4 Constellation RTK: Worth it?

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Introduction

About me

Masters student at Oregon State University

- Civil Engineering – Geomatics
- Advised by Dr. Mike Olsen

Undergrad research with Dr. Dan Gillins, now at NGS

- Comparing online static GNSS post-processing services
- https://ascelibrary.org/doi/10.1061/%28ASCE%29SU.1943-5428.0000256
- Email at jamiesom@oregonstate.edu if you want a copy

Please interrupt me if you have questions or want more detail!

Objectives

1. Set up testing course
   a. Solid true coordinates
2. Assess benefit of additional constellations under obstructed conditions
   a. Single base RTK

Number of Constellations	GPS	GLONASS	Galileo (GAL)	BeiDou (BDS)
4	X	X	X	X
3	X		X	X
2	X	X		
1	X			

Description

Equipment

Antenna

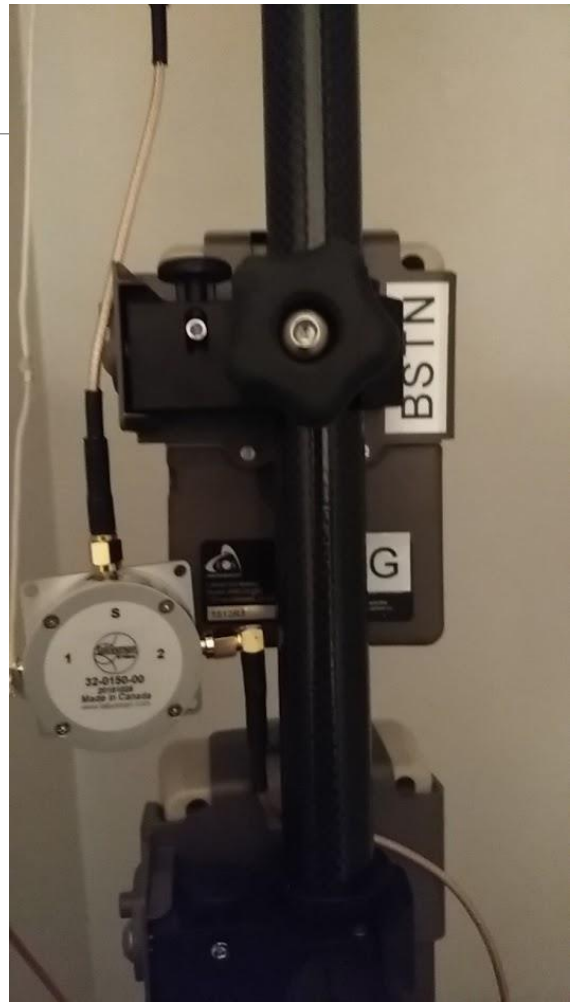
Receiver x2

- Arrow Gold

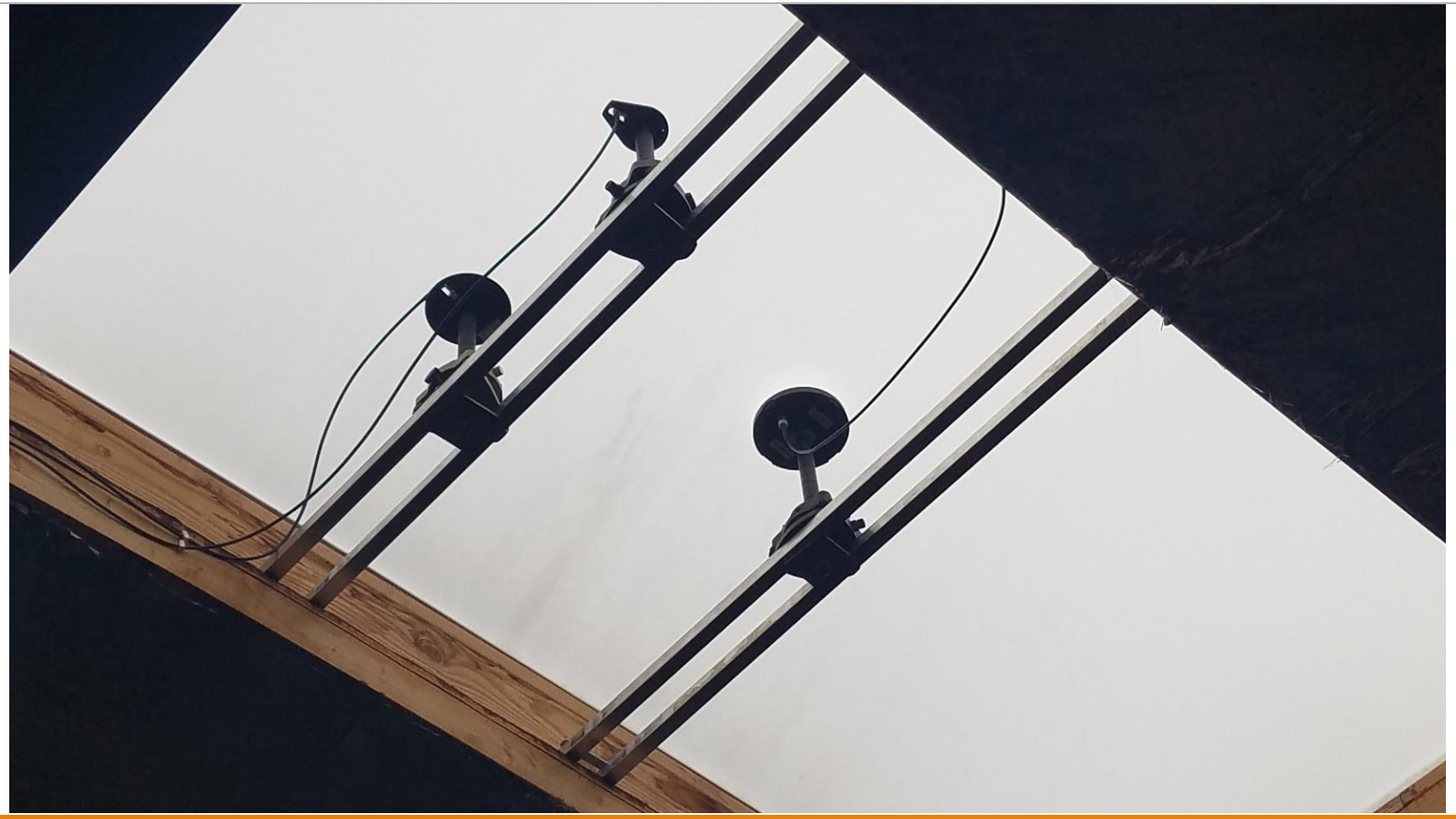
Android device x2

- Phones and tablets

2-meter fixed height pole + bipod



DMG RTK Base



PID:	BBFY98
Designation:	DMG1
Stamping:	DMG1 2018
Stability:	Monuments of questionable or unknown reliability
Setting:	Pavement (street, sidewalk, curb, etc.)
Description:	The mark is set in top of curb at the east edge of the parking lot behind the shared office building located at address: 15688 SW 72nd Ave., Tigard, OR References: From the back of the building to the disk is 39.50 feet. From the center line of the RR tracks to the disk is 38.00 feet. 103.00 feet north-northwest of the first cedar tree. The mark is used for GNSS position verification for various sensors.
Observed:	2018-05-22T12:57:00Z
Source:	OPUS - page5 1603.24

Close-up View

REF_FRAME: NAD_83(2011) | EPOCH: 2010.0000 | SOURCE: NAVD88 (Computed using GEOID12B) | UNITS: m | SET PROFILE | DETAILS

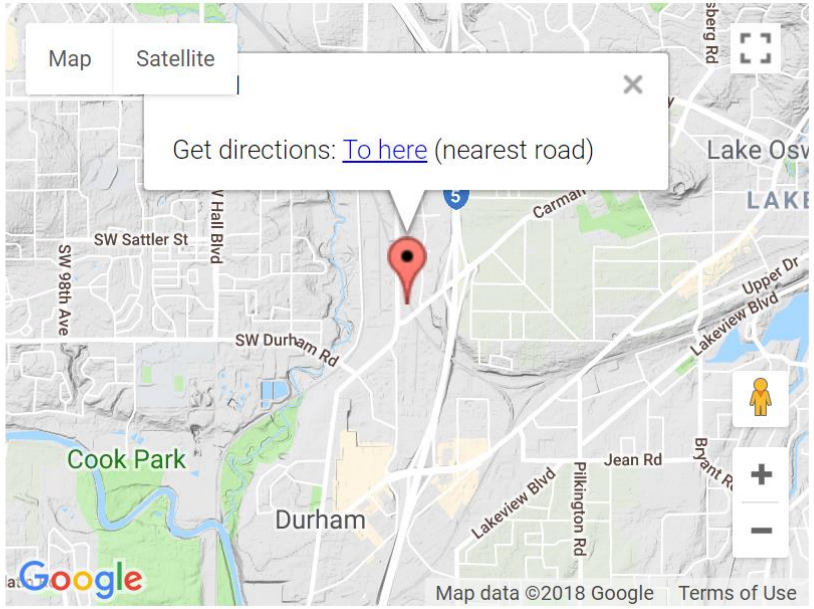
LAT:	45° 24' 23.00375"	± 0.003 m
LON:	-122° 44' 53.75573"	± 0.002 m
ELL HT:	26.119	± 0.041 m
X:	-2426459.316	± 0.015 m
Y:	-3772604.528	± 0.022 m
Z:	4519189.569	± 0.031 m
ORTHO HT:	48.996	± 0.048 m

	UTM 10	**SPC** 3601(OR N)
NORTHING:	5028127.601m	195770.052m
EASTING:	519699.776m	2324028.734m
CONVERGENCE:	0.17926182°	-1.59443844°
POINT SCALE:	0.99960477	0.99990317
COMBINED FACTOR:	0.99960068	0.99989908

CONTRIBUTED BY

mlarmstr
NONE

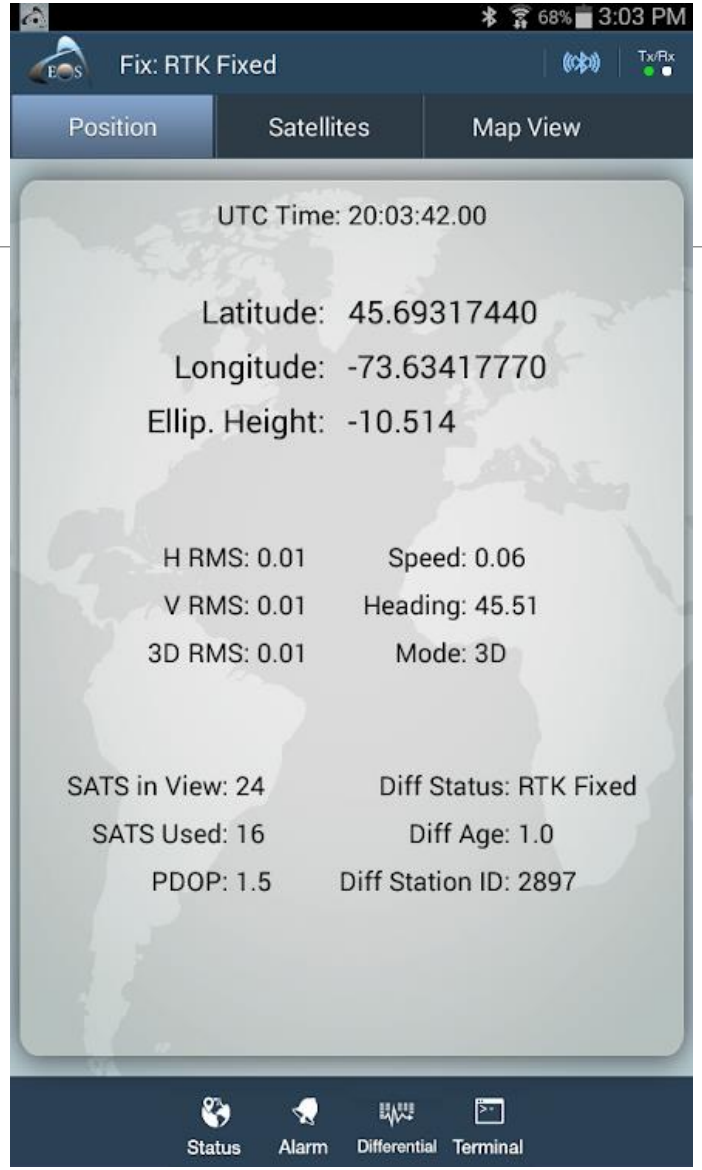
Horizon View

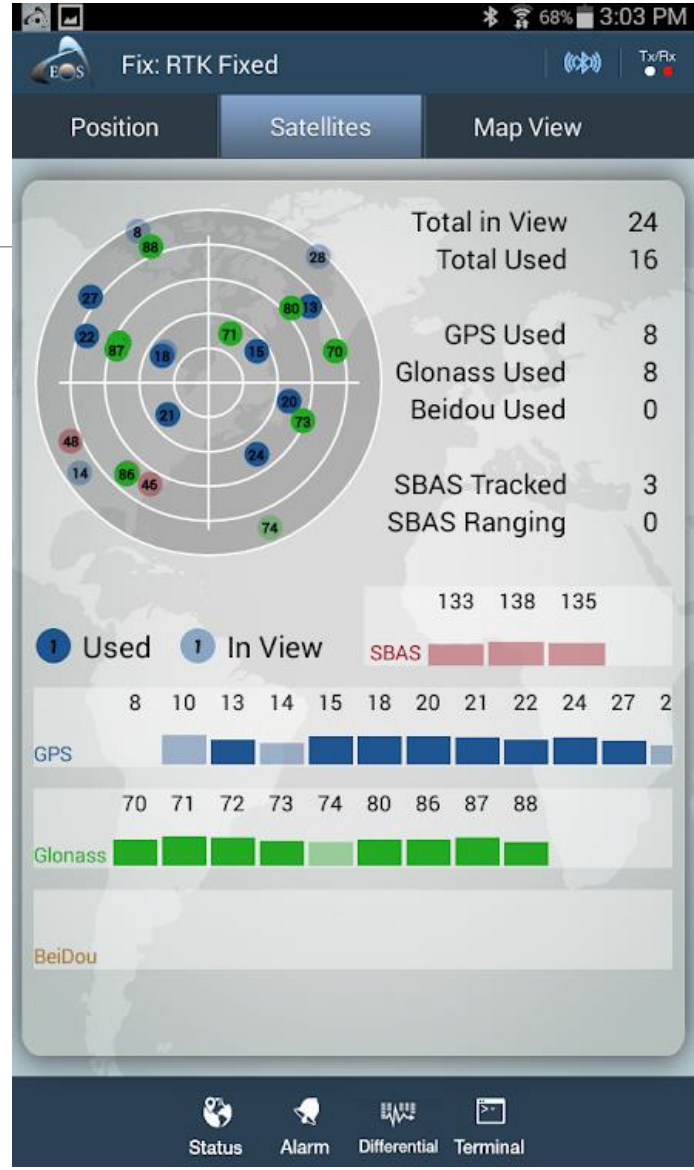


Equipment

Software

- EOS Tools Pro
  - Can see lots of info in real time
  - No easy way to save data





Equipment

Software

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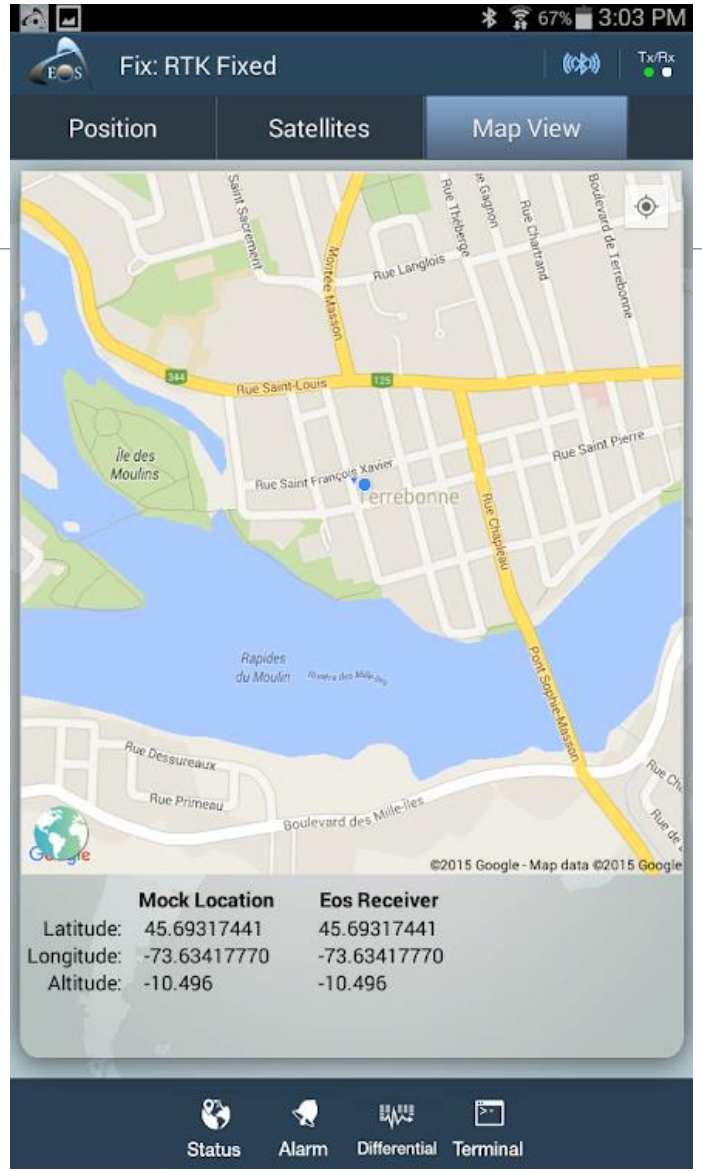
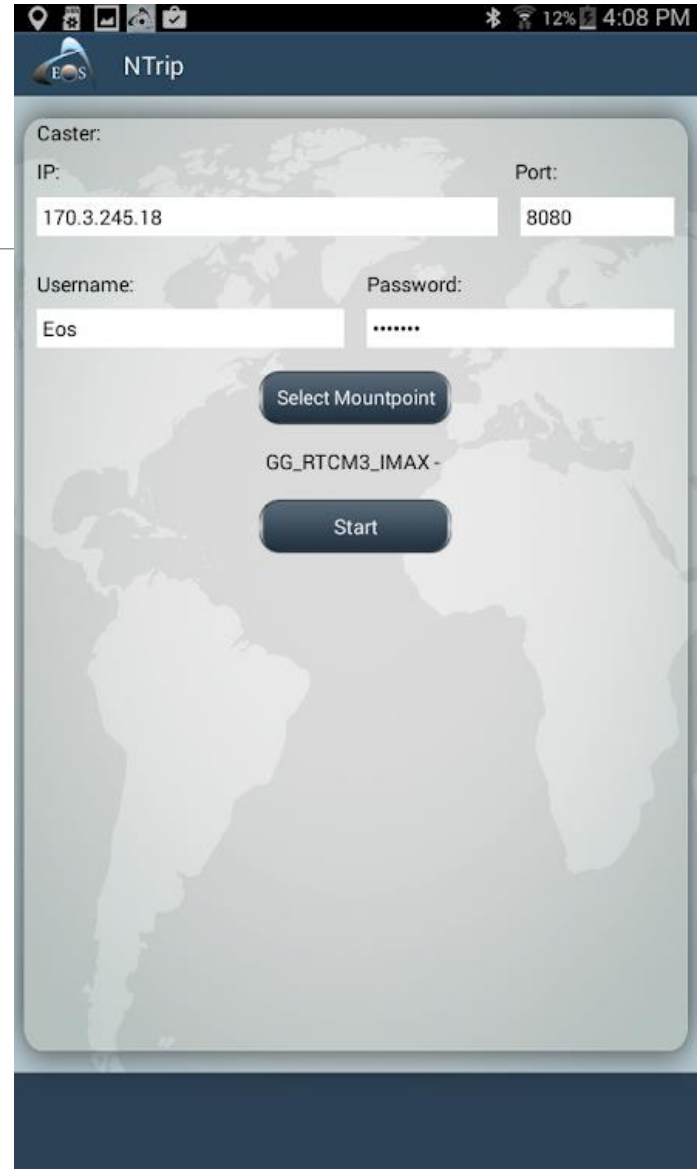
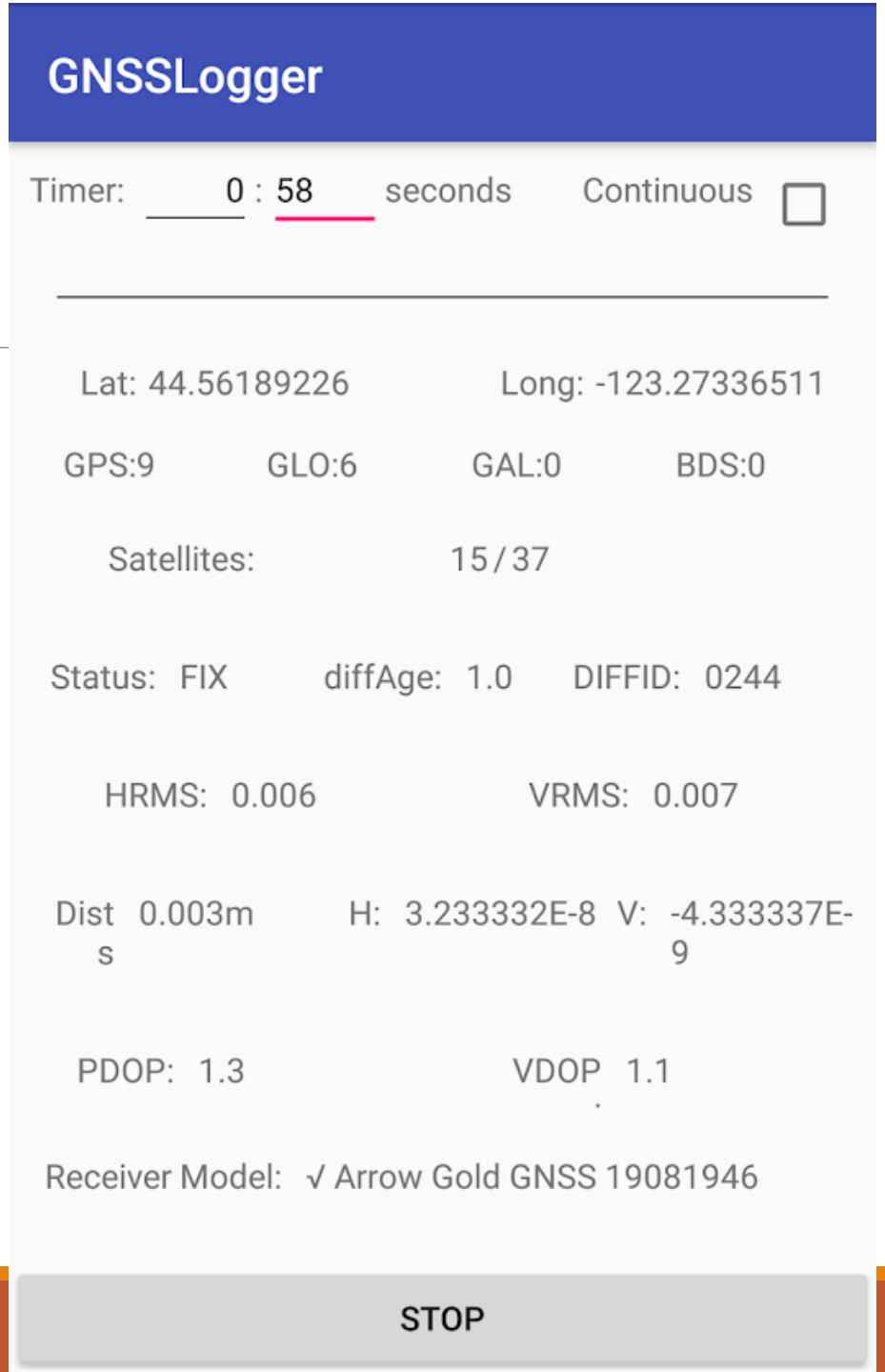




