Remote Sampling of River Discharge Using Radar and Sonar

Combining RiverSonde Radar and Channel Master ADCP Provides a New Angle to an Old Measurement Problem

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Automated measurement of river discharge (i.e., the volume of water transported) remains an elusive goal for assessing and managing water resources.

Traditional discharge measurement involves manually collecting a grid of *in-situ* data, which makes it time consuming, labor intensive, data sparse and inherently unsafe. Although many of these limitations have been solved using acoustic Doppler current profilers (ADCPs) from moving boats, some significant goals remain to be reached: continuous monitoring of discharge at non-ideal sites and improved safety for field hydrographers, particularly during floods.

Improved safety for field workers motivated the U.S. Geological Survey's (USGS) Hydro 21 project to explore non-contact measurement of river discharge[1] by means of radar, including CODAR's prototype RiverSonde.[2]

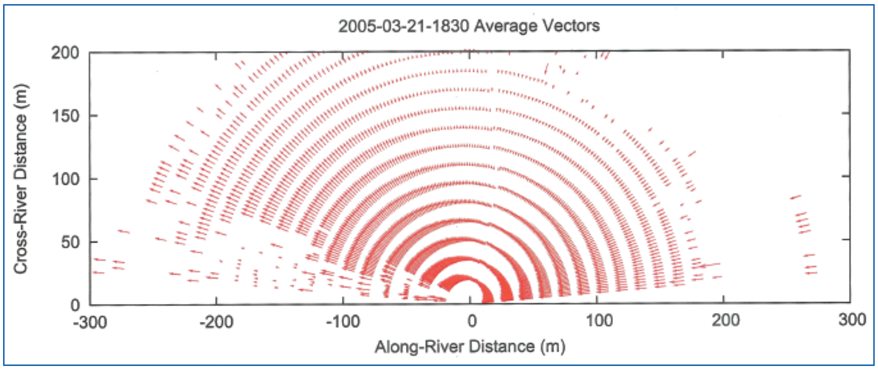
Operating from a single site on one bank, the RiverSonde radar continuously profiles surface currents across a specific section, giving a very detailed view of space-time variability for a broad range of river conditions. Compared with in-water equipment, RiverSonde offers reduced risk of loss, more flexible deployment and more reliable connectivity, especially at critical times for river measurements. In field trials measuring strong river flows, RiverSonde data has been demonstrated to provide a useful index for average flow.

The radar observes only surface currents. Understanding their correlation with subsurface flows is critical in using the radar data as an index of discharge or transport. In this work, the radar data was intercompared with two sonar devices that remotely measure subsurface currents. For all of the instruments in this report, measurements of velocity were averaged for some distance across the section. In principle, instruments that either profile or integrate currents across a river should better match the integral quantity desired than would a spot measurement.

The Channel Master ADCP horizontally profiles across mid-depth flows. In addition to producing a more complete data set, the Channel Master only operates from one bank and has shown to be less expensive to install and maintain than earlier acoustic methods.

(Left) The RiverSonde antenna mast. Three 0.5-meter Yagi antennas are arranged symmetrically in a tight sector. A weather station atop the antenna mast provides wind and meteorological data.

(Below) The RiverSonde surface current vector field. These vector maps are the intermediate data product used to compute the velocity profile across the river. One of these maps is created every 15 minutes.



