Making progress and Wanting More: One-year near-surface current measurements from a surface mooring in the Gulf Stream and other thoughts about long-term surface moorings

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Abstract-Recently, as part of the CLIMODE (CLIVAR Mode Water Dynamics Experiment) a surface mooring was placed at 38 N, 65W, a location that was at times in the core of the Gulf Stream. The surface mooring survived the first year at this 5000m deep site, and the second deployment failed after 2 months. Two Nortek current meters provide some of the first direct near-surface current time series from such a location, and represent progress in sustained sampling from surface moorings. At the same time, the ability to sustain surface moorings for a year at a time presents challenges for current meters. After one year, it is hard to escape biofouling and, at times, damage from fishing gear. Such concerns lead to using current meters with no moving parts, but the present trade off between sampling and power in most instruments typically constrains one to four samples per hour, not frequent enough to either match the sustained sampling rate of temperature and salinity now possible or to resolve high frequency processes of interest. Once per minute sampling and proven accuracy as can be obtained by a Vector Measuring Current Meter (VMCM) would be desirable for near-surface moored deployments.

I. Background

In this paper we present some new current meter measurements made recently from a surface mooring deployed off New England, at 38.5°N, 65°W, at a site that was at times in the core of the Gulf Stream. Both the deployment of a surface mooring at such a location and the collection of direct near-surface current meter data were challenges. We had some success at both and report that here.

The plan for the mooring was to do two one-year deployments. The first year deployment was successful, deployed in November 2005 and recovered in November 2006. During January of the second year the mooring line parted. We discuss the mooring design and offer some thoughts about why the second deployment failed. The requirement for near-surface velocity observations was driven by two needs. One was to obtain accurate estimates of the air-sea exchanges of heat, momentum, and freshwater and by the use of bulk formulae to make these estimates that require measurement of the wind velocity relative to the surface current. The second was to observe the near-surface velocity structure in support of examining the dynamics and heat balance of the upper ocean. Our work was done as part of CLIMODE (CLIVAR Mode Water Dynamics Experiment), which had a focus on the processes that form 18°C mode water in the region. Knowledge of the near surface velocity structure is essential to understand the processes that govern the structure and heat content of the upper ocean, especially processes such as horizontal advection and shear-driven mixing.

This paper presents more discussion of the need for and utility of near-surface currents in this project, the mooring design, including our approach to obtaining near-surface currents, the performance of the current meters, and some thoughts on the continuing need for accurate near-surface current meters.

II. Motivation

The location of the surface mooring (Fig. 1) was chosen to be near the formation of Eighteen Degree Water (EDW). This region is believed to be located south of the Gulf Stream, where strong currents with steep isopycnals favor large-scale baroclinic instabilities. It is also a region of large air-sea heat exchanges, due to the winter time advection of cold air from the polar and Canadian regions over the warm waters of the Gulf Stream. The mooring was located close to the Gulf Stream in order to sample the meteorological conditions and quantify air-sea fluxes upstream of the region of formation.

The in-situ measurements of air-sea variables and the computations of high accuracy air-sea fluxes are key to the CLIMODE project as it sets the correct atmospheric forcing responsible for EDW formation. EDW is believed to be created in part by air-sea exchanges which trigger convective motion and deepening of the mixed layer. Water mass properties are set at the interface with the atmosphere and then get sheltered in the oceanic interior after restratification occurs at the surface in late spring. However, past estimates of EDW formation and dissipation rates [1] did not agree with rates of injection in the subtropical gyre [2, 3], which challenged this formation process. Another process was put forward, where baroclinic instabilities near the frontal current also participate in EDW formation. Our in-situ measurements will be used to validate and improve maps of air-sea fluxes provided by numerical weather products and remote sensing. This in turn will allow us to quantify the role of each EDW formation process, and a better understanding of oceanic eddy mixing in the upper ocean.

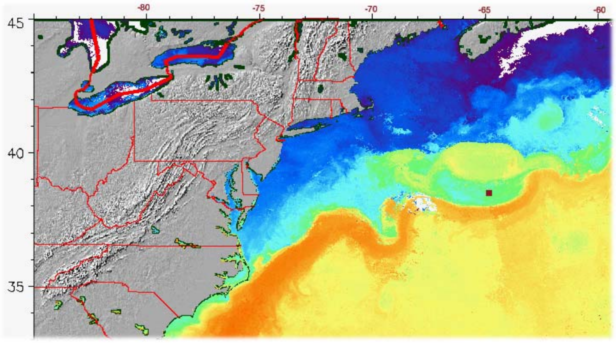


Figure 1. Gulf Stream SST. Square indicates Climode surface mooring location.