Equipment

Software

- EOS Tools Pro
  - Can see lots of info in real time
  - No easy way to save data
- GNSS logger
  - Custom app
  - Records data from EOS Tools Pro
  - Records about everything that EOS Tools Pro makes available
    - Would be nice if we could have Signal-to-Noise ratio
  - One file per setup, with one line per second of data



Site

20 stations

Varying obstruction percent

- 45 to 88% obstructed**
  - **Had an issue with software classifying some clouds as obstruction
  - Lower obstruction values are larger than what they should be
  - All photos taken within 20 minutes, so similar conditions
- Not entirely representative of conditions
- Still useful as relative ranking

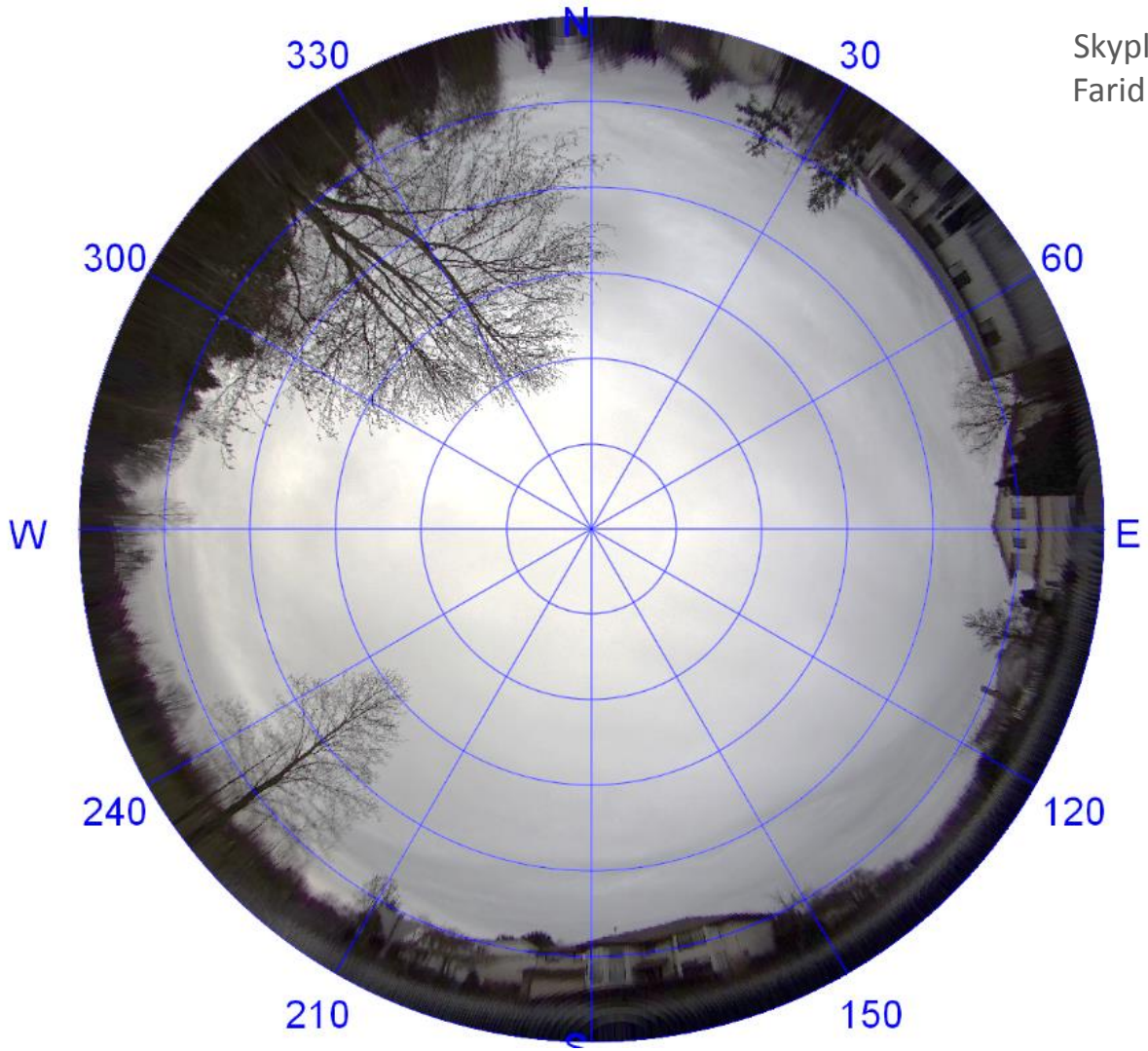
Obstruction direction

- Tried to choose points with obstructions in different directions
- Ex. Not all with a tree to North


6
8
5
7
9
4
3
14
13
11
10
12
2
1
20
15
19
16
17
18
0 5 10 20 30 40
N

Station 18

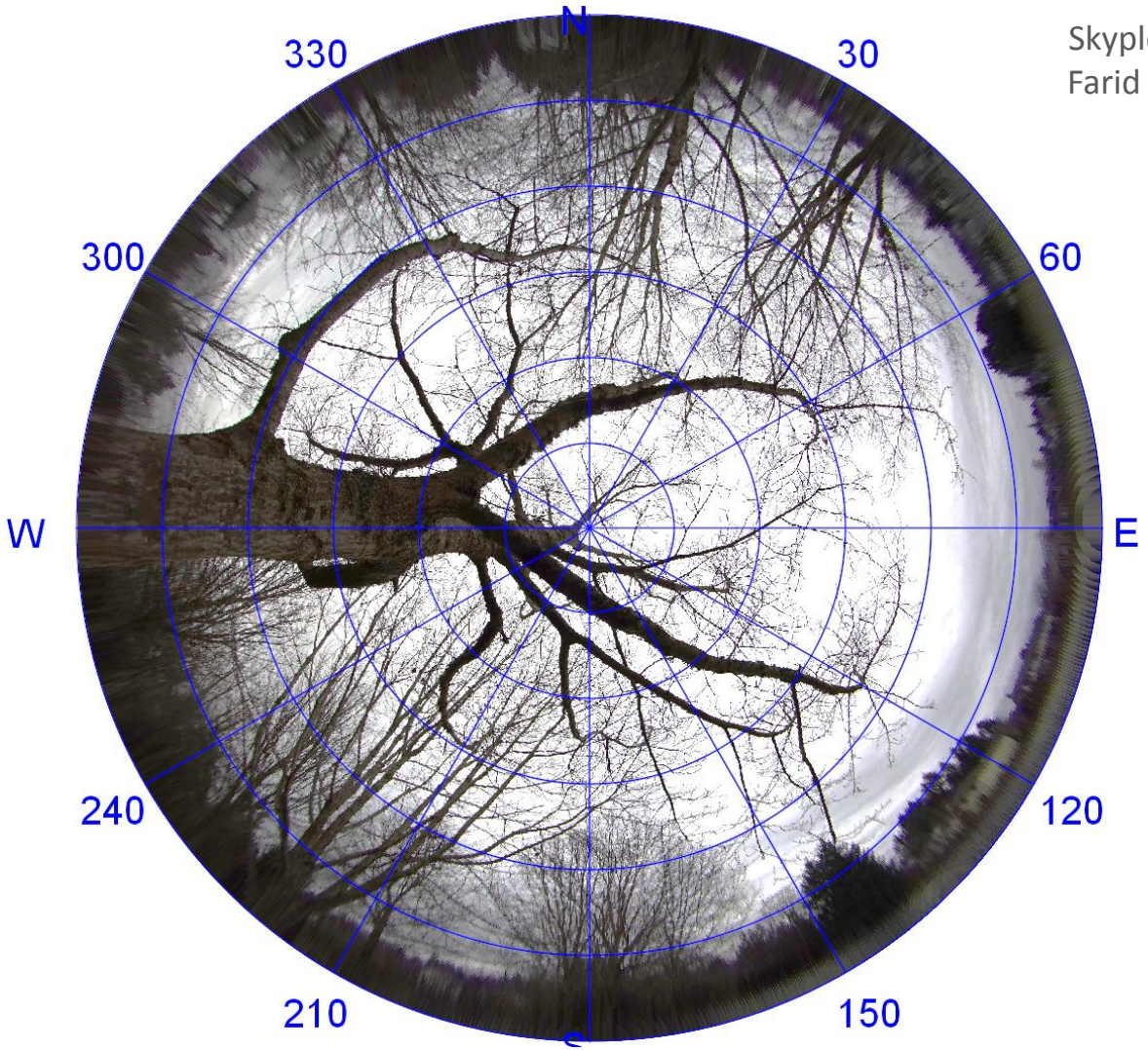
Low Obstruction



Skyplot credit to Farid Javadnejad

Station 04

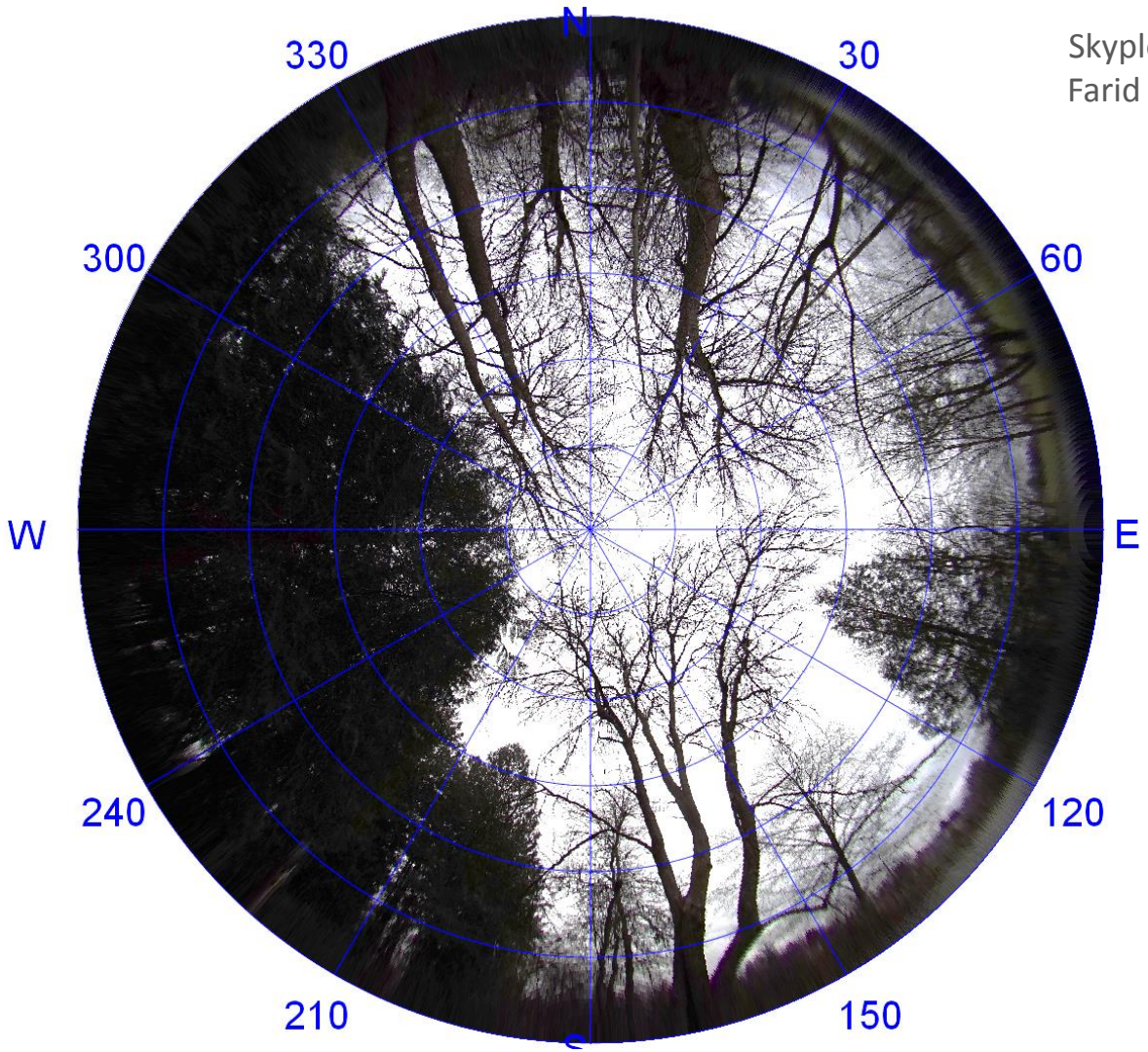
Low-Medium



Skyplot credit to Farid Javadnejad

Station 11

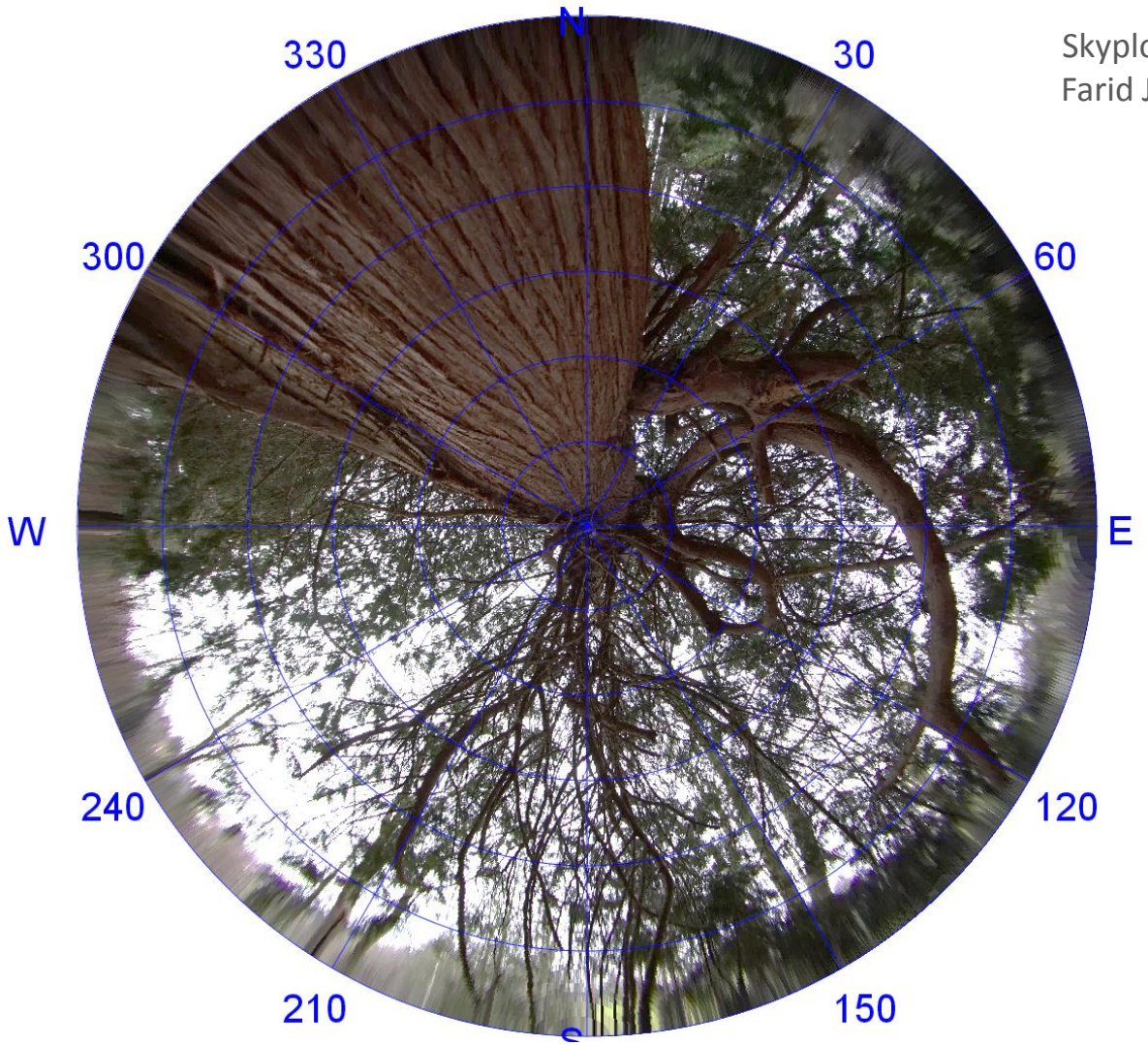
Medium-High



Skyplot credit to
Farid Javadnejad

Station 12

High



Skyplot credit to Farid Javadnejad

“True” Coordinates

Finding ground truth

1. Field work
   a. Static GNSS occupations
   b. Total station measurements
2. Office work
   a. GNSS processing
   b. Combining GNSS and total station measurements
      i. Least squares adjustment using Microsurvey StarNet

Field Work

Static Sessions

- Goal: Three 5-hour sessions
- Reality: Three 3- to 5-hour sessions

Total station

- Two different days, two different instruments
  - Either side of RTK data collection
  - Both 1” precision
- 3+ independent measurements (set-ups) for each station
  - Total station set to average from 3 measurements
- Arbitrary setup locations (resection)
  - No instrument height errors introduced
  - 3+ overlapping stations per setup
- Adjusted before use
  - One by Kuker-Ranken, one by me

Office Work – GNSS

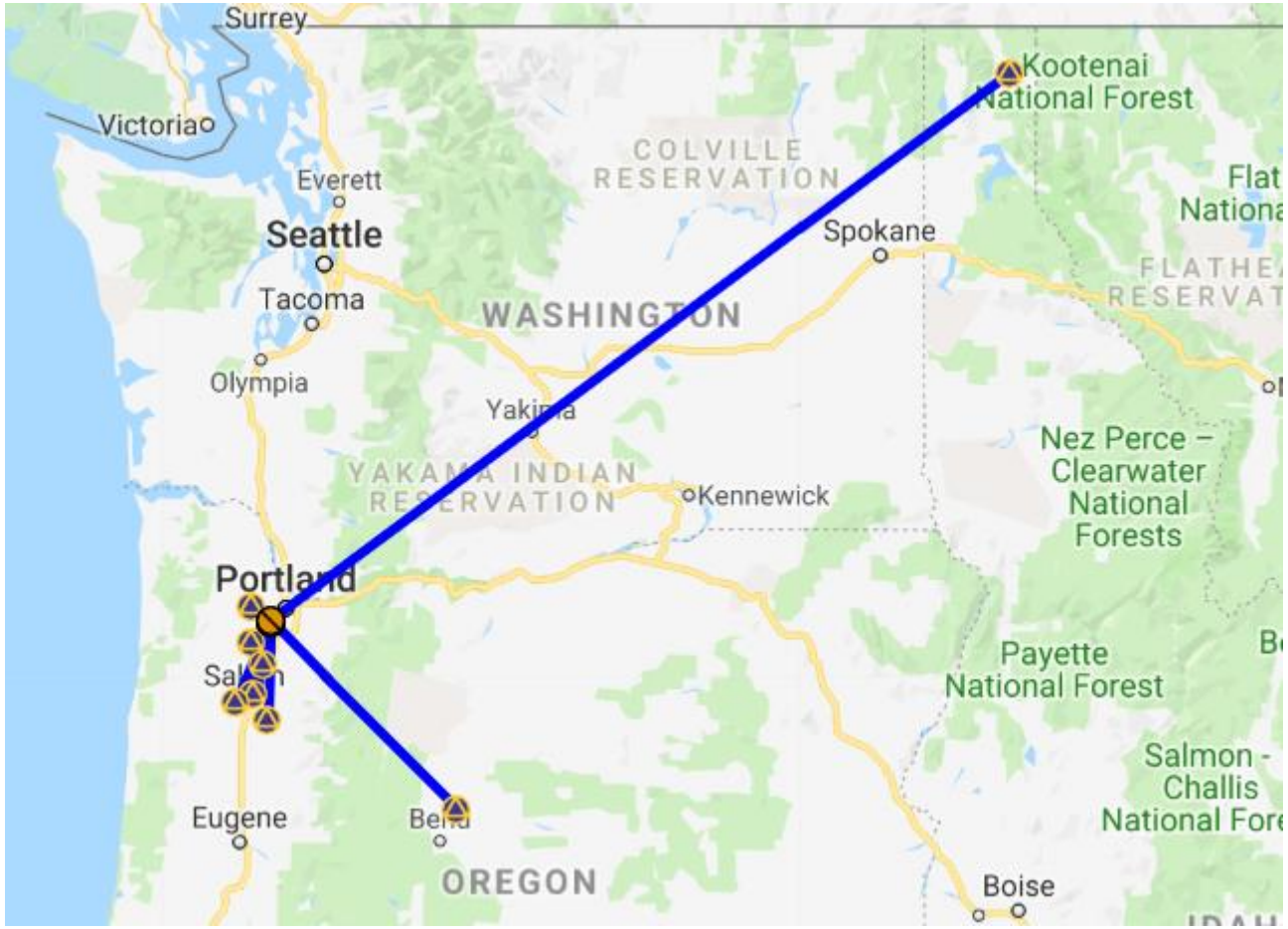
Online Services that do the work for you

- OPUS-Static (Relative Positioning)
  - GPS only
  - Issues with solution quality
    - Observations used < 50%
      - 7 of 15 observations
    - 1 observation wouldn't process at all (station 01)
    - Mostly stations 08 and 15
- Trimble Centerpoint RTX (Precise Point Positioning)
  - GPS, GLONASS, Galileo, BeiDou
  - Solution quality
    - 7 of 15 with standard deviation greater than 0.015 m
    - Stations 08, 15, and 02
  - Agreed well with OPUS solutions

