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IROWG -2, Estes Park Colorado
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Ground-Based GPS Occultation Utilizing Modernized Signals

Outline

- Background
- Data Collection
- Post-Processing
- Open Loop Results
- Summary and Future Work

Background

Radio Occultation (RO)

- Measurement of the change in amplitude and phase of GPS signal due to atmospheric interference
- Technique used to derive refractivity, density, pressure, temperature, and humidity

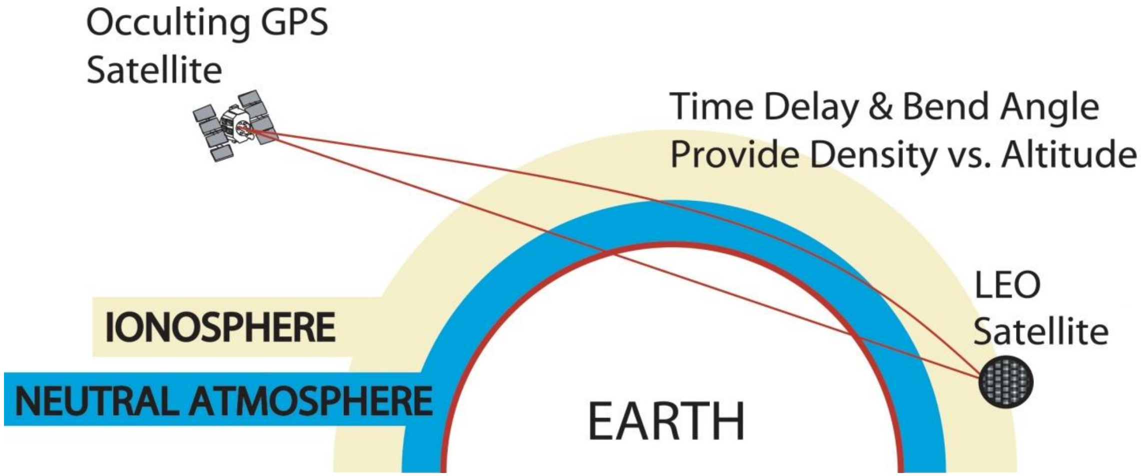


Illustration courtesy Broad Reach Engineering

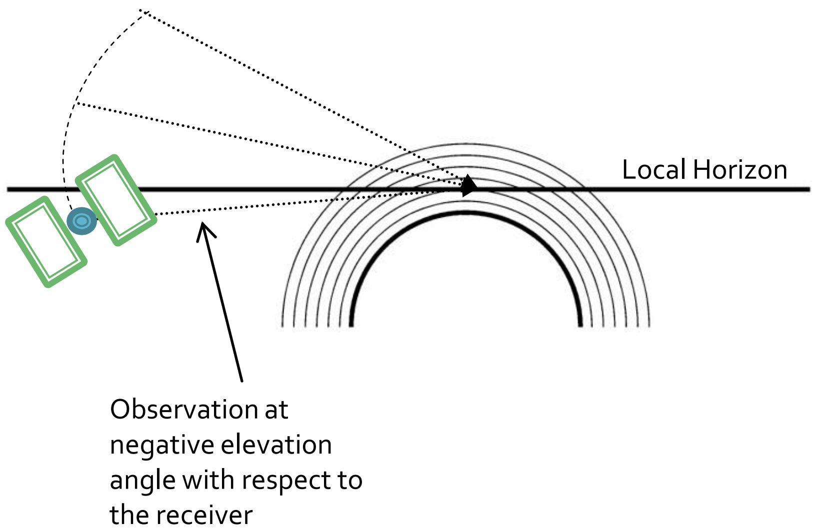
New Generation RO Receiver

- JPL's RO receivers aboard COSMIC satellites currently limited to GPS L1 C/A and L2 codeless tracking
- Exploring algorithms for a new occultation receiver architecture
  - Capable of tracking dual frequency measurements from new signals/constellations

Algorithm development is difficult without raw IF data from an occultation scenario!

