Civil & Construction Engineering

COLLEGE OF ENGINEERING

Positioning and Remote Sensing using GNSS
(GNSS research activities at OSU)

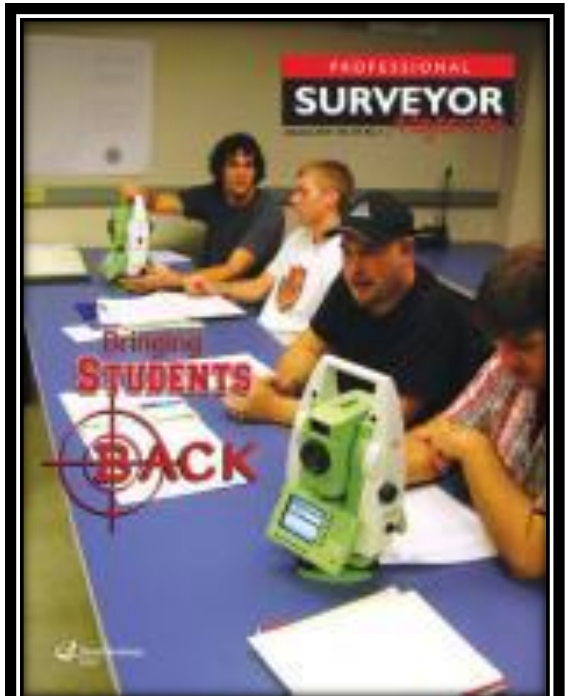
Jihye Park, PhD
Assistant professor of Geomatics
Oregon State University

OSU and CCE

- OSU is a leading public research universities located in Corvallis, Oregon
  - has State's Land grant, Sea Grant, Space Grant, and Sun grant designations
- School of Civil and Construction Engineering (CCE)
  - 38 faculty members (up to 50 with instructors and staff) in construction engineering management, *Geomatics engineering*, geotechnical engineering, innovative materials, ocean and coastal engineering, structural engineering, surveying, transportation engineering, and water resources engineering

Industry Partnership

- Recruit top students
- Expand course work and research to reflect industry advances
- Keep surveying as an integral part of our Civil Engineering program
- Provide the latest equipment, software, and workflows
- Prepare students to become licensed surveyors
- Produce work-ready graduates



CCE Geomatics at OSU

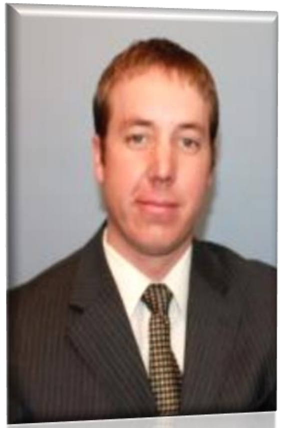

Robert Schultz


Jihye Park


Mike Olsen


Tracy Arras


Christopher Parrish


+1

Dan Gillins (Adjunct, now at NGS)

Many additional geospatial faculty in other departments

Geomatics Courses

- Least Squares Adjustments

- Positioning, Navigation, Geodesy
  - GNSS
  - Geodesy
  - Kinematic Positioning and Navigation

- Photogrammetry and Remote Sensing
  - 3D laser scanning and imaging
  - Photogrammetry
  - Coastal Remote Sensing
  - Digital Terrain Modeling

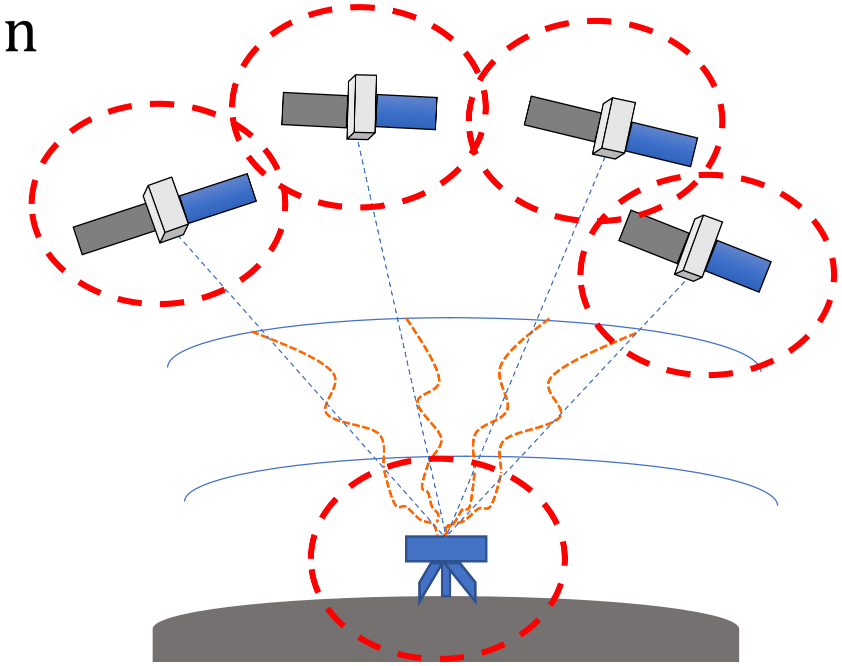
- Surveying
  - Surveying Theory
  - Plane Surveying
  - Highway Location and Design
  - Property Survey
  - Oregon Land survey law
  - Hydrographic Surveying (2018)

- Information Modeling
  - Engineering Graphics & Design
  - Virtual Design & Construction
  - Geospatial Information & GIS
  - GIS in water Resources
  - Advanced GIS
  - Advanced Virtual Design & Construction
  - Simulations for Operation Analysis

GNSS Applications: Positioning & Navigation

GNSS research topics

- Positioning
  - High accuracy RTK, Network based solution
  - Multi-GNSS based positioning
  - Post-earthquake rebuild and recovery
- Remote sensing
  - Weather monitoring and forecast
  - Hazard monitoring
  - Water level monitoring

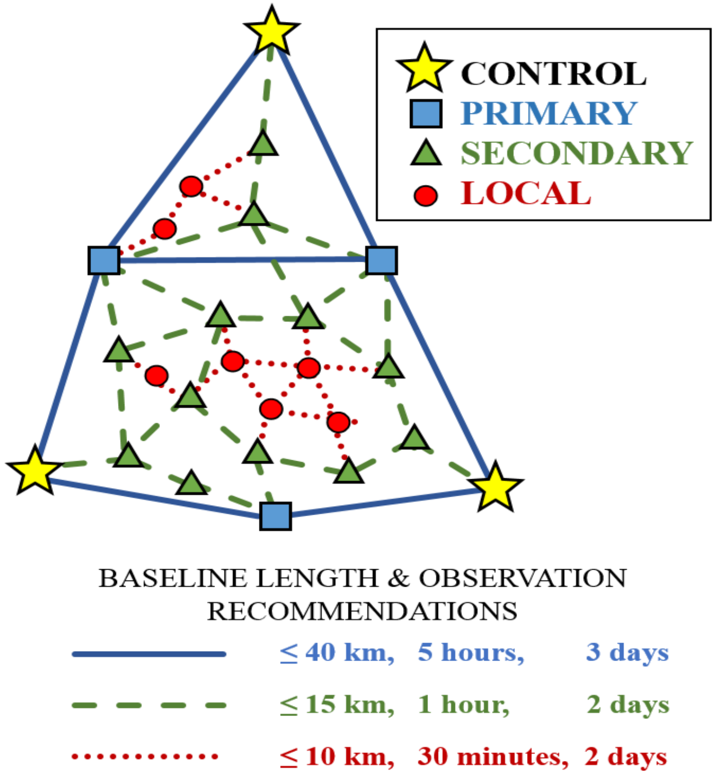


GNSS positioning: NGS-OSU Partnership

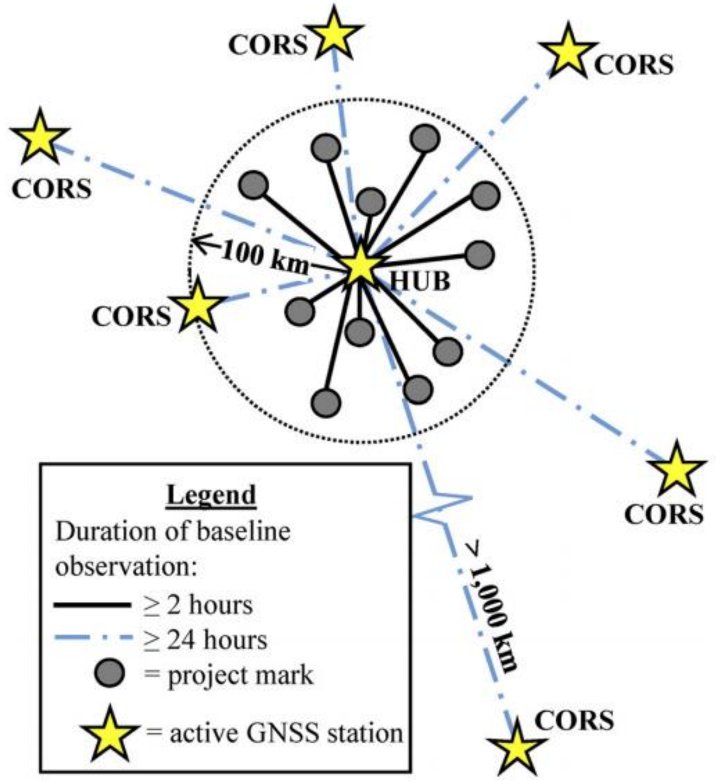
- GNSS survey campaign in western Oregon: Accuracy of real-time networks (2014 – 2015)
- Network Adjustment for height modernization (2015– 2016)
- NGS 58/59 updates: Assessment of network solution using OPUS-Projects : Accuracy of OPUS-Projects (2016– 2017)
- Multi-GNSS PPP software development (2017-current)
  - On going project started in October 2017

Static survey campaigns processed in OPUS project (FY2017)

- Considering the technical innovation of GNSS, NGS58 is out dated.
  - Mc i-GNSS
  - Imp
  - De regional netw
  - Hig
- OPUS-I
  - Hub



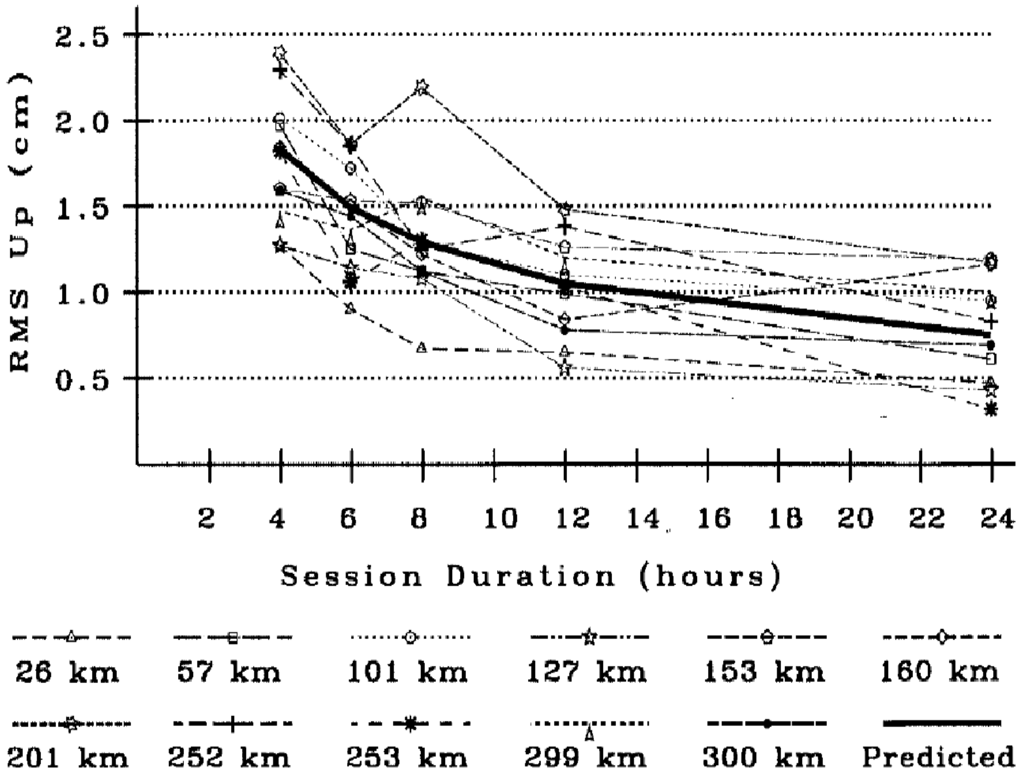
Loop network design in NGS58



Hub network design (Gillins and Eddy, 2016)

OPUS-Projects

- Released to the public in 2013
- Free, web-based software
- Meant for processing numerous static GPS sessions on multiple project marks
- Uses PAGES for baseline processing
- Combine multiple sessions into a survey network by least squares