Office Work – GNSS

More hands-on: OPUS-Projects

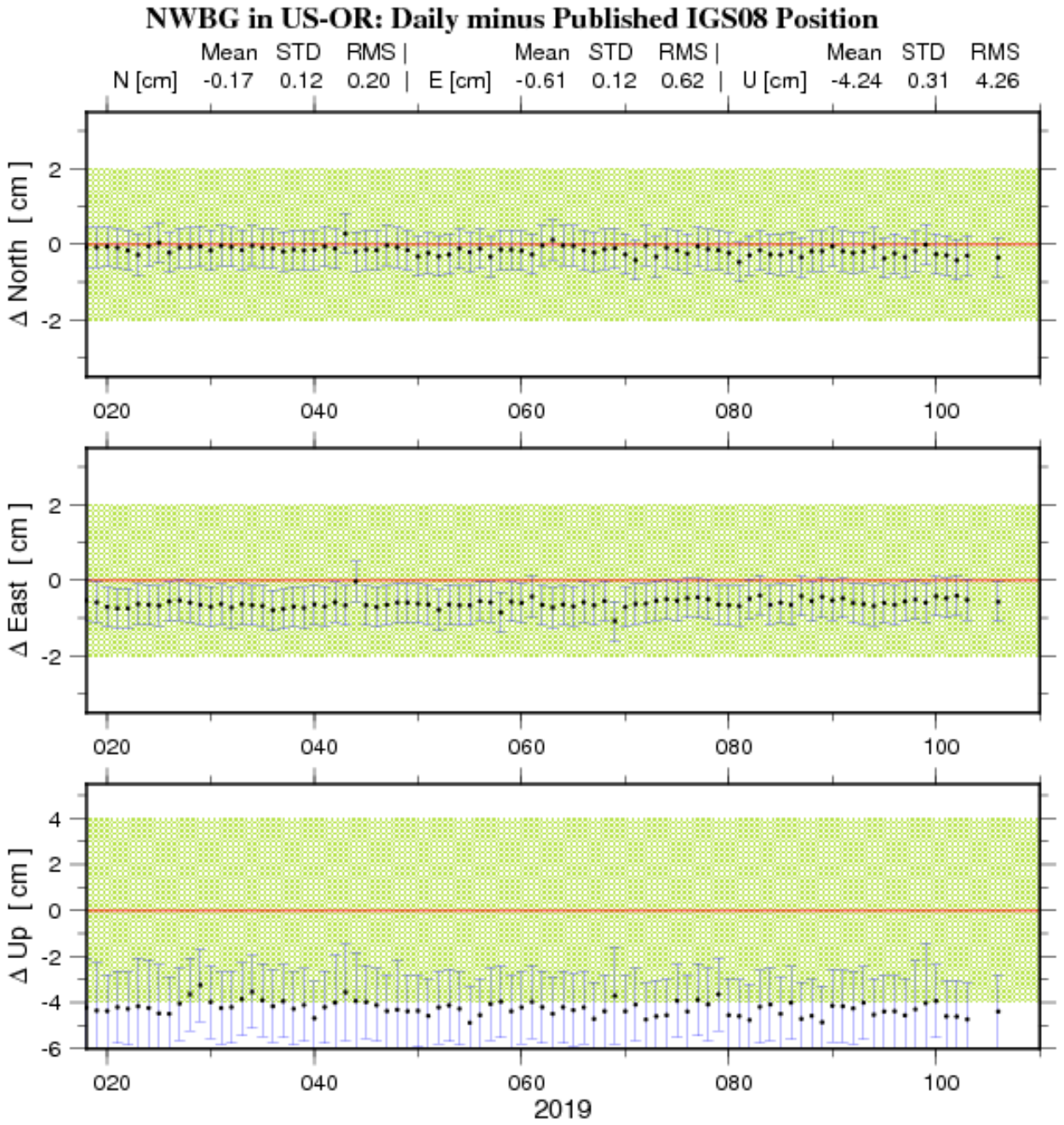
- Really powerful tool
  - Required manager training (free)
  - Can fine-tune and get better solution
  - Can also make a mess of it



Office Work – GNSS

More hands-on: OPUS-Projects

- Really powerful tool
  - Required manager training (free)
  - Can fine-tune and get better solution
  - Can also make a mess of it
- Choosing CORS
  - Time-series plots
  - Check short-term near survey date
  - Don’t want:
    - Consistent bias
    - Large variability
  - Okay:
    - Both high/low
    - Within error bars (1 std dev)



Office Work – StarNet

GNSS baselines

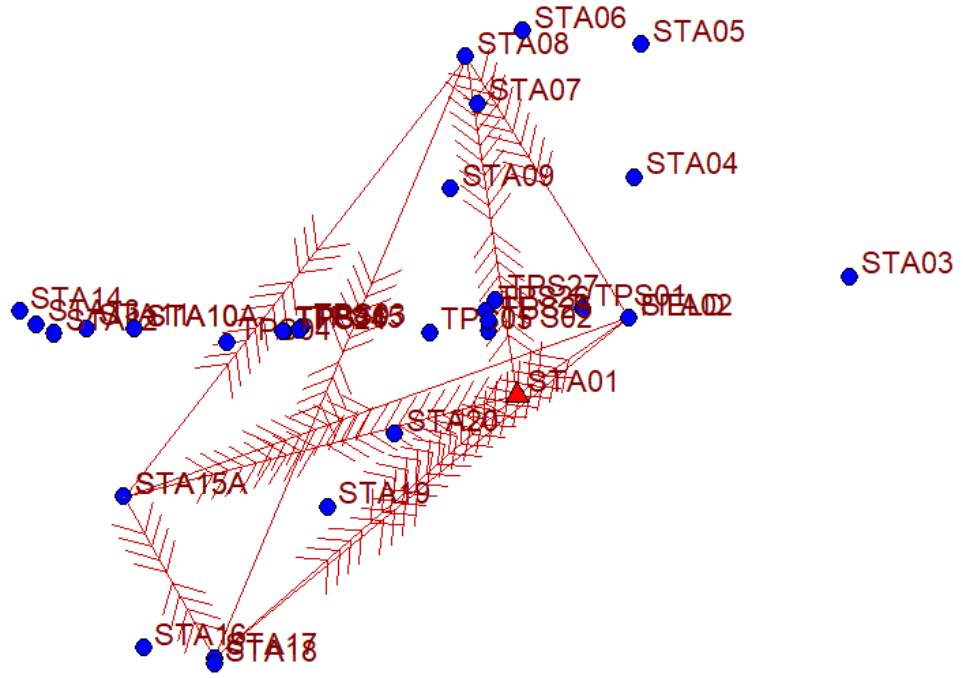
- Export from Leica Infinity

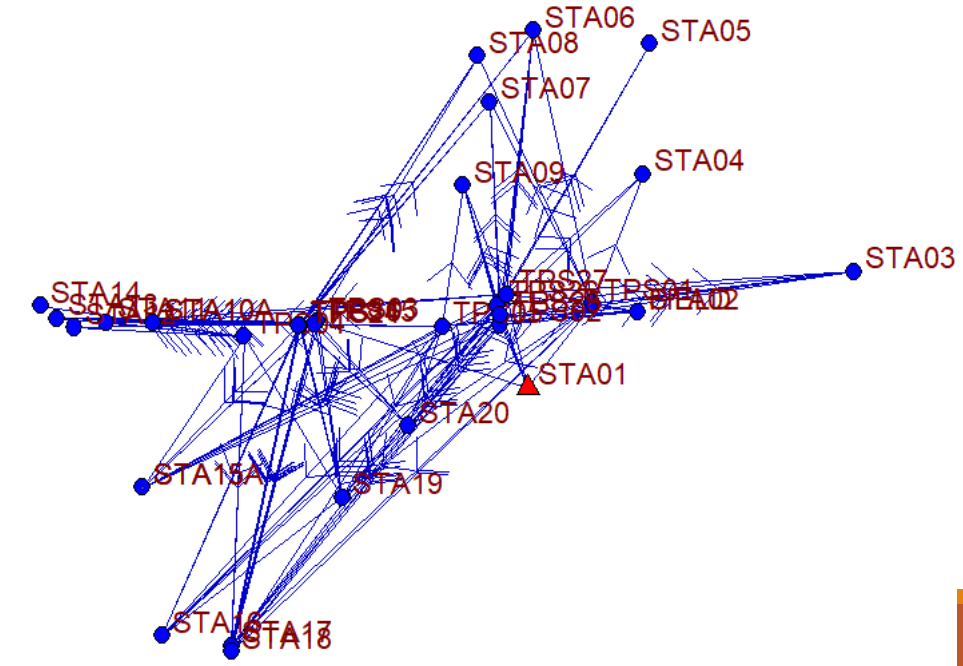
GNSS coordinates

- From OPUS-S, TrimbleRTX, and OPUS-Projects
- Weighted with provided standard deviations

Total Station measurements

- 3+ independent shots, each averaged from 3 measurements
- Angle and distance





Office Work – StarNet

Have to hold 1 point fixed

- Chose the station with best agreement between static coordinates
- Chose the coordinates with smallest estimated standard deviations

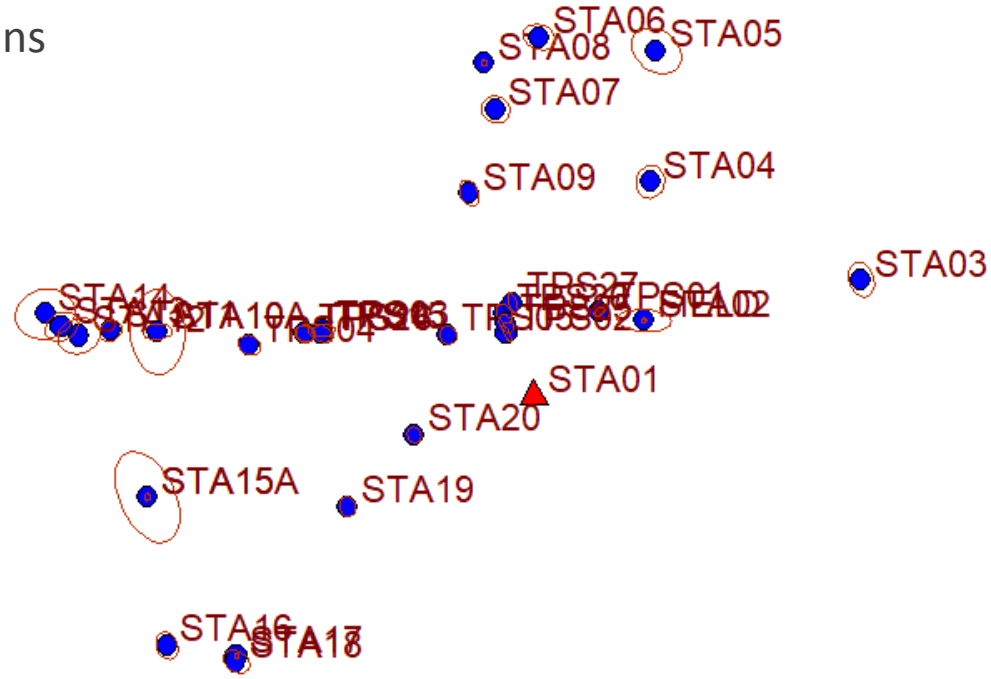
Error ellipses

- Shown multiplied by 1000
- Can help you find errors

Data format

```
#TPS03 March 2019
# From-At-To          AngleRight   HzDist   VertDist
#M STA01-TPS03-STA01BS   0 00 00.0    -        -
M STA01-TPS03-STA20    31-41-52.8 37.4622 2.0288
M STA01-TPS03-STA18    87-23-40.4 92.5482 0.9569

#OPUS-S Session A
C STA02 2319542.828 199310.830   34.142   0.006    0.011    0.041
```



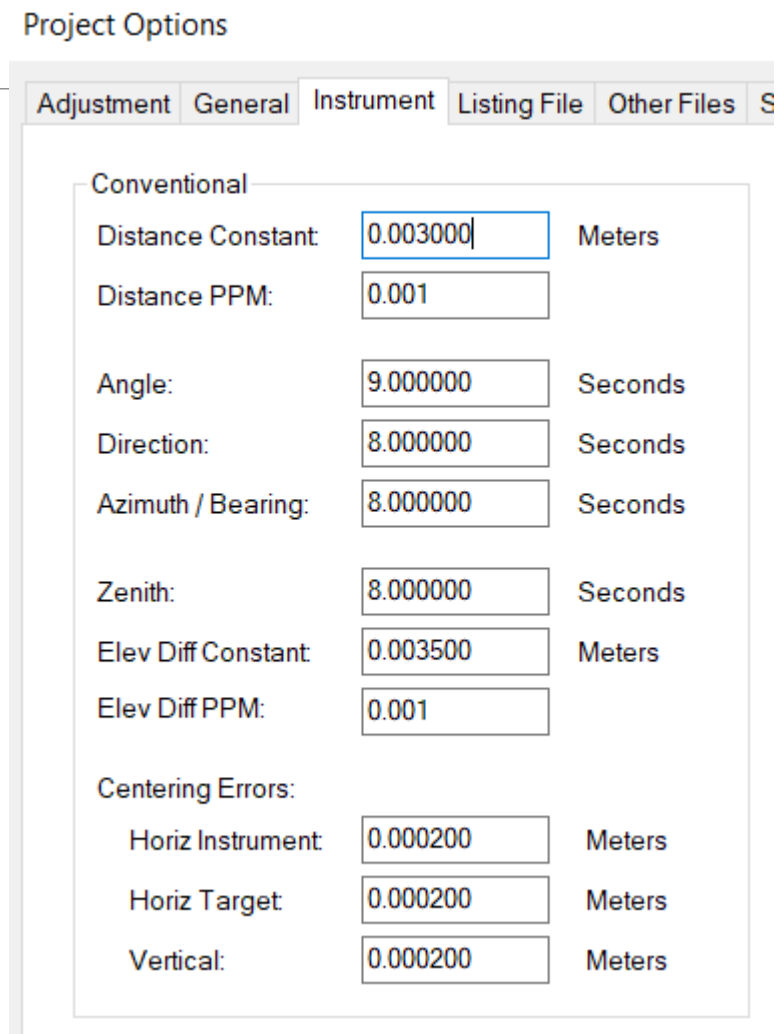
Office Work – StarNet

Chi-Squared Test

- Want error factors about 1
- Means you're estimating errors correctly
- Edit estimated errors in project options

```
Statistical Summary
Observation      Count    Error Factor
  Angles           112           1.008
  Distances        112           1.059
  Elev Diffs       112           0.992
  GPS Deltas       366           0.994
  Total            702           1.006

Chi-Square Test at 5.00% Level Passed
  Lower/Upper Bounds (0.944/1.056)
```



RTK Testing

RTK testing – Setup

Two receivers hooked up to same antenna

- Test two constellations at the same time
- 4-constellation and 2-constellation
- 3-constellation and 1-constellation

Number of Constellations	GPS	GLONASS	Galileo (GAL)	BeiDou (BDS)
4	X	X	X	X
3	X		X	X
2	X	X		
1	X			

RTK testing

Aimed for 15 rounds

- i.e. 15 set-ups per mark
- Achieved 13.5 to 14 rounds
- Over 4 days

Observation length

- If fixed: 30 sec
- If float: 180 sec (3 min)

Raw Data

What's in the raw data

GNSS logger writes:

- Date/Time
- Lat/Long
- mslHeight & geoid separation
- Satellites
- RTK info
- Estimated RMS
- PDOP

What I added to each line:

- From file name
  - Station number
  - Number of constellations
- State plane coordinates
- Delta easting, northing, up (ellipsoid)

Summarized using:

- RMS, percent fix

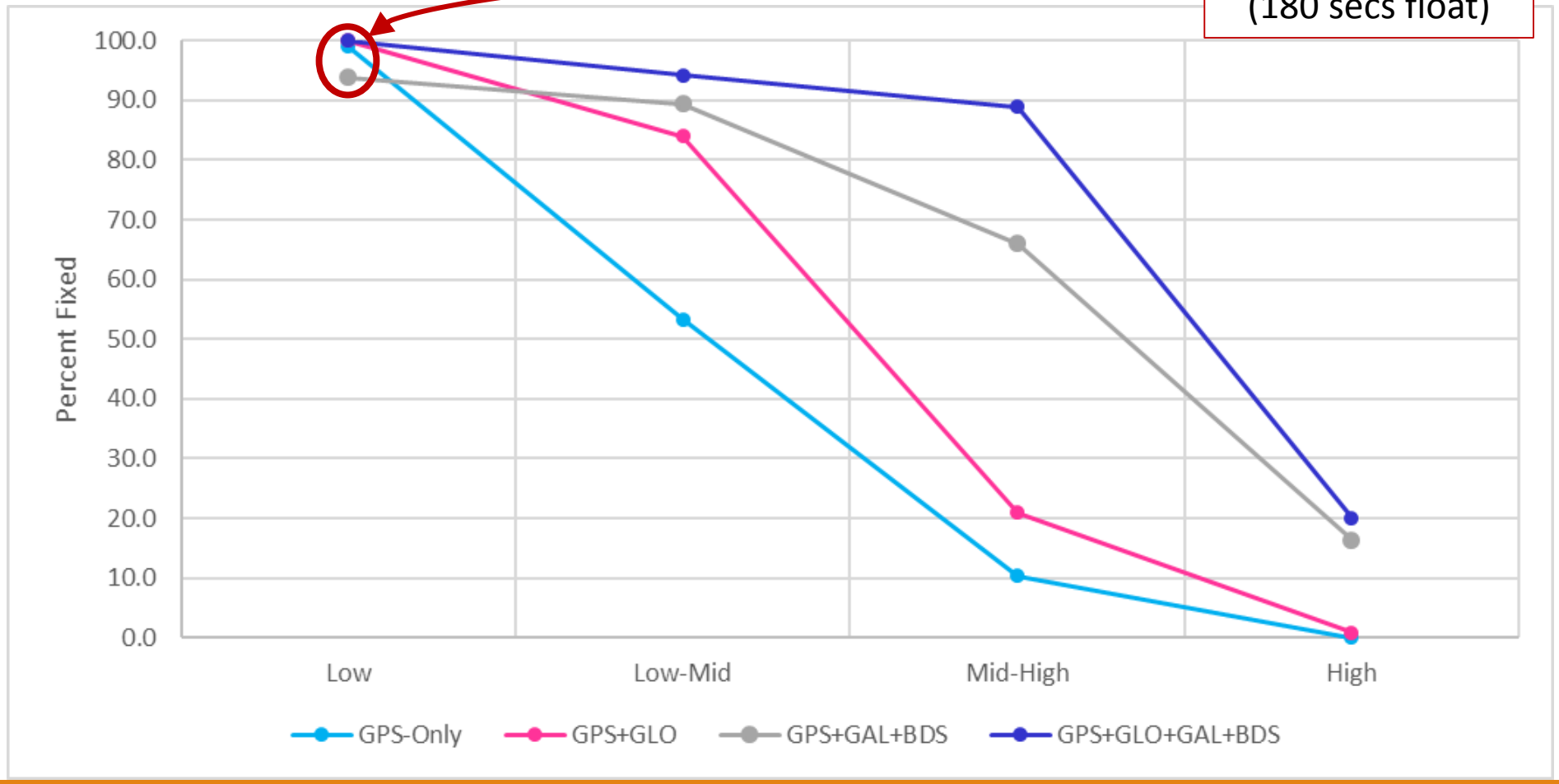
Date	UTC_time	Lat	long	mslHeight	undulation	Sats	SatsInView	satGPS	satGLO	satGAL	satBDS	diffStatus
20190103	235937	45.4369096773333	-122.807211957833	56.723	-20.405	9	38	9	0	0	0	FIX
20190102	231926	45.4369096683333	-122.807211956333	56.736	-20.405	8	38	8	0	0	0	FIX
20190103	235935	45.4369096798333	-122.807211959166	56.728	-20.405	9	38	9	0	0	0	FIX
20190103	235941	45.4369096816666	-122.807211957499	56.725	-20.405	9	38	9	0	0	0	FIX

diffID	diffAge	EstHRMS	EstVRMS	VDOP	PDOP	receiverModel	fileName
244	1	0.004	0.005	1.4	1.6	â^šArrowGoldGNSS19081946	1SL1946-1-20190103h15m59s18.csv
244	1	0.004	0.004	1.5	2.1	â^šArrowGoldGNSS19081946	1SL1946-1-20190102h15m19s18.csv
244	1	0.004	0.004	1.4	1.6	â^šArrowGoldGNSS19081946	1SL1946-1-20190103h15m59s18.csv
244	1	0.004	0.004	1.4	1.6	â^šArrowGoldGNSS19081946	1SL1946-1-20190103h15m59s18.csv

Results

Percent Fix vs Obstruction

This difference is 1 observation (180 secs float)



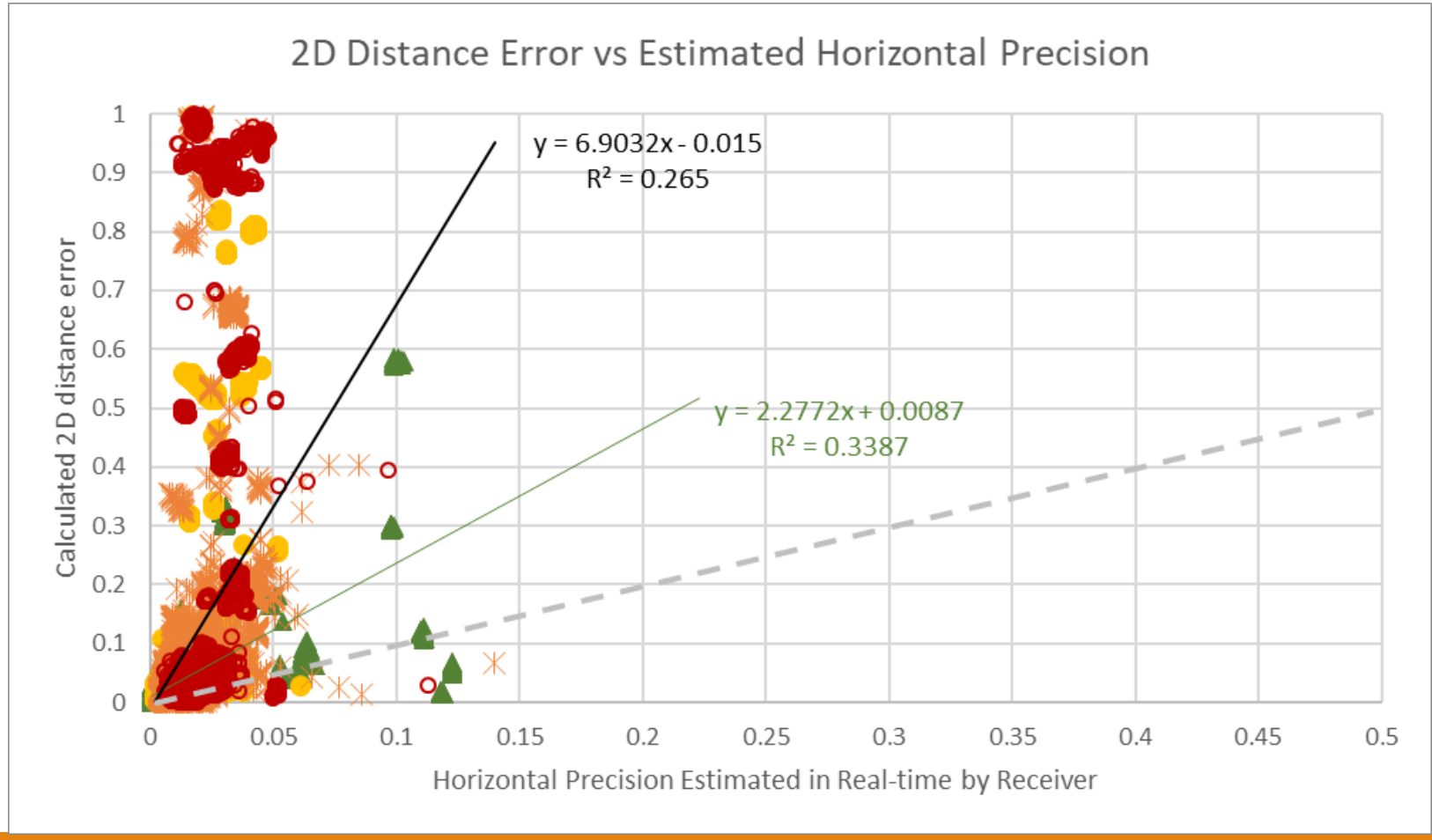
Receiver Estimated Precision

Ideal

- Receiver correctly estimates precision
- Estimated precision = calculated error
- 1:1 relationship

Reality

- Receiver overstating precision
  - By about 7x overall
- Better for less obstructed marks
  - About 2x for low obstruction



Quick Outlier Removal

Following plots exclude

- Float solutions
- Receiver estimated precision > 1 m
  - Horizontal or Vertical
- Horizontal residual > 1.5 m
  - In case of misnamed points
  - Closest distance of two stations ~1.6 m

