European
Global Navigation
Satellite Systems
Agency

GNSS Measurements Update

GNSS Raw Measurements from Android Phones

GSA Raw Measurements Workshop, Prague, 30 May 2018

v1.02

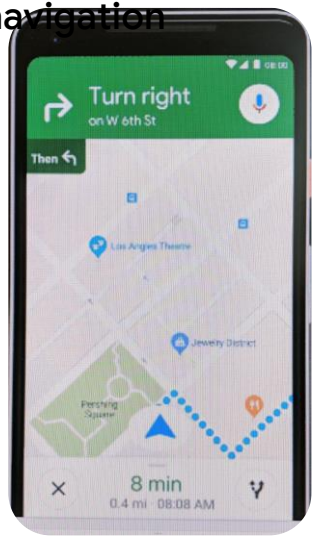
Frank van Diggelen
Google

What if we had one meter accuracy in phones?

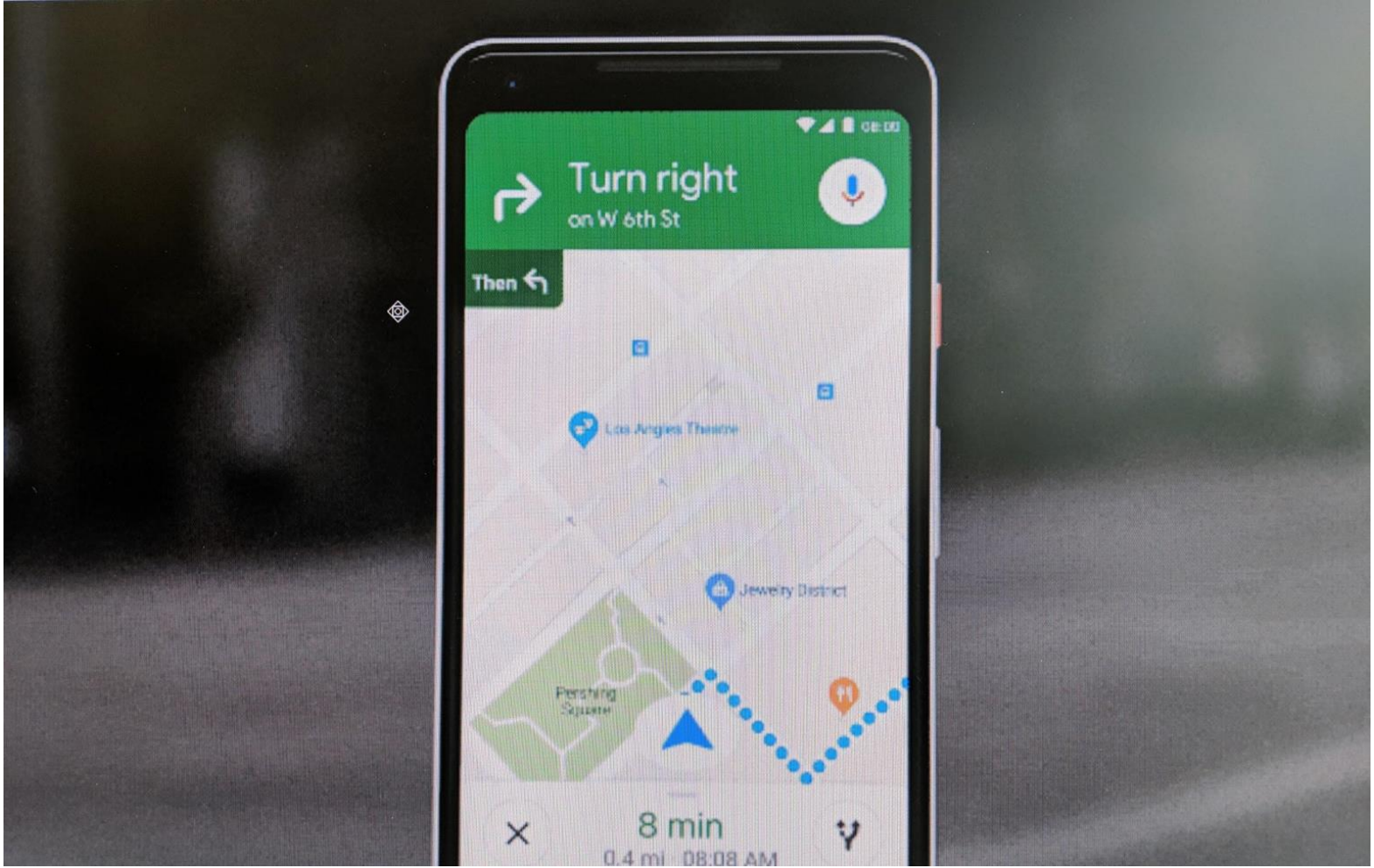
Lane-level vehicle navigation

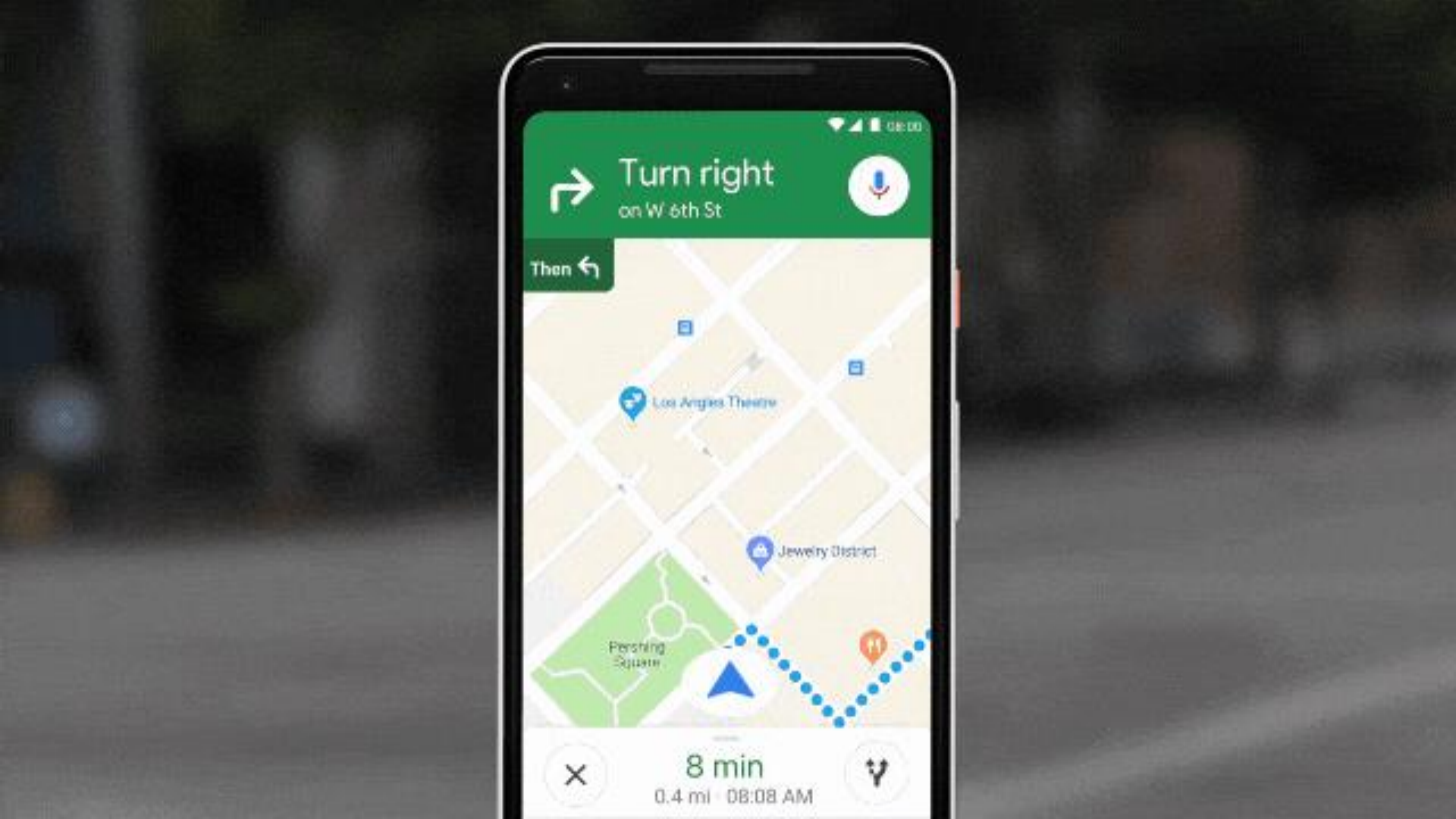
What's the fastest route using carpool lanes?

Pedestrian navigation



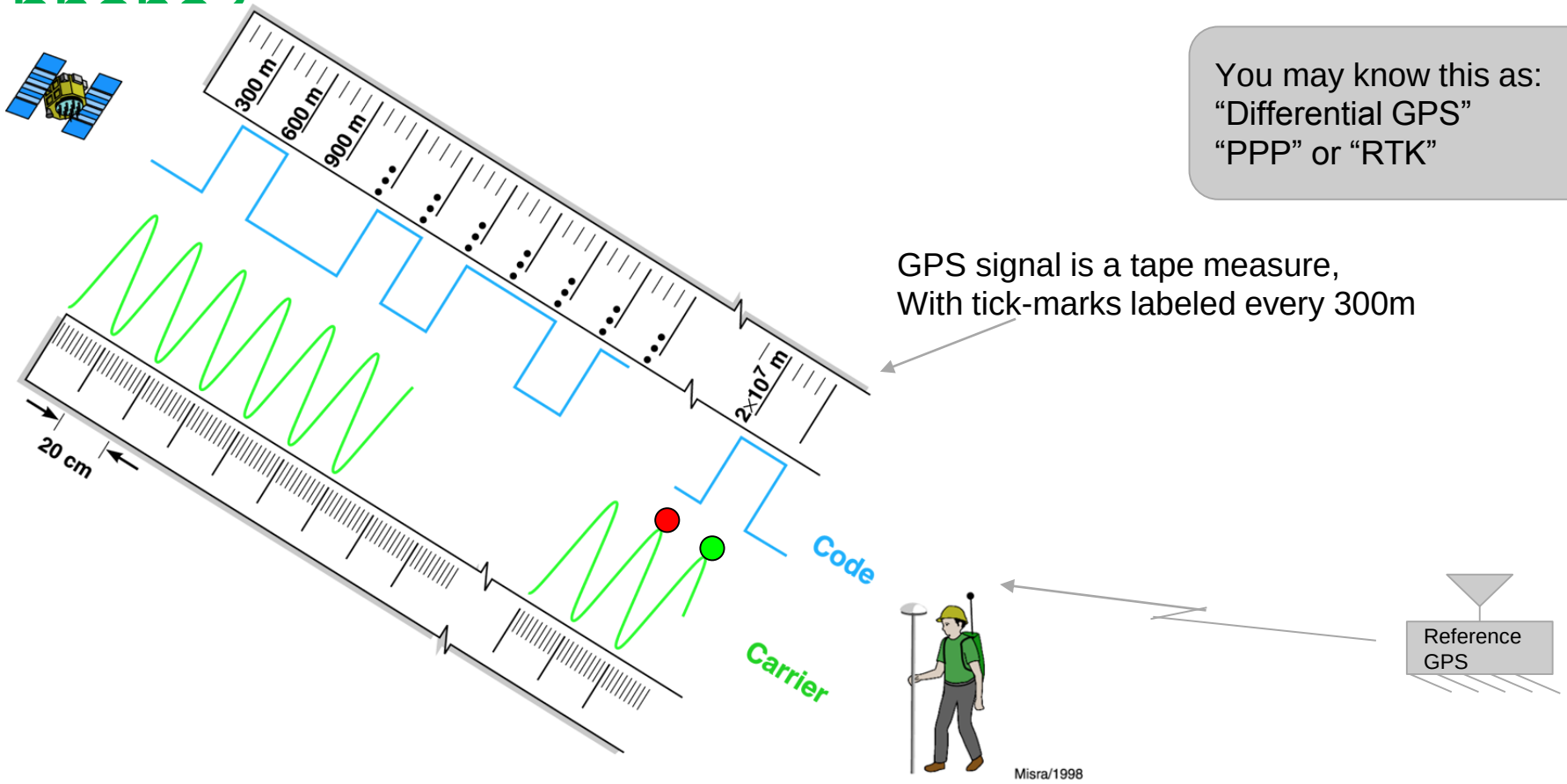
Which side of the road am I?


Turn right
on W 6th St
Then
Los Angeles Theatre
Jewelry District
Pershing Square
8 min
0.4 mi · 08:08 AM


Turn right
on W 6th St
Then
Los Angeles Theatre
Jewelry District
Pershing Square
8 min
0.4 mi · 08:08 AM

What if we had centimeter accuracy from a phone?

