Use of Remotely Sensed Data to Determine Channel Bathymetry

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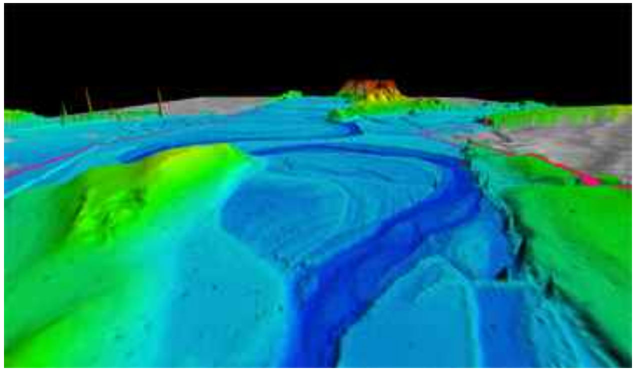

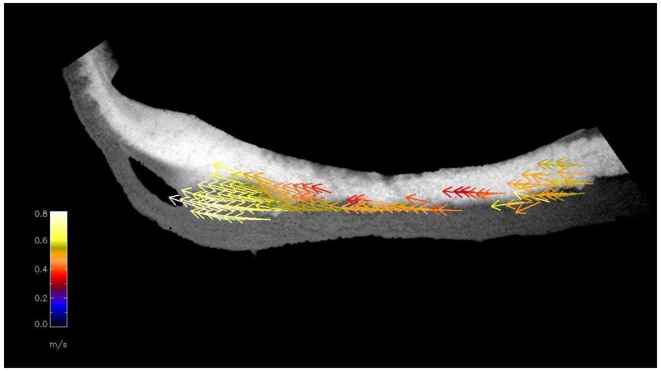

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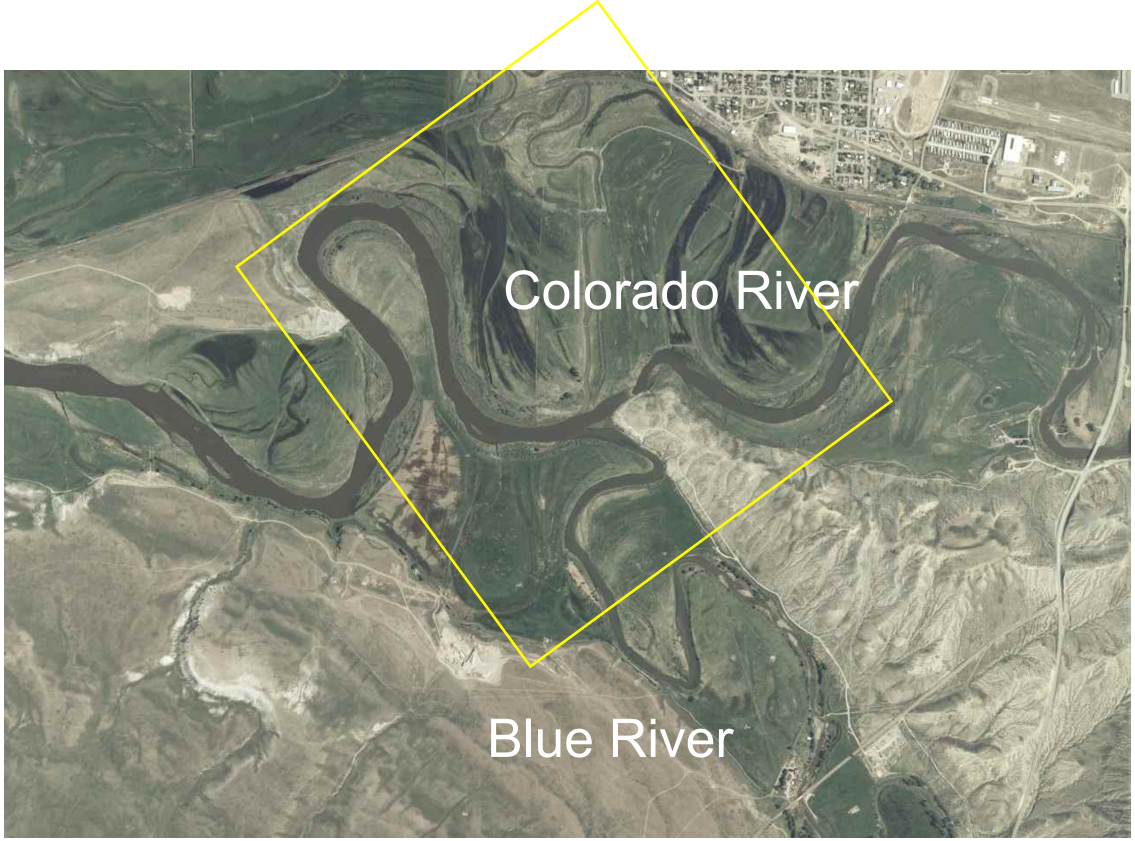
Overview

1. Evaluation of remote sensing technologies
   - Bathymetry – USGS EAARL-A (Kinzel and others, 2007 J. Hydraulic Engineering; Kinzel and others, in press, JAWRA)
   - Surface velocity – Areté Associates' (AROSS-F) (Kinzel and others, 2012, ASCE Hydraulic Methods and Experimental Methods Conference)

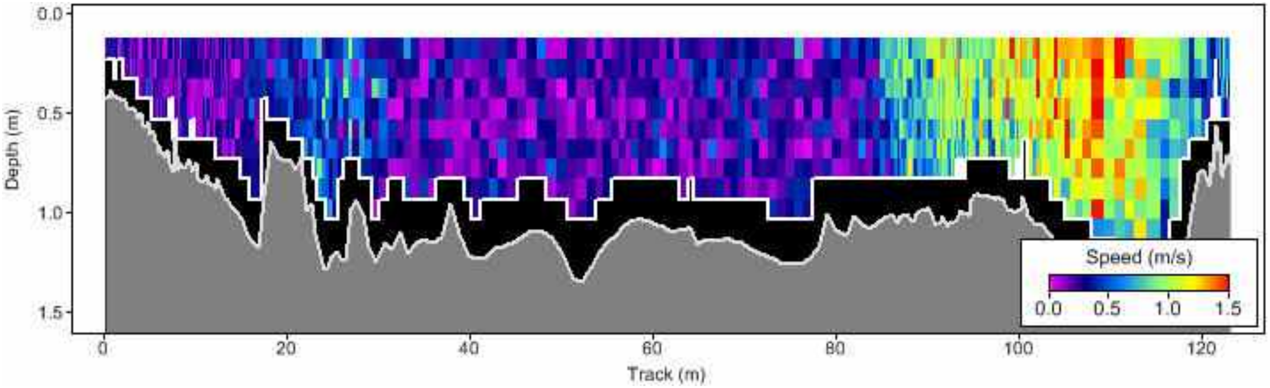
2. Computational modeling (inversion) for depth retrieval from remotely sensed data
   - Example from the Kootenai River – (Nelson and others, 2012, Proceedings RiverFlow 2012)

