Characterization of the Riverine Environment through Passive Remote Sensing

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LONG-TERM GOALS

The long term goal of the proposed work is to transition an airborne passive remote sensing system to help the Navy and its mission partners to characterize surface water transport and battlespace environments more efficiently and safely.

OBJECTIVES

The objective of this effort is: (1) understand the physical processes acting above and below the air-water interface in rivers that drive the coherent structures in the thermal skin observed in the infrared imagery; (2) develop the capability to use airborne time-series infrared imagery to derive surface currents in rivers and estuaries; and (3) use this emerging capability to explore river hydrodynamics.

APPROACH

A development objective of the DARPA Infrared Riverine Intelligence System (IRIS) was to retrieve water currents from an airborne mid-wave infrared sensor and to successfully transition this capability to agencies supporting the operating forces. The signal of interest is coherent skin temperature modulations on the water surface that advect downstream. The reliability of the skin temperature signal and its dependence upon a range of environmental conditions and development of data collection guidance were of direct interest to the IRIS program.

The thermal skin is a small (~0.2°C Celsius) mean temperature difference between the water surface and the interior water column. The thermal skin is thin (O(1 mm)) and is maintained most of the time due to the flux of heat between the water and the atmosphere. The thermal skin layer in channel flows such as rivers and estuaries has been modeled by [1] and observed by [2,3,4,5,6]. Features in the water column such as surface gravity waves, internal gravity waves, whitecaps, secondary flows and turbulence strain the surface layer and generate coherent surface surface temperature modulations.

Boils are an example of subsurface turbulence that can disturb the skin layer by their extreme current divergence [7]. Boils act for a short time to remove the thermal layer entirely so that the surface temperature approaches the subsurface bulk water temperature [8, 9, 10]. These boils have spatial...
scales comparable to the water depth [11], and can be meters or larger in horizontal scale. In addition to strong disturbances from boils, surface layer straining can be caused by flows and turbulence often associated with secondary flows in the channel caused by bends [12,13,14], vegetation beds [15] and bottom roughness variations [16], bathymetry variations [17], or confluences [18,19]. The surface skin layer is strained by these flows on horizontal scales of meters or larger, creating long-lasting surface temperature signals [20,21].

It is these moderate- to larger-scale variations in surface temperature that we set out to detect and track with the aircraft camera system. Other investigators [3,4,5,22,23] have examined small sections of rivers and estuaries from a boat or river bank and found temperature variations that they can detect and track remotely over a long enough period of time to estimate the current. We set out to adapt this technique to an airborne imaging system to derive currents across long stretches of rivers and estuaries.

The thermal signal required for current retrievals is expected to depend upon external environmental factors including the net surface heat flux and river morphology. However, one expects a net surface heat flux and hydrodynamic-driven spatial-temporal variations to be common in rivers. In addition, the assumption that the thermal variations are advected at the local mean surface vector enables measurement of the currents. Our experience on a variety of rivers under a variety of environmental conditions bears this out.

During the DARPA IRIS program, two airborne IR imaging systems were deployed on a Twin Otter: the Airborne Remote Optical Spotlight System – Infrared (AROSS-IR) and Fixed-IR/OE (AROSS-F). In addition, a Cliff-based InfraRed Imaging System (CIRIS) was installed at the top of the Palisades overlooking the Hudson River and a piling instrumented with an air-sea flux package, CTDs and current meters was deployed within the camera field of view. This combined system collected data for two 10-day periods. The AROSS-IR and CIRIS both incorporated a large-format (1 megapixel) mid-wave infrared (MWIR) camera and a large-format (11 megapixel) EO panchromatic camera. The AROSS-F is composed of two large-format MWIR cameras and two large-format EO panchromatic cameras, but fixed to the aircraft instead of positioner mounted with all other AROSS systems.

A series of four Riverine Dynamics Experiments (RIDE 1-4) were carried out during IRIS to collect data for use in algorithm development and validation, and to explore the underlying dynamics controlling skin-temperature modulations (see Table 1.) The various test sites were chosen to provide a variety of environmental conditions as well as leverage available data from other researchers and government agencies. The test sites included locations in New York, Connecticut, Pennsylvania, Delaware, Virginia, Maryland, North Carolina, Georgia, Ohio, Idaho, Colorado, Utah, Wyoming, Oregon and Washington.

WORK COMPLETED

During FY14, we have completed post-processing and quality control from the RIDE #4 (September 2011) data collection. The data products include surface current vectors on 32 m grids over the reaches we sampled. This includes data from the Columbia River, Snake River, Blue River and Colorado River. The data is now available to other investigators (including ONR, USGS and NRL) in support of their ongoing research. We documented the current measurement methodology, comparison to ground truth and example retrievals from various rivers (see Dugan et al 2014). We began analysis of the spatial characteristics of imagery observed on the Hudson river at the Palisades.
### Table 1. Summary of IRIS data collections.

<table>
<thead>
<tr>
<th>RIDE #</th>
<th>Airborne Collections</th>
<th>CIRIS operations on Hudson</th>
<th>Data Collection Collaborations</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIDE #1 August 2010</td>
<td>Kootenai River (Idaho) Hudson River, Connecticut River Delaware River</td>
<td>– 24/7 imagery from Palisades – Heat flux from piling – Boat CTD and ADCP</td>
<td>NRL &amp; NPS- Kootenai LDEO - Hudson</td>
</tr>
<tr>
<td>RIDE #2 November 2010</td>
<td>– 24/7 imagery from Palisades – Heat flux from piling – Boat CTD and ADCP – Boat mounted LWIR imagery</td>
<td>LDEO - Hudson</td>
<td></td>
</tr>
<tr>
<td>RIDE #3 December 2010</td>
<td>Potomac River Susquehanna River Chesapeake Bay Cape Fear River Kings Bay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIDE #4 September 2011</td>
<td>Columbia River Snake River (WY) Colorado River Blue River</td>
<td></td>
<td>NRL - Columbia River UWY - Snake River USGS - Colorado River</td>
</tr>
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**Figure 1. RIDE#4 current retrievals in the Hanford Reach area of the Columbia River.**
RESULTS

Figure 1 illustrates current retrievals on the Hanford Reach area of the Columbia River, obtained using RIDE#4 airborne imagery collected in strip map mode and 64 m grid tiles. The retrievals were obtained using the Maximum Cross Correlation (MCC) algorithm over a 30 s dwell, with a 4 s frame interval. Current retrievals were obtained for a 35 km stretch of the Columbia River, from the Priest Rapids Dam eastward, which was surveyed in less than 15 minutes of flight time. This result enables the development of an operational capability to obtain surface current surveys on long stretches of rivers, estuaries or coastlines, and to do so rapidly.

IMPACT/APPLICATIONS

The U.S. Navy seeks to remotely sense the littoral, estuarine and riverine environments using unmanned systems. Knowledge of the environment will help assure mission success through better battlespace characterization and improved forecasting. The use of unmanned systems will eventually allow the Navy to characterize surface water dynamics and battlespace environments more efficiently and safely by using data only from remote sensors. In addition, the U.S. Geological Survey seeks to remotely sense river morphology and dynamics to improve its ability to monitor and predict surface water and sediment transport and validate their models.

RELATED PROJECTS


REFERENCES


**PUBLICATIONS**