You may know this as:
“Differential GPS”
“PPP” or “RTK”

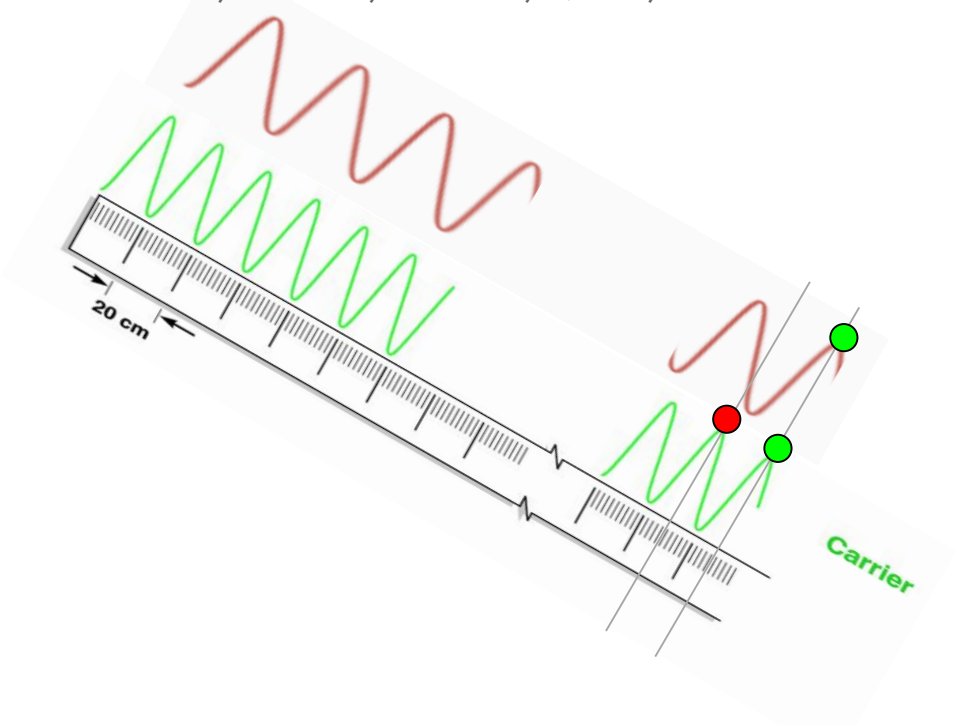


GPS signal is a tape measure,
With tick-marks labeled every 300m

Image credit: “GPS, Signals, Measurements, and Performance”, P. Misra, P. Enge, 2001.

Dual Frequency ...

Today all smartphone GPS/GNSS is on one frequency band: L1.
L5 is a new frequency band supported by these *GNSS* systems:
GPS, Galileo, BeiDou, QZSS, IRNSS.



Second frequency ⇒ faster convergence to carrier-phase accuracy.

Sample applications …

Research	Education	Accuracy	Crowd-sourced	Testing	Consumer
Atmosphere	GNSS	D-GNSS	Jammer detection	Monitoring:	Sports
Iono	RF	RTK/PPP	Weather	Data	Golf
Tropo	Sig Processing	GIS		Accuracy	Drones
NMA (Auth.)	Orbits	Surveying		Antenna patterns	Mapping
				Rx Clock	Walking Nav
					Landscaping
					Geocaching

Measurements, Tools and Analysis

1. Raw GNSS Measurements
2. Logging and Analysis Tools
3. What's new in 2018
4. Hands-on exercises
5. Future: apps and research

Location APIs, Measurement APIs

aka *Google Play Services*
Most Android phones have this (not China)

Location APIs, android.gms.location

- Places
- Geofencing
- Fused Location Provider (FLP)
- Fit
- Activity Recognition
- Nearby

All Android phones have this

Measurement/Sensor APIs, in android.location

- Location
- GnssMeasurement
- GnssClock

GNSS Raw Measurements
All phones with:
GNSS chips build date ≥ 2016
OS ≥ Android N (Nougat)

https://g.co/GnssTools

which phones have GNSS Raw Measurements:

Model	Android version	Automatic Gain Control	Navigation messages	Accumulated delta range	HW clock	Global systems
HTC U11 Plus	8.0	no	no	no	yes	GPS GLONASS
HTC U11 Life	8.0	no	no	no	yes	GPS GLONASS
Huawei Mate 10	8.0	no	yes	yes	yes	GPS GLONASS
Huawei Mate 10 Pro	8.0	no	yes	yes	yes	GPS GLONASS QZSS
Google Pixel 2 XL	8.0	yes	no	no	yes	GPS GLONASS GALILEO BeiDou QZSS
Google Pixel 2	8.0	yes	no	no	yes	GPS GLONASS GALILEO BeiDou QZSS
Sony Xperia XZ1	8.0	no	no	no	yes	GPS GLONASS
Samsung Note 8 (Exynos)	7.1	no	yes	yes	yes	GPS GLONASS GALILEO BeiDou
Samsung Note 8 (QCOM)	7.1	no	no	no	yes	GPS GLONASS GALILEO BeiDou
LG V30	7.1.2	no	no	no	yes	GPS GLONASS
Moto X4 2017	7.1	no	no	no	yes	GPS GLONASS
Essential PH-1	7.1	no	no	no	yes	GPS GLONASS
Moto Z2	7.1	no	no	no	yes	GPS GLONASS
HTC U11	7.1	no	no	no	yes	GPS GLONASS
OPPO R11	7.1	no	no	no	yes	GPS GLONASS GALILEO BeiDou
Huawei Honor 9	7.0	no	yes	yes	yes	GPS GLONASS
Samsung S8 (Exynos)[1]	7.0	no	yes	yes	yes	GPS GLONASS GALILEO BeiDou QZSS
Samsung S8 (QCOM)[2]	7.0	no	no	no	yes	GPS
Huawei P10	7.0	no	yes	yes	yes	GPS GLONASS GALILEO BeiDou QZSS
Huawei P10 Lite	7.0	no	no	no	yes	GPS
Huawei Honor 8	7.0	no	yes	yes	yes	GPS GLONASS BeiDou
Huawei Mate 9	7.0	no	yes	yes	yes	GPS GLONASS BeiDou
Huawei P9	7.0	no	yes	yes	yes	GPS GLONASS BeiDou
Google Pixel XL	7.0	no	no	no	yes	GPS
Google Pixel	7.0	no	no	no	yes	GPS
Nexus 6P[3]	7.0	no	no	no	no	GPS
Nexus 5X[3]	7.0	no	no	no	no	GPS
Nexus 9 (non cellular version)[4]	7.1	no	yes	yes	yes	GPS GLONASS

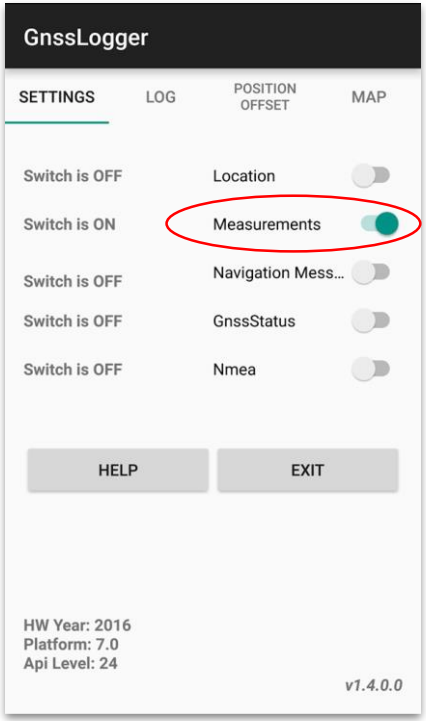
Logging and Analysis Tools

GNSS Logger

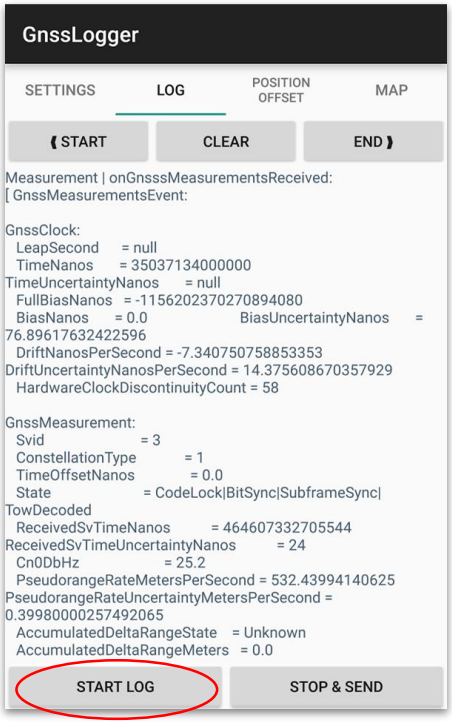
GNSS Analysis

Logging the raw data on your phone:

1,

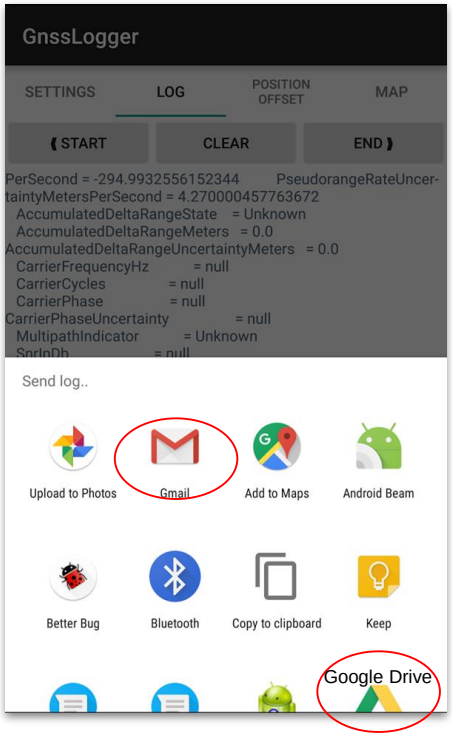


2,

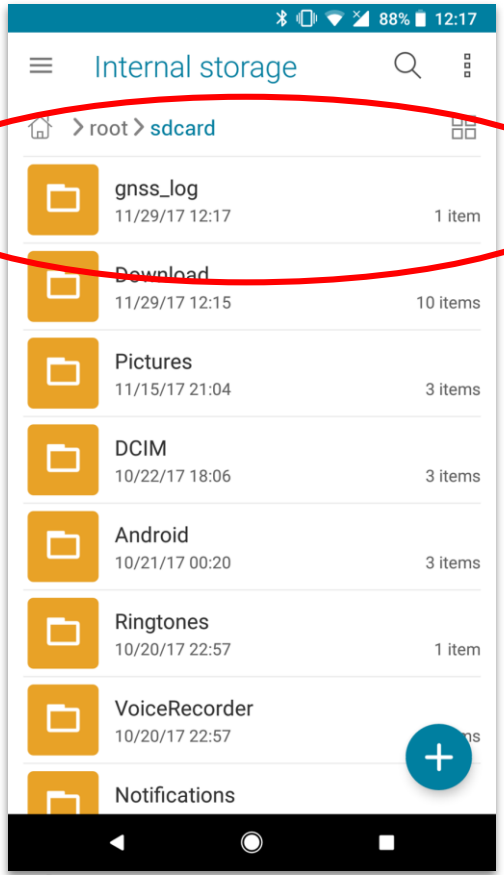


3,

4.



Logged Data is stored locally, on the phone:



What’s new in 2018

Phone:

- Duty Cycling control
- Analysis on phone

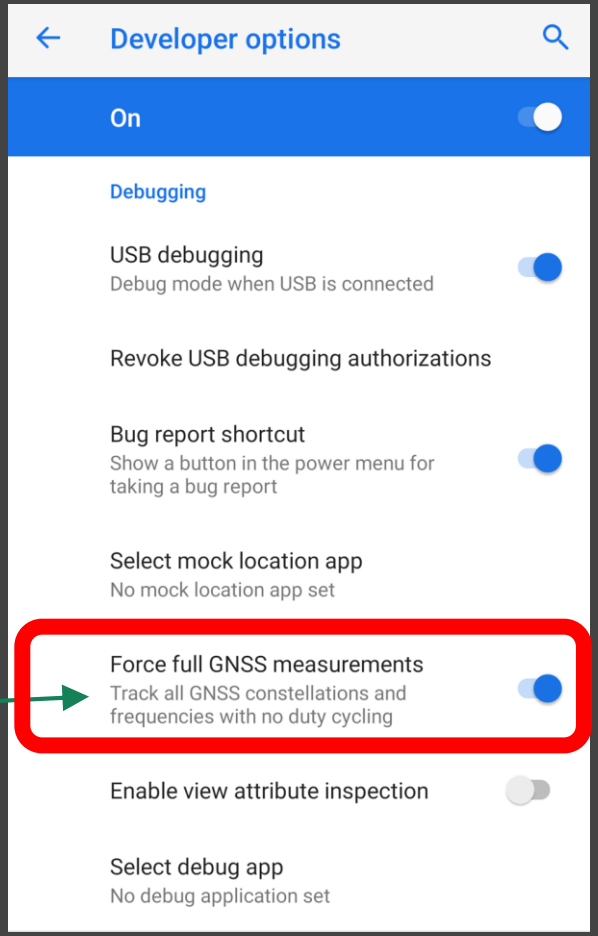
Desktop

- L5/E5
- Mission Planning
- C/No comparison of different phones
- Error analysis for moving receiver
- Smoothed and Raw pseudoranges
- Log of derived data
- Iono & Tropo control

