Remote Sensing of River Discharge to Expand the USGS Streamgaging Network

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ESSIC

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** All data herein is considered provisional and subject to change **

The Need

The current USGS streamgaging network in the United States, particularly in Alaska, does not provide full coverage in space and time.

Given the access limitations to many rivers, methods are needed to increase the spatial and temporal density of the gaging network including:

- satellite platforms
- ConFiRM (Calibration oF River Measurements)
  - CalVal of top width, slope, velocity, and discharge using ground-based and rapid deployment of equipment including:
    - Fixed- and drone-based velocity radars and LSPIV cameras
    - Ungaged basins with little or no historical discharge records

The Goal

Develop and test methodologies to estimate river discharge from remotely-sensed (RS) observations with the goal of establishing discharge records where historical streamflow information is lacking.

The Objectives

Develop an approach (presented here) that couples the USGS dynamic surface-water extent product with satellite altimetry to estimate discharge from satellite observed water-surface height, slope, width, and calibrated with minimal ground-based measurements.

Establish reach scale remote sensing gaging stations in un-gaged and remote rivers that:

- Are more stable in time than cross-section based stations, reducing the frequency of supplemental ground-based measurements in un-gaged and remote basins
- Produce time series of estimates of discharge, depth, and velocity in river reaches going forward in time and enabling the reconstruction of past time series from archived RS observations

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Overview – Remote Sensing Observational Data – Dynamic Mapping of Rivers

- Observations of Dynamic Stage and Water Surface Slope
- Along-channel variation of Width and Meander Length
- Channel morphology and Meander Pattern

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USGS Dynamic Surface Water Extent (DSWE)

http://remotesensing.usgs.gov/ecv/SWE_overview.php

Detect whether surface water is present in any clear, shadow free Landsat pixel.

Provisional Version1 data available by request.

Currently assessing inclusion of Sentinel sensor data for Version2.

Comprehensive system in place for product evaluation/application (see poster).

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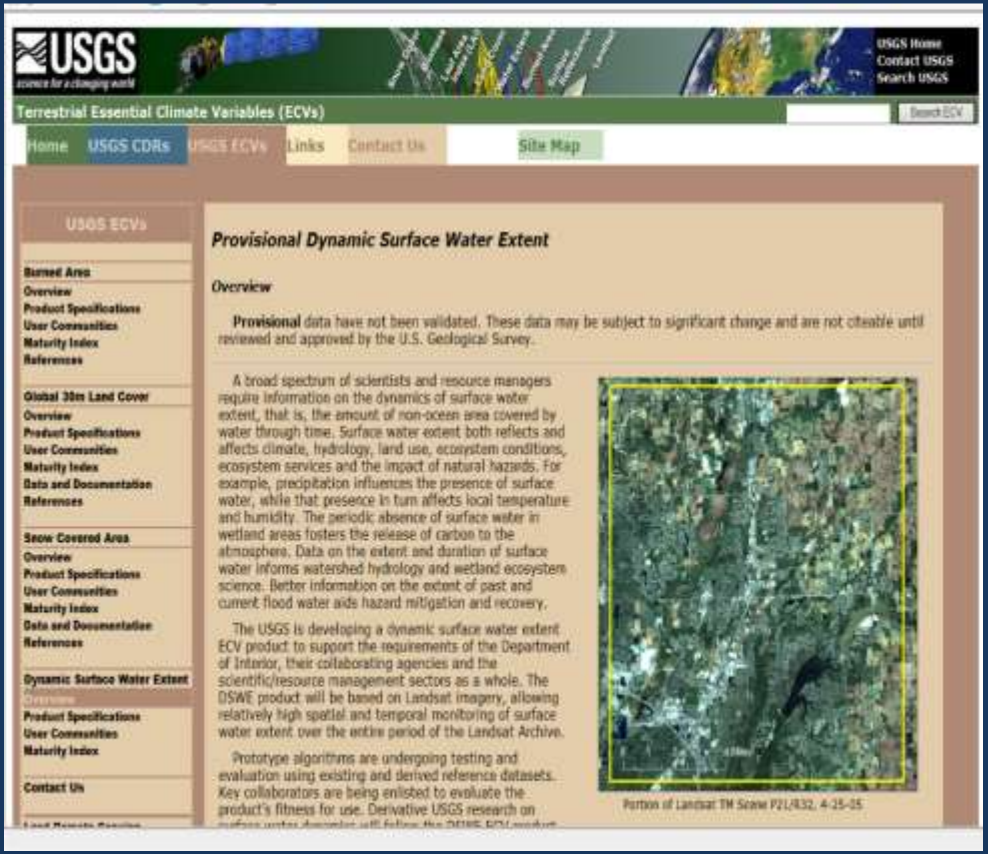

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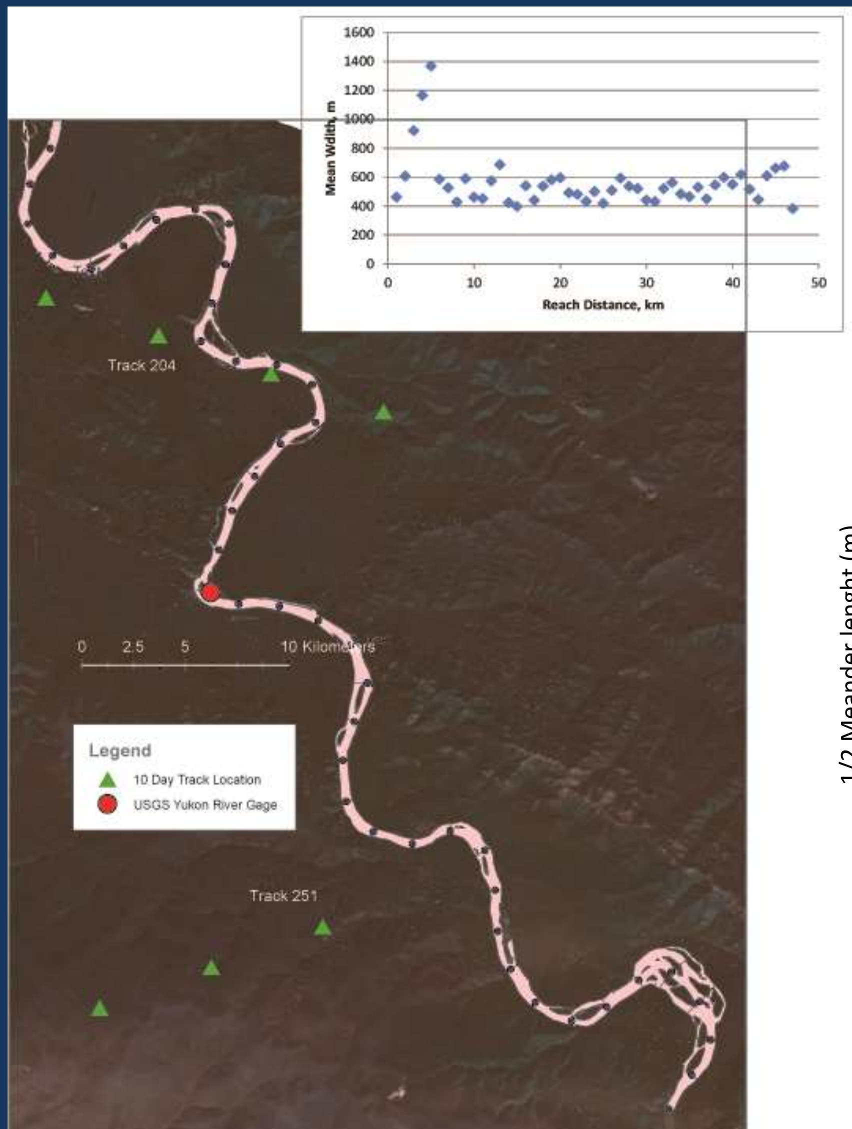
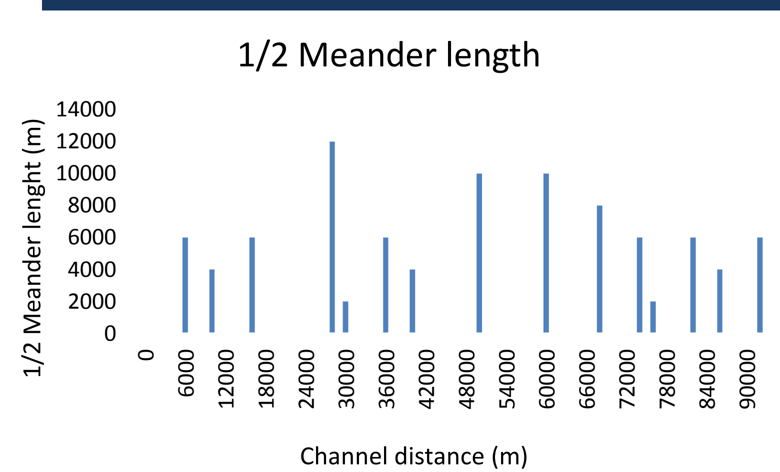
Dynamic Surface Water Extent (DSWE)

Variation in width along river channel



Reach Analysis – Yukon River near Eagle, Alaska.

Landsat image analysis of width variation and meander length.