Our primary tool for estimation of the air-sea fluxes was via the bulk formulae. These formulae require knowledge of the wind relative to the surface current. With the potential for the Gulf Stream to exceed 2.5 m s^{-1}, the surface current in the vector difference between the surface wind and the surface current could not be ignored. We needed to place a current meter very near the surface, just under the surface mooring. We placed one Nortek Aquadopp at 10 m depth. For two reasons, we placed a second Nortek at 20 m. First, as a backup for the 10m instrument. Second, we were interested in the near-surface velocity structure and vertical shear of the current.

III. Mooring Design

The diagram of the mooring we deployed is shown in Figure 2. The surface buoy provided the platform on which to mount meteorological sensors and associated data logging and telemetry hardware [4]. The 3-m diameter closed-cell foam buoy has a well for batteries and data loggers. The superstructure of the buoy provides location for mounting the meteorological sensors. In support of the goal of estimating the air-sea fluxes, sensors were mounted to obtain all the mean meteorological variables used in the bulk formulae approach [5] and, in recognition of the uncertainties possibly associated with the use of this method in the conditions anticipated in the winter in the Gulf Stream, sensors were also mounted for estimating fluxes using direct covariance flux methods [6]. In anticipation of rough conditions, most sensors were duplicated, some triplicated.

In the bridle of the buoy we fitted a strain gauge tension cell (second deployment only), which sampled at a 5 Hz rate for 16 minutes of each hour. The data was stored in the buoy data logger.

In addition to the two Nortek current meters, there were temperature and salinity sensors on the bridle of the buoy and at 5m depth and temperature sensors at 15m and 40m and every 40m below that, down to 660m (a pressure sensor was also mounted on the deepest instrument to correct for depth changes due to mooring line tilts).

Designing a surface mooring to survive Gulf Stream currents presented a new challenge. Computer modeling was done using two programs – WHOI Cable, a relatively recent dynamic design program (also having static design capabilities), and SURFMOOR, a static design program used at WHOI for the last 25 years. Static numbers from both programs yielded very similar results. Early in the design process, it became obvious that some portion of the upper wire rope section of the mooring should have drag-reducing fairing installed. The predicted loads at the buoy and the anchor were simply too great.