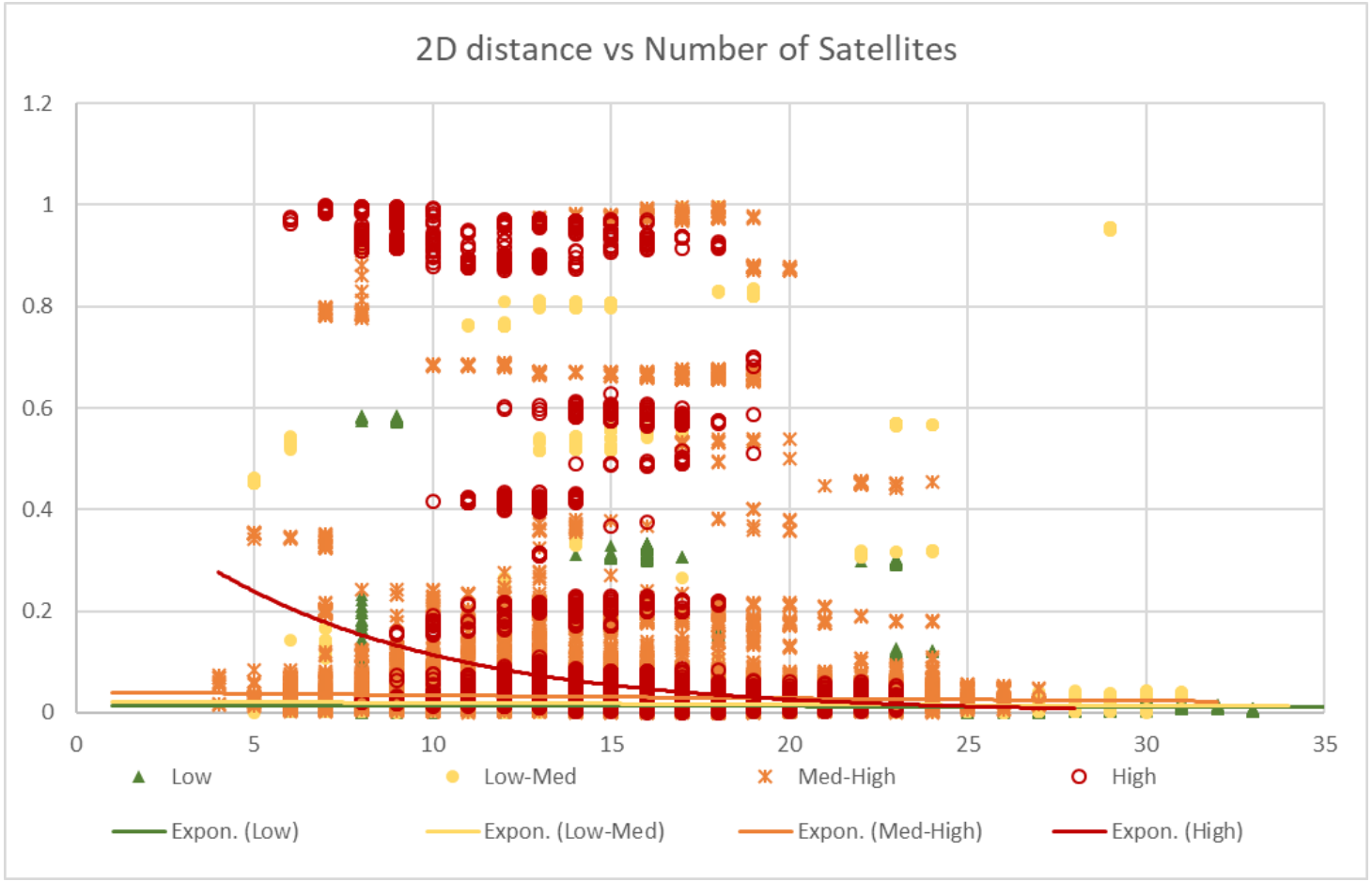
Later will perform more thorough outlier removal

- Need to look at large vertical residuals
- Collected two rounds with all receivers running 4 constellations
  - Visual inspection: no obvious bias

Increase Satellites, Reduce Horizontal Error?

Horizontal residual

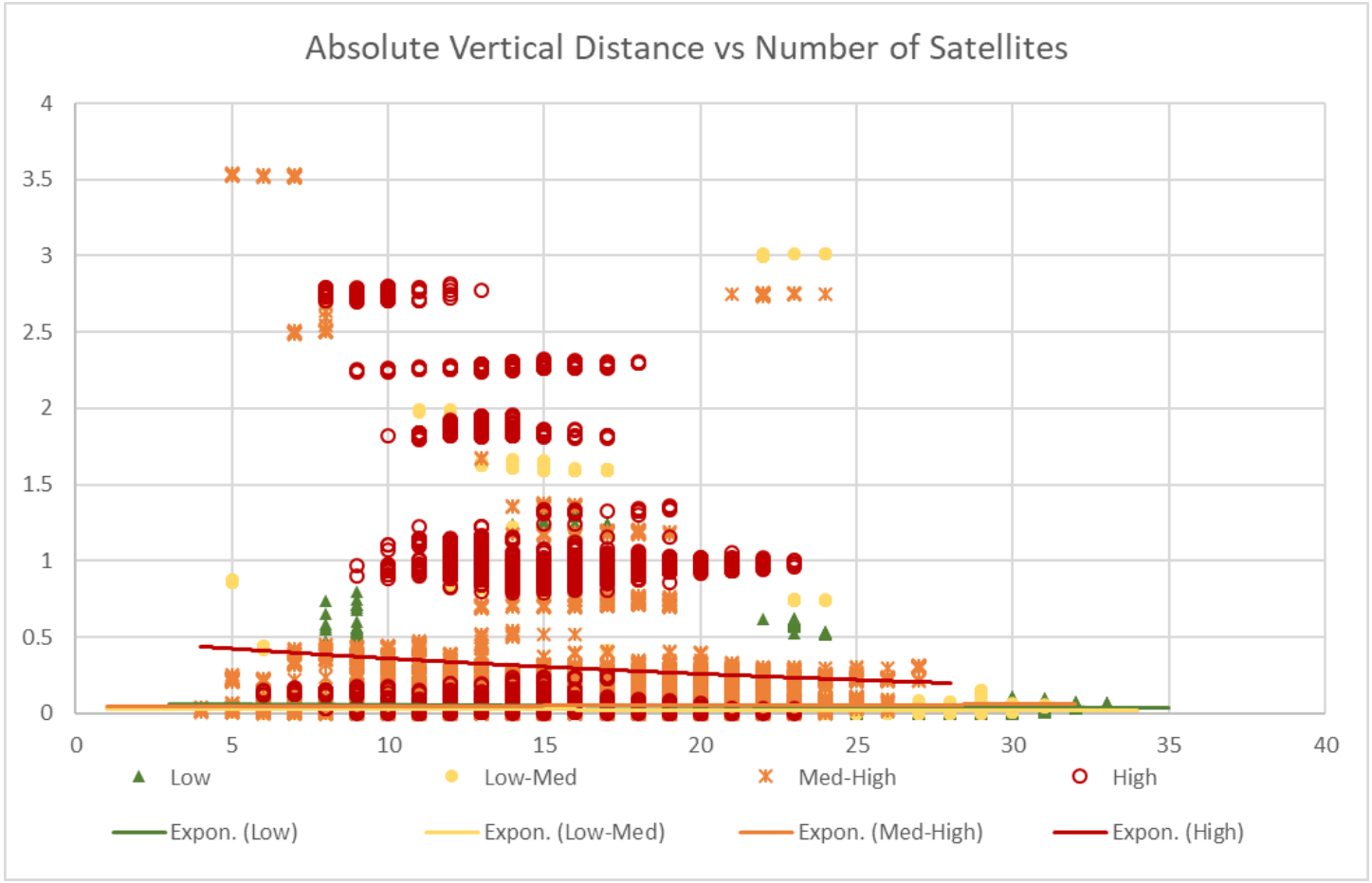
- Low – Medium obstruction
  - More satellites (regardless of constellation) does not reduce residual
- High obstruction
  - More satellites tend to reduce horizontal residual

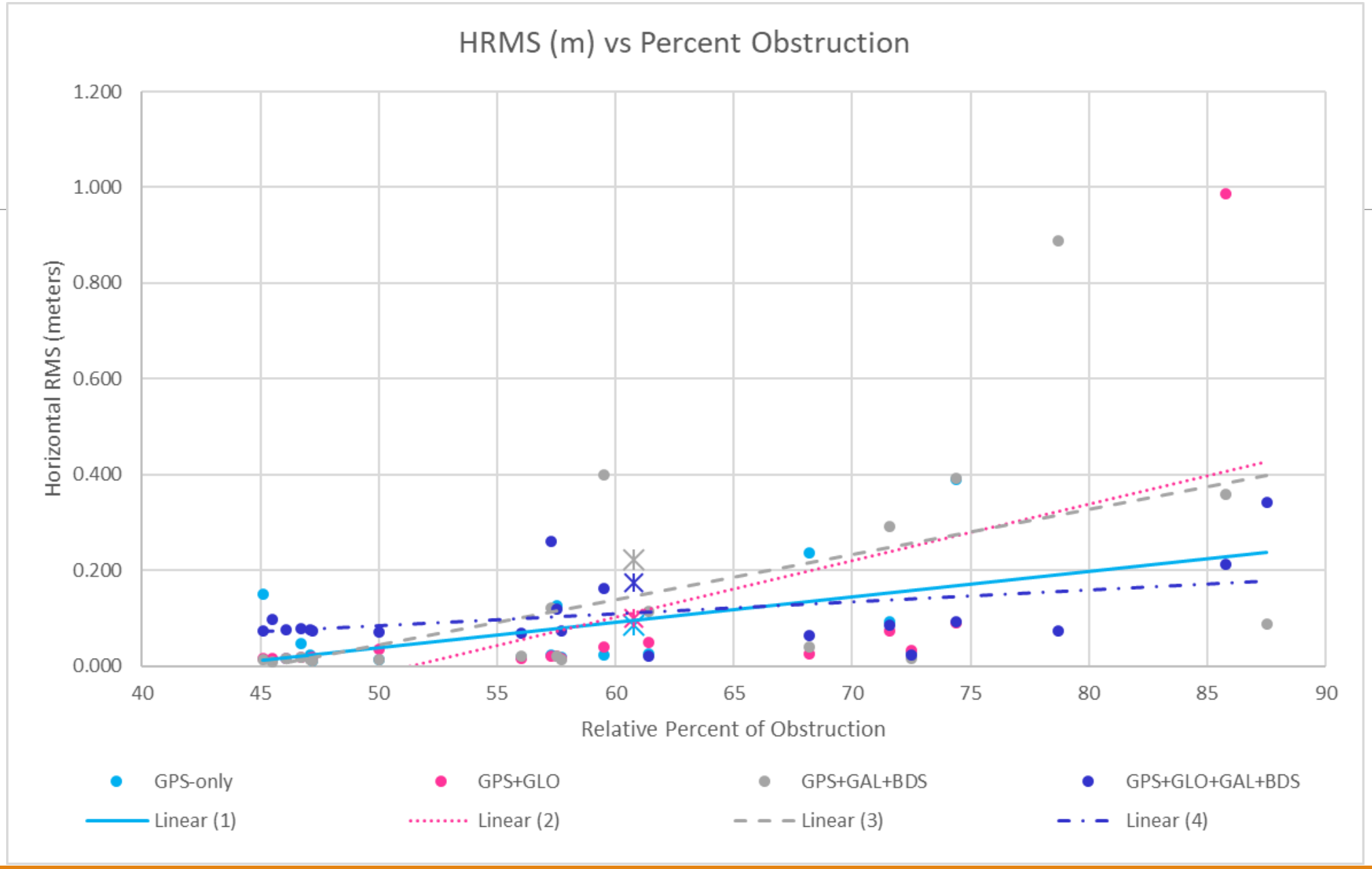


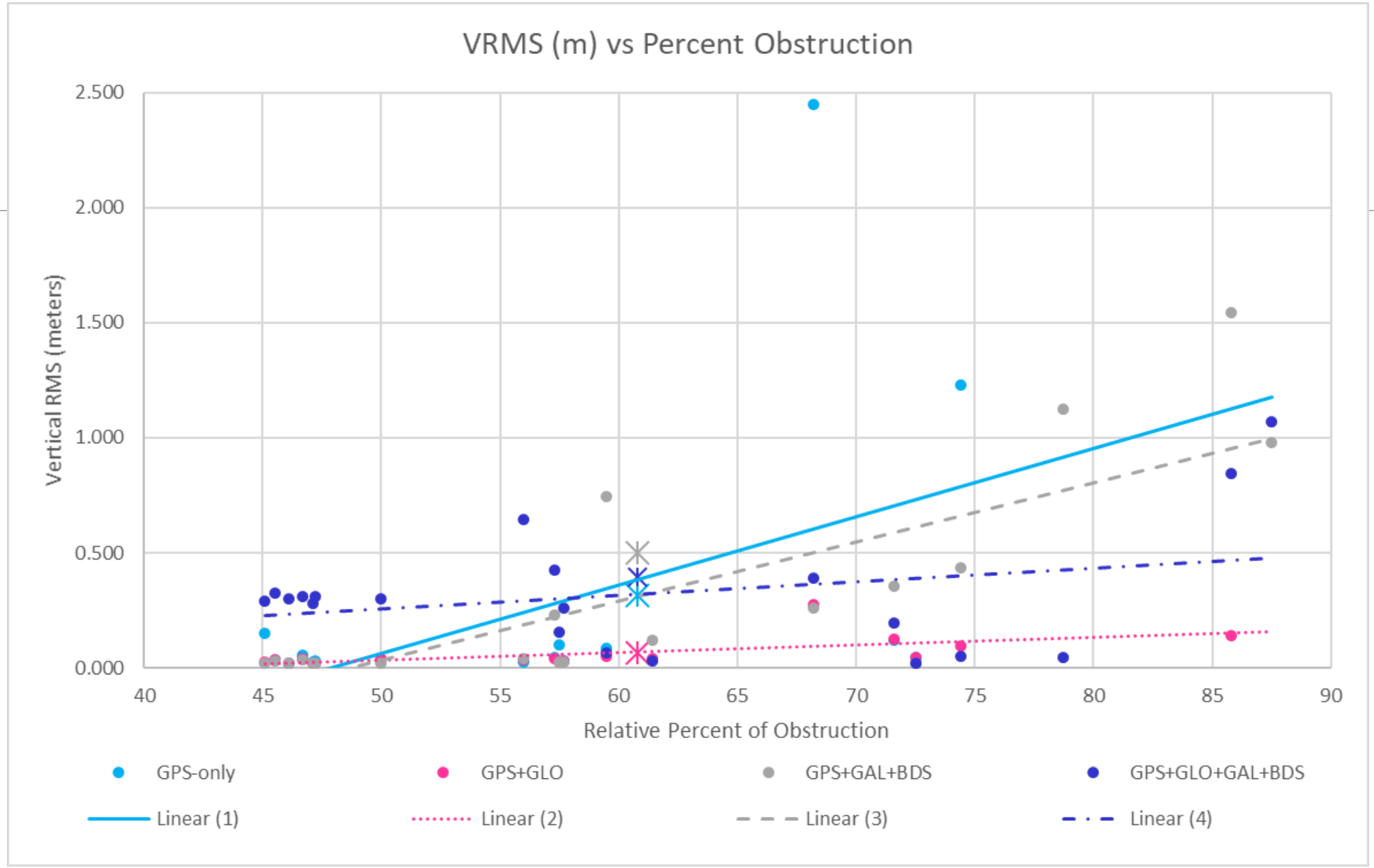
Increase Satellites, Reduce Vertical Error?

Vertical residual

- Similar result
- Low – Med obstruction
  - More satellites have no obvious impact on vertical residual
- High obstruction
  - More satellites reduce vertical residual

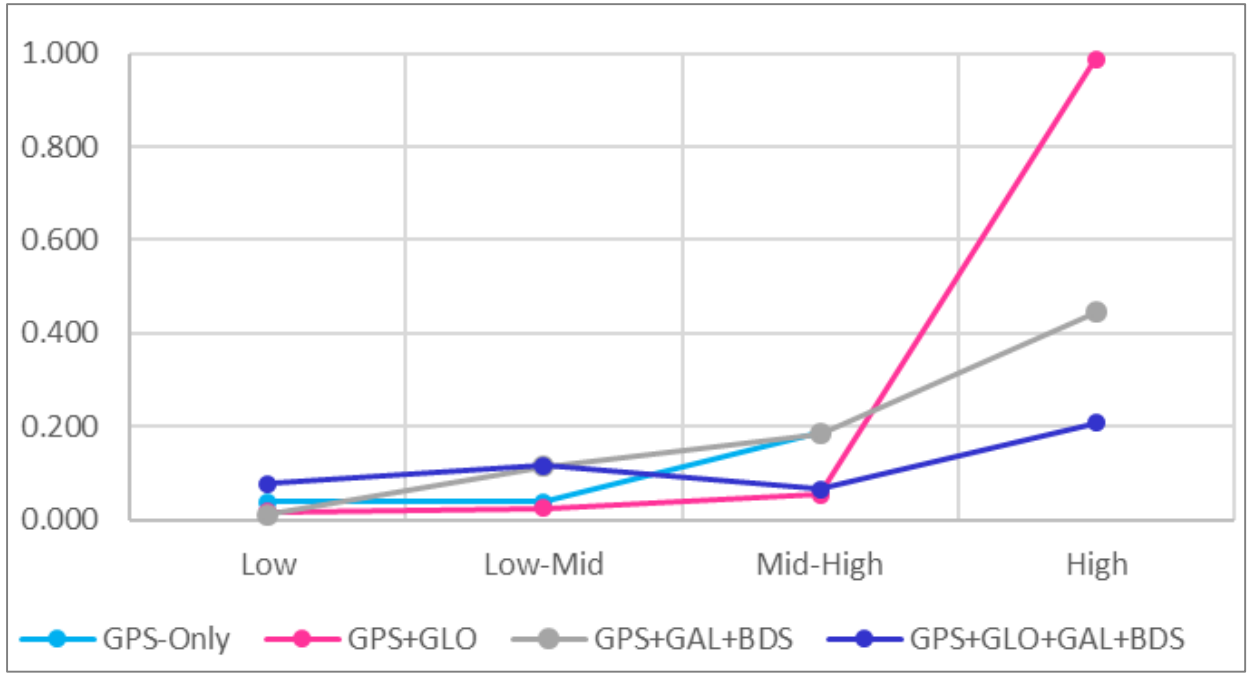



HRMS (m) vs Percent Obstruction
Horizontal RMS (meters)
1.200
1.000
0.800
0.600
0.400
0.200
0.000
40
45
50
55
60
65
70
75
80
85
90
Relative Percent of Obstruction
GPS-only
GPS+GLO
GPS+GAL+BDS
GPS+GLO+GAL+BDS
Linear (1)
Linear (2)
Linear (3)
Linear (4)

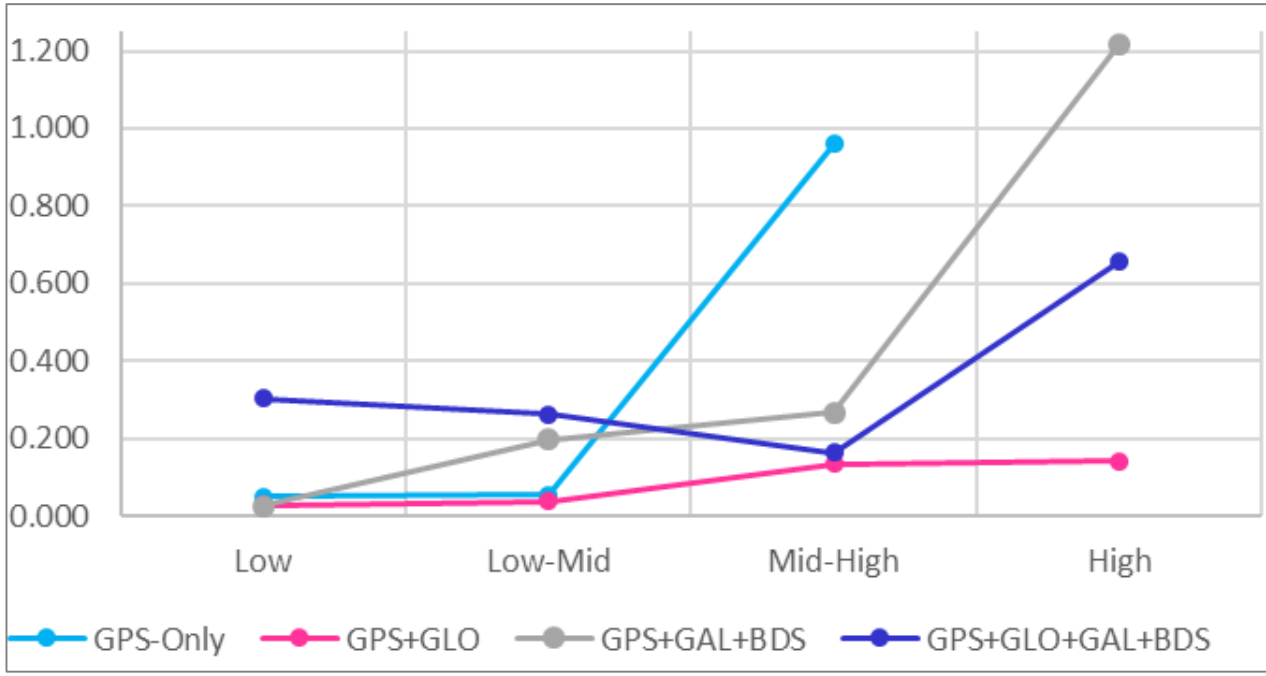

VRMS (m) vs Percent Obstruction
Vertical RMS (meters)
2.500
2.000
1.500
1.000
0.500
0.000
40
45
50
55
60
65
70
75
80
85
90
Relative Percent of Obstruction
GPS-only
GPS+GLO
GPS+GAL+BDS
GPS+GLO+GAL+BDS
Linear (1)
Linear (2)
Linear (3)
Linear (4)