Terrestrial RO

- Data collection from an elevated vantage point provides similar geometric aspects of RO from LEO
  - Vertical profiling capability, although disturbances to signal are not as dramatic as space-based experiments
  - Ample collection opportunities
- Mountain-based and airborne RO experiments performed in literature
  - Lulich et. al, Olsen et. al, Hu et. al, Aoyama et. al



Motivation

- Collect raw IF data from an occultation-like scenario for software-defined radio algorithm development and testing
- Demodulate GPS L1/L2/L5 signals
  - Develop open/closed loop tracking schemes
  - Estimate carrier frequency, signal strength

Main focus of this experiment is the development of signal processing algorithms from ground-based occultation scenarios

Data collection

Signals of Interest

GPS L2C

- Broadcast on Block IIR-M and Block IIF satellites
- Same chipping rate as L1
- Two longer (interleaved) PRN codes

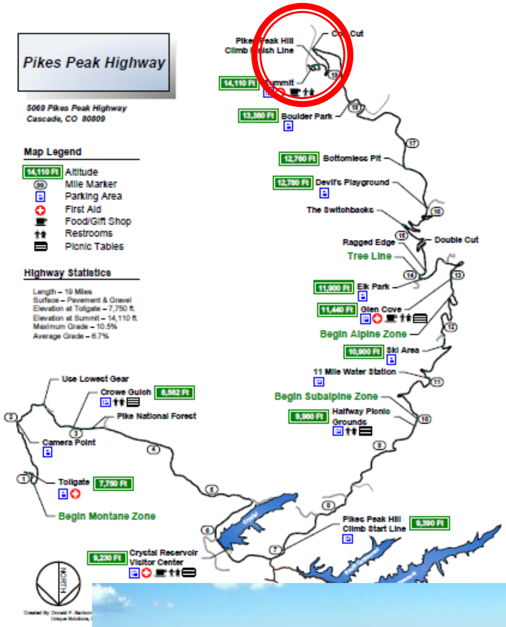
GPS L5

- Broadcast on Block IIF satellites only
- Chipping rate 10x higher than L1
- Two PRN codes with additional Neuman-Hoffman modulation
- Higher powered signal

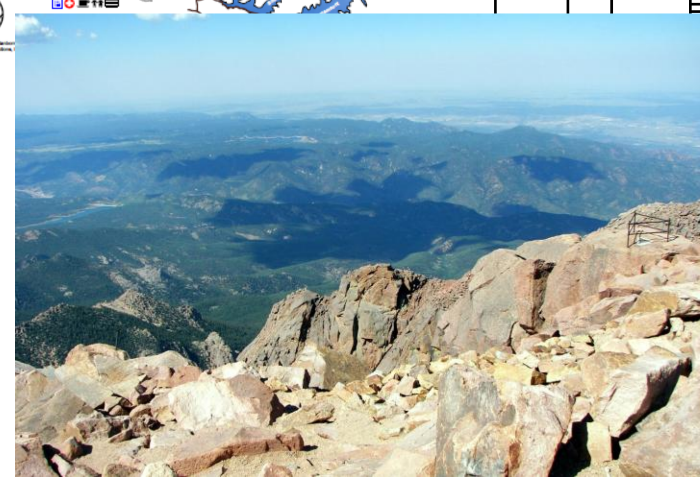
Limiting Factor: Collection of L5 signal
Only broadcast on PRNs 1 and 25

Collection Location and Time

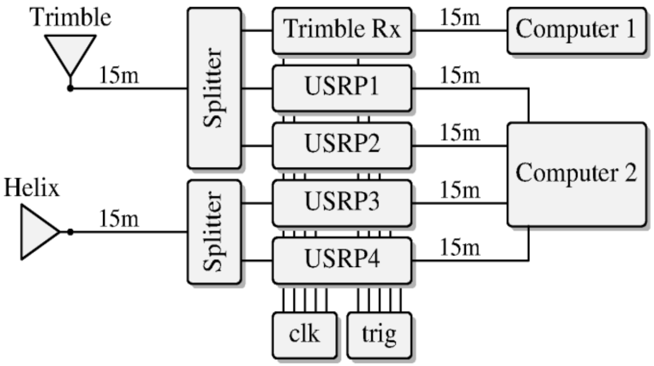
- Trade study performed on various mountain locations to obtain "good" occultation profile from PRN 1 or PRN 25
- Optimal solution: eastward-pointing collection on the summit of Pikes Peak, Colorado on October 21, 2011