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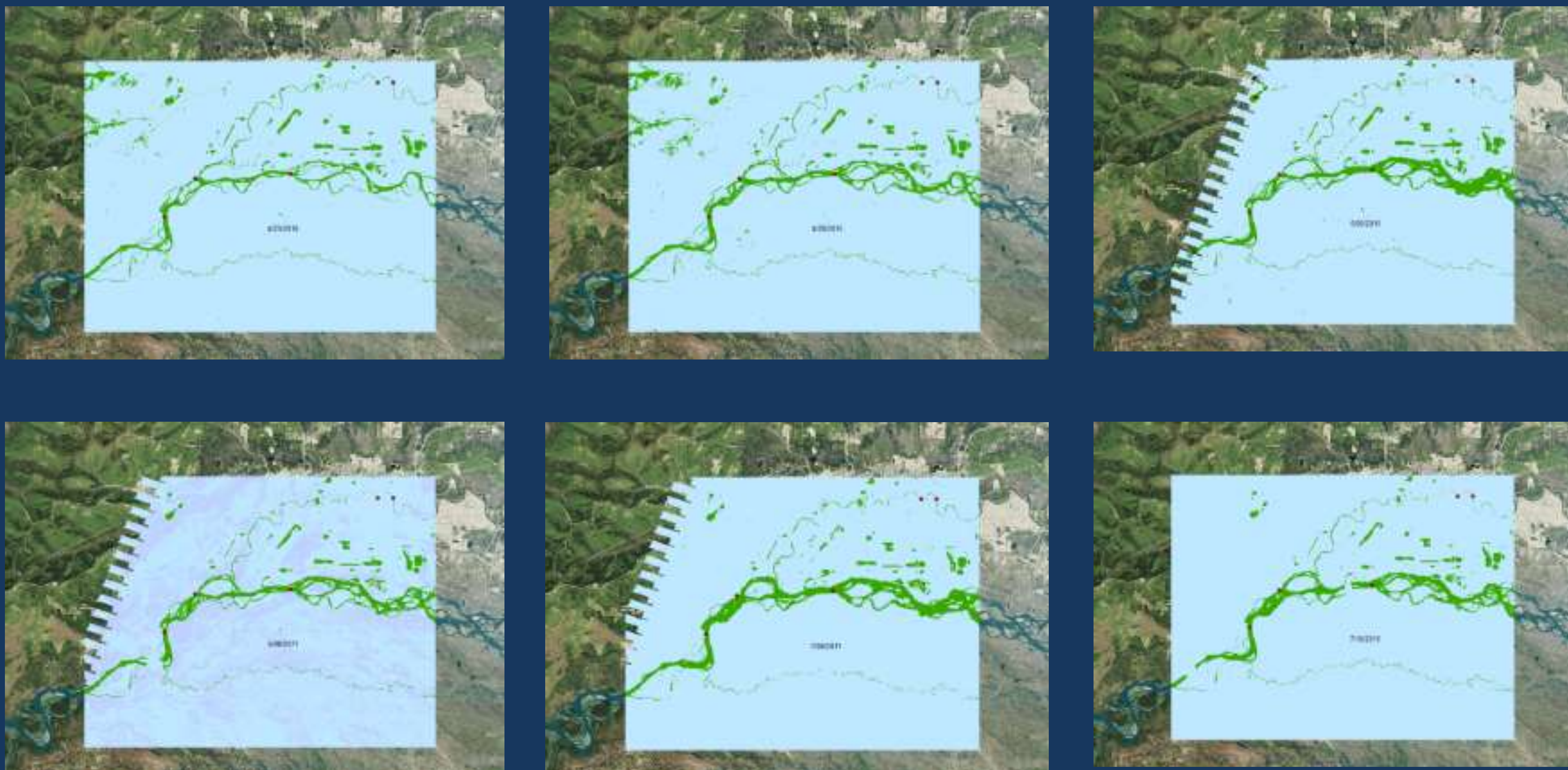
Time Series of Water Area - Tanana and Chena Rivers near Fairbanks, Alaska from DSWE



Temporal Resolution – 7 days depending on Clouds and overlapping orbital paths

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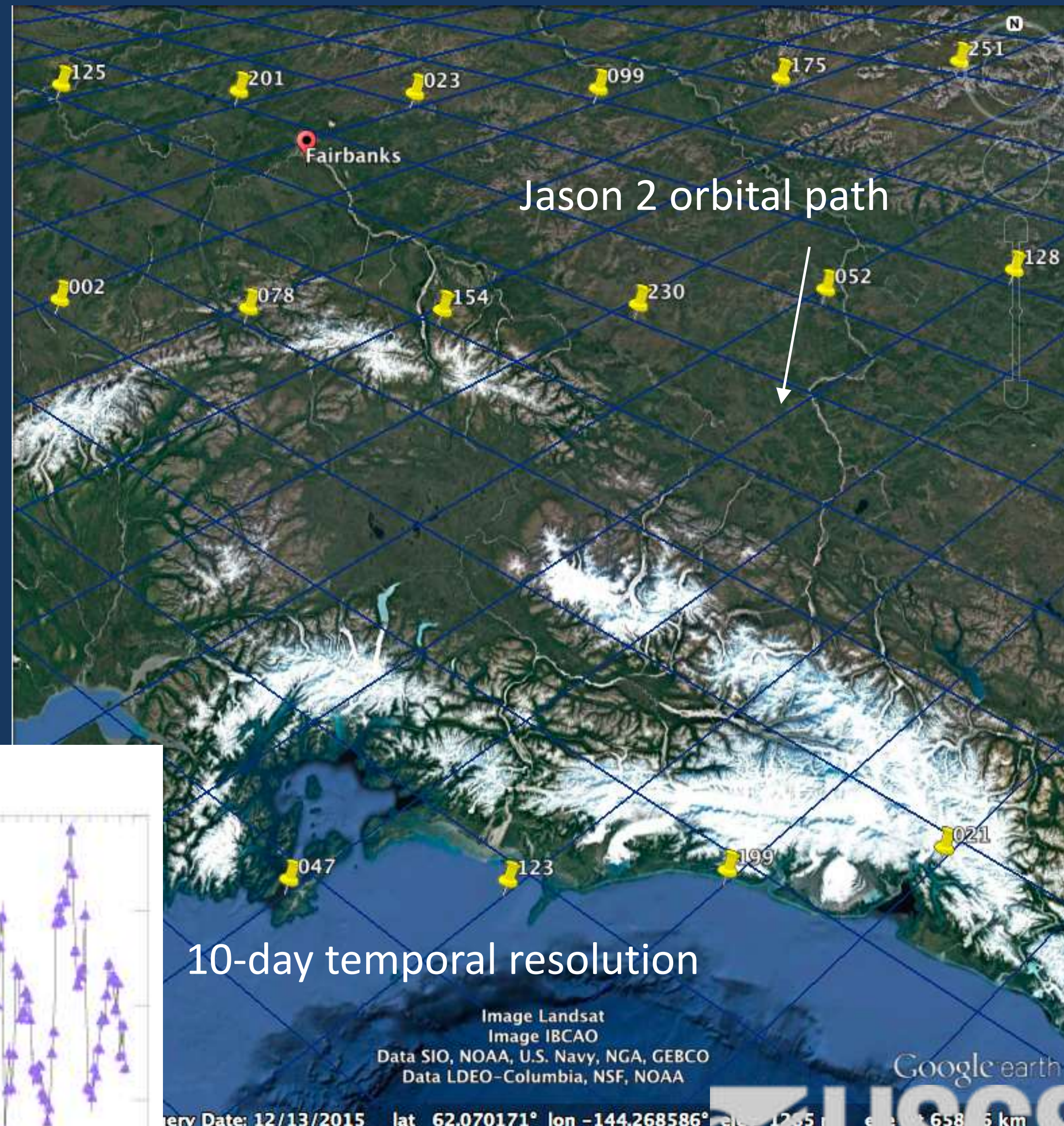
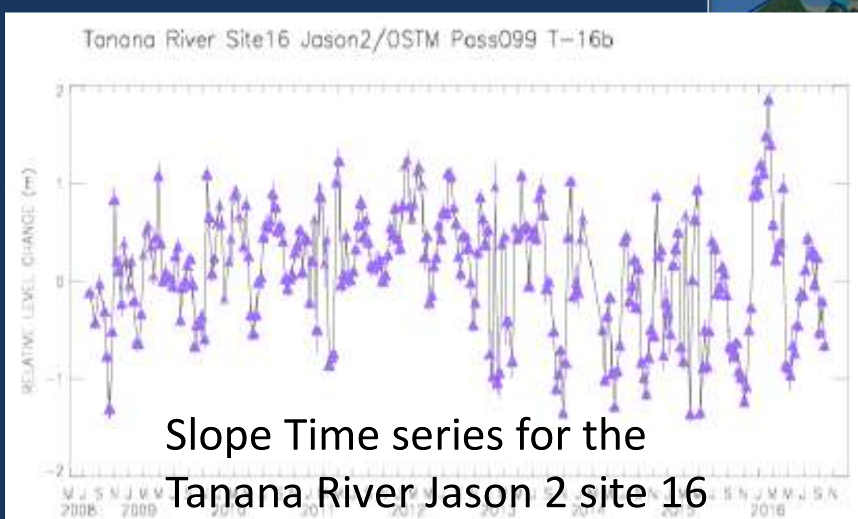
Jason 2 Satellite tracks – Tanana and Chena Rivers near Fairbanks Alaska