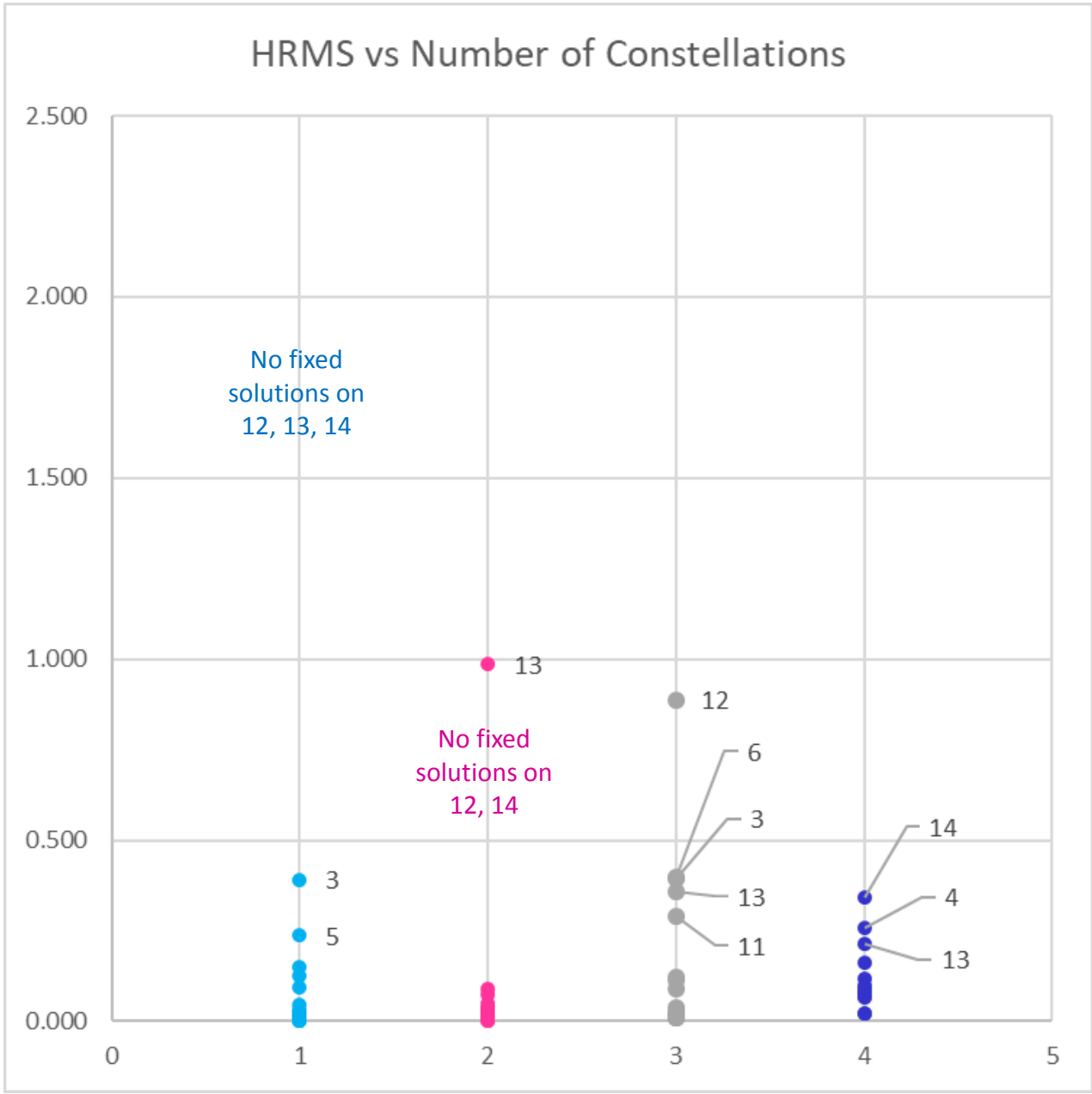
RMS vs Obstruction Category

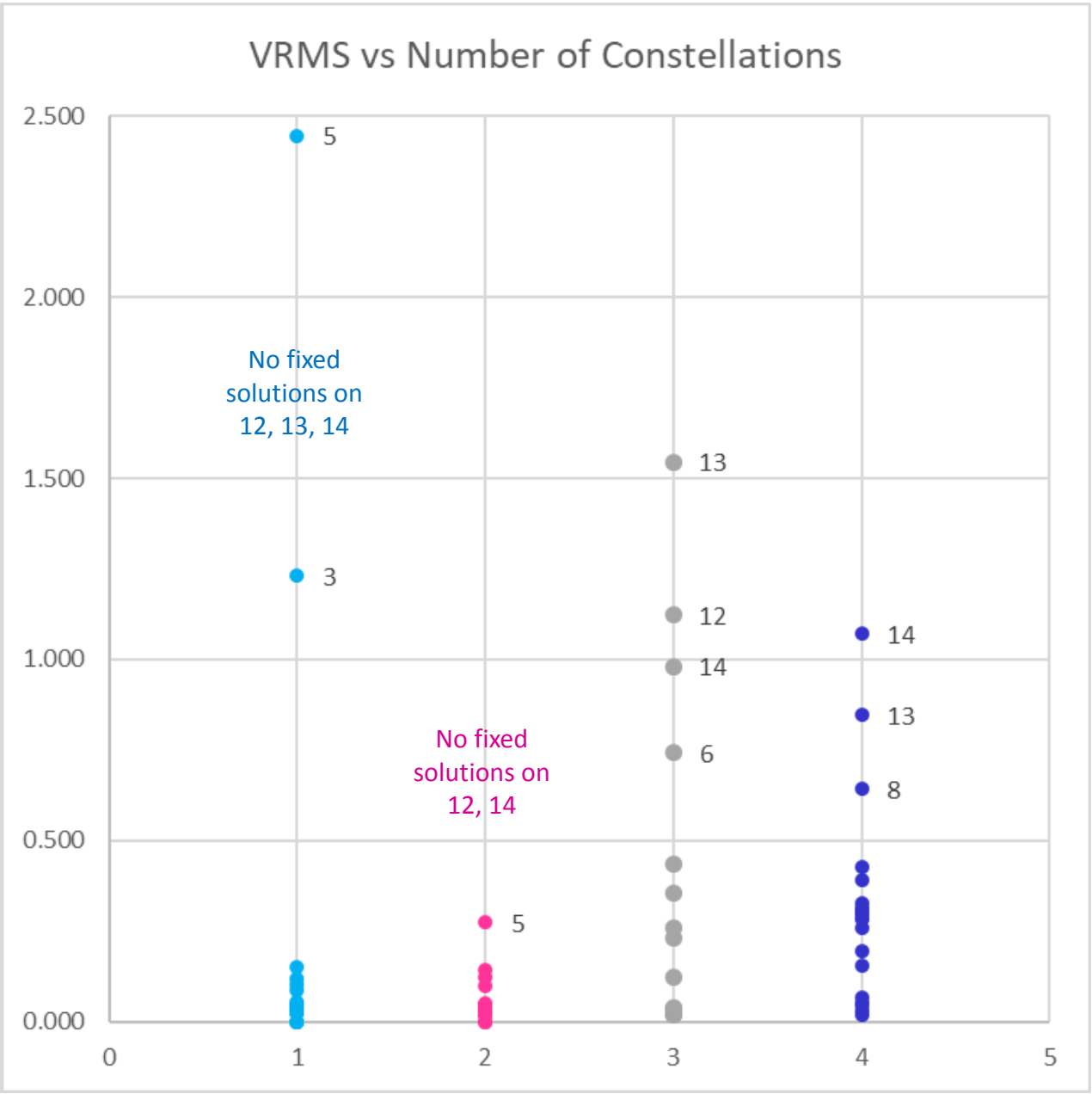
HORIZONTAL RMS (M)

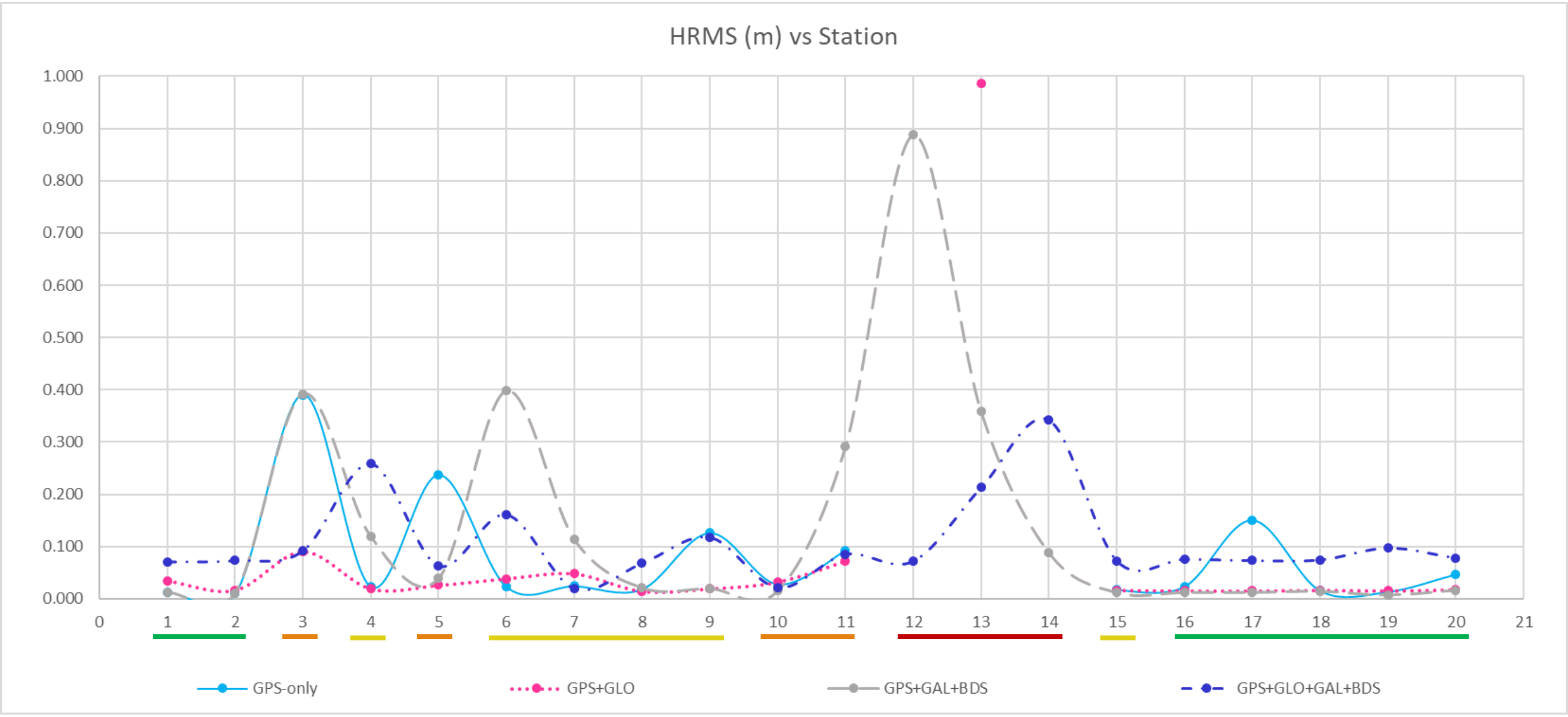


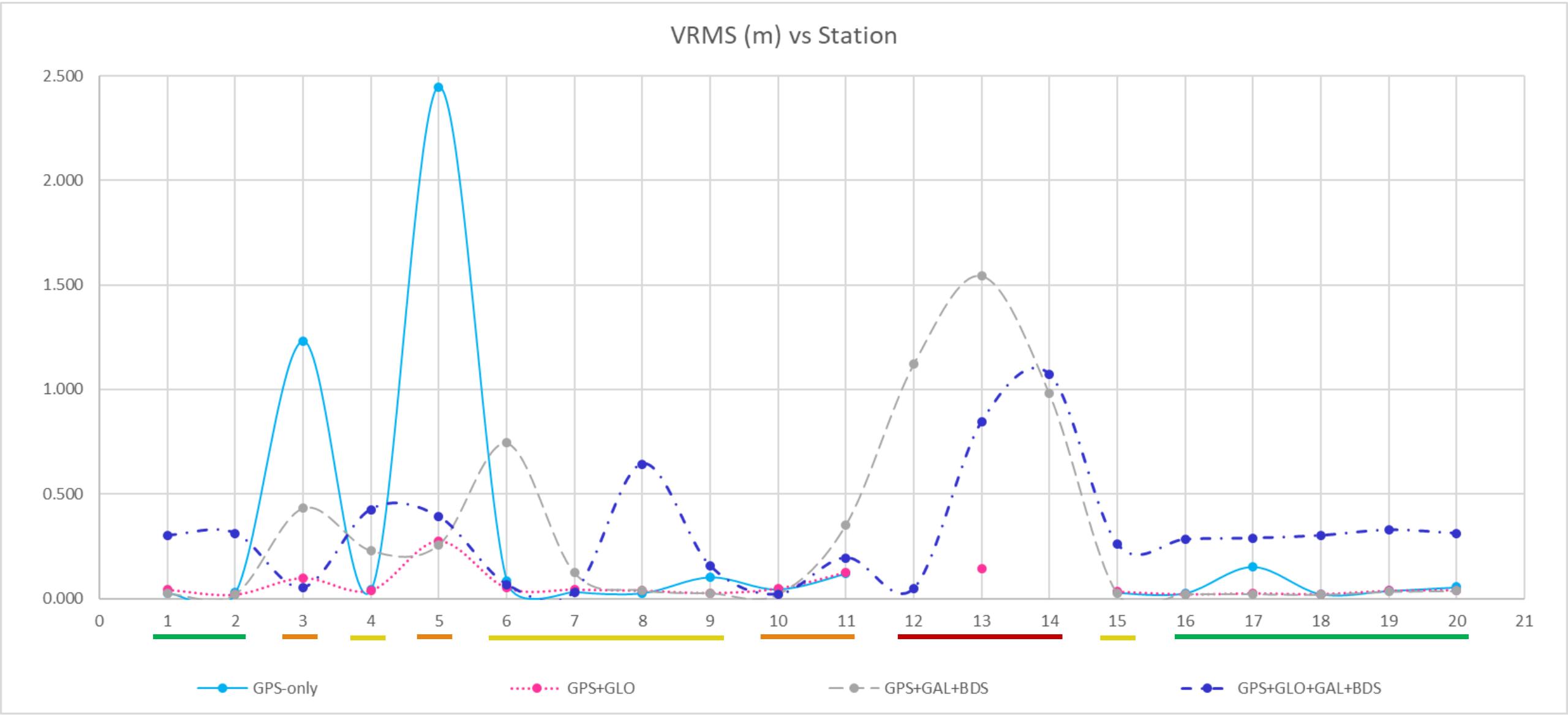
VERTICAL RMS (M)

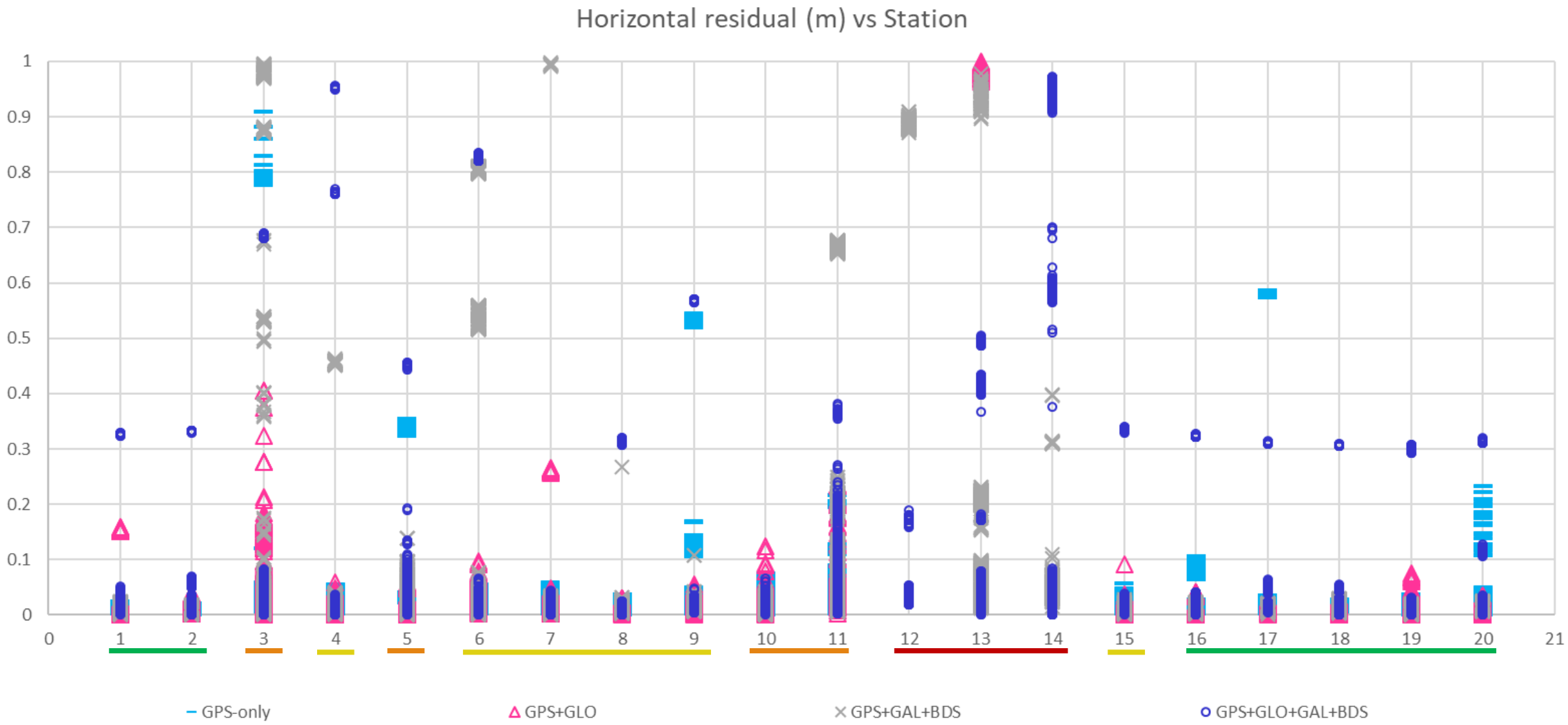


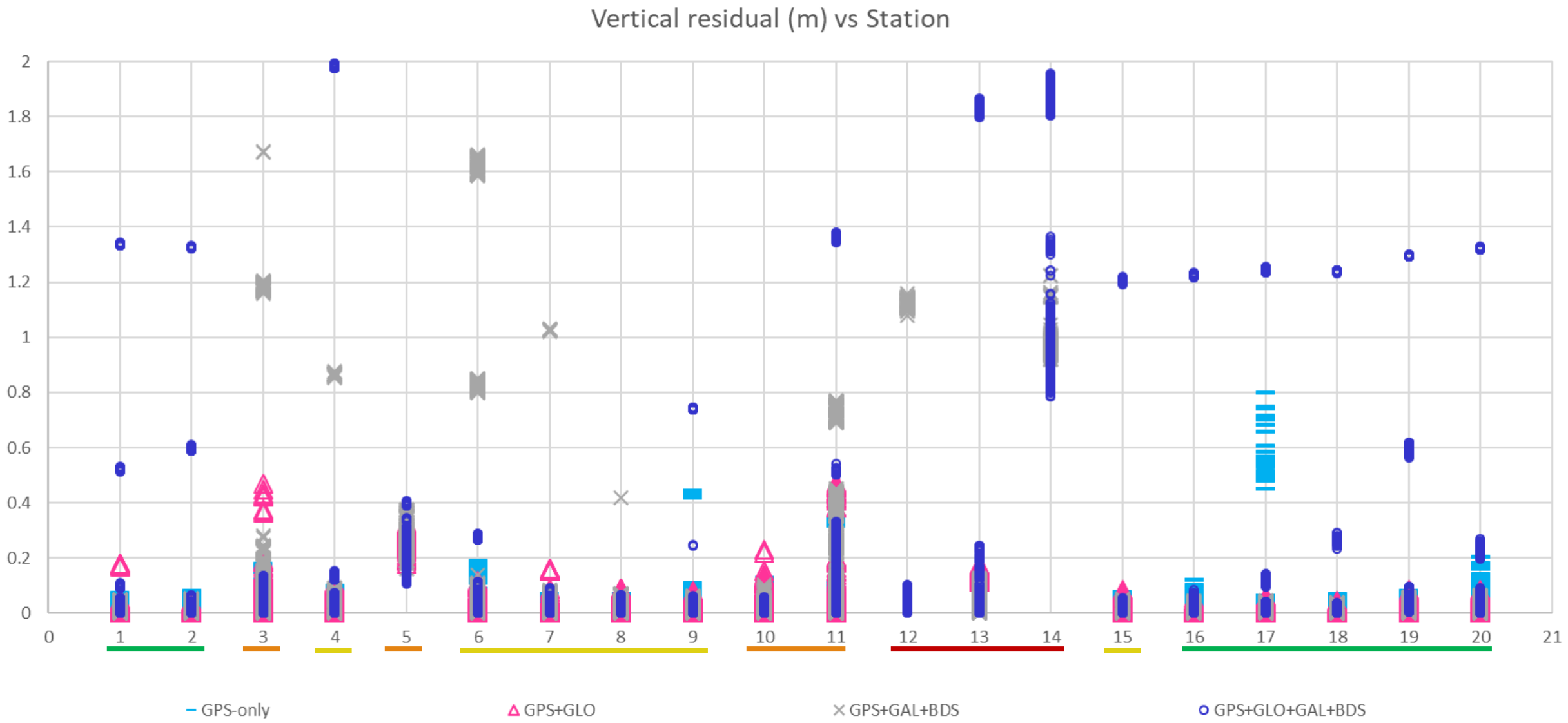

HRMS vs Number of Constellations
2.500
2.000
1.500
1.000
0.500
0.000
0
1
2
3
4
5
No fixed solutions on 12, 13, 14
No fixed solutions on 12, 14
3
5
13
12
6
3
13
11
14
4
13


VRMS vs Number of Constellations
2.500
2.000
1.500
1.000
0.500
0.000
0
1
2
3
4
5
No fixed solutions on 12, 13, 14
No fixed solutions on 12, 14
5
3
13
12
14
6
5
14
13
8


HRMS (m) vs Station
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
GPS-only
GPS+GLO
GPS+GAL+BDS
GPS+GLO+GAL+BDS


VRMS (m) vs Station
2.500
2.000
1.500
1.000
0.500
0.000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
GPS-only
GPS+GLO
GPS+GAL+BDS
GPS+GLO+GAL+BDS


Horizontal residual (m) vs Station
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
GPS-only
GPS+GLO
GPS+GAL+BDS
GPS+GLO+GAL+BDS


Vertical residual (m) vs Station
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
GPS-only
GPS+GLO
GPS+GAL+BDS
GPS+GLO+GAL+BDS

Conclusions

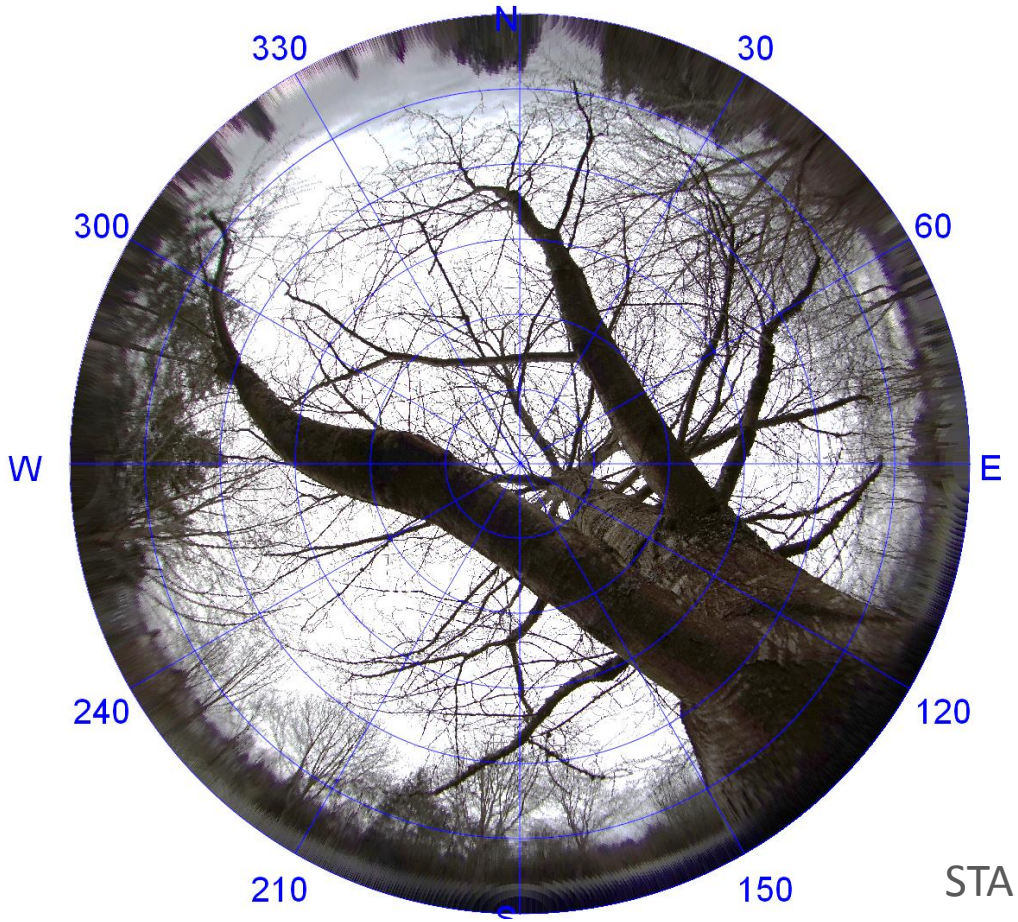
Conclusions

Additional Constellations

- Accuracy
  - Difficult to say
  - Generally, seems to help accuracy
  - May be some noise issues with too many satellites
- Percent Fixed
  - More constellations help
  - Best indicator of field conditions
- Field Efficiency
  - Additional satellites help a lot
  - 3 and 4 constellations pretty similar
  - 3/4 noticeably better than 2

Additional Time at Point

- Accuracy: No visible trend once fixed



STA 06

Questions?

