ILLINOIS INSTITUTE OF TECHNOLOGY

Space Weather Lab

GNSS Reflectometry for Studies of Surface Ice And Water Conditions

Roohollah Parvizi, Boris Pervan and Seebany Datta-Barua.

Illinois Institute of Technology

Supported by: NASA award NNX15AV01G

SCPNT Stanford Center for Position, Navigation and Time

Outline

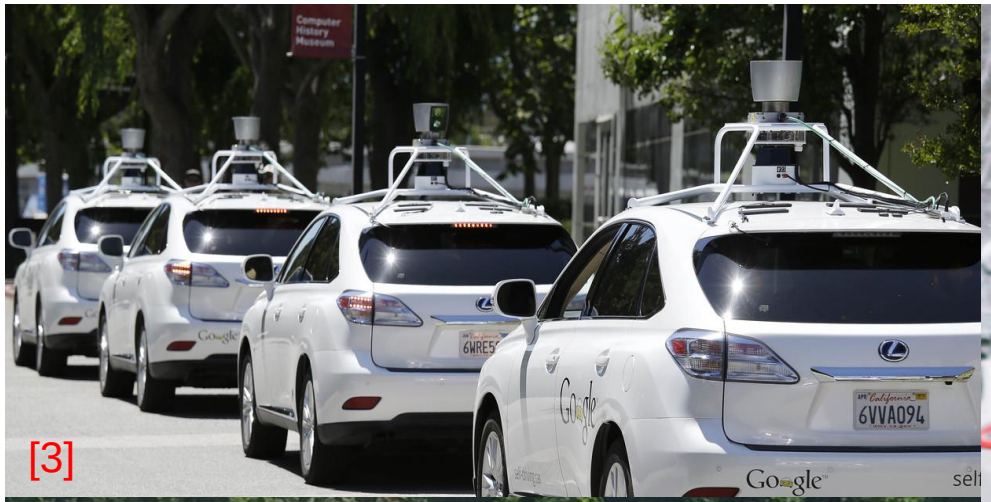
- Motivation
  - Why GNSS-R
- Objective
  - Detecting GNSS-R
- Background
  - Delay Doppler Map
- Method
  - What are our sensors
  - Data Campaigns
  - Signal Processing
- Results
- Conclusion

Motivation

[1]: https://www.bikebandit.com/blog/black-ice-the-invisible-winter-threat

[2]: https://www.news-journal.com/news/police/icy-roads-run-out-of-wreckers

Motivation



[3]

[4]

[5]

[3]: https://www.wsj.com/articles/laser-eyes

[4]: https://www.teslarati.com/tesla-lidar-sensors-spotted-testing-palo-alto/

[5]: https://www.detroitnews.com/story/business/autos

Motivation

LiDAR disadvantages:

- Expensive, costly.
- Unreliable for water surface and breaking waves.
- It is affected by rain.
- Low operating range (500-2000m).

Motivation

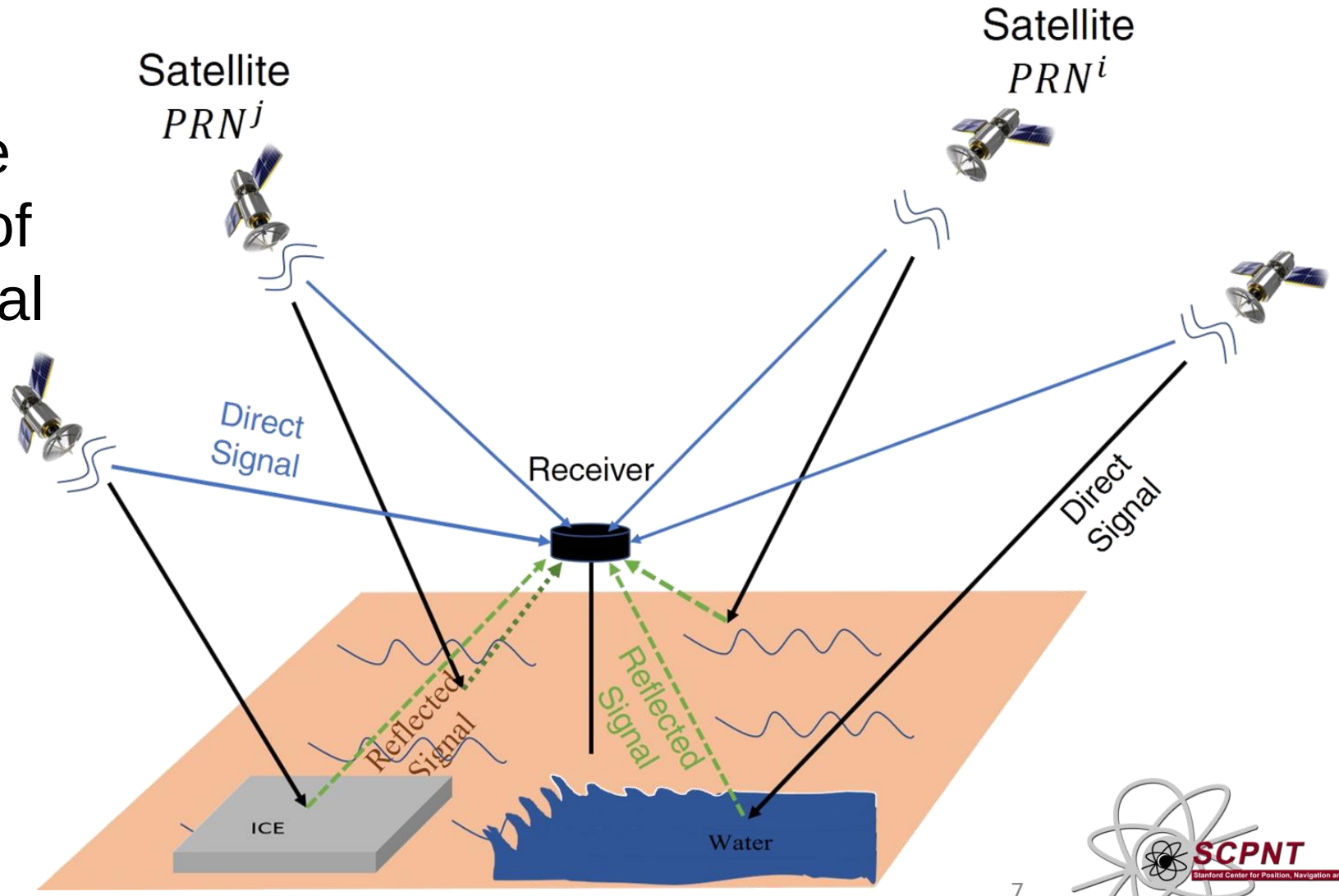
Can we do better with GNSS?

- Lower cost.
- Widespread coverage and availability.
- Unaffected by precipitation and cloud cover.
- Potentially better resolution.

GNSS-Reflectometry

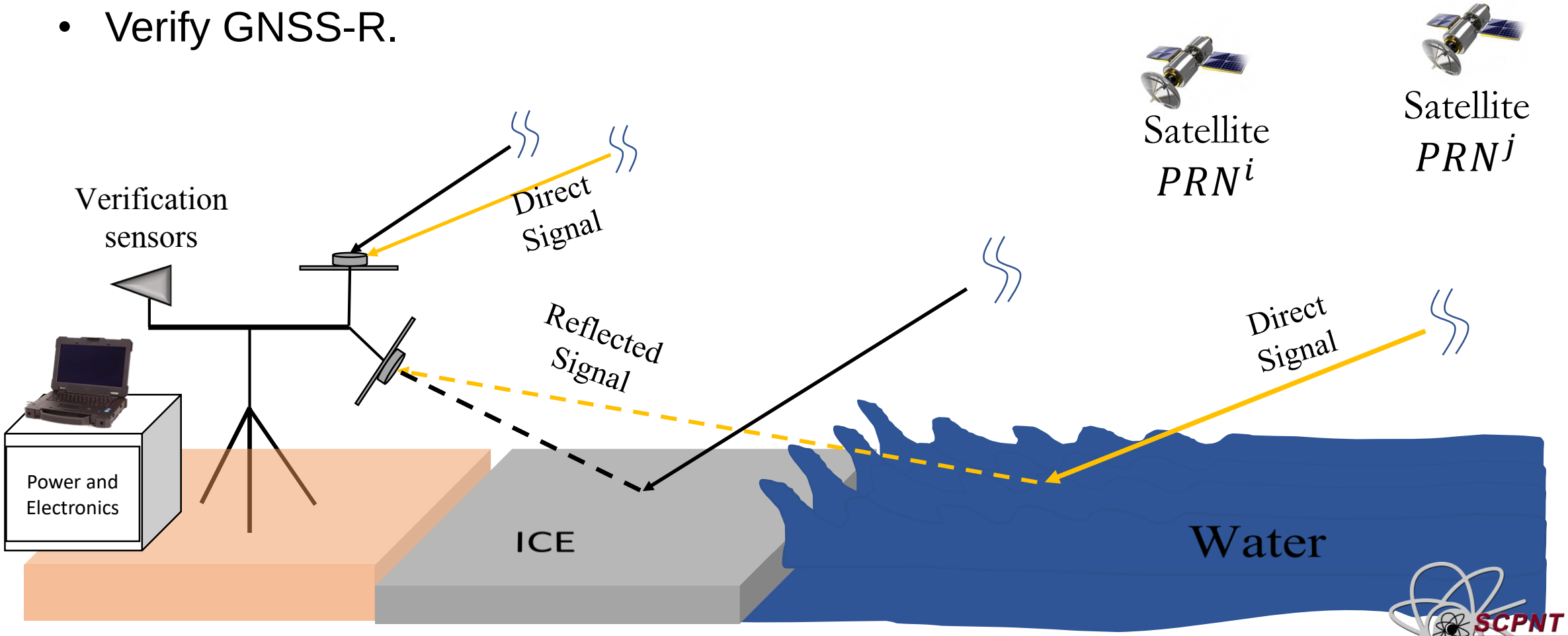
GNSS-R:

- The study of the characteristics of a reflected signal

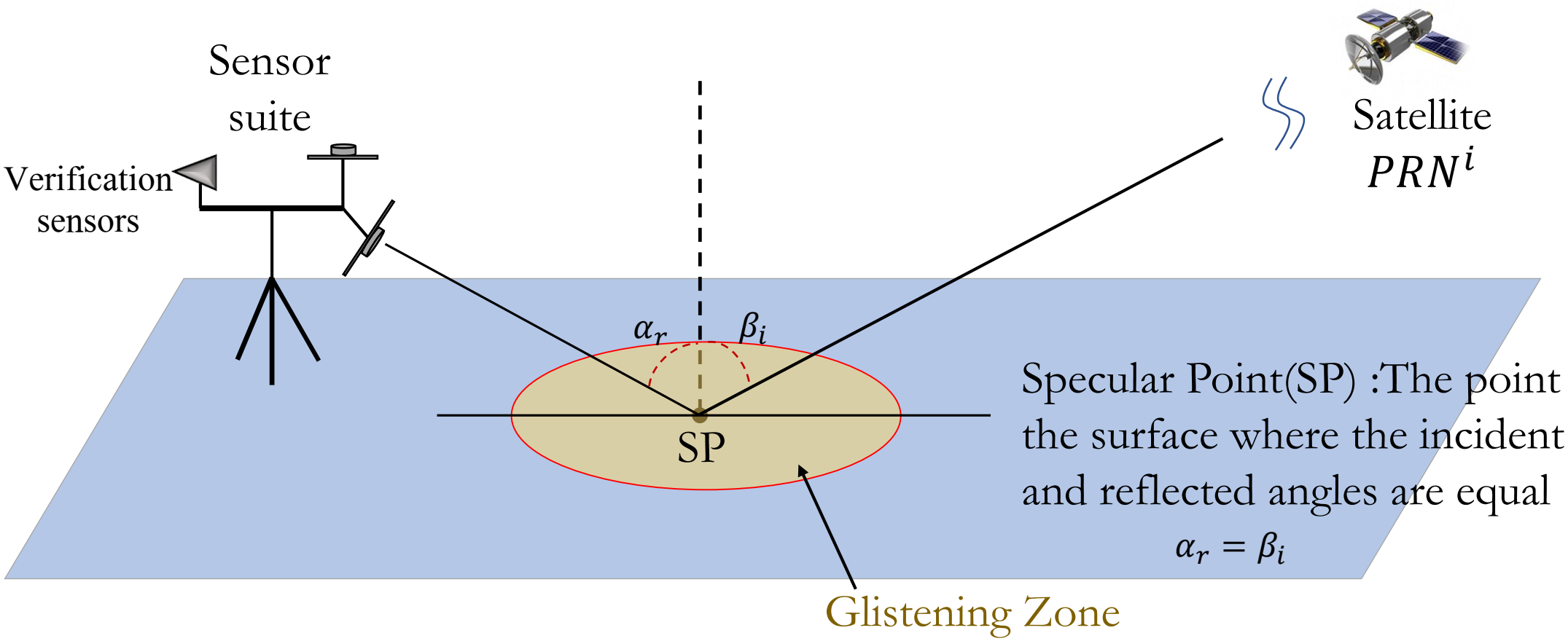


Objective

- Detect reflected GNSS signals from the water/ice surface.
- Verify GNSS-R.



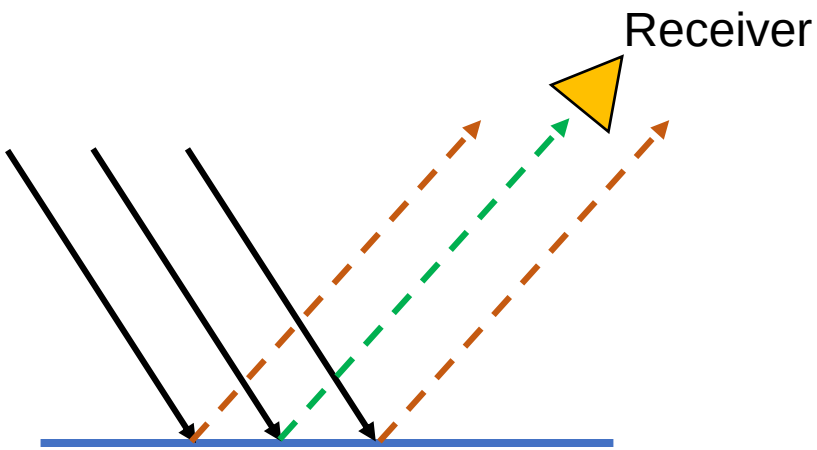
GNSS Reflection Signal

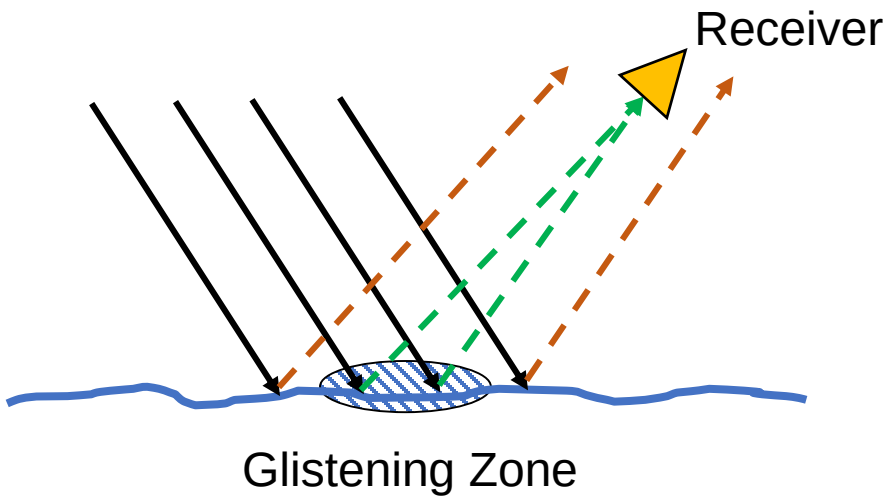


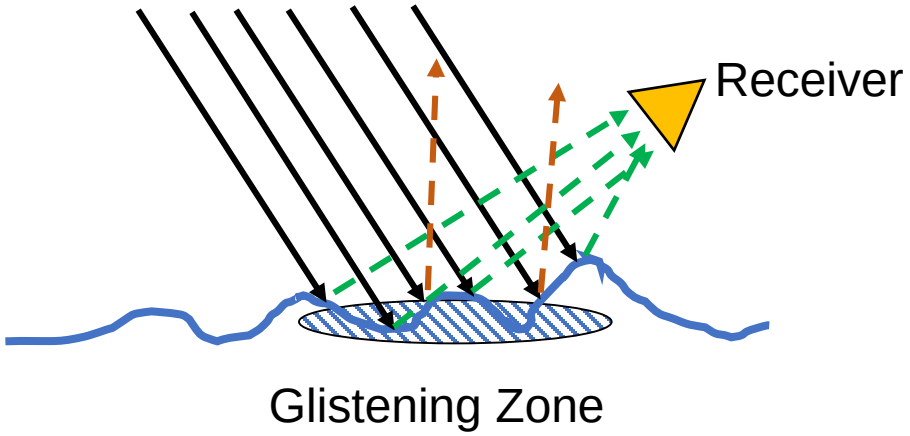
Specular Point(SP) :The point on the surface where the incident and reflected angles are equal