Satellite	Signal	Rising/Setting	Time	Azimuth	Elevation
PRN 7	L2C	Setting	09:53	145.495°	19.939°
			09:58	146.346°	17.810°
			10:03	147.137°	15.695°
			10:08	147.869°	13.593°
			10:13	148.543°	11.506°
			10:18	149.160°	9.436°
			10:23	149.721°	7.382°
			10:28	150.226°	5.346°
			10:33	150.674°	3.329°
			10:38	151.067°	1.332°
			10:41	151.299°	0.000°
PRN 12	L2C	Rising	11:20	298.276°	0.000°
			11:25	299.485°	1.615°
			11:30	300.662°	3.225°
			11:35	301.807°	4.919°
			11:40	302.918°	6.609°
			11:45	303.993°	8.325°
			11:50	305.030°	10.068°
			11:55	306.028°	11.837°
			12:00	306.984°	13.633°
			12:05	307.896°	15.456°
			12:10	308.761°	17.307°
			12:15	309.578°	19.185°
PRN 15	L2C	Setting	11:23	258.102°	7.278°
			11:28	256.322°	6.086°
			11:33	254.569°	4.879°
			11:38	252.840°	3.662°
			11:43	251.133°	2.439°
			11:48	249.444°	1.214°
			11:53	247.781°	0.000°
PRN 1	L5	Setting	11:02	43.342°	20.228°
			11:07	42.325°	18.517°
			11:12	41.423°	16.774°
			11:17	40.630°	15.004°
			11:22	39.940°	13.213°
			11:27	39.351°	11.405°
			11:32	38.856°	9.583°
			11:37	38.452°	7.753°
			11:42	38.134°	5.915°
			11:47	37.899°	4.075°
			11:52	37.744°	2.234°
			11:58	37.658°	0.000°
PRN 25	L5	Rising	12:43	311.535°	0.000°
			12:48	312.209°	1.784°
			12:53	312.831°	3.596°
			12:58	313.396°	5.430°
			13:03	313.902°	7.285°
			13:08	314.346°	9.161°
			13:13	314.724°	11.056°
			13:18	315.033°	12.970°
			13:23	315.269°	14.902°
			13:28	315.428°	16.849°
			13:33	315.504°	18.811°
			13:38	315.492°	20.786°
PRN 5	L2C	Rising	12:57	178.811°	0.000°
			13:02	177.936°	1.726°
			13:07	177.089°	3.501°
			13:12	176.271°	5.319°
			13:17	175.478°	7.179°
			13:22	174.707°	9.080°
			13:27	173.956°	11.021°
			13:32	173.220°	13.001°
			13:37	172.498°	15.018°
			13:42	171.784°	17.071°
			13:47	171.075°	19.159°
PRN 29	L2C	Rising	13:46	279.099°	0.000°
			13:51	280.578°	1.443°
			13:56	282.055°	2.903°
			14:01	283.524°	4.377°
			14:06	284.985°	5.866°
			14:11	286.437°	7.371°
			14:16	287.878°	8.893°
			14:21	289.307°	10.433°
			14:26	290.723°	11.992°
			14:31	292.125°	13.570°
			14:36	293.512°	15.170°
			14:41	294.883°	16.791°
			14:46	296.235°	18.435°
			14:51	297.570°	20.102°
			14:34	333.648°	0.000°
			14:39	331.994°	0.769°
			14:44	330.293°	1.461°
			14:49	328.549°	2.071°
			14:54	326.766°	2.598°
			14:59	324.580°	3.117°
			15:04	323.097°	3.393°
			15:09	321.220°	3.659°
			15:14	319.320°	3.837°
			15:19	317.017°	3.933°
			15:24	315.471°	3.927°
			15:29	313.531°	3.841°
			13:47	84.594°	20.064°
			13:52	86.305°	18.528°
			13:57	88.001°	16.996°
			14:02	89.681°	15.468°
			14:07	91.345°	13.942°
			14:12	92.992°	12.419°
			14:17	94.622°	10.898°
			14:22	96.233°	9.378°
			14:27	97.826°	7.858°
			14:32	99.399°	6.339°
			14:37	100.952°	4.819°
			14:42	102.483°	3.298°
			14:47	103.992°	1.776°
			14:52	105.722°	0.000°