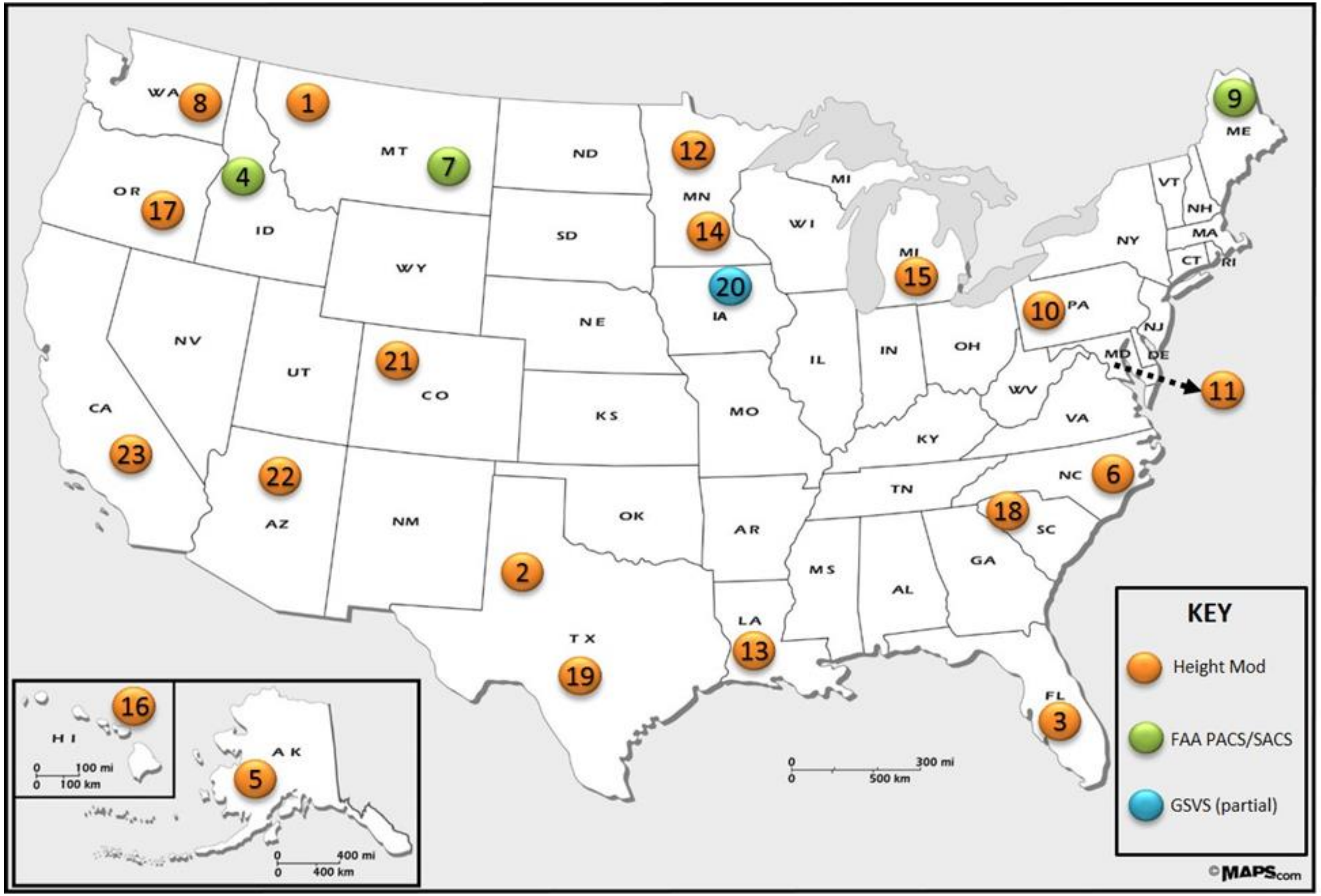
Accuracy of PAGES (Eckl et al., 2001)

$$RMS_h = \pm \frac{k}{\sqrt{T}} = \frac{3.7cm}{\sqrt{T(\text{hr})}}$$

Selection criteria of GPS projects

- Condition of surveying campaigns
  - Occupation hours > 2hr
  - Survey conducted no prior to 2010
  - Surveying marks >=5 per session
- CORS availability for network construction
  - Good distribution of control stations
  - No data gaps
- Ionospheric activity (Kp Index<4)
- Good coverage of entire U.S.

Selected GPS projects in the NGS IDB



No.	GPS Network	State	% Days of k_P > 4	No. of CORS	No. of Marks	No. Sessions	Sessions Occupation Time [min - max in hour]
1	GPS2830	MT	10	7	13	10	[5.5 - 26.5]
2	GPS2868	TX	0	7	38	9	[12.5 - 152.2]
3	GPS2877	FL	33	7	6	3	[23.0 - 24.8]
4	GPS2895 (FAACOE)	ID	0	6	5	2	[4.5 - 9.1]
5	GPS3158	AK	50	7	5	2	[12.5 -26.0]
6	GPS2912	NC	0	7	5	2	[6.1 - 7.0]
7	GPS2914 (FAAOOU)	MT	0	6	6	2	[5.5 - 11.8]
8	GPS2926	WA	5	7	27	22	[8.6 - 512. 3]
9	GPS2937 (FAAAUG)	ME	0	7	5	2	[6.2 - 13.3]
10	GPS2929	PA	0	7	16	3	[2.0 - 6.6]
11	GPS2965	MD	25	6	13	4	[4.1 - 24.0]

No.	GPS Network	State	% Days of k_P > 4	No. of CORS	No. of Marks	No. Sessions	Sessions Occupation Time [min - max in hour]
12	GPS2983	MN	0	7	15	4	[4.5 - 16.2]
13	GPS2995	LA	0	7	8	14	[2.7 - 58.0]
14	GPS2997	MN	0	7	7	2	[6.5 - 8.6]
15	GPS3013	MI	0	7	20	11	[4.6 - 7.1]
16	GPS2939	HI	0	5	6	3	[4.1 - 95.9]
17	DANGNGS	OR	0	7	18	15	[30.0 - 100.0]
18	SC58-59A	SC	0	13	26	7	[20.0 - 81.8]
19	GSVS1120	TX	6	20	18	33	[38.2 - 71.9]
20	GSVS14C	IA	0	7	207	27	[15.8 - 59.2]
21	GSVS17	CO	11	14	226	38	[37.5 - 156.4]
22	GPS2831	AZ	10	10	34	10	[10.4 - 68.1]
23	GPS2516	CA	0	7	15	6	[12.1 - 143.9]

Number of Marks per Session

Calculate % sessions with greater than **5** marks observed

GPS2830 *(0%)*

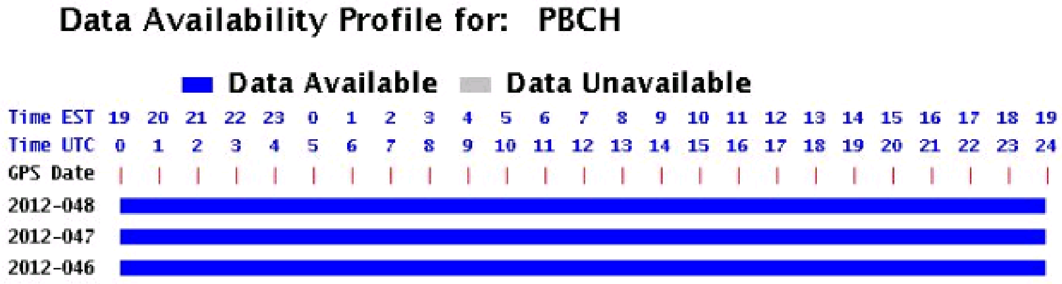
MARKS	2011-061 A	2011-062 A	2011-063 A	2011-068 A	2011-069 A	2011-074 A	2011-075 A	2011-173 A	2011-174 A	2011-199 A	MARKS
e091					●	●		●			e091
g547		●	●								g547
k542										●	k542
mcab		●		●							mcab
mdoc		●									mdoc
n360					●	●	●				n360
powb	●			●						●	powb
q256					●	●		●			q256
s544	●		●	●							s544
t272		●	●	●							t272
todd								●	●		todd
v358					●		●	●	●		v358
x046									●		x046

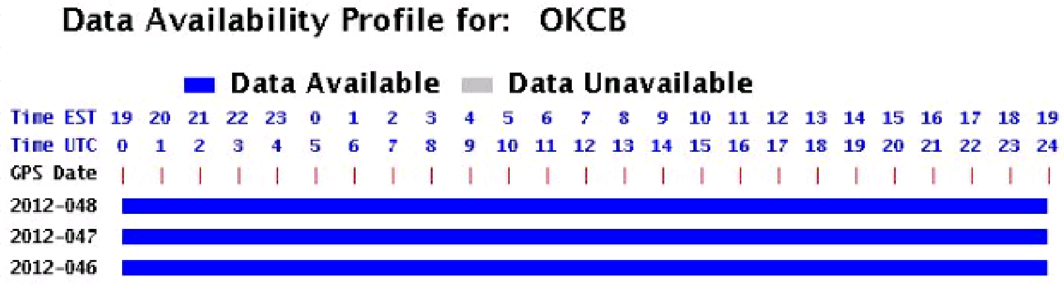
GPS2926 *(100%)*

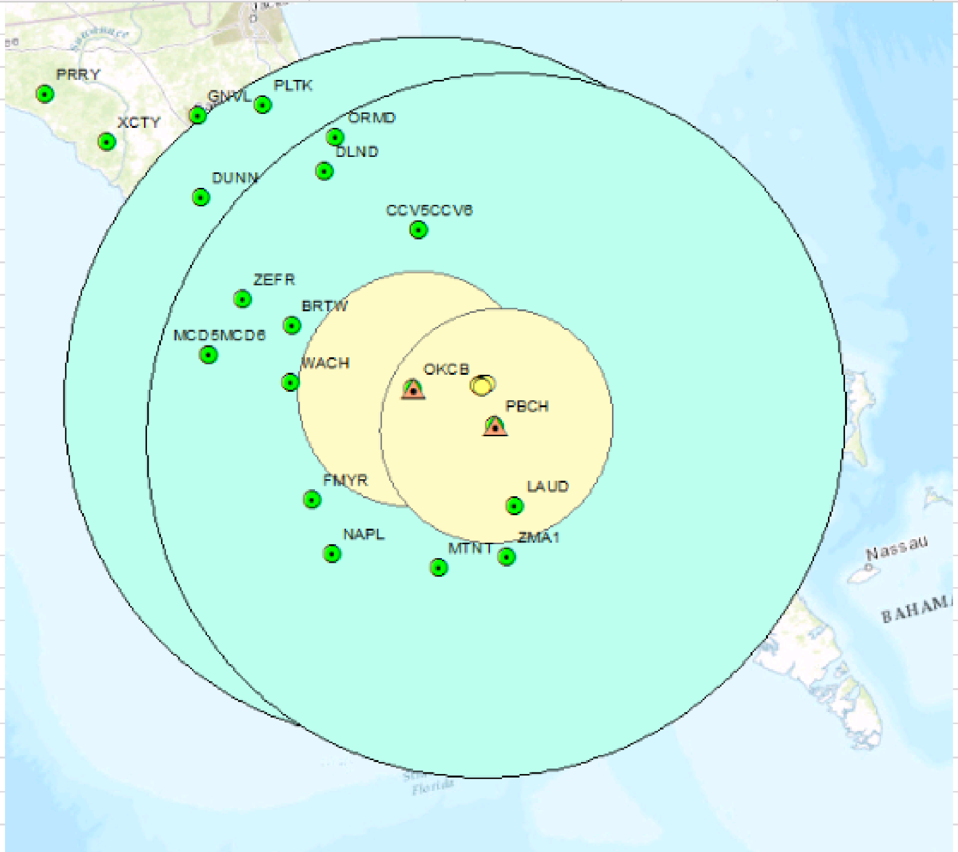
MARKS	2011-069-A	2011-069-B	2011-076-A	2011-083-A	2011-090-A	2011-097-A	2011-104-A	2011-111-A	2011-118-A	2011-125-A	2011-132-A	2011-174-A	2011-202-A	2011-209-A	2011-251-A	2011-258-A	2011-265-A	2011-272-A	2011-279-A	2011-286-A	2011-286-B	2011-293-A	2011-300-A	2011-304-A	MARKS
0127	⊘	⊘	●	●	●		●	●	●	●		●					●	●	●						0127
0137			●					●									●								0137
0139					●					●			●	●	●	●			●		●	●			0139
0141													●	●	●	●					●	●	●		0141
0382			●	●				●	●								●	●							0382
0627						●					●		⊘		●						●		●	●	0627
0699															●	●					●	●	⊘		0699
1507	●	●			●		●			●		●		●		●			●			●			1507
1593						⊘					⊘													⊘	1593
1621	●	●	●				●	●				●					●								1621
1858	●	●					●					●		●		●						●	●		1858
2548	●	●					●	●				●					●								2548
3215					●	●				⊘	●		⊘		●				⊘		●			●	3215
5643				●	●	●			●	●	●							●	●					●	5643
6479									●									●							6479
9780				●		●			●		●							●						●	9780
arli	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	arli
cncr	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	⊘	⊘	●	●	●	cncr
coup	●	●	●	●	●	●	⊘	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	coup
linh	●	●																							linh
lsig			●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●		●	●	●	lsig
p442	●	●	●	●	●	●	●	●	●	●		●			●	●	●	●	●	⊘	⊘	●	●	●	p442
pfld	●	●	●	●	●	⊘	●	⊘	●	●	●	●	●	●	●	●	●	●	●	⊘	⊘	●	●	●	pfld
qmar	●	●	●			●	●	●	●	●	●		●	●	●	●	●	●	⊘	⊘	⊘	●	●	●	qmar
samm	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	⊘	⊘	●	●	●	samm
ufda	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	ufda
vern	●	●	⊘	●	●	●	●	●	●	⊘	●	●	●	●	●	●	●	●	●	●	●	●	●	●	vern

			CORS ID			
Data Availability	Est. Network Accuracy (cm)		HUB (2)	Control (8)	Distant (3 to 5)	
	Vertical	Horizontal	~ 100 km	~ 100 - 300 km	~ 1,000 km	Note
			PBCH	ZMA1	HAMM	
			OKCB	MTNT	TN15	
				NAPL	DOBS	
				FMYR	AL20	
				WACH	NCJA	
				BRTW		
				CCV5		
				CCV6		

Survey Day				
Number	GPS	Month	Day	Year
1	46	Feb	15	12
2	47	Feb	16	12
3	48	Feb	17	12



