Canal and river tests of a RiverSonde streamflow measurement system

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Abstract – Results of field tests of a RiverSonde streamflow radar are compared with *in-situ* current measurements at a canal and a river in central California during June, 2000. Typical water velocity in the middle of the canal was about 0.45 $m\,s^{-1}$ and 0.30 $m\,s^{-1}$ at the edges. Velocity in the river was about 20% lower with similar cross-channel variation. Differences between the RiverSonde and *in-situ* velocities were 6–18% of the mean flow, with similar differences among the various *in-situ* velocities. In addition to the surface velocities, the total volume flow was estimated based on the *in-situ* depth measurements. Volume flow for the canal was about 37 $m^3\,s^{-1}$ and for the river was about 64 $m^3\,s^{-1}$, with differences between the various radar and *in-situ* techniques of less than 10%.

INTRODUCTION

Recently a RiverSonde streamflow radar was developed based on a standard SeaSonde radar [1]. The SeaSonde normally is operated over salt water at HF (3–30 MHz) to measure ocean surface currents [2]. It was modified to operate at UHF (350 MHz) and wide FM sweep width (10–30 MHz) to match the expected water wavelengths and channel dimensions. Transmit power was about 1 W, and maximum range over fresh water was a few hundred meters. A bistatic geometry was used for the antennas, with transmit and receive antennas on opposite sides of the water channel, as illustrated in Fig. 1. As with ocean current observations, current is estimated from the shift of the position of the first-order Bragg line from its still-water position, taking into account the increase in Bragg wavelength due to the bistatic scattering angle [3, 4]. The backscatter Bragg wavelength for the water waves is 0.43 m, and water waves up to about 0.55 m contribute to the bistatic scattered energy. For bistatic scattering, the radar measures the component of current perpendicular to the constant-delay ellipse. Total currents were computed assuming that the flow was parallel to the channel and that cross-channel flow was negligible.

A 2-element broadside transmit antenna with a ground screen reflector provided a broad floodlight illumination of the water surface, with the main lobe directed downriver and a null directed toward the receiver to limit the dynamic range required of the receiver. A 3-element array was used at the receiver. Conventional time delay and Doppler processing provided range resolution of 10–30 m and velocity resolution of about 2.5 $cm\,s^{-1}$. MUSIC direction finding [5] was used to determine the bearing of the signals at the receive antenna. The bistatic geometry complicates the processing somewhat but results in a received signal strength which is nearly independent of scattering position across the water channel. In these early tests the transmit antenna was connected to the radar system by a coaxial cable stretched across the water, but in the final version the transmitter is expected to be a stand-alone unit independently powered and synchronized to the radar controller.

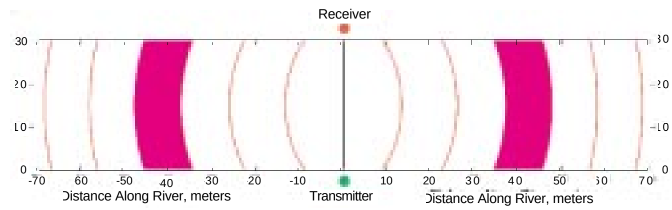

Figure 1: Bistatic scattering geometry. Transmitter and receiver are on opposite sides of a river or canal. Contours of constant time delay are ellipses, and velocity is measured in a direction perpendicular to the ellipses. A scattering cell at 40 m range is highlighted.

EXPERIMENT

Two locations were used for the initial field tests in June 2000. The first site was on the Delta-Mendota Canal in central California. The canal is about 30 m wide with a concrete-lined channel and flat bottom. The water flow is well controlled, and a bridge provides convenient support for the transmit cable. Radar observations were made 20–60 m downstream of the bridge. The bridge is supported by several pillars in the water, resulting in some turbulence immediately downstream from the pillars. This site provided an ideal test bed for the early tests.

The second site was on the American River in downtown Sacramento, California. This is a natural river about 110 m wide and represents a realistic environment for a typical deployment. Radar observations were made about 150 m past a bend in the channel. There were no obstructions in the water at this site. The river bottom was irregular and included both muddy and rocky areas.

Extensive *in-situ* measurements were made at both sites by the U. S. Geological Survey. These measurements included submerged flow meters suspended from a small boat at several locations and depths across the water channel, floating tennis balls optically tracked by a TV camera, an optical surface flowmeter, bottom depth probing with a weighted line, and an anemometer for wind measurements.

