WATER LEVEL MONITORING IN DIFFERENT REGIONS OF THE U.S. USING GNSS-REFLECTOMETRY

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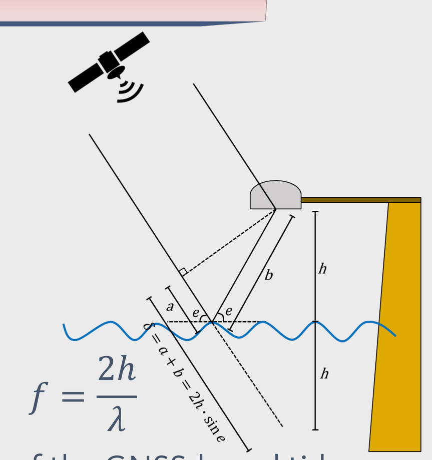
Abstract

Accurate and seamless coastal water level observations are crucial for monitoring climate change, mean sea level, and storm surge. Although the water level changes have been measured using local measurement instruments at coastal sites for centuries, the spatial distribution of these sites is typically limited to locations with infrastructure. GNSS-Reflectometry (GNSS-R) is being investigated as tool for water level monitoring. By calculating the phase delay of the GNSS radio signals reflected by the water surface, the temporal variation of the water level can be observed. The advantage of this system is twofold: 1) It is non-contact and measures water levels as it is based on remote sensing technique. 2) resulting water level measurements are tied directly to a global reference frame that it significantly contributes to the consistent vertical datum. In this study, we processed data from Continuously Operating Reference Stations in Louisiana (CALC) and Alaska (AT01), which are operated by NGS and UNAVCO. The resulting water levels were compared with observations from stations in the NOAA's National Water Level Observation Network (NWLON). The CALC station was selected specifically for performance evaluation during hurricane Harvey. The GNSS-R results show a strong agreement with the published observations and datums from the NWLON stations. The peak storm surge induced by hurricane Harvey is clearly observed in the data from CALC. Data from the AT01, located in St. Michael Alaska, show tidal characteristics not represented in the published predictions. The results from this study show many promising applications for GNSS-R derived water levels, such as tidal datum determination, predictions and validation of vertical datum separation models.

Background

GNSS-Reflectometry (GNSS-R)?

- Multipath is one of the error sources in GNSS measurement because it causes additional path delay
- The multipath, however, can be utilized to obtain information about the reflected surface, which is GNSS-R
- GNSS-R has been used in various applications such as soil moisture monitoring, snow depth estimation, ocean wind analysis, and **water level monitoring**

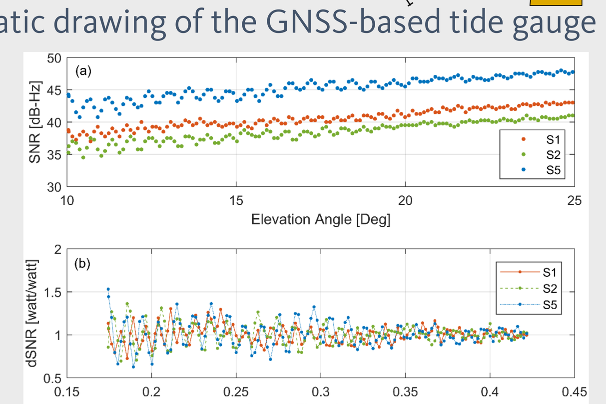


$$f = \frac{2h}{\lambda}$$

Schematic drawing of the GNSS-based tide gauge

GNSS-R based Water Level Monitoring

- Use SNR data collected from regular geodetic GNSS receiver
- The multipath effect on the SNR observation appears in the form of oscillations
- The frequency of the oscillation depends on the geometry between satellite, reflector and antenna
- Therefore, the frequency of the oscillations can be converted to antenna heights form the water surface