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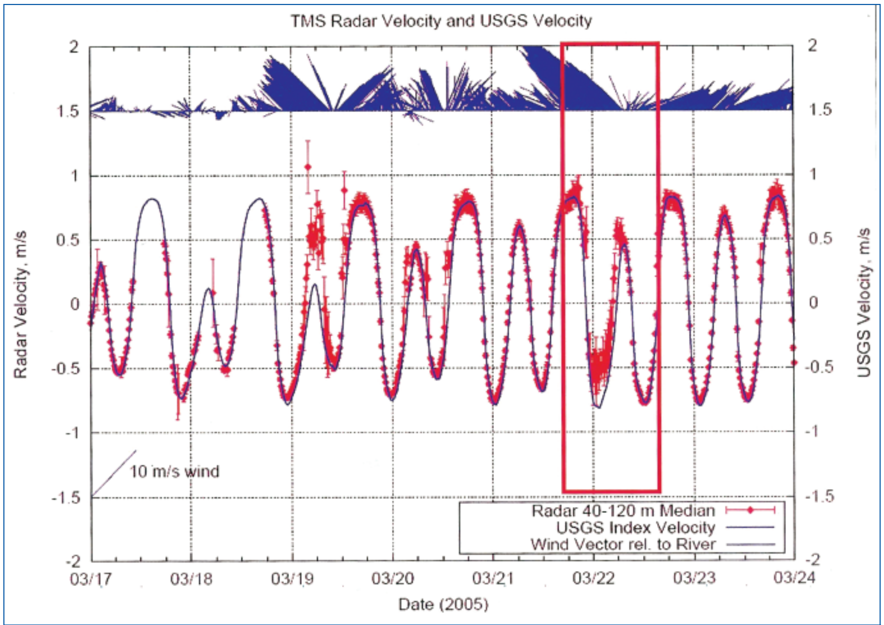


A time series of RiverSonde, ultrasonic velocity meter and wind data. Spatially averaged values for surface and subsurface currents are overlaid with concurrent wind vectors. Wind blowing to the north is directed up the page. Conditions during the stormy period of March 22 are highlighted.

Field Study

This article looks at data from a field study in the California Delta that compared the RiverSonde radar data with two acoustic methods for collecting a time series of river currents. The study was conducted in the spring of 2005 at a USGS field site in the Threemile Slough, located 100 kilometers upstream the Sacramento River from where it enters San Francisco Bay. The slough is 200 meters wide and 10 meters deep; it interconnects the Sacramento and San Joaquin rivers and sees strong tidal flows to one meter per second.

The USGS site had a pre-existing acoustic measurement of discharge that calculates the difference in the travel time of signals aimed in reciprocal horizontal directions. This integral measurement is interpreted to be a calculation of average current. Deploying a 600-kilohertz Channel Master ADCP allowed for the recording of subsurface conditions with a similar space-time grid to that of the radar. The Channel Master was deployed below a small pier that housed the 350-megahertz RiverSonde radar.

During most of the time at Threemile Slough, the RiverSonde data was highly correlated with currents measured with the USGS acoustic travel-time system.[3] Through periods of high winds, however, the data diverges. This article focuses on one week that included stormy weather.

RiverSonde Radar

RiverSonde is an ultra-high-frequency (UHF) radar operating at around 350-megahertz. Both hardware and data processing are derived from the established marine SeaSonde high-frequency radar system, used for ocean surface current mapping. RiverSonde is a reasonably compact package that uses three 0.5-meter Yagi antennas arranged symmetrically in a tight sector. RiverSonde transmits one watt of power from the central antenna, which results in a measurement range of 250 meters that it receives on all three antennas.

Surface current speed is determined from the Doppler shift of radar energy scattered by Bragg-resonant water waves. For the RiverSonde UHF frequencies, the relevant wavelength is 0.5 meters, which is quite common for ripples on water surfaces affected by slight winds or currents. In order to achieve sufficient spatial resolution across the river—five-meter-range cells—RiverSonde uses a chirp frequency sweep with a 30-megahertz bandwidth.

The system determines the arrival direction of the radar echoes in 1° steps by means of the multiple signal classification direction finding method. At this site, RiverSonde is configured with a 16-hertz sampling rate, and data are averaged every 15 minutes. The resolution of the water speed is 2.5 centimeters per second.

The coverage of the radar's surface current data resembles an unfolded hand fan. This current map is composed of a multitude of radial sequences. A given sequence has about a dozen vectors, each at a different range from the radar. The magnitude of the radial vectors changes with the intersection of the radar's pointing angle and the flow direction. The vectors are largest near the banks, where the radar is looking along stream. In the middle of the map, where the radar is pointing across stream, the angle of intersection is perpendicular. That results in the radial current vectors reducing to zero.