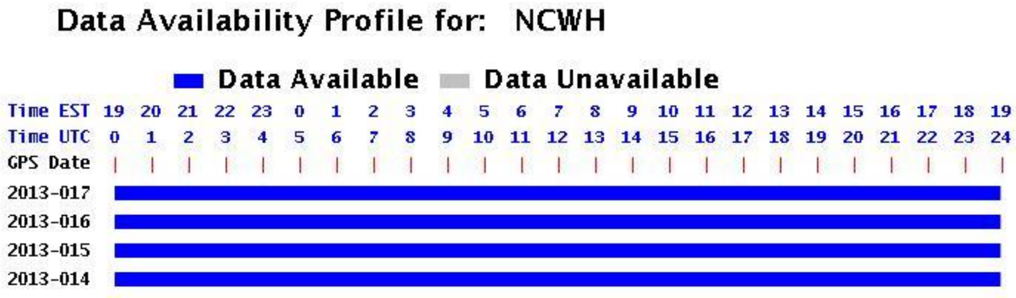




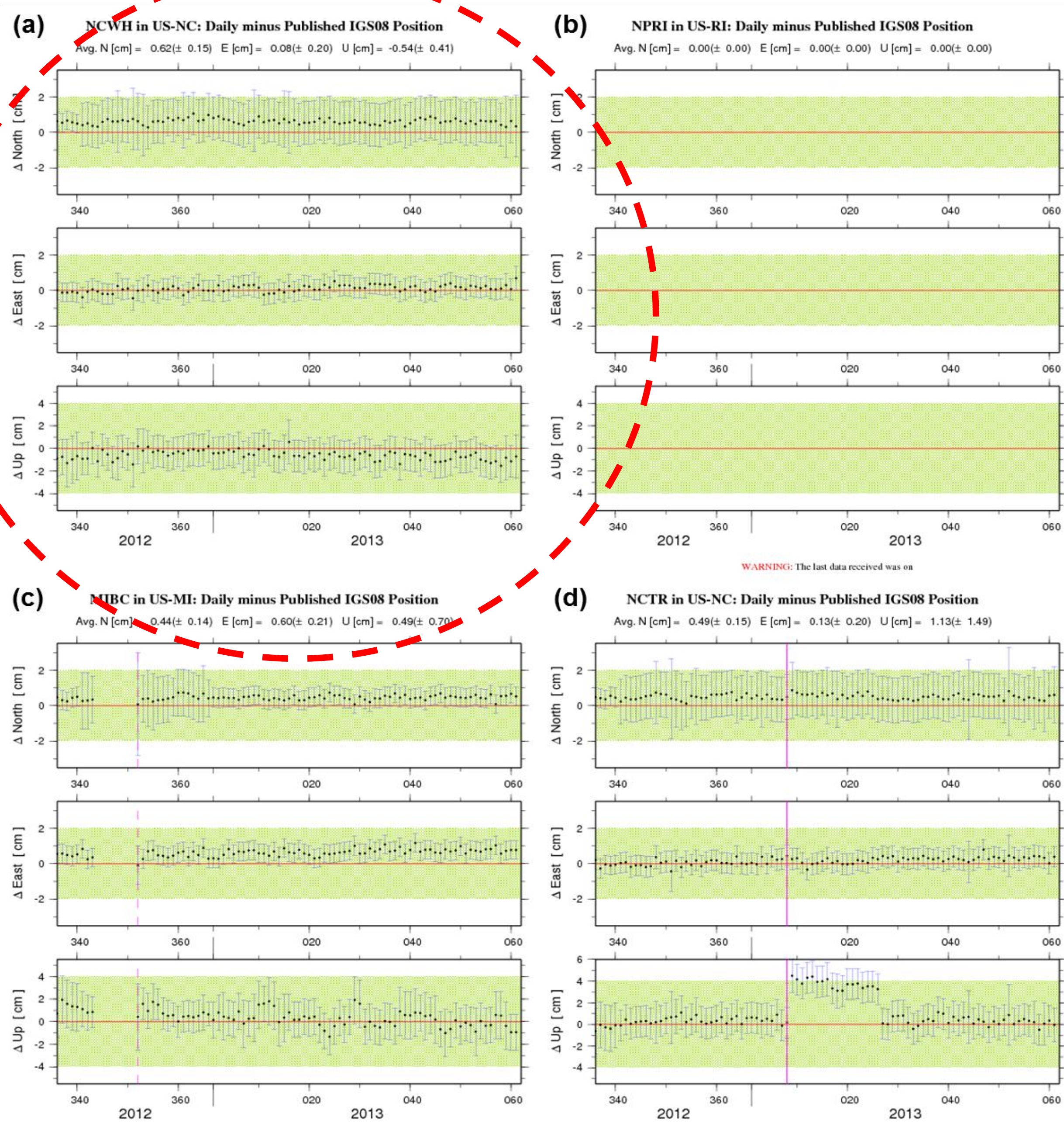
Example (GPS2877)

2 HUBs
8 Control CORS
5 Distant CORS

CORS selection



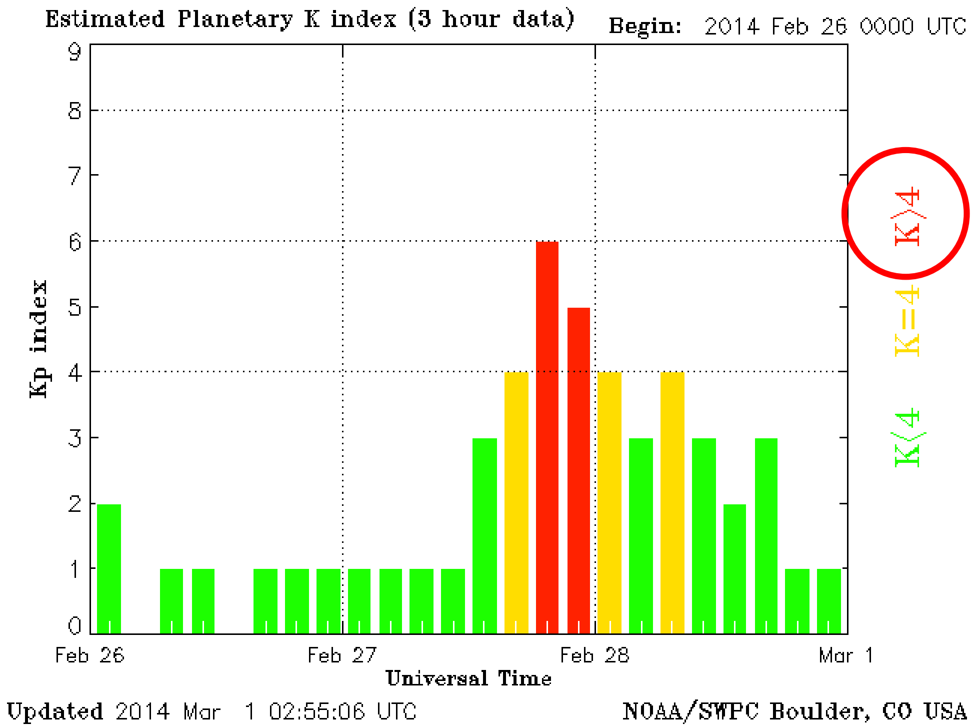
Type		CORS	uN	uE	uh	sN	sE	sh	2DRMS	3DRMS	Note
HUB	<100km	NCWH	0.62	0.08	-0.54	0.15	0.2	0.41	0.67	0.96	
HUB	<100km	NCLU	0.73	0.06	0.41	0.17	0.17	0.53	0.77	1.02	
Control	<300km	SCWT	0.73	-0.11	0.52	0.15	0.18	0.44	0.77	1.03	
Control	<300km	NCJV	0.56	0.11	0.29	0.16	0.41	0.46	0.72	0.90	
Control	<300km	NCSF	0.63	0.15	0.12	0.11	0.16	0.51	0.68	0.86	
Control	<300km	NCTR	0.49	0.13	1.13	0.15	0.2	1.49	0.57	1.95	antenna, radome, elevation, cable change
Control	<300km	COLA	0.07	0.17	1.76	0.16	0.19	0.51	0.31	1.86	
Control	<300km	NCPO	0.09	-0.19	0.08	0.14	0.17	0.56	0.30	0.64	data unavailable during the first surveying day (014.2013)
Control	<300km	NCGO	0.55	0.19	0.24	0.16	0.18	0.48	0.63	0.83	
Control	<300km	NCKN	0.57	0.08	-0.15	0.17	0.15	0.5	0.62	0.81	
Distant	~1000km	ZME1	0.64	0.05	-0.02	0.2	0.22	0.75	0.71	1.03	
Distant	~1000km	ILUC	0.88	0.09	1.84	0.4	0.38	1.38	1.04	2.53	
Distant	~1000km	NYRM	0.47	0.33	0.27	0.16	0.23	0.59	0.64	0.91	
Distant	~1000km	NPRI	-	-	-	-	-	-	-	-	data unavailable
Distant	~1000km	MIBC	0.44	0.6	0.49	0.14	0.21	0.7	0.79	1.16	receiver, firmware change



Ionospheric Activity

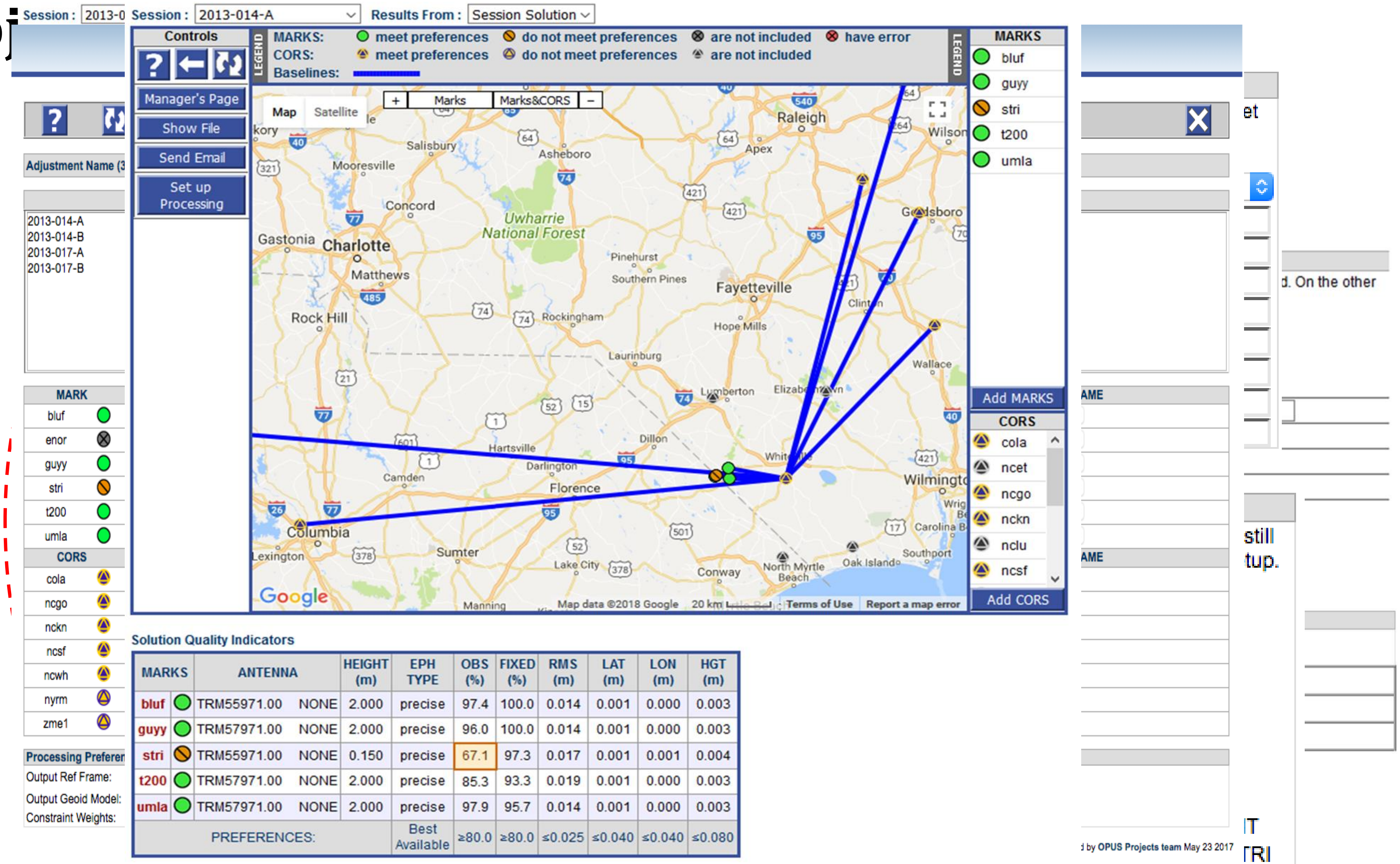
NOAA's Space Weather Prediction Center (SWPC) archive:

- Kp index indicates global geomagnetic activity
- Geomagnetic storms possibly derive significant disturbances in the ionosphere



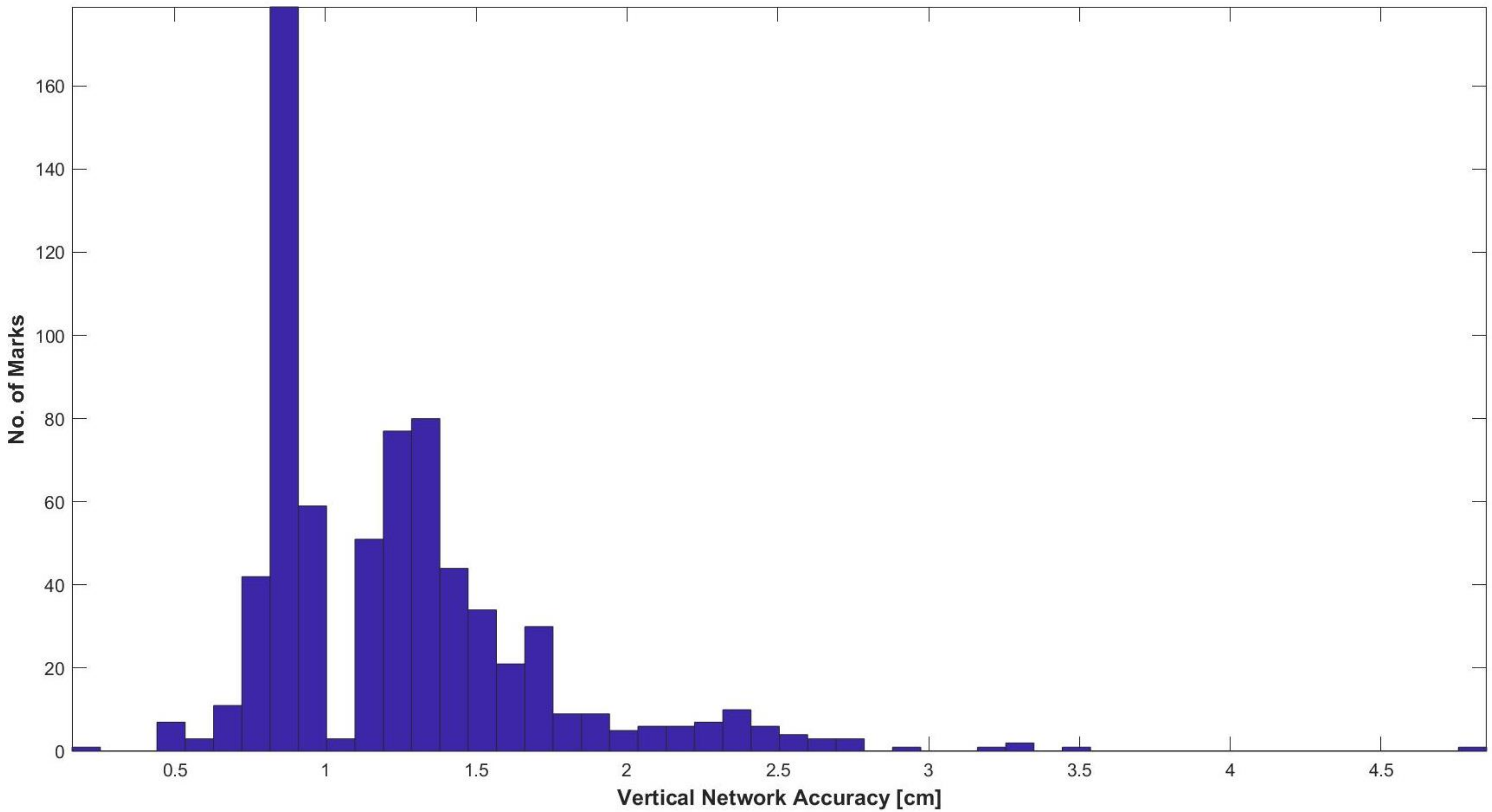
	Project: GPS2877				
Day Number	DOY	Month	Day	Year	Kp > 4? y=1, 0=n
1	46	Feb	15	12	1
2	47	Feb	16	12	0
3	48	Feb	17	12	0