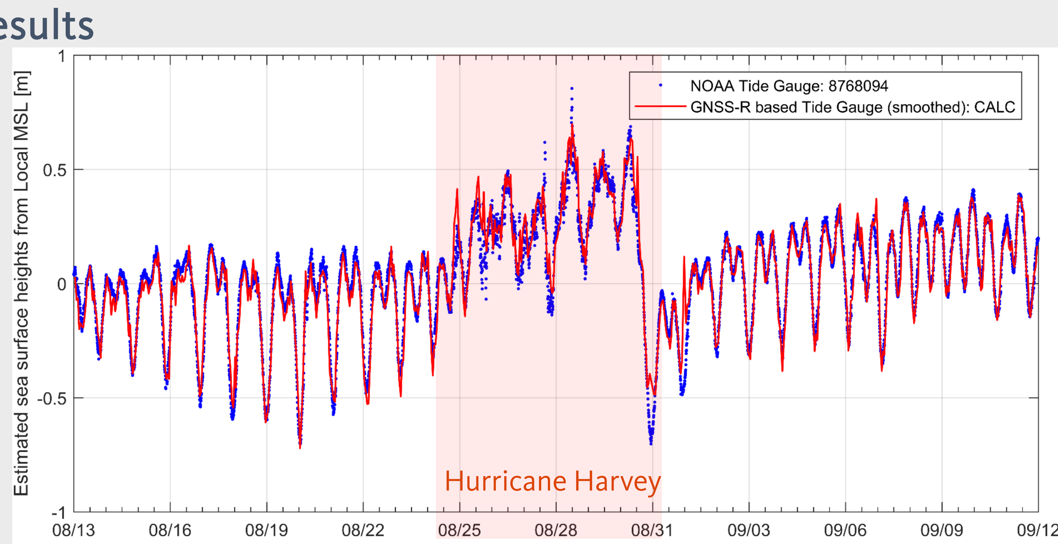
SNR data analysis procedures

Case study1: Hurricane Harvey

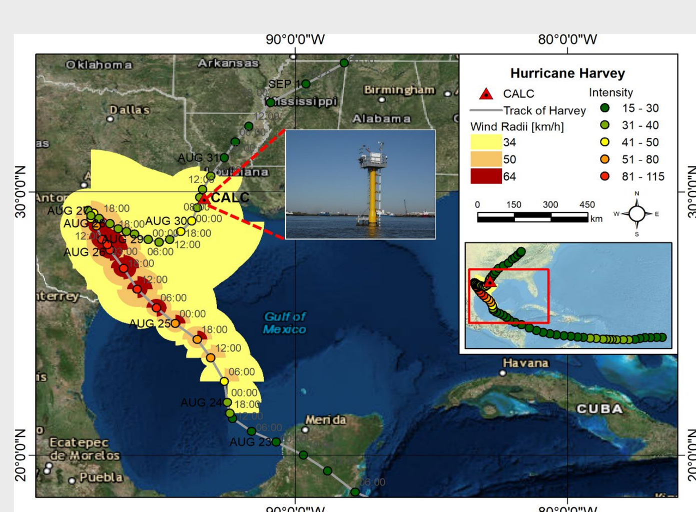
Dataset

- GNSS-R based tide gauge: CALC, in Cameron, LA
- Co-located NOAA tide gauge station (ID: 8768094)
- Analysis periods: 8/13/2017 – 9/12/2017

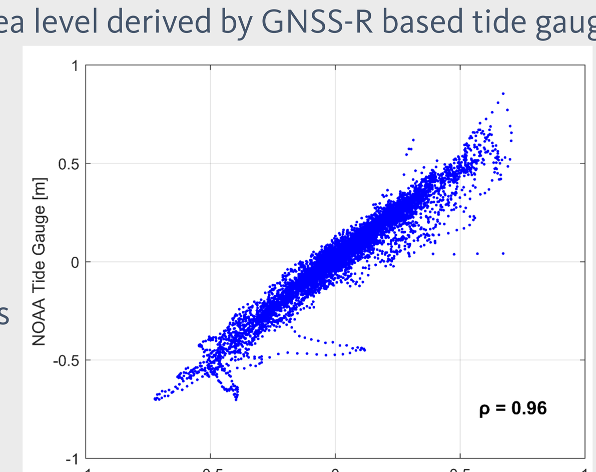
Results



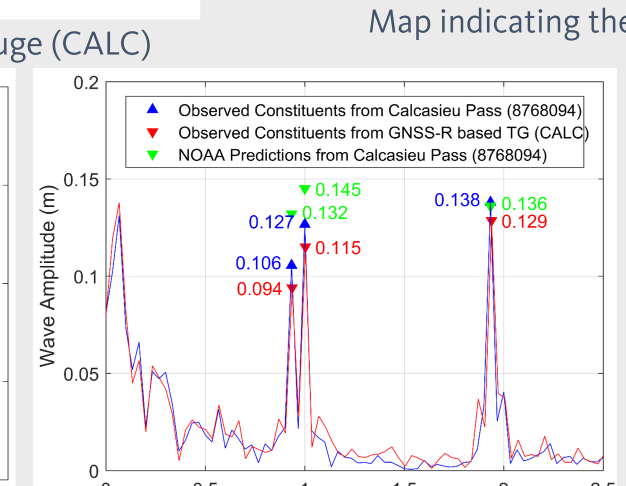
Time series of sea level derived by GNSS-R based tide gauge (CALC)