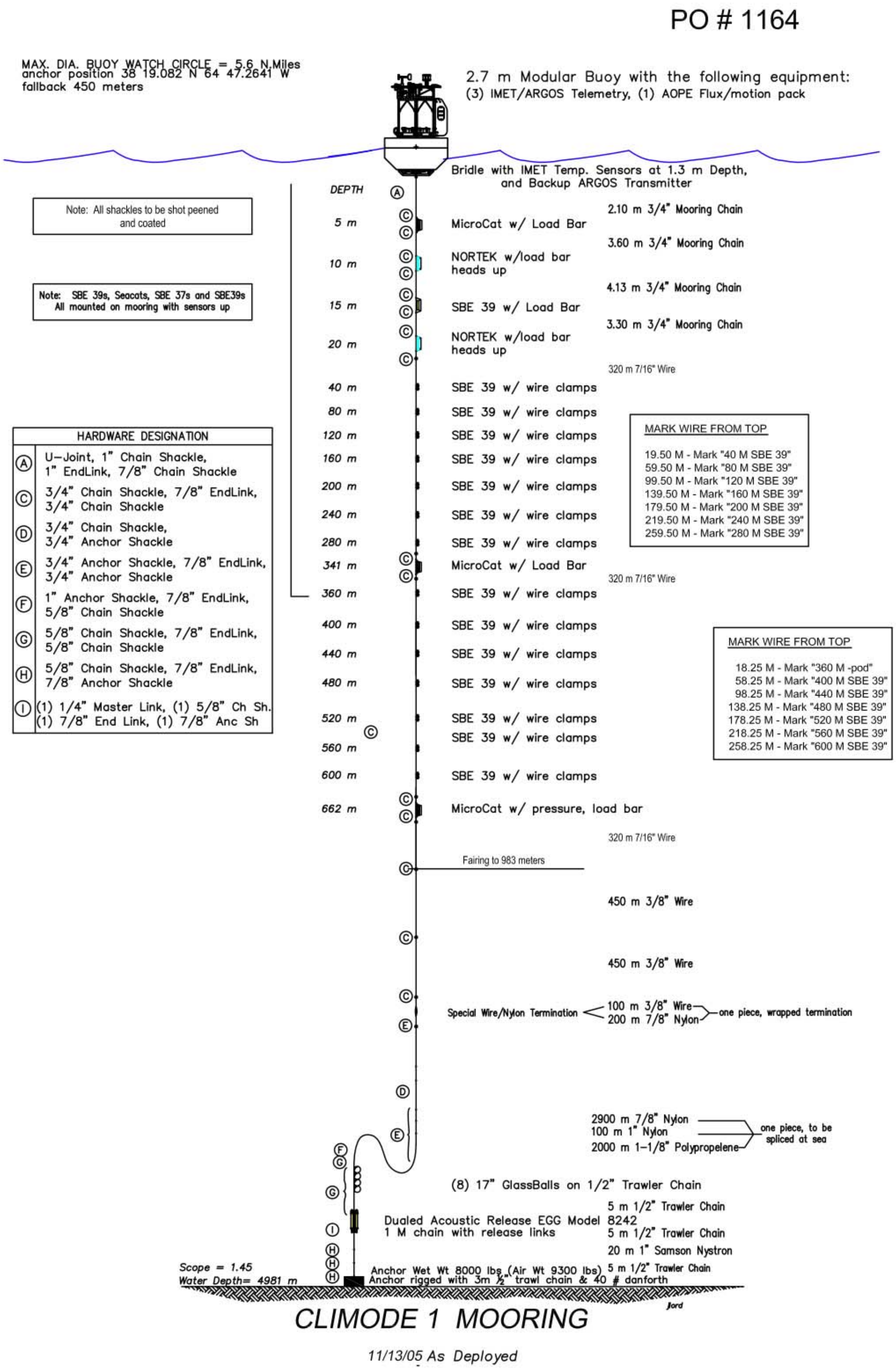
Various scenarios were run using different wire diameters and various total lengths of fairing. The best compromise used roughly 1000 meters of 7/16” wire rope with clip-on fairing for the upper portion, 3/8” wire without fairing for the next 1,000 meters, then synthetic line from there to the bottom – Nylon above and Polypropylene below to give the lower portion of the mooring the familiar inverse catenary “S” shape. The scope of the mooring (slack length divided by water depth) was 1.45, resulting in a watch circle diameter at the buoy of 5.6 nautical miles at the extreme current profile (Table 1). This configuration resulted in a predicted buoy tension of 7,512/7,552 LBs (SURFMOOR /WHOI Cable) and anchor tension of 6151/6288 LBs(SURFMOOR/WHOI Cable) in the extreme current.

TABLE 1

Peak Current		Extreme Current	
Depth(m)	Speed(cm/sec)	Depth(m)	Speed(cm/sec)
0	260	0	300
100	260	150	300
600	100	450	150
1000	50	750	95
1200	40	1000	70
1500	30	2000	30
5000	30	5000	30

(currents linearly interpolated between depths)

The failure two months into the second year deployment remains a mystery. Although the mooring parted at the highest current experienced, a bit over 2.5 m/sec, the one-inch nylon which was the point of failure was the strongest portion of the mooring, other than the ¾” chain. Buoy tension at the time of failure was consistent with computer predictions of tension caused by the measured currents.