3. Future Work / Connections

Field Site – Colorado Blue Confluence



In Situ Measurements



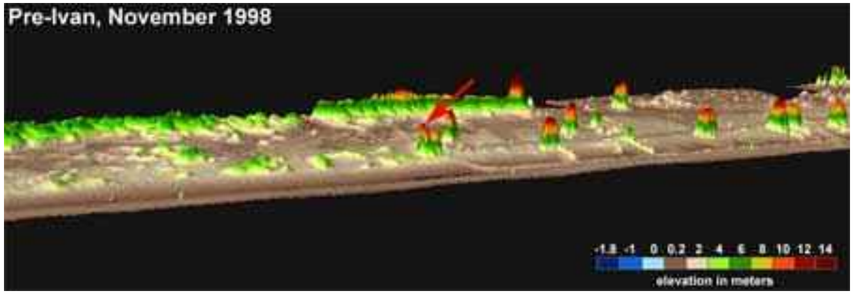
Bathymetry EAARL-A

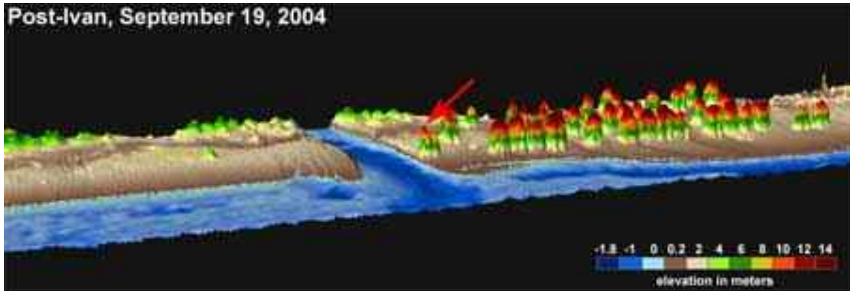
- Experimental Advanced Airborne Research LiDAR
- Green laser designed to survey coral reefs in clear, shallow water – built by C. Wayne Wright (NASA) now USGS
- Applications – Coral Reefs (Brock and others, 2004)

  Coastal Erosion (Sallenger and others, 2004)

  Coastal Vegetation (Nayegandhi and others, 2006)

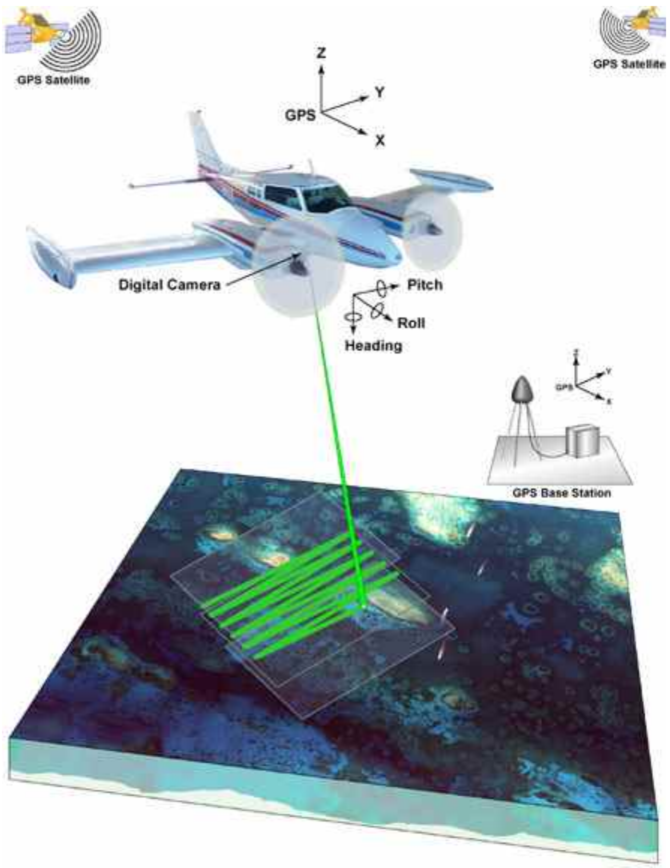
  Rivers (Kinzel and others, 2007; McKean and others, 2008)





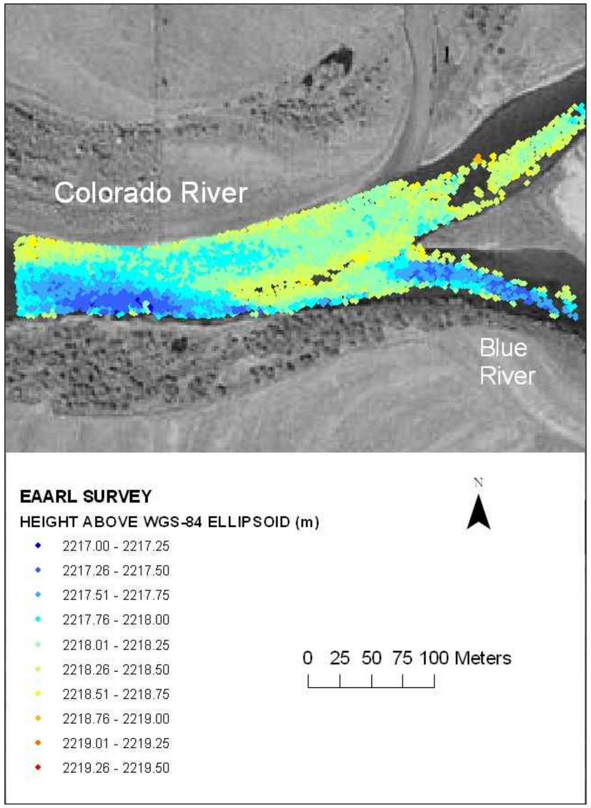
Images from USGS Hurricane Ivan Impact Studies web site (http://coastal.er.usgs.gov/hurricanes/ivan/lidar/breach.html)