Jason-2 data presentation from Charon Birkett, UMD

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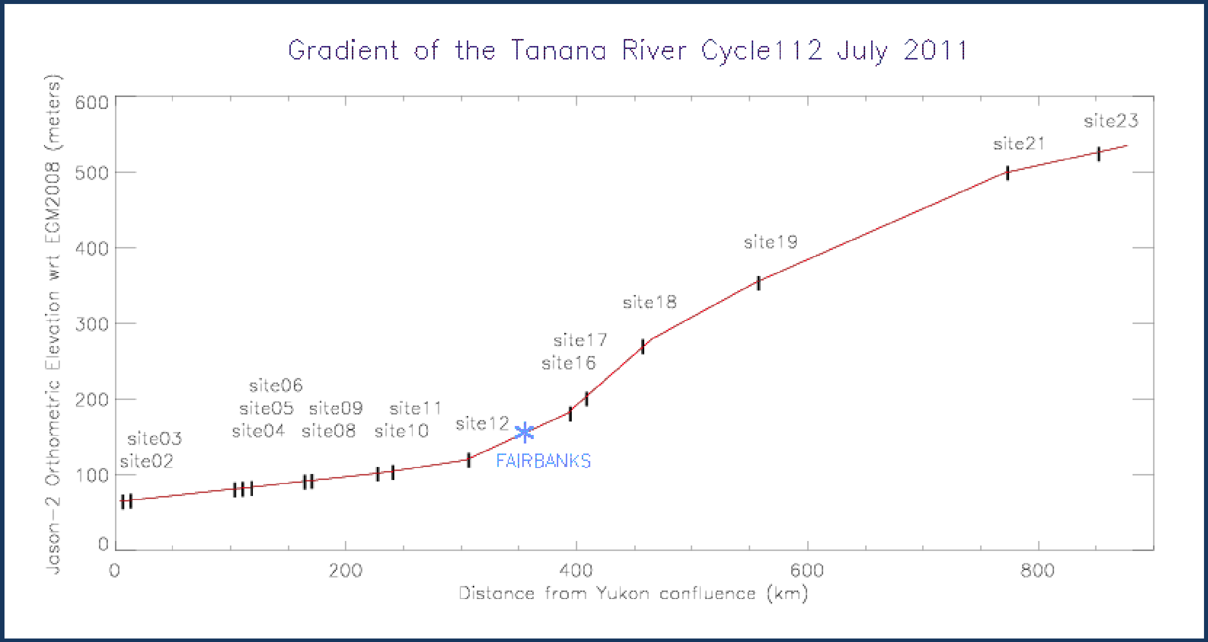
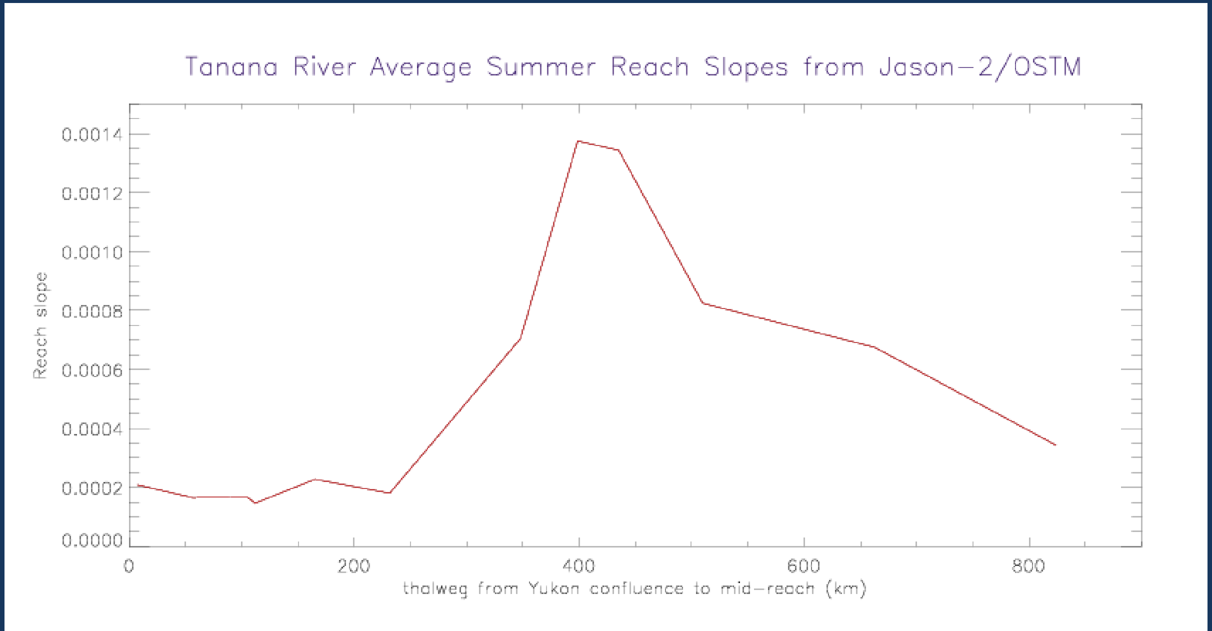
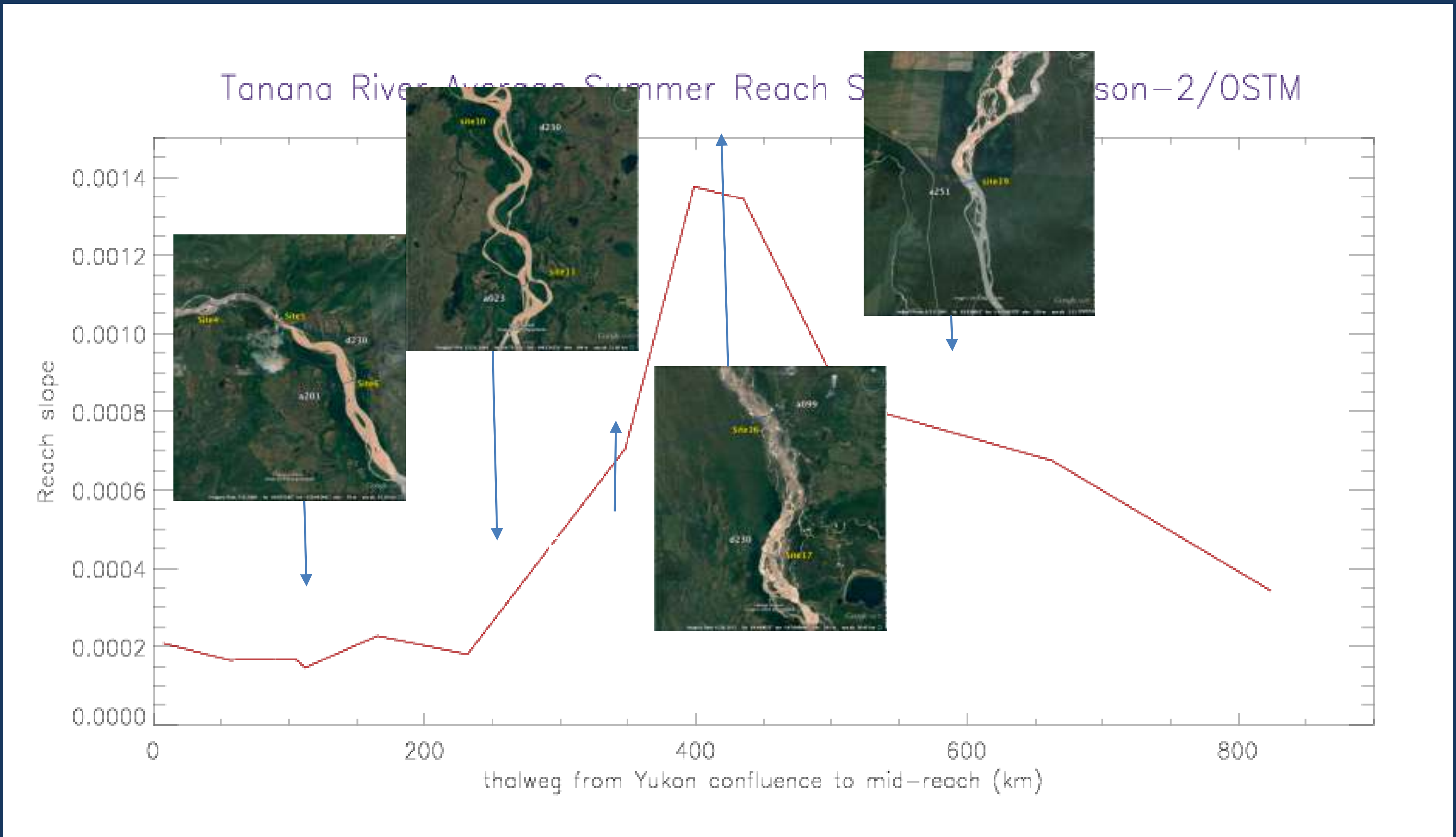
Mapping River Water Surface Slope – Tanana River



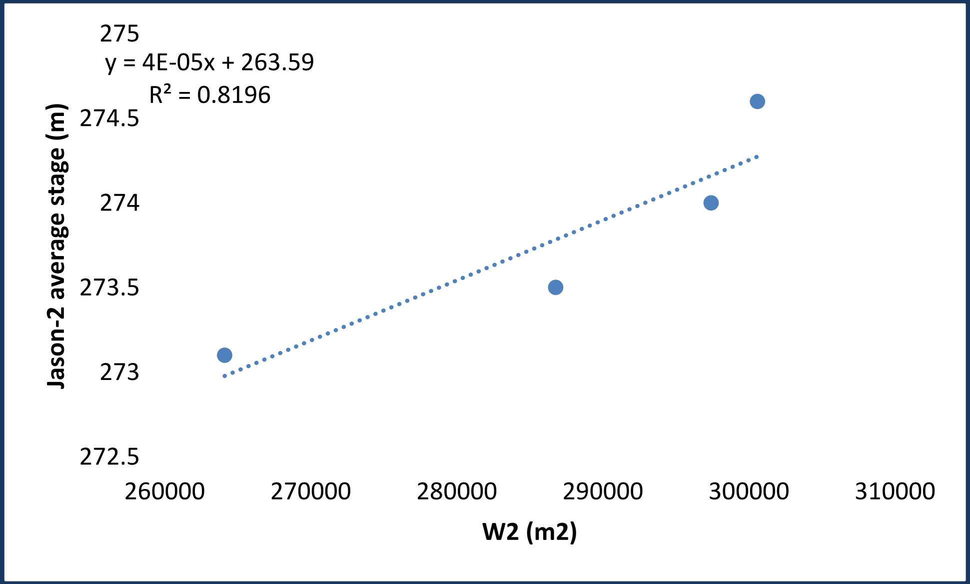


Mapping the River Channel Water Surface Slope as it relates to channel pattern – Tanana River



A practical necessity using different satellite platforms – non-coincident observations

There are many more height observations from Jason 2 than width observations from Landsat due to cloud cover.



