



### **GNSS-R History**

- 1988: Georgiadou and Kleusberg "On carrier signal multipath effects in relative GPS positioning"
- "extreme multipath interference can render useless GPS observations for precise positioning applications"



1986 (~4)

the boundary between land and sea

GNSS-R Interference patterns from a planar surface below an antenna had a **distinct frequency** related to the height of the antenna above the surface.



### **SNR Oscillation Frequency**





### AT01





### **GNSS-R History**

 2017: Larson et al. 10-year comparison at Friday Harbor, Washington, between a GPS-IR analysis and collocated tide gauge (350 m SE) showed daily averages to be in agreement at the 2-cm level



SC02 (Friday Harbor) GPS



My Start with GNSS-R Shelter Cove, CA RECON December 1-4, 2022





## Shelter Cove, CA



BACK336a00.22 .gz BACK336a15.22\_.gz BACK336a30.22\_.gz BACK336a45.22\_.gz BACK336b00.22\_.gz BACK336b15.22\_.gz BACK336b30.22 .gz BACK336b45.22\_.gz BACK336c00.22\_.gz BACK336c15.22\_.gz BACK336c30.22 .gz BACK336c45.22\_.qz BACK336d00.22\_.gz BACK336d15.22\_.gz BACK336d30.22\_.gz BACK336d45.22\_.gz BACK336e00.22\_.gz

3,841,784 GZip File 12/1/2022 3:15:39 PM 4,147,418 GZip File 12/1/2022 3:30:25 PM 4,239,622 GZip File 12/1/2022 3:45:49 PM 4,424,211 GZip File 12/1/2022 4:00:32 PM 4,260,002 GZip File 12/1/2022 4:16:36 PM 4,124,577 GZip File 12/1/2022 4:30:24 PM 3,918,243 GZip File 12/1/2022 4:46:06 PM 3,834,197 GZip File 12/1/2022 5:01:29 PM 3,789,097 GZip File 12/1/2022 5:15:47 PM 3,864,674 GZip File 12/1/2022 5:30:28 PM 3,837,553 GZip File 12/1/2022 5:45:38 PM 4,106,515 GZip File 12/1/2022 6:00:34 PM 4,129,858 GZip File 12/1/2022 6:15:38 PM 3,887,867 GZip File 12/1/2022 6:30:16 PM 3,433,531 GZip File 12/1/2022 6:45:50 PM 3,594,523 GZip File 12/1/2022 7:00:25 PM 3,436,760 GZip File 12/1/2022 7:15:22 PM



## Shelter Cove GNSS-R Data



 $oldsymbol{J}$  At the boundary between land and sea

# Going Forward

- Algorithm Development (Strandberg INVSNR)
  - \* 2.0 Kalman Filter latency 15 min.
  - Quality Control / Quality Assurance
- Low Power setup with real-time communication
- \* Automated near real-time processing with data access
- Address NWLON Gaps with ACORN







### 2020 SNR GPS Only









J At the boundary between land and sea





Combining data from different GNSS systems enhances spatial and temporal coverage => increased precision.







JOA Surveys, LLC At the boundary between land and sea



























### Data Access – ERDAP





### Data Access – AOOS





# Going Forward

- Algorithm Development (Strandberg INVSNR)
  - \* 2.0 Kalman Filter latency 15 min.
  - Quality Control / Quality Assurance
- Low Power setup with real-time communication
- Automated near real-time processing with data access
- Address NWLON Gaps with ACORN



### Address NWLON Gaps with ACORN\*

### \* <u>ACORN</u> – Alaska's Continuously Operating Reference Network (ACORN)



Peter Flint State of Alaska Department of Natural Resources (3:30 Today)



Sitka	SKAA	GNSS
Cordova	CDVA	GNSS
Kake	KAKE	GNSS
Hoonah	HNAH	GNSS
Angoon	ANGN	GNSS
Tenakee Springs	TNKE	GNSS





### Address NWLON Gaps with ACORN\*

WhittierWHTRGNSS-RCraigCRG1GNSS-RWrangellWRGLGNSS-R



Site Considerations Power Obstructions Security Data Transfer Stability Maintenance

**GNSS-R** 



### **NWLON Gaps CRG1**



GNSS-R & 9450522 Tide 11/10 – 12/12

# Craig has been identified as an NWLON coverage gap despite Tsunami Tide Gauge **9450522**.

AWS GNSS-R Processing 2/08-2/21









### **NWLON Gaps CRG1**

## CRG1 GNSSR - 9450522 MWWL Residual 11/08 to 12/10 2023





### **NWLON Gap WRGL**





AWS GNSS-R Processing 2/08-2/21

AZ 155-345 ELEV 3-10

JOA Surveys, LLC At the boundary between land and sea

### NWLON Gap WRGL 11/07/2023

### 945 1204 Wrangell Alaska

Bench Mark Elevation Information					
Stamping or Designation		MLLW	MHW	Ellip	Ortho
NO 6 1954		12.275	7.68		
NO 9 1971		13.958	9.363		
945 1204 BM5 (PID BBDG97)	8/12/2019	17.591	12.996	13.740	16.601
945 1204 BM5 (PID BBDG97)	7/30/2013	17.591	12.996	13.679	16.540
1204 A 2001		7.802	3.207		
1204 B 2001		7.676	3.081		
WRGL (OPUS)	11/22-12/01	11.504	6.909	7.622	10.484