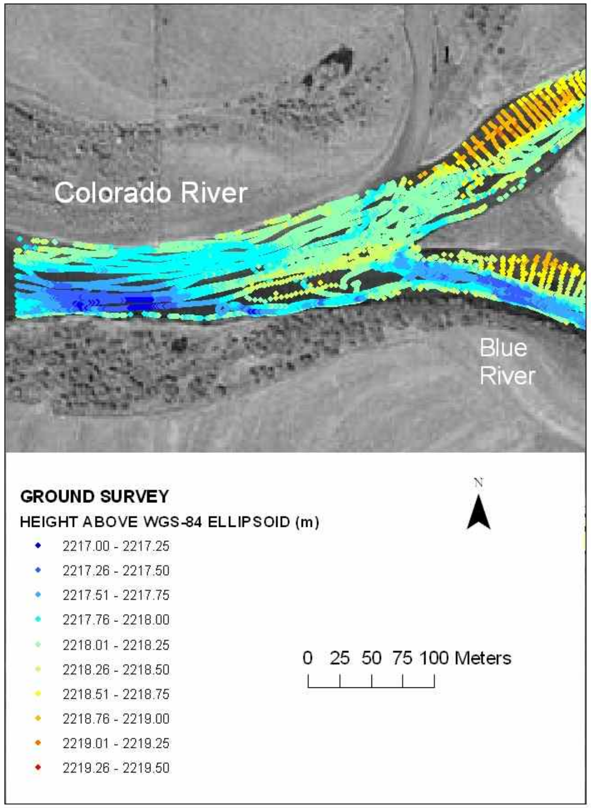
Bathymetry EAARL-A



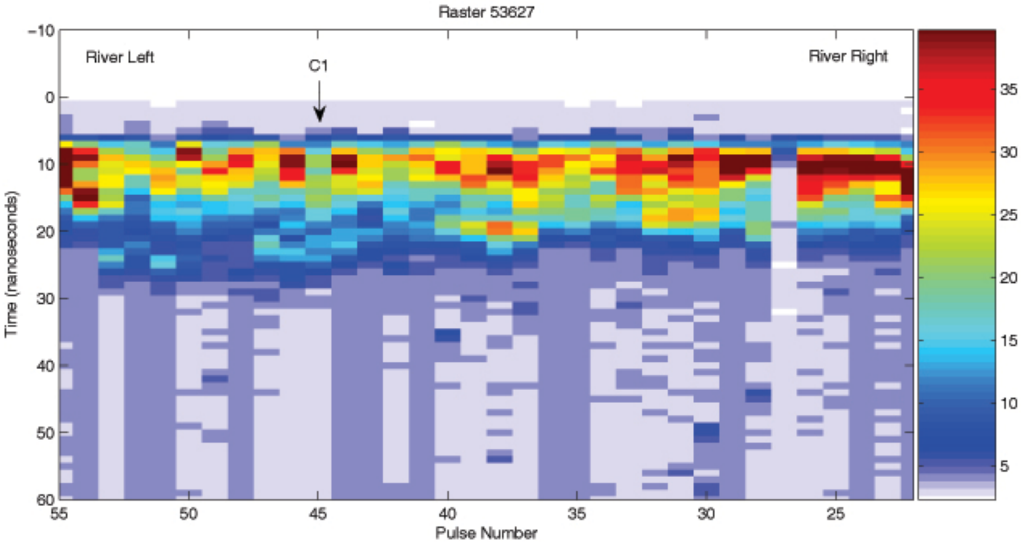
- Raster scanning 'full waveform', low power (70µJ) green (532nm) topo-bathy lidar
- Maximum Pulse Rate = 5000Hz
- Swath width 240m at altitude of 300m
- Inertial Measurement Unit (IMU), and precision kinematic Global Positioning System (GPS) receivers
- 15-20 cm diameter footprint
- Digitizer sample interval 1ns (15cm in air, 11cm in water)
- Digital RGB and CIR imagery