OPUS Proj

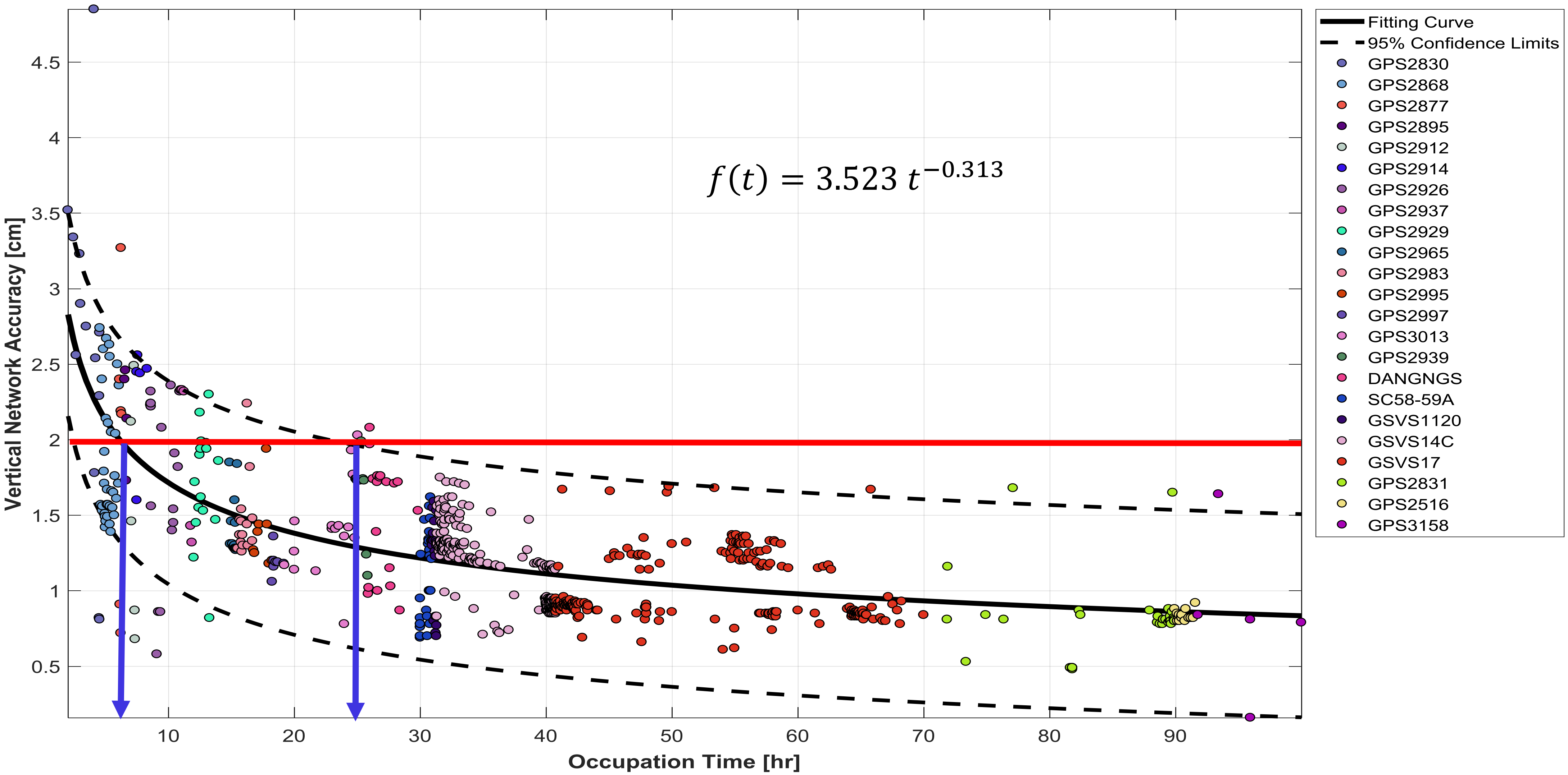


MARKS		ANTENNA		HEIGHT (m)	EPH TYPE	OBS (%)	FIXED (%)	RMS (m)	LAT (m)	LON (m)	HGT (m)
bluf		TRM55971.00	NONE	2.000	precise	97.4	100.0	0.014	0.001	0.000	0.003
guyy		TRM57971.00	NONE	2.000	precise	96.0	100.0	0.014	0.001	0.000	0.003
stri		TRM55971.00	NONE	0.150	precise	67.1	97.3	0.017	0.001	0.001	0.004
t200		TRM57971.00	NONE	2.000	precise	85.3	93.3	0.019	0.001	0.000	0.003
umla		TRM57971.00	NONE	2.000	precise	97.9	95.7	0.014	0.001	0.000	0.003
PREFERENCES:					Best Available	≥80.0	≥80.0	≤0.025	≤0.040	≤0.040	≤0.080

Histogram of the network accuracy (height)



Network accuracy (vertical) vs Occupation times



Min [cm]	Max [cm]	Mean [cm]	RMSE [cm]	R-squared
-1.38	2.58	-0.00	0.33	0.52

New generation, multi-GNSS Processing Capability for the National Geodetic Survey (NGS) (FY2018 - present)

MOTIVATION

- ✓ Increased demand of high accuracy GNSS
- ✓ Various applications of GNSS
- ✓ Multi-constellation GNSS
- ✓ New generation GPS

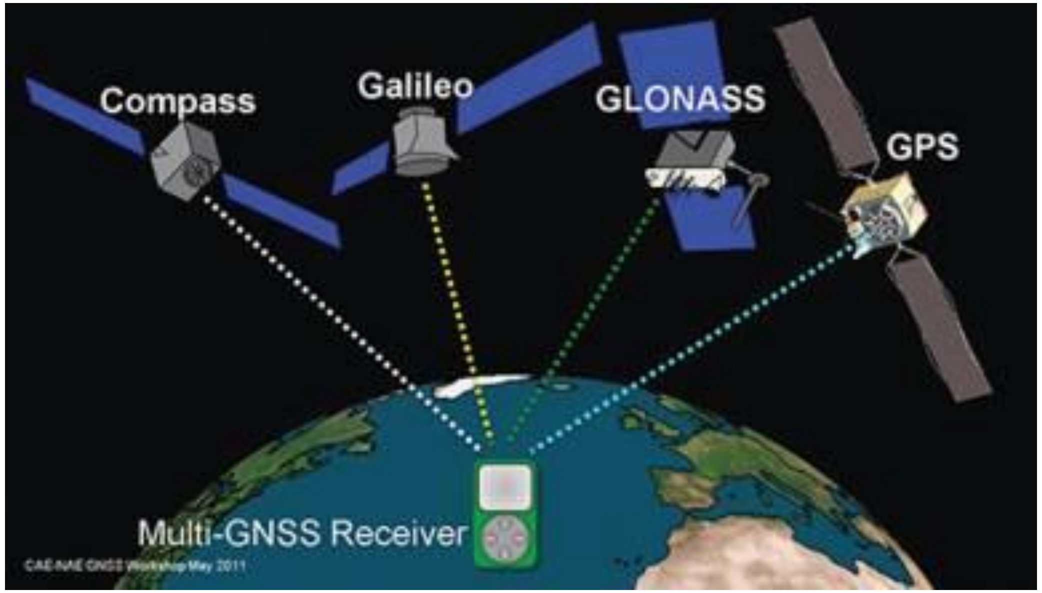


Image credit: Inside GNSS (http://insidegnss.com/the-international-gnss-monitoring-and-assessment-service/)

Multi-GNSS PPP

$$P_{i,q}^{k} = \rho_i^k + I_{i,q}^k + T_i^k + c\left(dt_i - dt^k + \tau^{sys}\right) + b_q^k + b_{i,q} + M_{i,q}^k + e_{i,q}^k$$

$$\Phi_{i,q}^{k} = \rho_i^k - I_{i,q}^k + T_i^k + \lambda_q N_{i,q}^k + c\left(dt_i - dt^k + \tau^{sys}\right) + \lambda_q\left(\varphi_0^k - \varphi_{i.0}\right) + B_q^k + B_{i,q} + m_{i,q}^k + \varepsilon_{i,q}^k$$

where a superscript k and subscript i denote a satellite, k, and a station, i, respectively for frequency, q. $\Phi_{i,q}^k$ is the carrier phase observation and $P_{i,q}^k$ is code observation of GNSS signal (frequency q band (e.g., L1, L2, L5, E1, E6, E5, etc.).

ρ_i^k is the range between the station i and the satellite k; $I_{i,q}^k$ is a ionospheric delay on q; T_i^k is a tropospheric delay, λ_q is the wavelength of signal q, $N_{i,q}^k$ is an integer ambiguity of the phase observation of q, dt_i and dt^k are the clock errors of receiver and satellite respectively, φ_0^k and $\varphi_{i.0}$ are initial fractional signal phases at the satellite and receiver, respectively; $B_q^k, B_{i,q}, b_q^k, b_{i,q}$ are inter-frequency biases;

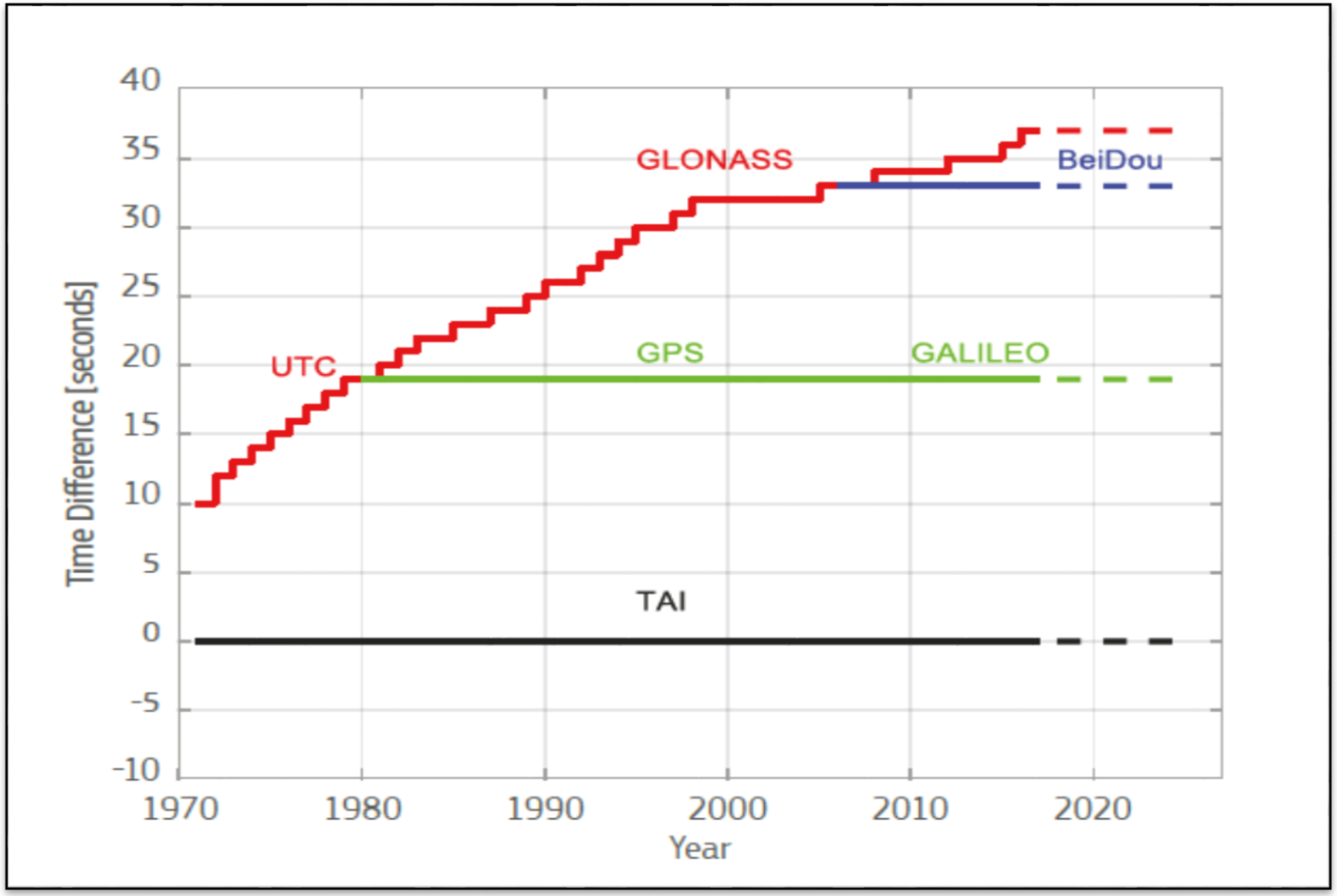
$m_{i,q}^k$ and $M_{i,q}^k$ are multipath errors of phase and code observations; τ^{sys} is the time offset for the system time of GNSS system with respect to a chosen reference

$\varepsilon_{i,q}^k$ and $e_{i,q}^k$ are observational noises

Reference systems

- GPS: WGS84
  - **Will be used as a reference** for multi-GNSS processing
  - Most recent realization : WGS84 (G1762, Mid-October 2013)
- GLONASS: PZ-90
  - Most recent realization is PZ-90.11 GRS, which is based on ITRS at 2010.0
- Galileo: Galileo TRF (GTRF)
  - Most recent realization : GTRF16v01 is aligned with ITRF2008
- BeiDou: China Geodetic Coordinate System 2000 (CSGS2000) with CGCF
  - Aligned to ITRS and referenced ITRF97