$$\alpha_r = \beta_i$$

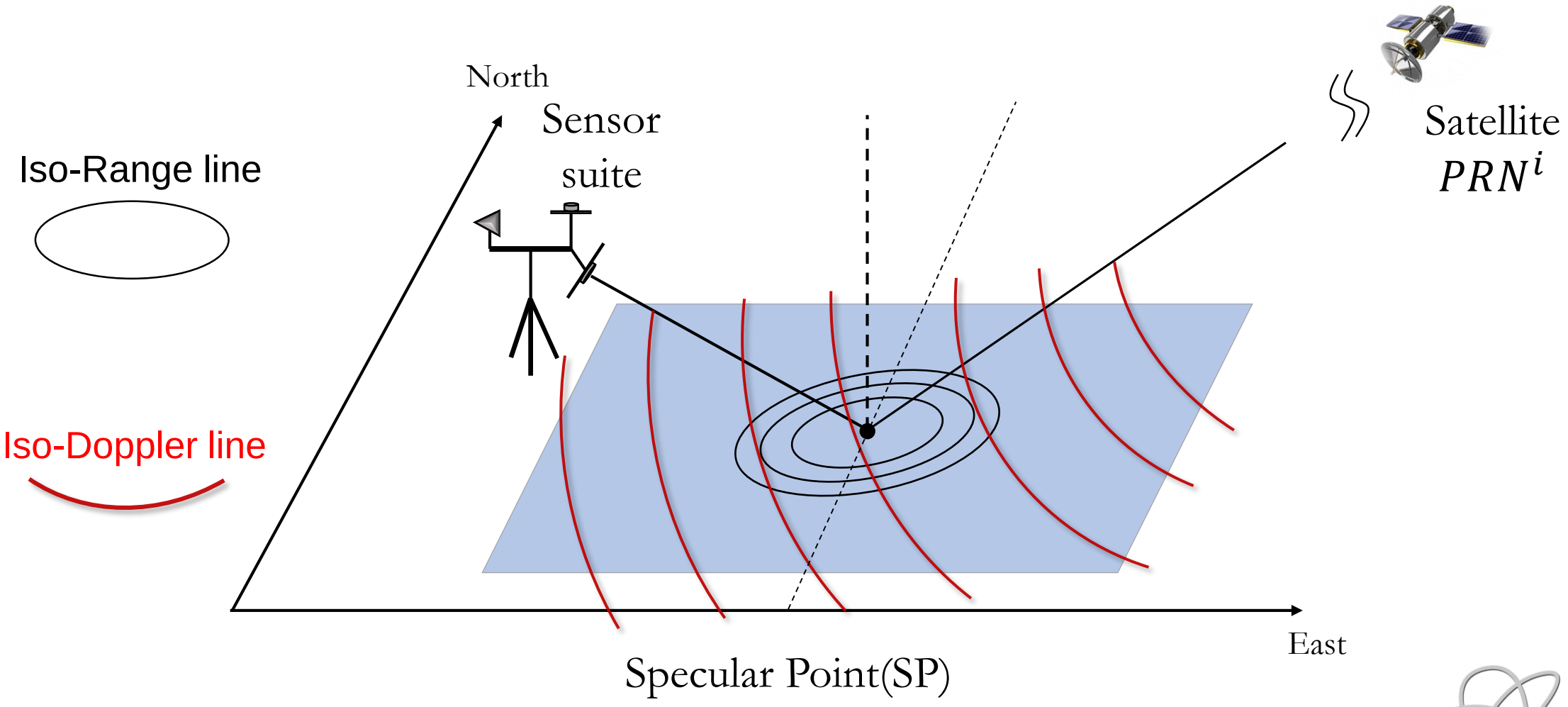
Glistening Zone





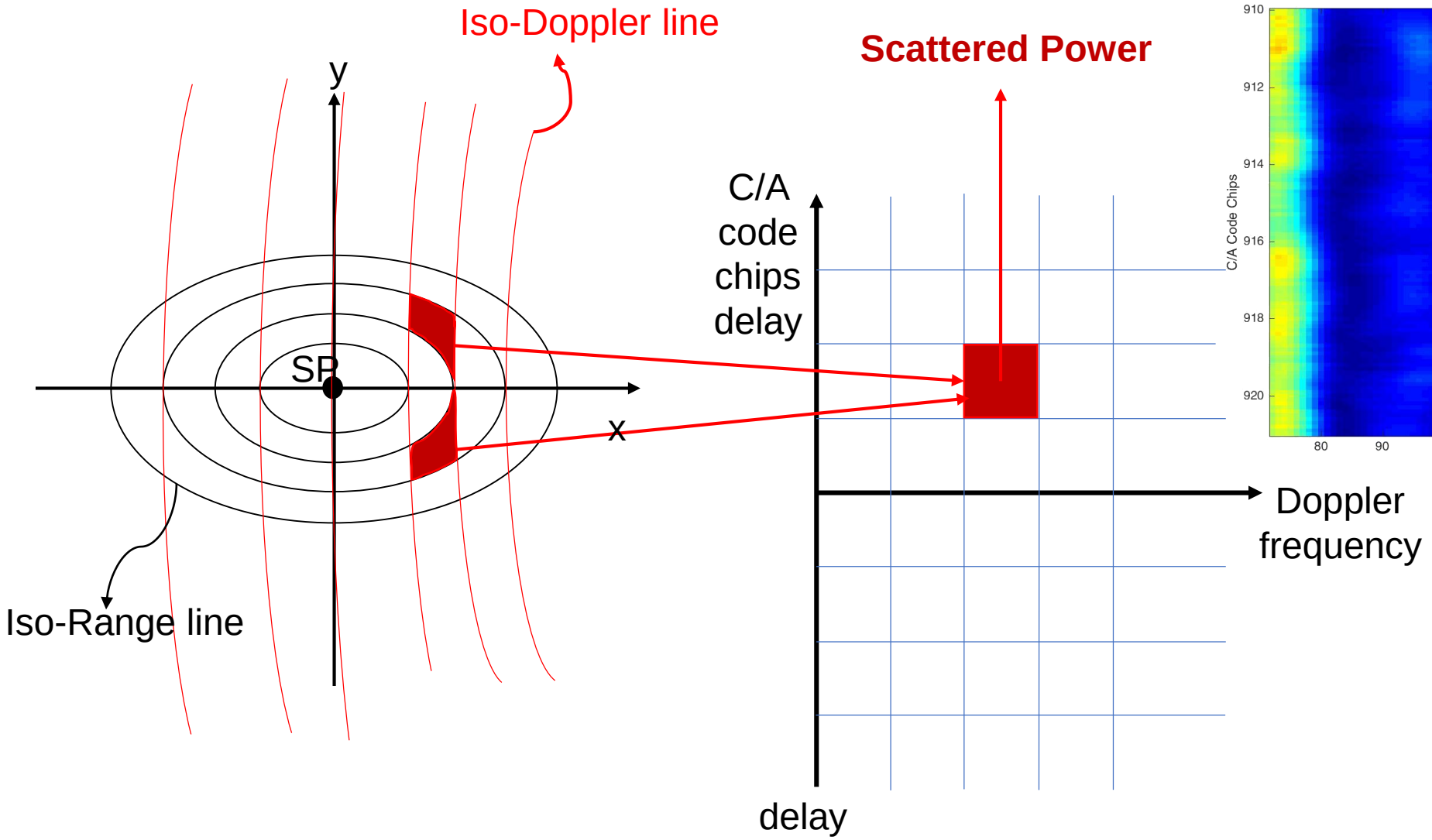


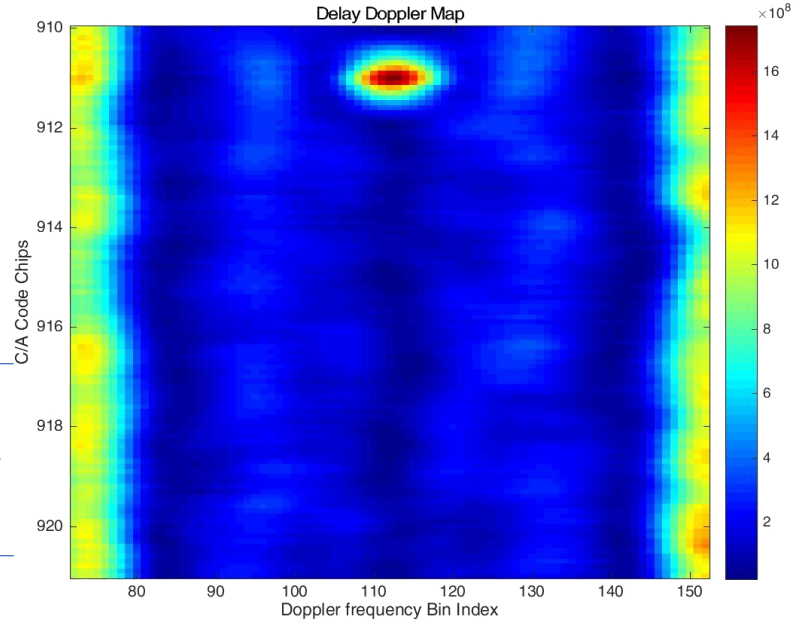
Delay Doppler Domain



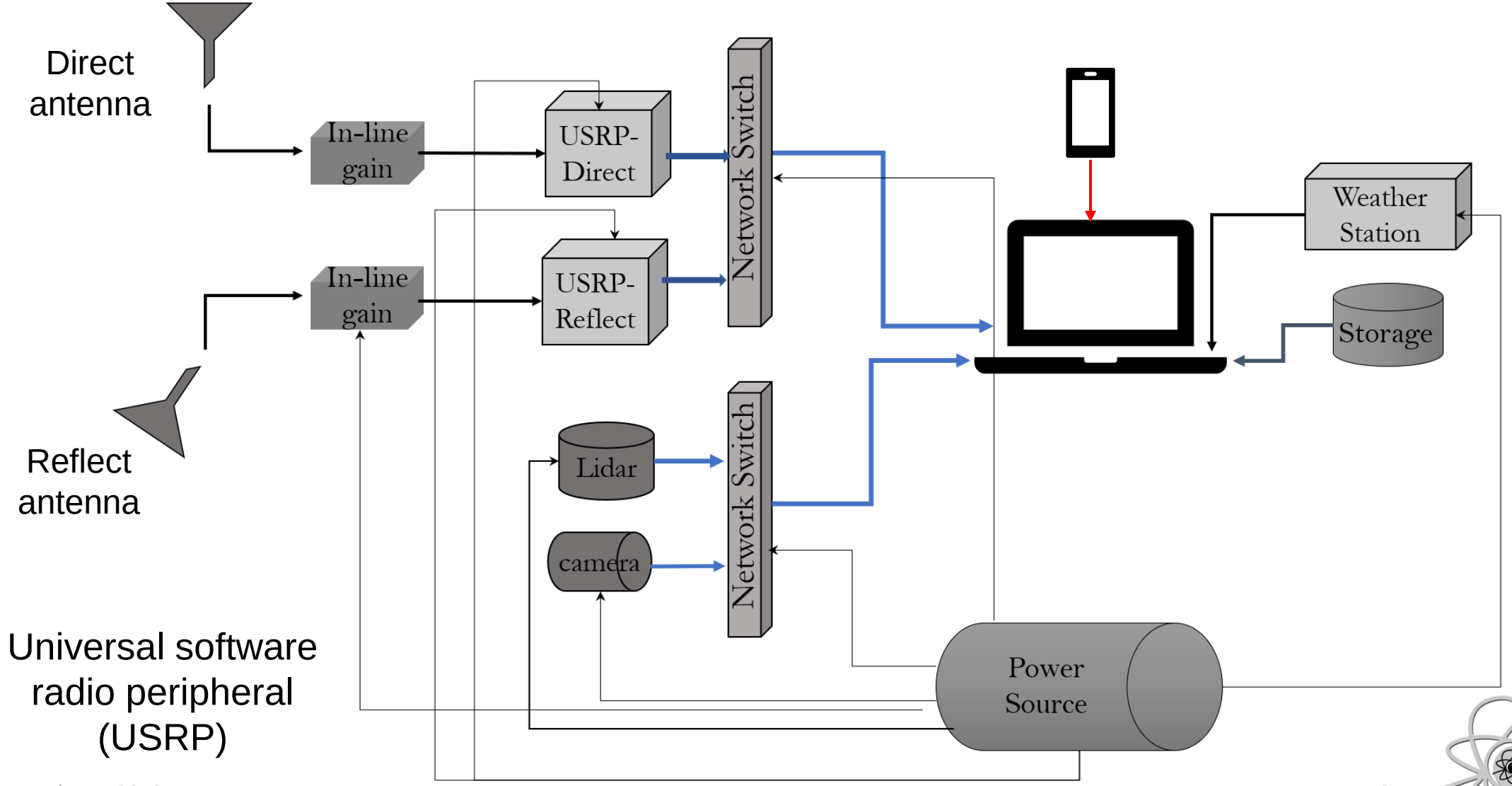
Spatial Domain and Delay Doppler domain

Space Weather Lab

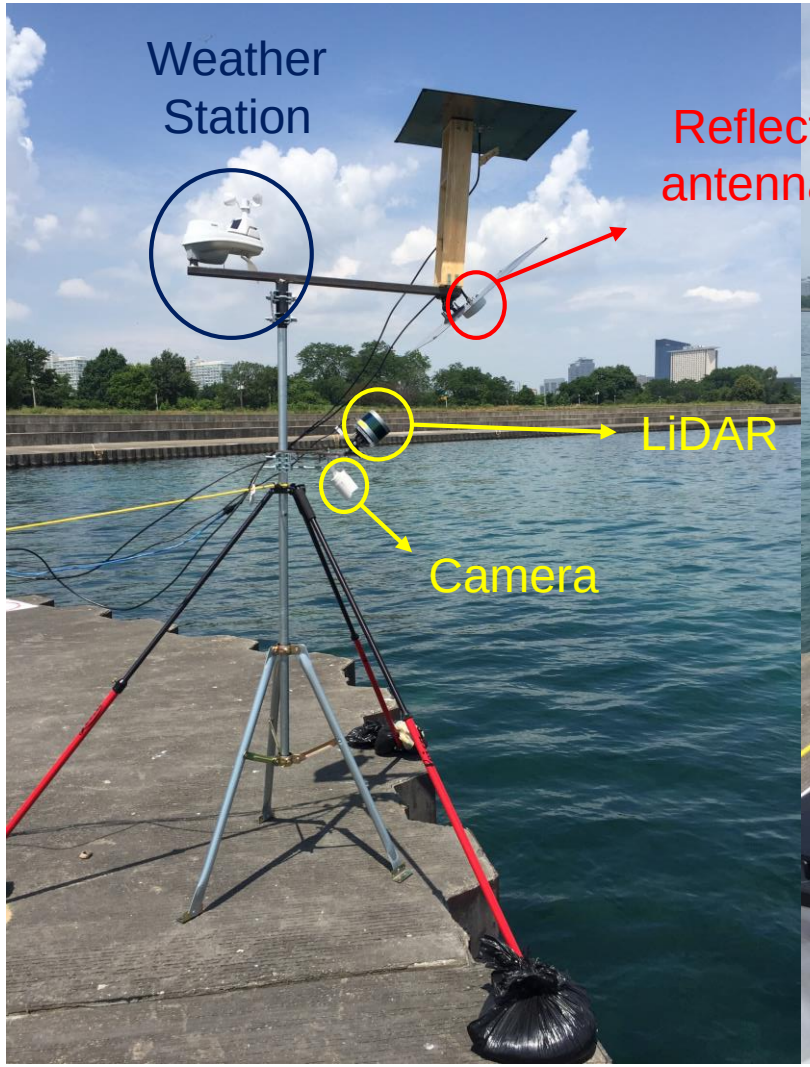




Sensor Suite



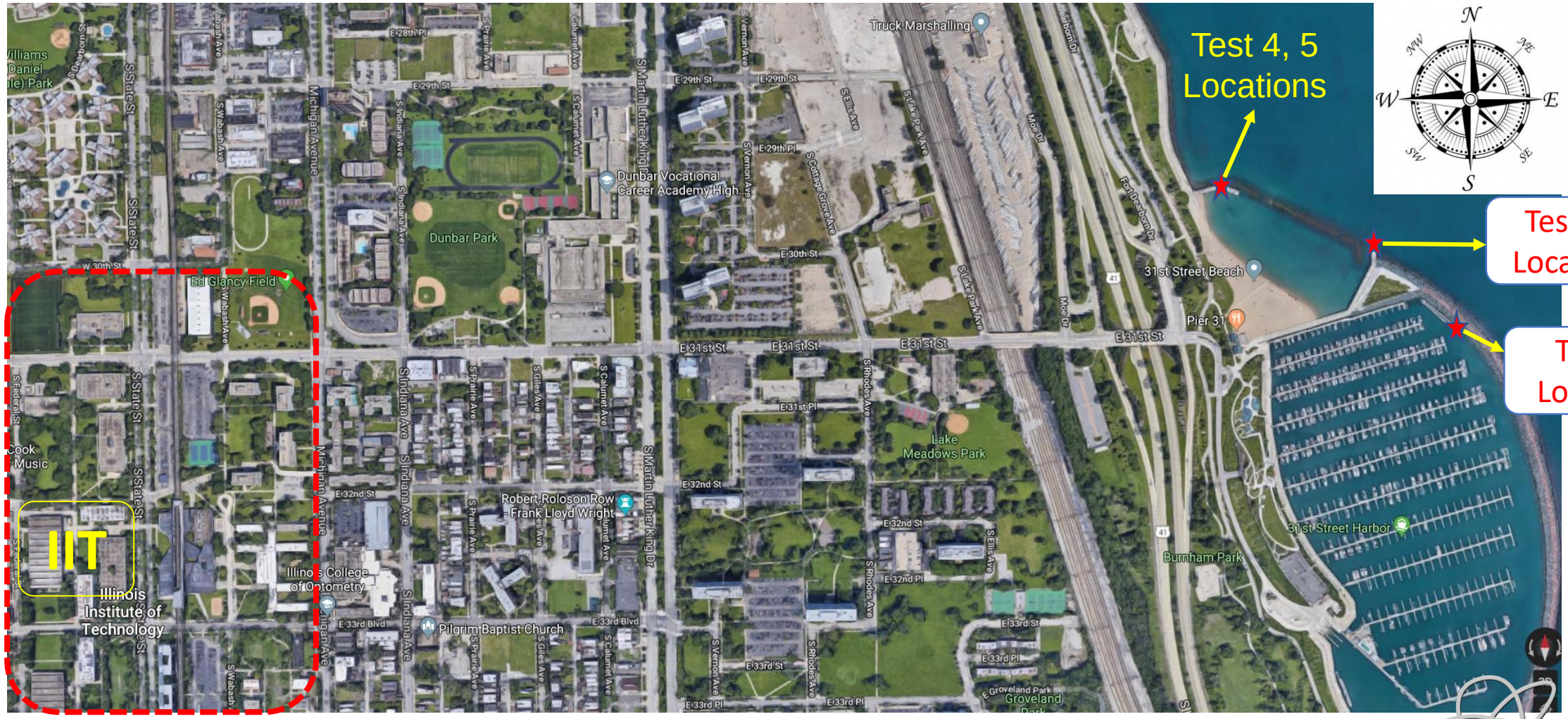
Sensor Suite



ILLINOIS INSTITUTE OF TECHNOLOGY

Test Locations

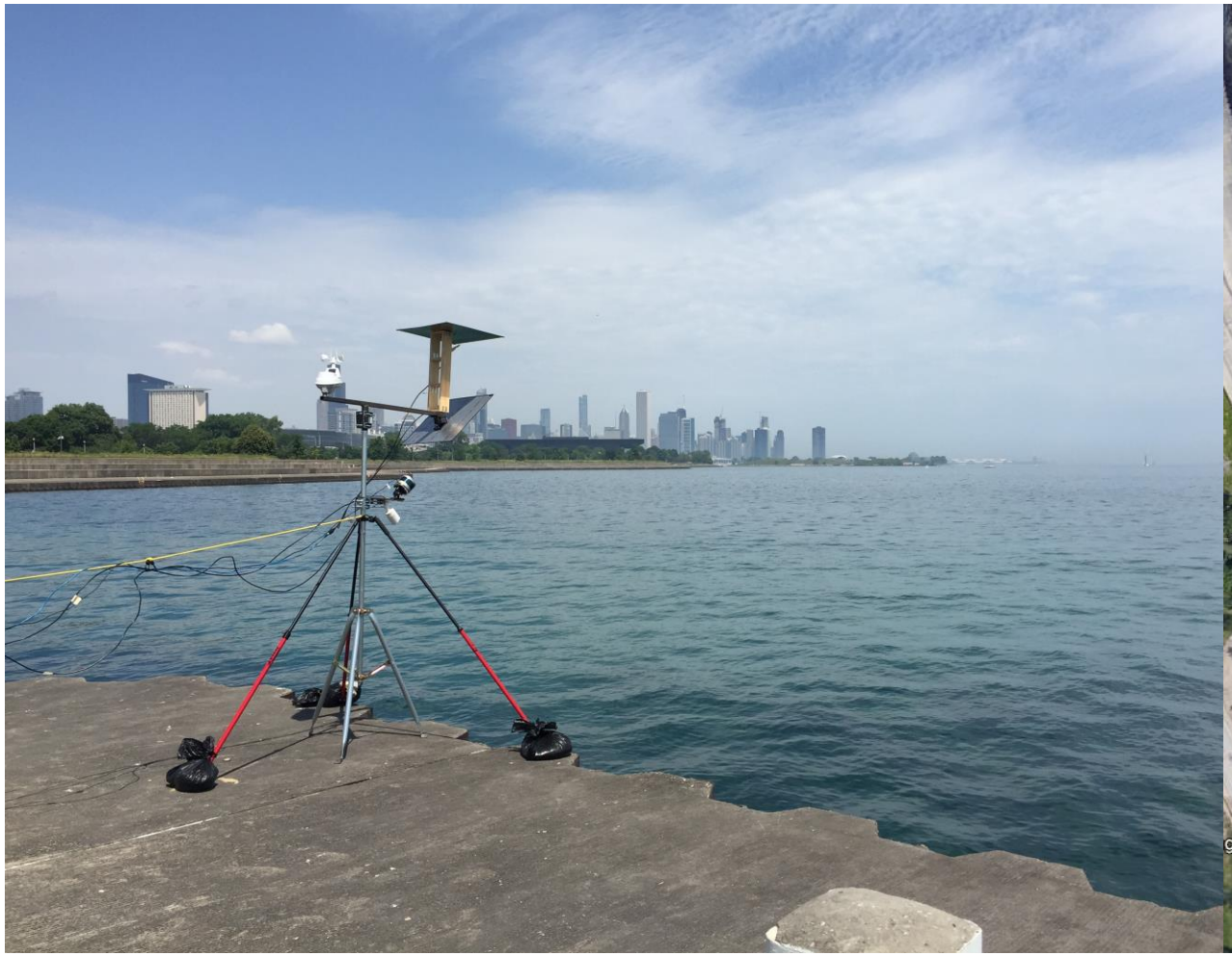
Space Weather Lab

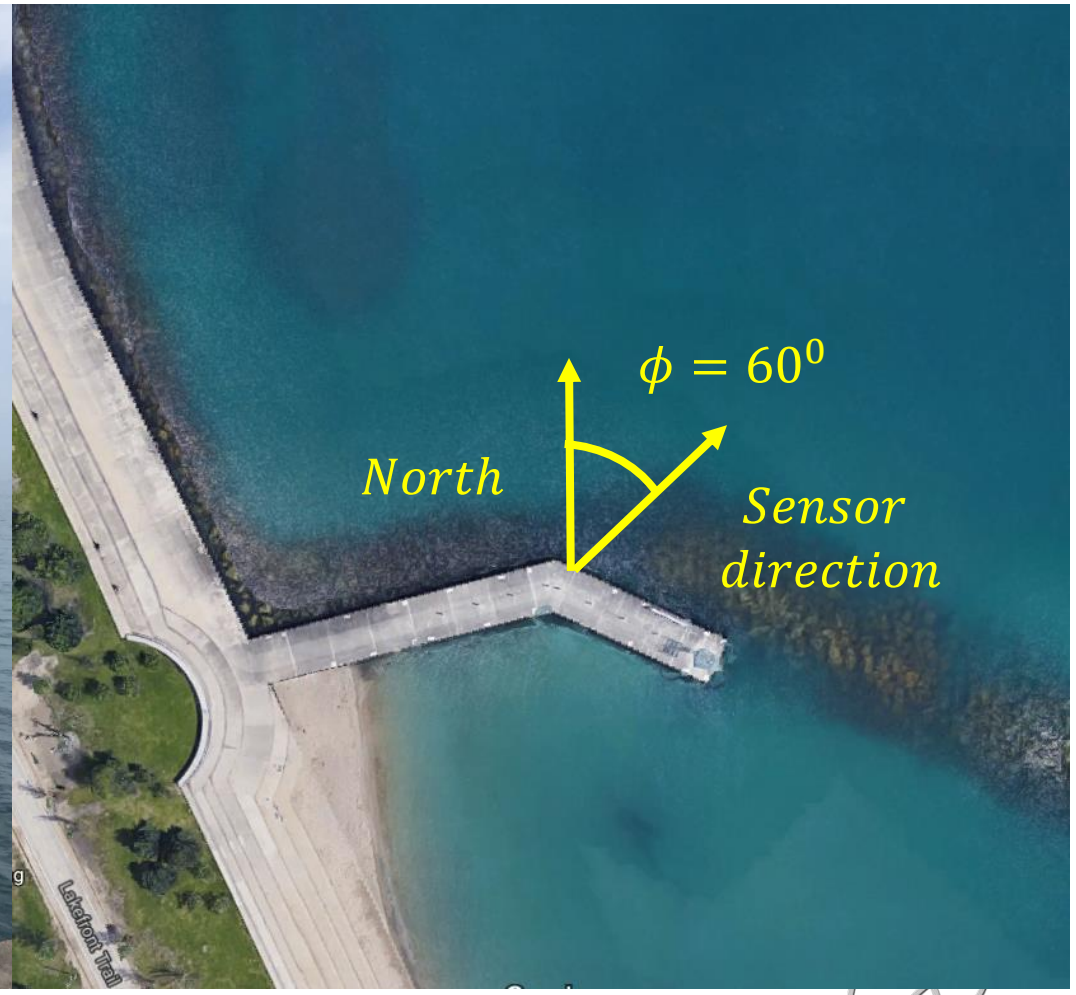


SCPNT Stanford Center for Position, Navigation and Time

Test 2 Location

Test 5 Location





ILLINOIS INSTITUTE OF TECHNOLOGY

Data Campaigns Info

Space Weather Lab

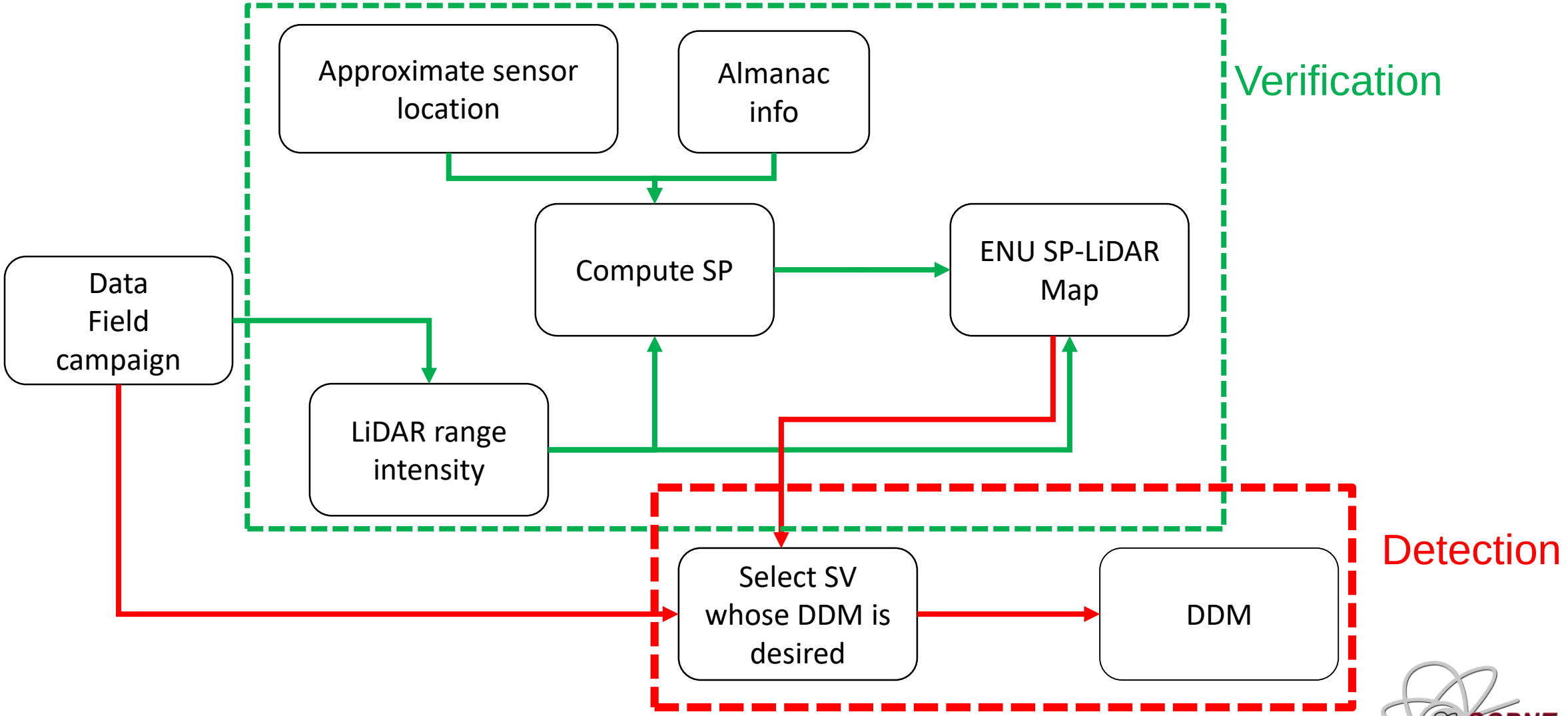
Data campaign info	Test 02	Test 05