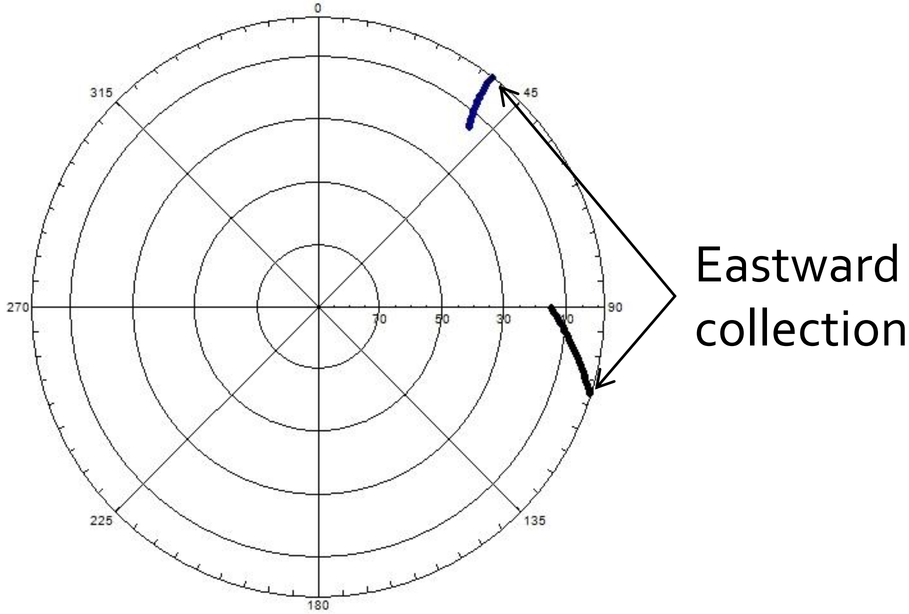


Hardware Setup



- Two antennas
  - Helix (horizontal) and Trimble dish (omni-directional)
- Four RF front-ends
  - Dual-frequency IF data from each antenna
- One Trimble NetR9
  - Verification of position and available constellation
- Two computers
- Data storage drive
- Rubidium clock

Data Collected



- PRNs 1 and 17 chosen for fast setting geometries
- High sampling rate used to collect wideband L5 signal
- Bandwidth reduced at other frequencies

PRN/ SV	Freq	Time Start (UTC)	Duration (min)	Azimuth (deg)	BW (MHz)	Int Freq (kHz)
1/63	L1/L5	17:30	42	38	4/20	420/450
17/53	L1/L2	20:15	60	100	2/2	100/100

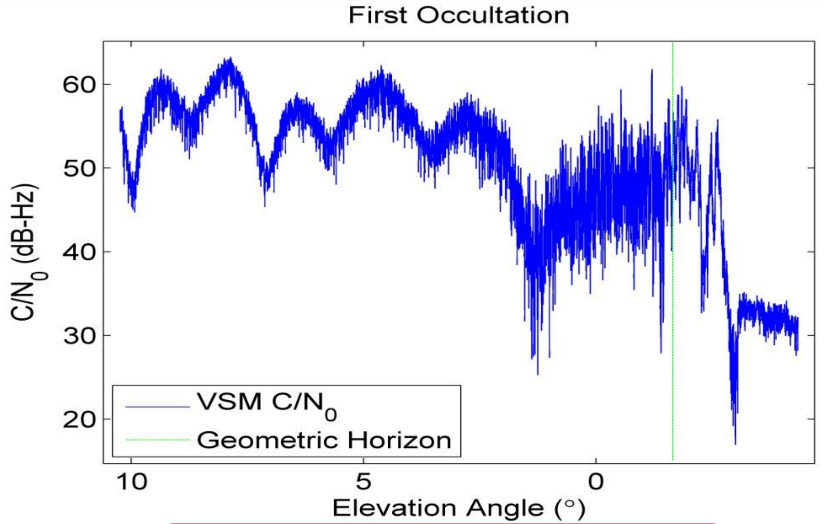
Post-Processing

Acquisition Strategies

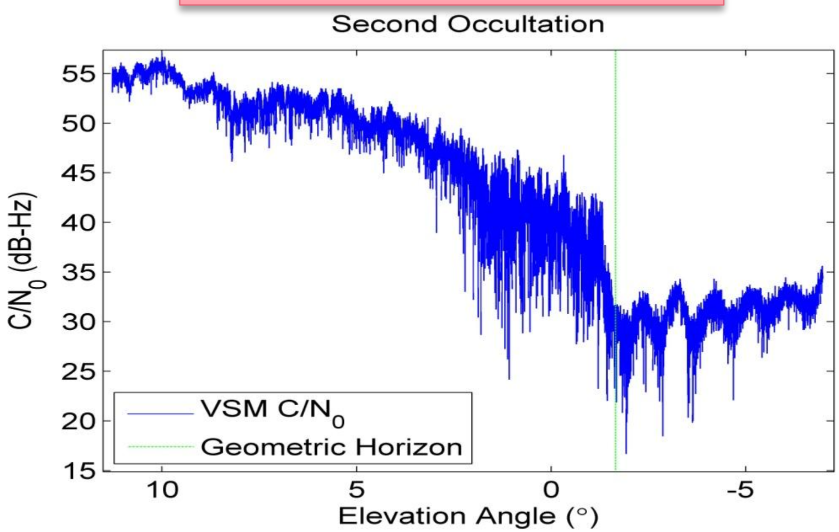
- L1
  - 10 ms coherent
  - 10 non-coherent sums
  - Alternating blocks
    - Avoids navigation data bit modulation
- L2C
  - 20 ms coherent on CM code
  - Alternate with 1 µs blocks of zeros
    - Avoids determining code phase of CL code
- L5
  - 20 ms coherent on Q5 code
  - One-full length of NH code
  - No I5 demodulation
    - Q5 is dataless channel

These acquisition schemes were used as an preliminary inspection of the data. The CL and I5 codes would be utilized to maximum power in future studies.