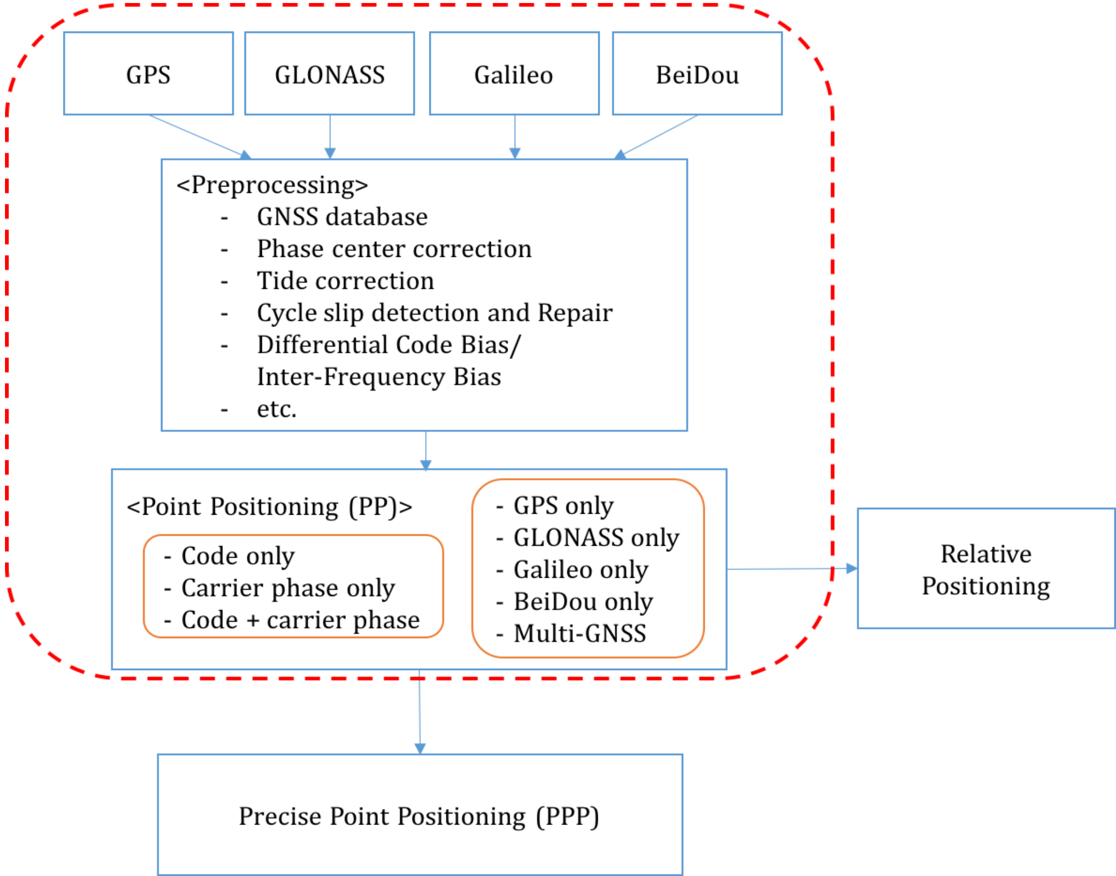
Time difference between GNSS
(GSA GNSS 2018)



PP to PPP

- Tide effects, earth rotation, phase wind-up, hardware biases, antenna phase center offset, atmospheric delays

- What to be improved?
  - Multi GNSS hardware biases
  - Cycleslip detection/repair
  - Ionospheric residual or Ionosphere Free
  - Tropospheric residual
  - Ambiguity Resolution



"Improved post-earthquake rebuild and recovery"

Mission

The CLiP(Cascadia Lifelines Program) conducts research that will allow Oregon's lifeline providers to implement value- and cost-informed decisions to mitigate damage to Pacific Northwest infrastructure as the result of Cascadia subduction zone earthquakes.

http://cascadia.oregonstate.edu

CLiP - workshop

- First session: PLSO 2018 in January 2018
  - *23* attendees interested in participating
- Second session: ODOT Surveyors conference in March 2018
  - *12* more attendees signed up!

- **CLiP workshop in August 2018 at OSU**
  - CSZ working group: https://secure.engr.oregonstate.edu/mailman/listinfo/cszsurveyorsworkgroup

½ day workshop @ OSU (7 August 2018, need your input!)

- Working group of 20+
- Formulate leadership
- Discuss background of challenges and resources
- Develop framework for post-event response
- Set plan for working group
- Establish best practices for current surveys and post-event surveys
- Identify outreach/educational activities for workforce.

Interested? Email to: Jihye Park, Mike Olsen, Chris Parrish in Geomatics at OSU

GNSS meteorology

- To monitor & forecast weather
- Meteorological parameters in the atmosphere (up to 50km altitude) derive the signal delay → Tropospheric delay
- By extracting the wet delay part and converting to Precipitable Water Vapor
- Applicable to severe weather monitoring/prediction

Monitoring Hurricane path by GNSS derived Precipitable Water Vapor (PWV) analysis

- ❑ To monitor the humidity before/during/after severe weather event

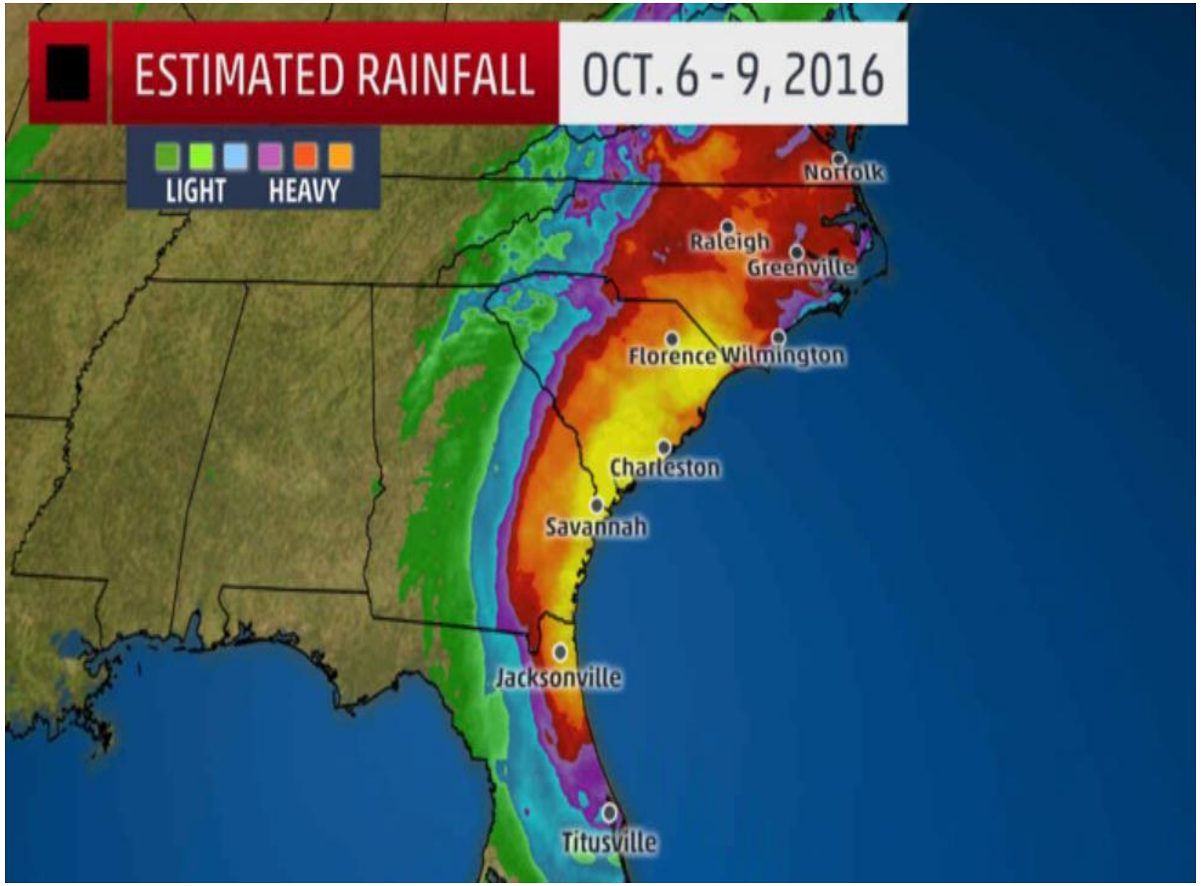
- ❑ Can be further extended to "*modeling*" and "*prediction*"

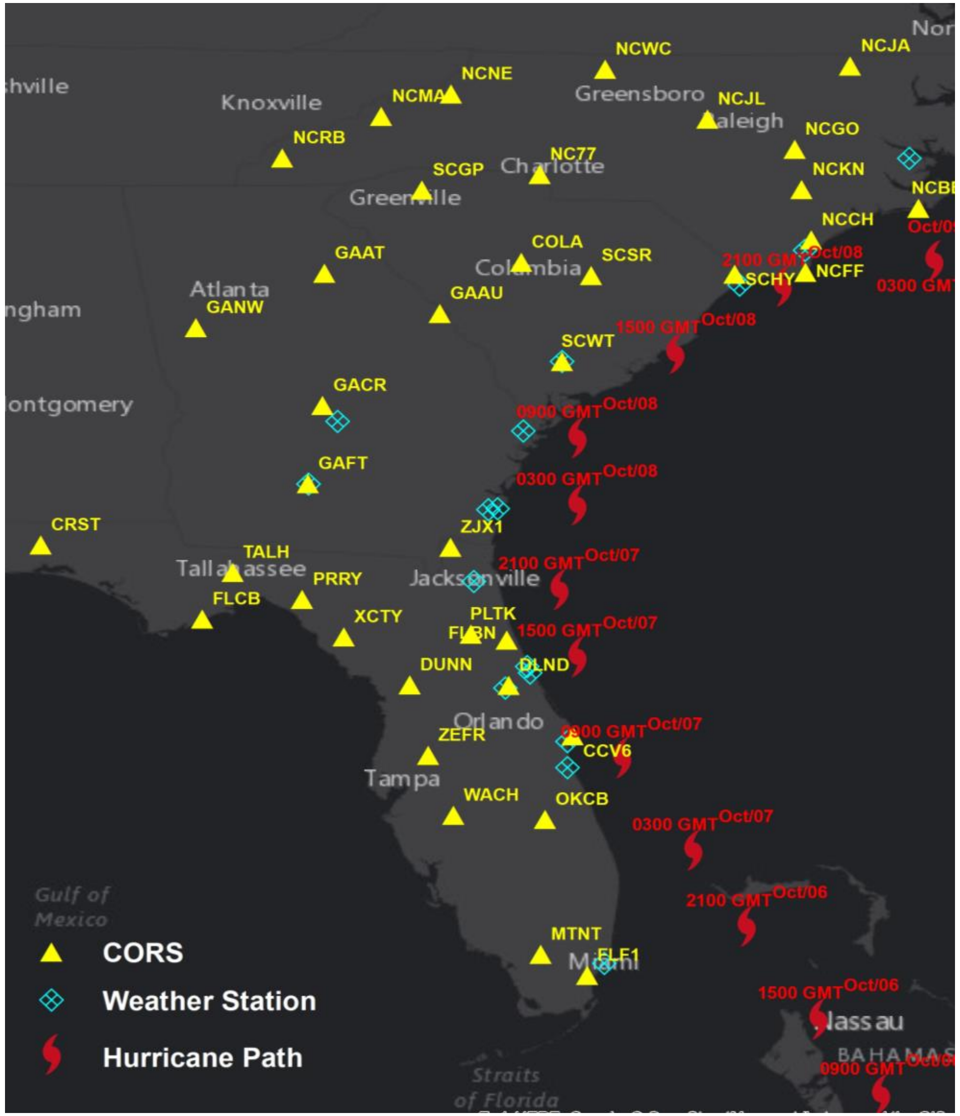
- ❑ ***Case study:*** Hurricane Matthew in Oct 2016 (Florida, Georgia, and South-Carolina)

(Tahami et al., 2017)

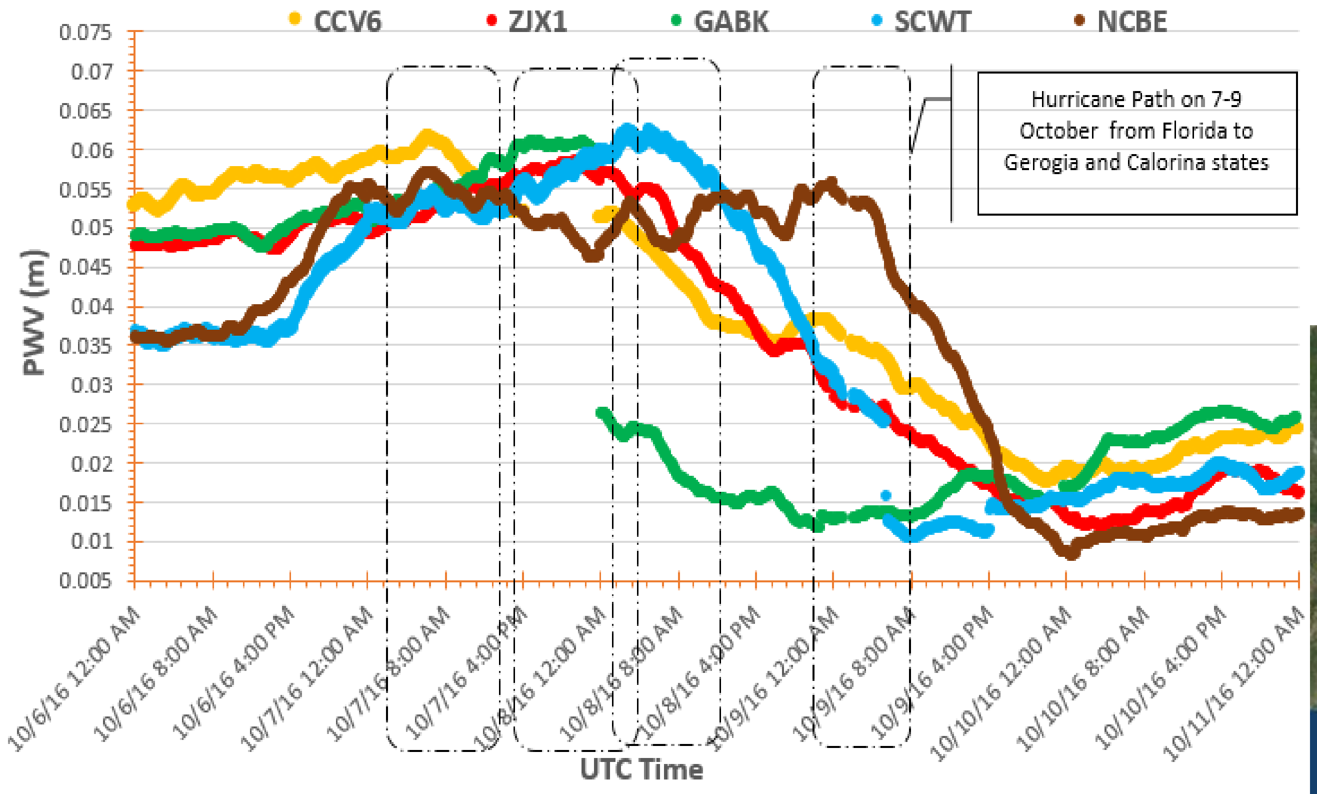
Tracking hurricane path using CORS observations