Date	Tue Jan 23 14:35:48 2018	Thu Jul 05 12:13:28 2018
Sensor Location	Latitude: 41.8388924° N	Latitude: 41.84066 ° N
	Longitude: 87.603140° W	Longitude: 87.60698° W
	Height:3 m	Height: 3 m
Sample rate	5 MHz	5 MHz
USRP_dir RF gain	31 dB	31 dB
USRP_ref RF gain	31 dB	31 dB
USRP_dir inline gain	0 dB	30 dB
USRP_ref inline gain	30 dB	40 dB
Look direction(azimuth angle)	208^0 (southwest)	60° (northeast)
Condition	**Ice**	**Water**

SCPNT Stanford Center for Position, Navigation and Time

Post-Processing

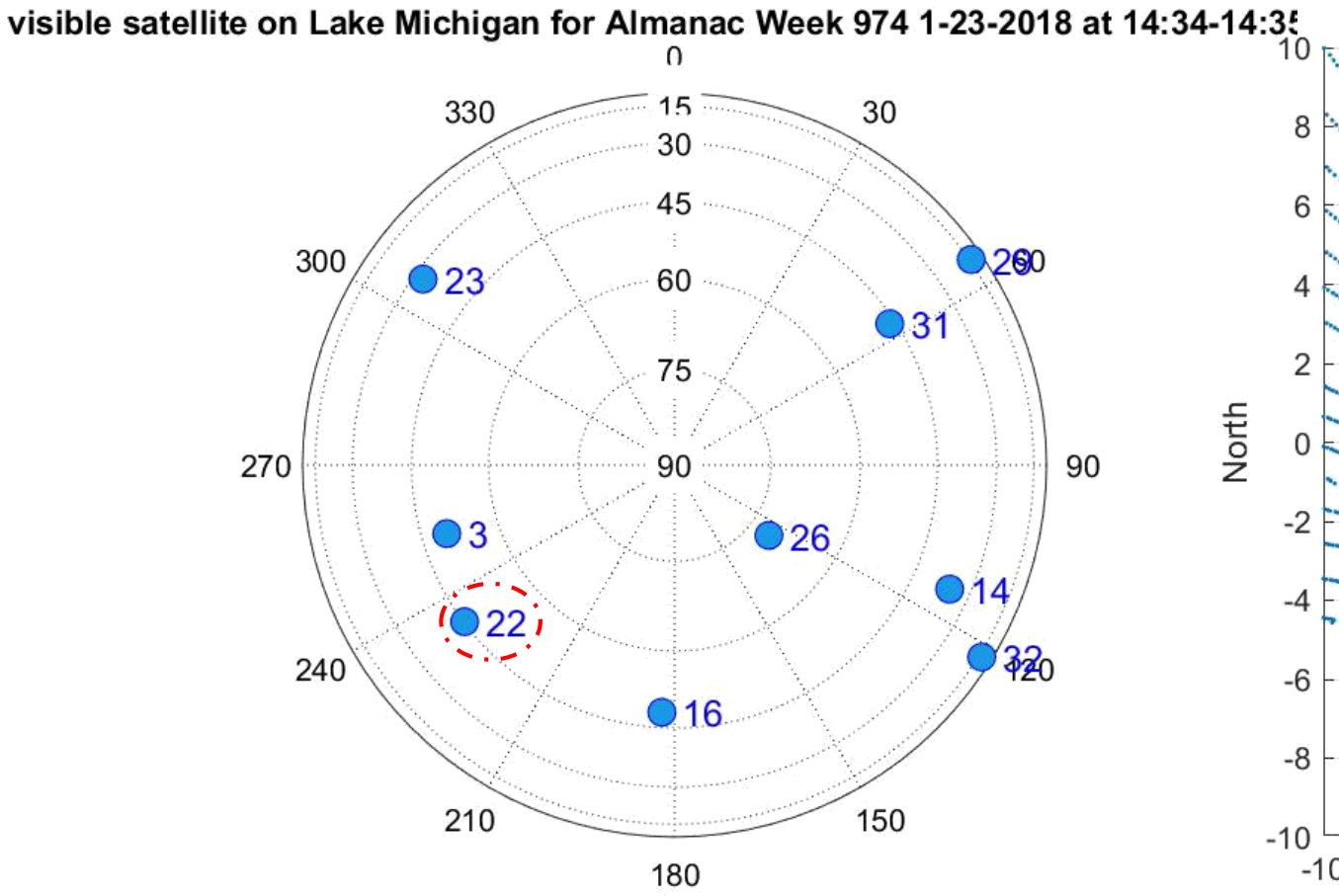
- Verification:
  - Evaluate surface condition with weather station.
  - Determine where SPs are.
  - Compare SPs with LiDAR.
- Detection:
  - DDM for SP on the water/ice.

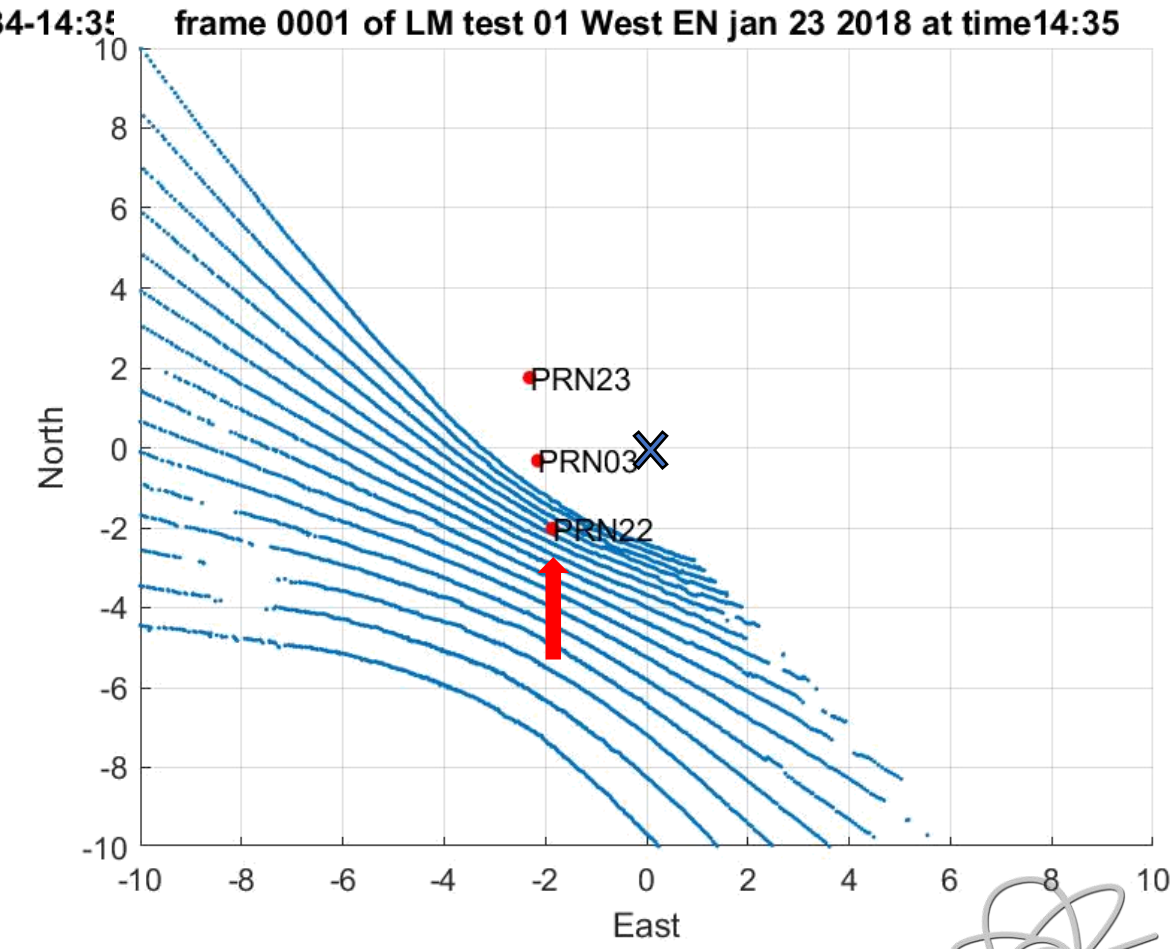
Post-Processing



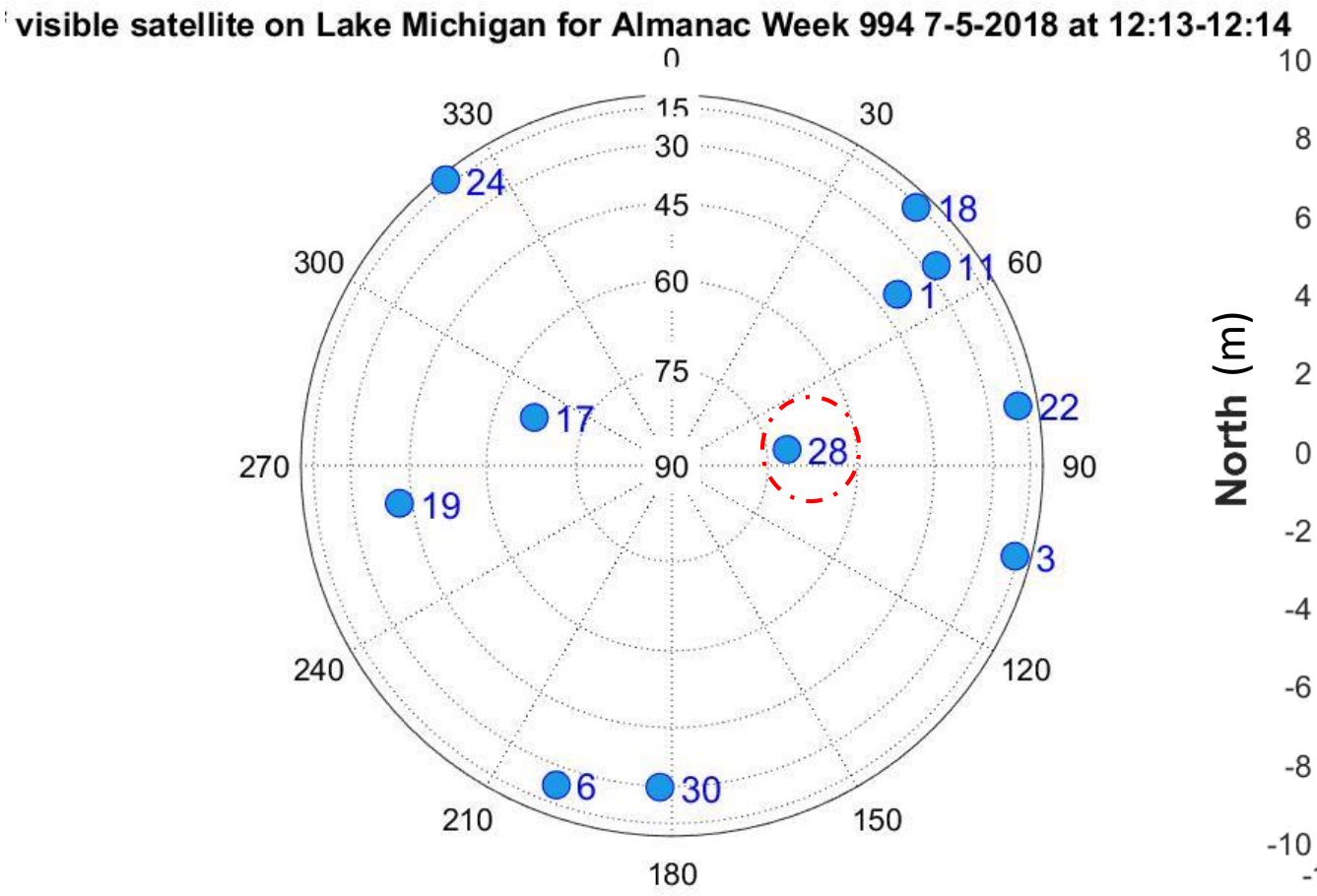
Sky Plot and SP-LiDAR, Test 2 (ice)