Closed Loop



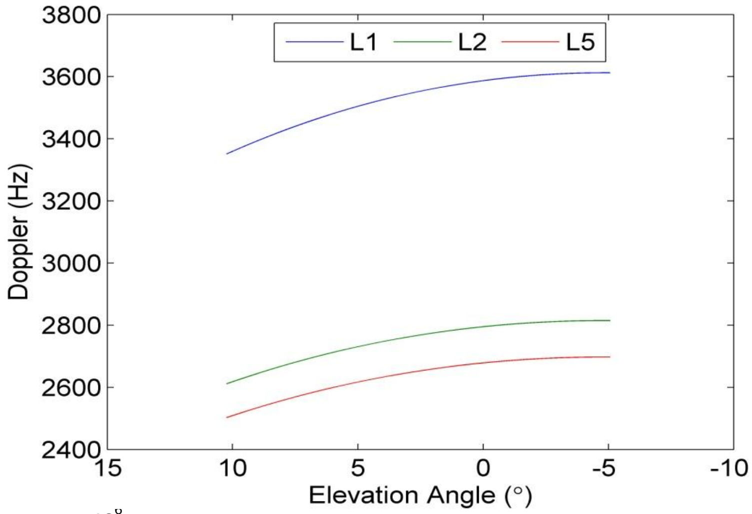
L1 Signal ONLY

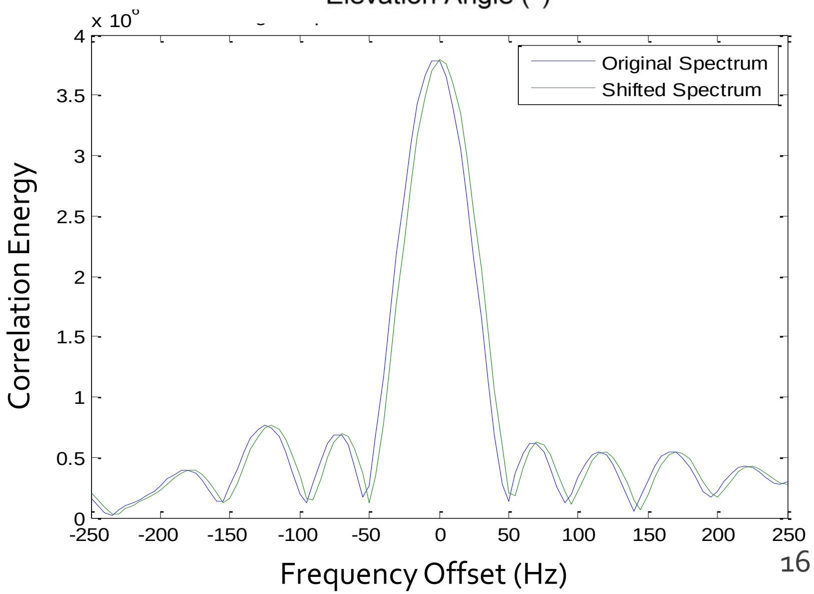


- Phase-locked loop (PLL) used to adjust frequency of replica based upon previous measurements
- Not optimal technique for tracking in lower troposphere
  - Need strong SNR and low dynamics
- Cannot be (easily) used for rising occultations

Open Loop

- Performed acquisition at set intervals to obtain estimates of carrier frequency and signal strength
  - Determined Doppler shift with model from IGS products
  - Limited frequency search space to main lobe about Doppler model
  - Applied least-squares sinc matching to fine-tune peak frequency estimate