Duty cycling control,
For continuous carrier phase

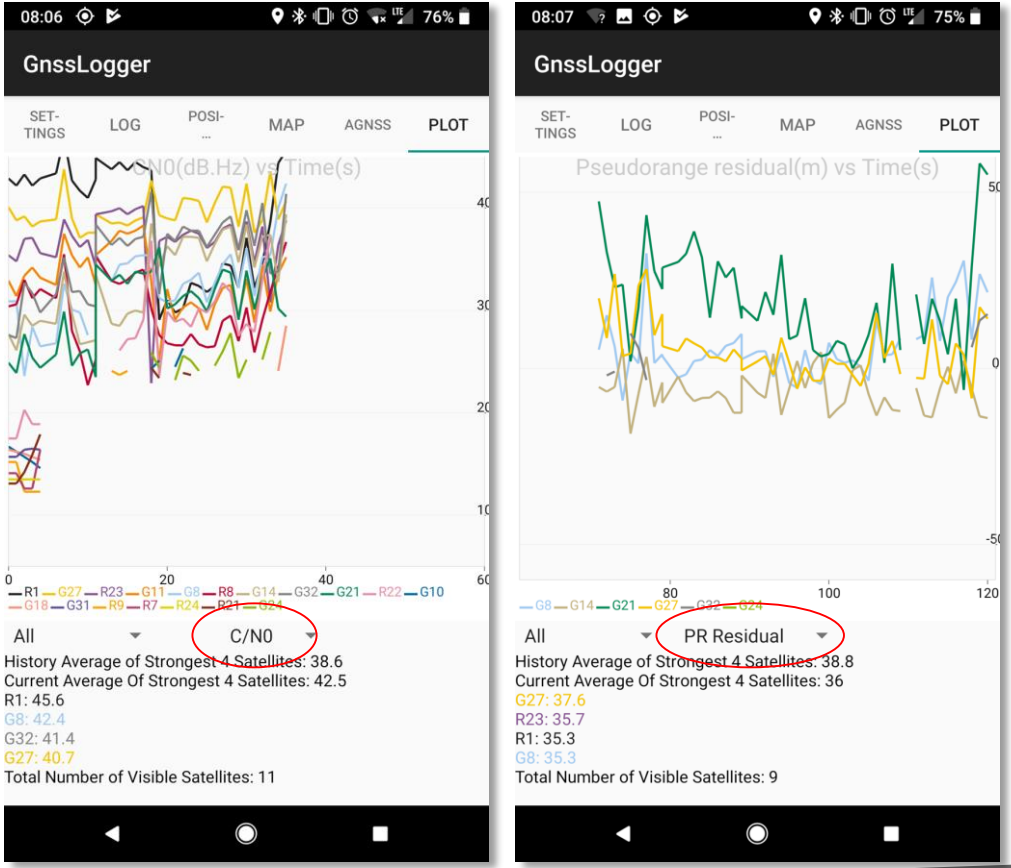
In Android P:

developer option	Full GNSS, track all available GNSS, with no duty cycling

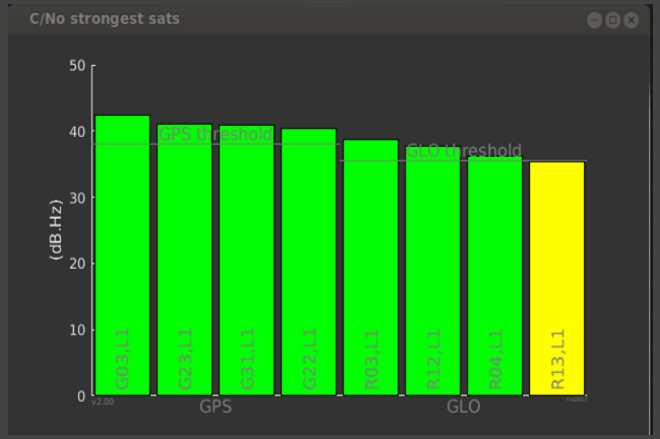


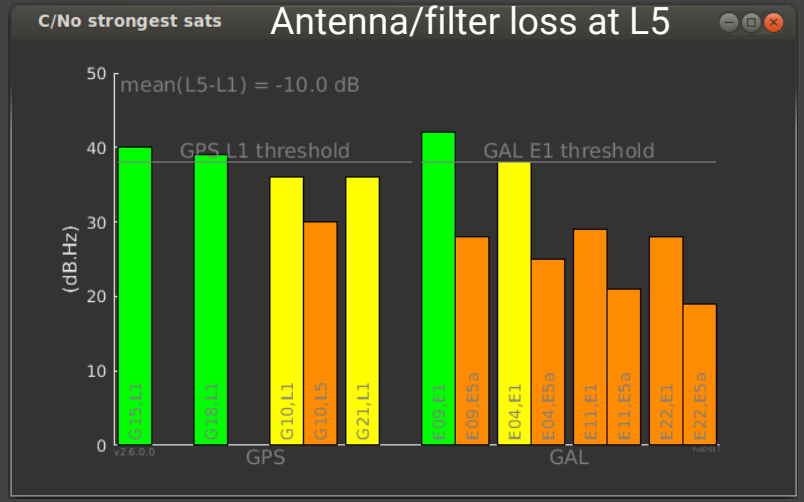
Analysis on Android

On the phone



L1-only → L1, L5 C/No





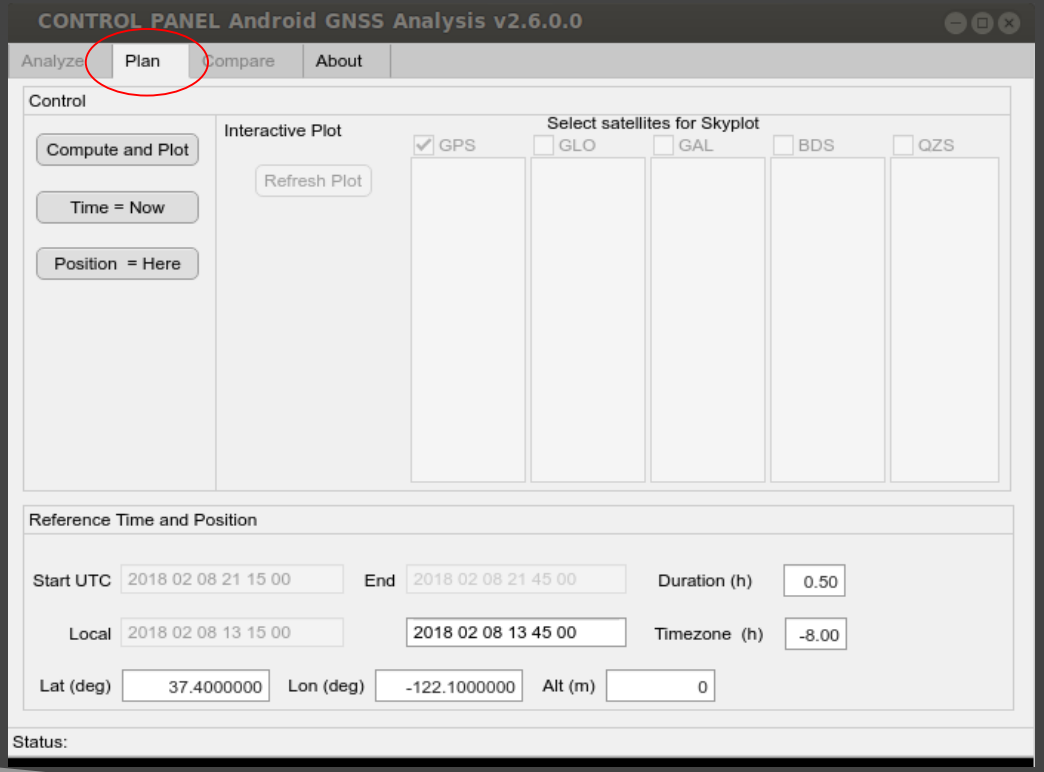
Simulated measurement data to illustrate functionality of tools

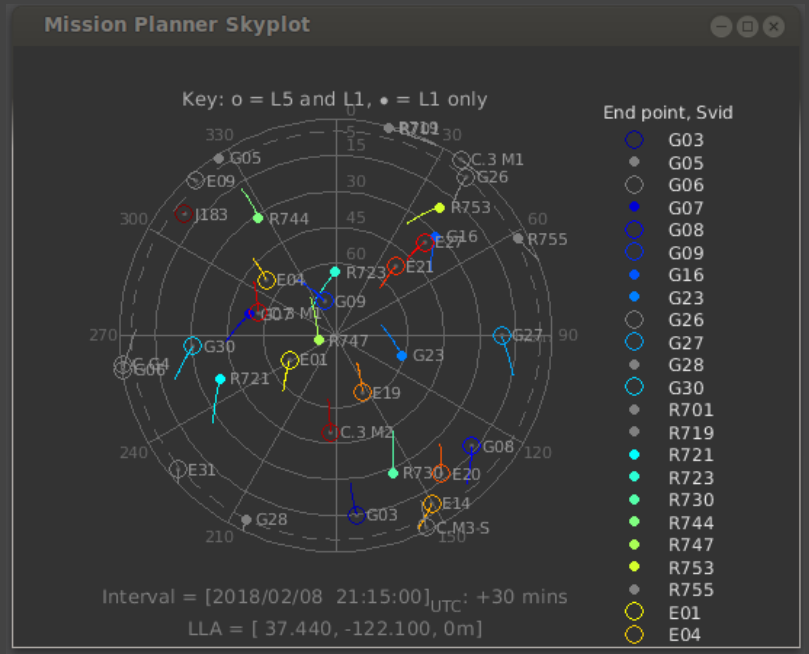
Minimum C/No with 0 dBi RHCP antenna with 2dB Front End Noise Figure		
	GPS (dB.Hz)	GAL (dB.Hz)
L1/E1	45.5	47
L5/E5a (I + Q)	49	49
L5/E5a (I only)	46	46

From ICDs for GPS and Galileo

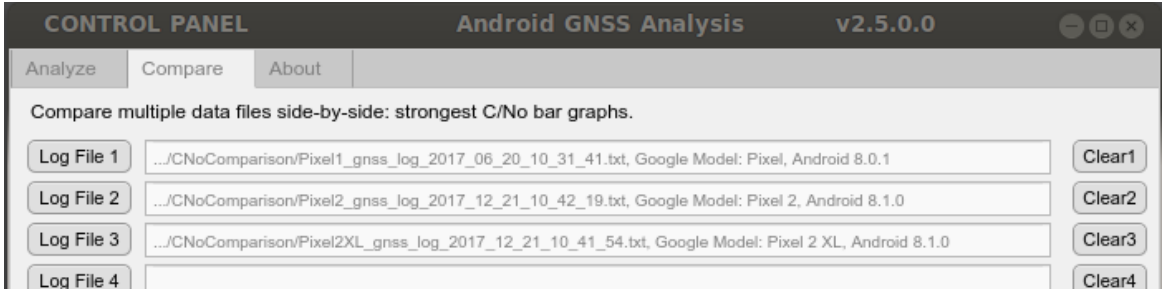
Mission Planning

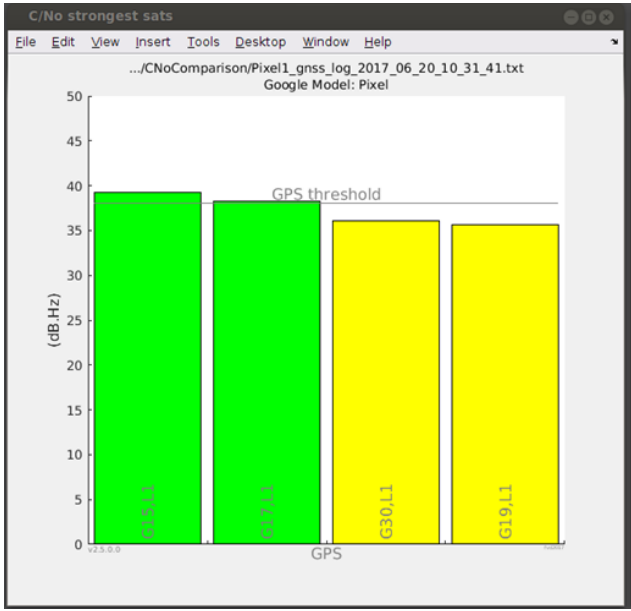
New feature: see where all the GNSS satellites are, at any time, from any place