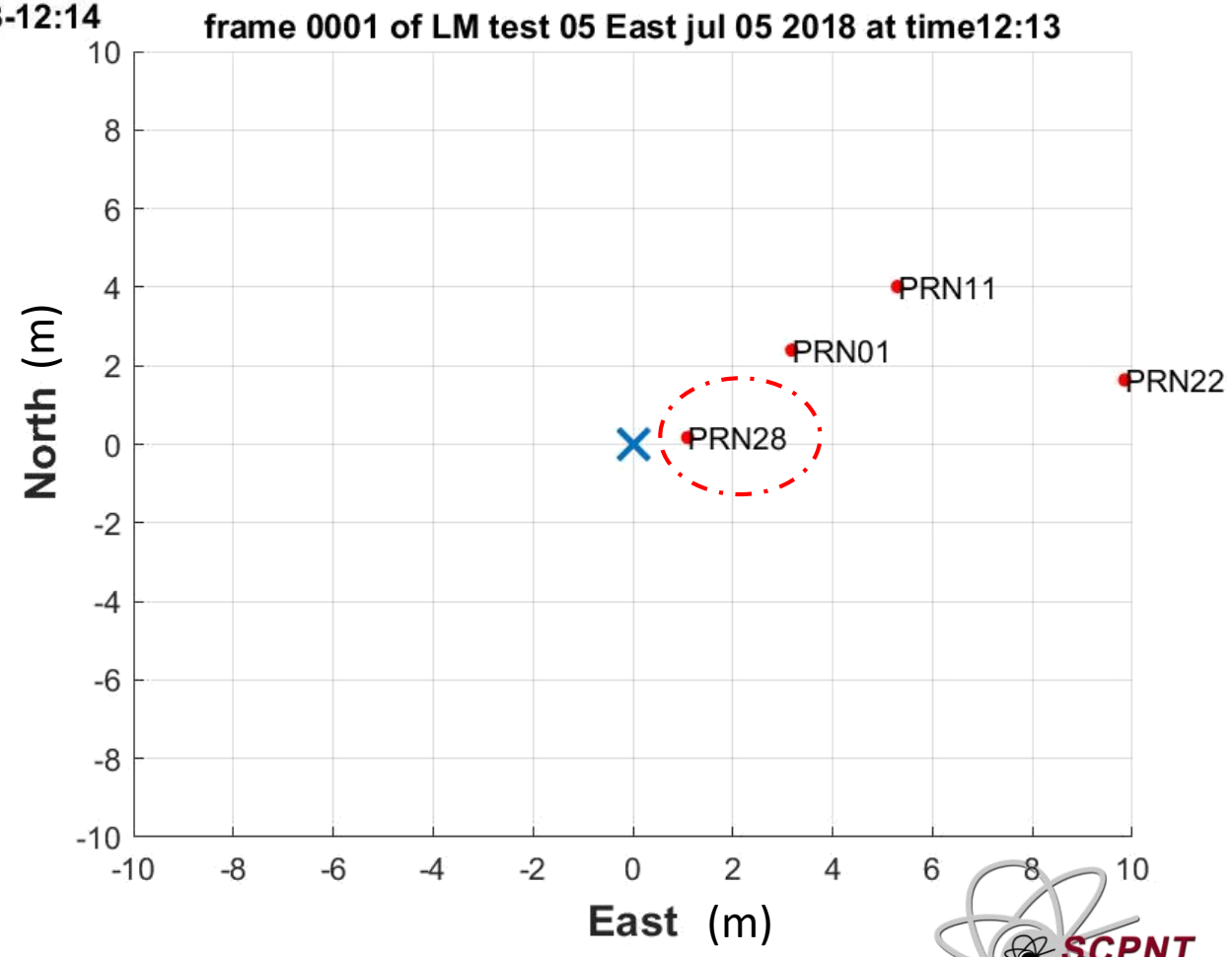
Space Weather Lab



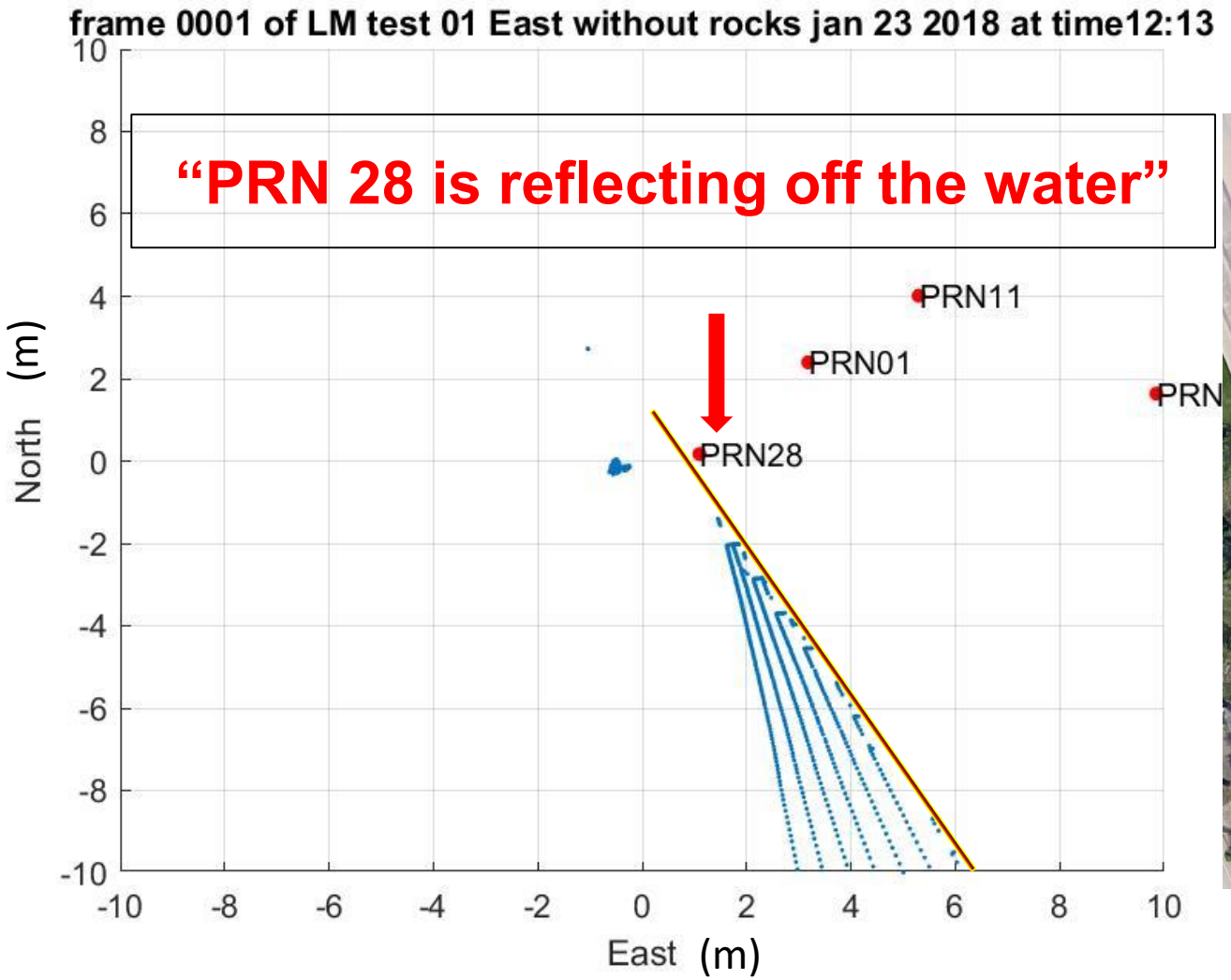


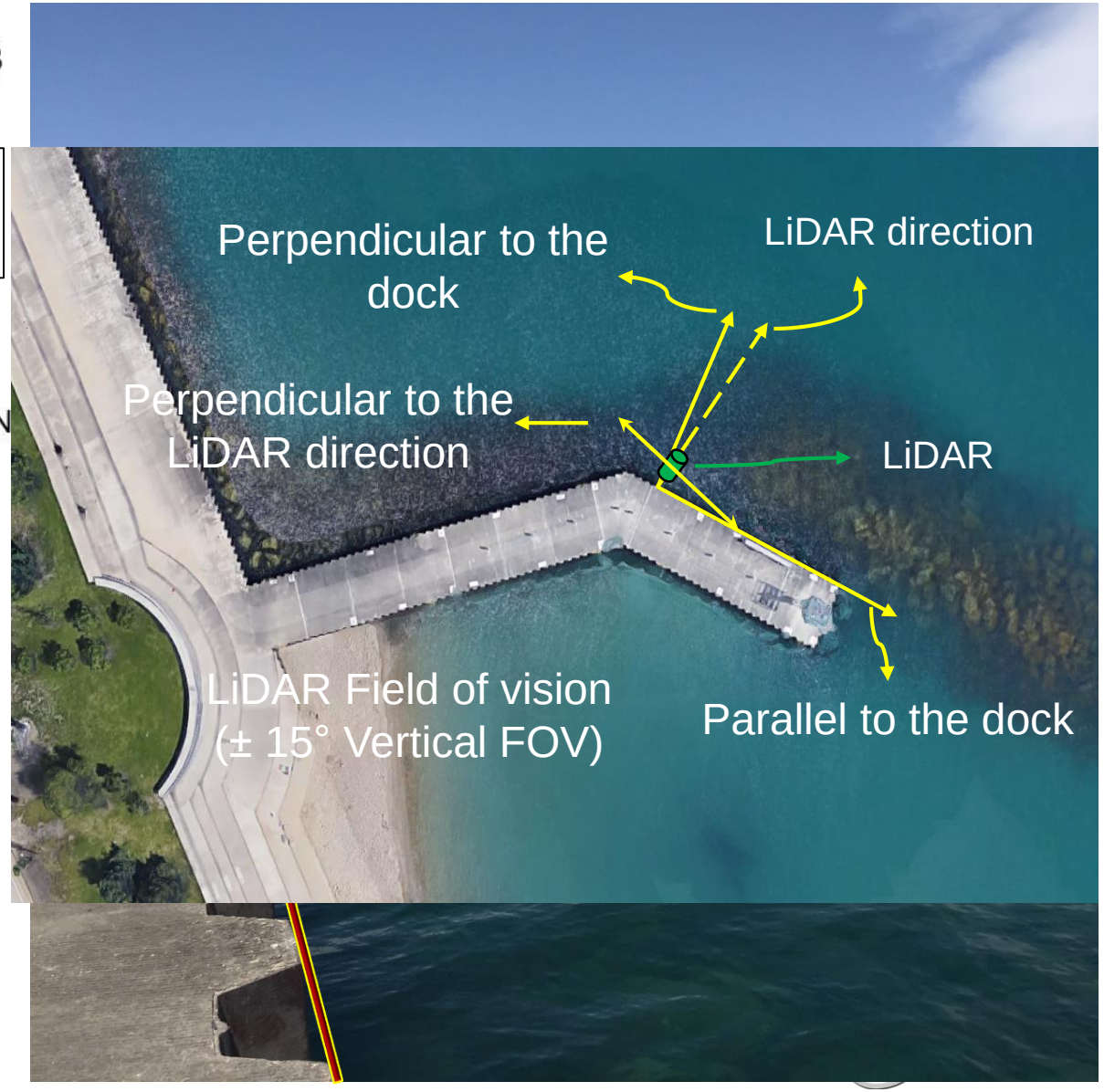
Sky Plot and SP, Test 5 (water)





SP-LiDAR Map


frame 0001 of LM test 01 East without rocks jan 23 2018 at time12:13
"PRN 28 is reflecting off the water"
PRN11
PRN01
PRN28
North (m)
East (m)
10
8
6
4
2
0
-2
-4
-6
-8
-10
-10
-8
-6
-4
-2
0
2
4
6
8
10

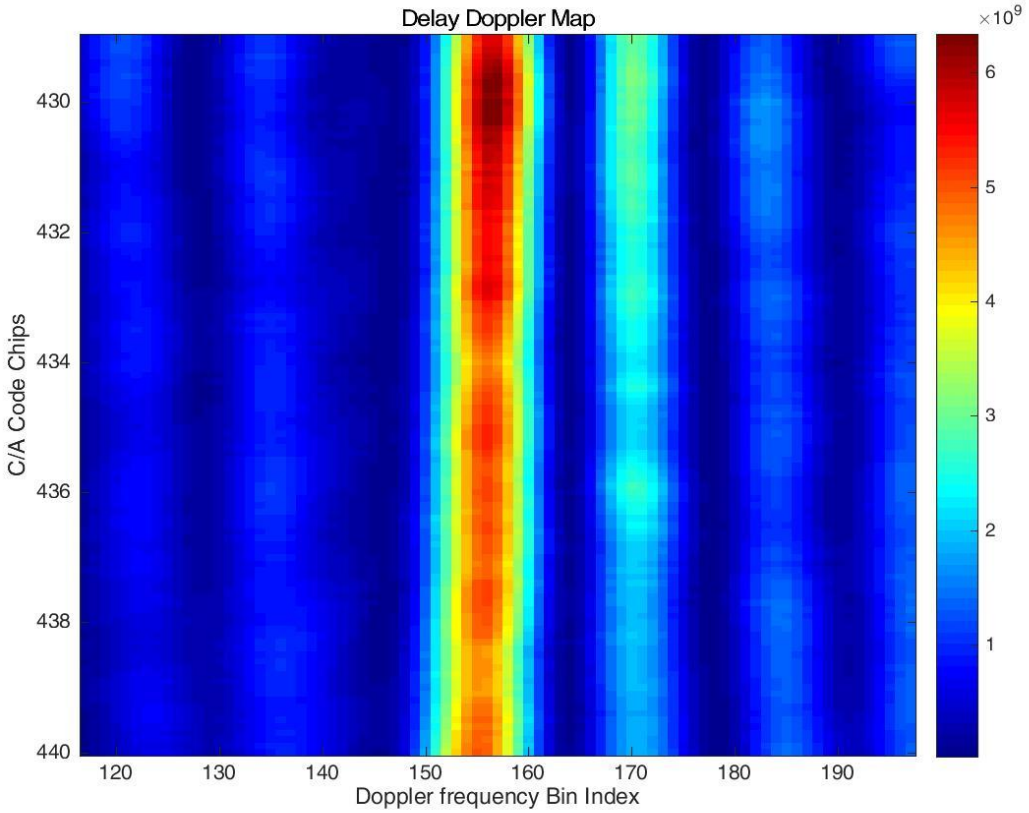

Perpendicular to the dock
LiDAR direction
Perpendicular to the LiDAR direction
LiDAR
LiDAR Field of vision (± 15° Vertical FOV)
Parallel to the dock

Incoherent DDM for PRN 28 Test 5 (water), Method 1

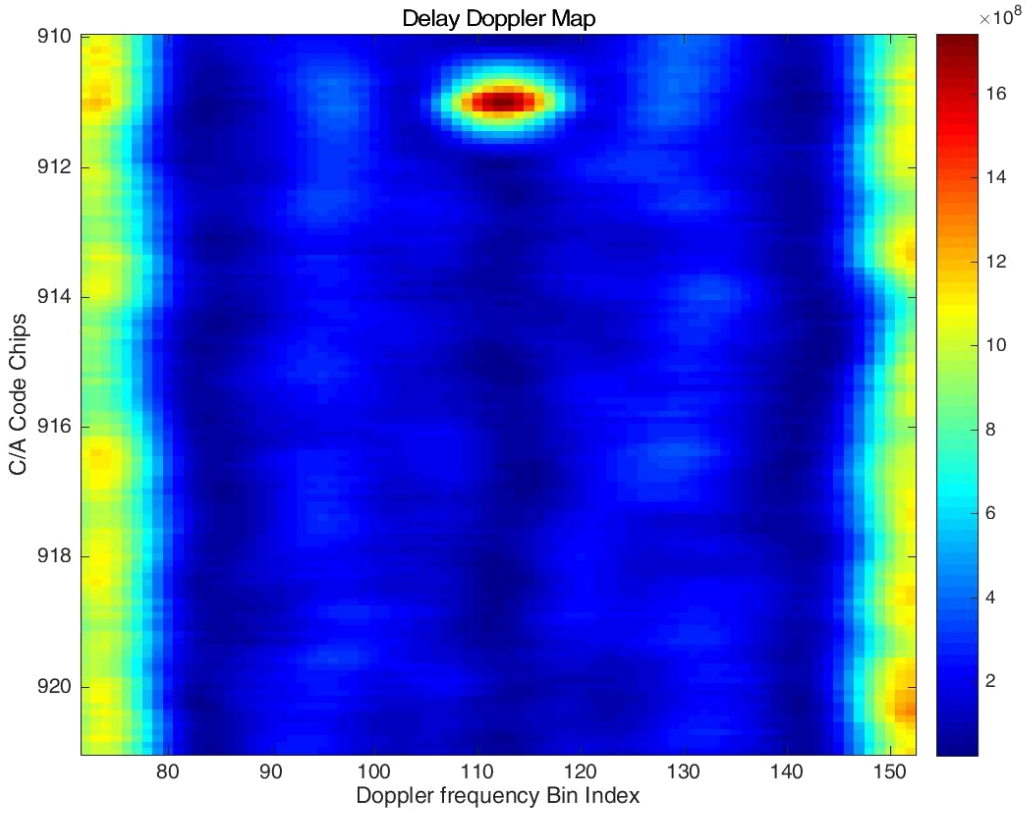
ILLINOIS INSTITUTE OF TECHNOLOGY

Space Weather Lab

Reflected Signal



Direct Signal



[7]:R.Parvizi, H. S. Zadeh, L. Pan, B. Pervan, S. Datta-Barua, " **Multi-sensor Study of Lake Michigan's Surface using GNSS-Reflectometry***", Proceedings of the 29th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2018)*, Miami, Florida, September 2018

SCPNT Stanford Center for Position, Navigation and Time

DDM-Processing

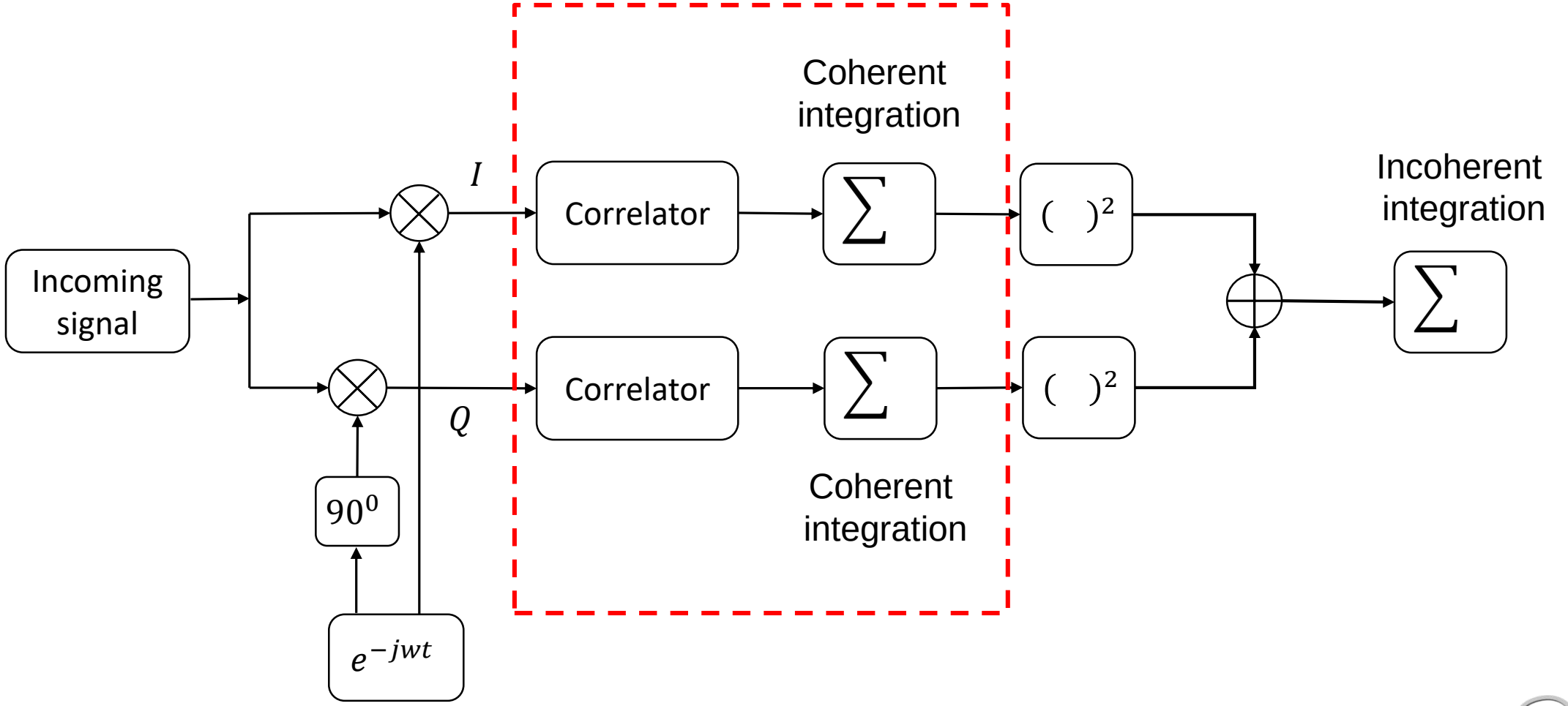
Problem:

- Weak and noisy signal: direct signal not acquired by SDR, reflected signal band unexplained.