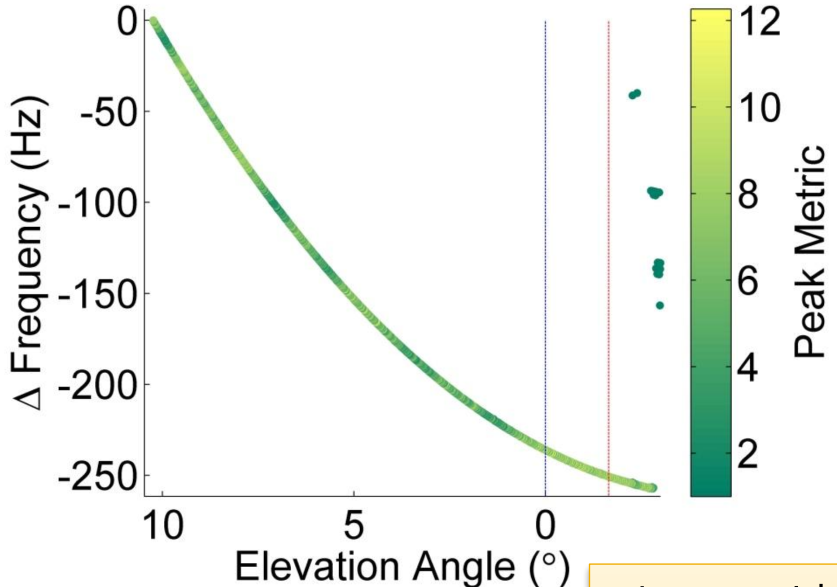
Open Loop Results

Estimates Obtained

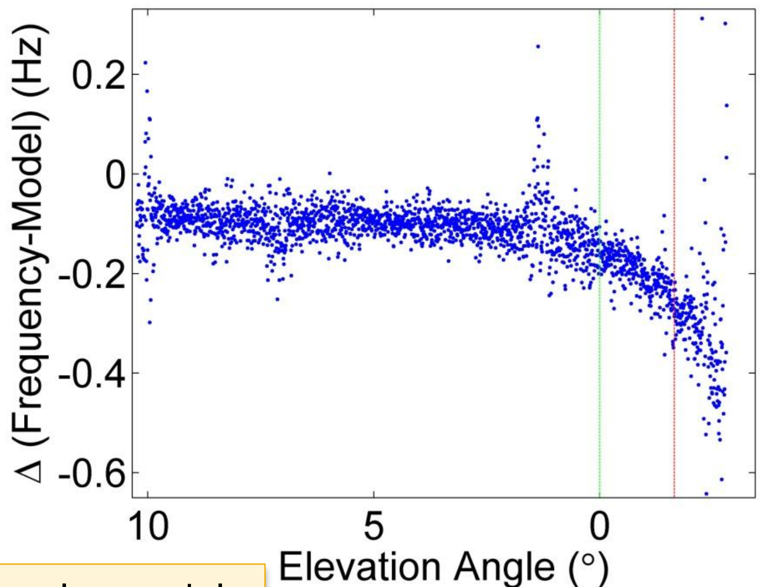
- Carrier frequency
  - Difference from initial frequency at first epoch
- Signal strength
  - Ratio of 1^{st} correlation peak to 2^{nd} highest peak
- Frequency comparison to Doppler model
  - Difference in Doppler frequency with respect to Doppler model (predicted from precise ephemerides and receiver position)
- Accumulated Phase Deviation
  - Integration of Doppler differences

PRN 1- L1

CARRIER FREQUENCY



FREQUENCY COMPARISON



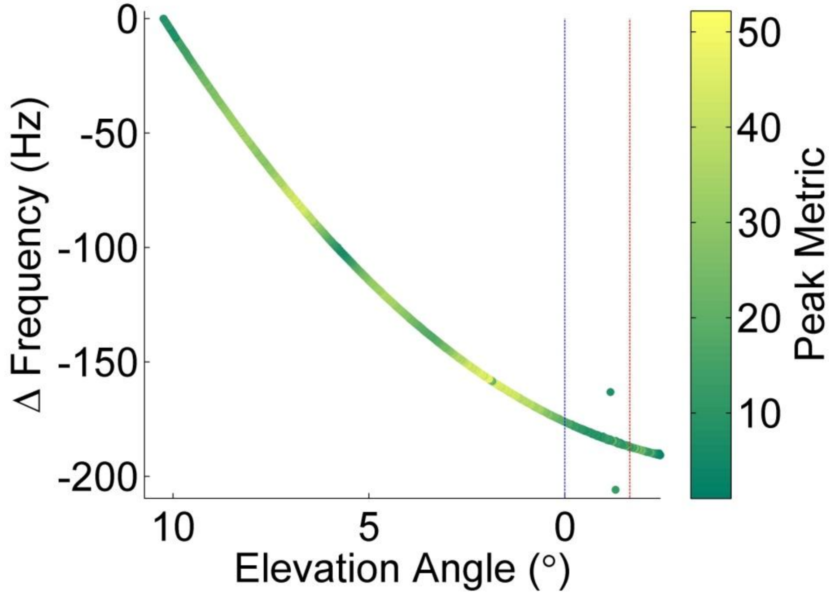
OL tracking continues past geometric horizon

Agrees with Doppler model until local horizontal, then the measured carrier frequency is more negative than the model – More delay to the signal