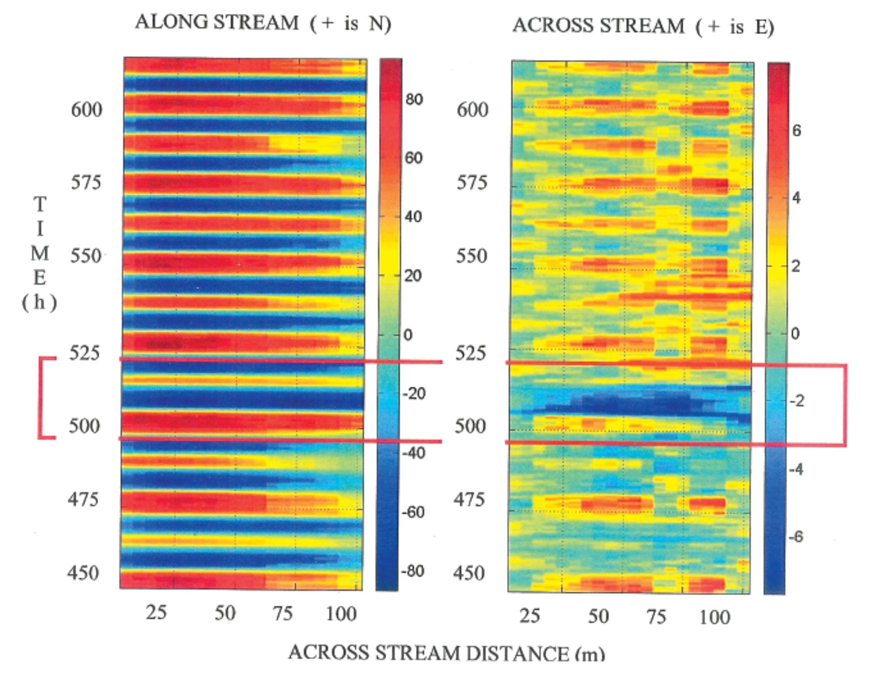
In processing, these data are subdivided into five-meter segments across the river and parallel to the bank. For each segment, a least-squares fit is made to compute the average water speed parallel to the bank. For an average surface current across the section, the median value of surface currents in the segments between 40 and 120 meters was used.

Time series of 15-minute RiverSonde values were plotted together with wind vectors from the collocated weather station. These data were compared with subsurface current data from the USGS travel-time system, or ultrasonic velocity meter (UVM). The latter measures the average speed for subsurface currents across the section. The two independent measures of an average current showed a striking overall correlation, for the most part, though deviations arose at times of high winds.

The average values used in this article represent different spatial regions depending on the instrument type. No adjustments were made to the average values, however, because the strong tidal flows in Threemile Slough have negligible lateral shear.

Channel Master ADCP

A 600-kilohertz Channel Master ADCP was deployed in this study. It is a two-beam ADCP that measures the time series of a horizontal profile of two components of flow. In the case of the river, these components are generally chosen to be along and across-stream. The Channel Master is installed at a depth suitable for measuring currents at the middle depths of the water column, which permits the longest measurement ranges. Measurement resolution was set to five meters in range and 10 minutes in time. The ADCP burst sampled at three hertz for



Channel Master ADCP currents (in centimeters per second) during the week of March 19 through 26. Elapsed time in hours since March 1, 2005, is increasing up the page. Scales for the water speeds are shown at the right of each plot. Conditions during the stormy period of March 22 are highlighted.

20 seconds. The level measured was four to five meters below the surface, depending on tidal stage.

At the Threemile Slough site, a strong tidal signal dominated the variability in both time and space. Channel Master profiles were matched to the time grid of the radar data and showed strong tidal variability and a varying profiling range with tidal stage and water conditions. The data used for average flow are from a 70-meter segment on the western side of the slough, which is about one third of the total width. ADCP boat surveys indicate that currents in this segment are similar to the rest of the section.

For ADCPs that profile horizontally, measurement range is largely controlled by water depth rather than by instrument frequency. At Threemile Slough, the Channel Master ADCP reported data to 90 to 100-meter ranges. The range for high-quality data, however, was about two-thirds the measured range. In the far reaches, the acoustic beam has a greater vertical extent that can intersect the riverbed. The current data can, therefore, be biased low when the signal processing unavoidably includes echoes scattered from the non-moving bed.