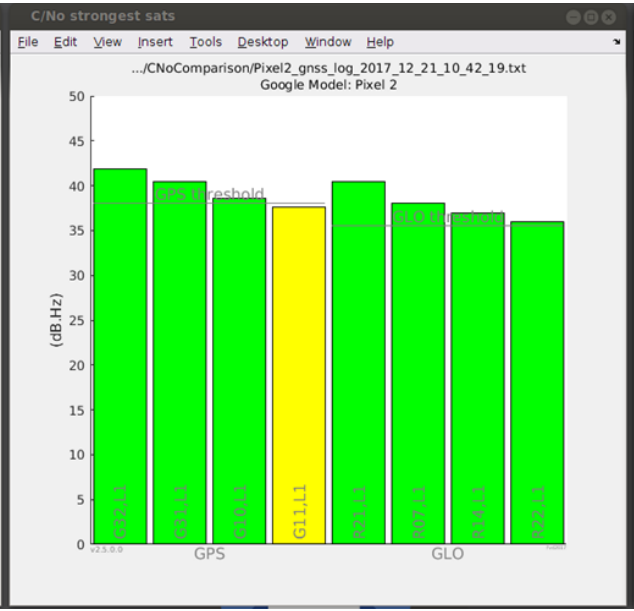


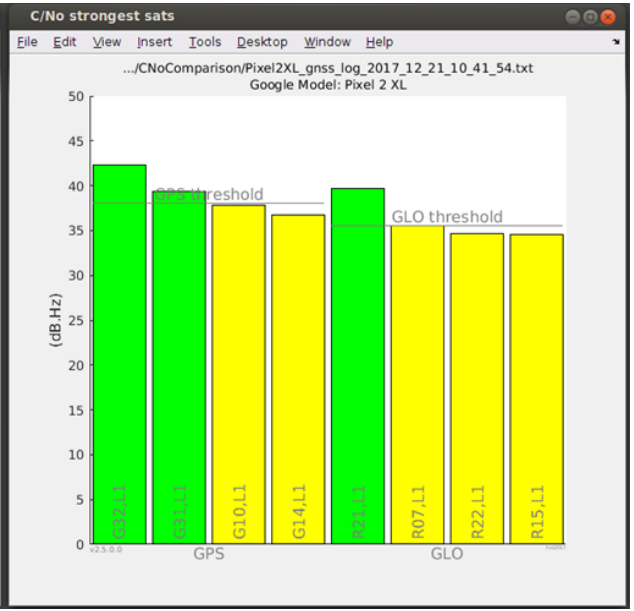


C/No comparison from different phones

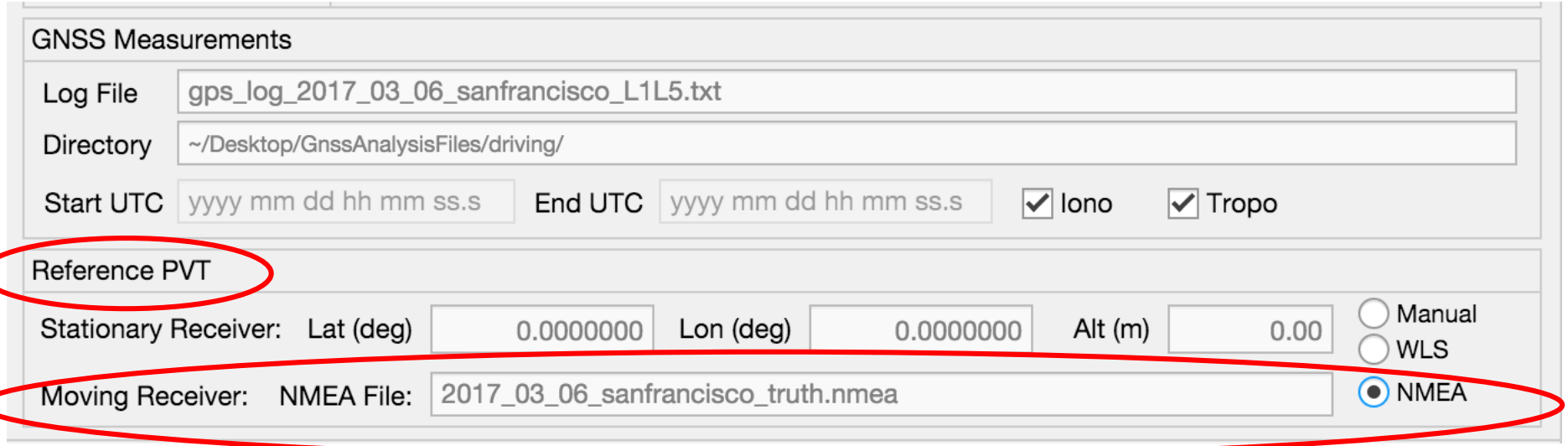




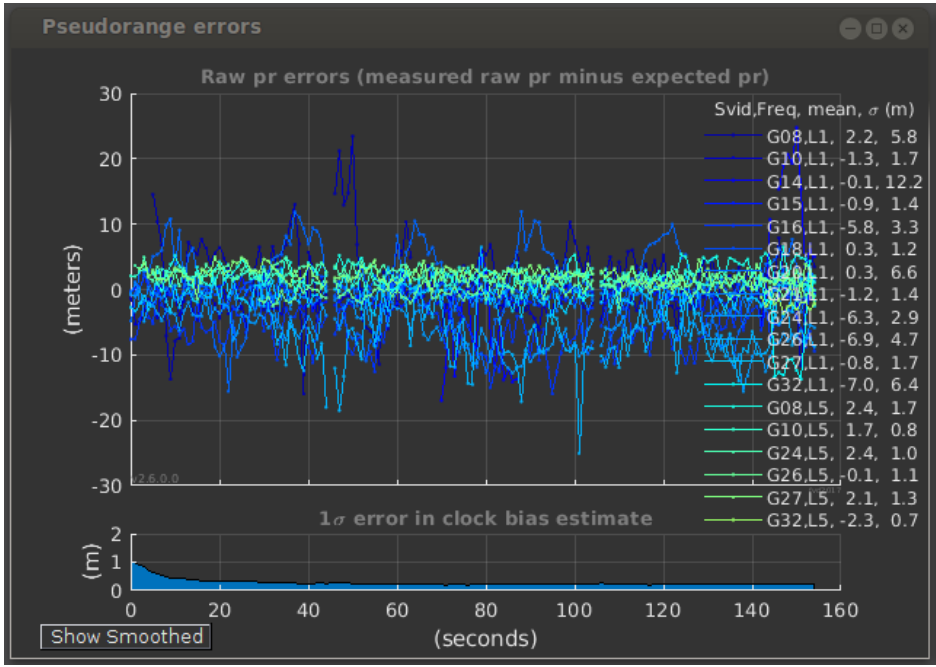


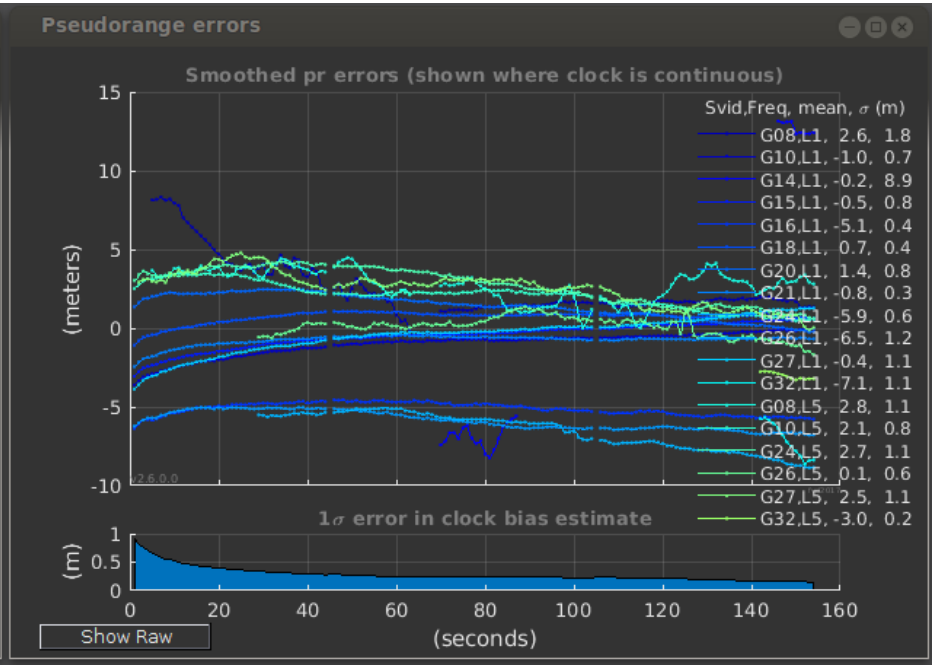


Measurement error for moving receiver

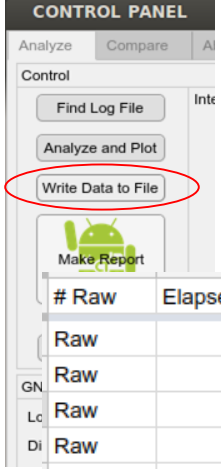


Plots from raw and smoothed pseudoranges





Similarly for WLS (Weighted Least Squares) position plots

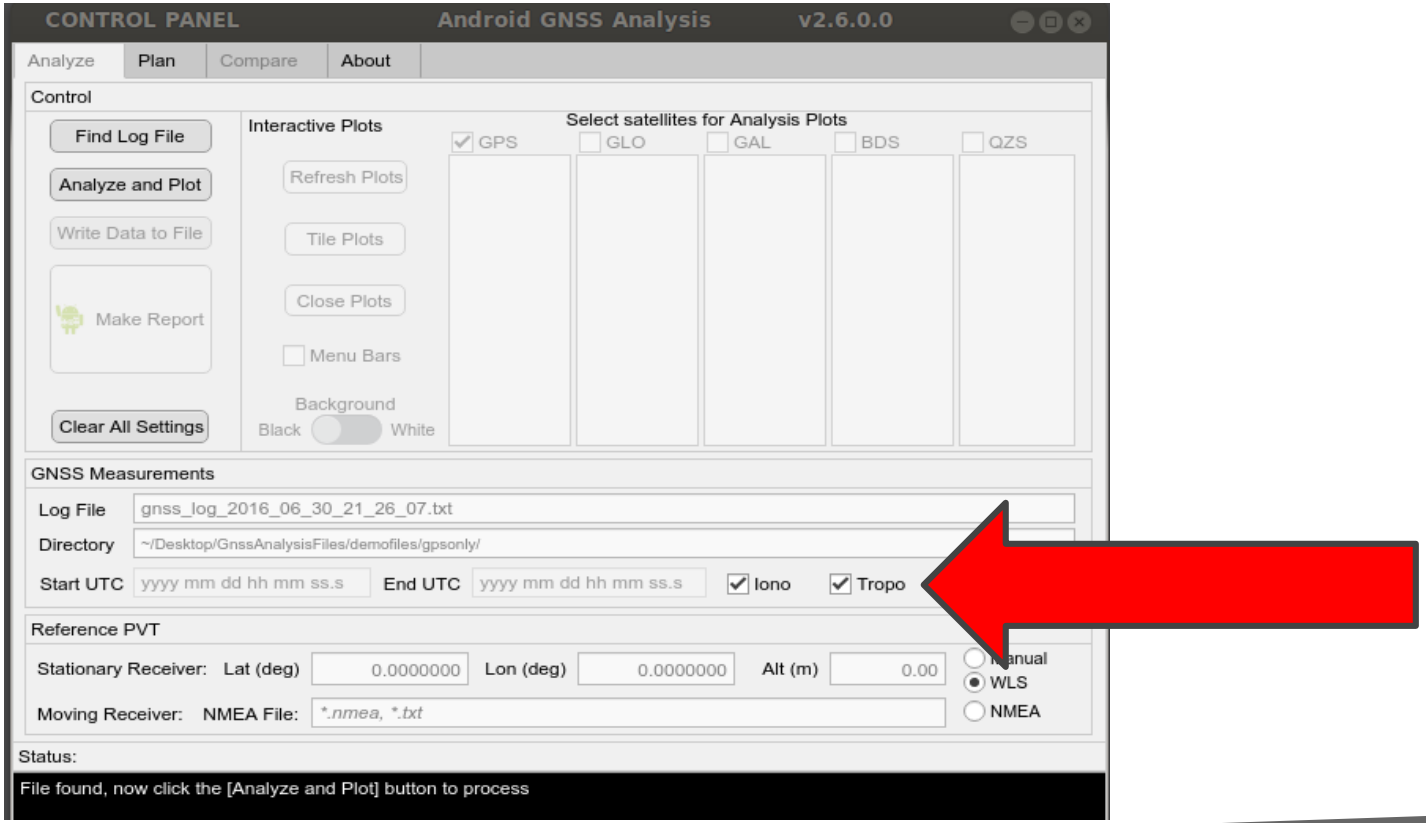


Log file of derived data

# Raw	ElapsedRealtime	TimeNanos	FullBiasNanos	BiasNanos	BiasUncertaintyNan	DriftNanosPerSe	DriftUncertaintyN	HardwareClockD	Svid	State	ReceivedSvTimeNanos
Raw	72066156	72077939000000	-1151285108458	0	29.04968824	-10.44367167	9.725224775	188	2	15	422786326364257
Raw	72066156	72077939000000	-1151285108458	0	29.04968824	-10.44367167	9.725224775	188	3	15	422786311362544
Raw	72066156	72077939000000	-1151285108458	0	29.04968824	-10.44367167	9.725224775	188	6	15	422786328163499
Raw	72066157	72077939000000	-1151285108458	0	29.04968824	-10.44367167	9.725224775	188	12	15	422786324938402
Raw	72066158	72077939000000	-1151285108458	0	29.04968824	-10.44367167	9.725224775	188	17	15	422786318854444
Raw	72066158	72077939000000	-1151285108458	0	29.04968824	-10.44367167	9.725224775	188	19	15	422786325655597
Raw	72066159	72077939000000	-1151285108458	0	29.04968824	-10.44367167	9.725224775	188	24	15	422786327049332
Raw	72066160	72077939000000	-1151285108458	0	29.04968824	-10.44367167	9.725224775	188	25	15	422786314218724
Raw	72066160	72077939000000	-1151285108458	0	29.04968824	-10.44367167	9.725224775	188	28	15	422786314963456