A relation is developed between width and height.

Height is used to estimate width.

The upcoming NASA SWOT mission (launch 2021) will provide coincident observations of width, stage, and slope.

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Supplemental information –

Assumptions from river hydraulic data – HYDRoSWOT data base

Data available for calibration –

Modeling and national hydrography data – Calibration to Mean flow

Limited discharge measurements from ground or aerial platforms – Calibration to individual measurements

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HYDRoSWOT DataBase - USGS Measurement Data

Assembled discharge measurements from USGS streamgages at unobstructed cross- sections using ADCP measurements, high water mark and gage height of zero flow.

https://www.sciencebase.gov/catalog/item/57435ae5e4b07e28b660af55

Table 1 – HYDRoSWOT - Hydraulic and channel geometry database.

Table Name	Number of Records	Number of Fields	Minimum Date	Maximum Date
HWM [1]	13,905	14	10/6/1932	11/25/2014
GZF [2]	32,936	13	12/11/1930	11/25/2014
ADCP [3] and Boat Measurements	223,764	56	10/7/1940	11/25/2014

1 = High water mark; 2 = Gage-height of zero flow; 3 = acoustic Doppler current profiler

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HYDRoSWOT DataBase - USGS Measurement Data

Selected fields of interest for each streamgage measurement:

- Drainage Area at the gage
- Latitude and Longitude of the gage
- Elevation of the gage
- Discharge
- Flow width
- Maximum and mean depth of flow
- Maximum and mean velocity of flow

Anticipate adding channel slope at each gage in the near future.

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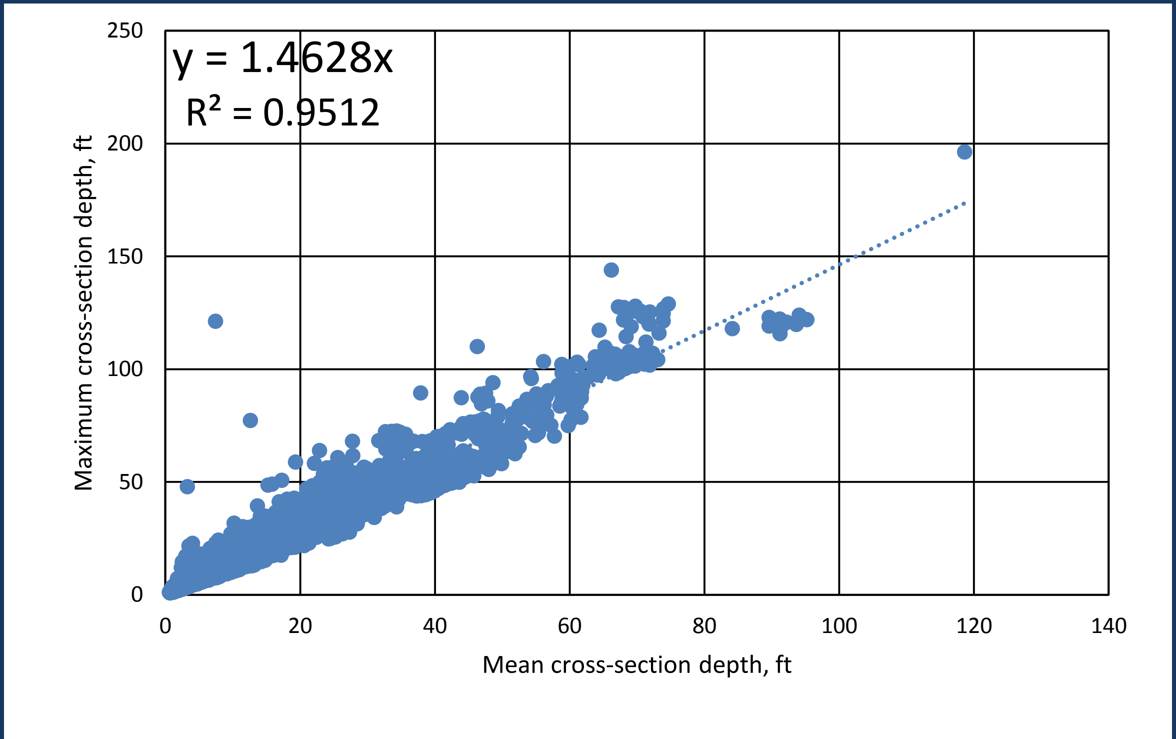
Example – Based on HYDRoSWOT data, the ratio of maximum to mean depth can provide a general guide to channel cross-section shape.

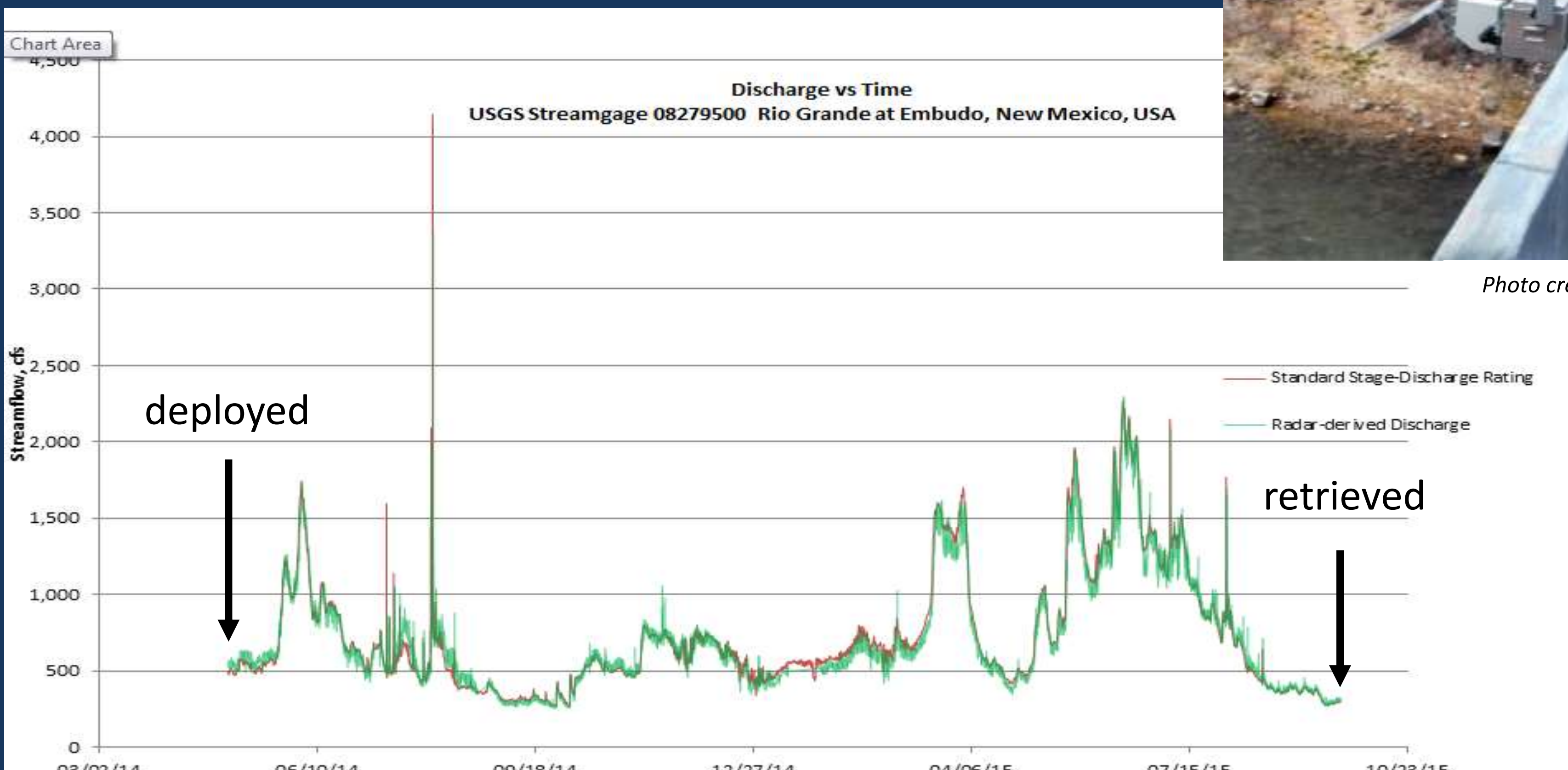


Based on 30,000 flow measurements in rivers across the US, the ratio of mean to max depth is approximately 1.5, which indicates a general parabolic shape.

USGS remotely sensed, ground-based stage and velocity radars for Cal/Val – ConFiRM

USGS Streamgage: Rio Grande at Embudo, New Mexico, USA.

Photo credit JT Minear



Comparison of streamflow derived from standard stage-discharge rating and real-time continuous-wave radars for the USGS streamgage 08279500 Rio Grande at Embudo, NM.