PLSO Willamette Chapter Student Appreciation Night

May 30th

Corvallis, OR

Look for email April 30th

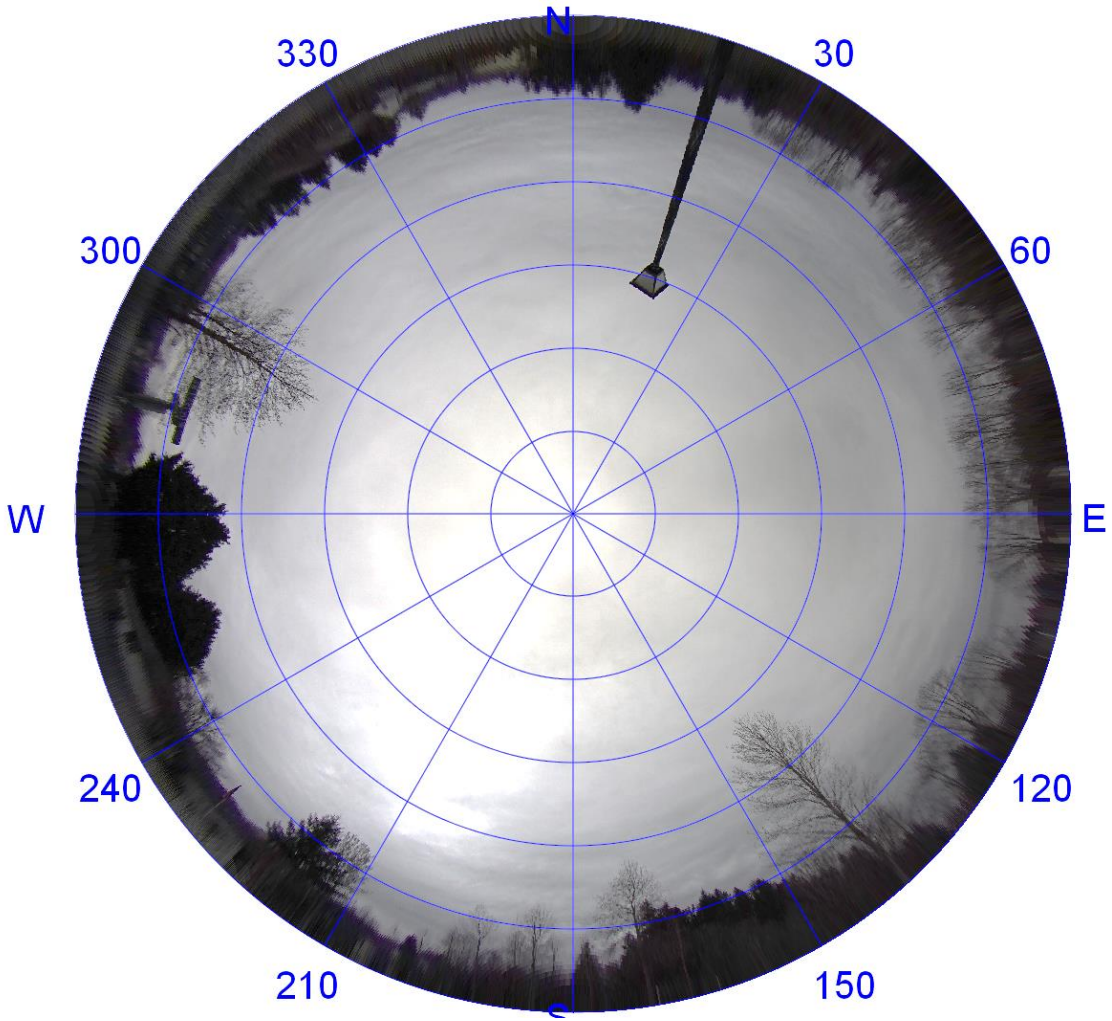
RTN observation duration & baseline length (< 50 km)

Tale of Two RTNs: Rigorous Evaluation of Real-Time Network GNSS Observations

Mahsa Allahyari, S.M.ASCE; Michael J. Olsen, Ph.D., A.M.ASCE; Daniel T. Gillins, Ph.D., P.L.S., M.ASCE; and Michael L. Dennis, P.E., L.S., M.ASCE

