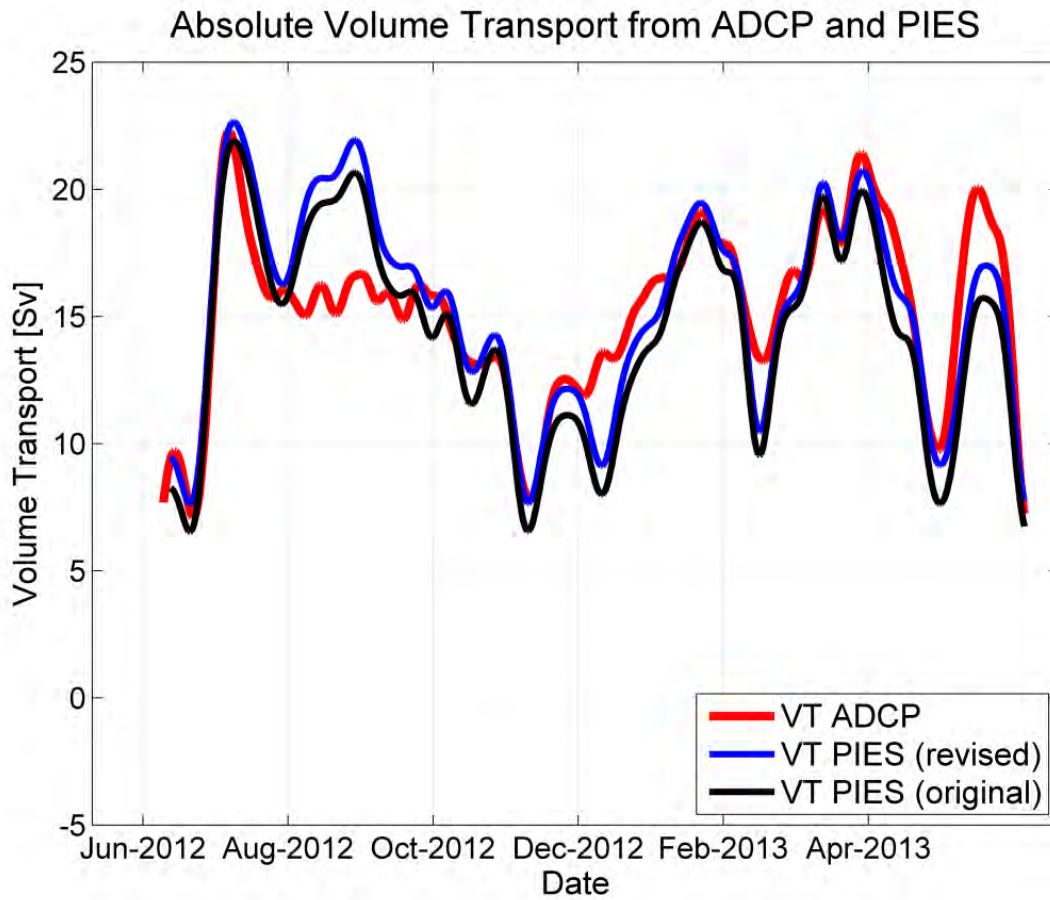


Figure 9: Time series of the Kuroshio volume transport across the M line from the ADCP, and the updated and original PIES processing.