Map indicating the study area



Correlation analysis between GNSS-R tide gauge (CALC) and the co-located tide gauge

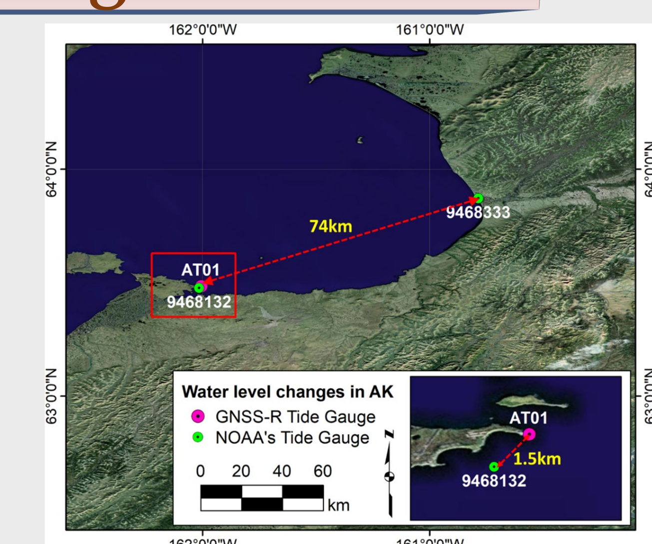


Spectral comparison between GNSS-R based sea level and sea level measurements at the co-located tide gauge

Case study2: Sea level changes in AK

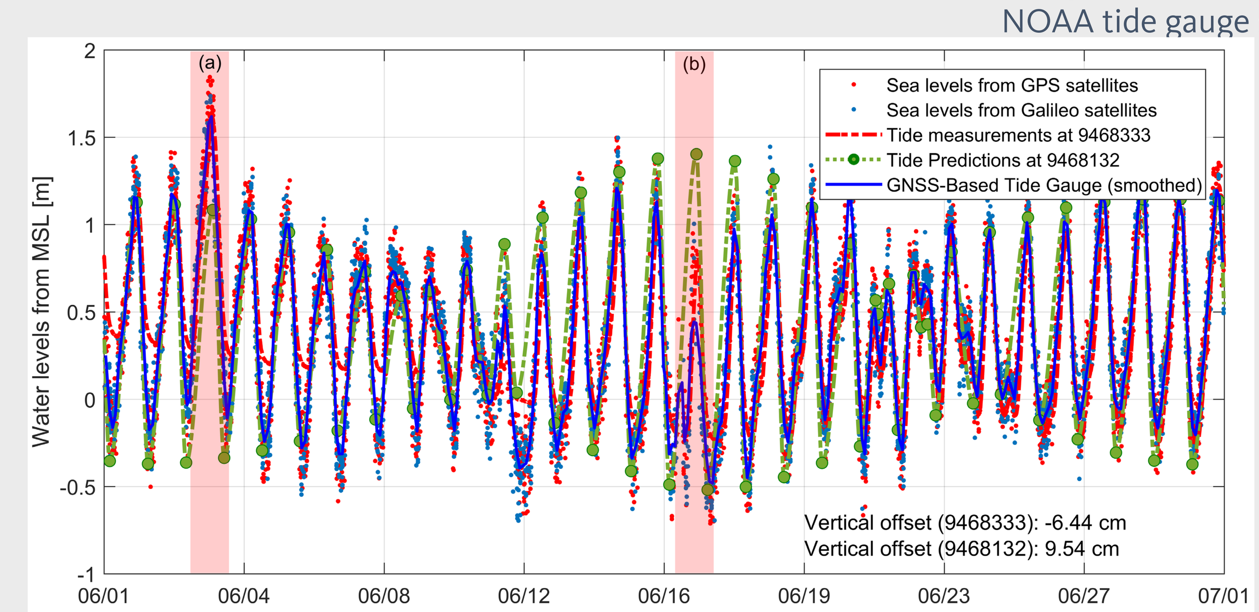
Dataset

- Processing Period: 6/1/2018 – 6/30/2018
- GNSS-R based tide gauge: AT01 in St. Michael, AK
- Nearby NOAA tide gauges
  - 9468132 in St. Michael (about 1.5 km from AT01)
    - It is the closest tide gauge, but there's no actual observation available
    - It only provides tide predictions
  - 9468333 Unalakleet, AK (about 74 km from AT01)
    - It provides water level observations