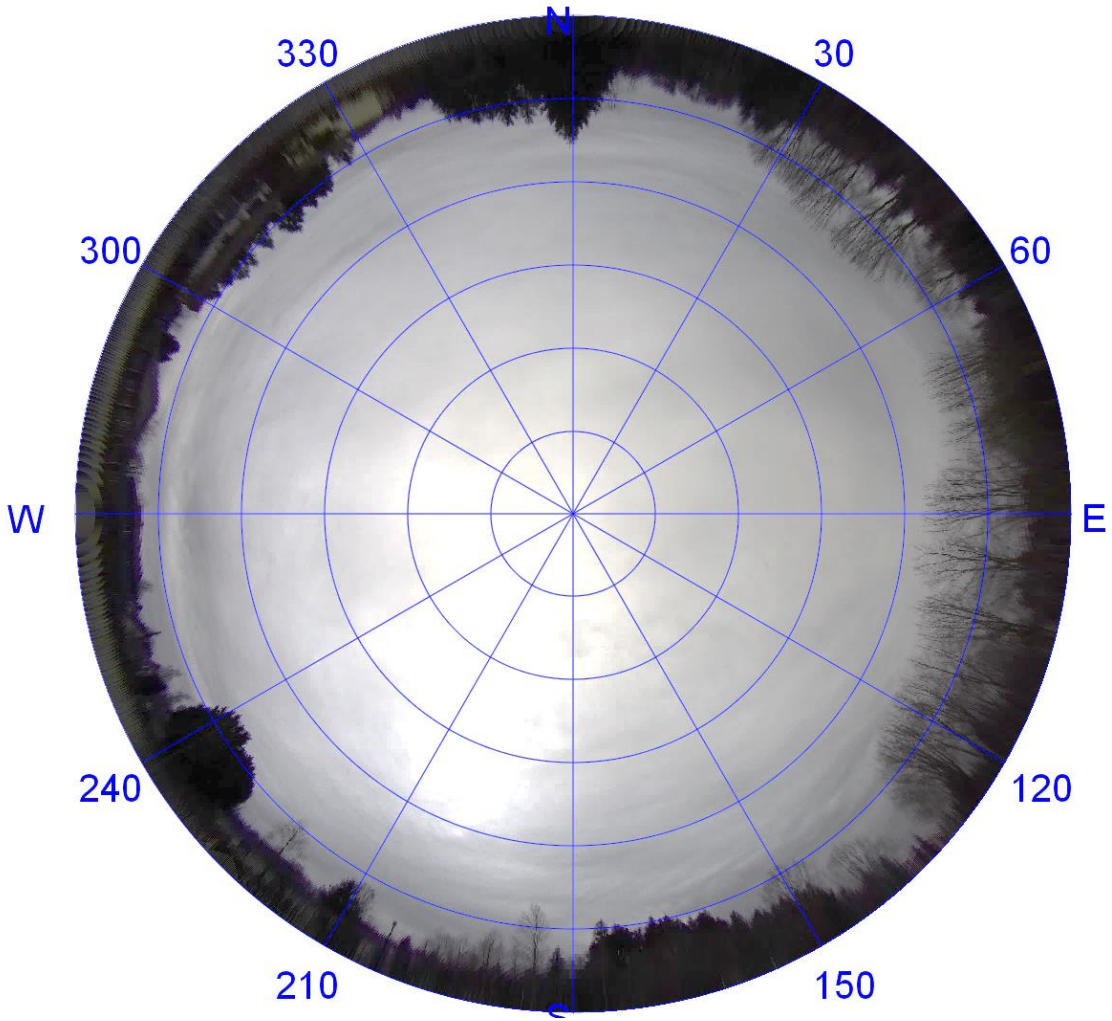
Station 01

50% Obstructed



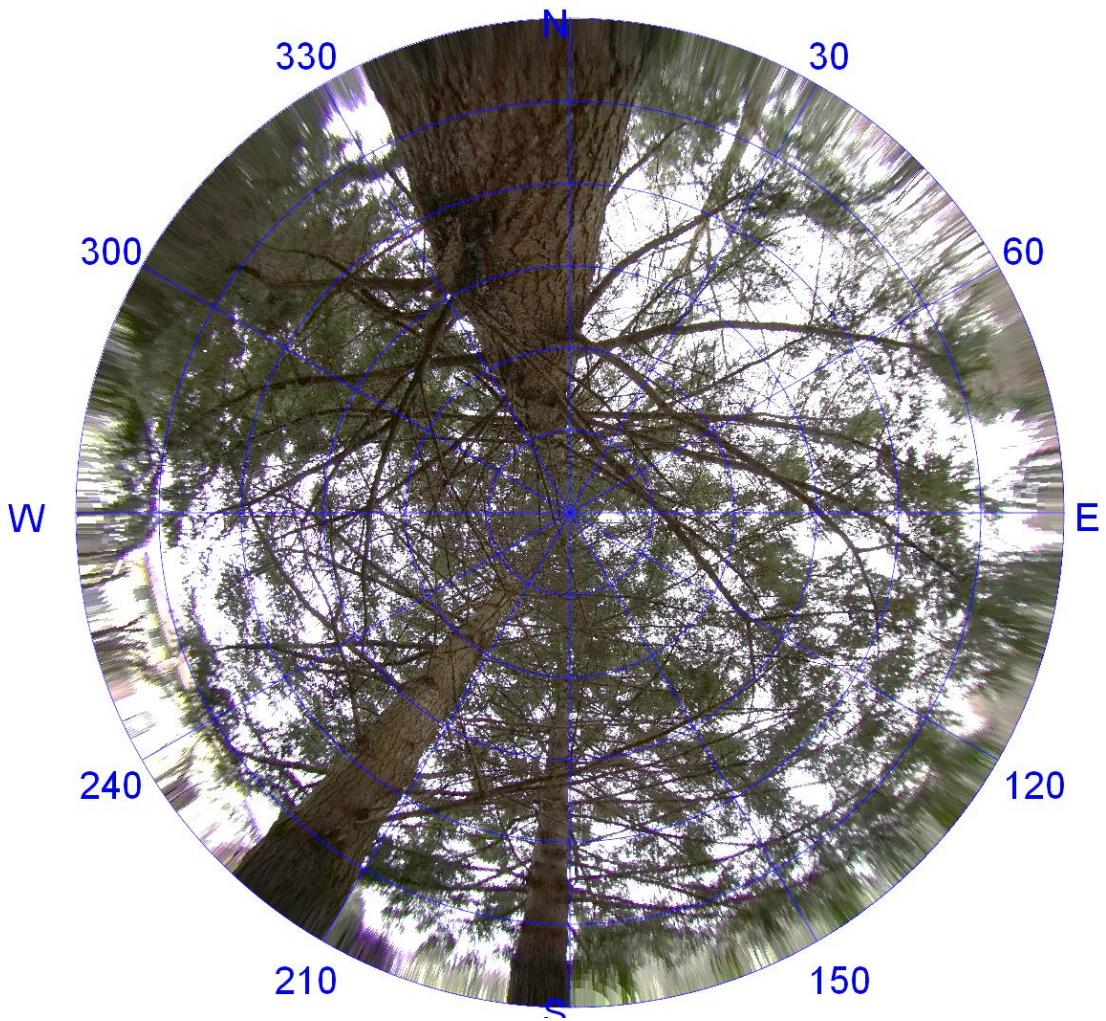
Station 02

47% Obstructed



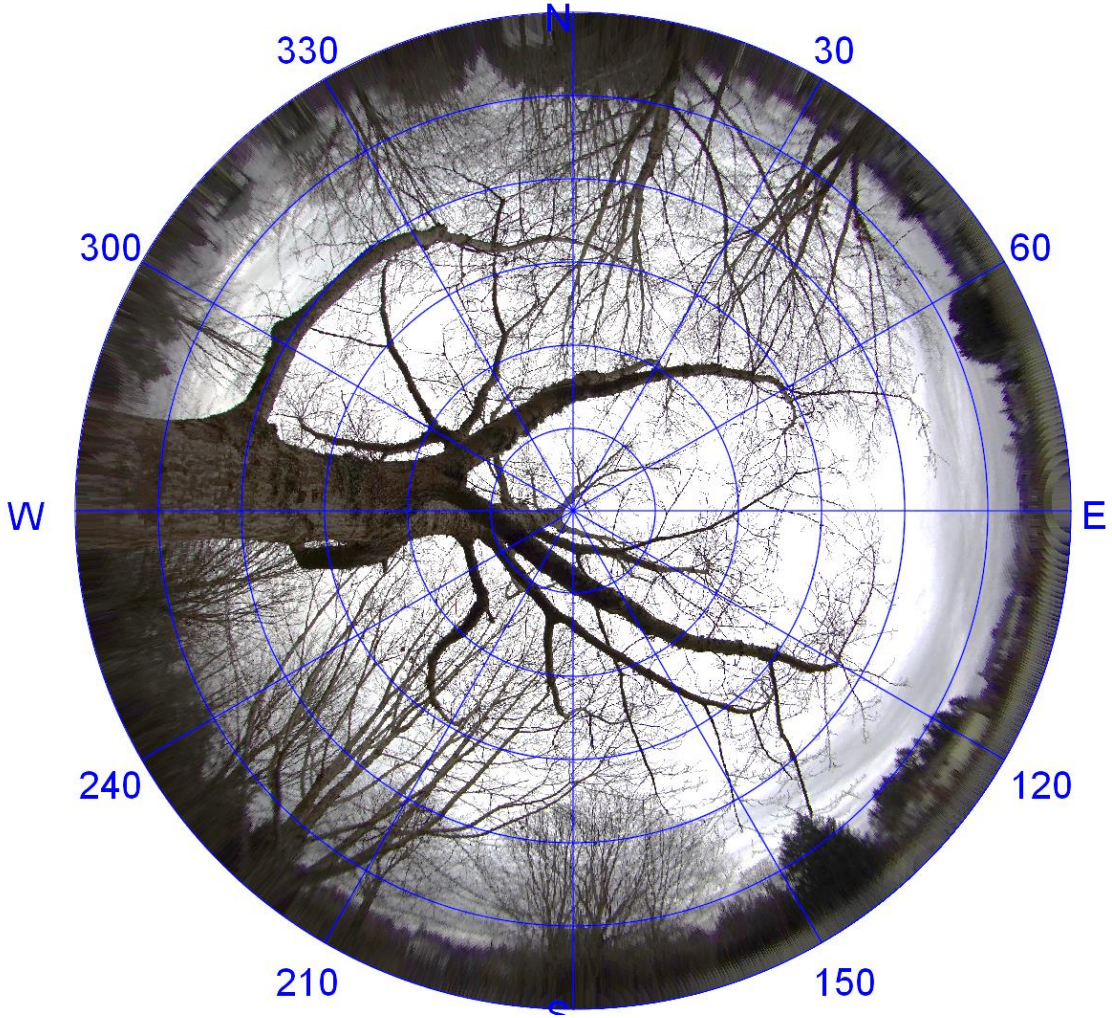
Station 03

74% Obstructed



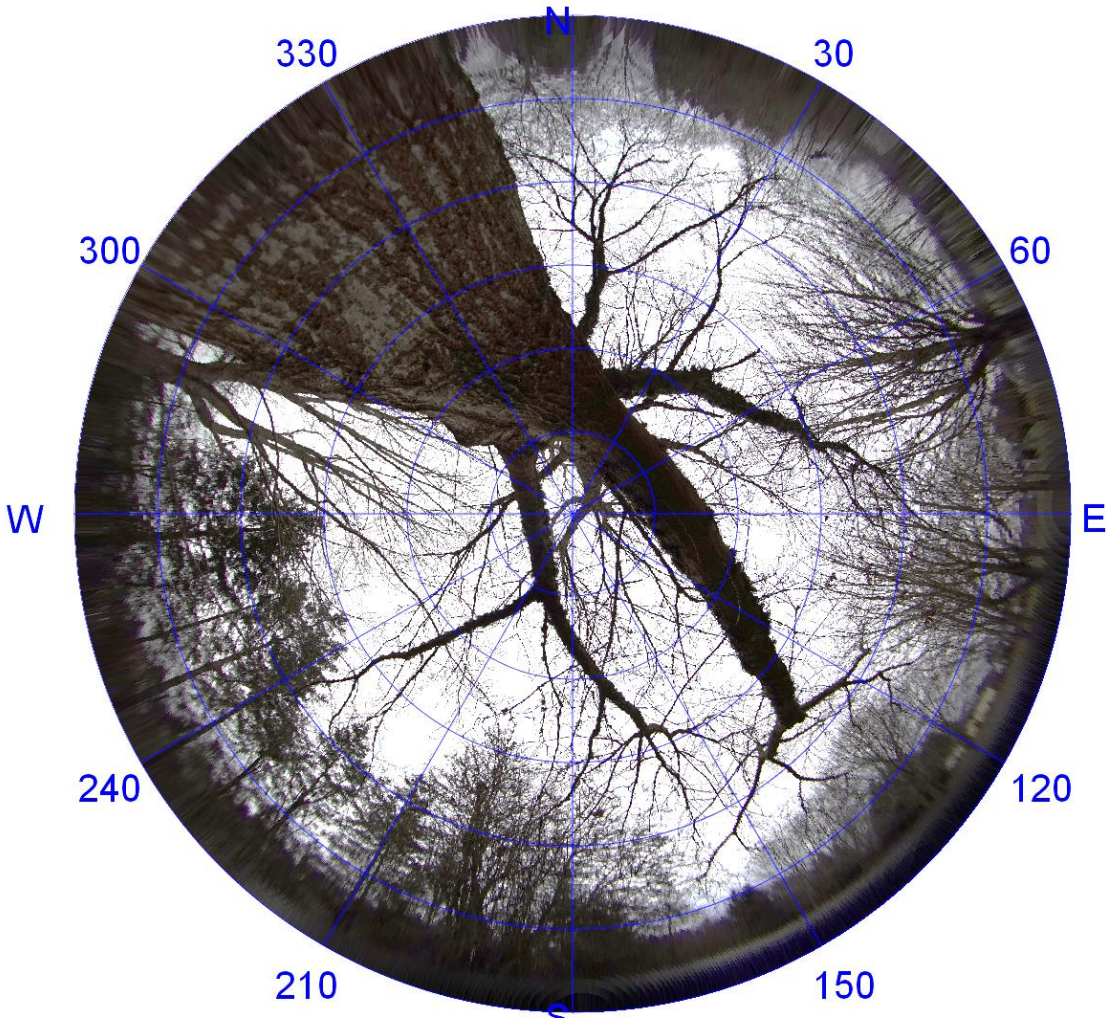
Station 04

57% Obstructed



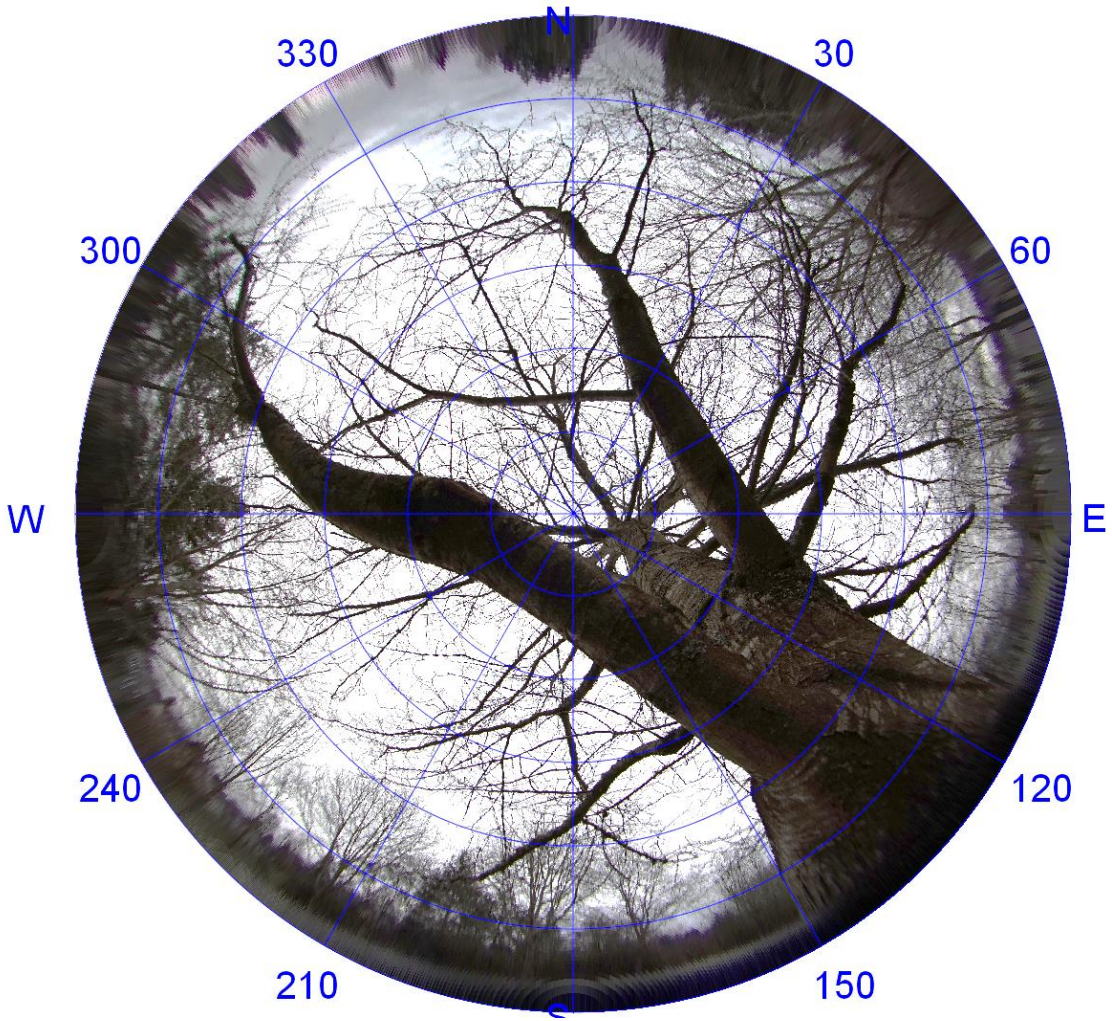
Station 05

68% Obstructed



Station 06

60% Obstructed



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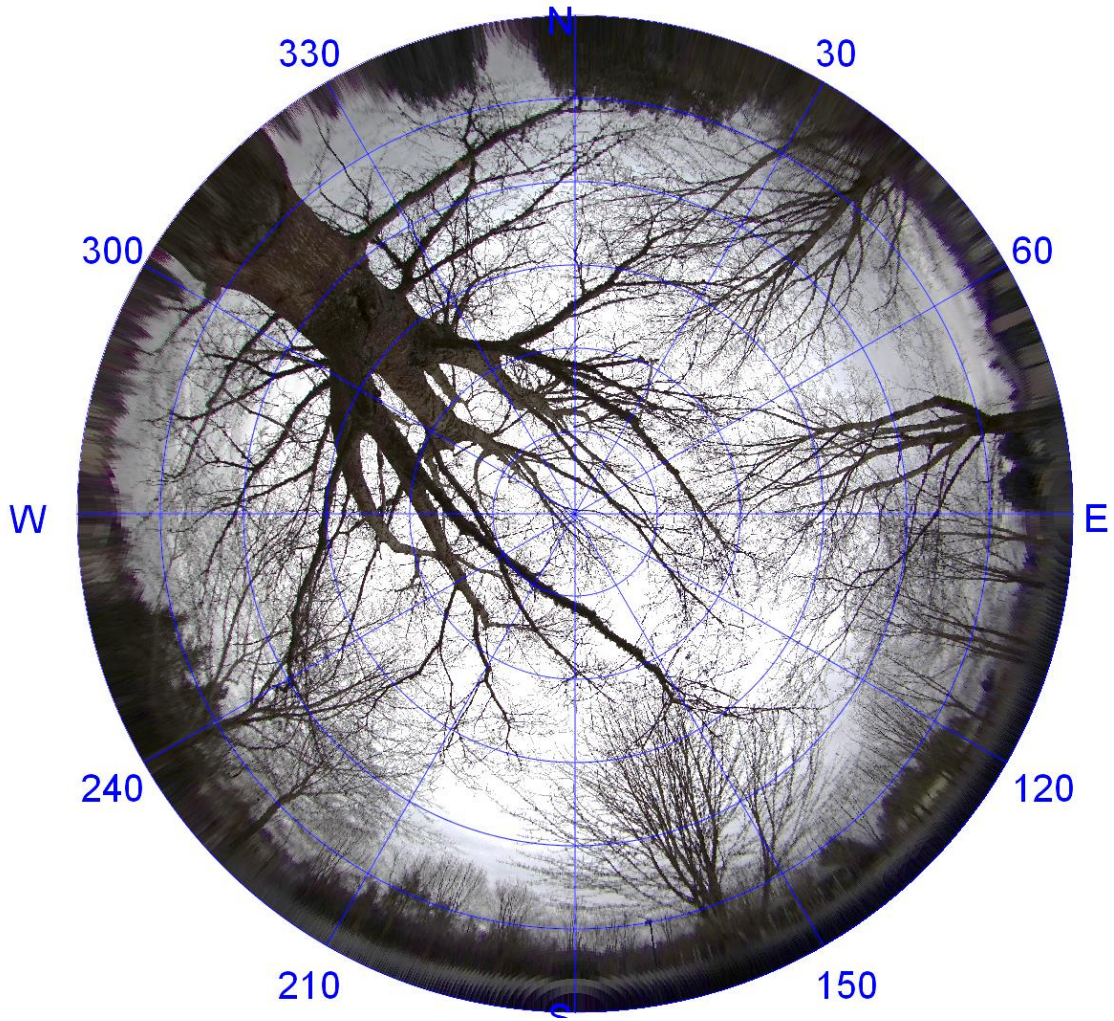
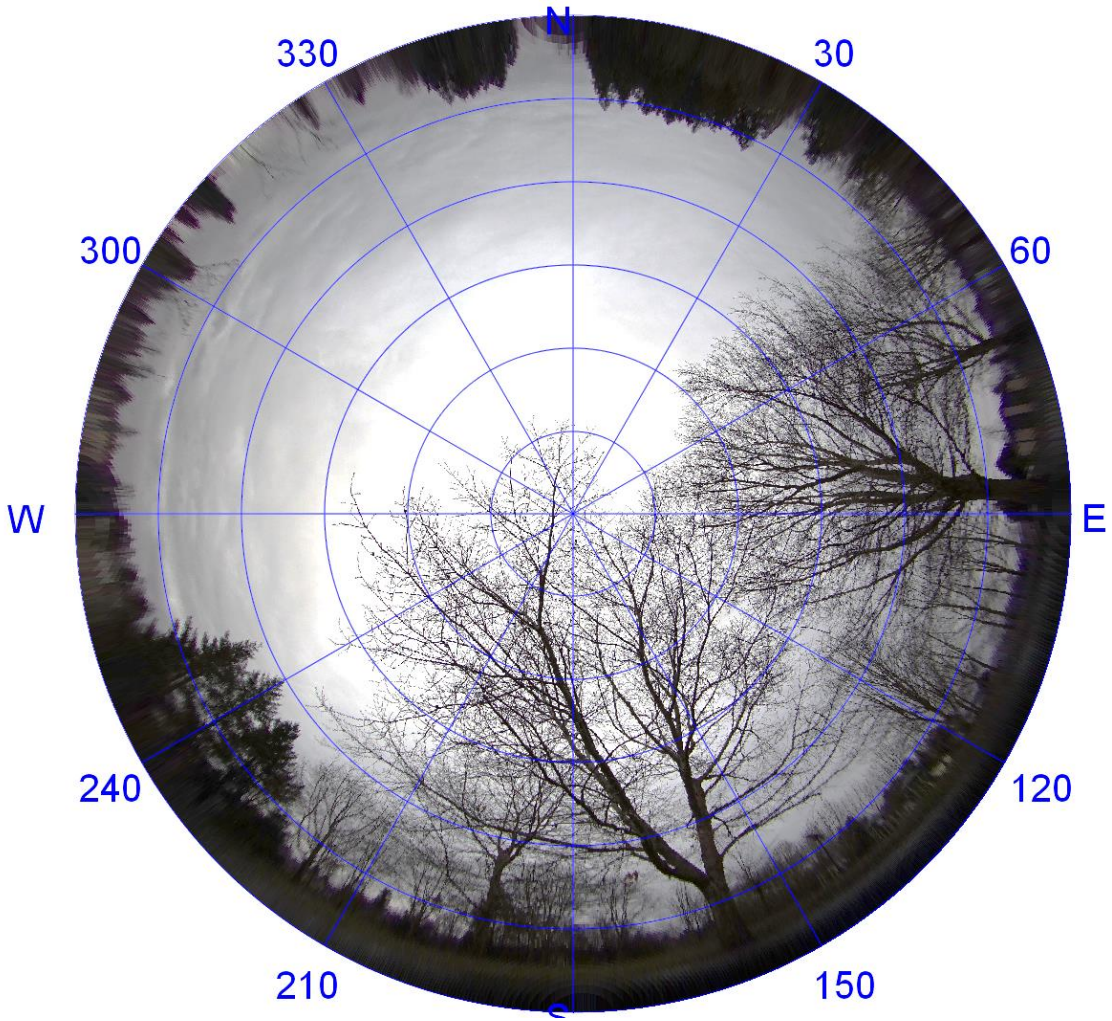