How is discharge compute d and what variables change to generate real-time discharge:

The Probability Concept parameter, ϕ or u_{avg}/u_{max}, established on 4/30/14 remained unchanged and used to compute subsequent Qs; however, umax and area, which are measured in real-time differ:

9/27/14 at 0300:

$Q = \phi\, u_{max}\, A$

$Q = \mathbf{0.606} \times 2.87\ ft/s \times 157\ ft^2$

$Q = 273$ cfs vs 273 cfs

6/14/15 at 2000:

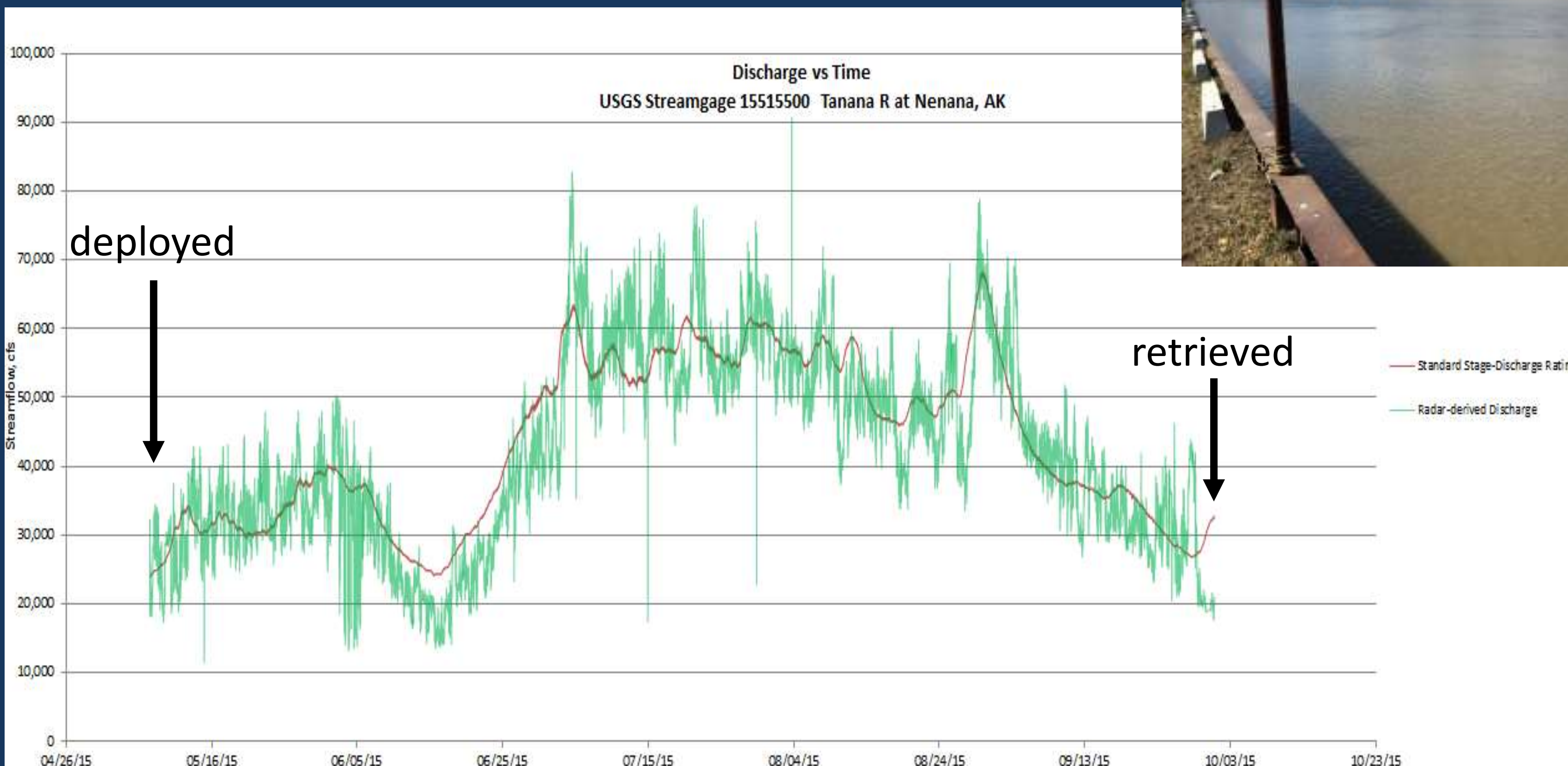
$Q = \phi\, u_{max}\, A$

$Q = \mathbf{0.606} \times 8.60\ ft/s \times 420\ ft^2$

$Q = 2,188$ cfs vs 2,220 cfs

USGS Ground-based Radar – Wide with high sediment load – note high scatter due to sample duration or wind drift.

USGS Streamgage: Tanana at Nenana, Alaska USA.



Comparison of streamflow derived from standard stage-discharge rating and real-time continuous-wave radars for the USGS streamgage 15515500 Tanana River at Nenana, AK.

Discharge Algorithm Development

Testing Manning Equation (MAN) with a logarithmic modifier for change in resistance with depth, and Prandtl-von Karman (PVK) Equation with base flow resistance estimated from channel characteristics and various options for calibration.

MAN: $$Q = \frac{\left[W*\left((h-B)*(1-\left(\frac{1}{1+r}\right))\right)^{1.67}*S^{0.5}\right]}{n}$$

PVK: $$Q = 2.5 * W * Y * (g * Y * S)^{0.5} * (ln\left(\frac{Y}{y_0}\right) - 1)$$

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Discharge Algorithm Variable Definitions

where: Q = the river discharge, (m^3/s)
W = the width of flow, (m)
h = the water surface stage (height) above a common datum, (m)
S = the water surface slope between observations of stage
n = the Manning roughness (resistance) coefficient
B = the stage of zero flow, (m)
r = the assumed channel shape coefficient.

Y = $(h - B) * (1 - (\frac{1}{1+r}),$ (m)
y_0 = roughness height, (m)
g = gravitational constant, 9.81 m/s^2

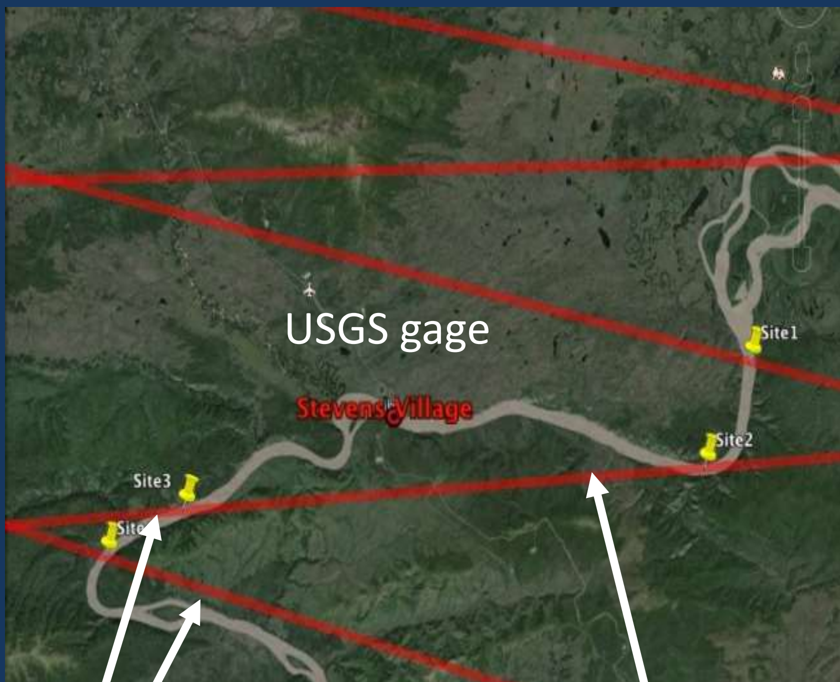
Remotely-sensed Hydraulic Features Used to Compute Discharge

Observed Feature	Variable of Interest	State	Source
Water Surface Area	Reach averaged width	Dynamic	Landsat DSWE
Water Surface Height	Change in depth	Dynamic	Jason2 Satellite altimetry
Water Surface Height	Water surface slope	Dynamic	Jason 2 Satellite altimetry
Channel Pattern	Index to roughness	Static	Landsat DSWE

Case Study for Yukon River at Eagle and Stevens Village – Stage and Slope from Jason-2 Altimeter

Jason-2 flight lines

Stevens Village



Jason-2 flight lines

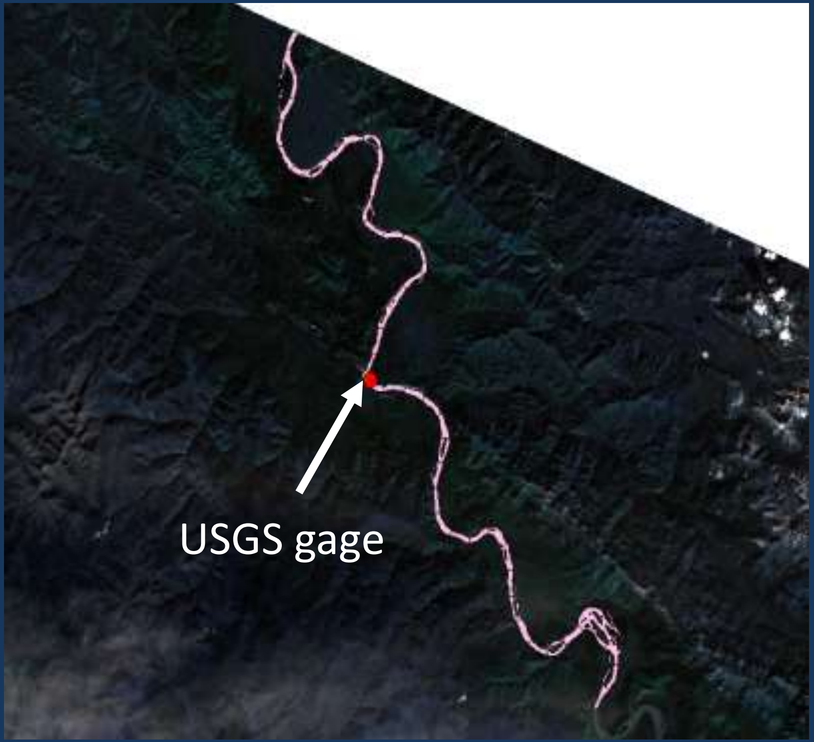
Jason-2 flight line used for stage and slope

Eagle

USGS gage

Jason-2 flight lines used for stage and slope

Case Study of Yukon River at Eagle and Stevens Village – Reach Averaged Width and Channel Meander Pattern



Landsat image with channel water surface area delineated Using the Dynamic Surface Water Extent (DSWE).