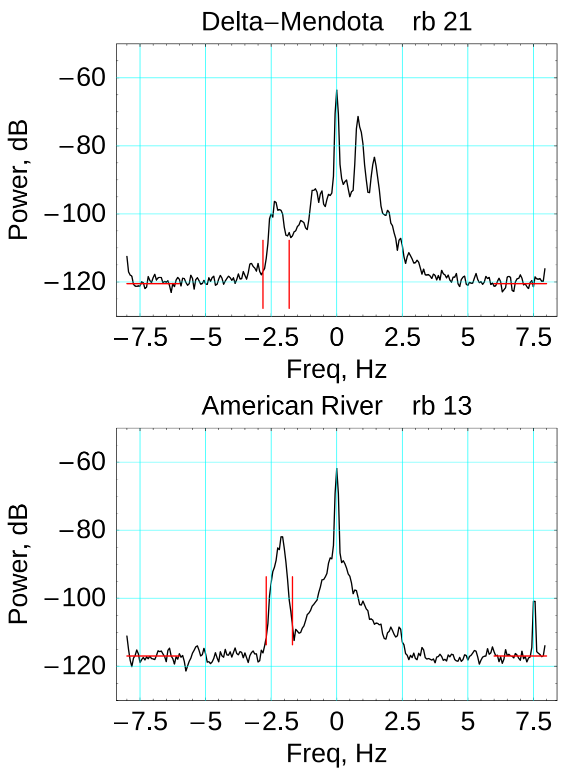

Figure 2: Spectrum of received energy at the Delta-Mendota Canal on 5 June 2000 (top) and at the American River on 7 June 2000 (bottom). The waves are moving predominately toward the radar at the canal and away from the radar at the river. The short red lines indicate the estimated noise level and the region of the spectrum selected for MUSIC direction finding.

Radar echoes from the water were seen out to several hundred meters at both sites. Fig. 2 shows received power spectra obtained at the Delta-Mendota Canal and the American River. In both cases the scattering is predominately first-order even at the short radar wavelength used for this experiment, with the first-order energy clearly identifiable. The spectrum from the canal is complicated by a nearly cross-channel wind. The spectrum from the river is simpler, resulting from the wind blowing nearly downriver. In both cases the antennas were looking downriver, and energy from the negative Bragg line (from waves receding away from the radar) was processed. Spectral broadening is due both to the bistatic geometry and current variation across the river.

Velocity

Fig. 3 shows the current velocities as a function of distance across the channel for the Delta-Mendota Canal test on 5 June. Results for 6 June were similar. The RiverSonde and *in-situ* results are in good agreement except for a region within about 8 m of the receive antenna. The reasons for that disagreement are not clear, but may be due to distorted antenna patterns. Fig. 4 shows the velocity profiles for the American River on 7 June. The velocities for the river were similar to those for the canal, with similar cross-channel variation.

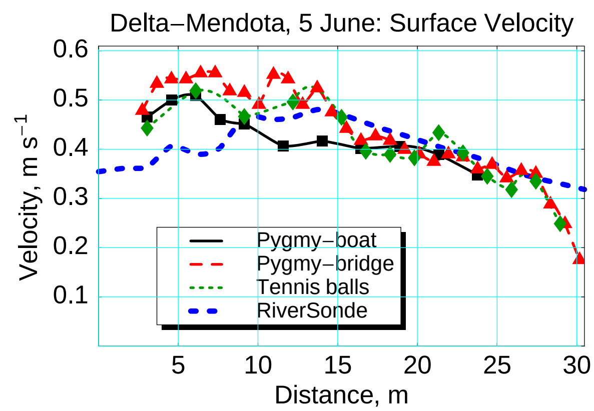

Figure 3: Delta-Mendota velocity profiles for 5 June 2000. Distance is measured across the channel from the bank near the receive antenna. The *in-situ* measurements were from a flow meter suspended from a small boat about 60 m from the bridge (Pygmy-boat) or with the boat tethered to the bridge (Pygmy-bridge), and from optical tracking of floating tennis balls (Tennis balls). The RiverSonde measurements are shown as a thick dashed blue line.