# MEAS	TimeNanos	Svid	CarrierFrequenc	Cn0DbHz	AzDeg	ElDeg	RawPrM	RawPrUncM	RawPrErrorM	SmPrM	SmP
MEAS	72077939000000	6	1575420000	33.5	83.7	62.483	20690041.29	3.298	-3.098	20690038.62	
MEAS	72077939000000	12	1575420000	34.6	314.554	41.623	21656901.04	2.998	-2.457	21656898.63	
MEAS	72077939000000	17	1575420000	39.1	55.133	25.21	23480825.77	1.799	0.201	23480822.96	
MEAS	72077939000000	19	1575420000	42	43.12	48.227	21441891.39	1.199	-0.459	21441892.53	
MEAS	72077939000000	24	1575420000	30.4	250.632	57.707	21024060.15	4.197	-2.266	21024059.72	
MEAS	72077939000000	25	1575420000	27.5	303.286	7.635	24870579.66	5.696	-6.677	24870574.92	
MEAS	72077939000000	28	1575420000	30.6	109.618	8.509	24647314.63	4.197	-7.244	24647316.64	

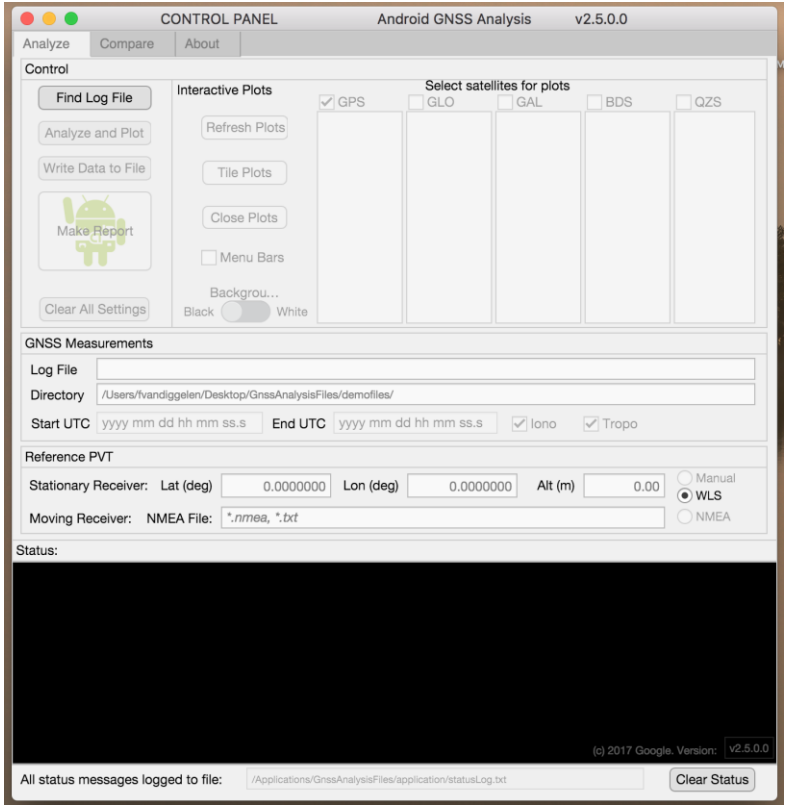
Iono & Tropo control



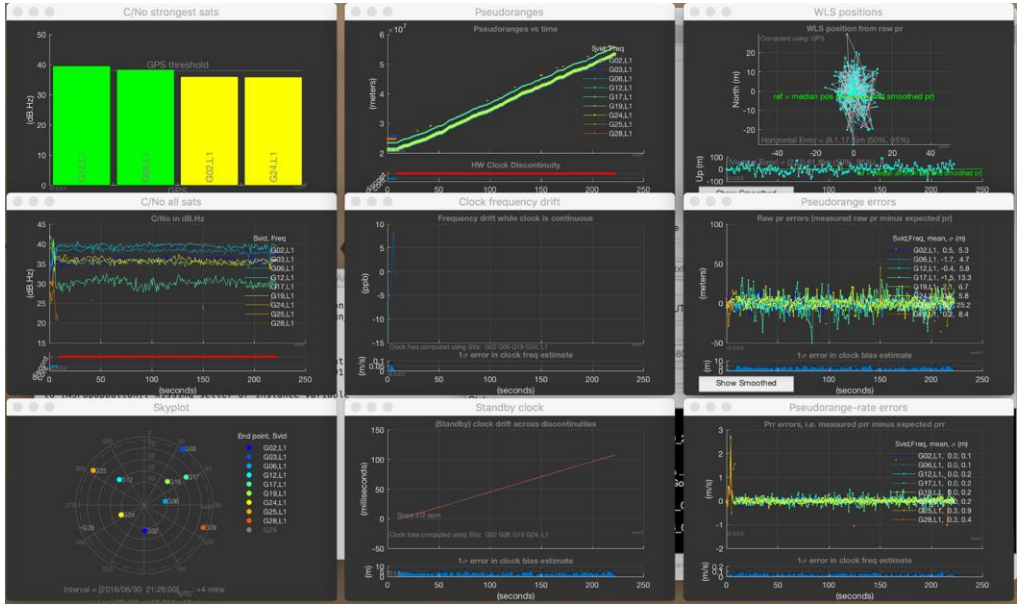
Hands-on exercises

1. .../GnssAnalysisFiles/demofiles/
    - The demo log file you downloaded with the desktop app
    - We will use this to learn the capabilities of the analysis tools
2. .../GnssAnalysisFiles/driving/
    - GPS dual-frequency log file with ground-truth nmea
    - Use this to analyze reflections in urban canyons
3. .../GnssAnalysisFiles/ionotropodemo/
    - GNSS log file, stationary, at a known position, open sky
    - Example of how to analyze iono and tropo errors.

Exercise #1 .../GnssAnalysisFiles/demofiles/



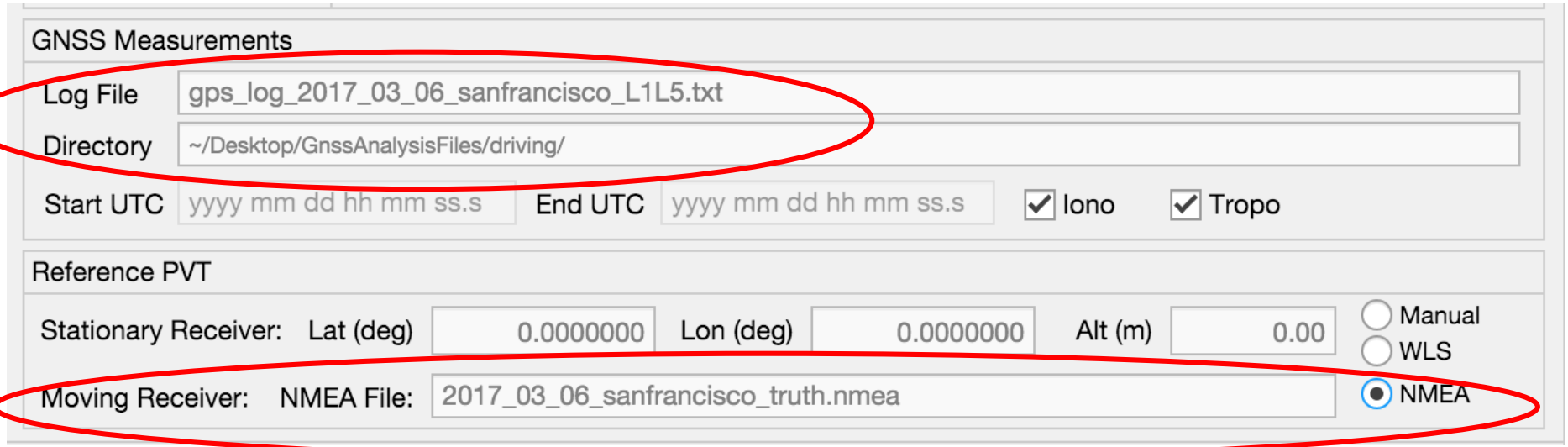
RF | Clocks | Measurements



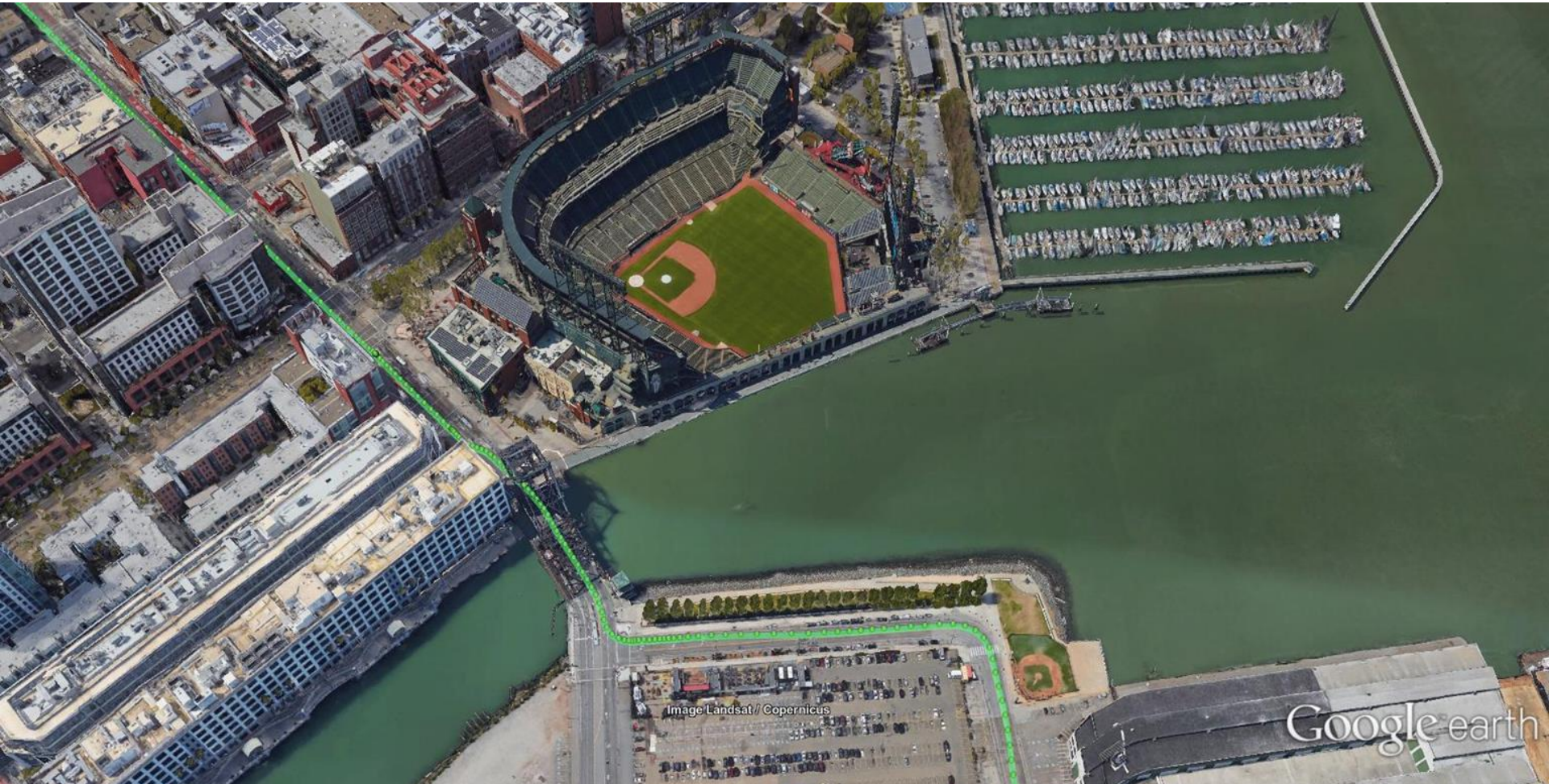
Download log files for the following exercises

https://sites.google.com/corp/view/gnsstutorial

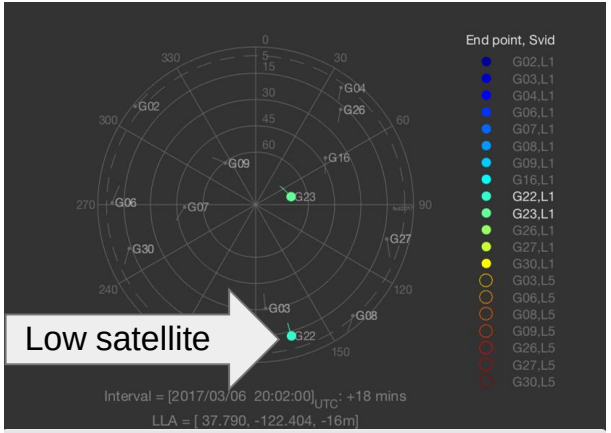
Exercise #2 .../GnssAnalysisFiles/driving/