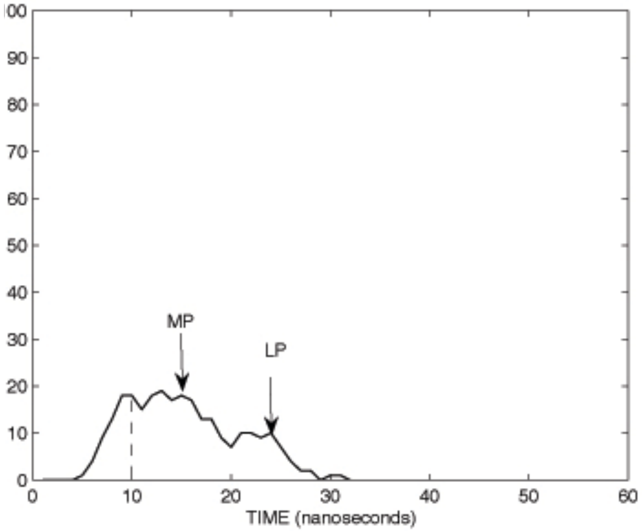
EAARL-A and Ground Survey


EAARL-A Survey

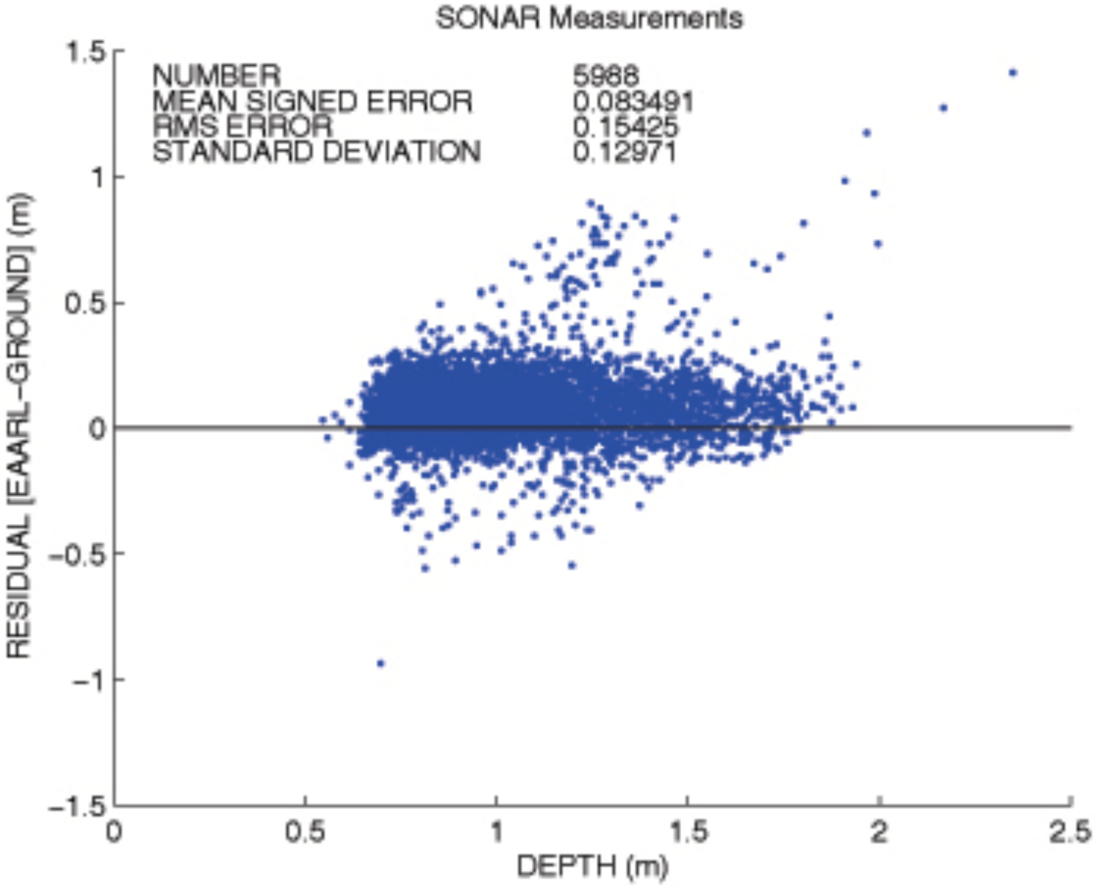

Ground Survey

EAARL-A Flight Sample Transect



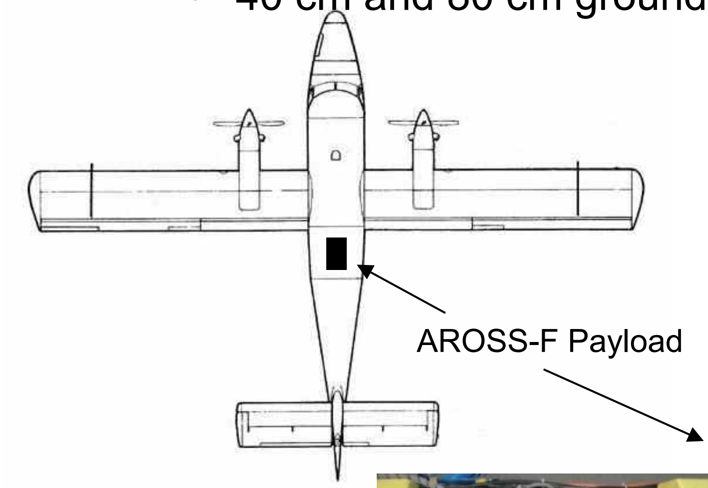


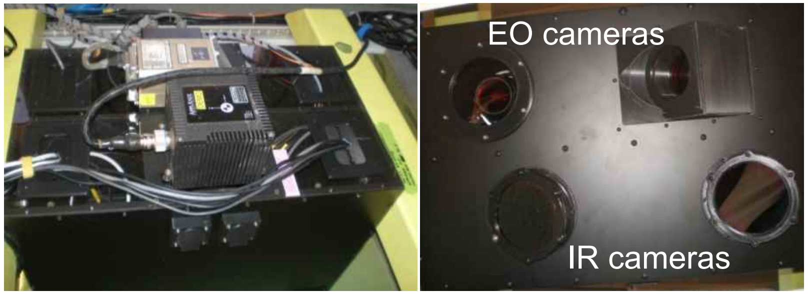
EAARL-A
Sonar Measurements Scatter Plot

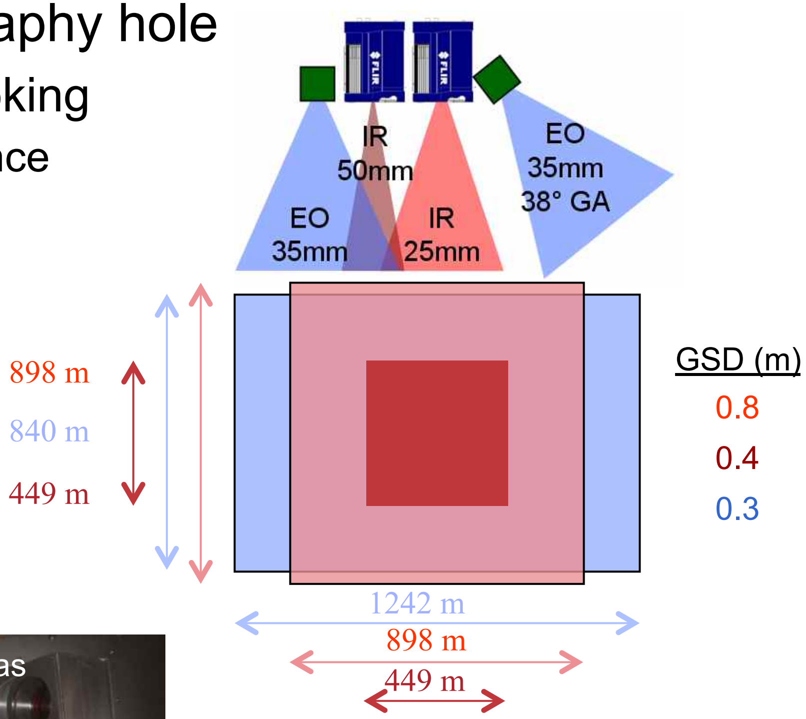


Surface Velocity AROSS-F

- MWIR (λ = 3-5 μm) and EO cameras from AROSS-F mounted vertically over Twin Otter aerial-photography hole
  - High and Low resolution MWIR nadir-looking
    - 40 cm and 80 cm ground sampling distance







Footprints and GSDs for a nominal flight altitude of 4,000 ft. AGL

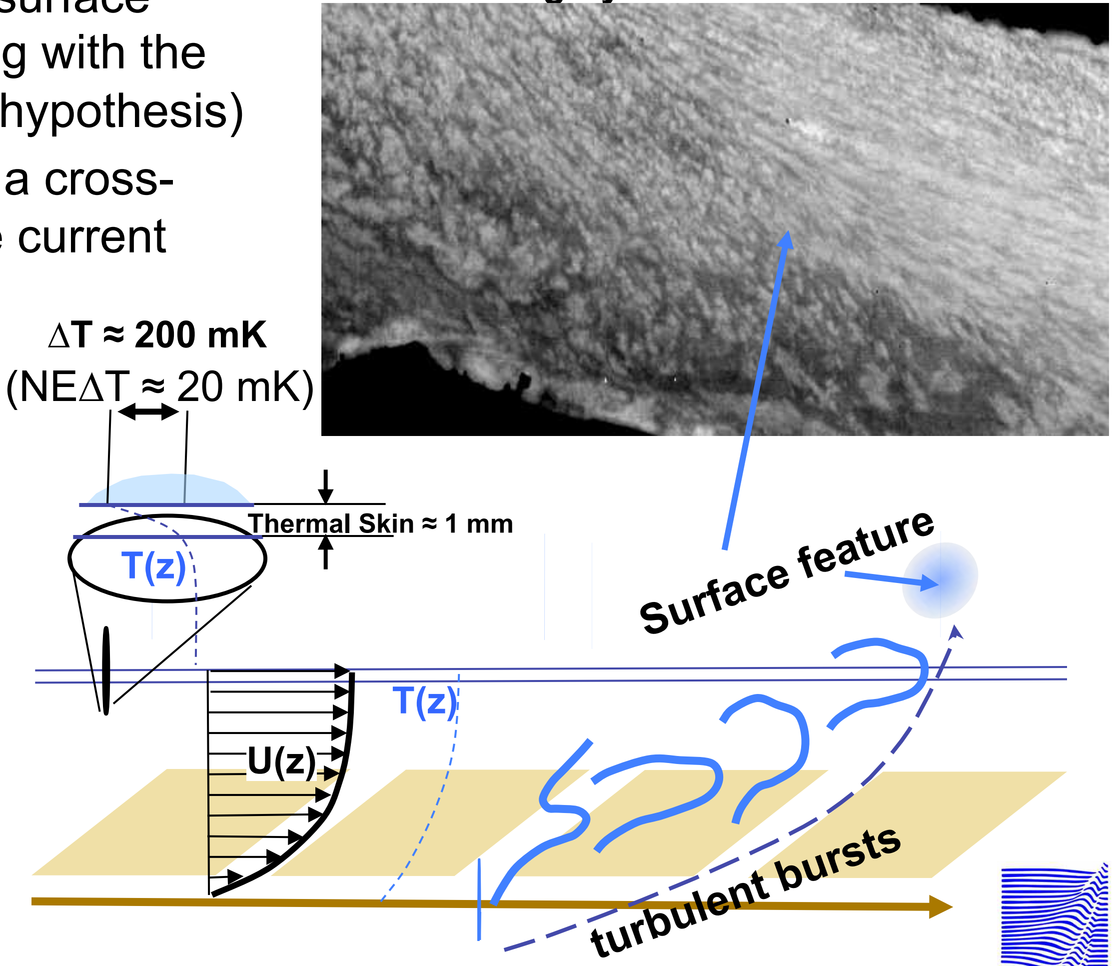
MWIR Riverine Phenomenology

IR Imagery allows for day-night capability and higher resolution than EO

- Turbulence in river generates a surface expression that is advected along with the mean flow of the river (Taylor's hypothesis)
- Surface feature is tracked using a cross-correlation algorithm to measure current
- Requires heat flux at the thermal skin on the order of ΔT ~ 200 mK
- Typical MWIR camera sensitivities (noise equivalent delta temperature, **NEΔT)** are on the order of 20 mK