Hurricane Matthew in Oct 2016

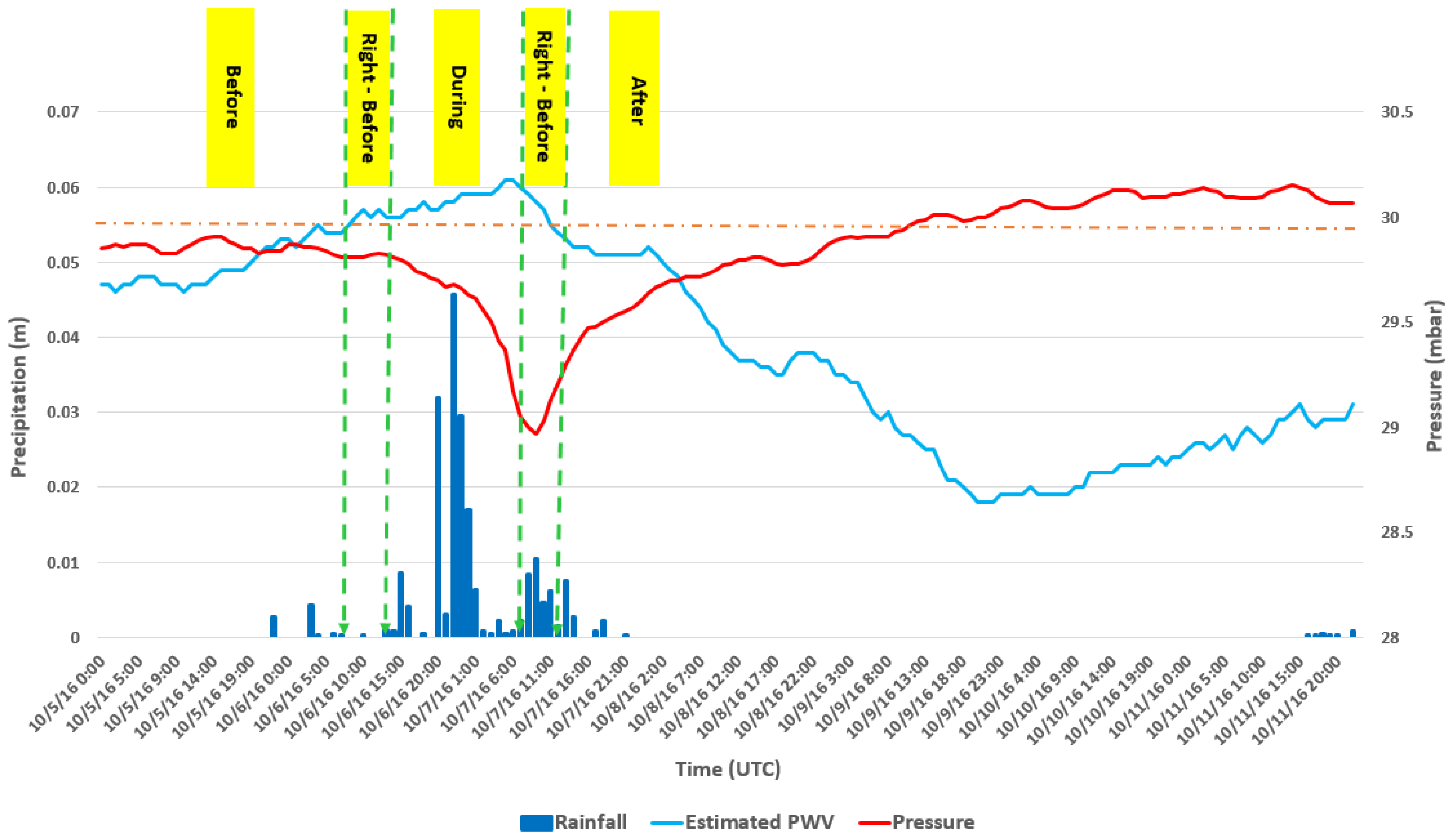




PWV variation Monitoring During Hurricane Matthew



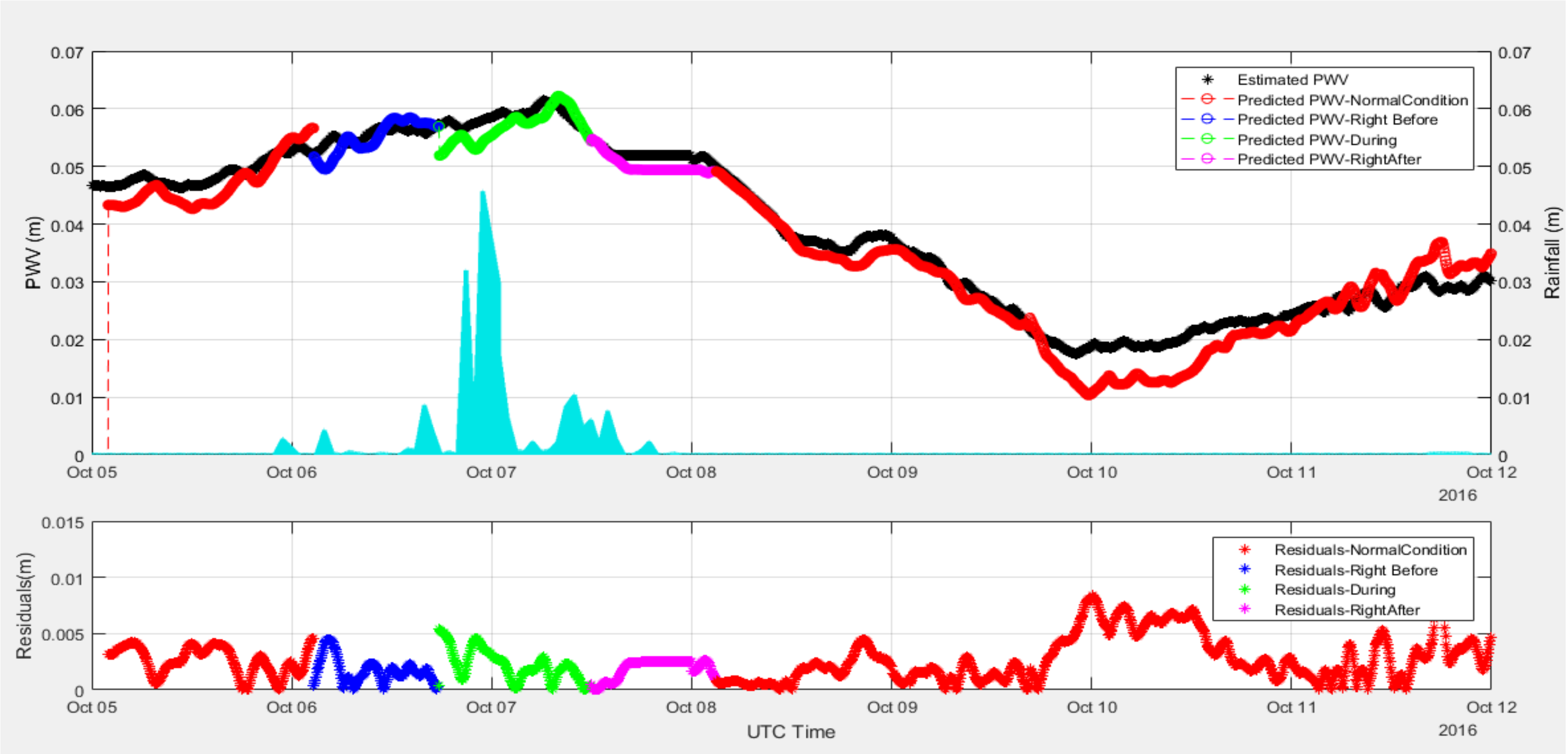
Classification of Hurricane for Statistical Data Analysis



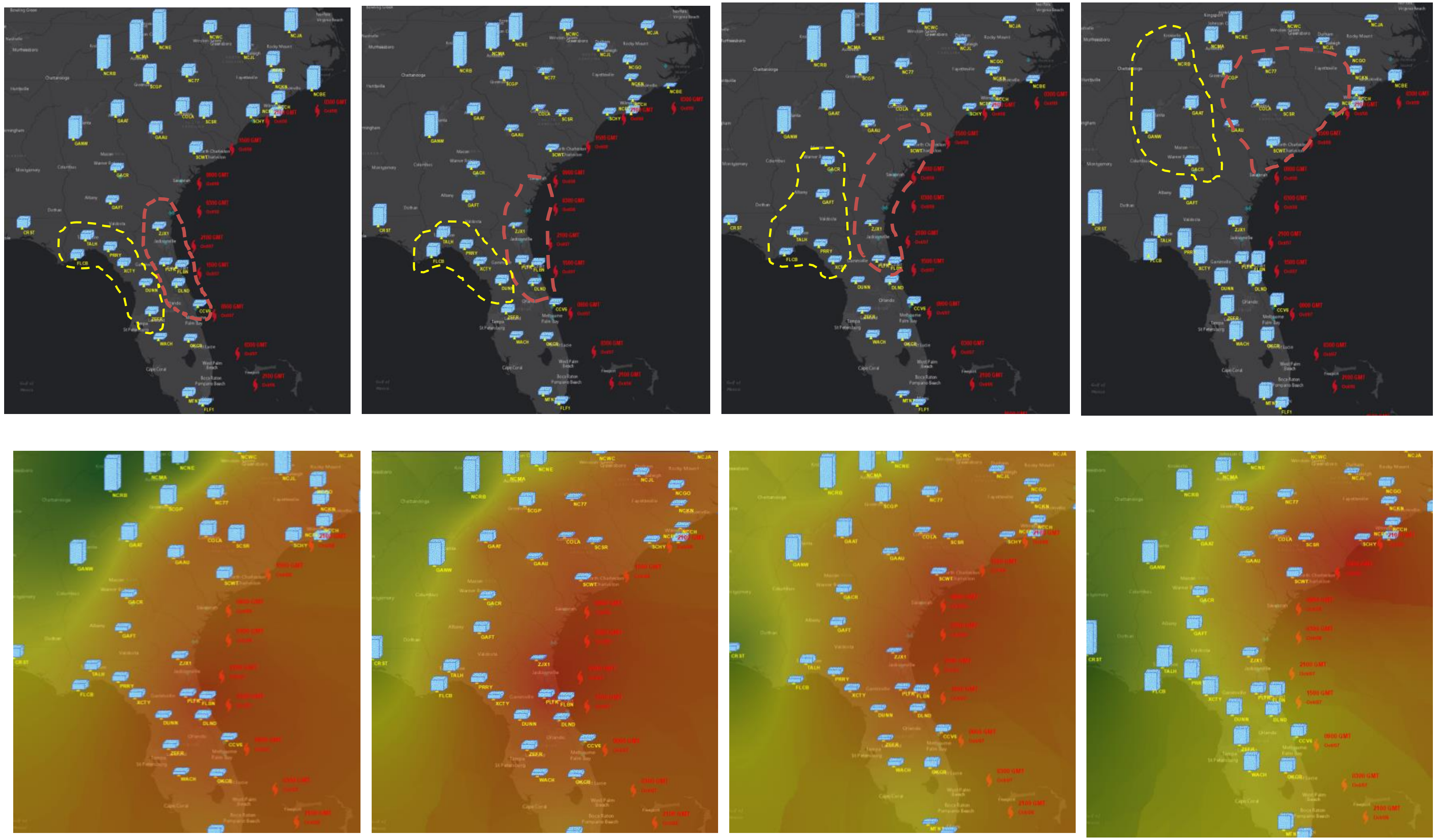
Statistical GNSS Data Analysis for Hurricane Path Prediction

$$(PWV_{t+1}) = \overline{PWV_t} + c_1(PWV_t - \overline{PWV_t}) + c_1(P_t - \overline{P_t}) + c_3(T_t - \overline{T_t}) + c_4(RH_t - \overline{RH_t}) + e$$

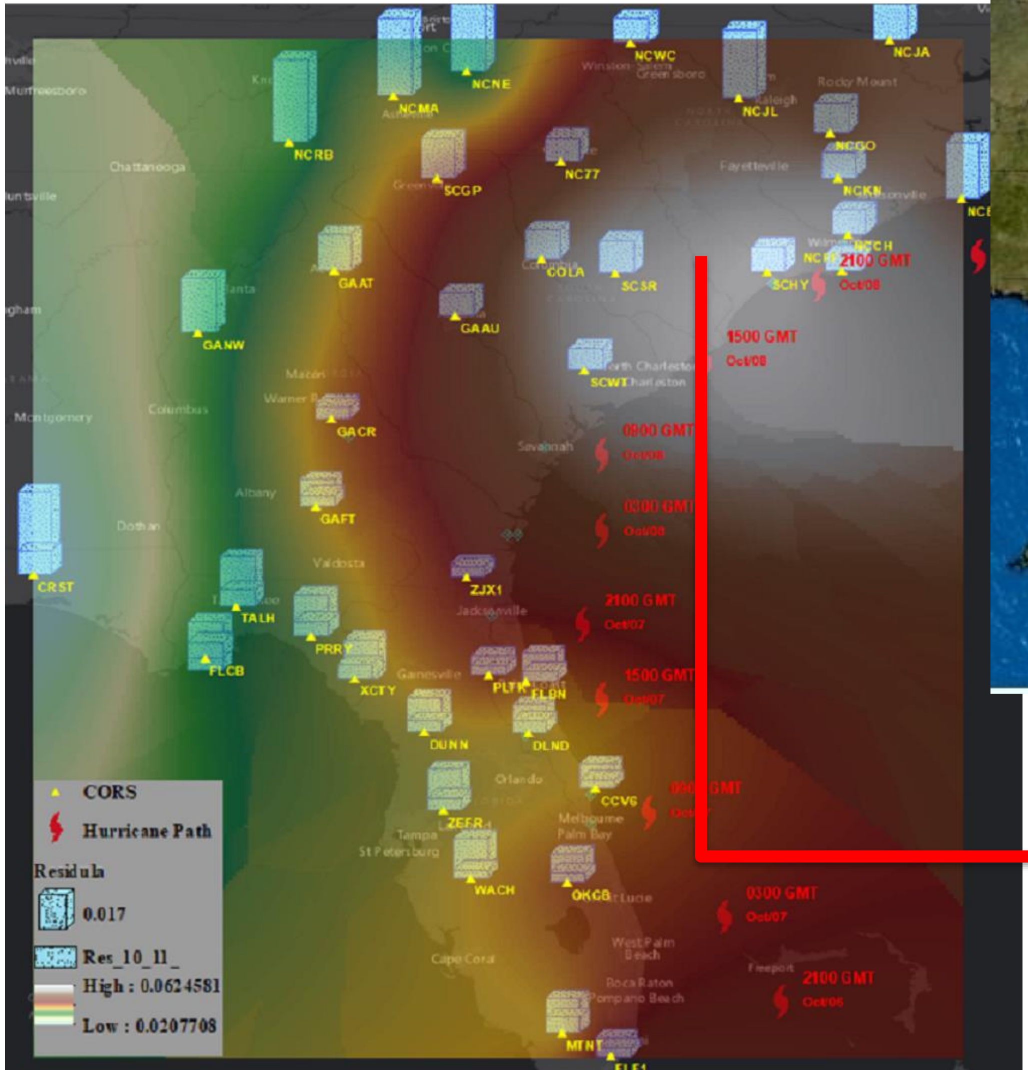
P is pressure, T is temperature, RH is relative humidity, c consists of regression coefficients and e is the error term.