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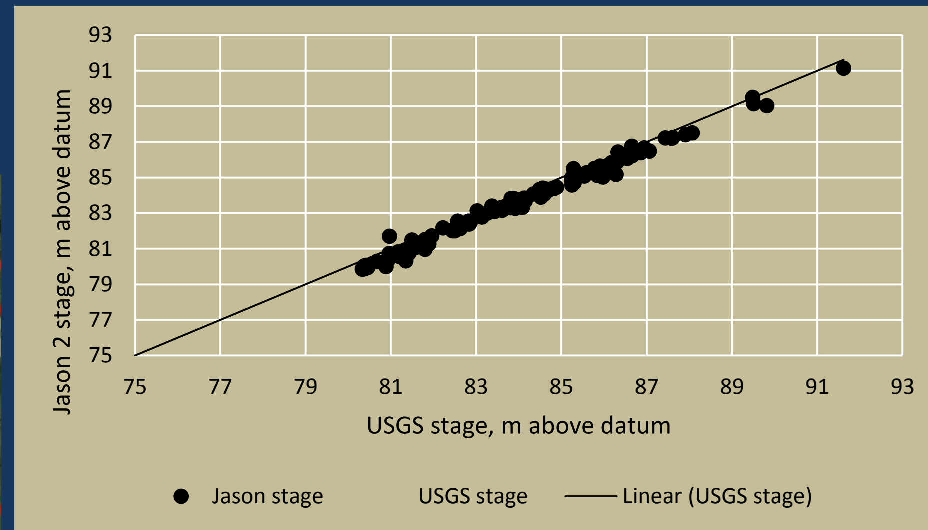
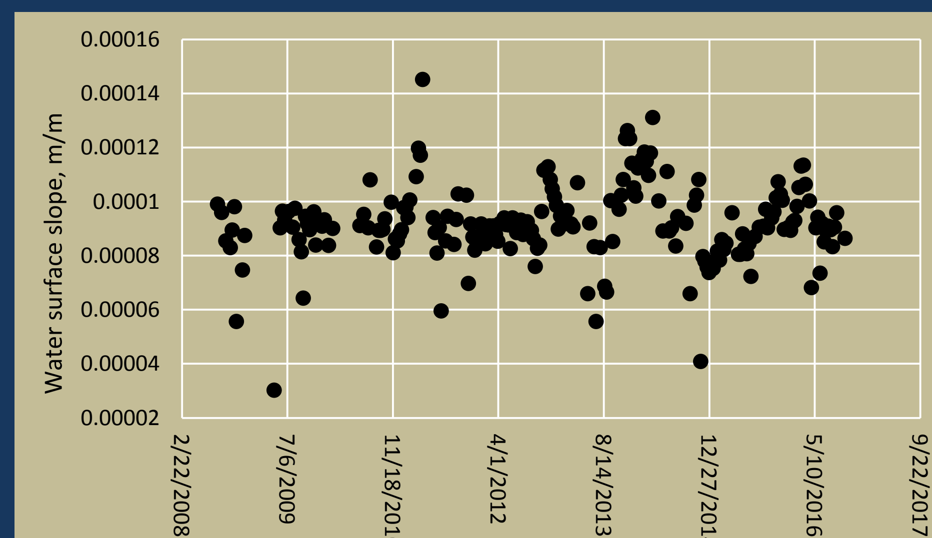
Case Study for Yukon River at Stevens Village

Jason-2 flight lines

Jason-2 flight lines

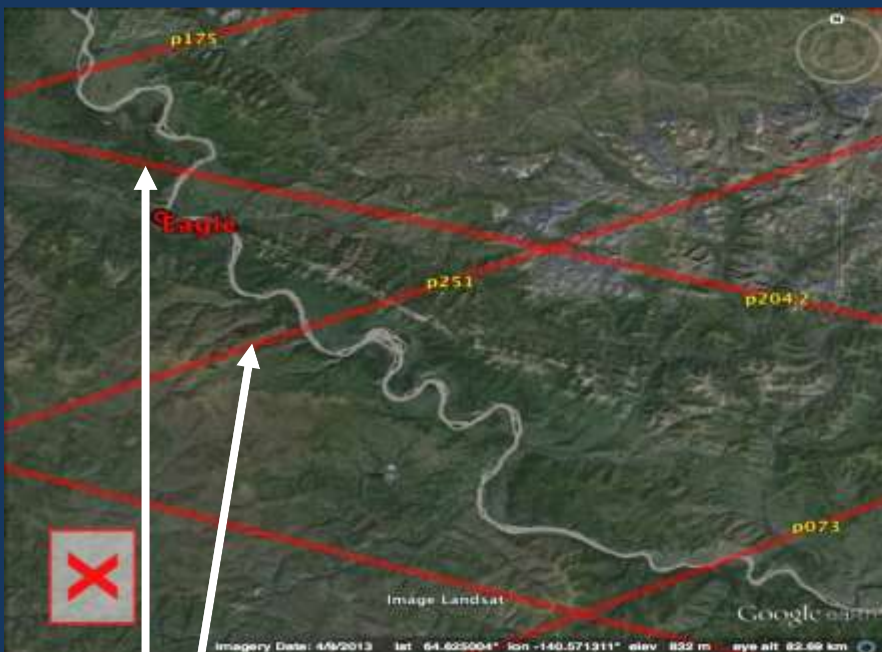
Jason-2 flight line used for calculations



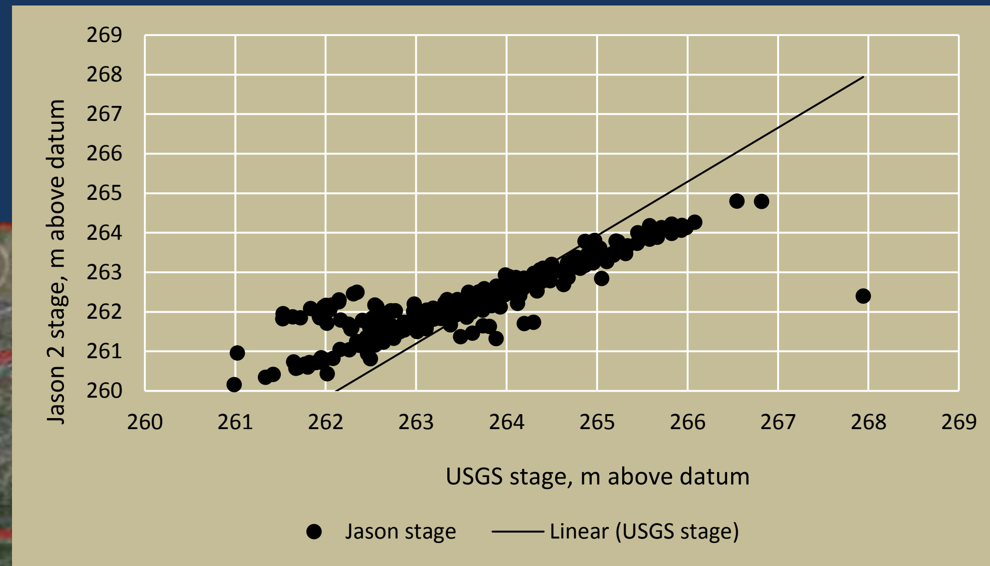


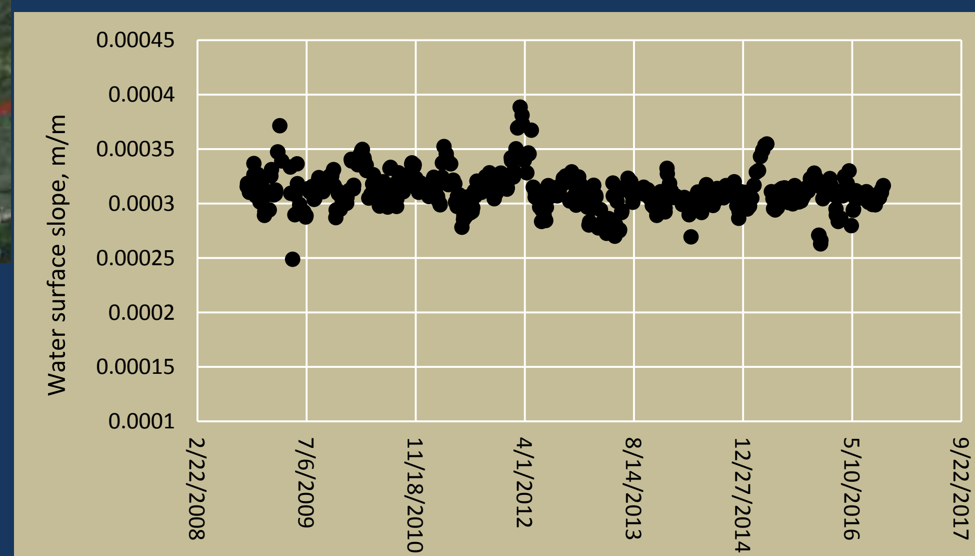
Case Study for Yukon River at Eagle

Jason-2 flight lines



Jason-2 flight line used for calculations





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Uncalibrated – Based on estimates of flow resistance and roughness height derived from channel morphology (Bjerklie, D.M., 2007. Estimating the bankfull velocity and discharge for rivers using remotely-sensed river morphology information, Journal of Hydrology 341: 144-155) and scaled as a log function of stage.

$V_b = 1.37 * (\lambda_c S)^{0.32}$

$n_b = \frac{{Y_b}^{0.67} * S^{0.5}}{V_b}$

$n = n_b * (1 + \log(\frac{H-B}{h-B}))$

V_b - bankfull mean velocity
Y_b - bankfull mean depth
n_b - bankfull Manning flow resistance
n - Manning flow resistance
λ_c - Resistance length
S - water surface slope

Calibrated – Using three discharge measurements assumed available from limited ground-based measurements collected during the eight year period of record.