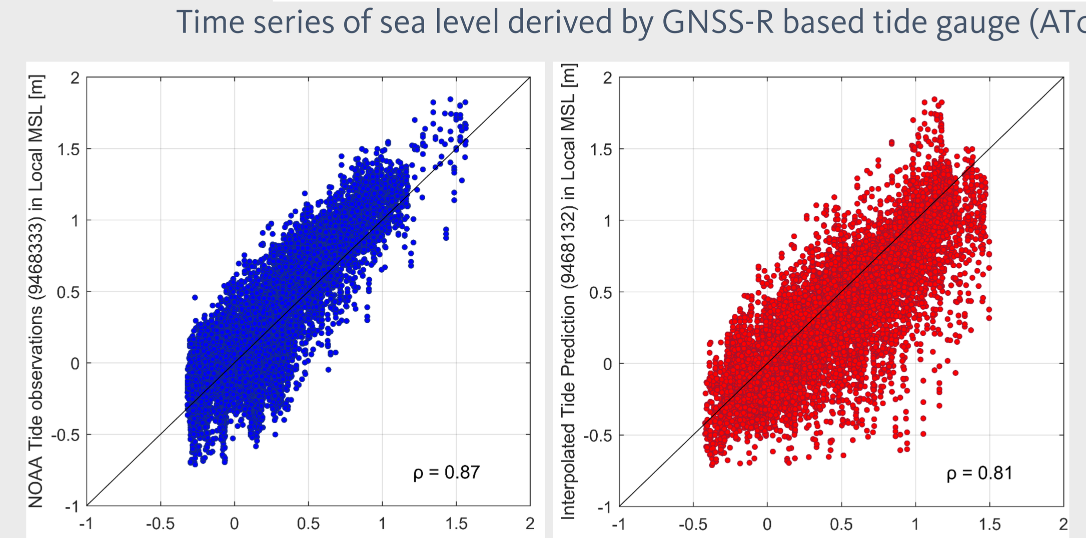


Map indicating the locations of AT01 and two NOAA tide gauge stations

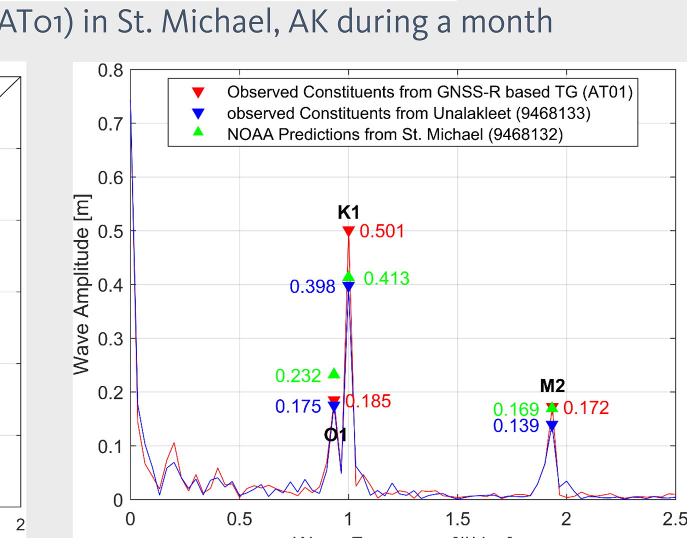
Results



Time series of sea level derived by GNSS-R based tide gauge (AT01) in St. Michael, AK during a month



Correlation analysis between GNSS-R tide gauge and Unalakleet (left) and St. Michael (right) tide gauges