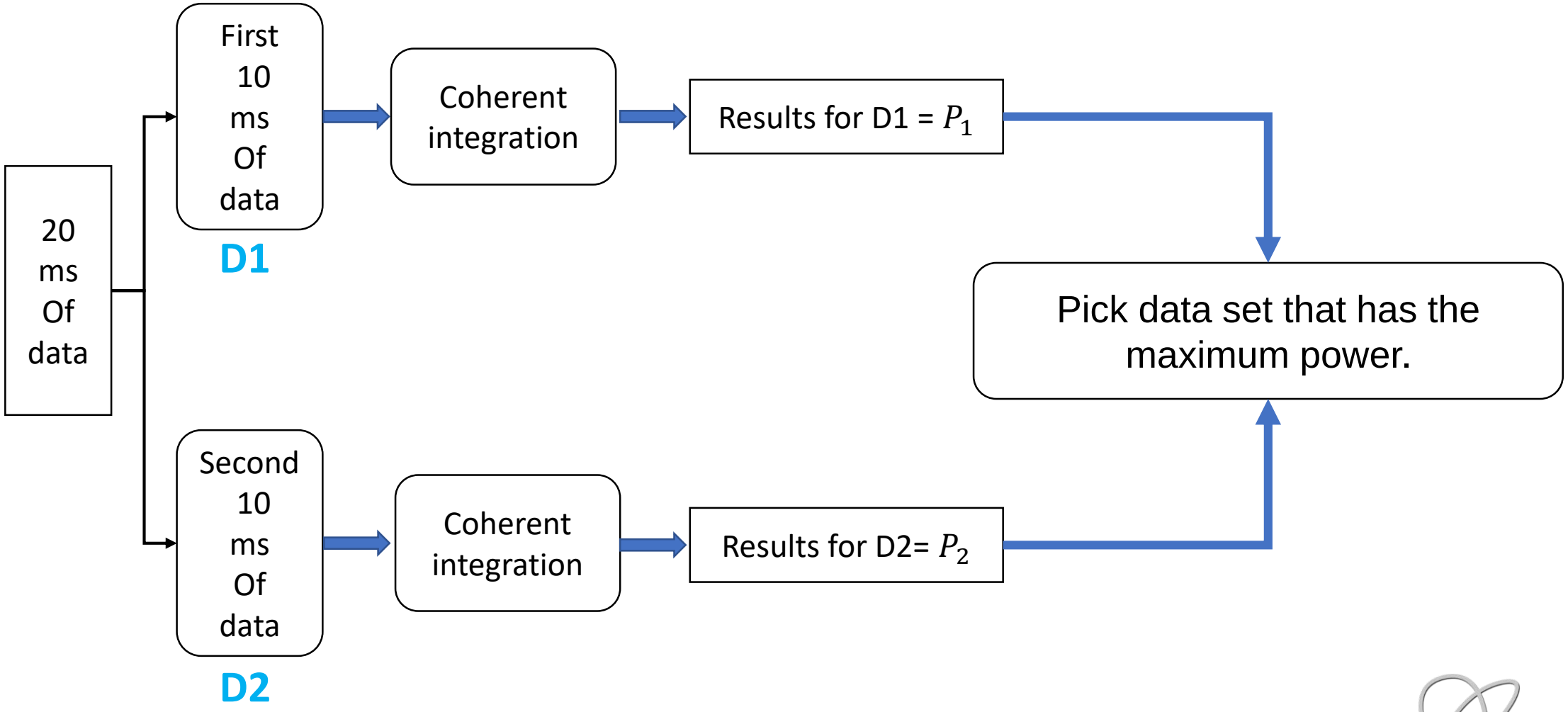
Solution:

- Use auto-correlation peak to test the direct signal for acquisition.
  - Method 2: Incoherent integration.
    - 20 ms, 100 ms, 500 ms and 1s
  - Method 3: Coherent integration
    - Coherently 10 ms
  - Method 4: Differentially coherent integration
- Generate reflected DDMs for the Method (4) that successfully acquires direct signals.

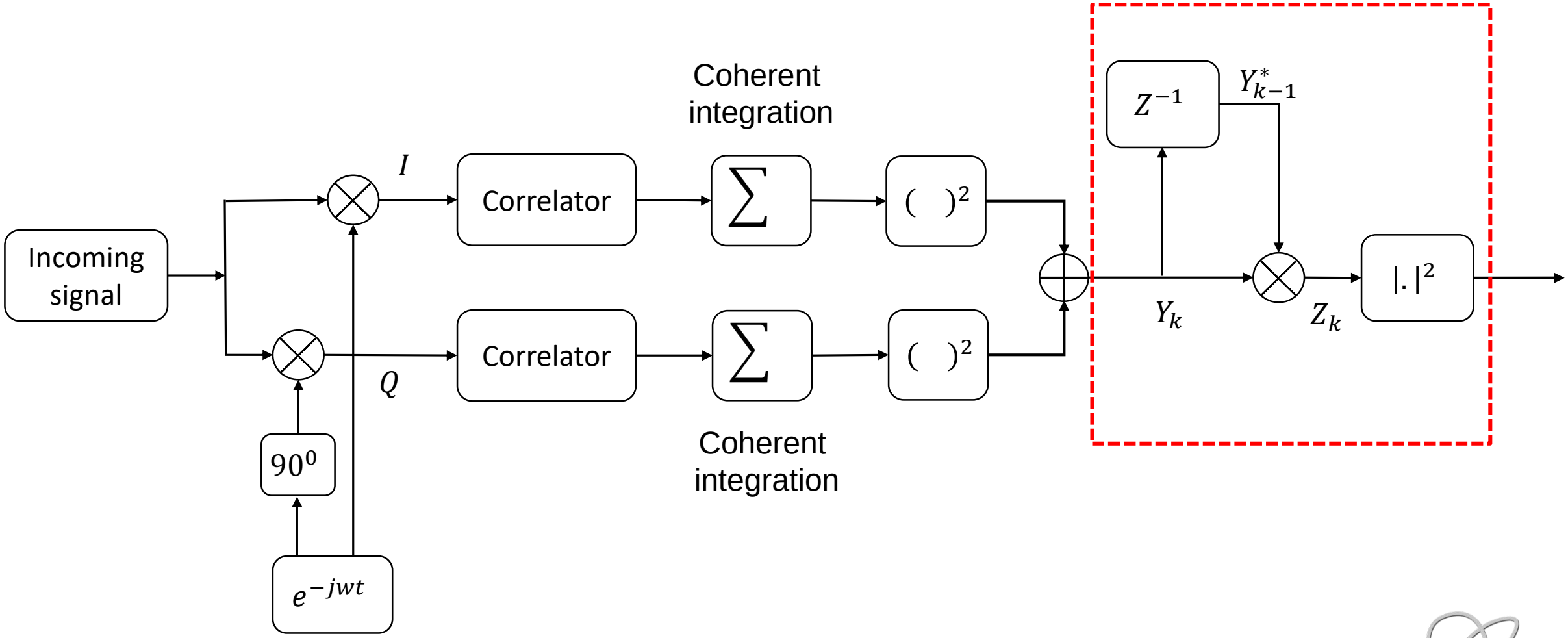
Method 2: Incoherent DDM Processing



Method 3: Coherent DDM Processing



Method 4: Coherent differential integration

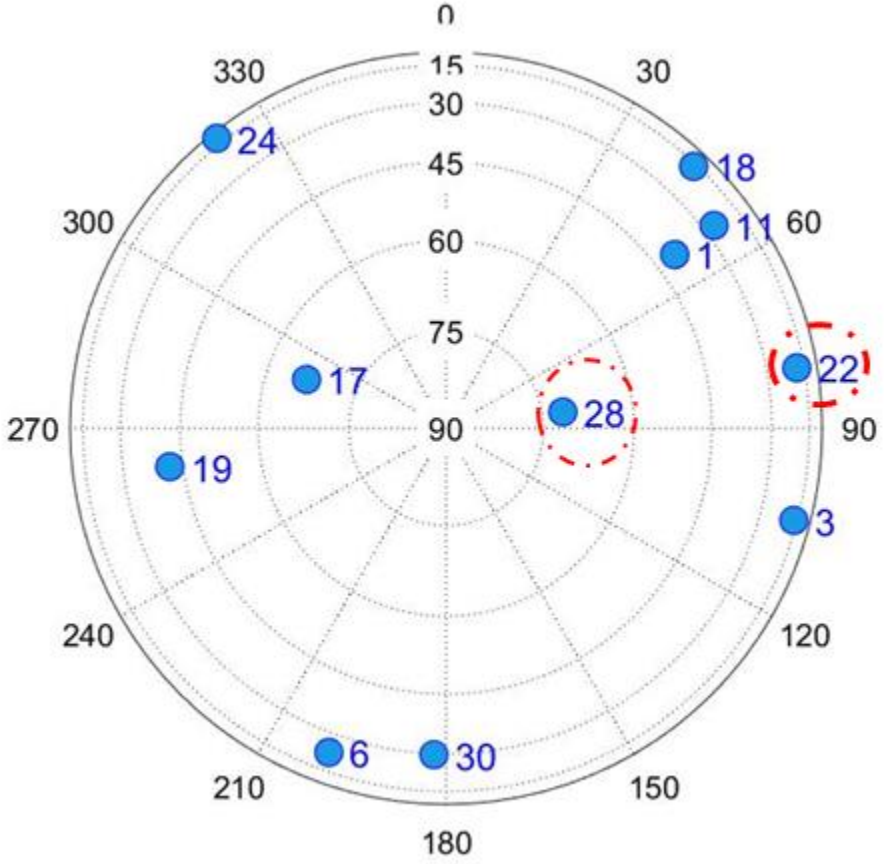


M. H. Zarrabizadeh and E. S. Sousa, "A Differentially Coherent PN Code Acquisition Receiver for CDMA Systems", IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. 45, NO. 11, NOVEMBER 1997