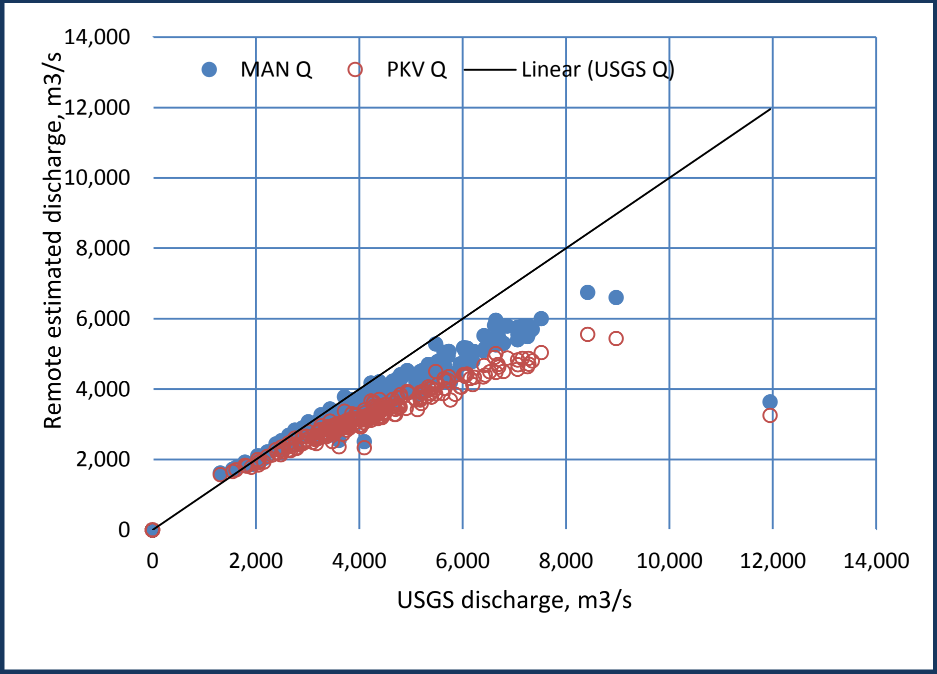
Calibration function – $n = n_b * (\frac{H-B}{h-B})^x$

x - variable exponent
H - bankfull stage
B - bottom stage
h - stage at flow

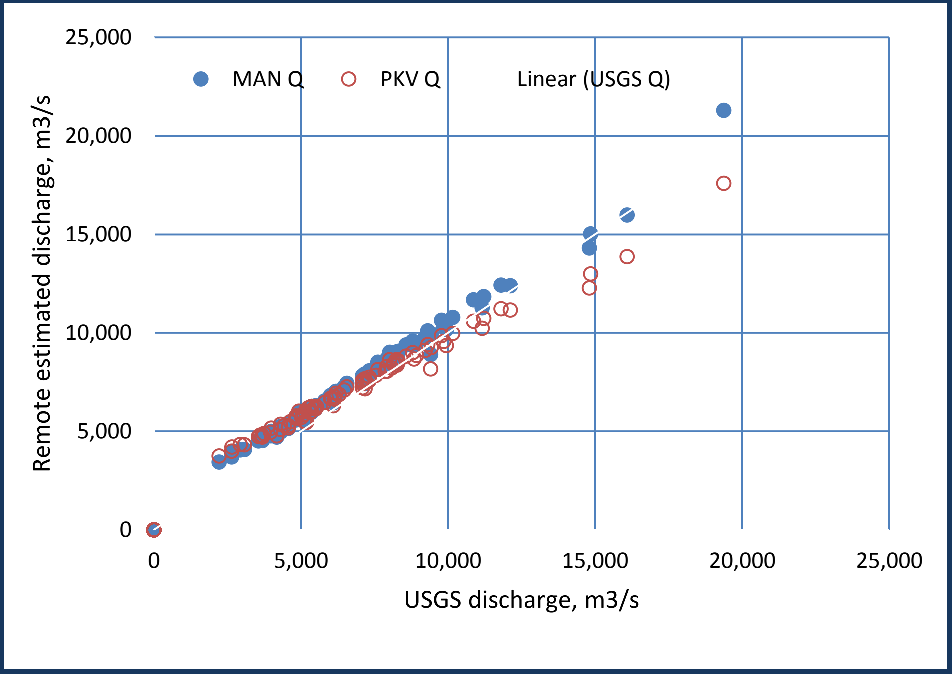
Varying n_b and x to match the three measurements.

Estimation of Discharge - Results

Eagle Uncalibrated



Stevens Village Uncalibrated



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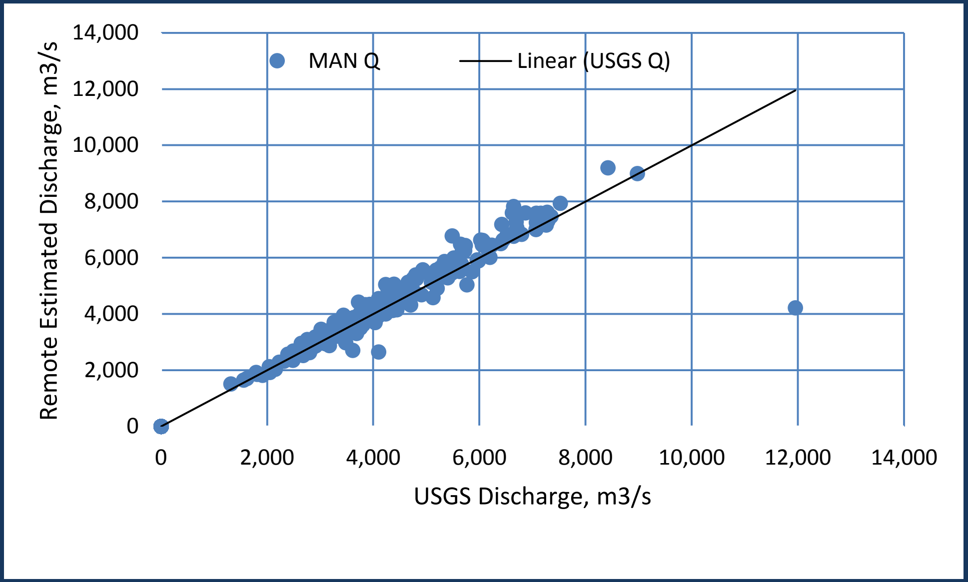
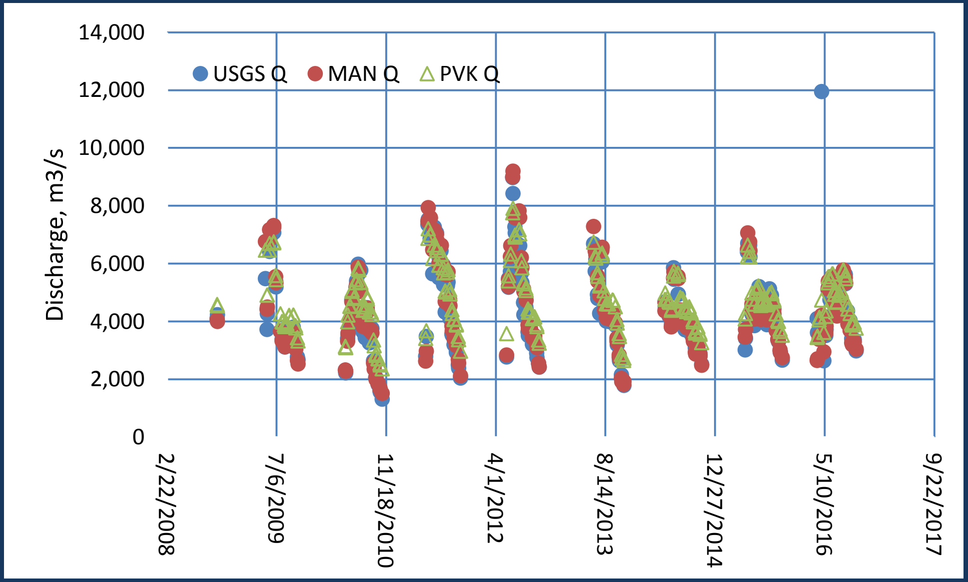
Eagle Calibrated





Eagle Alternate Calibration	USGS	Remote MAN	Remote PKV	Error MAN percent
Mean	4273.79	4364.25	4741.80	0.02
Stdev	1427.48	1457.91	1065.78	0.08
Coef. Var.	0.33	0.33	0.22	
Max	11952.15	9196.48	7919.32	0.23
Min	1316.01	1507.01	2365.23	-0.65
	MAN	PKV		
NSE	0.83	0.70		
NRMSE	0.06	0.07		