HARDWARE DESIGNATION	
Ⓐ	U-Joint, 1" Chain Shackle, 1" EndLink, 7/8" Chain Shackle
Ⓒ	3/4" Chain Shackle, 7/8" EndLink, 3/4" Chain Shackle
Ⓓ	3/4" Chain Shackle, 3/4" Anchor Shackle
Ⓔ	3/4" Anchor Shackle, 7/8" EndLink, 3/4" Anchor Shackle
Ⓕ	1" Anchor Shackle, 7/8" EndLink, 5/8" Chain Shackle
Ⓖ	5/8" Chain Shackle, 7/8" EndLink, 5/8" Chain Shackle
Ⓗ	5/8" Chain Shackle, 7/8" EndLink, 7/8" Anchor Shackle
Ⓘ	(1) 1/4" Master Link, (1) 5/8" Ch Sh. (1) 7/8" End Link, (1) 7/8" Anc Sh

MARK WIRE FROM TOP

19.50 M - Mark "40 M SBE 39"
59.50 M - Mark "80 M SBE 39"
99.50 M - Mark "120 M SBE 39"
139.50 M - Mark "160 M SBE 39"
179.50 M - Mark "200 M SBE 39"
219.50 M - Mark "240 M SBE 39"
259.50 M - Mark "280 M SBE 39"

MARK WIRE FROM TOP

18.25 M - Mark "360 M -pod"
58.25 M - Mark "400 M SBE 39"
98.25 M - Mark "440 M SBE 39"
138.25 M - Mark "480 M SBE 39"
178.25 M - Mark "520 M SBE 39"
218.25 M - Mark "560 M SBE 39"
258.25 M - Mark "600 M SBE 39"

Figure 2. Climode 1 mooring design.

Fig. 3 shows the tension measured by the load cell (sampled at 5Hz for 16 minutes at the bottom of the hour) prior to the breakup. Tension rose quickly from 4000 to more than 8000 pounds on January 31 2007 around 2300 UTC. Fast sampling tension data indicates oscillations at 3 to 4 seconds period, similar to wave motion inferred from the motion package. The wave height was not very high though.

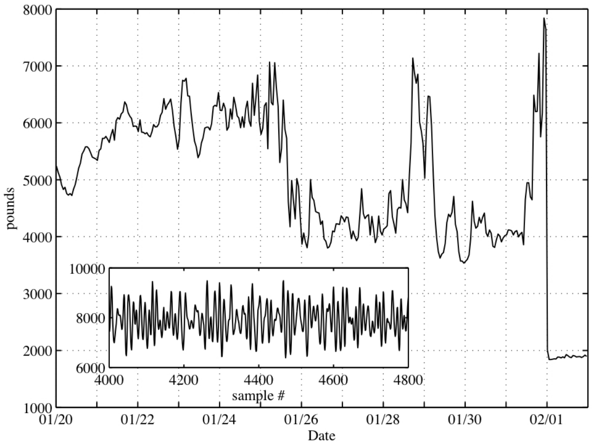


Figure.3. Tension in pounds on Climode 2 buoy averaged over 16 minutes. Insert: last 800 samples prior to mooring detachment.

IV. Performance of current meters

Two Nortek Aquadopp current meters were mounted on the Climode mooring, at 10m and 20m depths. Overall the current meters seemed to have worked properly. The signal to noise ratio was 4 to 5 for Climode 1 and higher for Climode 2 (instrument at 20m had a slightly lower SNR). Typical values for Aquadopp at 10m depth on Climode 1 for noise and signal are 16 and 70 respectively. The surface mooring was hit by a ship and we suspect this happened on January 19 2006 near 0830 UTC. The signal values for the shallow Aquadopp decreased to values near 50 after this collision (its pressure record also shows a large spike at time of collision, from about 10 to 100 dbars, with a slow relaxation after one day). The deeper current meter was unaffected. However, its pressure record shows a slow drift towards smaller values. Upon recovery, it was seen that a barnacle was lodged on the strain gauge and probably caused this slow drift as it developed.

The first deployment lasted 1 year as planned, from November 2005 to November 2006. The second deployment immediately followed the first one but lasted only 2.5 months because the mooring broke free on January 31 2007. Upon recovery of Climode 1, the vanes on the two current meters were broken. Since the vane should position the instrument facing the current, the difference between the instrument heading and the current direction should be near 180°. The data shows (Fig 4) that the vanes on Climode 1 probably broke around the same time (around November 24 2005) and that for most of the remaining deployment the instrument was measuring the current downstream. (Fig 5)

