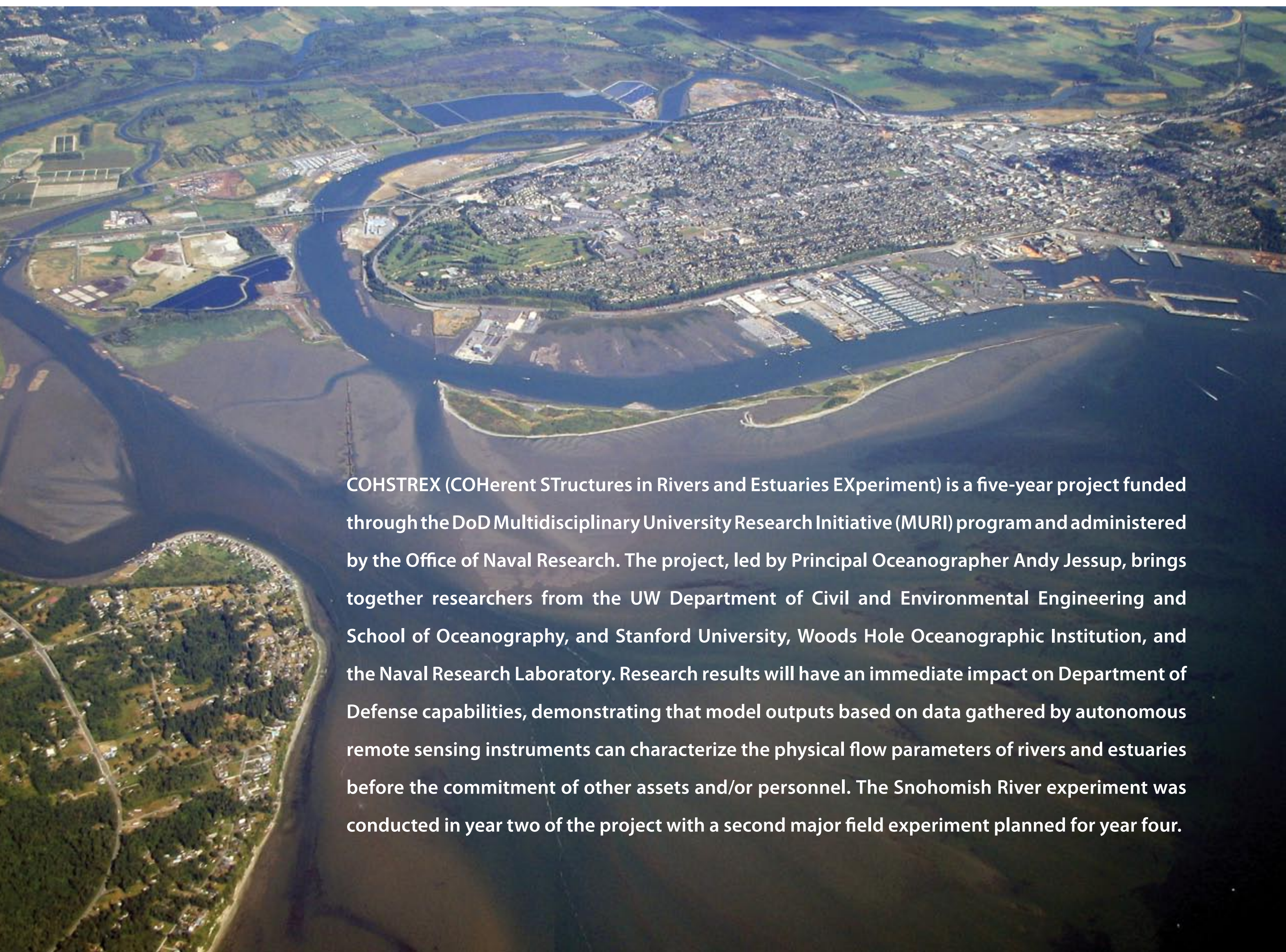
Remote Sensing of Coherent Structures Reveals Riverine Flow

Trina Litchendorf



COHSTREX (COHerent STructures in Rivers and Estuaries EXperiment) is a five-year project funded through the DoD Multidisciplinary University Research Initiative (MURI) program and administered by the Office of Naval Research. The project, led by Principal Oceanographer Andy Jessup, brings together researchers from the UW Department of Civil and Environmental Engineering and School of Oceanography, and Stanford University, Woods Hole Oceanographic Institution, and the Naval Research Laboratory. Research results will have an immediate impact on Department of Defense capabilities, demonstrating that model outputs based on data gathered by autonomous remote sensing instruments can characterize the physical flow parameters of rivers and estuaries before the commitment of other assets and/or personnel. The Snohomish River experiment was conducted in year two of the project with a second major field experiment planned for year four.