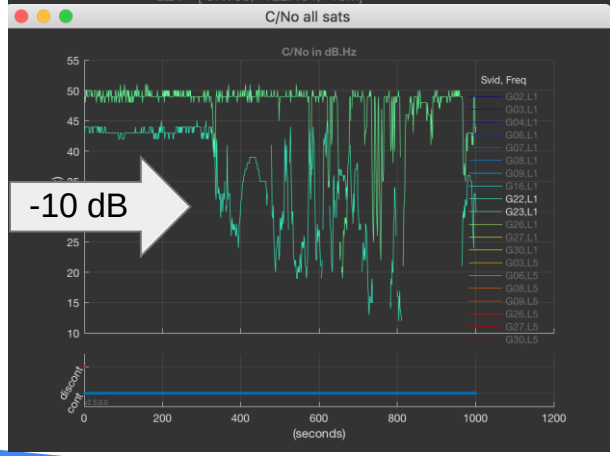


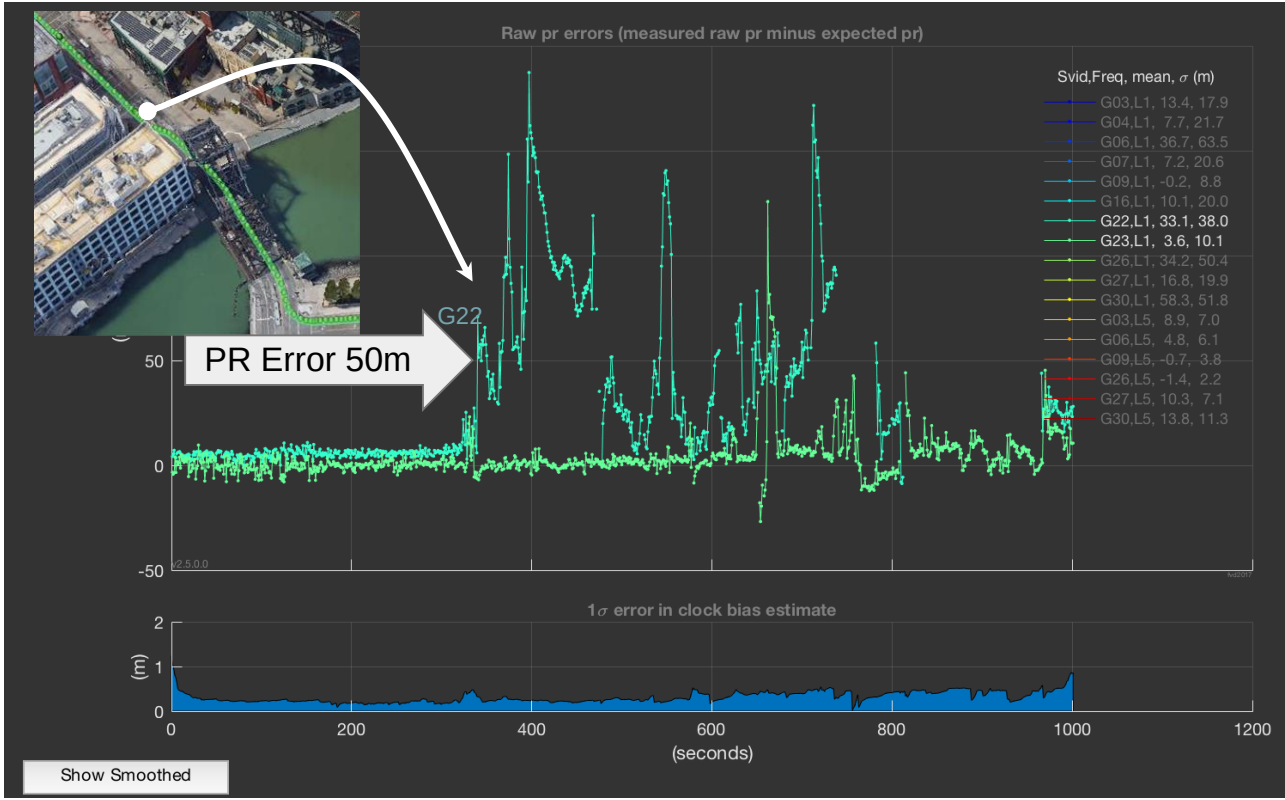
Analysis example, driving into San Francisco:



Analysis example, driving into San Francisco:







What happened with satellite G22?

Exercise #3 .../GnssAnalysisFiles/ionotropodemo/

1. Use true position for Reference PVT
2. Select highest satelltes to use for clock bias computation (CustomParam.txt)
3. Remove iono and tropo model from analysis

Then error plot will show all errors relative to the highest satellites.

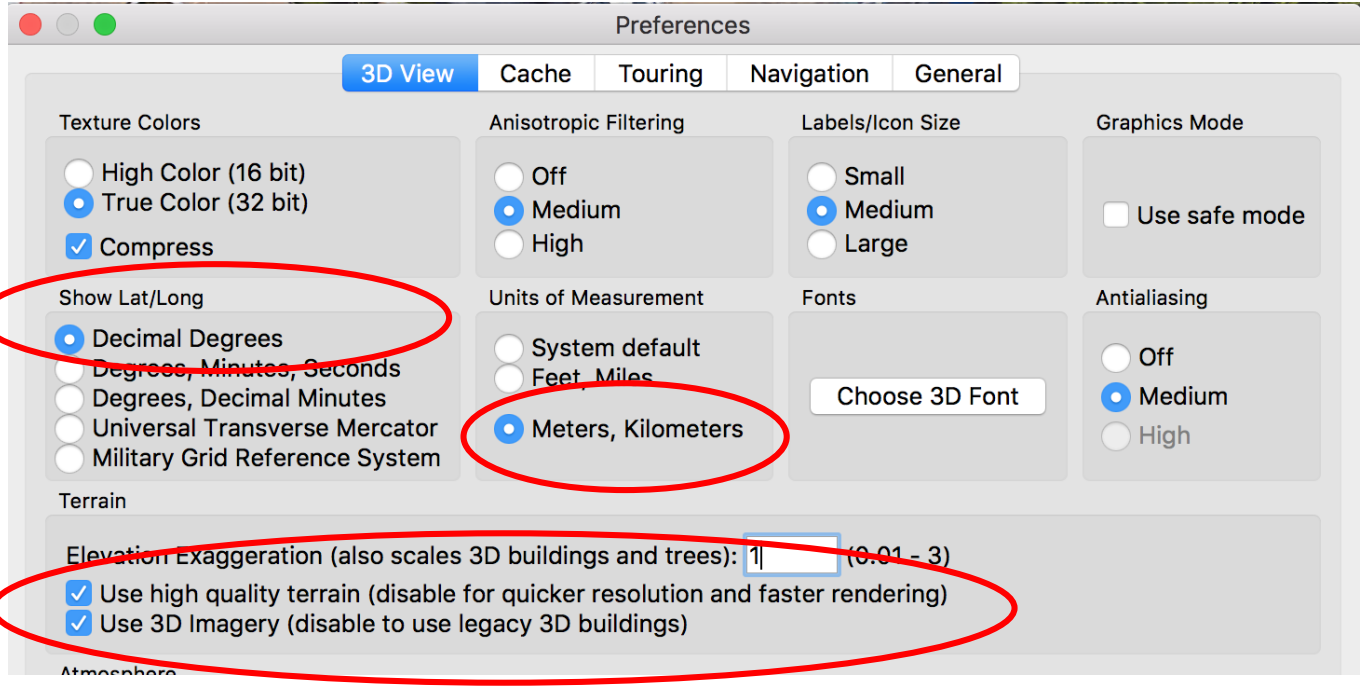
How to get true position from Google Earth (1)

Preferences …

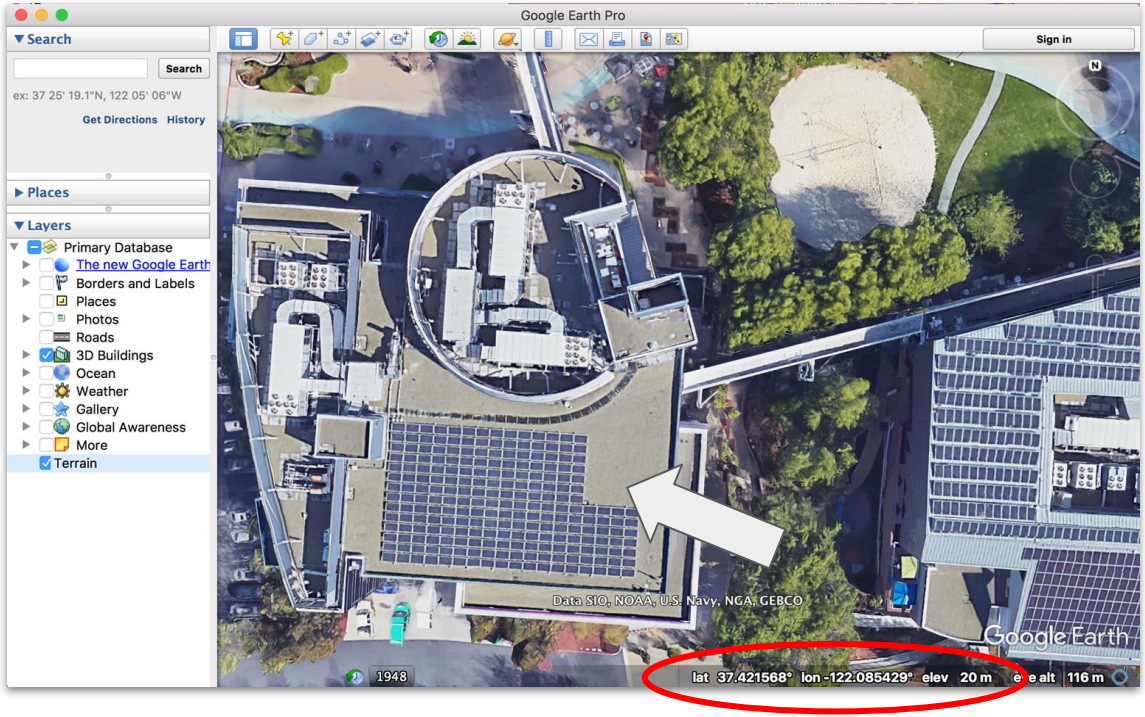
Show Lat/Long
  Decimal Degrees

Units of Measurement
  Meters,Kilometers

Terrain
  Use high quality terrain
  Use 3D imagery



How to get true position from Google Earth (2)



hG = height above Geoid,
 from Google Earth 3D Buildings, 20m
hS = height of stand = 1m
dE = -32, Ellipsoid - Geoid

hE = hG+hS+dE = 20+1-32 = -11 m.

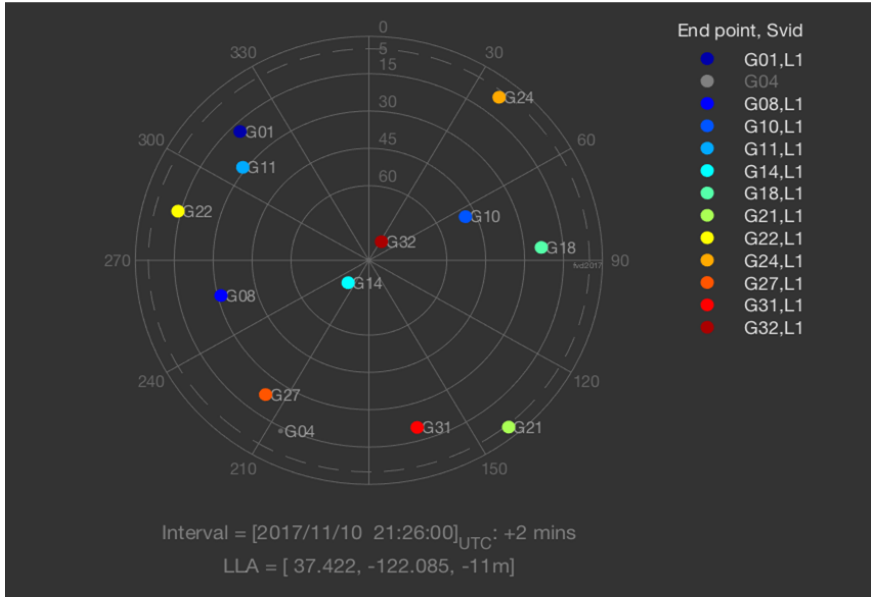
Rooftop true position: 37.421568, -122.085429, -11m

CustomParam.txt

```
%Currently supported:
%param.losSvid = list of svid to use for computing clock (Bc and BcDot)
%template for losSvid.Svid: must have .FreqBand, .Constellation, .Id
Svid1.Id = 32;
Svid1.FreqBand = GnssConstants.L1_BAND;
Svid1.Constellation = GnssConstants.GNSS_CONSTELLATION_GPS;
param.losSvid.Svids = {Svid1}; %pack in a cell array {}
```