Classified Residuals and Predicted PWV variation



Hurricane Path Prediction by Comparing the model's Residuals



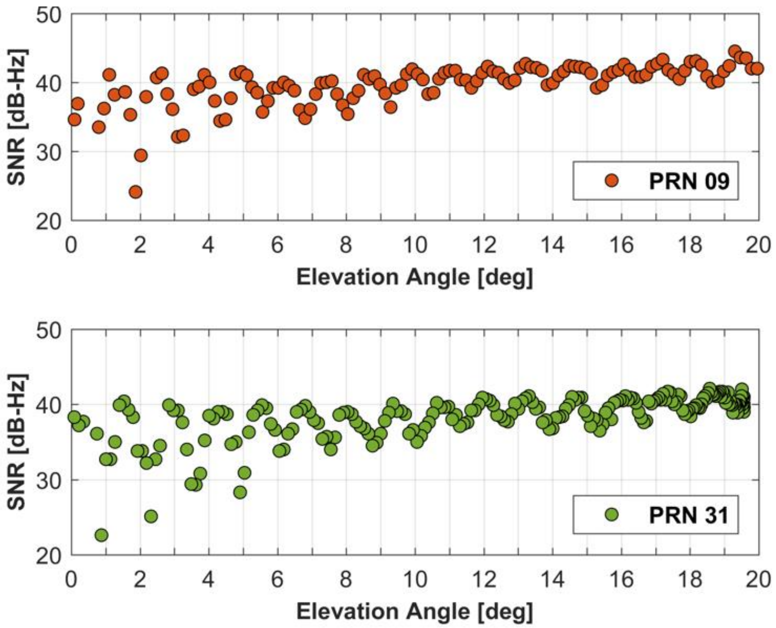
Hurricane is affecting south and North Carolina

GNSS-Reflectometry (GNSS-R)

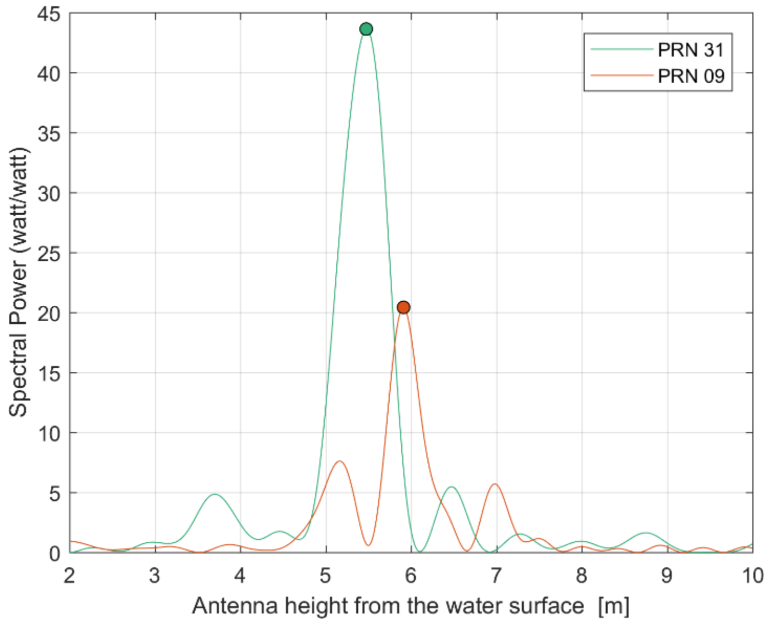
- Multipath is one of the error sources in GNSS measurement → to be minimized!
- These *multipath signals*, however, can be *used to obtain information* about the *reflected surface* → GNSS reflectometry.
- Used in various applications e.g., water level monitoring, soil moisture monitoring, snow depth estimation, ocean wind analysis.

GNSS-R: SNR based approach

- SNR (Signal to Noise Ratio) data analysis
  - SNR data from each observable
  - The *multipath effect* on the SNR observation appears in the form of *oscillation* of SNR w.r.t. elevation angles
  - The frequency of the oscillation is depend on the geometry between satellite, reflector and antenna, which means the frequency contains the information about the water level height.
  - The *frequency can be converted to antenna he*ights form the water surface.

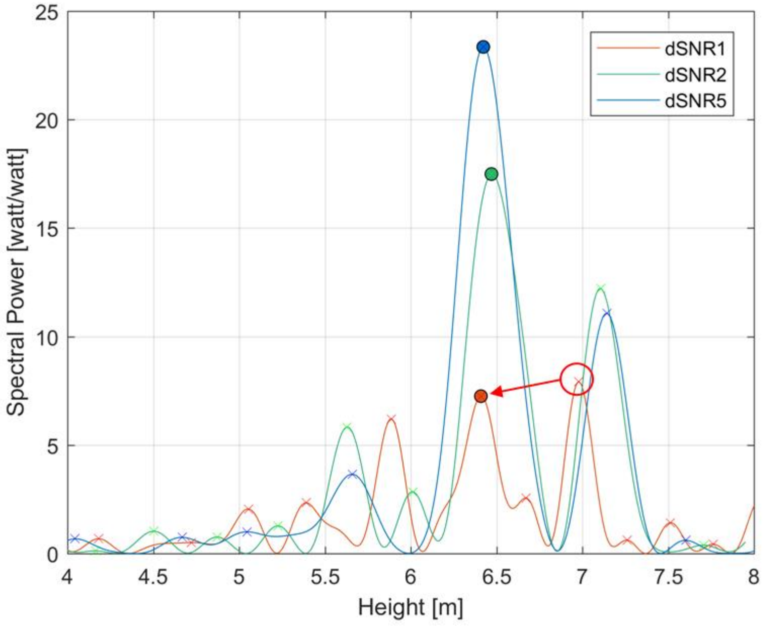


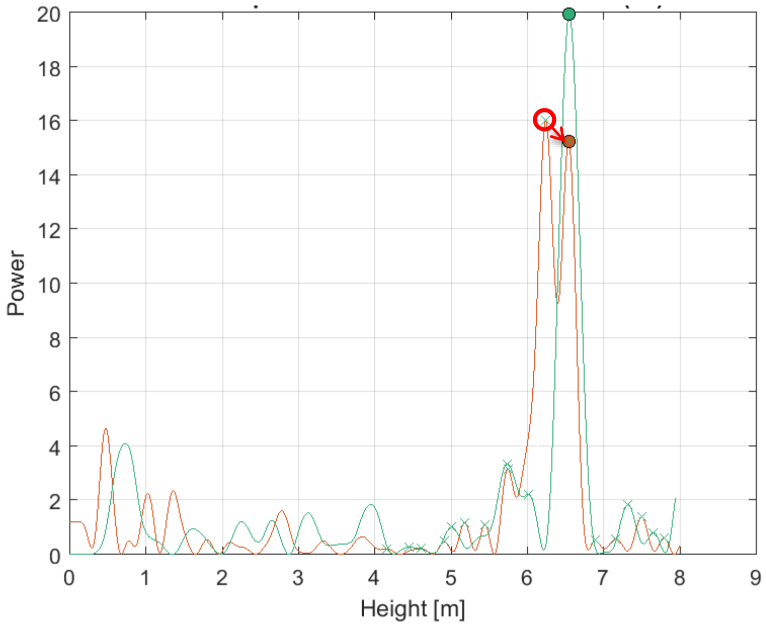
$$f = \frac{2h}{\lambda}$$



Enhanced Spectral Analysis

- The *determination of the dominant frequency* is mightily important because the height is directly converted from the frequency.
- A new method to precisely determine the frequency among the multiple peaks identified through spectrum analysis is suggested.
  - We take the advantage of *multi-frequency of GNSS signals*.
  - It is possible to minimize the error of the peak detection by *comparing* the dominant height extracted from the multiple frequencies based on *a local maximum* of each frequency signal.

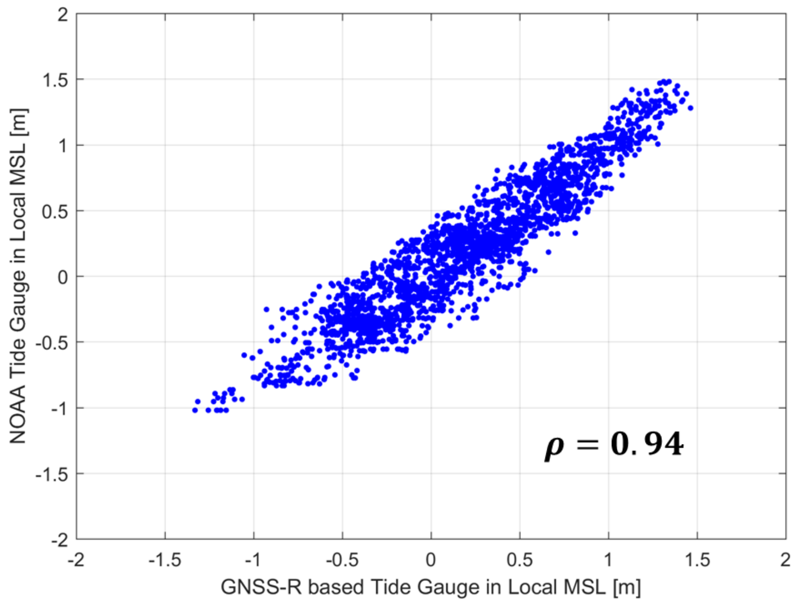


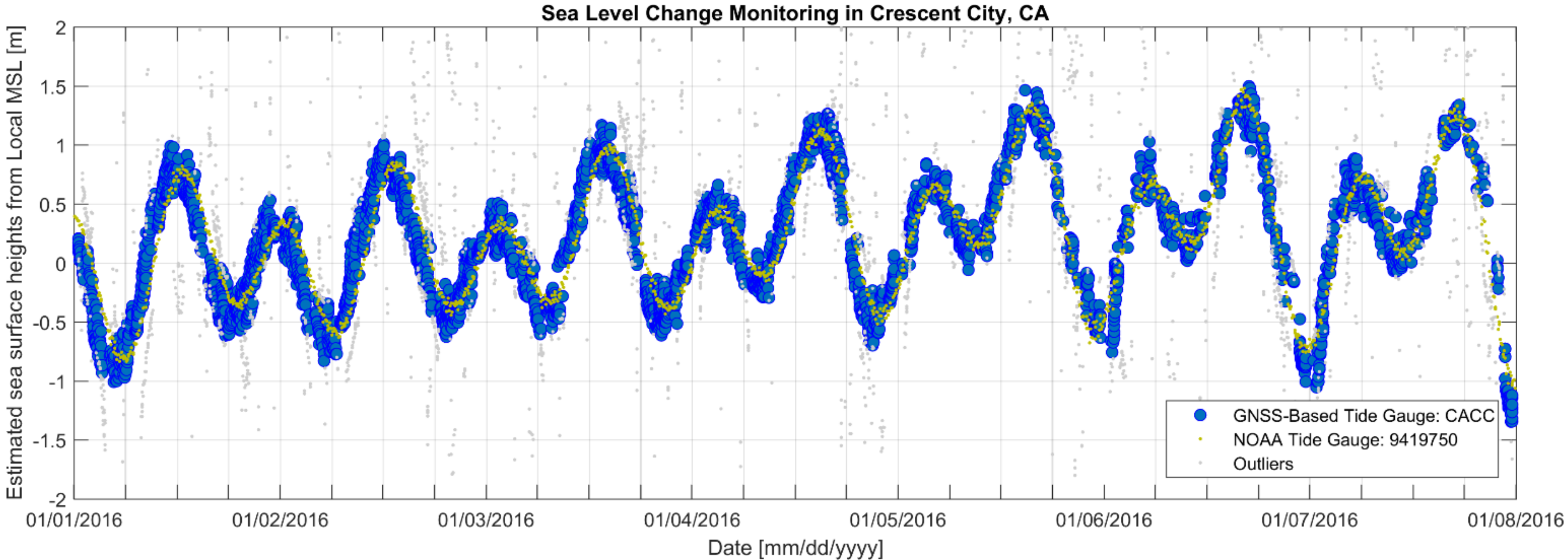


Case Study 1: CACC in Crescent City, CA

- Processed SNR data collected from NGS CORS CACC in Crescent City, CA
- NOAA tide gauge station (ID: 9419750) was also used for the comparison, which is *co-located* with CACC
- Analysis periods: *1 ~ 7 January, 2016*

- The GNSS-R technique successfully estimated the water level variation by showing a *good agreement with the co-located tide gauge station*.
- In addition, a *high correlation coefficient* of 0.94 was computed.
- GNSS-R based tide gauge provides water level height at approximately *4.4 second intervals* on average.





