Monitoring ocean water level in remote shoreline locations using GPS reflectometry

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Goals of Presentation

- Description of sensor
- Primary uses of sensor
- Infrastructure and system requirements for installation
- Test examples of collections in Alaska
- Possible new sites where sensor(s) could be installed
Alaska’s 3,000 km northwestern coastline has the same number of water level measurements as Delaware’s 50 km coastline.
Description of sensor

• New type of water level sensor
  • Accurate real-time measurement of water levels and extraction of tidal constituents

• Features:
  • GPS-based
  • Low-cost
  • Non-contact with water
  • Low-profile
  • Remote-deployable (needs no infrastructure)
  • No maintenance
GPS - Introduction

• GPS Satellites transmit signals
• Receivers on earth receive and decode the signals
• GPS is primarily used for location
  • E.g. car navigation, smart phones

• GPS has lots of other uses:
  
ASTRA builds GPS receivers for space weather monitoring
  • Development funded by US Air Force SBIR program
Installation Requirements

- **Equipment/Resources**
  1. ASTRA Receiver
  2. Dual frequency GPS antenna
  3. Power source
  4. Data Storage and/or Communication method
Installation Requirements

• Equipment/Resources
  1) ASTRA Receiver
  2) Dual frequency GPS antenna
  3) Power source
  4) Data Storage and/or Communication method

• Two types of installations
  • Land-powered installation
    • AC power & Cellular or Ethernet Comms
  • Stand-alone installation for remote locations
    • Solar panels & Battery & Iridium Comms

• Specifications
  • <2.5 Watts for GPS receiver
  • < 5 Watts total for GPS & comms & storage
  • Antenna is 5” diam x 2”
  • Total system size < 1 cubic foot (not incl. solar panels)
  • Total system weight < 10 lbs (not incl. solar panels)
GPS Receiver Uses

• ASTRA GPS receivers have been deployed:
  • From the Arctic to the Antarctic
  • Aboard aircraft
  • On Cube-Sats (toaster-sized satellites)
  • On Liquid Robotics Wave Glider Buoy
  • August 2018 - two NOAA TAO buoys

• ASTRA GPS receivers used for:
  • Measuring Ionosphere Activity (scintillation, TEC)
  • Soil Moisture
  • Snow Depth
  • Water level & tides
• Astra deployed an array of GPS receivers in Alaska for measuring ionospheric activity

• 5+ year continuous operation across Alaska
GPS Reflectometry: Using “Noise” as a new “Signal”

- GPS Multipath (reflections) add noise to typical measurements
- Multipath causes interference
- Resulting signal amplitude depends on relative phase of the two contributing signals
- As GPS satellites rise and set, varying signal amplitude contains information about antenna height above reflecting surface
AOOS Ocean Tide Pilot Program

Anchorage

Seward (GPS Installation)
Seward Pilot Installation

- ASTRA receivers 200m apart
  - Alaska SeaLife Center
  - Seward Marine Center

- NOAA Tide Gauge is 2400m from ASTRA receivers
GPS Antenna Location

- Antennas need a good view of the water
- In the Northern Hemisphere, it helps to have a clear view to the south
GPS Antenna Location

Antenna: 2” tall, 5” diameter
Year-Long Data Series

- Over 1 year of continuous water level data
- 5 meter tidal swings
Validated against NWLON data

- Accurate measurements
- Low cost system
- Easy to deploy
Accurate Measurements

• Accurate measurements
• Low cost system
• Easy to deploy
Frequency Analysis

- Frequency analysis shows tidal harmonic constituents
- ASTRA Receivers reproduce diurnal and semi-diurnal tidal motions
# Accurate Tidal Constituents

<table>
<thead>
<tr>
<th>Tidal Constituent</th>
<th>ASTRA (85.6%)</th>
<th>NOAA NWLON (96.9%)</th>
<th>NOAA Predicted Constituents</th>
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<tbody>
<tr>
<td>M2</td>
<td>1.146 ± 0.039</td>
<td>1.195 ± 0.018</td>
<td>1.198</td>
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<tr>
<td>S2</td>
<td>0.420 ± 0.041</td>
<td>0.458 ± 0.017</td>
<td>0.411</td>
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<tr>
<td>N2</td>
<td>0.199</td>
<td>0.206</td>
<td>0.245</td>
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<tr>
<td>K1</td>
<td>0.323</td>
<td>0.362</td>
<td>0.463</td>
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<tr>
<td>O1</td>
<td>0.270</td>
<td>0.285</td>
<td>0.289</td>
</tr>
</tbody>
</table>

ASTRA Constituents within 5 cm (!) of NOAA at 10% of cost.
Install Locations

- These receivers could be installed anywhere along the coast
  - Preferably with a southern view of the water, but we can use GPS satellites that are setting over the northern horizon
- We are planning additional installations in Anchorage and Homer
Install Locations

Many “North” facing coastlines have multiple options for installation

E.g. Kaktovik
### Sensor description

<table>
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<tr>
<th>Sensor description</th>
<th>ASTRA GPS Receiver</th>
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### Primary use(s)
- Ionospheric space weather
- Water level, tides
- Snow depth
- Soil moisture

### Test examples in Alaska

![Test examples in Alaska](image)

### Possible New Sites

![Possible New Sites](image)

### Infrastructure requirements:

**Benign to Extreme Environments**

- Land-based
- Standalone

- Kaktovik
Summary-2

- Accurate water level measurements
  - < 5 cm tidal constituents
- Installations possible in remote locations
- Low cost versus legacy NWLON sensors
- Low-cost means we could deploy multiple locations
- Sole-source is OK because this is an SBIR product
Novel Lidar for Water Measurement

Laboratory demonstration

These data highlight several milestones:

1) seamless land-to-water transition

2) <1 cm depth resolution

3) high precision subsurface mapping clearly identifying the two small rocks
Water Depth mapping

- Flowing water
- Depth Ranging from ~15cm to 1cm
- Centimeter Precision
- Bathymetry (Rock Garden)
- Notable depth change due to sloped flume

Water Depth (cm)

1cm x 1cm x 1cm resolution