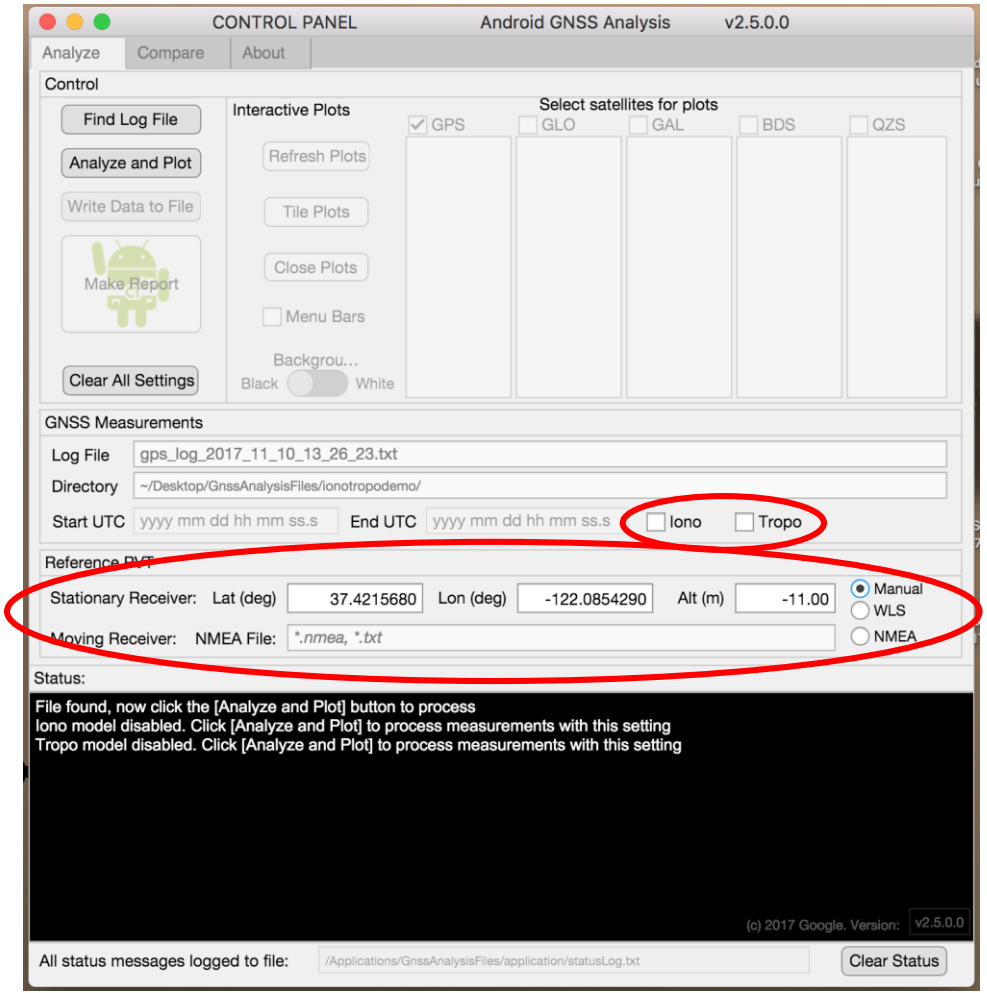
You edit these lines to choose the reference satellite(s) you want.

And place this txt file in the same directory as your log file.

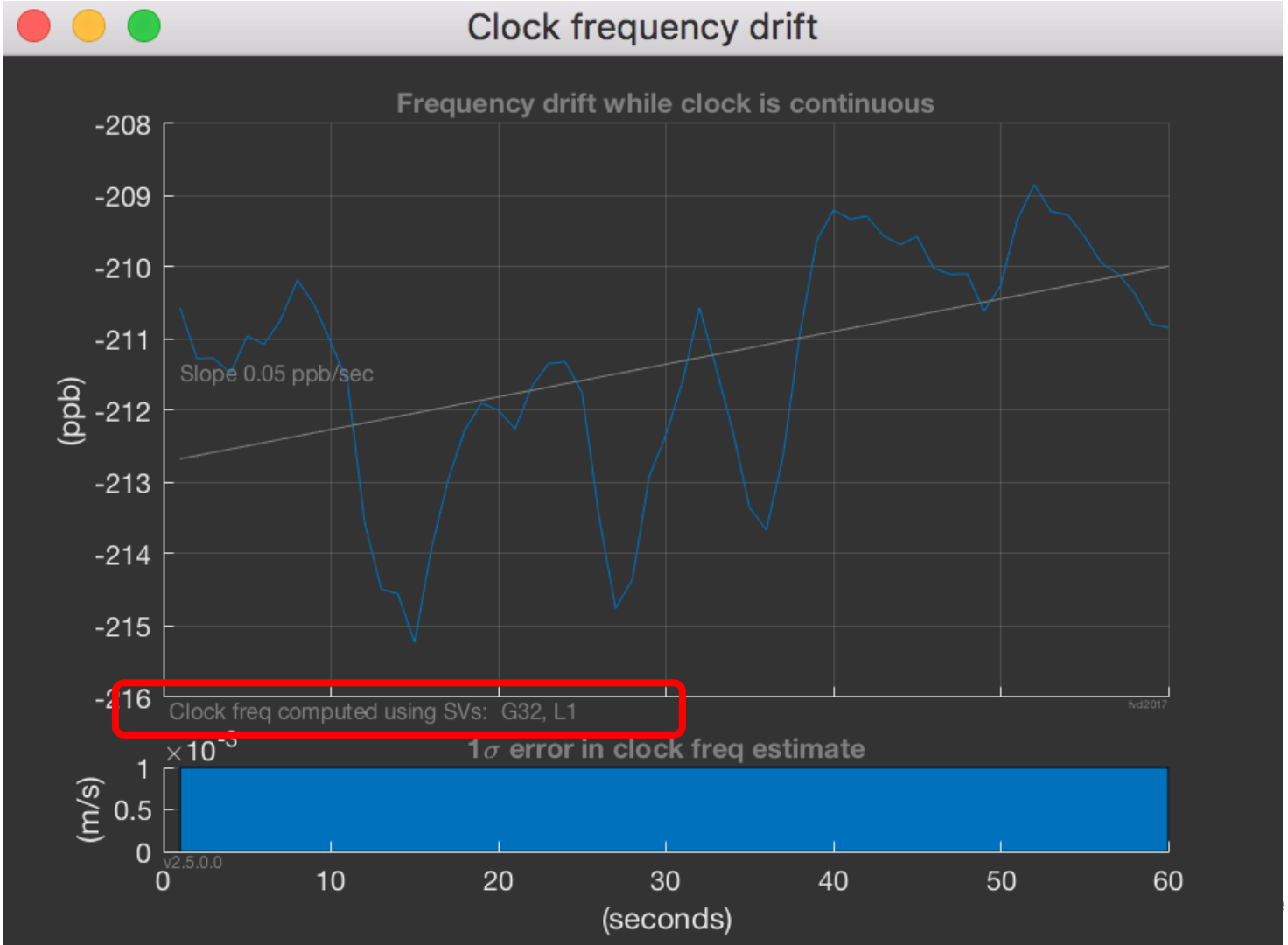


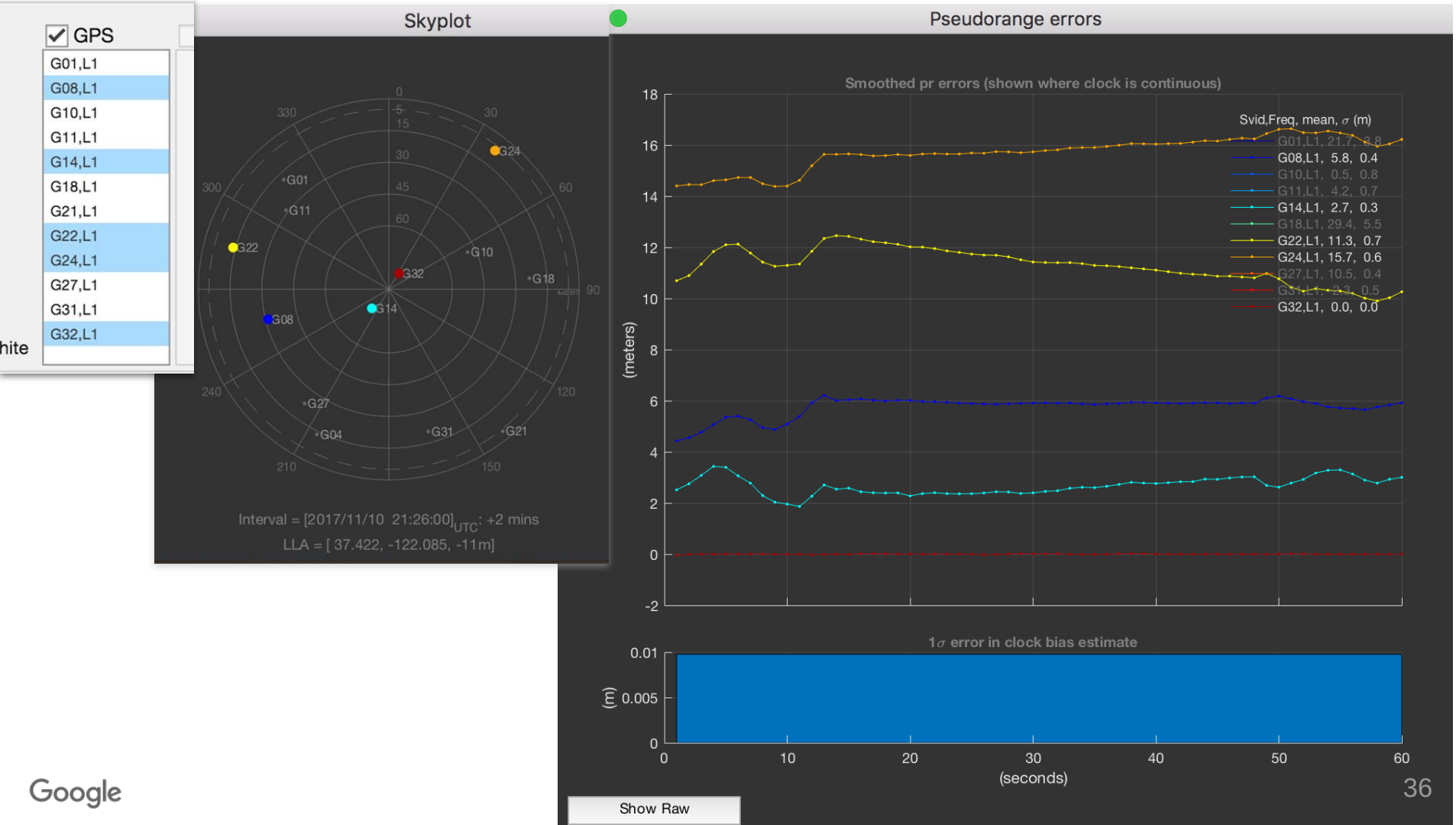
Analyzing, errors:

- iono +
- tropo +
- SIS[1]



[1]SIS errors = Signal In Space errors = errors after applying broadcast ephemeris and clock values


Clock frequency drift
Frequency drift while clock is continuous
-208
-209
-210
-211
-212
-213
-214
-215
-216
(ppb)
Slope 0.05 ppb/sec
Clock freq computed using SVs: G32, L1
fvd2017
1σ error in clock freq estimate
×10^-3
1
0.5
0
(m/s)
v2.5.0.0
0
10
20
30
40
50
60
(seconds)

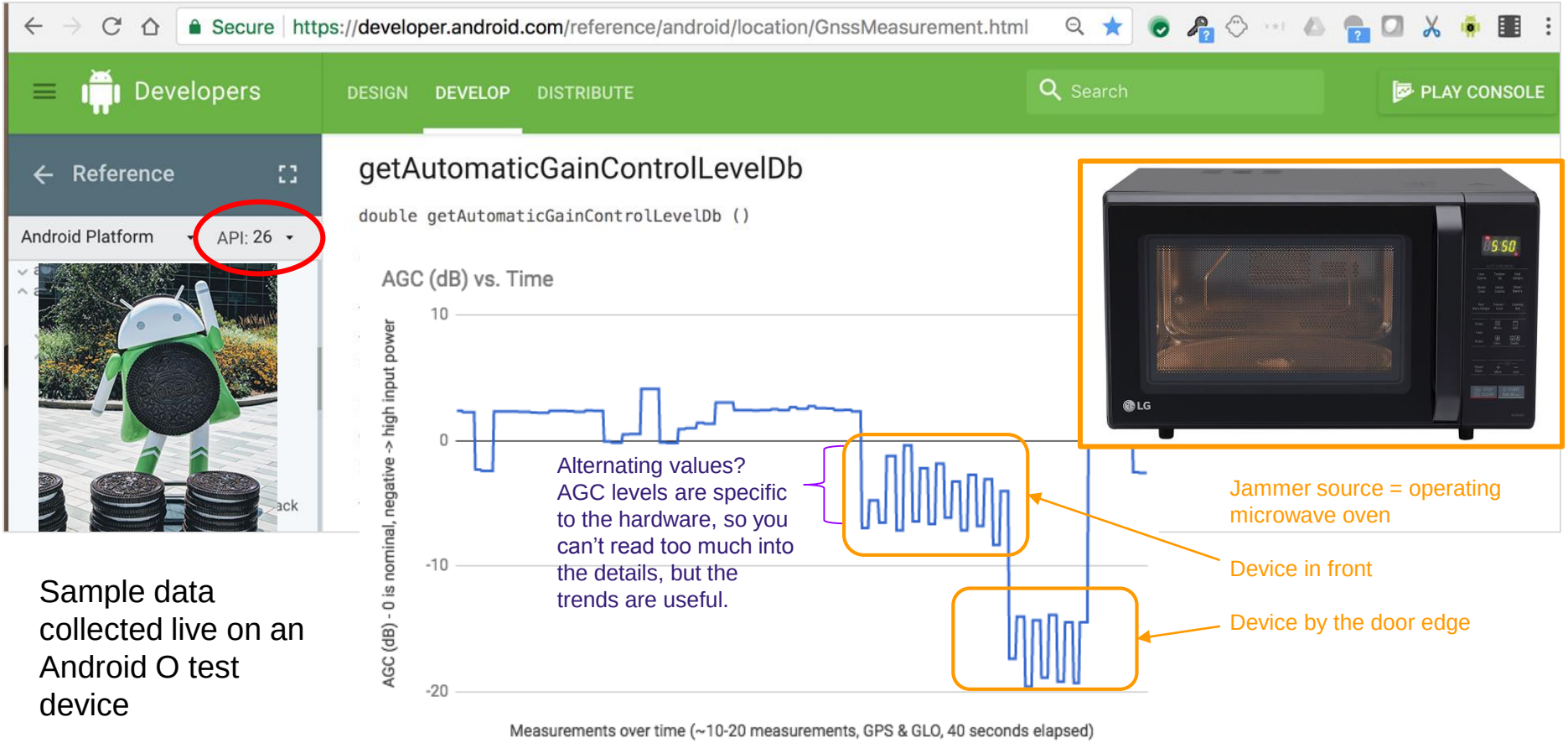

GPS
G01,L1
G08,L1
G10,L1
G11,L1
G14,L1
G18,L1
G21,L1
G22,L1
G24,L1
G27,L1
G31,L1
G32,L1
hite
Skyplot
0
30
60
90
120
150
180
210
240
270
300
330
5
15
30
45
60
G24
G01
G11
G22
G10
G32
G18
G08
G14
G27
G04
G31
G21
Interval = [2017/11/10 21:26:00]UTC: +2 mins
LLA = [37.422, -122.085, -11m]
Pseudorange errors
Smoothed pr errors (shown where clock is continuous)
Svid,Freq, mean, σ (m)
G01,L1, 21.7, 3.8
G08,L1, 5.8, 0.4
G10,L1, 0.5, 0.8
G11,L1, 4.2, 0.7
G14,L1, 2.7, 0.3
G18,L1, 29.4, 5.5
G22,L1, 11.3, 0.7
G24,L1, 15.7, 0.6
G27,L1, 10.5, 0.4
G31,L1, 2.3, 0.5
G32,L1, 0.0, 0.0
(meters)
18
16
14
12
10
8
6
4
2
0
-2
1σ error in clock bias estimate
(m)
0.01
0.005
0
0
10
20
30
40
50
60
(seconds)
Show Raw