JOA Surveys, LLC At the boundary between land and sea

945 1204 Wrangell, Alaska





9451204 Wrangell, AK

### NWLON Gap WRGL 11/07/2023

### 945 1204 Wrangell Alaska

Datum from 30 days of data in 2001 New Datum Requirements:

Recover / Refurbish benchmark network Level tie to GNSS antenna

MWWL data for "ground truth"

Power and Communication in place

NOAA's acceptance of tide data for NWLON - ?





# Going Forward

- Algorithm Development (Strandberg INVSNR)
  - \* 2.0 Kalman Filter latency 15 min.
  - Quality Control / Quality Assurance
- Low Power setup with real-time communication
- Automated near real-time processing with data access
- \* Address NWLON Gaps with ACORN



## Low Power Setup

#### Components

Simple RTK 3 (Septentrio Mosaic) GNSS Receiver with Ethernet Sierra Wireless Cell Modem Tallysman Veraphase 6000 GNSS Antenna

#### **Power Requirements** GNSS 0.6 W typical 1.1 W Max Cell Modem 2 W









#### ChatGPT Power Consult

#### You

I have a Septentrio Mosaic Go with power consumption of 0.6 W typical and 1.1 W max. I need to deploy it in Buras, LA from Jan. 20 to May 31. I plan to use an 18 Amp Hour 12 Volt Sealed Lead Acid Battery and a 20 Watt Solar panel to recharge the battery. Will this work?

#### 6 ChatGPT

Alright, let's recalculate the energy availability with the new parameters: a 25 Watt solar panel and a 21 Amp Hour 12 Volt battery. We'll then discuss the optimal orientation and elevation angle for the solar panel in Buras, Louisiana, for the period from February 1 to May 1, 2024.

- The total available energy (11377 Wh) is sufficient to cover the total energy consumption of 6621.6
  Wh for both devices over the period of February 1 to May 1.
- $^{\circ}\,$  The setup with a 21 Ah 12 V battery and a 25 W solar panel should be adequate for your needs.

Please note that solar panel efficiency can be influenced by many factors, including weather conditions and potential shading from nearby objects. Regular cleaning and maintenance of the panel can also ensure optimal performance.

Again, please keep in mind that these calculations are based on ideal conditions and average consumption values. It's advisable to have a buffer in your power calculations to accommodate for inefficiencies, environmental factors, and any unexpected increases in power usage.

Data dropouts due to power failures. X2 on the power requirements for the next iteration

## Low Power Setup

### Still need to tune these parameters

"station": "bura", "lat": 29.350609, "lon": -89.539937, "ht": -21, "antenna": "TWIVP6050\_CONE\_NONE.atx", "peak2noise": 5, "chunk\_days": 5, "knot\_spacing\_hours": 3, "knot\_spacing\_hours": 3, "rhlims": [2.0, 3.0],\* "sectors": [{"elvlims": [2.0, 12.0], "azilims": [160, 340]}

#### **ISSUES:**

#### Power

**Reflector height** – Is there a lower limit?

Mountain Village – Low bank on the Yukon River – FAIL Buckland 3 meter bank on the Buckland River - Excellent **Signal Interference** 

Too many reflecting surfaces around the antenna?











• C

• E • G

• R



# Going Forward

### \* Algorithm Development – (Strandberg INVSNR)

- \* 2.0 Kalman Filter latency 15 min.
- Quality Control / Quality Assurance
- Low Power setup with real-time communication
- \* Automated near real-time processing with data access
- Address NWLON Gaps with ACORN



304	29.7		36		36.1	
311	41.6		39.6		42.8	
313	4.9		41.3		39.6	
319	45.1		44			
325	4.7		43.2			
334	41.6		43.1			
343	37.6		4.4			
346	39.9		39			
362			34.2			
208	46.3	4.2		42.1	44.1	47
227	49.4	45.5		45.2	47.5	5
8		43.2	43.7	48.8		
9		44.1	39	49.5		
13		4.2				
14		41.1	44.4	47.4		
22		38				
27		43.8	45.3	45.9		
101		42.4	35.4			
111		34.5	39.7			
117		44.5	41.2			
118		41.9	42.2			

### **GNSS SNR Measurements**



**Spectral Analysis** SNR data 1 RH per arc

**INVSNR** SNR from physics - SNR from the receiver = 0

Physical model to analyze SNR data B-spline representation of sea level over time. Nonlinear least squares fit for parameter estimation.