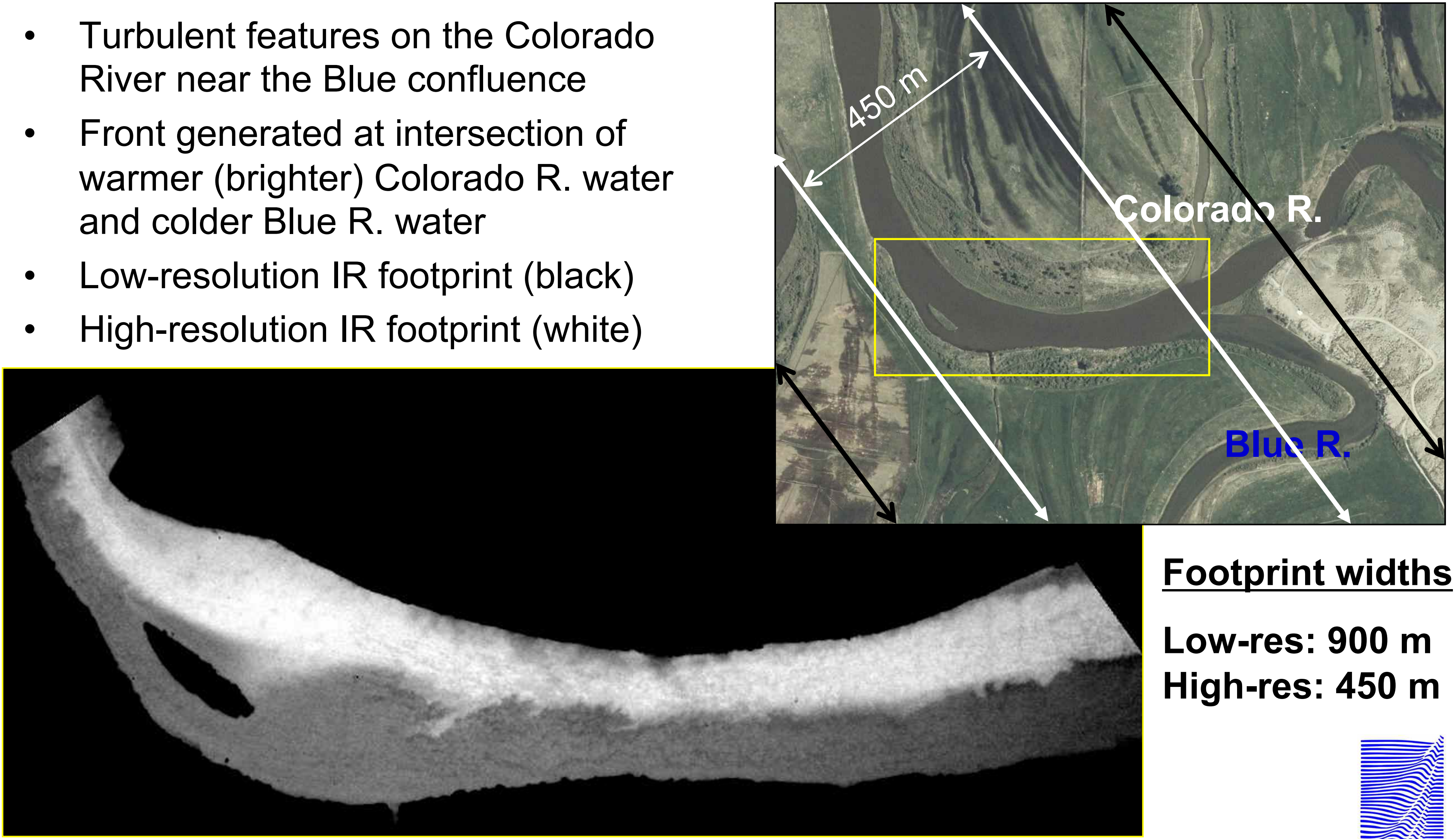
See Garbe et al (2004), Zappa and Jessup (2005), Veron and Melville (2010), Chickadel et al (2011),…

IR Imagery on Connecticut River



IR Imagery on the Colorado River

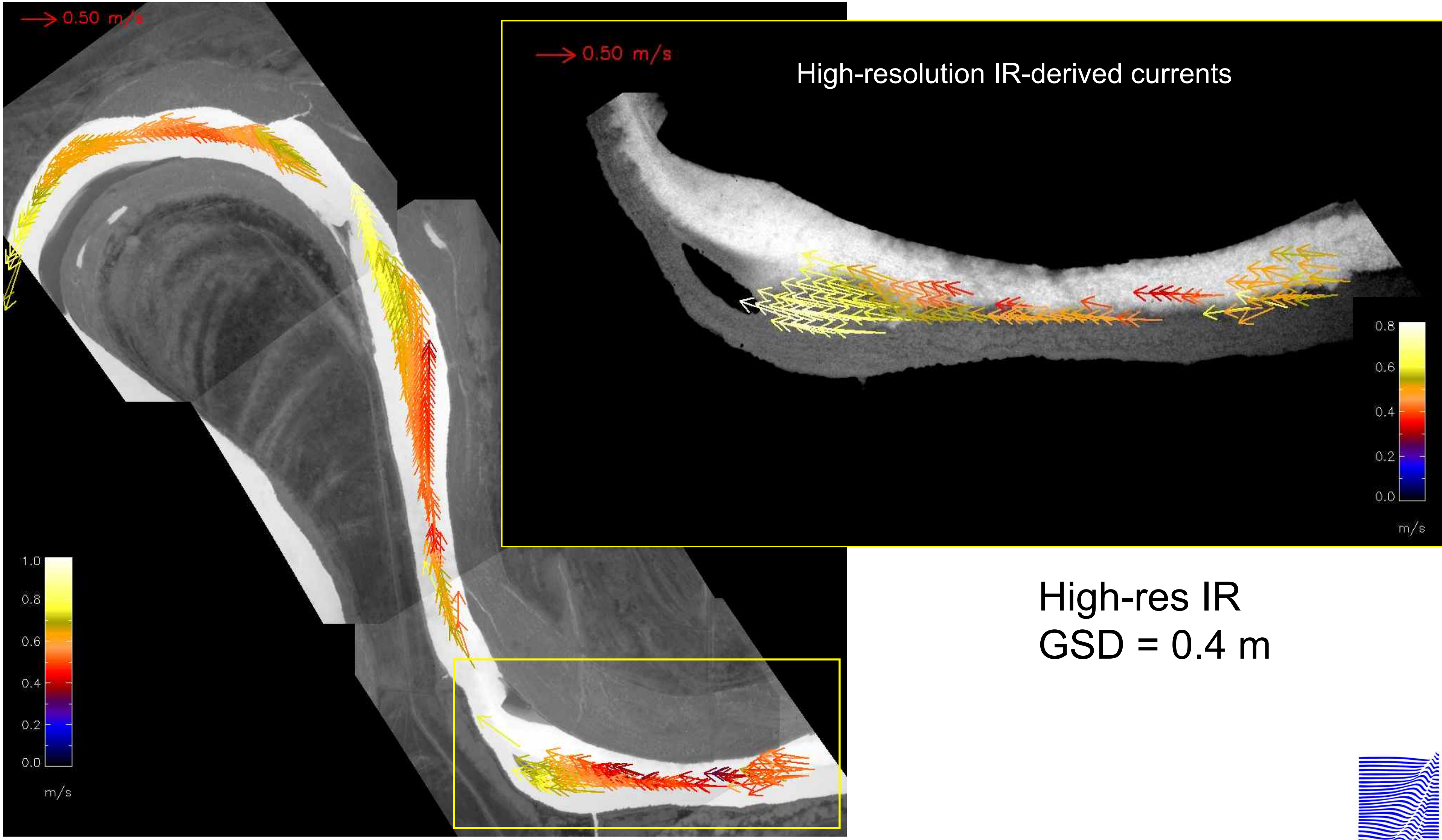
- Turbulent features on the Colorado River near the Blue confluence
- Front generated at intersection of warmer (brighter) Colorado R. water and colder Blue R. water
- Low-resolution IR footprint (black)
- High-resolution IR footprint (white)