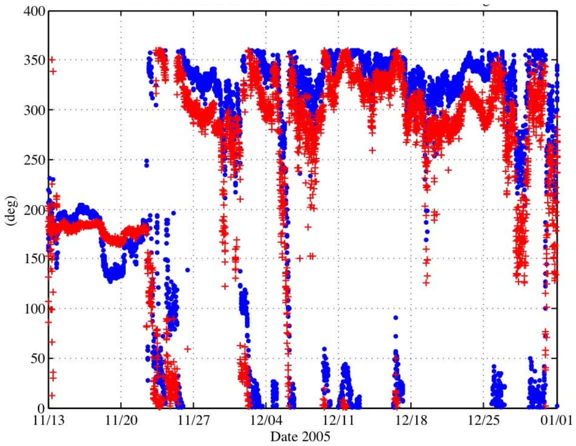


Figure.4. Difference between instrument and current heading on Climode 1. The presence of the vane is indicated by a 180 degree angle. Vanes seemed to have broken at about the same time around November 23 2005 for both instruments (10m=blue, 20m=red).

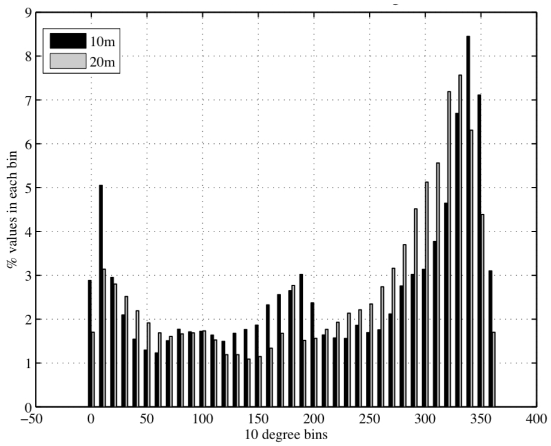


Figure. 5. Histogram of instrument and current angle difference for the whole Climode 1 deployment.

Upon recovery, current meters showed signs of biofouling and had moderate fishing gear entangled on them (Fig. 6). The vanes provided by Nortek for the Aquadopps on Climode 1 might have been too fragile. Indeed waves were rather high near November 24 2005. It is also possible that fishing gear tore up the vanes. Without the vanes the instruments tend to point downstream of the current and might therefore sample the flow that is perturbed by the mooring line. We cannot estimate here the extent of this contamination. For Climode 2, “homemade” vanes were installed on the instruments (Fig 7) and worked properly during the 2.5 months of the deployment. The protecting bar on the 10m Aquadopp was loose and might have interfered with its optical beams (Fig. 6)

During the buoy turnover cruise in November 2006 onboard R/V Oceanus, the ship was stationed for a period of 24 hours within one nautical mile of the buoy location for comparison of measurements from the buoy and the ship. Fig 8 shows the comparison between Climode 2 buoy after deployment and ship ADCP (30m depth bin). The wind was about 6 m/s during the whole station period and shifted from southeasterly to southwesterly at 0300 UTC.

Figure 6. Climode 1 10m Aquadopp at recovery (Nov. 2006). Note the fishing gear, broken protecting bars, and broken vane on the load bar, opposite side from the instrument.

Time series of current speed and direction are shown in Fig. 9 and 10, using hourly averaged data. The current was highest in the winter season. This is in part because the Gulf Stream meandering and shifting south in the winter, the mooring was trapped in the core of this major current intermittently. Winds are also plotted for comparison (note the 1/10 scaling factor) and are also stronger in winter. The winds were high and sustained before the Climode 2 mooring broke free. Recorded currents were also the strongest at that time. Current direction is also shown in a similar way in Fig 10. A strong eastward tendency is seen but the current also oscillates slowly as meanders develop. The gray line in Fig 10 shows the colinearity of the wind and current (antiparallel when negative).

Figure 7. Climode 2 Aquadopps before deployment (Nov. 2006). Vanes were made of plexiglass and 1/4" delrin for instruments at 10m and 20m depths respectively.

