Measuring Coastal Currents Using ADCPs on AUVs

Revealing Transport and Spread of Effluent and Water Properties

OVERVIEW

The invention of the ADCP revolutionized studies of coastal circulation worldwide. Working from moving vessels, ADCP operators measure continuous transects of full-depth current profiles, often around consecutive circuits throughout a tidal cycle. If each circuit is treated as a snapshot, then it should be completed before the current field changes significantly due to tidal variation.

Coastal waters receive discharge and runoff from land—both directly and through estuaries and inlets. This input has come under scrutiny due to deteriorating marine ecosystems, worsened by pollutants and excessive nutrient loading. Quantifying how effluent and water properties are transported and spread will help advance understanding of their impact on coastal waters.

To address these goals, small autonomous underwater vehicles (AUVs) can replace boats in coastal surveys, observing both flow fields and water properties continuously and concurrently—for instance, while tracking effluent plumes or river discharge.

Vehicles fitted with Teledyne RDI DVLs carry an embedded ADCP, which can measure coastal currents at many depths simultaneously—above and below the vehicle if a dual head is installed—while the AUV flies at a constant depth.

The DVL's pinpoint positioning improves not just the vehicle's trajectory but the quality of data and images gathered at high sampling rates.

Hydroid REMUS 600, showing four faces of an uplooking ADCP. A matching set look downward.

Credit: Hydroid, Inc.

Products: ADCPs on AUVs

Application:
Mapping Coastal Currents Using AUVs

Product Lines:
Teledyne RDI Marine Measurements and Navigation

Organization:
Scripps Institution of Oceanography

Principals:
Eric Terrill
Peter Rogowski

Location:
North Carolina and Southern California USA

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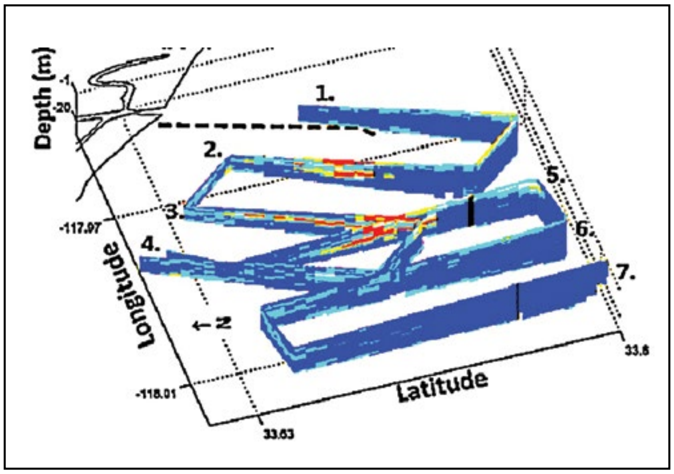
Transects of ADCP profiles collected during spatial surveys enable end-users to be better informed in order to describe local circulation patterns and to assess the mechanisms driving ocean processes. As well, maps of ADCP-based velocity fields permit detailed comparison with output from coastal circulation models, allowing for validation, calibration, and even refinement of the models.



AUV path during a survey of a discharge plume. AUV transect numbers are shown. Warm colors indicate location of effluent.

Credit: Rogowski, P. and E. Terrill (2015). http://bit.ly/2HIIMnl

SITUATION

The fate and effect of pollutants and effluent discharged into coastal waters are significantly influenced by how coastal currents and density stratification vary with location, depth, and time. In particular, currents affect the transport, dispersion, and mixing of properties that are suspended or dissolved in the water. Thus, knowing current fields facilitates interpretation of property distributions.

Coastal marine scientists work with complex spatial distributions of water properties. Interpreting maps constructed from cast-based sampling can have considerable uncertainty, such as when assessing a plume's direction or spatial extent.

The desire for more effective monitoring of coastal waters has spurred interest in using portable AUVs. While underway, these vehicles measure simultaneous, high-resolution transects of water current profiles and water properties. This approach provides a cost-effective solution for repeated surveys and can be rapidly adapted if sensors show unexpected conditions, such as currents having reversed direction.

Although ADCPs are embedded on many AUVs, this means of mobile current mapping has not yet been widely exploited. Handling tidal variation is a challenge because surveys must be lengthy, ideally extending over a tidal period, and data processing is complicated, unraveling a record that blends changes in time and space. Nevertheless, methods of mapping multiple ADCP transects to fields of coastal currents have helped clarify complex coastal observations.