Footprint widths

Low-res: 900 m
High-res: 450 m

AROSS-F Current Retrievals



High-res IR
GSD = 0.4 m

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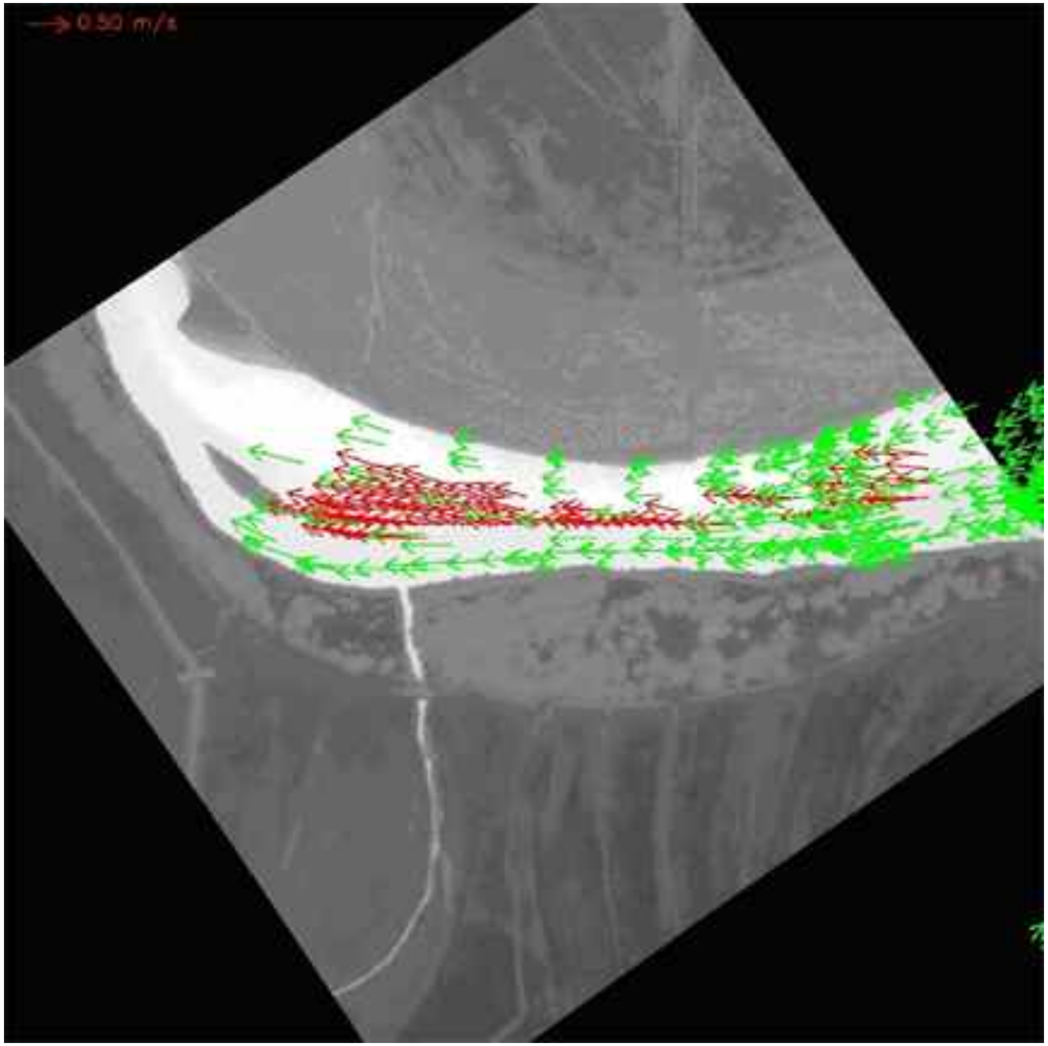
(OP 42 Run 2 at Night)

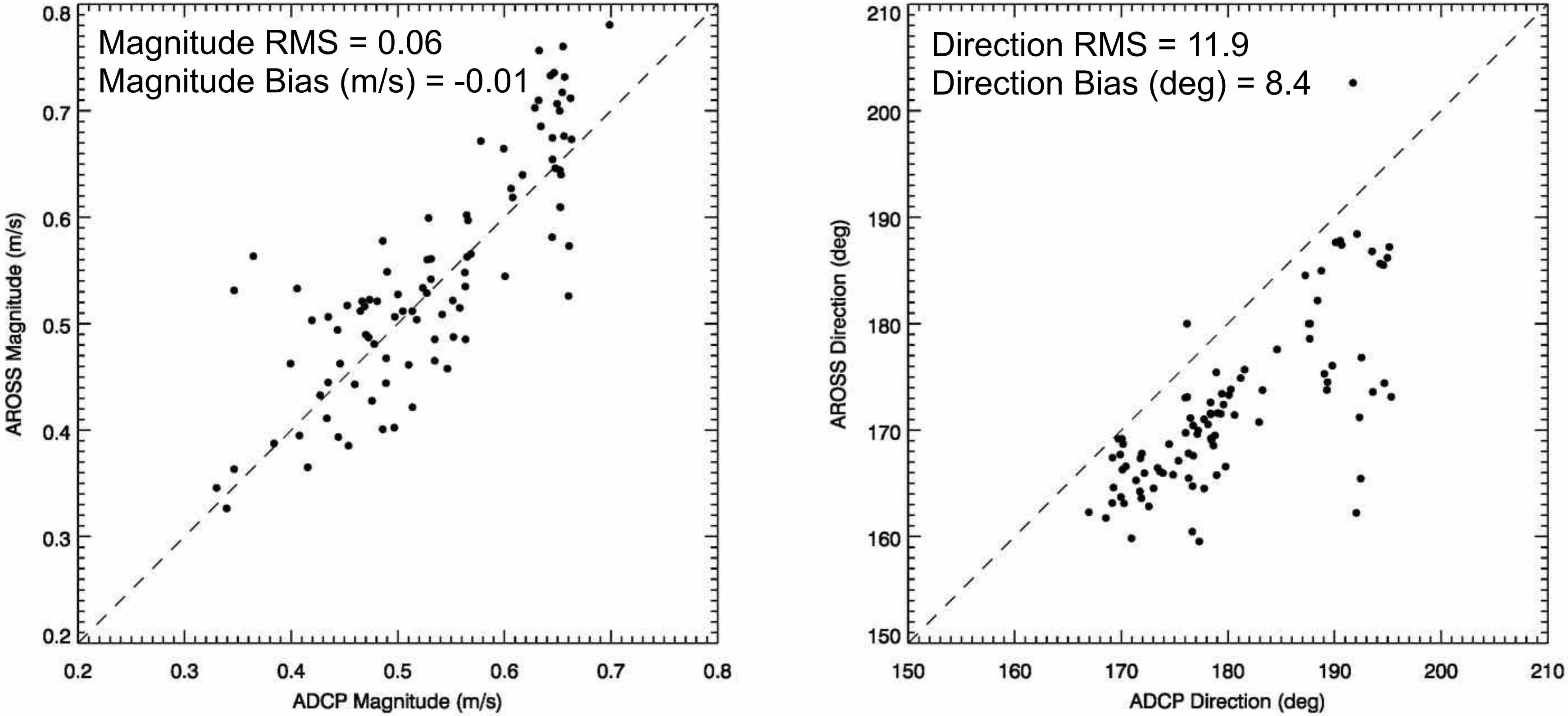
Areté
Associates

AROSS-F vs. ADCP Current Retrievals



Green – ADCP
Red – AROSS-F

AROSS-F versus ADCP Statistics



Average of ADCP (top bin) 8m radius around AROSS point

Inversion Modeling

- Normally, we take bed elevation, discharge, roughness and solve for velocity and water-surface elevation.
- Inverse method uses velocity and water-surface elevation to attempt to predict depth

  + Gives refined local information

  - Requires highly accurate data

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How do we solve for depth?