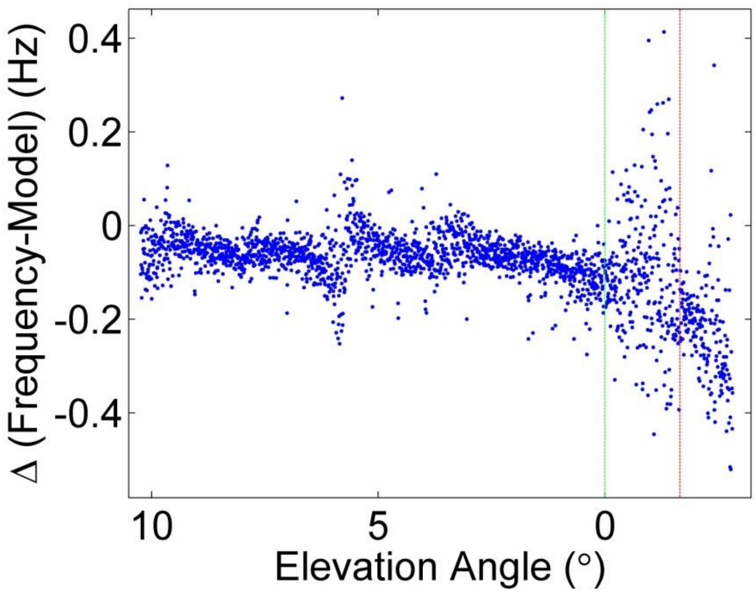
Small negative bias between model and measured Doppler frequency

PRN 1- L5

CARRIER FREQUENCY



FREQUENCY COMPARISON



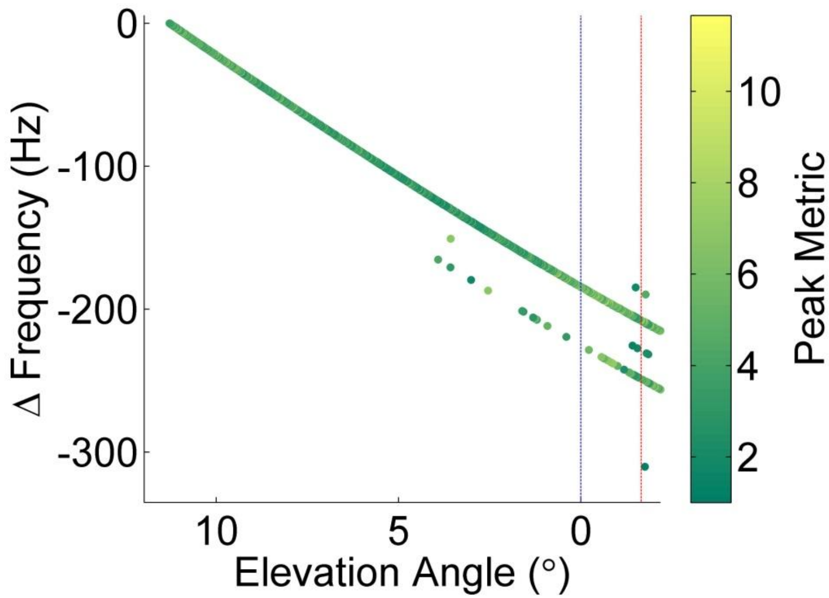
Higher peak metric

Similar agreement to Doppler model, with analogous signal delay at local horizontal

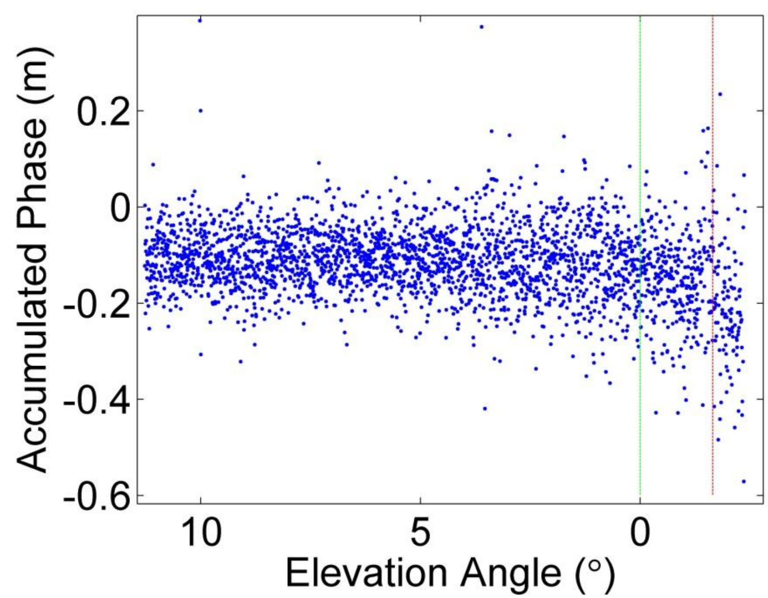
Negative bias still apparent between measured and Doppler frequency