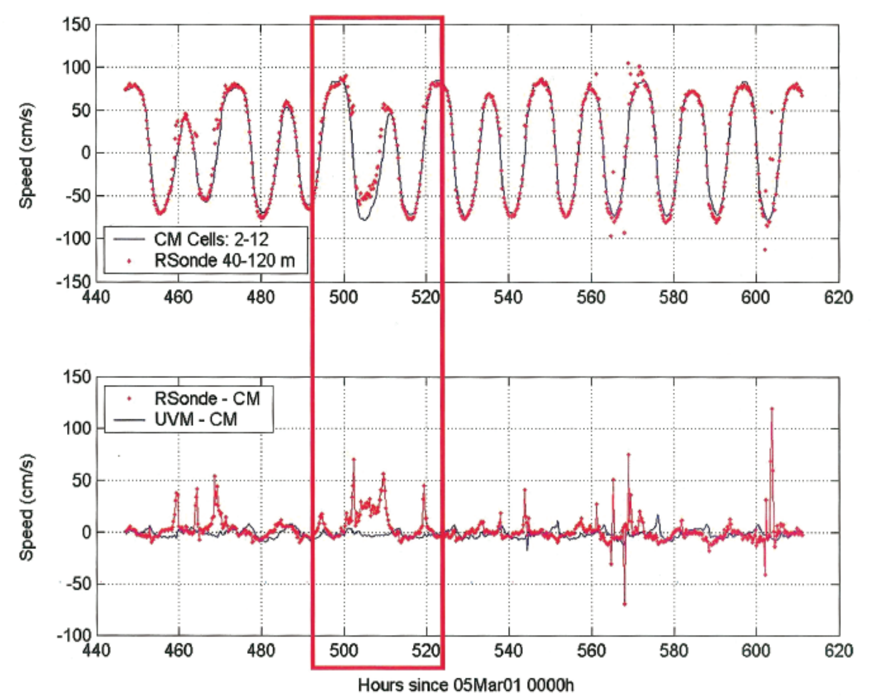
The Channel Master data were analyzed by using principal component analysis (PCA). The factor weightings indicated that averaging range cells two through 12 (10 to 70 meters) would create a representative index for the average current in the region, seen by the Channel Master. It is worth noting that the PCA method provides an objective answer to the burning question: "What is the range of the horizontal profile before data quality degrades?" The factor weightings of the principal components can reveal the range where the biased data begins, caused by echoes returning from the bed. Inspection of the much weaker across-stream component clearly confirmed this statistical result.

Stormy Weather

Over the course of many months, the RiverSonde radar data closely tracked the mid-depth currents using the acoustic systems. For this article, however, only data from the week of March 19 through 26, 2005 was focused on.

This was a period of stormy weather, a time when the radar currents are expected to be less reliable. This week was looked at to find symptoms of poor quality data that might provide a signature for screening the RiverSonde radar data during high winds.

Even throughout this week of unusually foul weather, the radar surface currents and Channel Master subsurface currents track closely, for the most part. It was only during times of very strong winds that the most persistent discrepancies occurred. At these times, the subsurface currents reported by the Channel Master and UVM still tracked each other closely. Because the average currents reported by the RiverSonde radar were biased high,



A time series of spatially averaged currents from the Channel Master ADCP and RiverSonde radar. Deviations of the radar surface currents from subsurface values are plotted in the bottom panel.

> ***"Automated measurement of river discharge (i.e., the volume of water transported) remains an elusive goal for assessing and managing water resources."***

they would not be a representative index for subsurface values at these times.

The bias, however, was not spatially uniform; rather it showed much higher values in a localized region adjacent to the downwind bank. This effect created very strong lateral shears in the RiverSonde data that were not in the Channel Master data. These anomalous shears, which were not found in the radar data during the rest of the study, provide a potential signature to screen out poor quality radar data during a time of strong winds.

The complete data set recorded at Threemile Slough lasted for many months. Spatially averaged values extracted from the various data sets track closely.

The RiverSonde radar's usefulness for remote sampling of average flow speed across a specific section is very encouraging. This performance is expected to be representative for well-mixed flow regimes. In addition, some useful progress has been made in defining the reliability bounds for the radar data at times of high winds.

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