- Steady, uniform flow over long reaches
- Use assumptions to reduce the governing equations to something we can directly solve for depth given reasonable input data on velocity and water-surface elevation
- Nonlinear data assimilation

Assumptions

- Incompressible
- Hydrostatic
- Quasi-steady
- Velocity components uncorrelated in the vertical
- No lateral stresses

Governing Equations

$$\frac{1}{1-N}\frac{\partial}{\partial s}\left(<u>h\right)-\frac{<v>h}{\left(1-N\right)R}+\frac{\partial}{\partial n}\left(<v>h\right)=0 \tag{1}$$

$$\begin{aligned}
&\frac{1}{1-N}\frac{\partial}{\partial s}\left(<u^2>h\right)+\frac{\partial}{\partial n}\left(<uv>h\right)-\frac{2<uv>h}{\left(1-N\right)R}=-\frac{gh}{1-N}\frac{\partial E}{\partial s}+\\
&\frac{1}{\rho}\left[\frac{1}{1-N}\frac{\partial}{\partial s}\left(<\tau_{ss}>h\right)+\frac{\partial}{\partial n}\left(<\tau_{ns}>h\right)-\frac{2<\tau_{ns}>h}{\left(1-N\right)R}\right]+\\
&\frac{1}{\rho}\left[\frac{1}{1-N}\left(\tau_{ss}\right)_B\frac{\partial B}{\partial s}+\left(\tau_{ns}\right)_B\frac{\partial B}{\partial n}-\left(\tau_{zs}\right)_B\right]
\end{aligned} \tag{2}$$

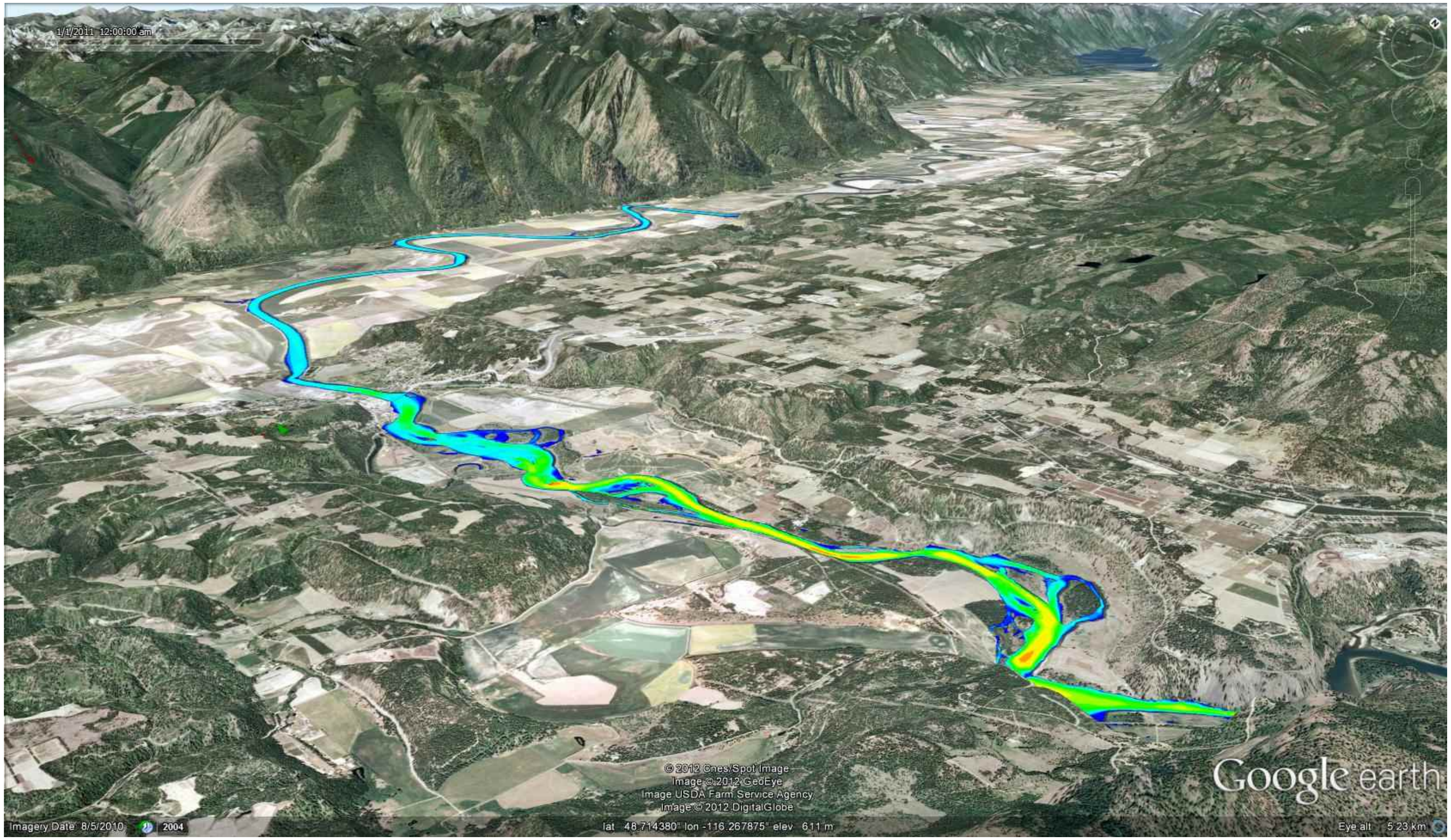
$$\begin{aligned}
&\frac{1}{1-N}\frac{\partial}{\partial s}\left(<uv>h\right)+\frac{\partial}{\partial n}\left(<v^2>h\right)+\frac{\left(<u^2>-<v^2>\right)h}{\left(1-N\right)R}=-\frac{gh}{1-N}\frac{\partial E}{\partial n}+\\
&\frac{1}{\rho}\left[\frac{1}{1-N}\frac{\partial}{\partial s}\left(<\tau_{ns}>h\right)+\frac{\partial}{\partial n}\left(<\tau_{nn}>h\right)-\frac{<\tau_{ss}-\tau_{nn}>h}{\left(1-N\right)R}\right]+\\
&\frac{1}{\rho}\left[\frac{1}{1-N}\left(\tau_{ns}\right)_B\frac{\partial B}{\partial s}+\left(\tau_{nn}\right)_B\frac{\partial B}{\partial n}-\left(\tau_{zn}\right)_B\right]
\end{aligned} \tag{3}$$

Rearrange and solve for depth

$$h = \frac{-\left(\tau_{zs}\right)_B}{\rho\left[\frac{g}{1-N}\frac{\partial E}{\partial s}+\frac{<u>}{1-N}\frac{\partial <u>}{\partial s}+<v>\frac{\partial <u>}{\partial n}-\frac{<u><v>}{\left(1-N\right)R}\right]}$$