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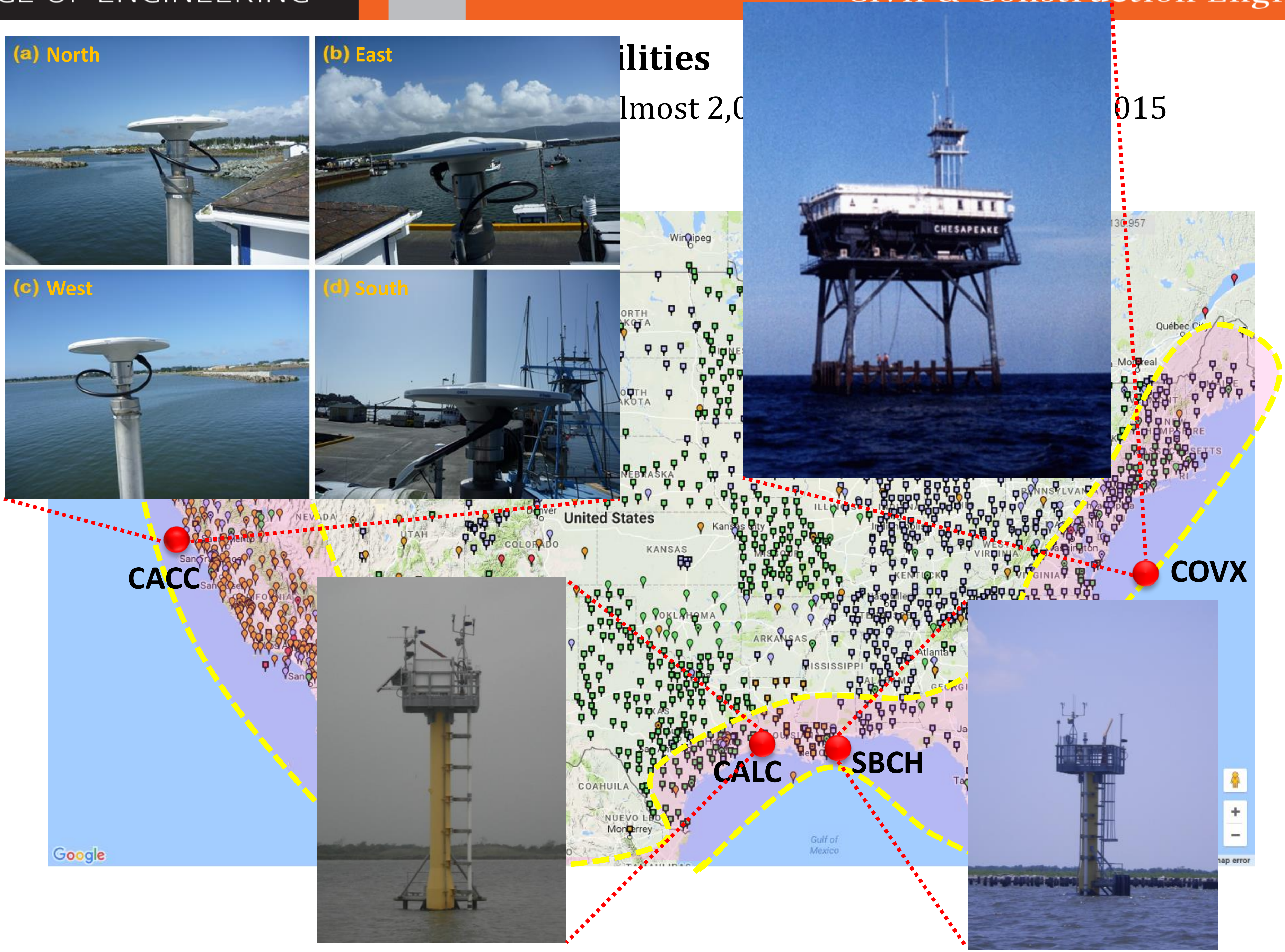
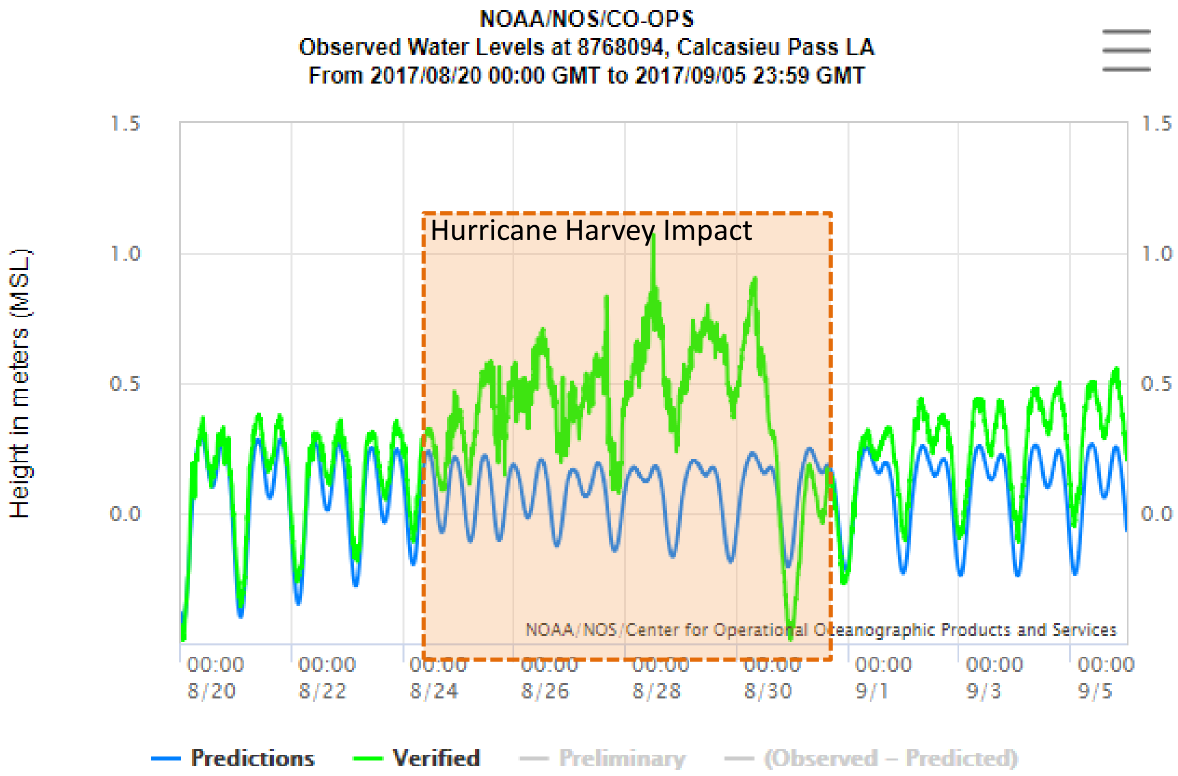
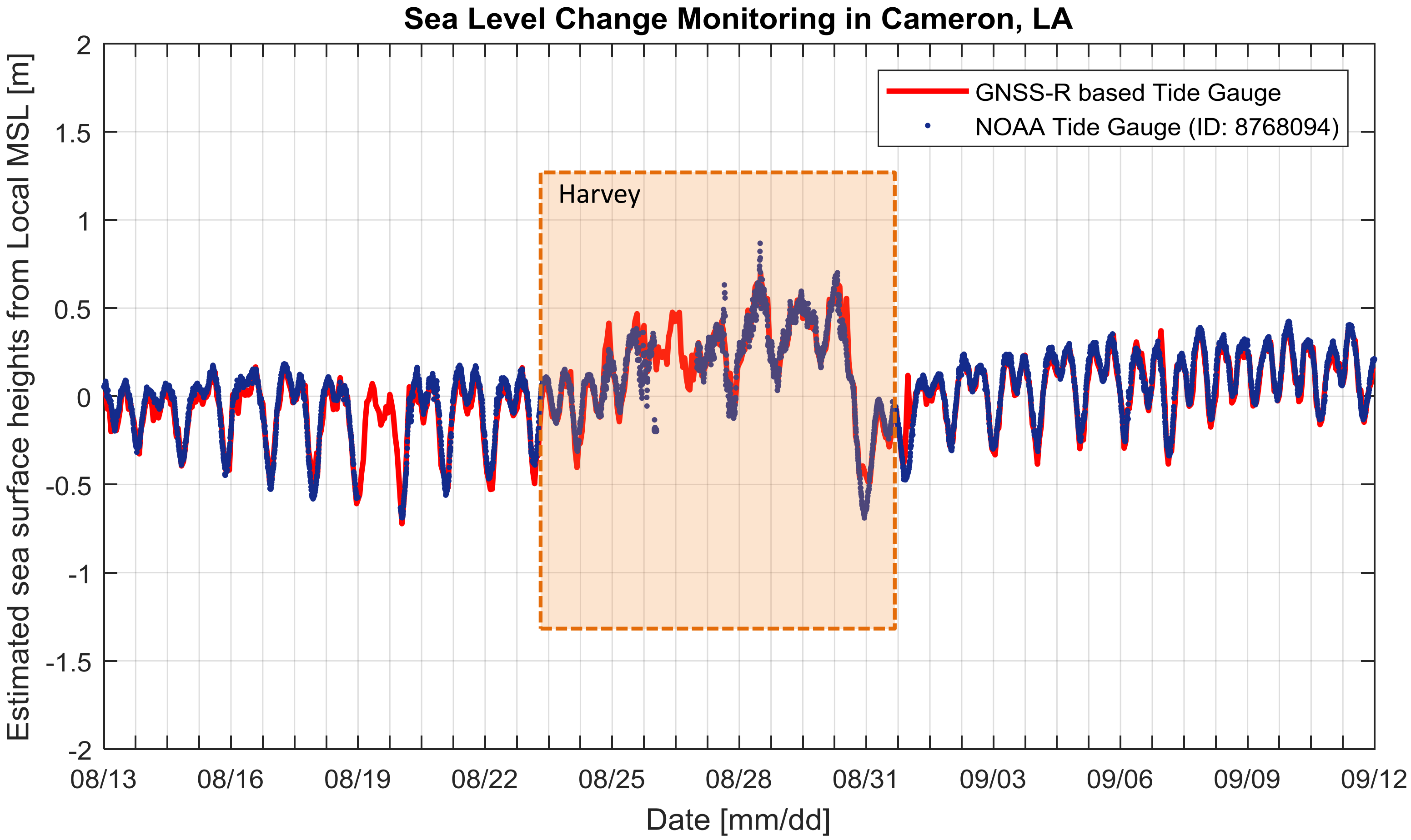


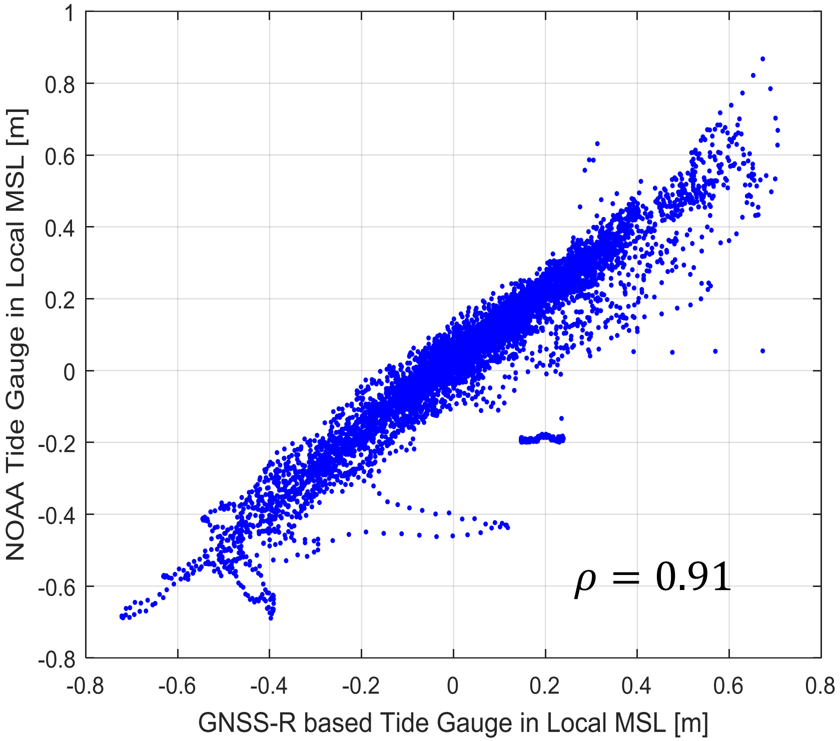
Case Study2: Hurricane Harvey

- Processed SNR data collected from NGS CORS CALC in Cameron, LA
- Co-located NOAA tide gauge station (ID: 8768094) was also used for the comparison
- Analysis periods: 8/13/2017 – 9/12/2017



- Overall, the sea level changes observed by GNSS-based tide gauge well represent the time series patterns of the co-located tide gauge station.
- Especially, the abruptly changing water level during the Hurricane Harvey could be successfully observed by utilizing the GNSS reflection signals.



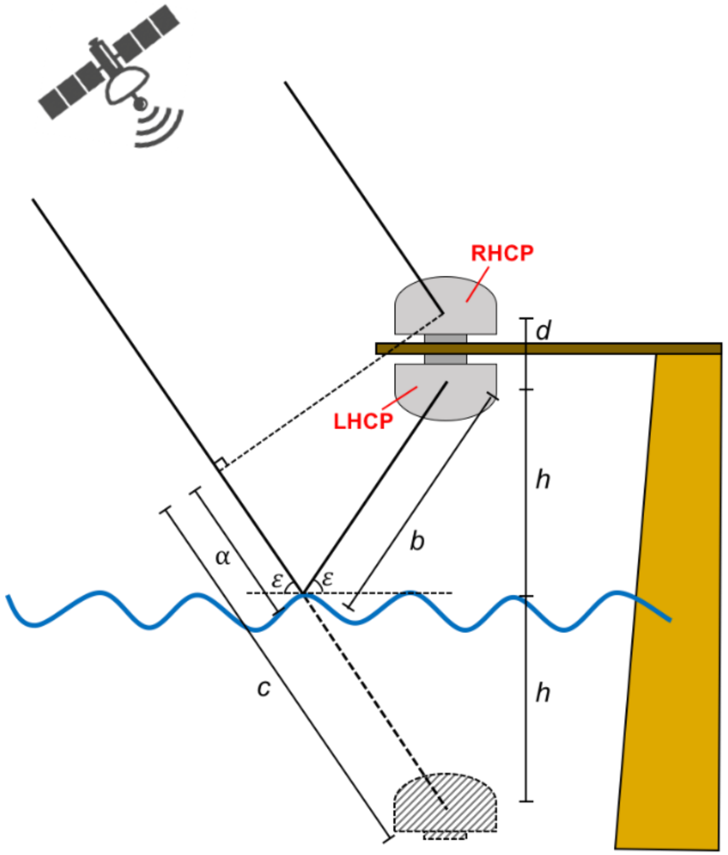


GNSS-R: Methodology 2

- Phase delay
  - Use the *path delay* that the *reflected signals* additionally experience with respect to the direct signals
  - Direct and reflected signals are separately collected through *dual antennas*.
  - Apply the characteristics of the GNSS signals: GNSS signal is RHCP, but a *single reflection changes the polarization* of the signal to LHCP.
    - RHCP (Right Headed Circularly Polarized)

      : Zenith looking, Direct signals, Regular antenna
    - LHCP (Left Headed Circularly Polarized):

      : Nadir-looking, Reflected signals, Specially designed antenna



$$h = \frac{(a+b)/\sin\varepsilon \; - d}{2}$$

GNSS-R equipment installation in Newport, OR

Thank you!

Questions?