PRN 17- L2

CARRIER FREQUENCY



FREQUENCY COMPARISON



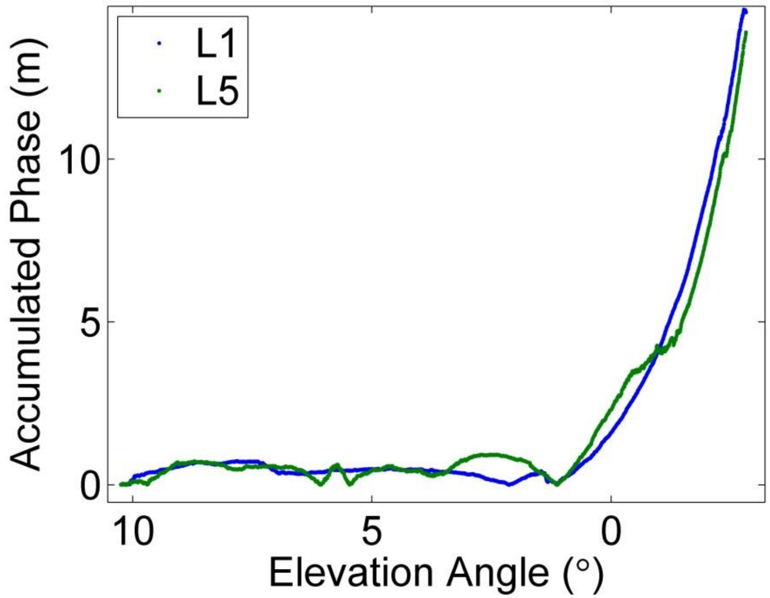
Weak signal power and additional signal found ~40 Hz below the main center frequency

Signal delay at local horizontal not obvious
Note: Center signal shown for frequency comparison

Negative bias still evident between measured and Doppler frequency

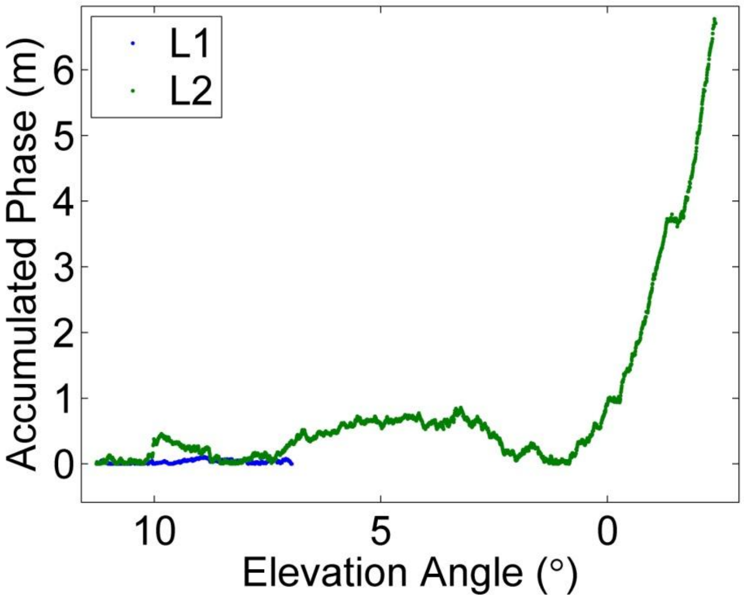
Accumulated Phase

FIRST OCCULTATION



Signal delay of approximately 15 meters found on both L1 and L5 signals

SECOND OCCULTATION



Signal delay of approximately 6 meters found on L2 signal

Summary and Future Work

Mountaintop Collection

- Tracking succeeded to negative elevation angles with PRN 1
  - Higher signal strength (both L1 and L5)
  - L5 PRN codes better for correlation
- Small signal path increase found
  - 15 meters on both frequencies from 1st occultation
  - 6 meters on L2 from 2nd occultation
- Possible hardware issues, multipath, or atmospheric inversion on 2nd occultation

Receiver Development

- Convert frequency measurements to atmospheric profiles
  - Compare with local radiosonde measurements
- Additional signals, frequencies, and modulations
  - GPS, GLONASS, Galileo, Compass

Questions