Table 1 summarizes the RMS velocity differences between the RiverSonde and *in-situ* measurements and between the various *in-situ* measurements for the 3 days of the experiment. RMS differences between the RiverSonde and *in-situ* measurements were 8–18% of the mean velocity, and differences between the *in-situ* measurements were 8–17% of the mean.

Volume Flow

The total volume flow for each site was computed by integrating the product of velocity and depth as measured by a weighted line dropped to the channel bottom at several points across the channel. The volume flows are summarized in Table 2. Because the various *in-situ* velocity measurements covered slightly different swath widths across the channel, the RiverSonde volumes were computed for the same swath as each of the *in-situ* measurements, as well as for the entire channel width (bank-to-bank). Differences in the magnitude of the current flow between *in-situ* and RiverSonde ranged from 0.3% to 10% of the *in-situ* flow for all 3 data sets.

Summary

The initial tests of the RiverSonde radar were encouraging. Signals with 20–50 dB SNR were achieved with less than 1 W

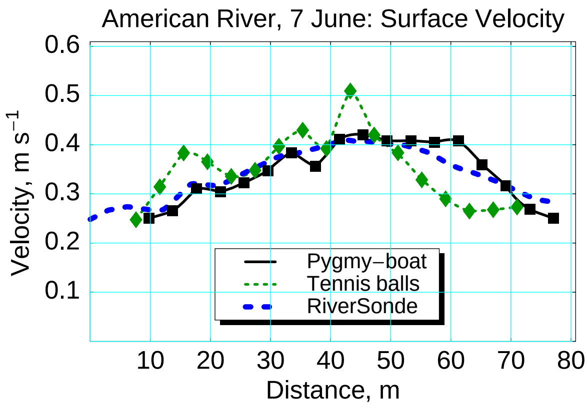

Figure 4: American River velocity profiles for 7 June 2000. Distance is measured across the channel from the bank near the receive antenna. The *in-situ* measurements were from a flow meter suspended from a small boat about 150 m from the radar (Pygmy-boat), and from optical tracking of floating tennis balls (Tennis balls).

of transmitter power at 350 MHz using a bistatic geometry. Spectral analysis of the echoes indicates that the dominant scattering process is first order. The frequency proved ideal, providing strong echoes even in morning periods when calm conditions were expected. RMS velocity differences between *in-situ* and RiverSonde measurements were 6–18% of the mean, and volume flow differences were 0.3–10% when using the bottom profile provided by direct sounding with a weighted string. Some improvements in the system are required, including the elimination of the cable between transmit antenna and radar hardware, and improvements in both transmit and receive antennas to reduce signals from unwanted directions. MUSIC direction finding with a 3-element array appears to work well.

Table 1: RMS Velocity Differences

Data Sets	$m\,s^{-1}$	% of Mean
Delta-Mendota, 5 June		
RiverSonde–Pygmy boat	0.0668	15
RiverSonde–Pygmy bridge	0.0790	18
RiverSonde–Tennis balls	0.0542	12
Pygmy boat–Pygmy bridge	0.0608	14
Pygmy boat–Tennis balls	0.0482	11
Pygmy bridge–Tennis balls	0.0336	8
Delta-Mendota, 6 June		
RiverSonde–Pygmy boat	0.0370	8
RiverSonde–Pygmy bridge	0.0746	16
RiverSonde–Tennis balls	0.0805	18
Pygmy boat–Pygmy bridge	0.0564	12
Pygmy boat–Tennis balls	0.0714	16
Pygmy bridge–Tennis balls	0.0645	14
American River, 7 June		
RiverSonde–Pygmy boat	0.0581	15
RiverSonde–Tennis balls	0.0657	17
Pygmy boat–Tennis balls	0.0654	17

Table 2: Volume Flow Measurements

Data Set	*In-situ* $m^3\,s^{-1}$	Same-Swath RS $m^3\,s^{-1}$
Delta-Mendota, 5 June		
Pygmy meter boat	33.84	34.63
Pygmy meter bridge	40.83	38.06
Tennis balls	39.13	37.75
Bank-to-bank RiverSonde		38.77
Delta-Mendota, 6 June		
Pygmy meter boat	33.50	33.22
Pygmy meter bridge	41.09	36.93
Tennis balls	36.70	33.22
Bank-to-bank RiverSonde		37.86
American River, 7 June		
Pygmy meter boat	64.08	64.25
Tennis balls	65.13	64.08
Bank-to-bank RiverSonde		70.88

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