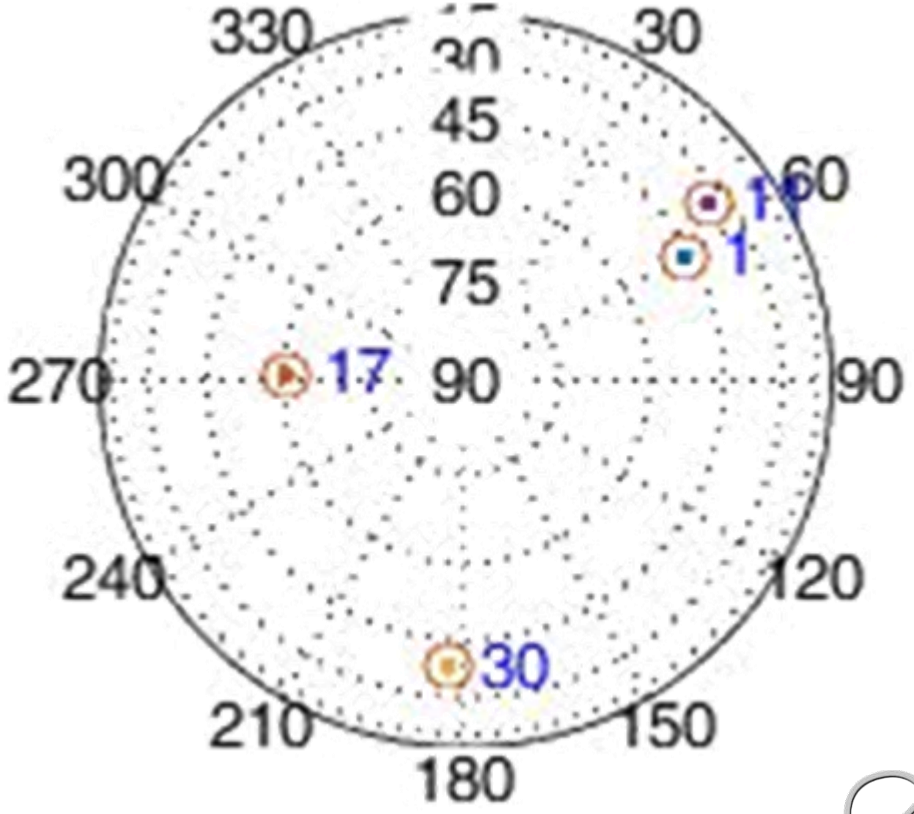
Evaluate Methods

for Direct signal at high and low elevations, Test 5

SKY plot
based on almanac info

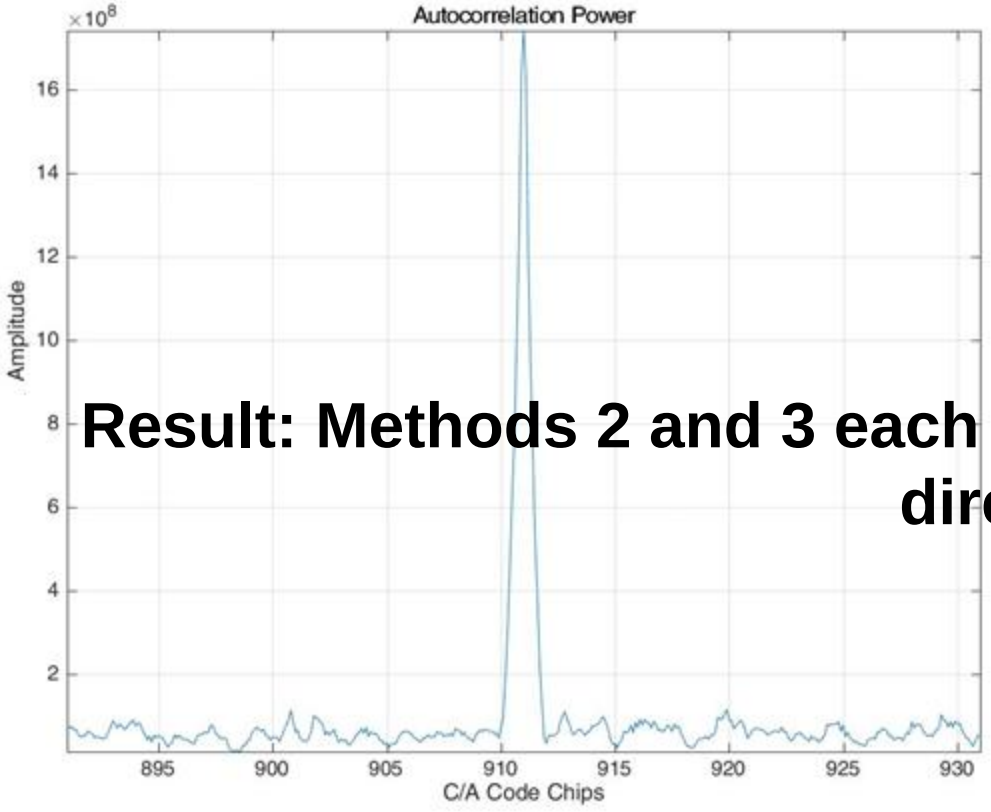


SKY plot
based on real GPS data

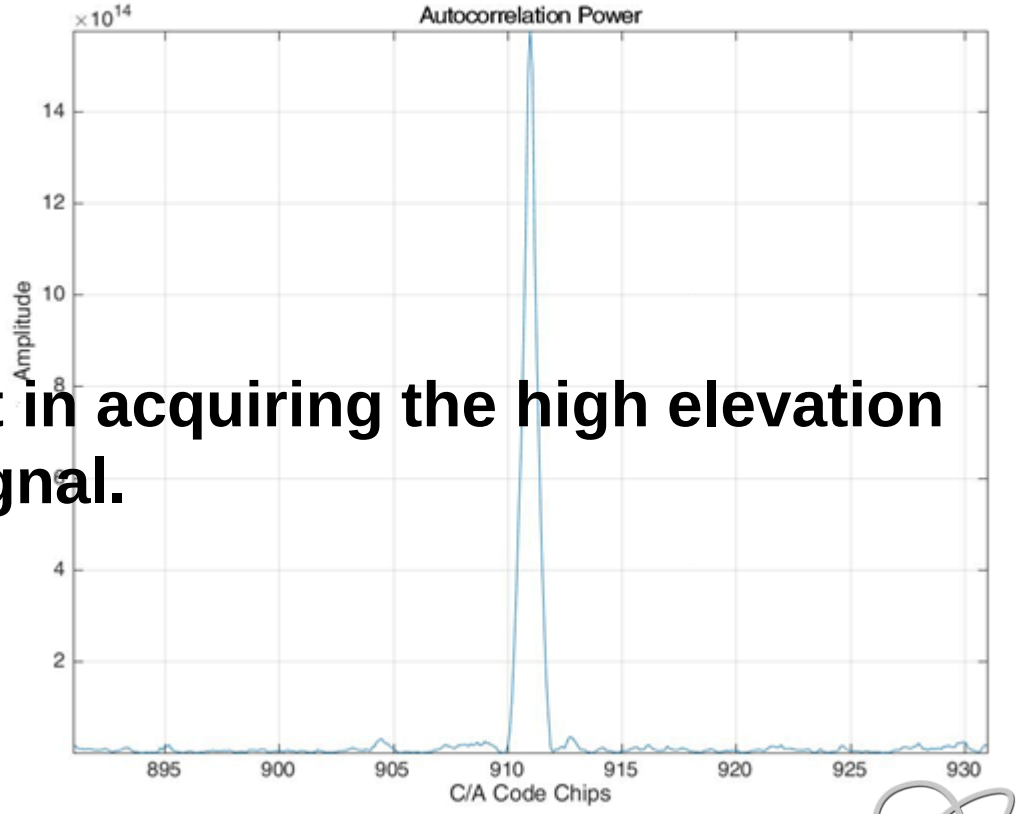


Autocorrelation of Direct Signal, PRN 28

Incoherent integration, method 2



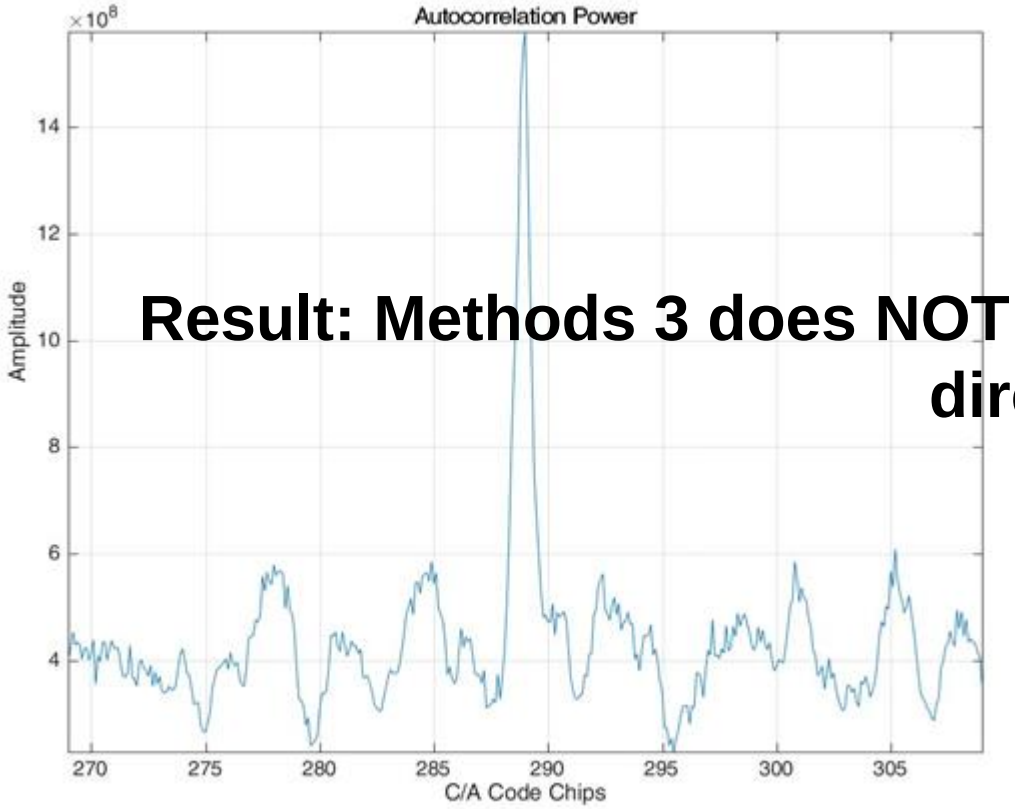
Coherent integration, method 3



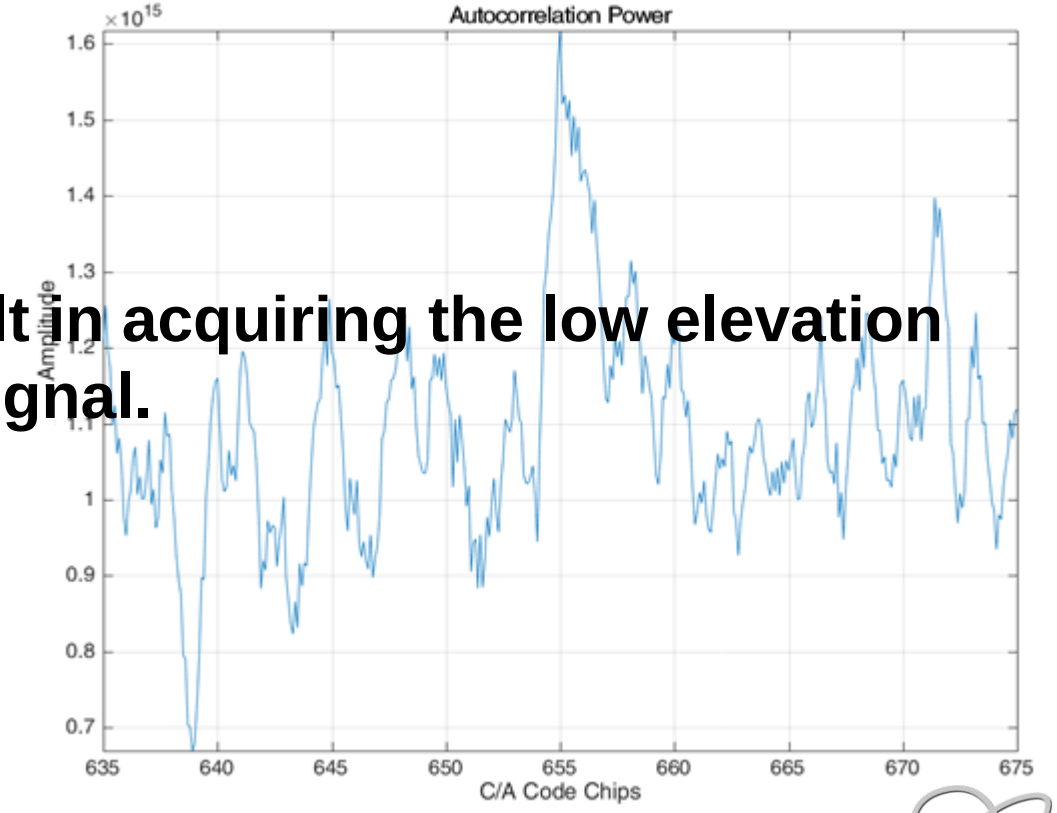
Result: Methods 2 and 3 each result in acquiring the high elevation direct signal.

Low elevation satellite, PRN 22, Direct signal

Incoherent integration, method 2



Coherent integration, method 3



Result: Methods 3 does NOT result in acquiring the low elevation direct signal.

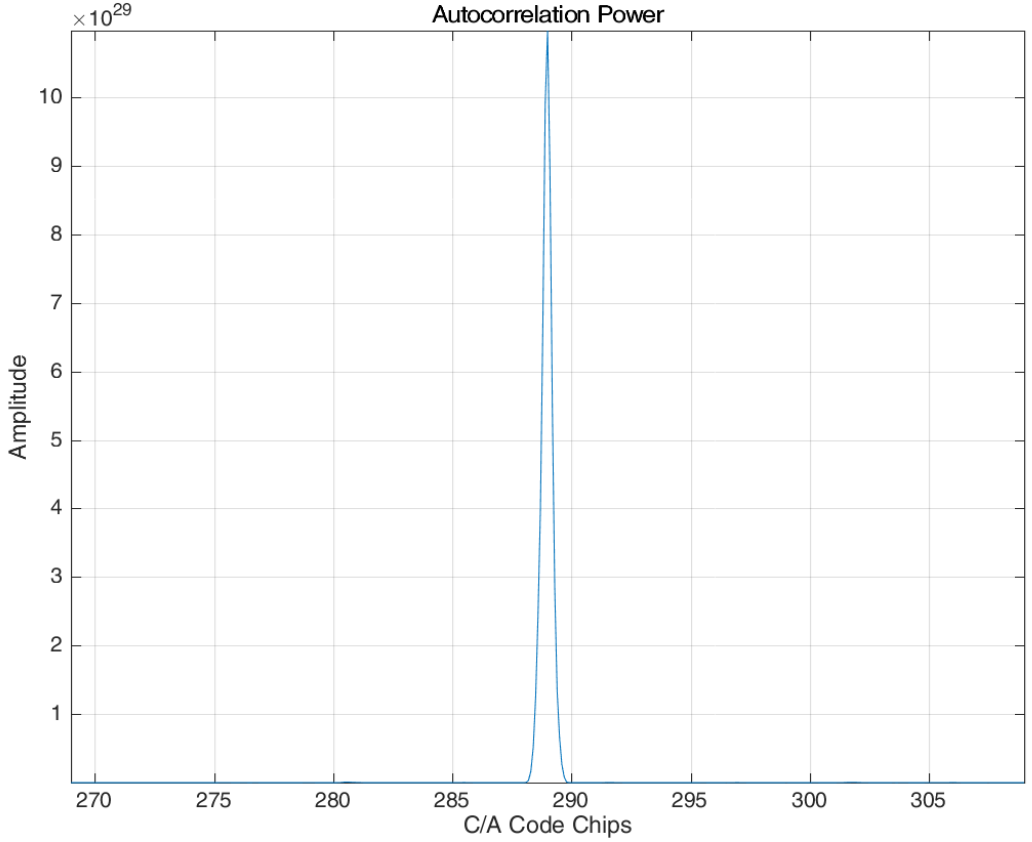
Low elevation satellite, PRN 22, Direct signal

Space Weather Lab

Result: Method 4 results in acquiring the low elevation direct signal and high elevation direct signal (not shown).

Next: Use Method 4 to generate DDM for the reflected signal.

Coherent differential integration, method 4



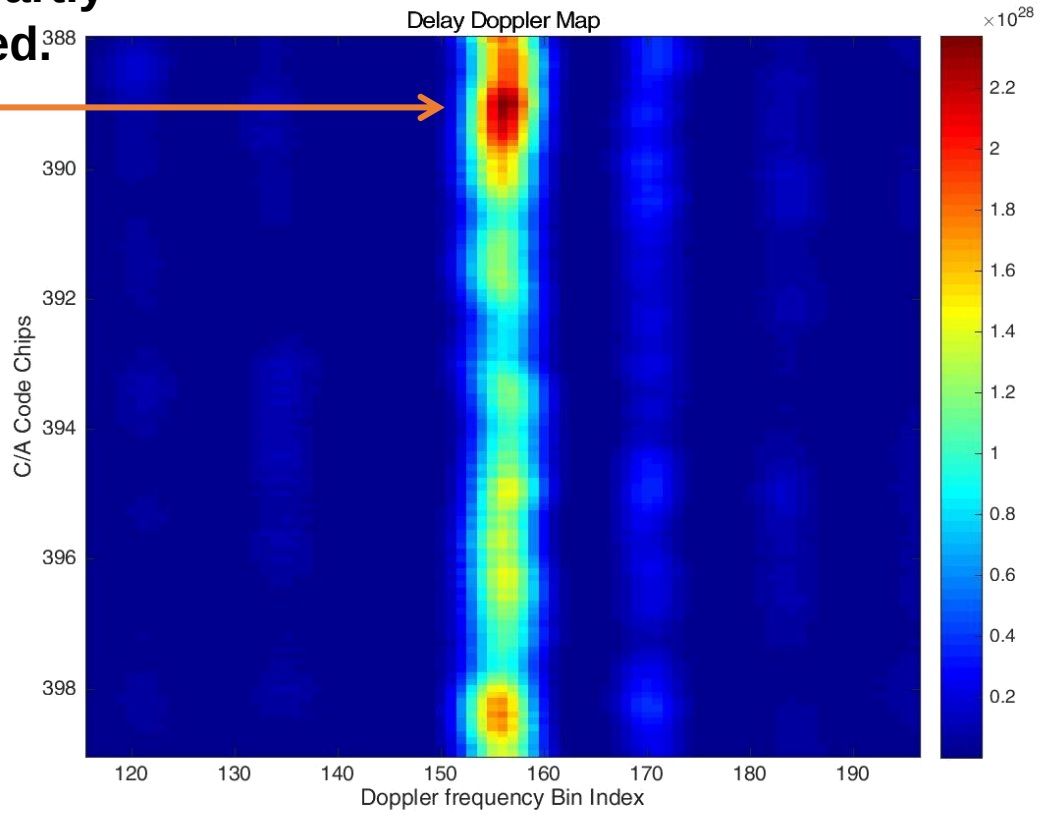
Method 4: Coherent differential DDM for PRN 28 Test 5 (water)

ILLINOIS INSTITUTE OF TECHNOLOGY

Space Weather Lab

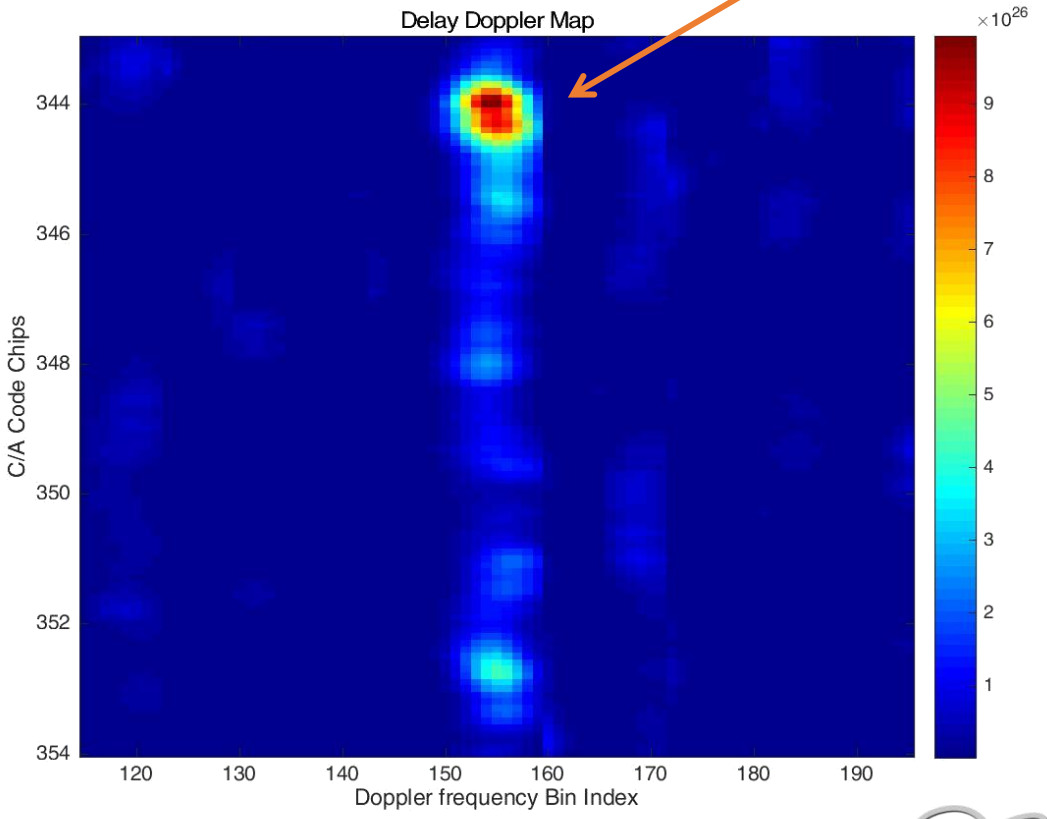
Band in C/A space partly mitigated.

Reflected Signal



Direct Signal

Acquired in C/A and Doppler.



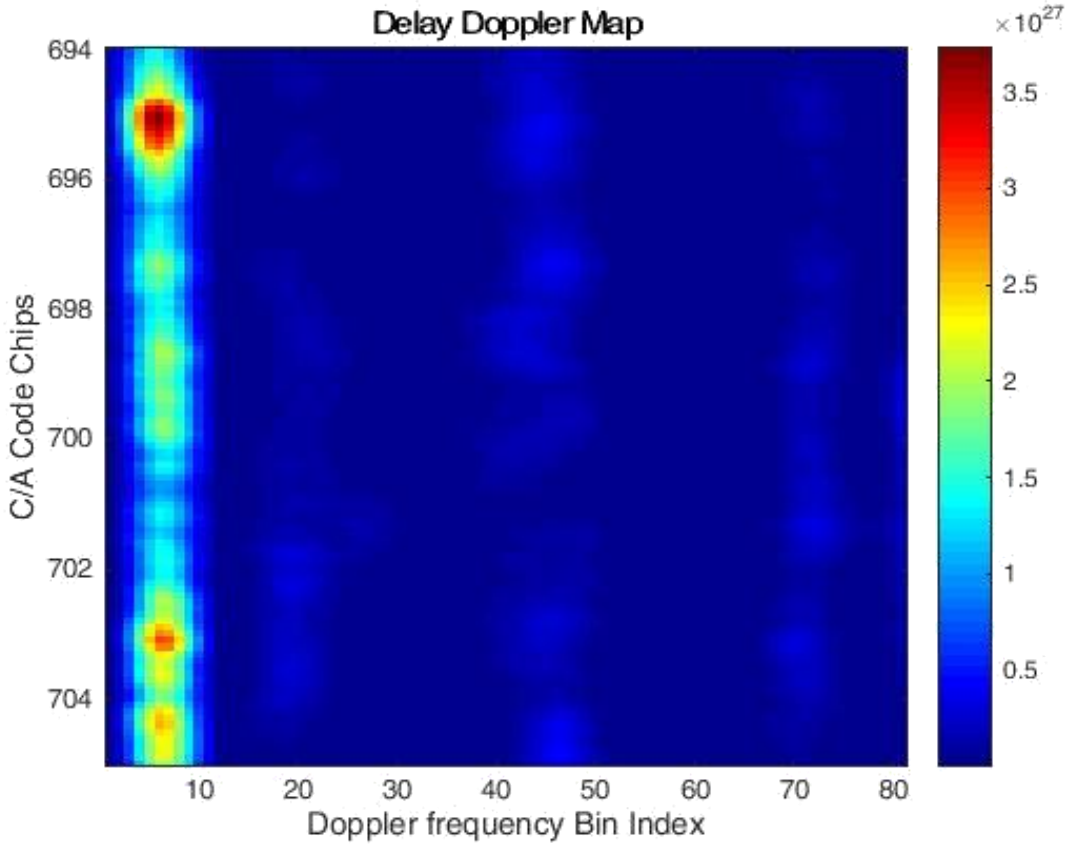
SCPNT Stanford Center for Position, Navigation and Time

Method 4: Coherent differential DDM for PRN 22 Test 2 (ice)