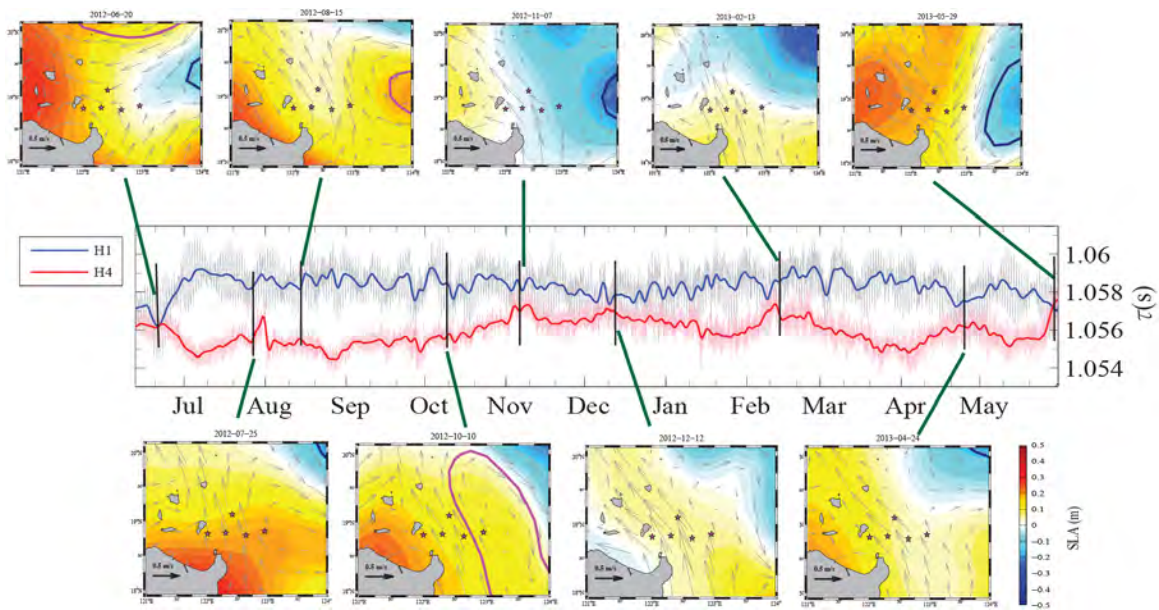


Fig. 10: Analysis of possible influences of mesoscale eddies on the various velocity and transport estimates.