Google

Future: examples of apps and research

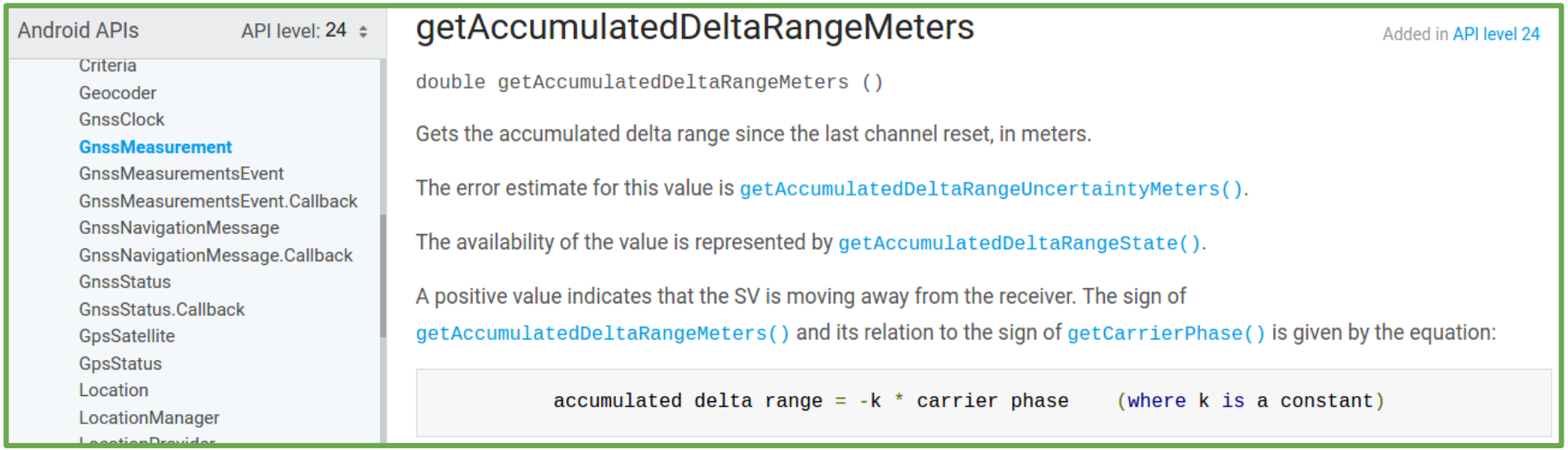
1. Jamming detection
2. Carrier-phase PVT
3. GNSS system monitor
4. Signal analysis (iono, tropo, SIS, multipath, radio noise)

1) Jamming detection



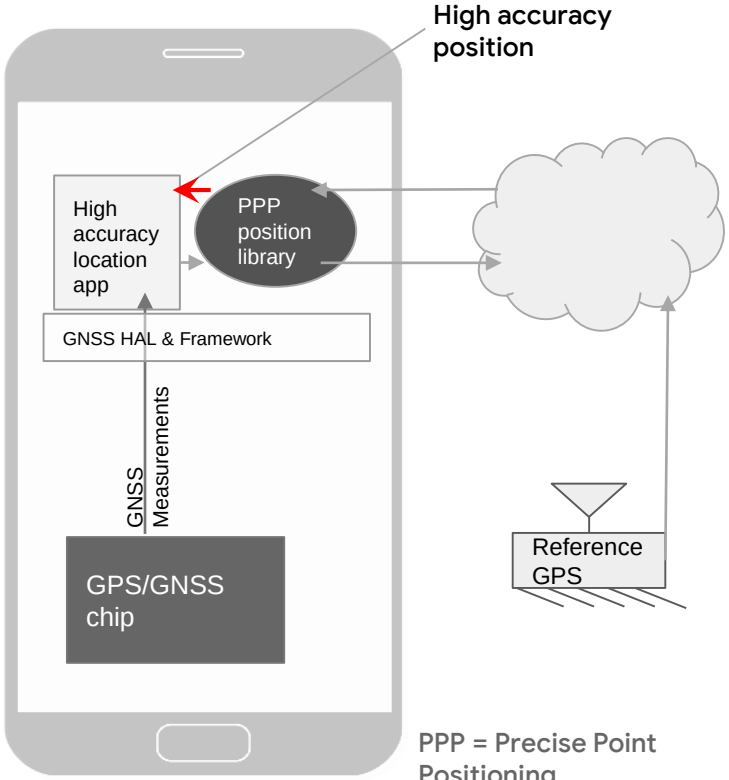
Sample data collected live on an Android O test device

2) Carrier phase = AccumulatedDeltaRange



ADR is continuous only when clock is continuous, and there is no duty cycling

Apps for high-accuracy GPS



PPP = Precise Point Positioning

L1 “PPP” <1m accuracy after a few minutes

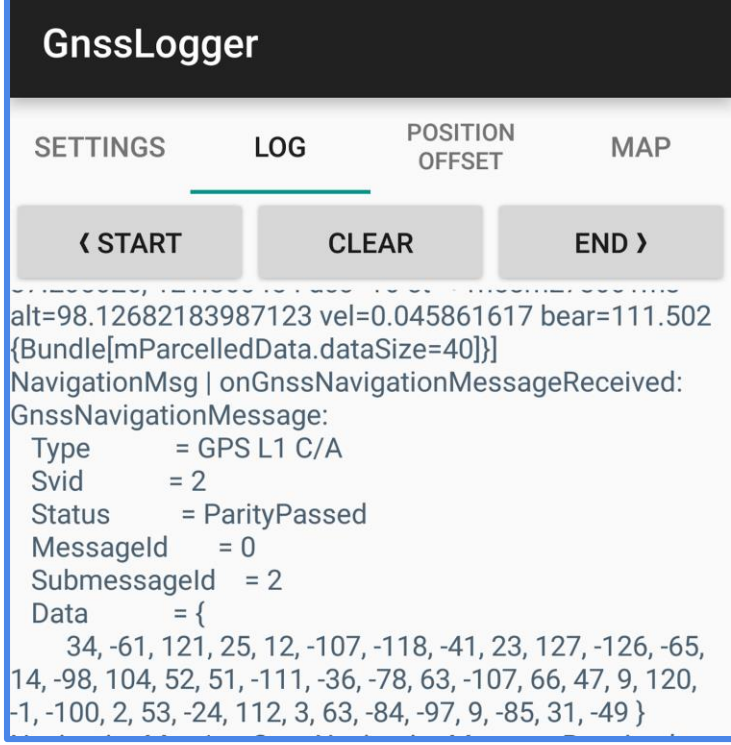
PPP Wizlite, from CNES

Public sources for code libraries and reference networks:

www.rtklib.org, RTKLIB: An Open Source Program Package for GNSS Positioning

www.igs.org, International GNSS Service

3) Decoded Nav data, in GnssLogger:

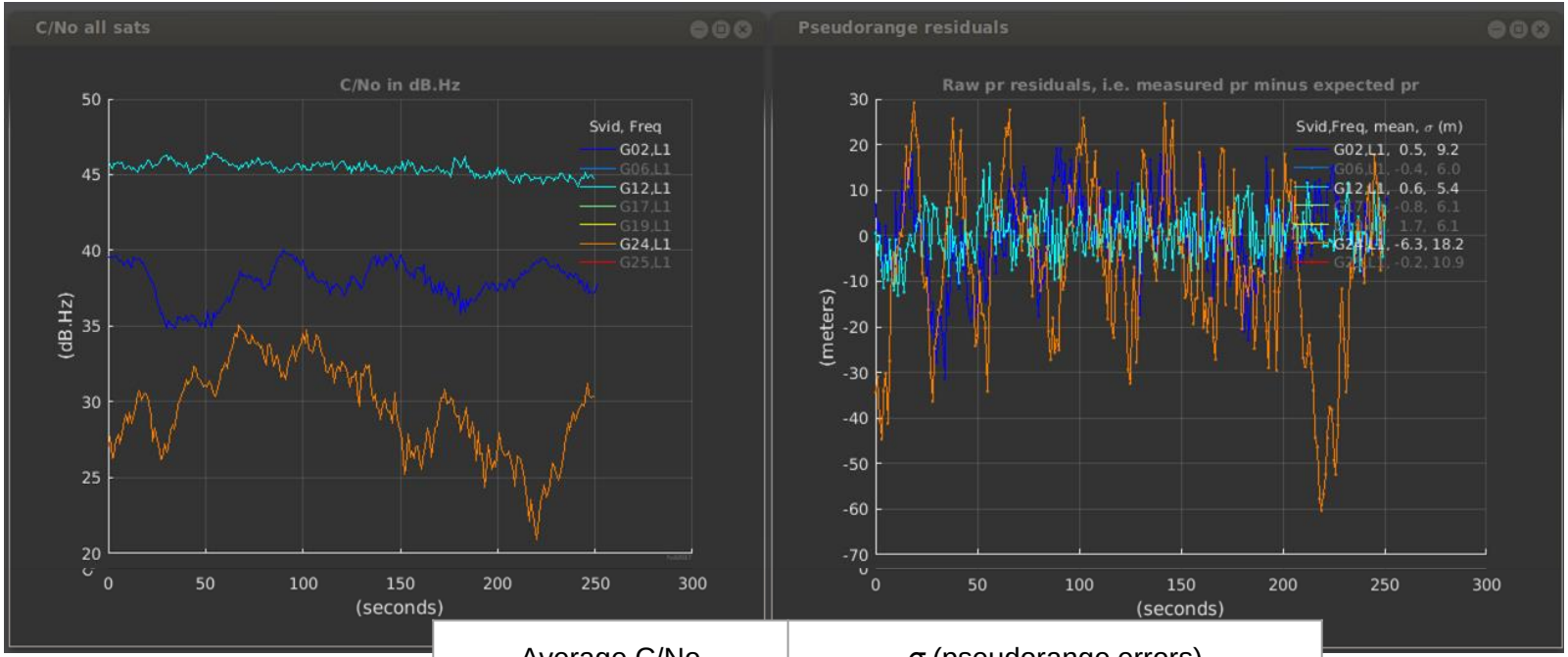


And in log file:

```
#
# Header Description:
#
# Version: 1.4.0.0, Platform: N
#
# Nav,Svid,Type,Status,MessageId,Sub-messageId,Data(Bytes)
Nav,2,257,1,0,3,34,-61,121,25,12,-108,107,35,0,33,-42,115,35,46,-77,-78,63,-5,-55,-81,29,76,25,-91,8,-23,106,-113
Nav,12,257,1,0,3,34,-61,121,25,12,-108,107,35,63,-5,2,54,6,-27,120,-7,63,-13,10,55,22,-69,6,-108,6,-99,-120,59,9,-
Nav,25,257,1,0,3,34,-61,121,25,12,-108,107,35,63,-8,-63,106,63,25,3,-49,63,-6,-55,-21,55,-49,35,111,6,-63,-56,18,
Nav,98,769,1,0,1,8,87,-128,22,-95,96,-81,-109,-100,30,-104
```

Decimal equivalent of each byte, for example: 0b00111111 = 63

4) Signal analysis: iono, tropo, SIS, multipath, and radio noise:



Average C/No	σ (pseudorange errors)
46 dB.Hz	5.4 m
37 dB.Hz	9.2 m
30 dB.Hz	18.2 m

Summary

- Get raw measurements from Android phones
- Details and software at https://g.co/GnssTools
- Much analysis you can do with the tools directly
- Save derived data, and do further analysis with it
- Pursue research, teaching, testing and app development based on these measurements

End,

Thank you.