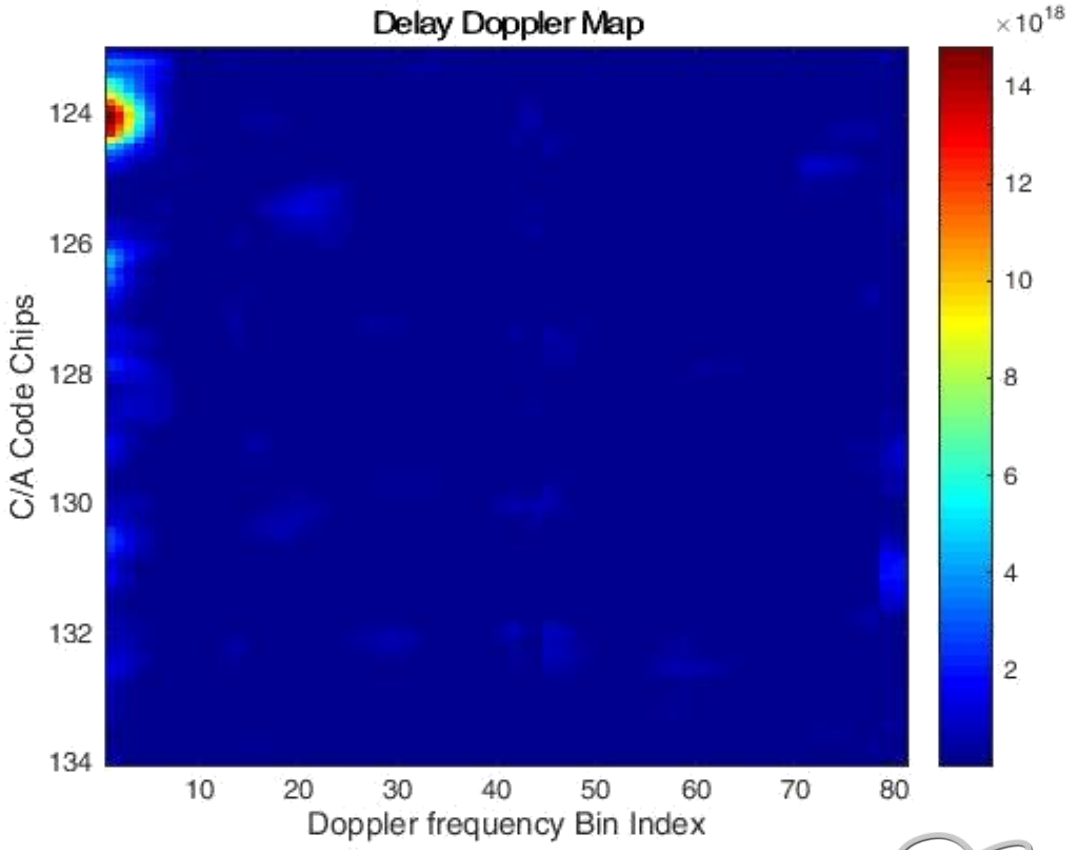
ILLINOIS INSTITUTE OF TECHNOLOGY

Space Weather Lab

Reflected Signal



Direct Signal



SCPNT Stanford Center for Position, Navigation and Time

Conclusion

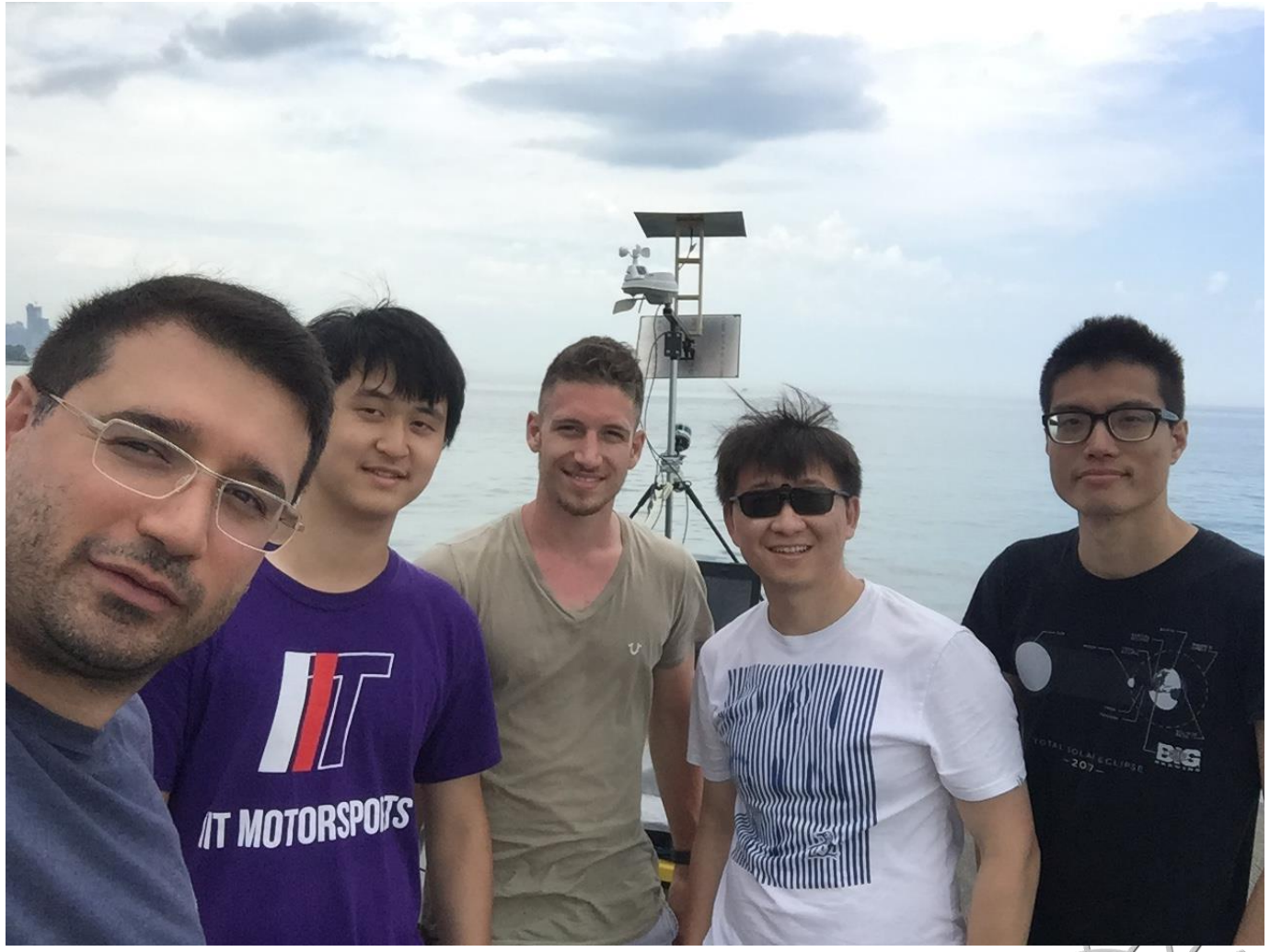
- Coherent, non-coherent, and coherent differential methods were studied for both direct and reflected GNSS signals.
  - Coherent differential method did a good job acquiring the low elevation satellite direct signal.
- We generated coherent differential DDMs for the reflected water/ice surface.
- Future work:
  - Further analysis of coherent differential DDMs.
  - Synchronization of multiple sensors.
  - Combination of signal processing methods.
  - Using accurate clock for USRPs, such as GPSDO.
- Additional data campaigns throughout 2018!

ILLINOIS INSTITUTE OF TECHNOLOGY

Acknowledgment

Space Weather Lab

Houshine Sabbagh Zadeh,
Li Pan,
Yang Su and
Ningchao Wang
for their advice and
technical support.



SCPNT
Stanford Center for Position, Navigation and Time

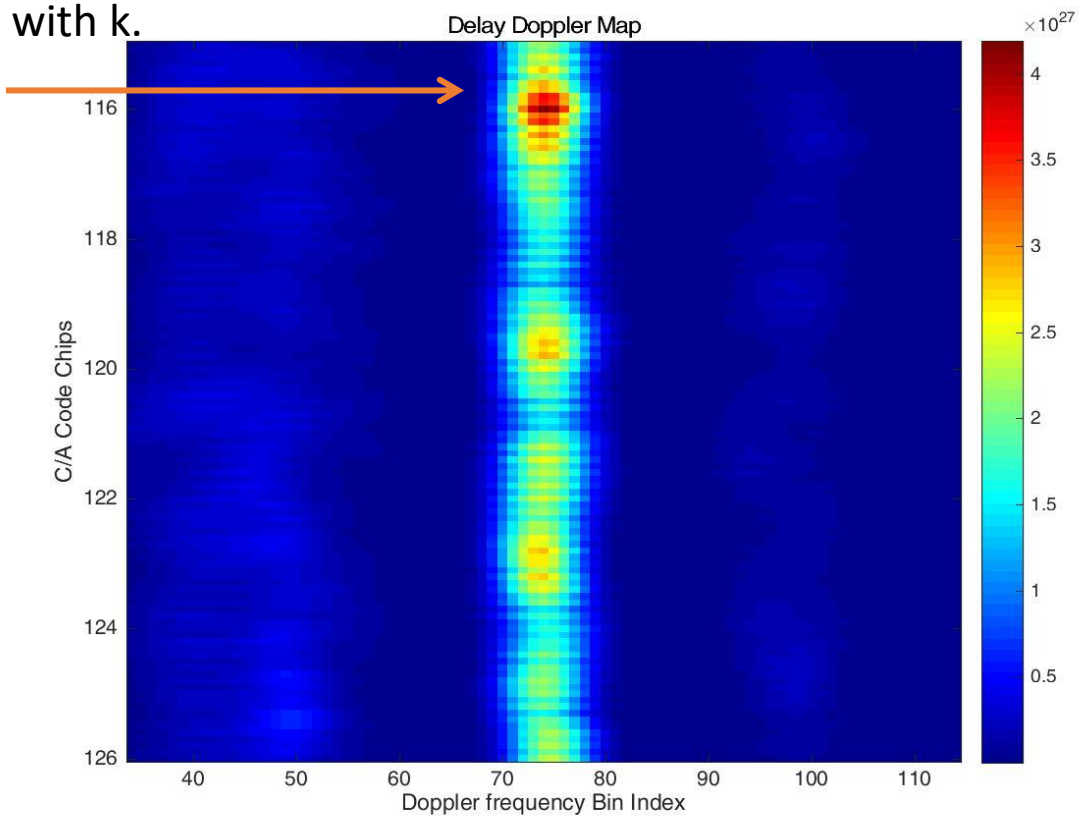
Thank YOU.

Extra Slides

Method 4: Coherent differential DDM for PRN 28 Test 5 (water), K=2

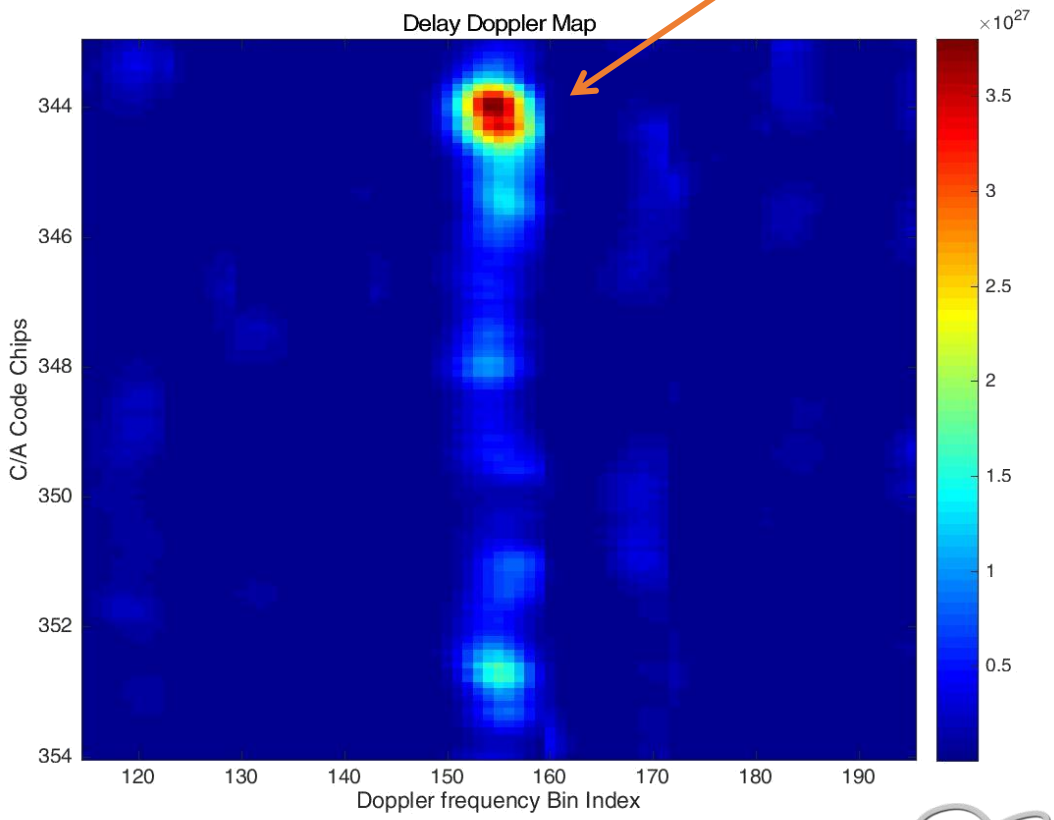
However, reflected peak chip and Doppler change with k.

Reflected Signal



Direct Signal

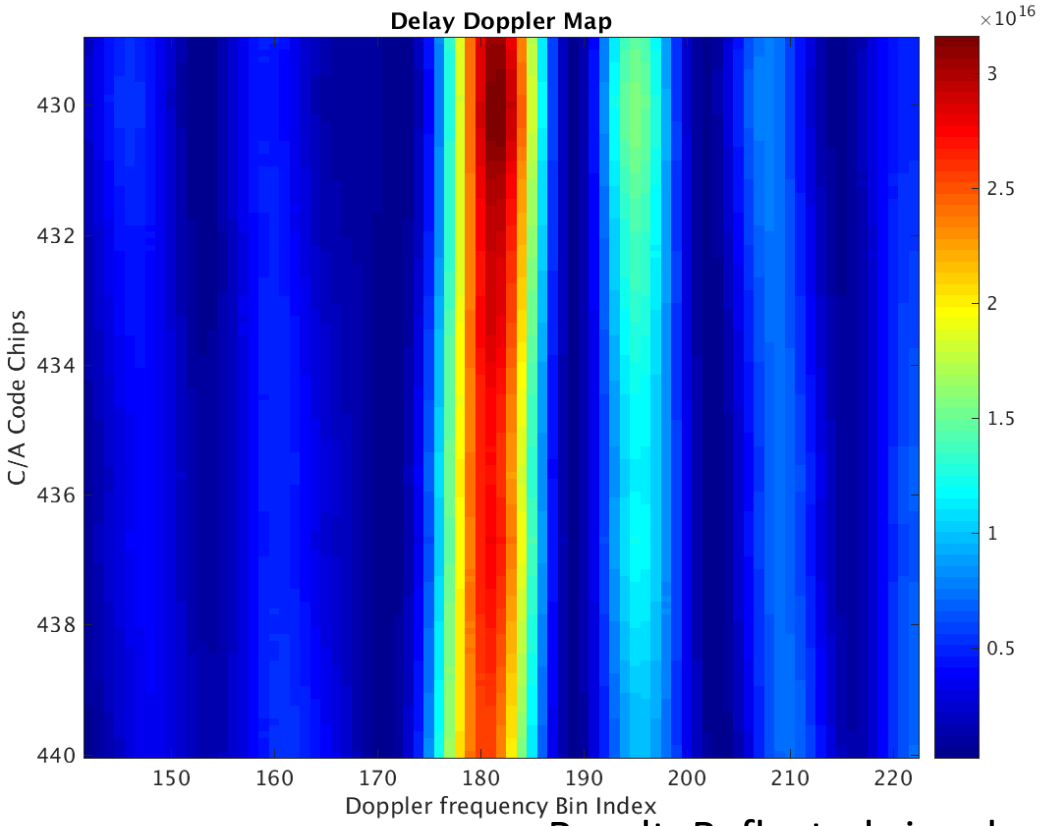
Acquired in C/A and Doppler.



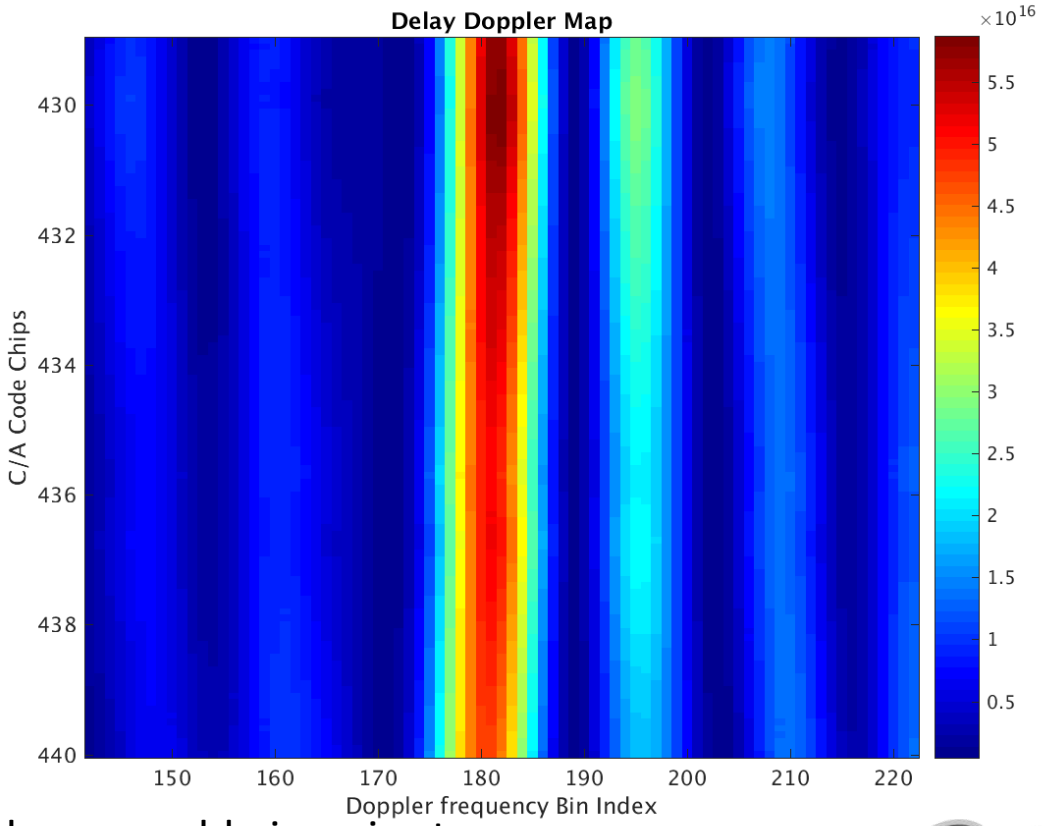
Method 2 DDM for PRN 28 Test 5 (water)

Space Weather Lab

Reflected Signal,500 ms



Reflected Signal,1000 ms



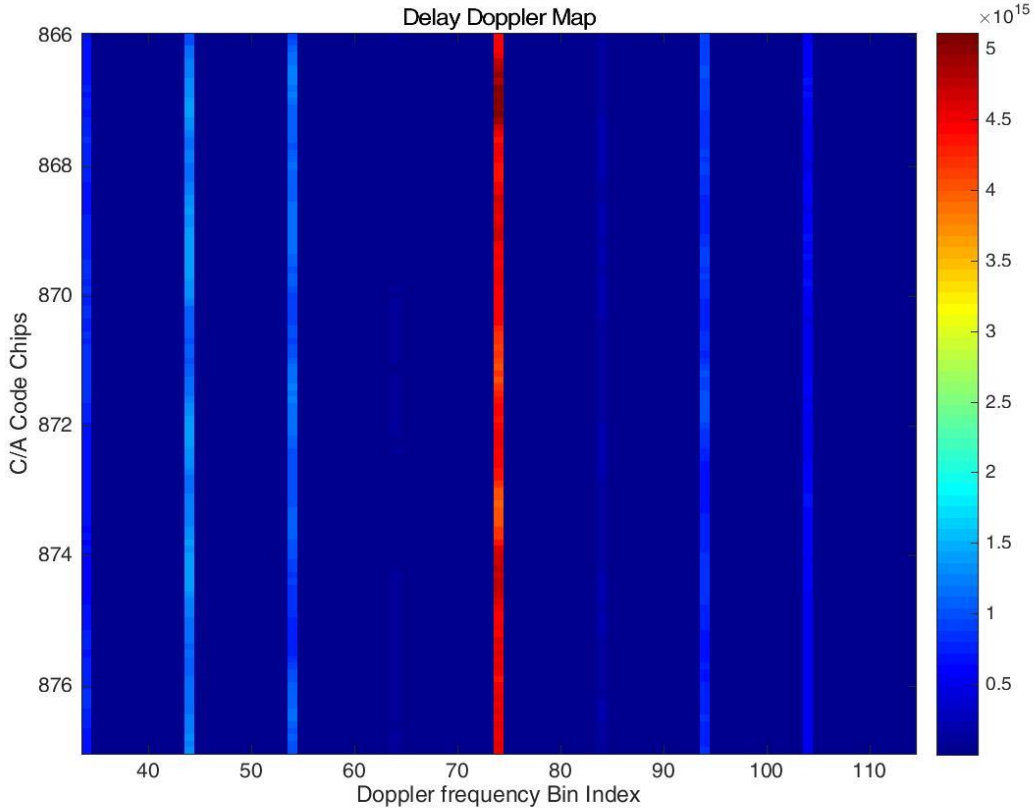
Result: Reflected signal assumed comparable in noise to low-elevation direct signal. Methods 2 and 3 do NOT result in a correct DDM (i.e., peak is not at the specular point).

