GNSS and Environmental Sensing

Kristine M. Larson
Professor Emerita
University of Colorado, Boulder
Outline

• Environmental Sensing with GNSS
  Interferometric Reflectometry (GNSS-IR)
• What can you do with GNSS-IR?
• New work
How I thought about GPS when I was a geodesist
How a reflections person sees the world
What are the physics behind GNSS interferometric reflectometry?

The frequency of reflection data depends on $H$, the GNSS transmit frequency, and the reflecting medium.

Footprint depends on $H$ and $e$. 
L2C SNR data for Marshall, Colorado

Observed Composite Signal

Hz

hours (UTC)

Direct Signal
Observed Composite Signal

Reflected signal is best measured with low elevation angle data
Why would you want to measure environmental signals with GNSS receivers?
Why would you want to measure environmental signals with GNSS receivers?

• Supplement other *in situ* sensors, many of which have very small footprints and/or are expensive to maintain.
Why would you want to measure environmental signals with GNSS receivers?

- Supplement other *in situ* sensors, many of which have very small footprints and/or are expensive to maintain.
- Satellites have very large footprints (and don’t work well in some conditions).
Why would you want to measure environmental signals with GNSS receivers?

• Supplement other *in situ* sensors, many of which have very small footprints and/or are expensive to maintain.
• Satellites have very large footprints (and don’t work well in some conditions).
• GNSS data are very “inexpensive.”
Why would you want to measure environmental signals with GNSS receivers?

- Supplement other *in situ* sensors, many of which have very small footprints and/or are expensive to maintain.
- Satellites have very large footprints (and don’t work well in some conditions).
- GNSS data are very “inexpensive.”
- Ground sensors are needed both for assimilation and satellite validation.
First Applications: Terrestrial Hydrology

- soil moisture: land-atmosphere interactions; runoff and infiltration; plant productivity.
- snow: timing and amount of runoff; influences climate.
- above-ground biomass: global carbon budget; influences climate.
Testing GNSS interferometric reflectometry

Plate Boundary Observatory (PBO)

+150 stations in Alaska

Source: Bill Hammond
Monitoring Snow
Installed a camera to take a picture of this stick every day.
Snow Climatology

PBO $H_2O$: p360

PBO H2O begins
Soil Moisture

Larson et al., 2008
Soil Moisture

Daily Soil Moisture Maps

Legend
- > 0.35 VSM
- 0.30 - 0.35
- 0.25 - 0.30
- 0.20 - 0.25
- 0.15 - 0.20
- 0.10 - 0.15
- 0.05 - 0.10
- 0 - 0.05
- Snow Present
- No Data / Sol’n

United States

Vol. Soil Moisture

p038

metSensor precip

NLDAS precip

mm

mm

Sep Oct Nov Dec Jan Feb Mar Apr

updated 17-Apr-2014

release 2.0
Monitoring Vegetation
Vegetation Water Content

PBO H$_2$O: qcy2

GPS

NMR

NLDAS Precip.

cm

NDVI

updated 07–Aug–2016
Normalized Peak Vegetation Water Content

More details: Small et al., Remote Sensing, 2018
Sea Surface
L2C SNR data for Marshall, Colorado

Reflected signal is best measured with low elevation angle data.
Kachemak Bay, Alaska

SNR data, PRN 29, PBAY, Day 127, 2012

Direct Signal

Low Tide

High Tide
Comparison between GPS and ‘Real’ Tide Gauge

Daily Comparison with NOAA tide gauge

RMS difference = 1.82 cm

Friday Harbor, WA

Monthly Comparison

RMS difference = 1.28 cm

Larson, KM, Ray, R. and SWP Williams, JOceanAtmTech, 2017
Ice Sheet Applications

Data from the IRIS GLISN network
Why use GNSS to measure snow accumulation on ice sheets?
Why use GNSS to measure snow accumulation on ice sheets?