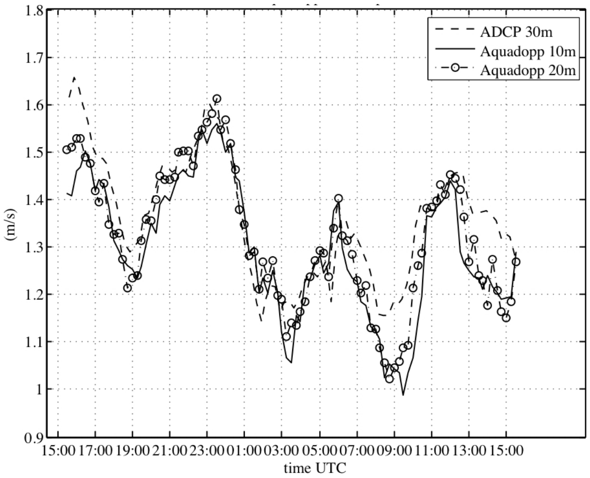


Figure. 8. Current (m/s) at 30m from ship ADCP and at 10m and 20m depths from current meters on mooring.

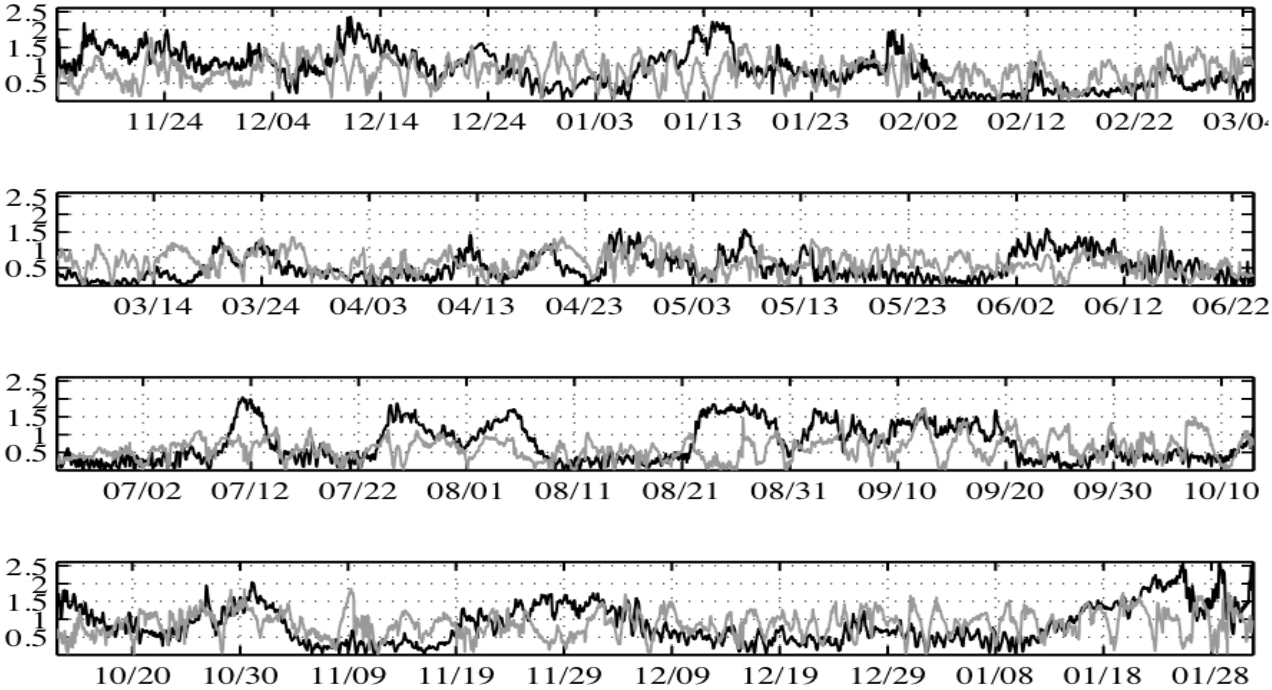


Figure 9. Current speed at 10m depth (black) and wind speed with a multiplicative factor 1/10 for scale homogeneity (gray). Hourly averaged data for the 15 months Climode deployment.