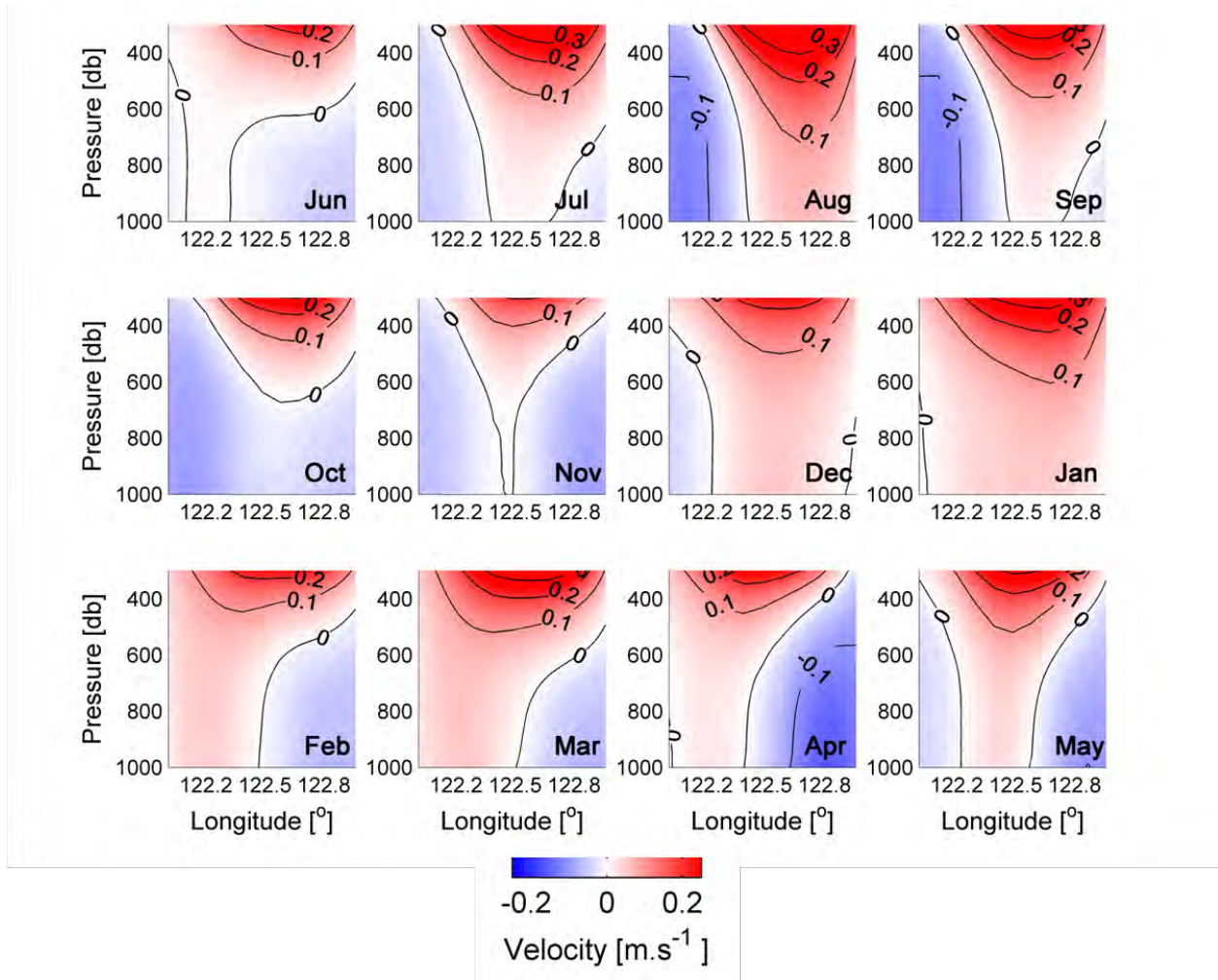


Figure 11: Monthly map of deep (>300 dbar) current across the HPIES-line. These current profiles based on IES and Seaglider could also be used to determine the structure of the level of no motion below the Kuroshio east of Luzon and its spatial and temporal variability. Note that evident depth variations of the level of no motion are visible from Figure 11.

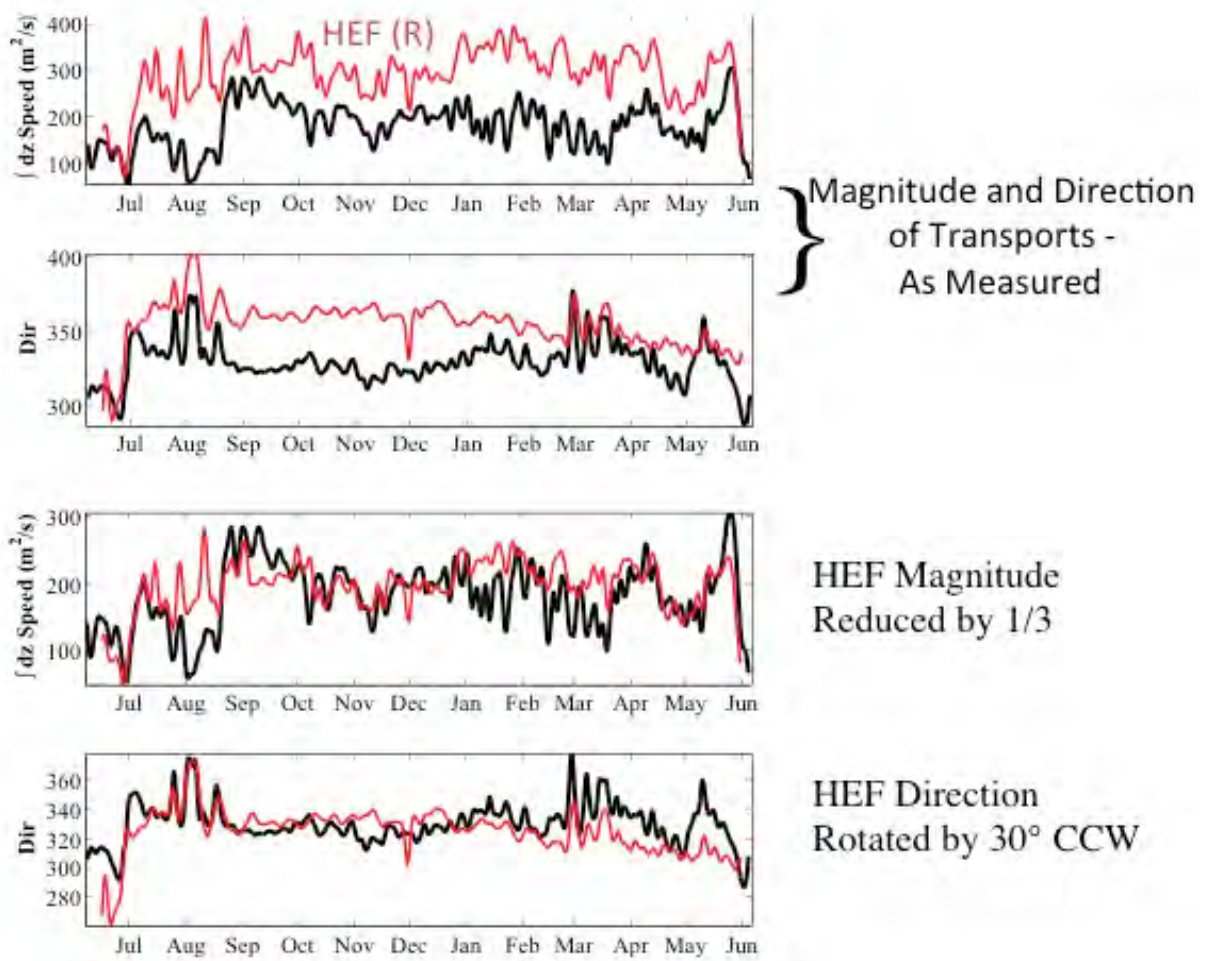


Fig. 12: Example of H2 time series from June 2012 to June 2013. The top two panels show volume transport per unit width (vertical integral of horizontal velocity) as observed by the HEF (red) and ADCP (black). The ADCP is averaged over upper 600 m. The HEF is over the 1343 m of the water depth. The differences 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.