In work off the coast of San Diego, researchers from Scripps Institution of Oceanography developed an AUV-based survey technique for detecting and mapping plumes. The vehicle used a Teledyne RDI DVL for navigation.

Off the coast of North Carolina, the DVL's embedded ADCP was used to map a river's discharge plume under varying environmental conditions. These current maps helped to reveal the mechanism causing unusual patterns in salinity sections.

ADCPS ON AUV:

- AUVs can provide continuous transects of water currents and water properties measured simultaneously
- Proven methods exist for merging ADCP transects into spatial maps of current fields
- Contour maps of water properties can show complex spatial patterns
- Seeing current fields helps explain distributions and changes of water properties

In a study off the coast of Orange County in California, the Scripps team explained unexpected changes in an outfall plume's movement by using ADCP profiles measured from their AUV.

SOLUTION: CONSTRUCTING CURRENT VELOCITY FIELDS

In 1990, coastal oceanographers at Woods Hole Oceanographic Institution introduced a spatial interpolation method that merged moving-boat ADCP transects to reveal spatial patterns in tidal and subtidal currents.

Over the next two decades, this approach evolved incrementally until researchers in New Zealand published a 2D interpolation method that combines statistics and physics, outputting depth-averaged current vectors on a uniform spatial grid.

Their method not only processes both horizontal components of ADCP data simultaneously but requires mass to be conserved—unlike velocity fields produced by processing each velocity component separately.

For tidal flows with spatial scales less than 10 km, the rate at which sea level rises/falls due to a flooding/ebbing tide is comparatively small. Omitting the first term in the following equation requires that circulating water masses not converge.

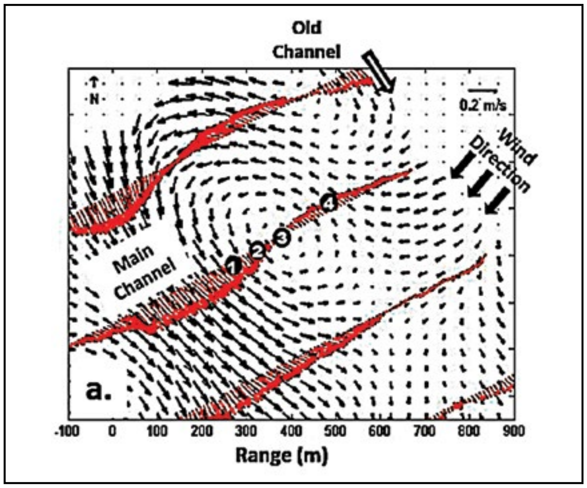
$$\partial\eta/_{\partial t} + \partial U/_{\partial x} + \partial V/_{\partial y} = 0$$

A specific form of 2D Thin Plate Splines outputs velocity fields that satisfy this physical constraint. Data processing works with the vertical integral of each velocity profile (U/V: east/north transport per unit width) rather than velocity per se. A similar 2D interpolation is made to the data set of water depths measured along the vehicle's track.

For each point on the output grid, the depth-averaged velocity is calculated as the ratio of interpolated 2D transport (per unit width) and water depth.

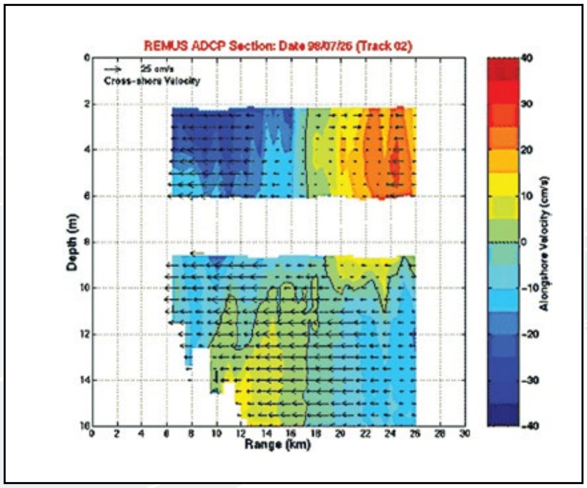
This 2D interpolator is applied in a least-squares smoothing fit, together with a "greedy fit" technique; the latter permits efficient computation while maintaining output quality. See Vennell reference for details.