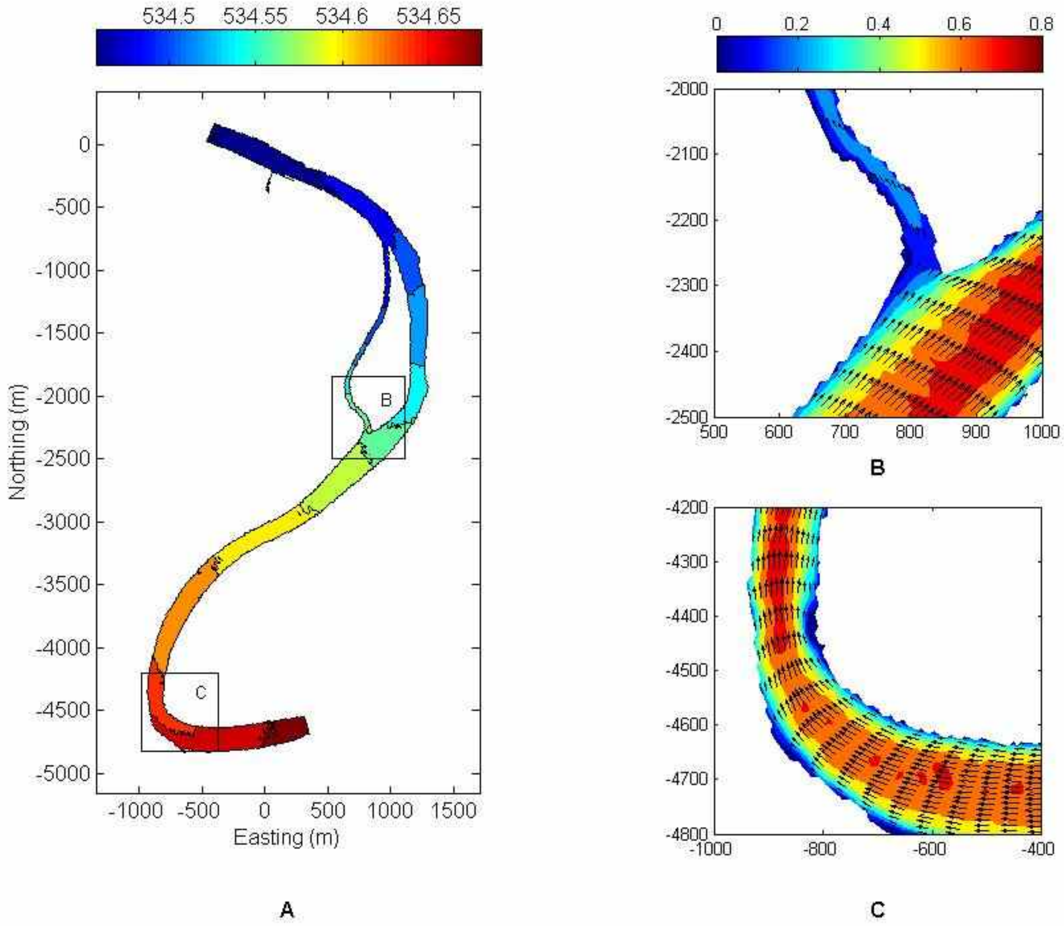
$$(\tau_{zs})_B = \rho C_d\sqrt{<u>^2+<v>^2}<u>$$

Example Application



- Kootenai River: Sand bed, flat, ~10m deep

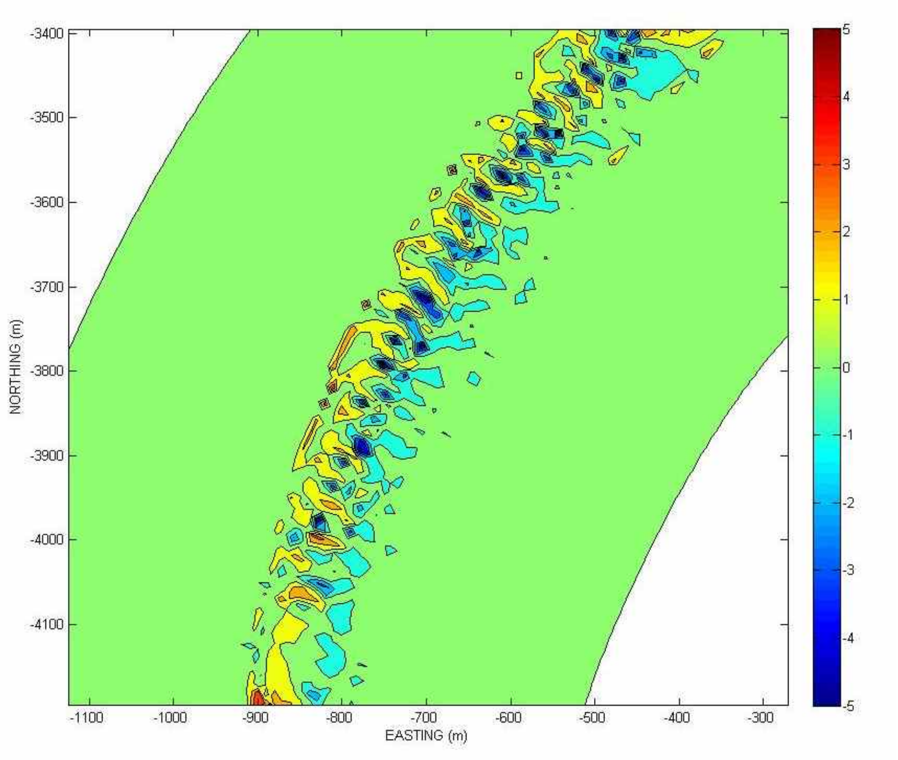
Model Computations



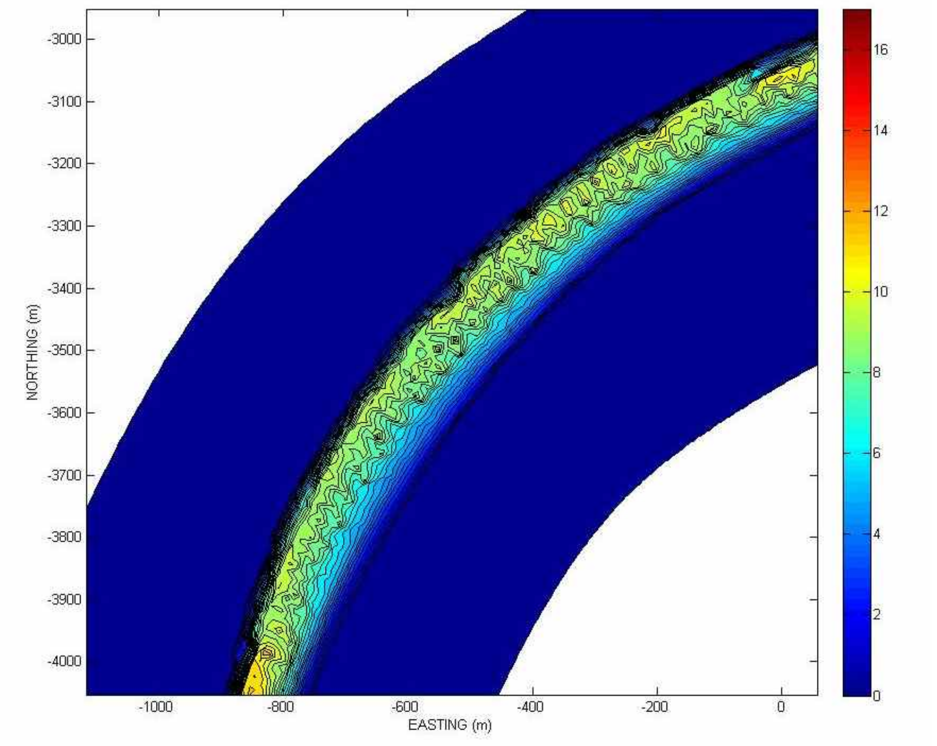
Predicted WSE

Predicted vertically-averaged velocity

Results - Inversion Model



Error (m)



Bed Elevation (m)

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Model assumes hydrostatic pressure, bedforms problematic

Future Work

- Bathymetry - Evaluation of EAARL-B (2x pulse rate, 10x power, 6x the point density)
- Surface velocity – Ground-based thermal imaging, Explore potential for additional collaboration Areté and AROSS-F
- Water-surface elevation – AirSWOT, Radar
- Further testing of inversion model to infer channel bathymetry from water surface elevation and surface velocity – Laboratory and field

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