Northward Transport

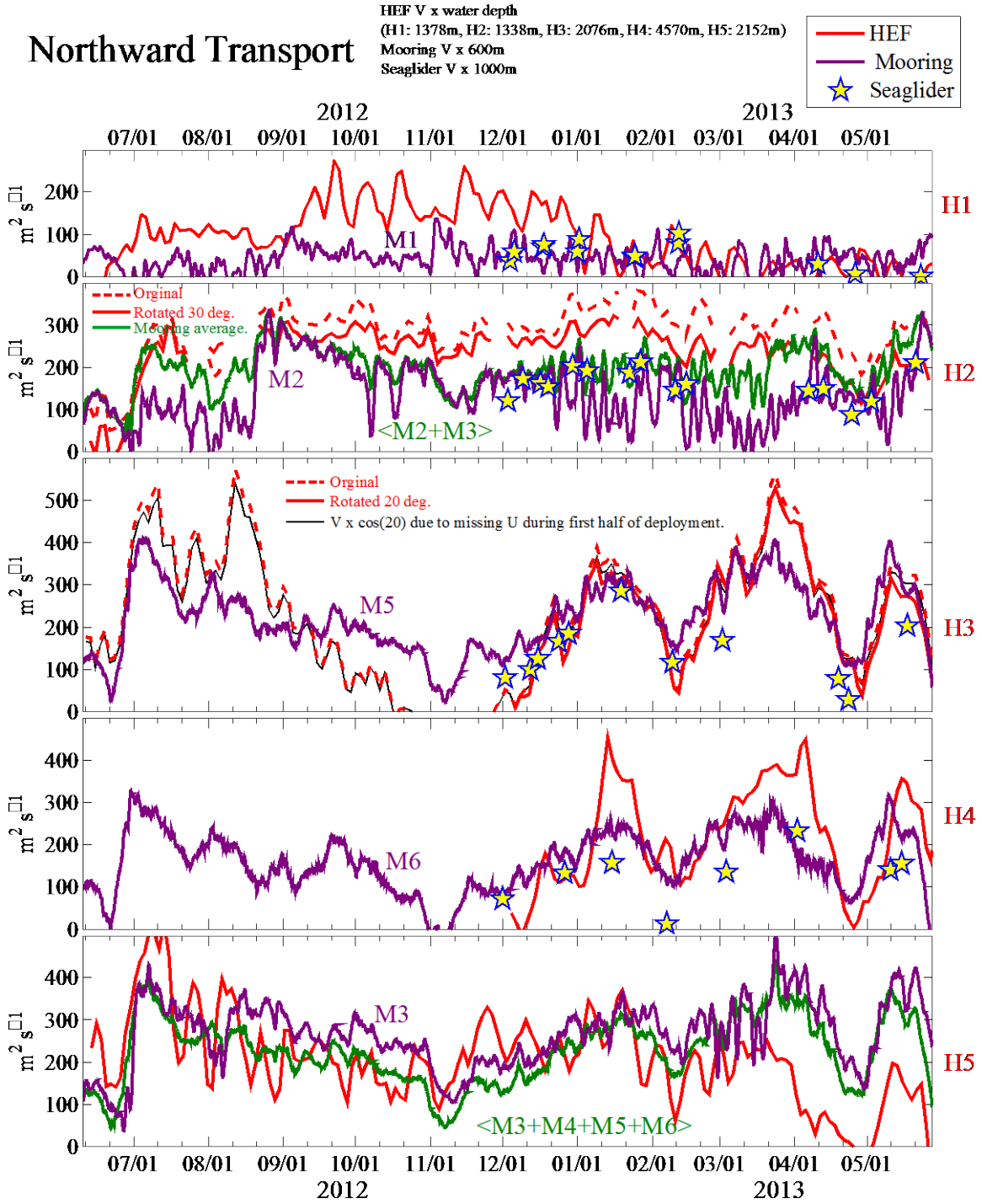


Fig. 13: Comparisons of HEF, Mooring and Seaglider northward volume transport per unit width. HEF values are average over total water depth, Mooring values are averages of 600 m and Seaglider transport is over upper 1000 m. Some differences in transport are expected because of the different vertical averaging intervals. (Let's redo H2 by reducing the amplitude by 1/3 and rotating CCW 30 deg.