Method 3 Coherent DDM for PRN 28 Test 5 (water), 10 ms

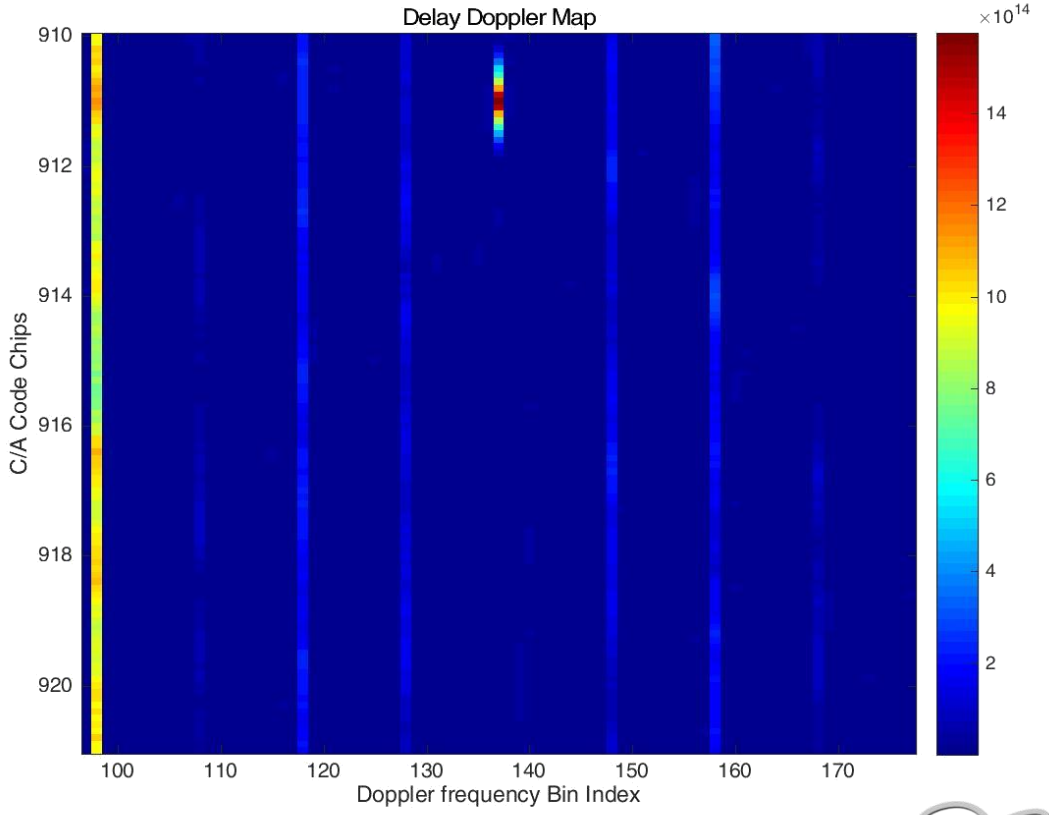
ILLINOIS INSTITUTE OF TECHNOLOGY

Space Weather Lab

Reflected Signal



Direct Signal



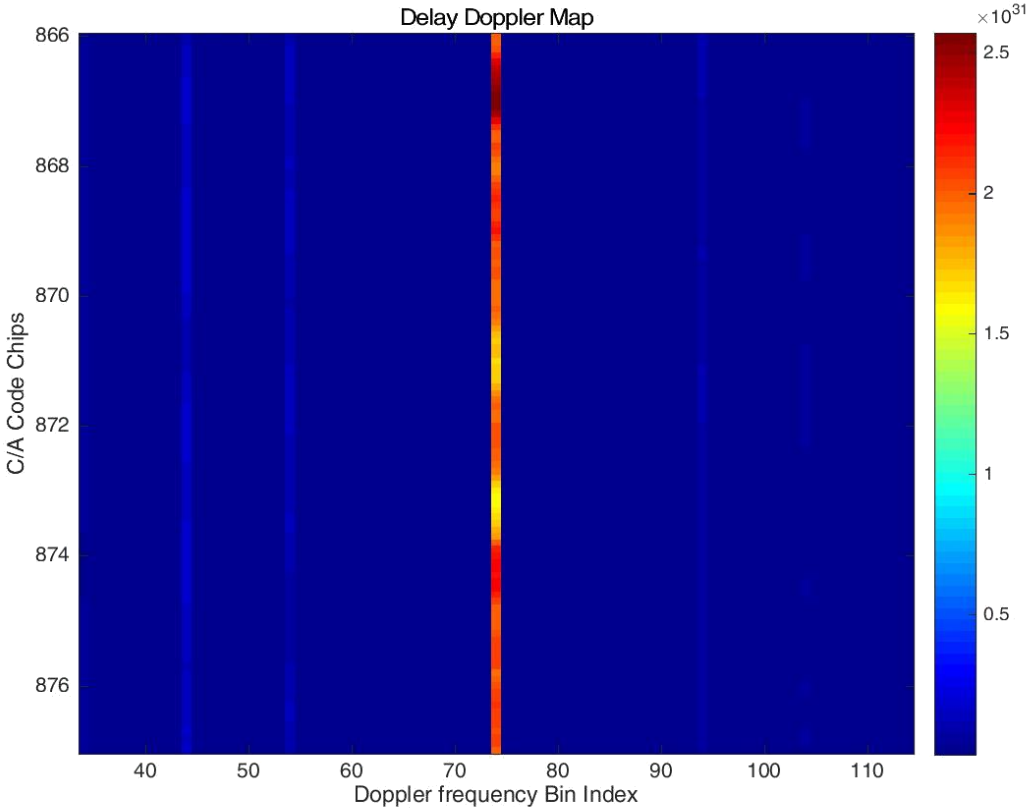
SCPNT Stanford Center for Position, Navigation and Time

Method 4: Coherent differential DDM for PRN 28 Test 5 (water)

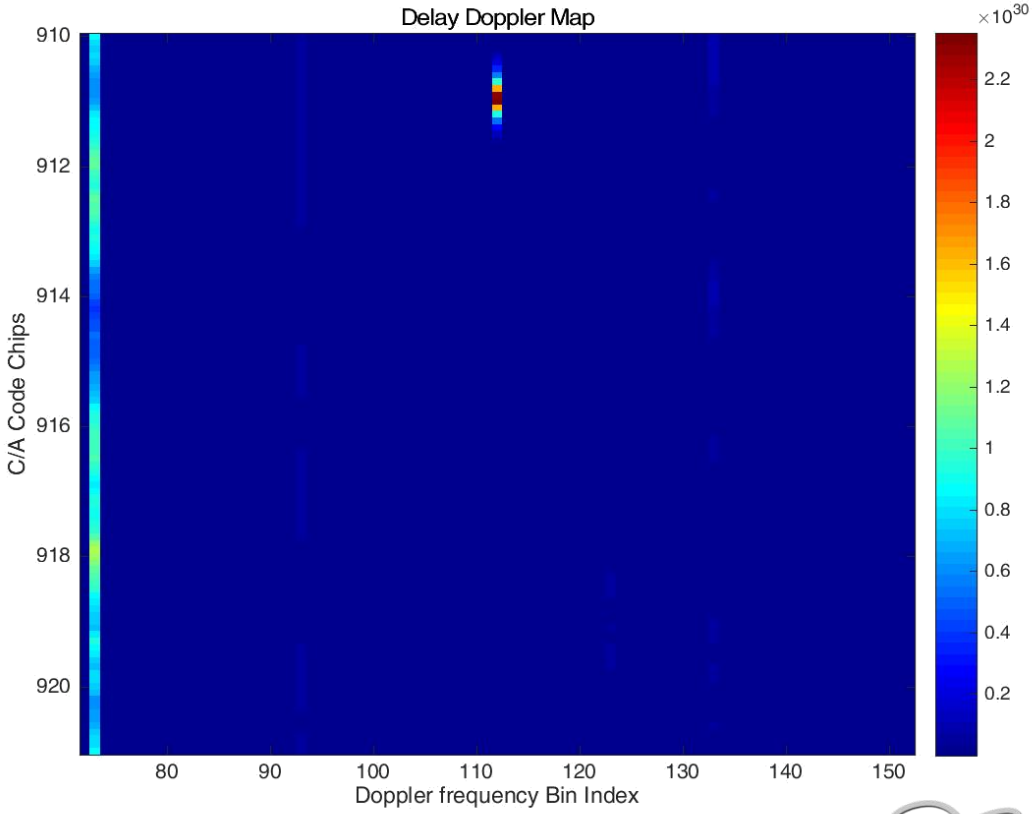
ILLINOIS INSTITUTE OF TECHNOLOGY

Space Weather Lab

Reflected Signal



Direct Signal



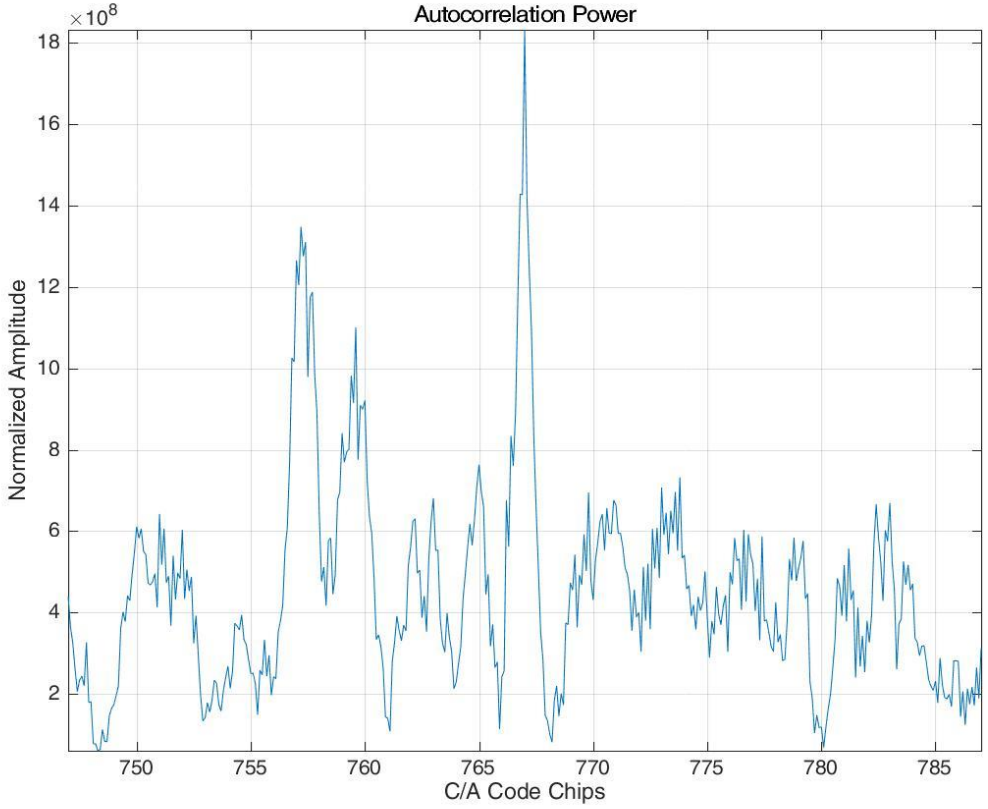
Result: Method 3 results in a DDM at the specular point (C/A chip 867).
However, band in C/A still exists in the reflected DDM only.

SCPNT Stanford Center for Position, Navigation and Time

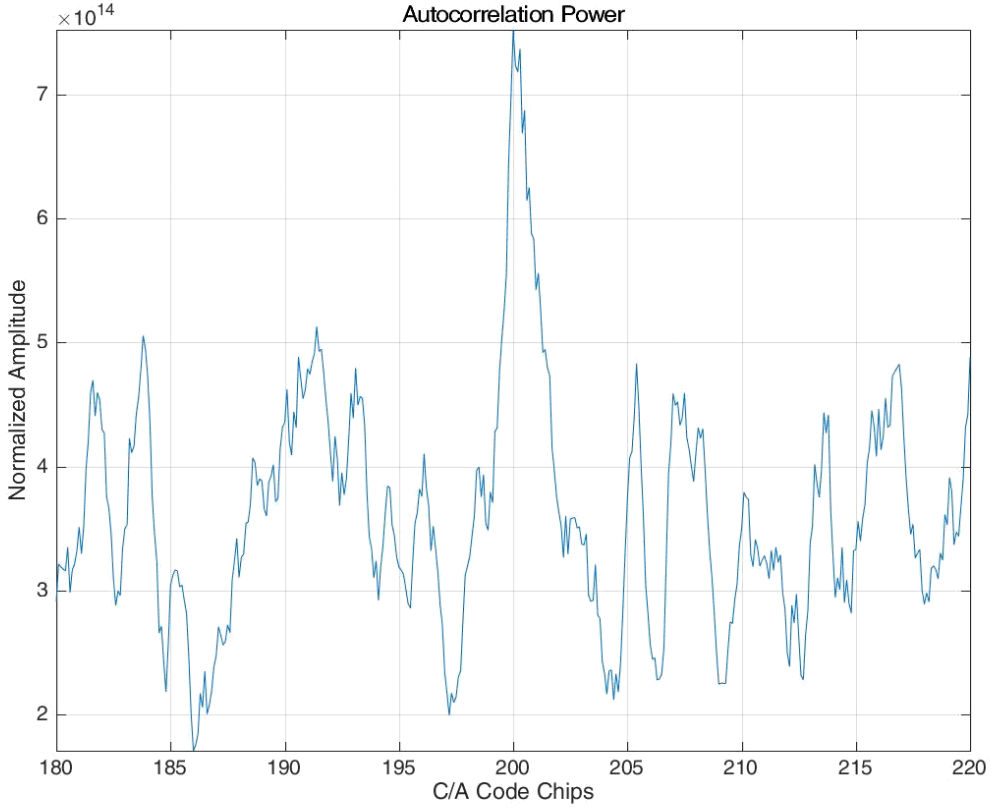
Low elevation satellite, PRN 3, Direct signal

Space Weather Lab

Coherent autocorrelation, 1ms



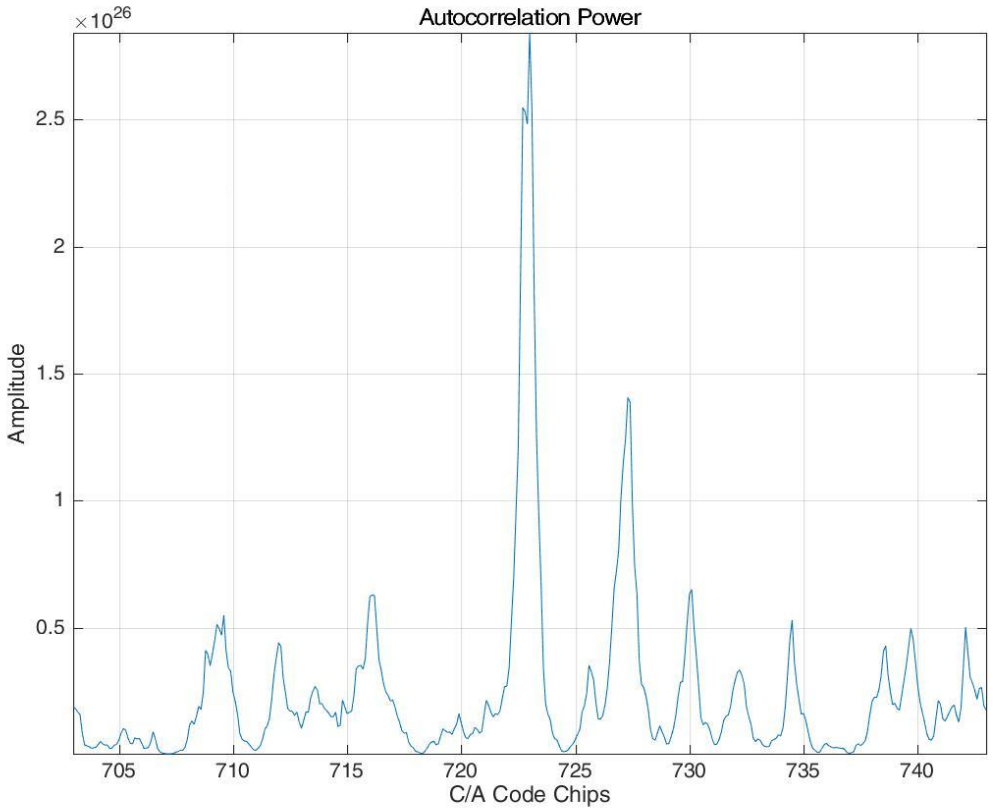
Coherent autocorrelation, 10ms



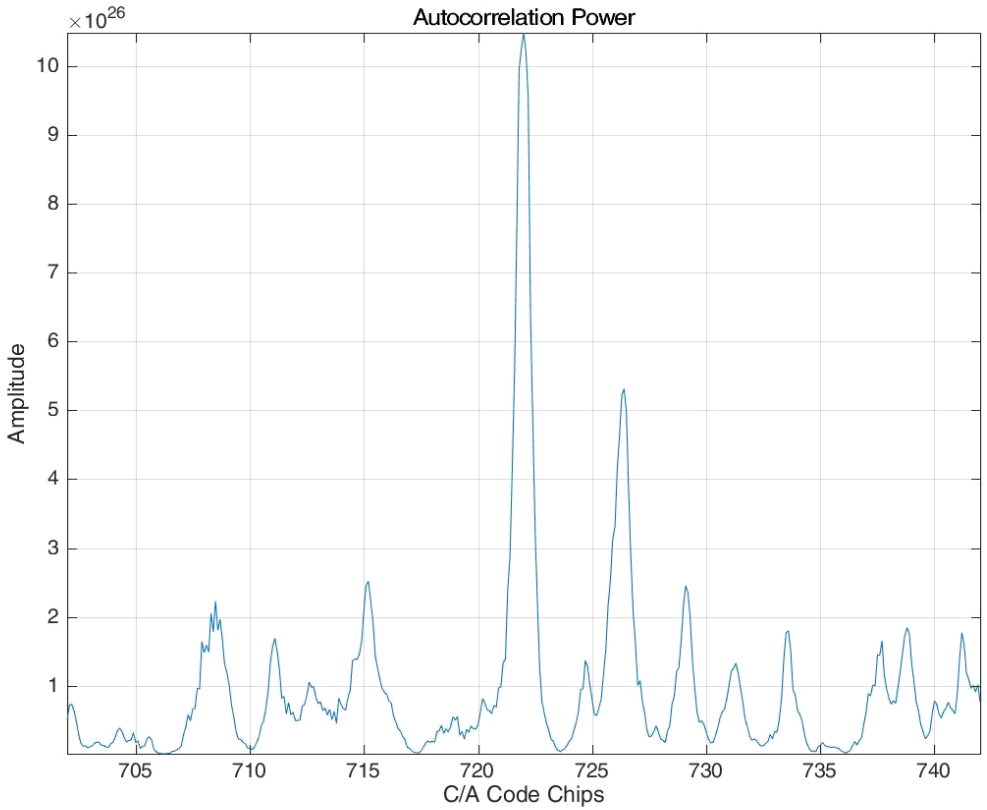
Low elevation satellite, PRN 3

Space Weather Lab

Coherent differential Autocorrelation , 1ms , K=1



Coherent differential Autocorrelation , 1ms , K=2



Incoherent DDM Processing, previous work: "Method 1"