Strandberg, J., Hobiger, T., & Haas, R. (2016). Improving GNSS-R sea level determination through inverse modeling of SNR data. *Radio Science*, 51(3), 289–301. DOI: 10.1002/2015RS005817







**Spectral Analysis** 

### **Processing Nuances – Knot Spacing**







Processing Nuances – Near Realtime Data Quality







Processing Nuances – Near Realtime Data Quality







#### G51C-0360 Advancing Water Level Measurements through GNSS Interferometry:

#### Experiences, Challenges, and Innovations from JOA Surveys LLC

Nathan Wardwell, Drew Lindow, James Mitchell



Example 6 Days of Data vs. Traditional Tide Gauge





Example 6 Days of Data vs. Traditional Tide Gauge











BUCK

A Septentrio Mosaic Go and a bubbler/<u>pressure based</u> water level sensor were installed on the left bank of the river at Buckland, Alaska for 3 summer months. The river has a tide signal but is also affected by upstream influences and experienced multiple <u>high water</u> events. The site shows the technique can successfully capture irregular water level variations on a river. The large footprint, calm water, and the <u>three meter</u> bank produced excellent results.

#### GNSS-R at JOA

JOA Surveys was founded in 2003 with an ambition to provide the highest quality water level data service in Alaska and beyond. To meet the unique environmental challenges of Alaska we are continually conducting research and development of novel water level measurement techniques. GNSS reflectometry (interferometry) offers unique advantages over traditional pressure or <u>radar based</u> tide gauges that makes it particularly attractive in Alaska. The primary benefit is that the system is capable of measuring water level obliquely and so it can be installed in areas that experience heavy winter sea ice and not get damaged. It also has the unique quality of measuring water level directly relative to a global reference frame.

As the GNSS-R technique and the GNSS constellations have grown JOA has been working to operationalize and validate the technique for real-world use. JOA's first exposure to GNSS-R was the processing of AT01 and PBAY, two UNAVCO permanent GNSS sites in Alaska, using a spectral analysis algorithm. Currently we are developing inhouse an improved processing algorithm based largely on the inverse modeling technique developed by Joakim Strandberg (Strandberg et al. 2016).

In the past three years we have deployed over a dozen temporary and permanent GNSS-R sites. Along the way we have learned that each deployment presents unique challenges and requires a carefully adjusted set of processing parameters to achieve the best results.

The next steps include the development of a set of QA/ QC tools, refinement of our processing algorithm, and developing automation to provide water level data in near real time.



Acknowledgements

inverse modeling of SNR data, Radio Sci., 51, 1285–1295, doi:10.1002/2016R5006057



**Results GLBX** 





**Results WHTR** 





**Results BUCK** 



JOA Surveys, LLC At the boundary between land and sea 1 sigma +/- 0.011 2 sigma +/- 0.022



### **Results BUCK**

### Can GNSS-R see the nonlinear response of the PAROS gauges at Buckland during a 2-

### meter rise in the water level?

**IOA** Surveys, LLC

At the boundary between land and sea





~ .005 m change in gauge difference



## Tide Sentinel 3





## Tide Sentinel 3







Precise Point Positioning (PPP) system overview https://novatel.com/en-gb/an-introduction-to-gnss/resolving-errors/ppp





Precise Point Positioning (PPP) system overview https://novatel.com/en-gb/an-introduction-to-gnss/resolving-errors/ppp







Precise Point Positioning (PPP) system overview https://novatel.com/en-gb/an-introduction-to-gnss/resolving-errors/ppp

### R&D

### Near Real Time L Band PPP GNSS PPP via L Band & Iridium

### **Worldwide Average Position**

Axis	RMS (m)	95% (m)
North	0.011	0.017
East	0.012	0.020
Height	0.030	0.052

### **Convergence Time**

- 10 cm in 1000 s
- 5 cm in 2000 s

Derived in static and dynamic conditions without any position filters.

\*Javad J-Star PPP Spec Sheet



# Going Forward 2024 GNSS-R

- \* Algorithm Development
  - \* Kalman Filter / Machine Learning
  - \* 1 hour Real Time Latency
  - \* Knot Spacing
  - Quality Control / Quality Assurance
- \* Low Power setup with real-time communication
  - \* Fugro / NGS 3 sites collocated with DNR Vdatum
  - Remote Comms (Iridium / Starlink)
- \* Automated near real-time processing with data access
  - \* Add other UNAVCO and Permanent sites
- \* Address NWLON Gaps with ACORN
  - \* Petersburg
  - \* TBD



## Questions





### Why can't we just use meters?



Source:

A WEBCOMIC OF ROMANCE, SARCASM, MATH, AND LANGUAGE.

JOA Surveys, LLC At the boundary between land and sea