Woods Hole Oceanographic Institution

# Upper Ocean Processes Group

# Technical Note

## Remaining Technological Challenges —A New Compass

A better understanding of the physics of the upper ocean and of air-sea exchanges is needed to address many issues. For example, we would like to be better able to predict the temporal and spatial variability in sea surface temperature. The ocean, through the exchange of heat, can greatly influence the atmosphere, both locally, by altering the vertical structure and stability of the marine atmospheric boundary layer, and globally, by driving large scale atmospheric convection. We would also like to be better able to predict the surface velocity of the ocean, in part because we could better quantify advection of heat and other properties, but also to guide search and rescue and oil spill containment operations. Clarifying how air bubbles are injected and entrained by flow in the upper ocean would facilitate studies of near-surface acoustics and of the ocean's role as a reservoir for greenhouse gases.

New observations are the key to developing the sought-after improvements to our understanding of the upper ocean and of air-sea exchanges. However, there are at present some significant shortcomings in our instrumentation and mooring technology. One particularly pressing problem, the need for a more accurate, low-power compass, is examined here.

The electronic, flux gate compasses now in use in instruments such as the Vector Measuring Current Meter (VMCM) have proven to be more robust and less costly to maintain than mechanical compasses. However, they show significant error. Calibration of true bearing against indicated bearing yields a roughly sinusoidal error curve with a peak to peak amplitude of typically 6° (Figure 1). This error is too large.

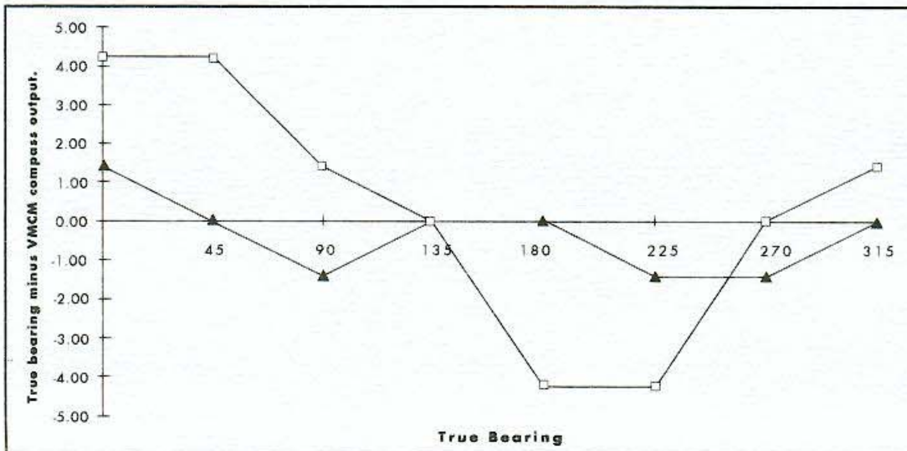


Figure 1. Typical (▲) and worst case error (□) in observed bearing versus true bearing for the flux-gate compasses in a selection of VMCMs.

Often, a closely-spaced vertical array of VMCMs is deployed, within several meters of each other, to measure the vertical shear of horizontal velocity as well as the vertical temperature gradient. The gradient Richardson number provides an indication of whether or not the vertical shear of velocity is large enough relative to the density gradient to cause overturning and mixing. With temperature gradients alone, $\mathrm{Ri} = \frac{\alpha g \Delta Z \Delta T}{(\Delta U)^2}$, where $\alpha$ is the coefficient of thermal expansion, $g$ is gravitational acceleration, $\Delta Z$ is the separation of two VMCMs, $\Delta T$ is the measured temperature difference, and $\Delta U$ is the measured velocity difference. Temperature can be measured to approximately 0.005°C, so T due to measurement uncertainty is 0.010°C. In the worst case, two VMCMs may be aligned so that the compasses are oriented so that direction differences in velocity are additive, twice the amplitude of the peaks in Figure 1. For two VMCMs, 5 m apart, in a 20 cm $s^{-1}$ flow measuring 0.1°C temperature difference and 6.93 cm $s^{-1}$ velocity difference so that Ri is close to its critical value of 0.25, consider the relative contributions of the temperature and direction uncertainties to a calculation of Ri. Temperature error gives a +/-10% change in Ri. In contrast, a 6° error between the two instruments contributes 100% error in estimating Ri. Reducing the error contribution from the compass to Ri to that comparable to the uncertainty from temperature requires the uncertainty in heading difference to be around 2.8°, or 1.4° for each VMCM.

Another application for current meters is their deployment on an array of moorings, where horizontal differences in the direction of the flow are of interest. Spatial gradients help define the horizontal structure of the wind-driven flow and of fronts, eddies, and other mesoscale ocean structures. The divergence of the flow in the upper ocean, $\left(\frac{\Delta u}{\Delta x}+\frac{\Delta v}{\Delta y}\right)$, where $u$ and $v$ are the east and north velocity components and $x$ and $y$ the east and north coordinates, provides an indication of how three-dimensional the flow is, whether or not there is significant upwelling or downwelling. Measurement of the relative vorticity, $\left(\frac{\Delta v}{\Delta x}-\frac{\Delta u}{\Delta y}\right)$, helps in the understanding of the dynamics of the upper ocean, for example, the frequency at which the resonant response (inertial oscillations) to impulsive wind forcing would be found. With GPS, our ability to locate and track the position of moorings has been greatly improved, so $\Delta x$ and $\Delta y$, can be determined with little error. If the error in horizontal gradient estimates comes primarily from the error in velocity, and if the error in measuring the speed differences of the flow is 5%, then in a 20 cm $s^{-1}$ flow, to keep the contribution to the error from the compasses of comparable size, the heading difference between the two current meters due to error should be 2.8° or less, or 1.4° for each instrument.

Thus, a new compass with an absolute accuracy of close to 1° is needed. Other aspects of performance cannot be neglected. The compass calibration should be universal. In other words, a compass set-up for +/- 1° error in the earth's magnetic field in Woods Hole, MA, should perform with the same error specification when deployed anywhere else on the earth, south of Iceland, at the equator or elsewhere. This calibration should not change with time. The compass should be able to be sampled frequently (several times a second) to permit vector-averaging in the surface wave zone or on a moving platform while not consuming power above that which could be provided by several D cells. Such low power consumption is essential if battery packs are to be kept small in instruments designed to be self-contained and capable of operating for one year or longer. Because moorings and buoys do not provide stationary, vertical platforms, the compass should ideally also provide two axes of tilt information. The vertical angular response functions of most current meter and anemometer sensors are known, and the accuracy of the measured horizontal flow can further be improved by correcting for the tilt of the instruments. To make the accuracy of this tilt correction comparable, the improved compass should measure tilts to an accuracy of 1°.

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