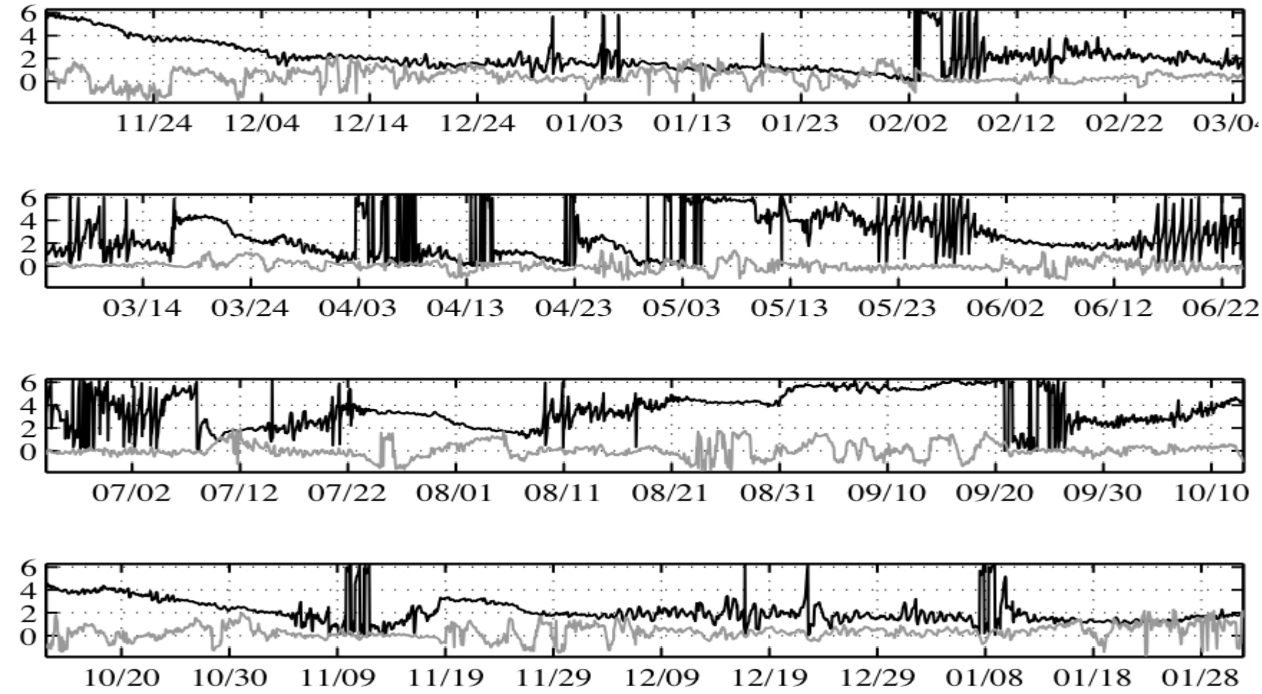


Figure 10. Current direction (radians) at 10m depth (black) and cosine (wind,current) times wind speed (gray). Hourly averaged data for the 15 months Climode deployment.

V. Discussion

In this paper we discuss our efforts to obtain near-surface velocity observations during the CLIMODE project. We made a step forward in surface mooring design and achieved some success at deploying such a mooring where it was often exposed to the currents of the Gulf Stream. The failure of the nylon in year 2 remains a concern and, unfortunately, a bit of a mystery. We were also pleased by the performance of the two Nortek Aquadopp current meters. Their small physical size and resulting low drag made them an appropriate choice. As far as we can tell, even without the fins, the current meter data looks good. Although the comparison between current meters and ship ADCP just before the Climode 1 recovery showed some discrepancy, we do not know whether it is due to real differences in the flow between the measuring sites. We had little to compare them to. The Climode 2 records were consistent and agreed well with the ADCP data from the ship.

One impression we are left with, though, is that obtaining accurate near-surface velocity observations near the surface remains a challenge that deserves continuing attention. This is a region where biofouling is at times intense and here damage from fishing gear may occur. It is also where proper averaging of surface wave orbital velocities and platform motion is required and where the platform to which the current meter must be attached will be far from stable.

Another impression is that the need for such observations remains. In low winds, the shallow penetration of solar insolation restratifies the upper few meters, and a better understanding of the physics of this restratification and subsequent mixing requires good, near-surface horizontal velocities. Indeed, there is not yet convergence of what the ‘real’ vertical profile of horizontal velocity is in the upper ocean, nor on the dynamics of all the processes that govern the vertical transport of horizontal momentum down from the sea surface. To illustrate this, Fig 11 shows the combination of temperature profiles from instruments below the buoy along with the current meter data. The period shown (June 12-19 2006) encompasses a sudden wind burst on June 15 which created an internal wave. Following the wind burst, the mixed layer deepens quite rapidly and regions of warm and cold water alternate, compressing the isotherms. An interesting feature following the internal wave is the decrease in stratification. Surely, a better spatial and temporal resolution of temperature and currents in similar regions would help determine what processes are at play there.