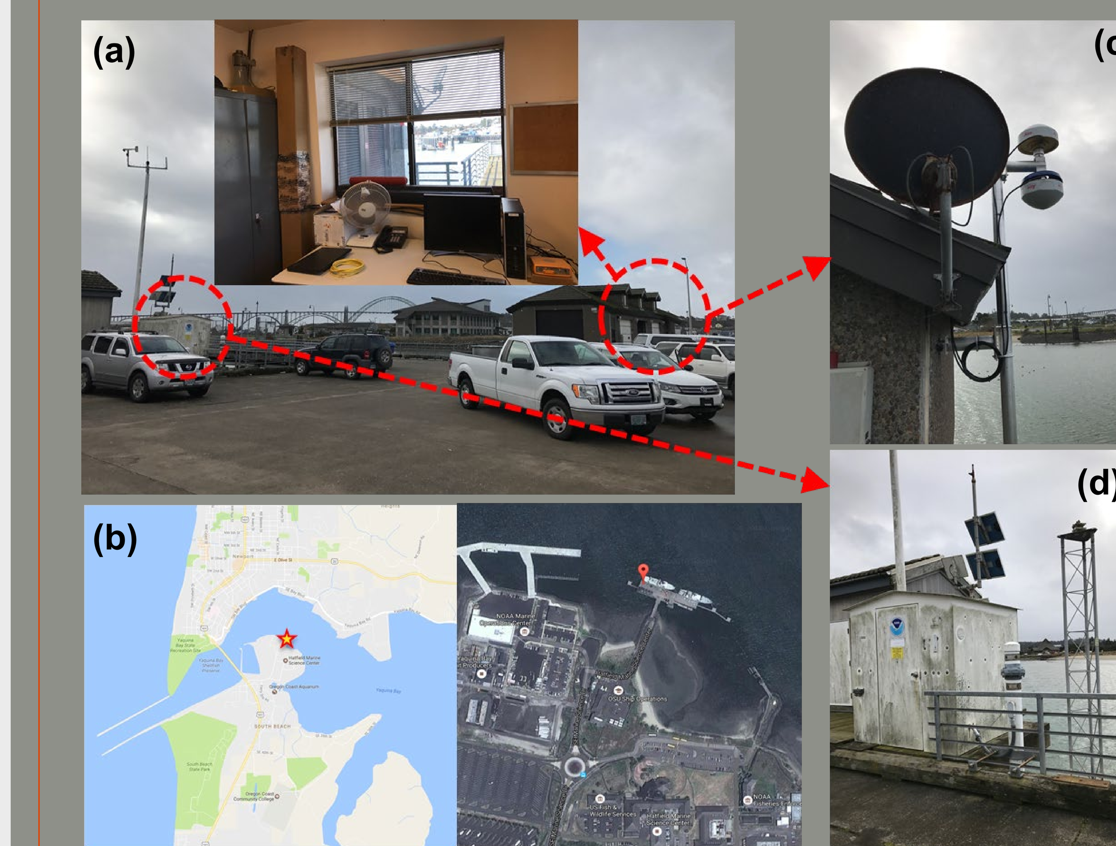
Spectral comparison between GNSS-R based sea level and sea level measurements at Unalakleet tide gauge

Harmonic constituents from the spectral analysis of AT01 and Unalakleet and prediction models

Tidal Constituent	Estimated from spectral analysis		Prediction models (by NOAA)	
	AT01	Unalakleet	Unalakleet	St. Michael
M2 [m]	0.162	0.139	0.155	0.169
K1 [m]	0.515	0.398	0.350	0.413
O1 [m]	0.184	0.175	0.210	0.232

GNSS-R equipment at OSU

- For the water level monitoring dual antenna GNSS-R equipment was installed in Newport, Oregon
- Direct and reflected signals are separately collected using dual antennas
  - RHCP: Zenith looking, Direct signals, Regular antenna
  - LHCP: Nadir-looking, Reflected signals, Specially designed antennas



Dual antenna GNSS-R equipment (AR20 choke ring antennas and AsteRx receiver) installed at Newport where (a) shows the nearby NOAA tide gauge station (station ID: 9435380) in left circle and OSU ship operation building in right circle, (b) shows the location of the OSU ship operation building, (c) is the dual antenna on top of the OSU operation building, and (d) is the NOAA gauge station.

Summary

- GNSS-Reflectometry (GNSS-R) was investigated as an alternative water level monitoring method
- The algorithms were evaluated through case studies
  - It was able to successfully detect the impact of storm surge due to the Hurricane Harvey in Cameron, LA with a high correlation coefficient of 0.96
  - The algorithms allow to detect meaningful harmonic constituents in all experiments including the case study in Alaska.
- The proposed algorithm allows a near-real time estimation of the actual height change of sea level, and it also effectively improved temporal resolution
- The results from this study show many promising applications for GNSS-R derived water levels, such as tidal datum determination, predictions and validation of vertical datum separation models.

Oregon State University

JOA Surveys, LLC
At the boundary between land and sea