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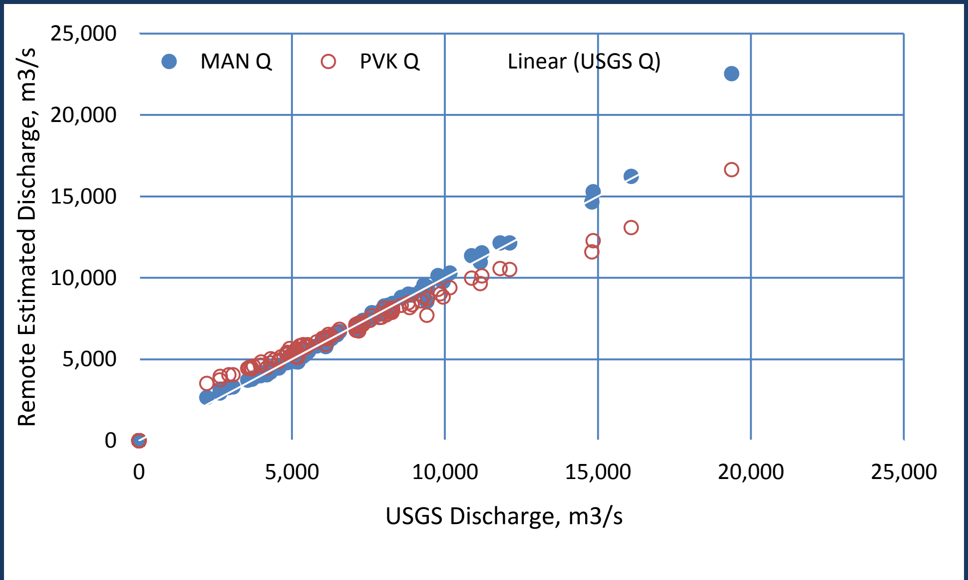
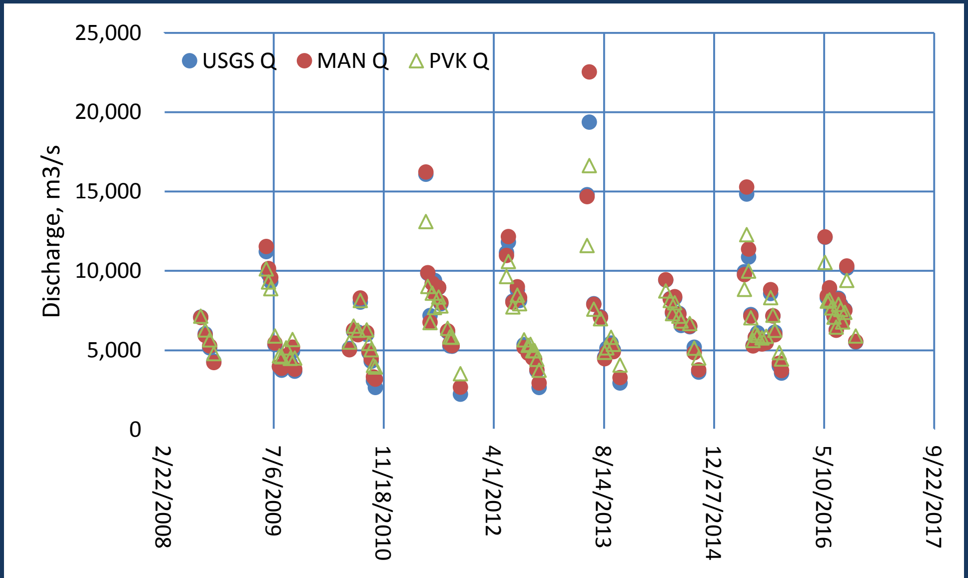
Stevens Village Calibrated





Stevens Alternate Calibration	USGS	Remote MAN	Remote PKV	Error MAN percent
Mean	6975.33	7047.00	6910.69	0.01
Stdev	3036.42	3202.90	2217.06	0.05
Coef. Var.	0.44	0.45	0.32	
Max	19370.90	22534.75	16639.64	0.20
Min	2221.09	2663.53	3518.61	-0.09
	MAN	PKV		
NSE	0.98	0.92		
NRMSE	0.02	0.05		

General Strategy for Using Satellite Information to Estimate Discharge and Develop RS gaging stations

To provide control on accuracy, a limited field calibration program will be needed.

The calibration can be accomplished:

- Using rapidly deployed and temporary gaging station installations used for a short period of time
- Modeling and hydrologic data to derive mean estimates of discharge
- Using aerial platforms to measure discharge and other hydraulic variables on a limited periodic basis – stay tuned for the next presentation by Jon Nelson and others

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For Fun - Contrast with USGS Remote Measurements at Eagle 1911 - 1914

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

W ATER·SUPPLY PAPER 345-F

THE DISCHARGE OF YUKON RIVER AT EAGLE, ALASKA

BY

E. A. PORTER AND R. W. DAVENPORT

Contributions to the Hvdrology of the United States, 1914-F

WASHINGTON

GOVERNMENT PRINTING OFFICE

1914

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Measurement of Stage and Discharge – 1911 – 1914: Early Remote Sensing

B. GAGE OF THE GEOLOGICAL SURVEY ON THE YUKON AT EAGLE, ALASKA.

This white strip was graduated in black paint at intervals of a quarter of a foot and the even feet were marked with numbers large enough to be read by a telescope from the hotel piazza at Eagle, about half a mile distant.

The only feasible method for making open-channel discharge measurements of the Yukon is by floats. About 2 miles above Eagle a stretch of channel was selected which is straight for about 1,000 feet and through which its cross section was believed to be practically uniform.

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Measurement of Velocity and Discharge 1911 - 1914

A. YUKON RIVER AFTER THE BREAK-UP.

The instruments used were a transit and a stop watch. The passage of ice cakes was timed and their location was determined by triangulation. As an ice cake crossed the upper range one man followed it with the transit telescope, the other went down to the lower range and when the float crossed signaled the transitman and noted the time.

In 1912 three measurements were made, two with ice and driftwood when it was coming down the river in sufficient quantities to serve as floats and one by means of bottle floats. For the bottle floats beer bottles were weighted with sand and were marked with flags stuck in the necks. White flags were found to be best adapted to be seen at a distance over the water surface. These floats were dropped by a boatman in a rowboat at intervals of about 75 feet across the stream above the upper range line.

Stage-Discharge Rating Curves for Yukon River at Eagle

1914

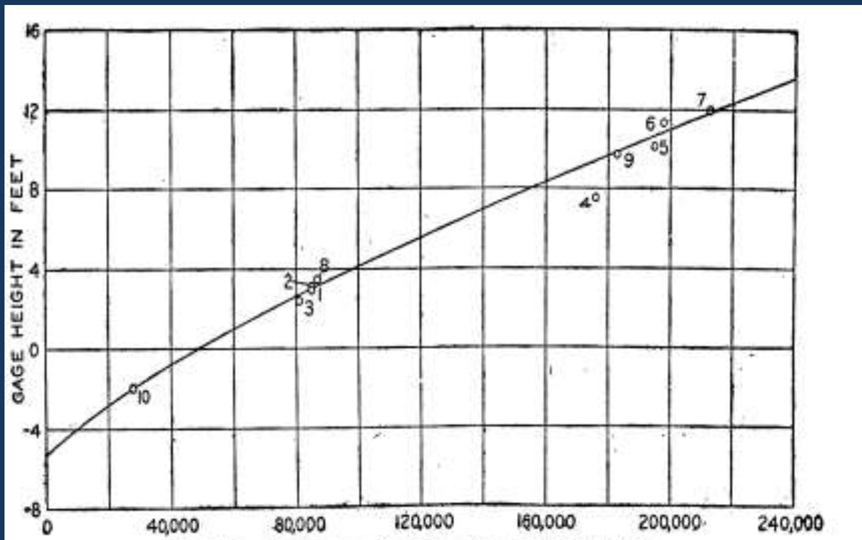
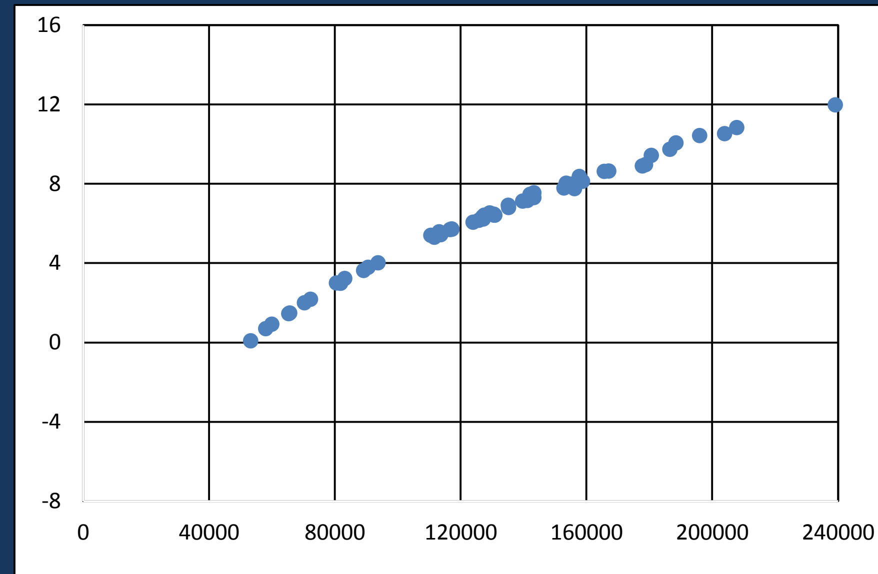


FIGURE 4.—Rating curve for Yukon River at Eagle, Alaska.

2017



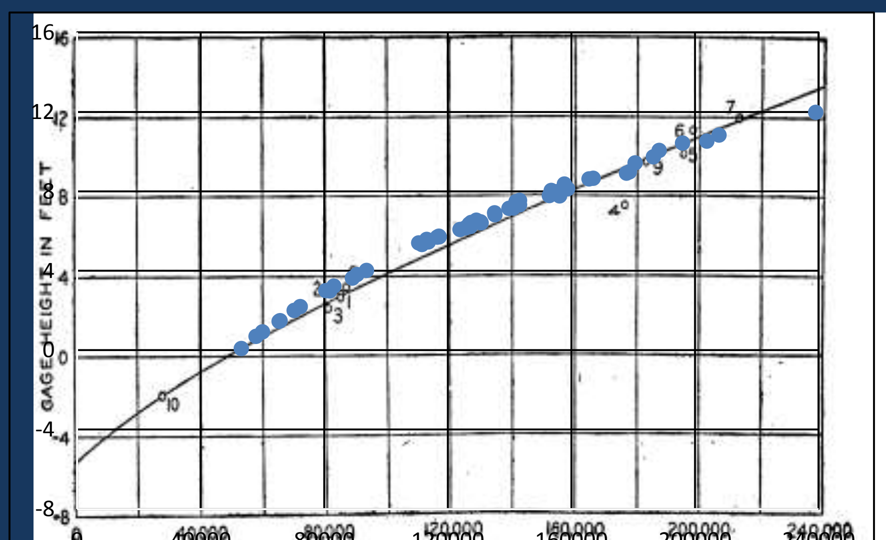


FIGURE 4.—Rating curve for Yukon River at Eagle, Alaska.

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