• Relatively large footprint (compared to other sensors)
Why use GNSS to measure snow accumulation on ice sheets?

- Relatively large footprint (compared to other sensors)
- Can use vertical positions to correct for snow compaction etc.
Why use GNSS to measure snow accumulation on ice sheets?

• Relatively large footprint (compared to other sensors)
• Can use vertical positions to correct for snow compaction etc.
• It’s relatively cheap, and simple to operate and maintain.
Why use GNSS to measure snow accumulation on ice sheets?

- Relatively large footprint (compared to other sensors)
- Can use vertical positions to correct for snow compaction etc.
- It’s relatively cheap, and simple to operate and maintain.
- Existing datasets can be analyzed.
Why use GNSS to measure snow accumulation on ice sheets?

- Relatively large footprint (compared to other sensors)
- Can use vertical positions to correct for snow compaction etc.
- It’s relatively cheap, and simple to operate and maintain.
- Existing datasets can be analyzed.
- Measures the surface - does not significantly vary depending on the wetness of the snow.
Acknowledgements: GLISN, IRIS, UNAVCO, Dean Childs.
Some New Things
Deliberate GNSS-IR

Ross Ice Shelf, Antarctica
Hurricane Laura

Water Levels Measured with Reflected GPS Signals During Hurricane Laura

K.M. Larson, T. Lay et al., submitted to Geophysical Research Letters

https://gnss-reflections.org

https://kristinelarson.net
Tsunami - Shumagin Islands, Alaska

Tsunami waves observed with reflected GPS signals

Coseismic

AC12, Chernabura, Alaska

Tides

K.M. Larson, T. Lay et al., submitted to Geophysical Research Letters
GNSS-IR Users?

- Those that don’t want to know what goes on under the hood (the Amazon experience). This category includes nearly all environmental scientists.
Kristine's GNSS-IR WebApp

Examples

Ross Ice Shelf, Antarctica:
- lorg
- phnx
- willy

Thwaites Glacier, Antarctica:
- khlr
- uthw
- lthw

Greenland:
- gls1
- gls2
- gls3
- smm3

Soil Moisture/Snow:
- p360
- p038
- p041
- p037

Water Levels:
- at01
- sc02
- mchn

Australia: L2C using RINEX3 files
- park
- mro1
- kat1
- mchl

Upload RINEX

Choose File: no file selected
Freq  MinRH  MaxRH  MinElAng
L1    0.4    8.0    5.0

MaxElAng  ReqAmp  PkNoise
25.0    8       3.0

Submit

Analyze RINEX data from archives

Station  Year  DOY  Freq
p038    2019  200  L1

ReqAmp  MinRH  MaxRH  MinElAng
8       0.4    8.0    5.0

MaxElAng  Pk2Noise  RINEX
25.0    3.0    2.11

Submit

RINEX 2.11, 10 MByte limit, lowercase (gz or Z allowed), filename is "ssssddd0.yyo and ssss is station name, ddd is day of year and yy is two character year. Upload must take less than 30 sec.
GNSS-IR Users?

• Those that don’t want to know what goes on under the hood (the Amazon experience). This category includes nearly all environmental scientists.

• Those that sort of want to know what is going on and are willing to install and use a modern programming language. Geodesists have these skills but are generally uninterested in measuring environmental signals.
Open source python:

```
gnssrefl 0.0.24
```

```
pip install gnssrefl
```
GNSS-IR Users?

• Those that don’t want to know what goes on under the hood (the Amazon experience). This category includes nearly all environmental scientists.

• Those that sort of want to know what is going on and are willing to install and use a modern programming language. Geodesists have these skills but are generally uninterested in measuring environmental signals.

• Those that are keen to make GNSS-IR better.
If you are interested in using or improving GNSS-IR, please feel free to contact me!

kristinem.larson@gmail.com
https://kristinelarson.net
https://github.com/kristinemlarson
@funwithgps