When it is important to retain the vertical structure in the coastal currents, other processing methods can be implemented, as exemplified by the lower graphic.



Transects of depth-averaged water velocity (red) merged via 2D interpolation to a uniform spatial grid.

Credit: Rogowski, P. and E. Terrill (2015). http://bit.ly/2HIIMnl



Contour map of components of coastal currents. Alongshore: color, Cross-shore: arrows. The view merges up- and downlooking ADCP profiles measured by a REMUS AUV.

Credit: Hydroid, Inc.

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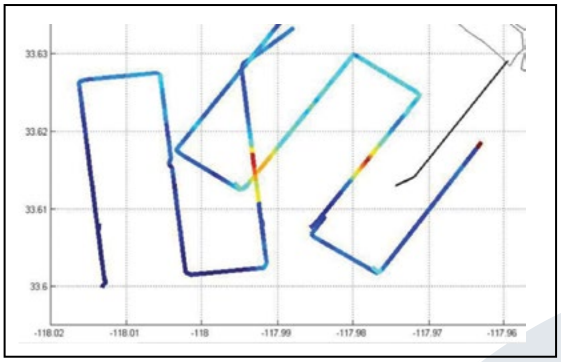
RESULTS

Untangling the physical mechanisms influencing a river plume after it enters the sea has been a long-standing challenge for coastal oceanographers. To this end, researchers from Scripps Institution of Oceanography deployed their AUV-based survey method to collect sets of high-resolution transects outside a river inlet in North Carolina.

For each of several days, ADCP transects were merged into an areal map of depth-averaged velocity, per previous section. Within each map, the plume of river discharge was evident. Plume trajectory and spread varied markedly with wind conditions and with alongshore currents in the receiving waters.

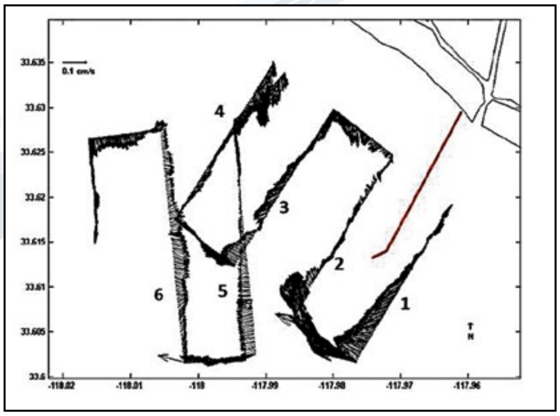
During alongshore wind conditions, a distinctive inshore eddy was found adjacent to the river plume. (See upper image on page 3.) Seeing the circulation of this eddy explained unusual patterns in salinity sections recorded concurrently with the ADCP sections.

In work off Southern California, the researchers used their AUV-based survey method for detecting and mapping an ocean outfall plume. While the AUV moved at 1.75 m/s, up- and downlooking Teledyne RDI ADCPs profiled water currents each second. After these transects had been merged into 2D velocity fields, some circulation patterns were more apparent—for instance, a large eddy around the outfall's nozzle.



AUV path during a survey of a discharge plume.
Warm colors indicate location of effluent.

Credit: Credit: Terrill, E., et al. (2014) http://bit.ly/32ayqEL



Velocity vectors show depth-averaged currents.
AUV transect numbers are shown.

Credit: Credit: Terrill, E., et al. (2014) http://bit.ly/32ayqEL

After interpreting their AUV-based measurements, the Scripps team reported that the plume was initially headed upcoast and had later stalled. Such changes had bedeviled workers surveying plumes by means of cast-based sampling from boats. In fact, the currents carrying the plume had reversed direction unexpectedly. This change was revealed by adjacent ADCP transects along the AUV's track (see AUV transects 5 and 6 in graphic above).

These impressive projects reveal the value of ADCP profiling from AUVs for explaining complex and evolving property distributions in coastal waters. Combining detailed velocity fields with sections of water properties offers a uniquely informative view.

REFERENCES:

Terrill, E., et al. (2014), Final Report—Orange County Sanitation District Outfall Diversion. http://bit.ly/32ayqEL

Vennell, R., and R. Beatson (2009), A divergence-free spatial interpolator for large sparse velocity data sets, J. Geophys. Res., 114, C10024, https://doi.org/10.1029/2008JC004973

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