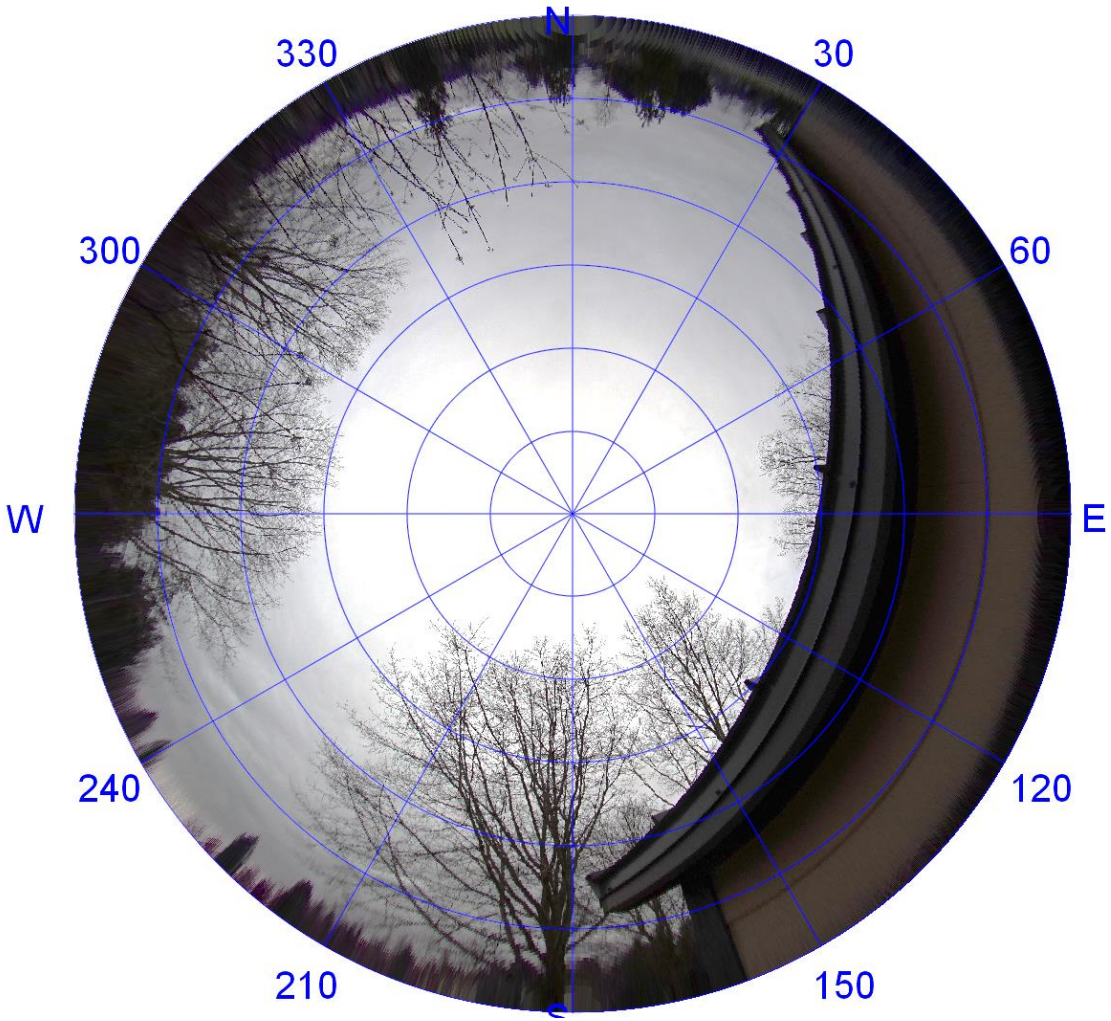
Station 08

56% Obstructed



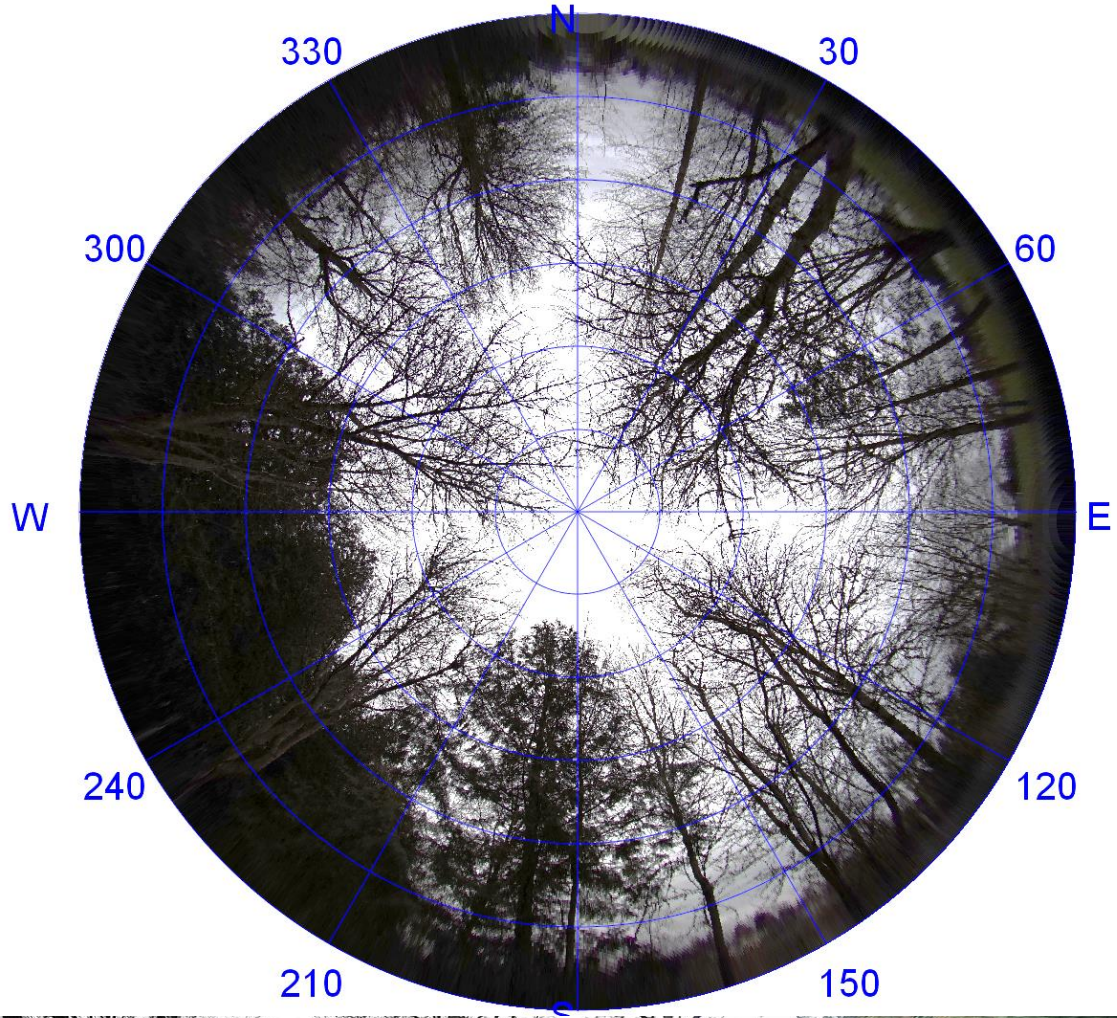
Station 09

58% Obstructed



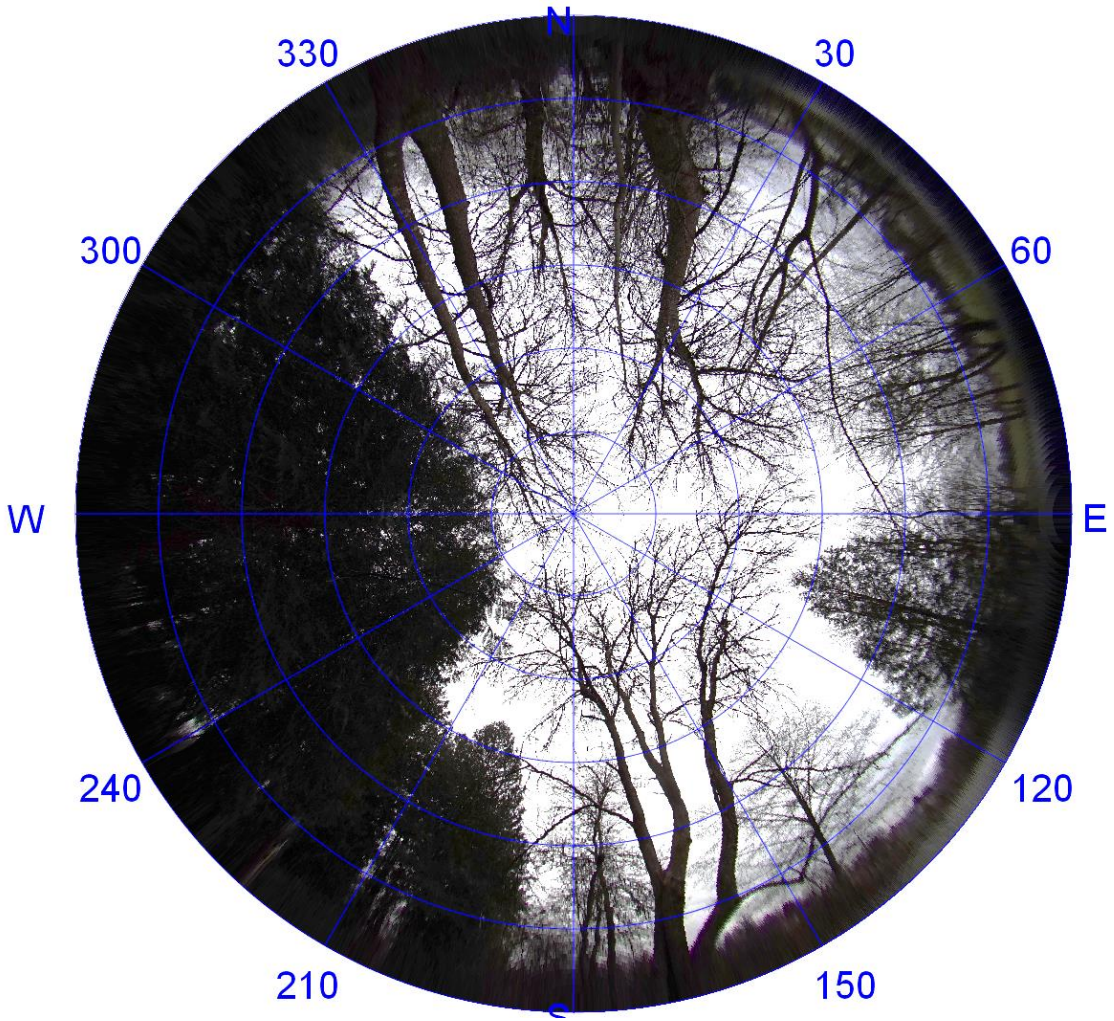
Station 10

72% Obstructed



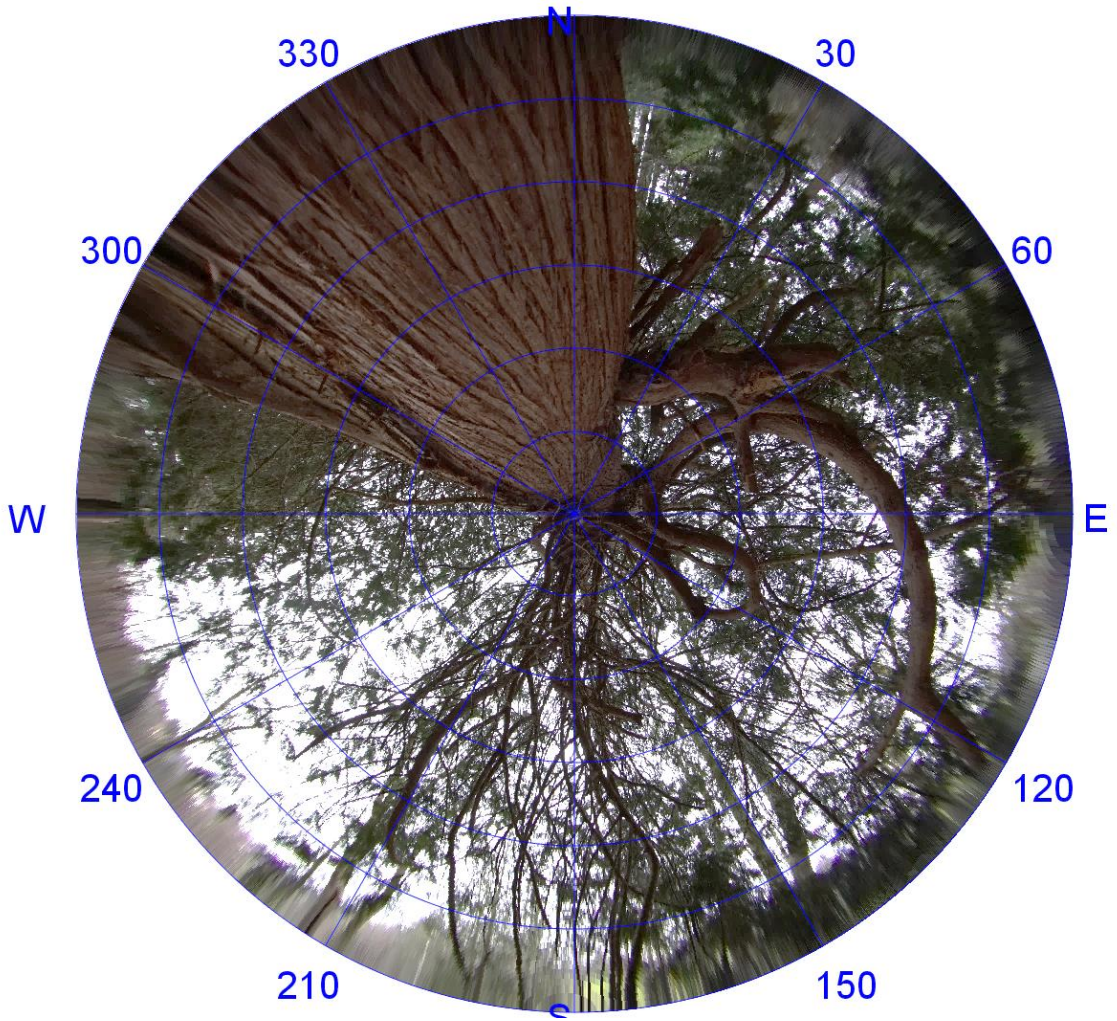
Station 11

72% Obstructed



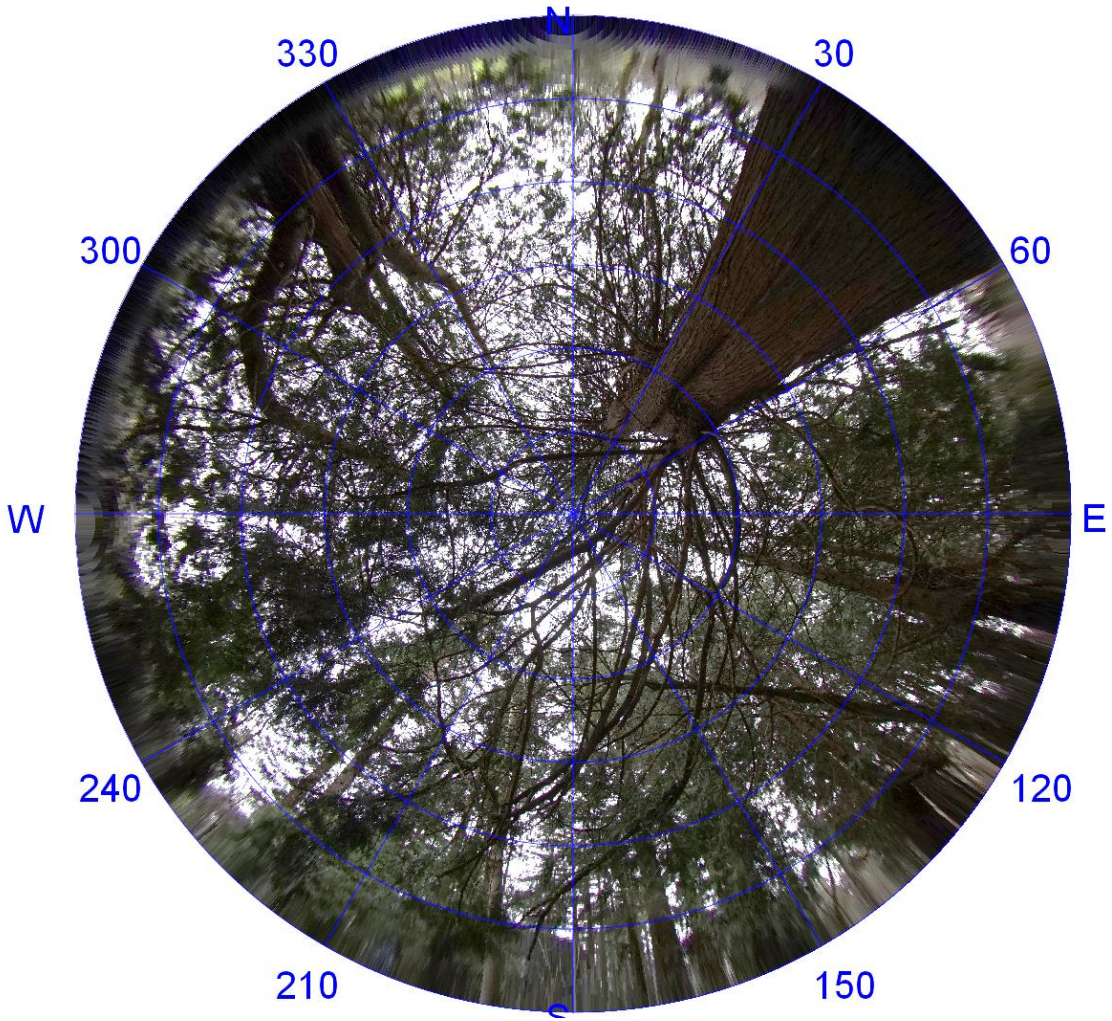
Station 12

79% Obstructed



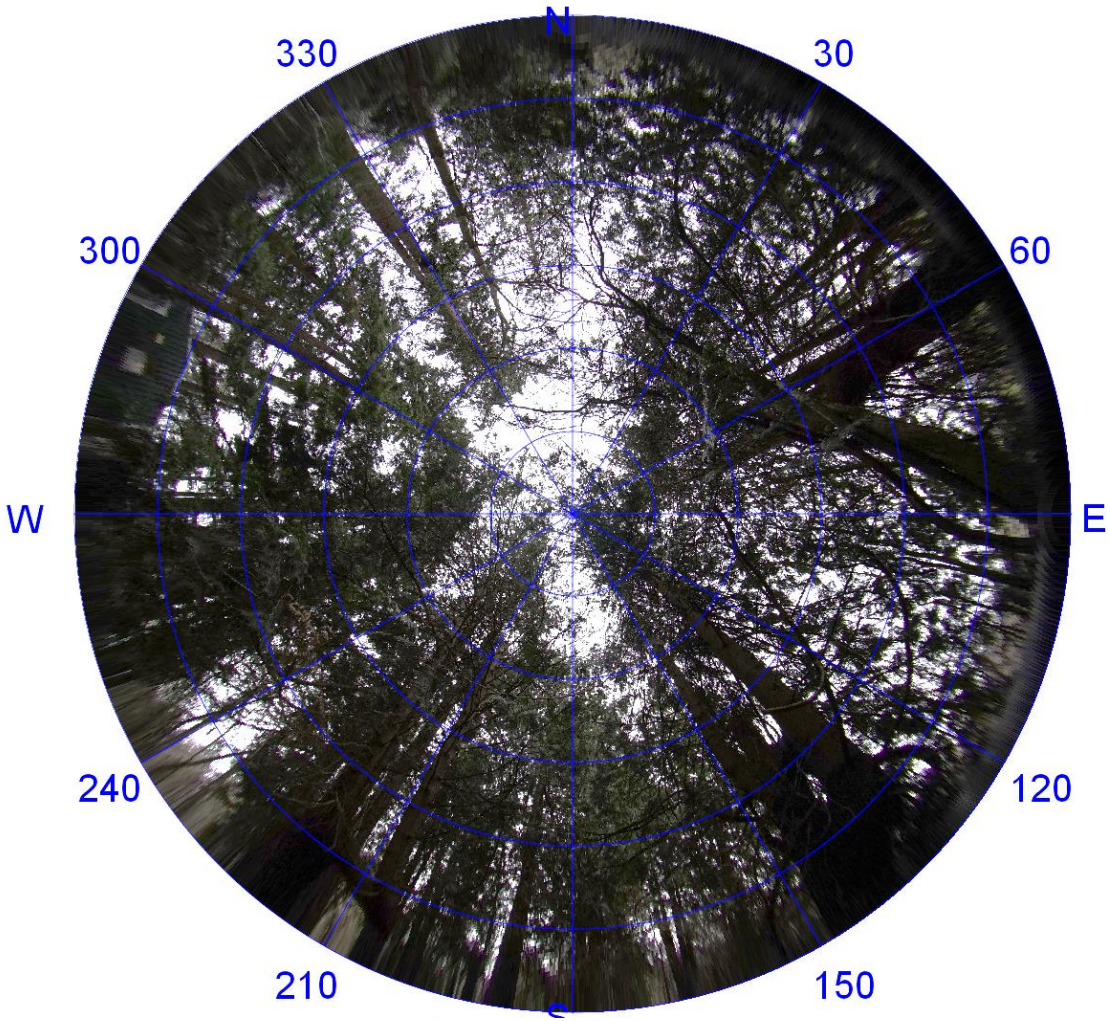
Station 13

86% Obstructed



Station 14

88% Obstructed



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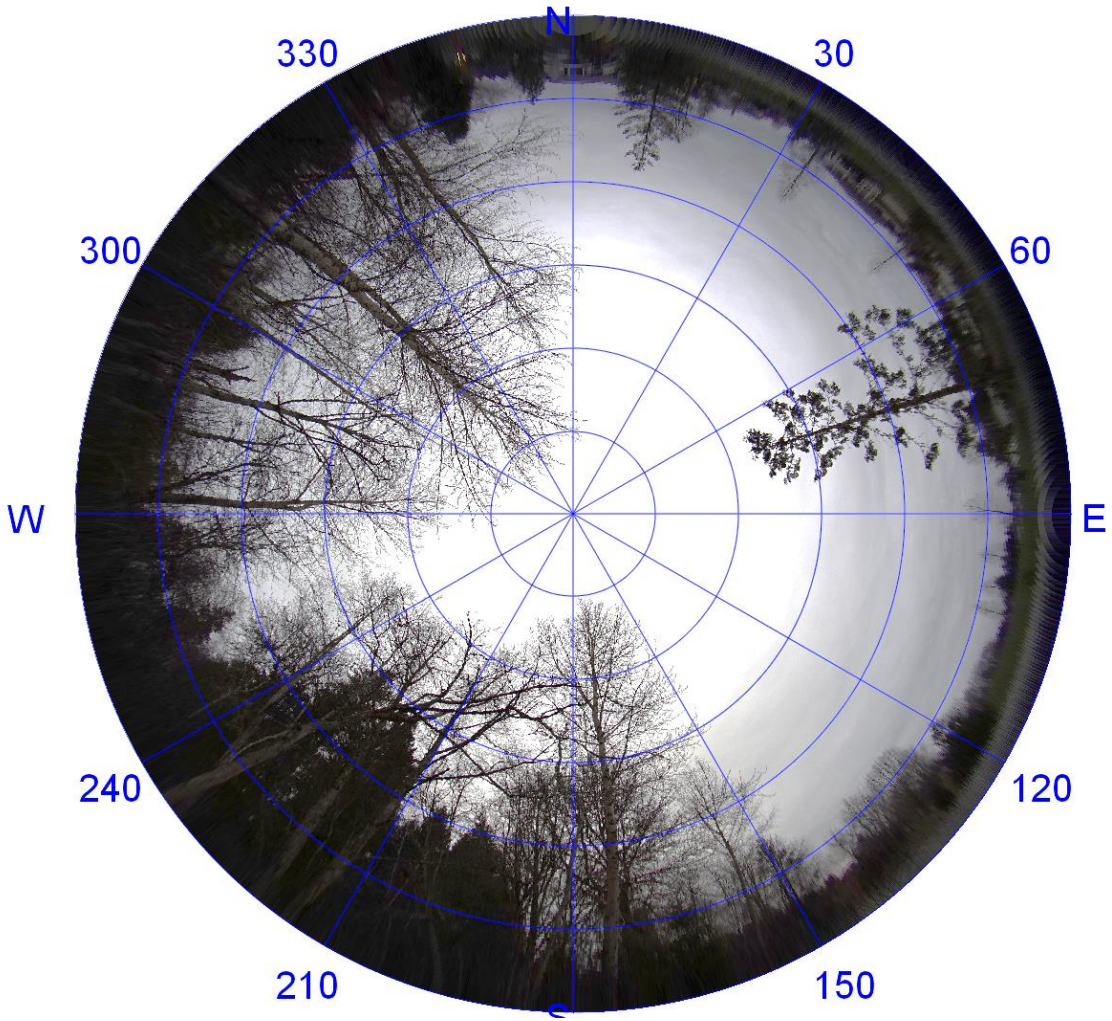
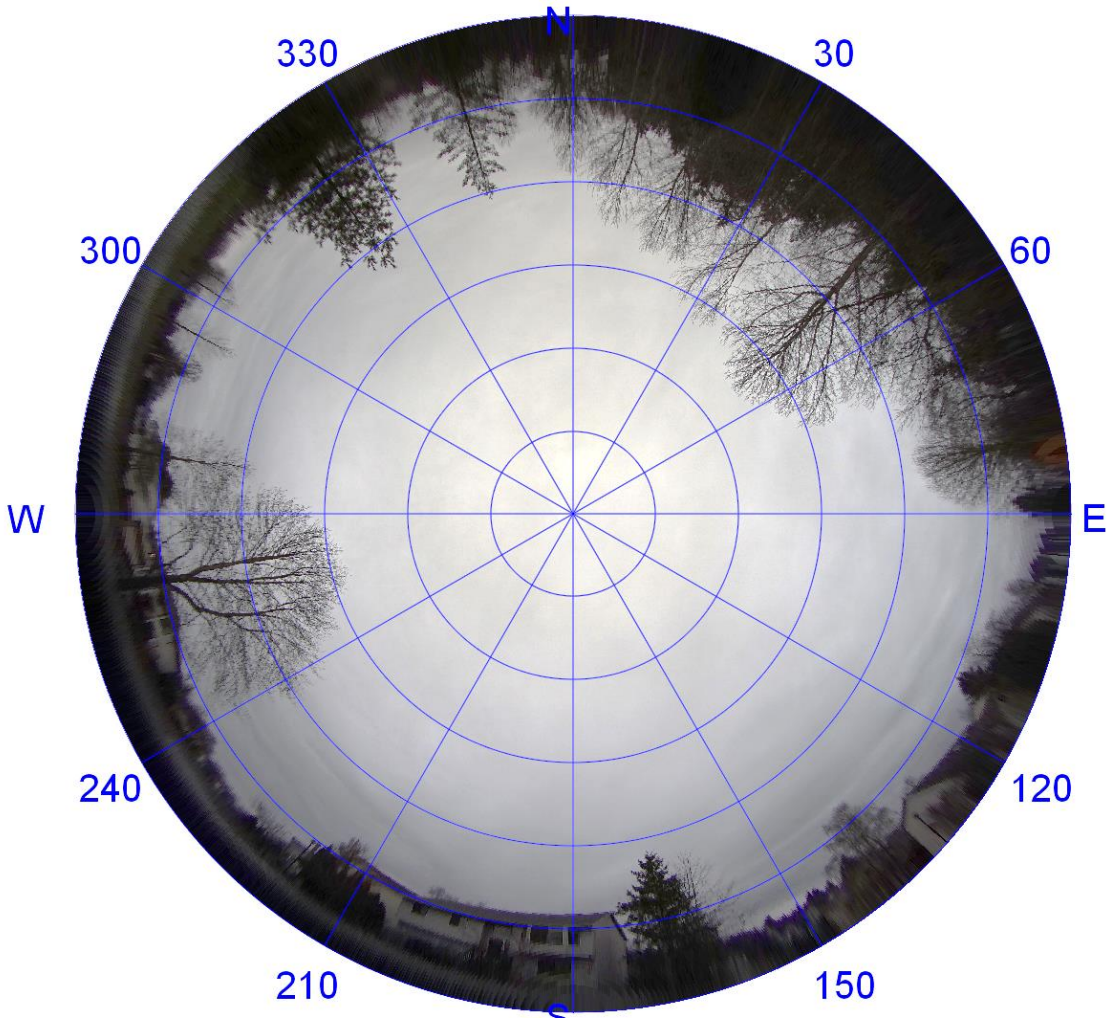


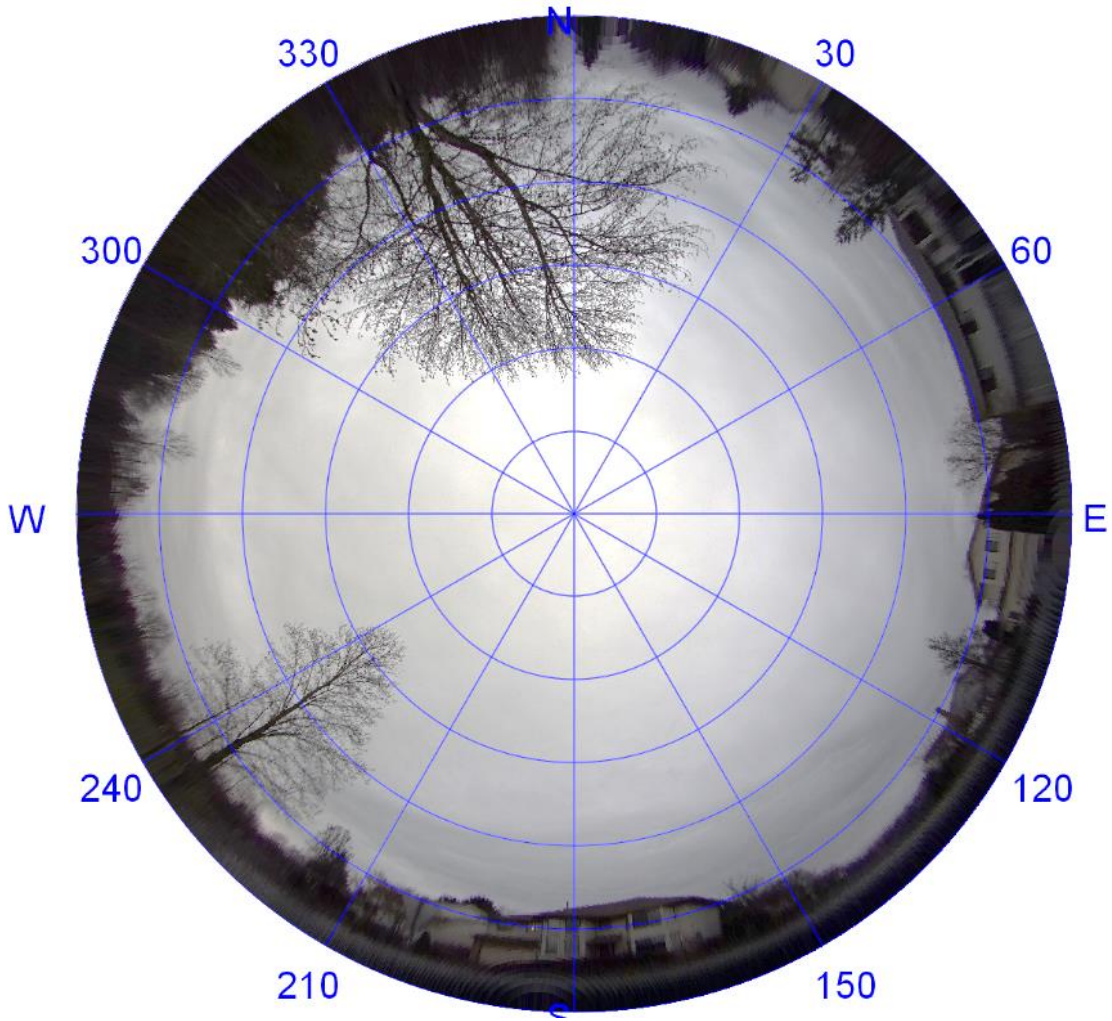
Station 16

47% Obstructed



Station 17

45% Obstructed



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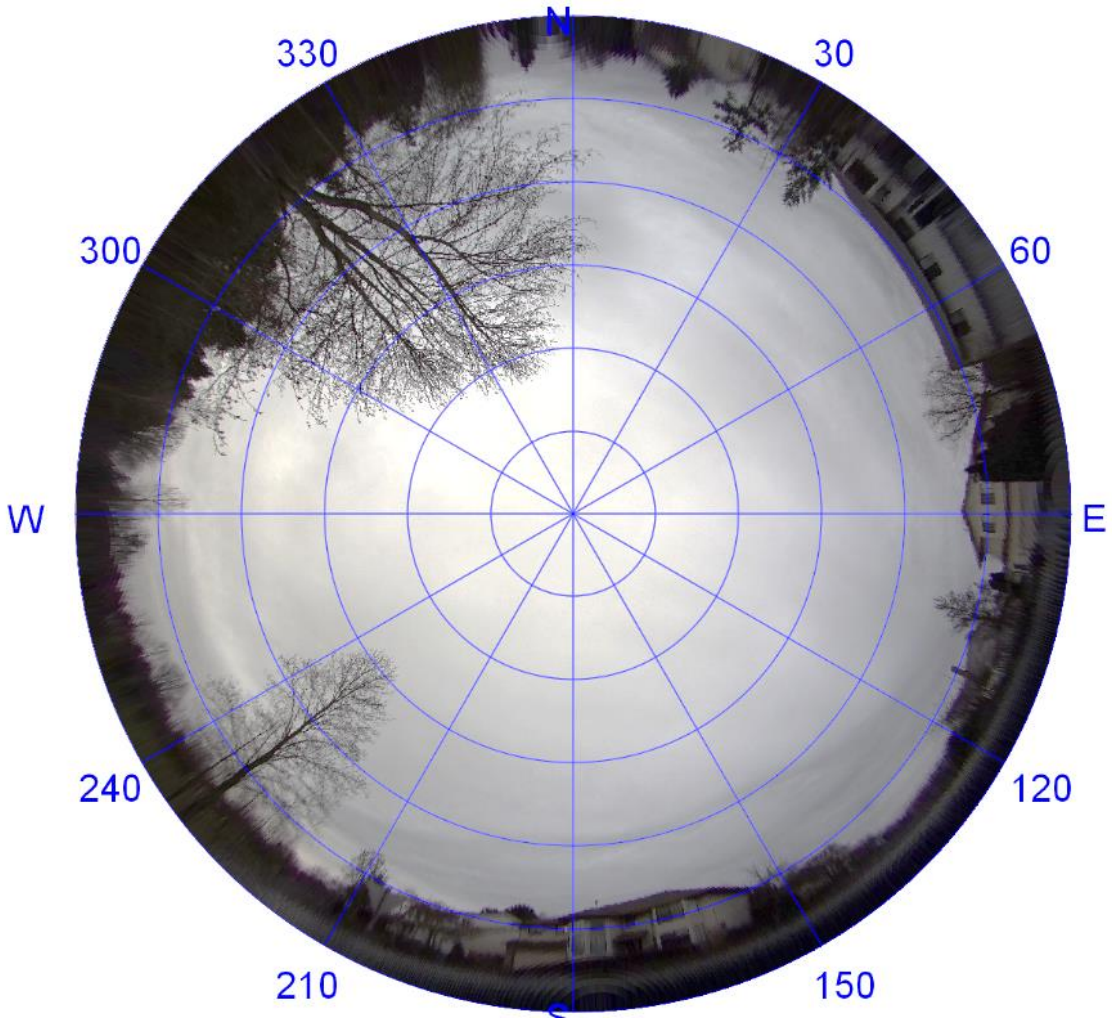

Station 19

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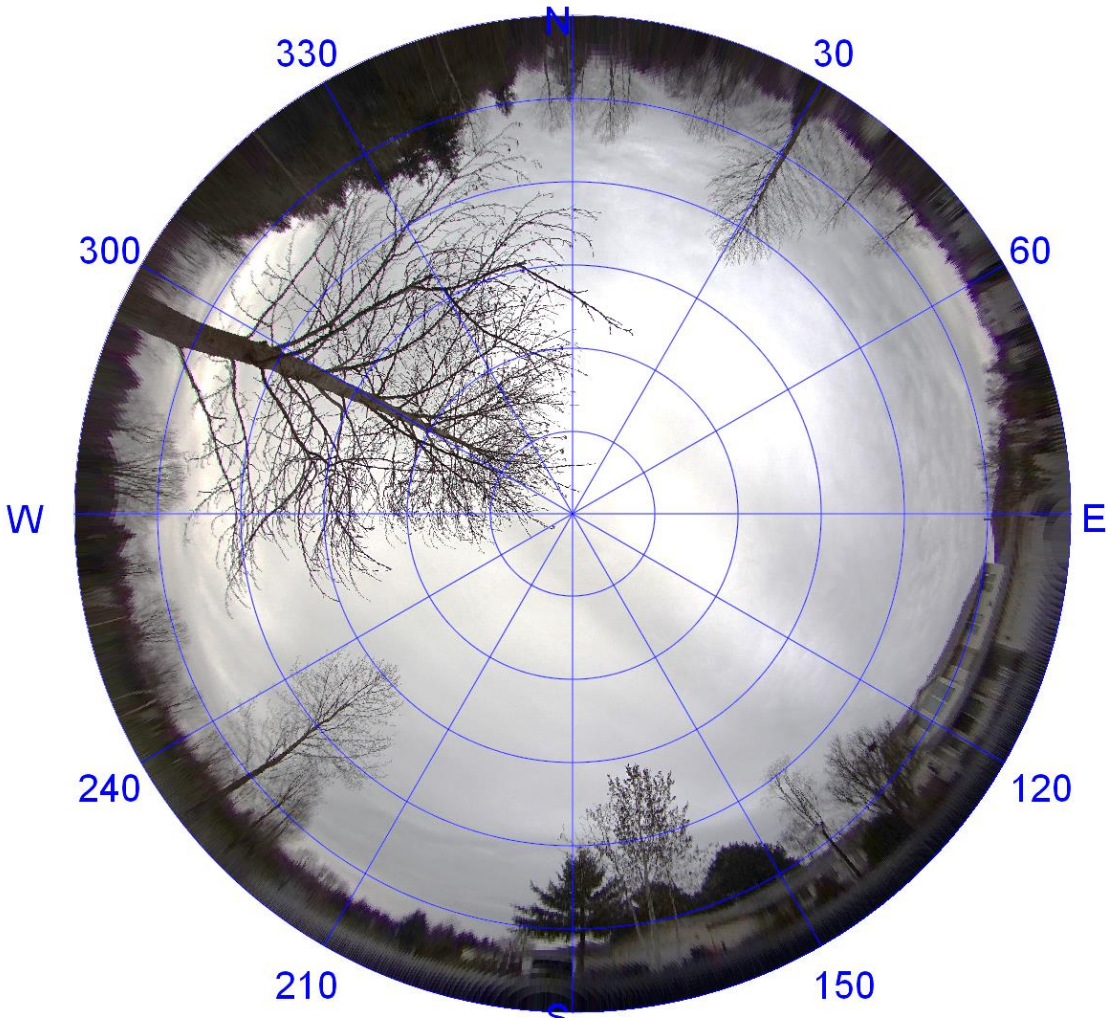

Station 20

47% Obstructed