For three weeks during summer 2006, APL-UW researchers lived and worked aboard a barge near the mouth of the Snohomish River in Everett, Washington. Here, where the Snohomish outflows to Puget Sound, they studied coherent structures on the river surface to determine the extent to which the remotely sensed infrared and microwave signatures can be used to guide numerical models that predict the river's flow. Coherent structures are generated by the interaction of the flow with bathymetric and coastline features; the interaction creates eddies and boils on the surface. These surface signatures can be detected with remote sensing instruments — infrared cameras, radiometers, and microwave radars. Mean velocity, bottom roughness, shear, turbulence, surface stratification, and temperature gradients may be inferred from the remotely sensed signatures of coherent structures.

To provide a stable platform for the remote sensing instruments and researchers on the river, two 20' x 40' spud barges were anchored in place with long pilings (spuds) driven down into the riverbed, allowing the barges to remain on station while riding up and down with the tide, which ranged up to 5 m at the study site. An infrared camera, two radiometers, a video camera, and a RiverScat microwave radar were mounted on the platform of an aerial lift crane secured to the barge deck. Fully extended, the crane elevated the sensor package 28 m above the water surface.

Aerial measurements were also taken from a Twin Otter aircraft outfitted with an infrared camera, radiometers, and a video camera. Oceanographer Trina Litchendorf was able to monitor the development of cold boil fields as a saltwater wedge moved up the mouth of the river. During the flood tide colder, denser water from Puget Sound moves up the river mouth along the bottom while the less dense river water flows over it to form a saltwater wedge. As the salt wedge passes over the sill, the turbulence brings the cold water up from below where it penetrates the warmer surface water; it was visible in the infrared imagery as cool boils.

The defining bathymetric feature of the study site is a rocky sill; as the tide rises and falls, flow over the sill and through the gap between the sill and the shore generates turbulent features. The convergence of the Snohomish River and Puget Sound waters through the gap is visible as a line separating sediment-laden fresh water from the clearer salt water in the video image (left), but is much more sharply defined in the infrared image (right) because the river water is significantly warmer. The infrared imagery provides a dramatic visualization of the vortices that occur along this shear line, as well as other mixing features downstream of the sill.

Oceanographer Kate Edwards is analyzing the infrared temperature data collected during these flights, which were timed to resolve the tidal cycle over the course of the experiment. The raw data are calibrated to give temperature, geo-referenced, then composited into a single view of the river. The resulting composites are analyzed for the signature of coherent structures and are compared to in-water measurements.

Another APL-UW team led by Principal Research Scientist William Plant mounted their pulsed Doppler radar RiverRad on the opposite shore of the Snohomish across from the spud barge position, and also flew their CORAR Doppler radar on a seaplane over the site. These radar observations, both long term and over a large spatial area, capture velocity data to provide a good measure of the river's variable current over ebb and flood.

Concurrent with the measurements from remote sensing instruments, postdoc Chris Chickadel and Senior Engineer Tim Wen deployed conductivity-temperature-depth sensors on a mooring with cable connections back to the barge. The data provided stratification information in real time to correlate changes in the boil temperature with the location of the saltwater wedge. The time series of temperature, salinity, and pressure show the typical behavior associated with the passage of the saltwater wedge on both ebb and flood tides. High-resolution acoustic Doppler current profilers (ADCPs) and acoustic Doppler velocimeters were also deployed to characterize the river hydrodynamics. A mooring with three Biosonics echosounders and an ADCP anchored downstream of the sill captured the subsurface signatures of the coherent structures. To resolve spatial and temporal variability in the river during a complete tidal cycle, profiles of turbulence were taken in the river during two 30-hour surveys. A REMUS autonomous underwater vehicle also mapped the riverbed.

All of these in situ and remote sensing data gathered during the COHSTREX field experiment are being used by researchers at Stanford University to develop numerical models to predict, interpret, and characterize coherent structures. The experiment demonstrates that remotely sensed signatures of coherent structures captured by mature imaging technologies can be used with in-hand numerical modeling schemes to provide a rapid and straightforward diagnostic tool to determine the navigability of rivers and estuaries.

Team members: Eric Boget, Chris Chickadel, Chris Craig, Kathleen Edwards, Andrew Jessup, Fred Karig, William Keller, Trina Litchendorf, William Plant, Peter Rusello, and Timothy Wen