It is straight forward to obtain temperature and salinity (and thus the information about the density structure) on moorings, for example, by attaching internally recording temperature/salinity recorders every meter along a mooring and on the bridle of the buoy and by setting them to record every minute for up to a year. It is not yet as easy to obtain horizontal velocities at the same time sampling and vertical resolution and with similar precision. When will we be able to obtain accurate (say to several percent) mean horizontal velocities sampled every minute, at every meter along the upper part of the mooring, right up to 1 meter below the sea surface?

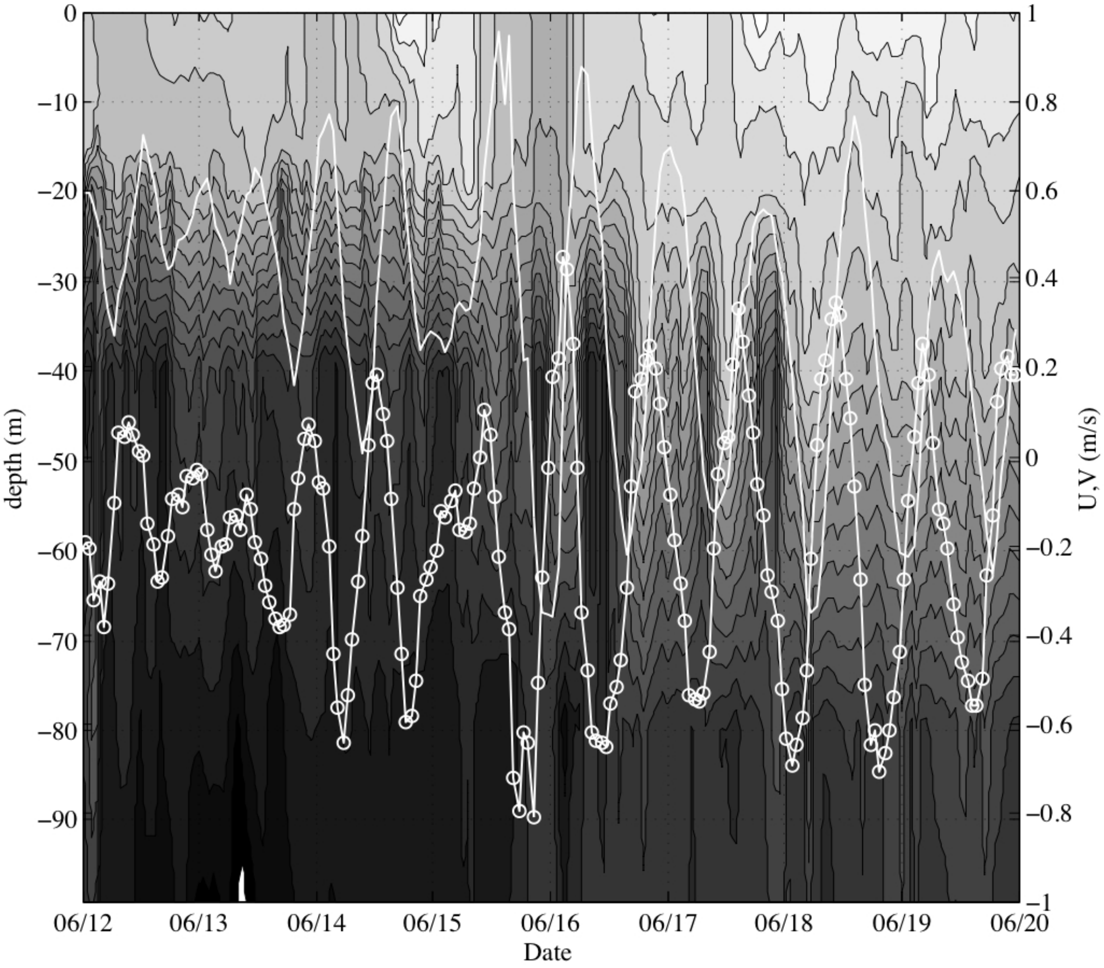


Figure 11. Temperature contours (C.I=0.5ºC). White lines are current components at 10m: east (solid) and north (circles).

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