Jet Propulsion Laboratory
California Institute of Technology

BeiDou Orbit Determination Processes and Products in JPL's GDGPS System

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Outline

- GNSS (GPS/BDS) with GIPSYx*
- Antenna Offsets
- Satellite Health - A Need For NABUs?
- Post-Processing
  - Quality Metrics: Residuals, Overlaps
  - Receiver Biases
  - A Year of Static BDS-Only PPP
- Real-Time
  - Quality Metrics: Orbit Differences vs Post-Processed
  - Kinematic PPP

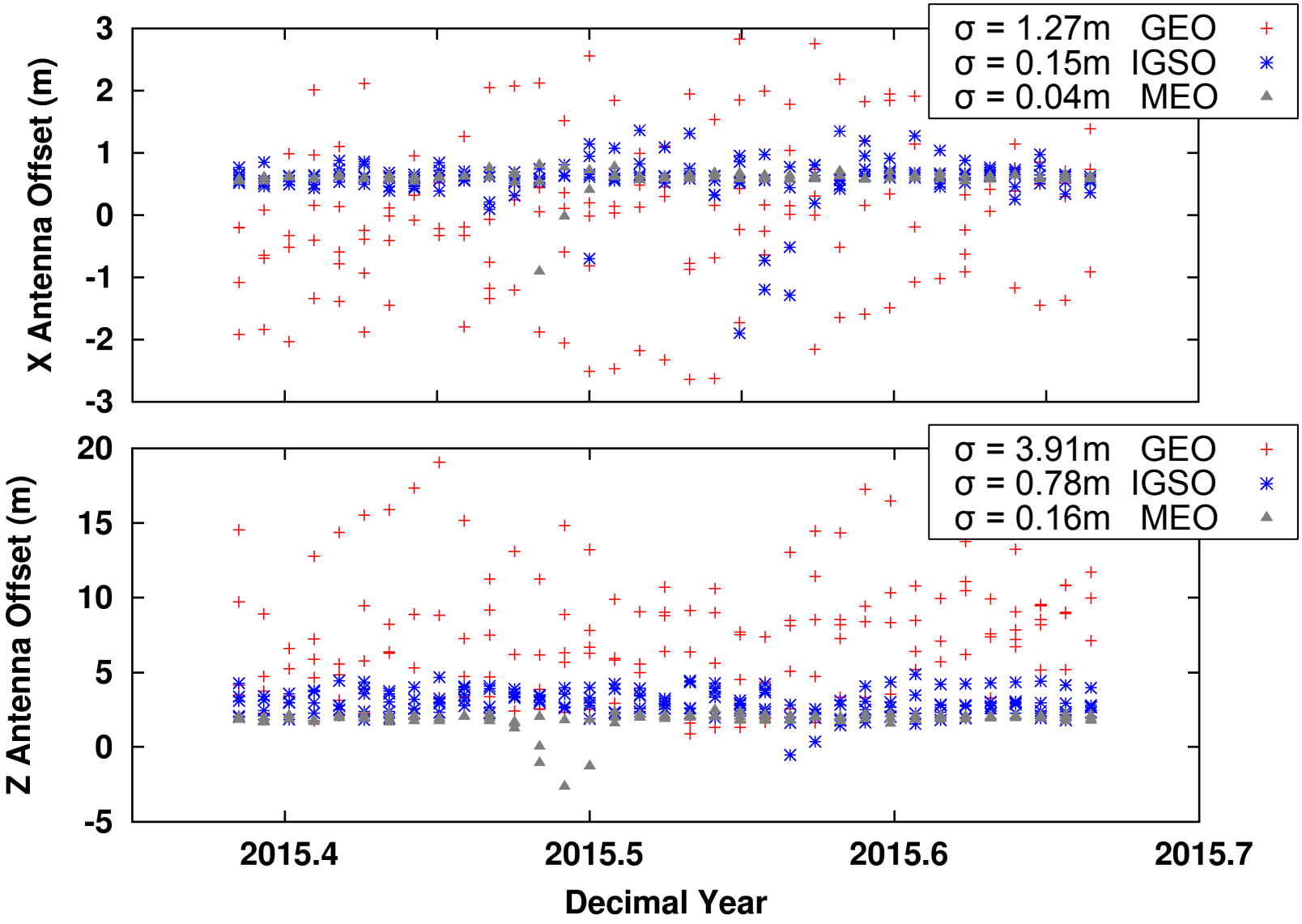
*Sibois et al., "Transitioning the JPL IGS Analysis Center Operations from GIPSY-OASIS to GIPSYx", Analysis Centers poster session

Strategies

Parameter	Post-Processed	"Real-Time"
Orbit Arc	78 hours	15 days
Data Rate	5 minutes	
Software	GIPSYx	GIPSYx
Strategy	Filter/Smoothed	Filter Only
GPS	Fixed to JPL Final	Estimated
BDS	Estimated	
Antenna Offsets	IGS (GPS) / JPL (BDS)	
EOP	Fixed to IERS Final*	
Gravity Field	EGM08 12 x 12	
BDS Attitude	Orbit Normal - GEO Yaw Normal - IGSO / MEO	
BDS Force Model	CODE 5-Parameter	

*But, see Bertiger et al., "GPS-based Real-Time and High-Rate Estimation of Earth Orientation Parameters", AGU, 2014

Antenna Offset Estimates

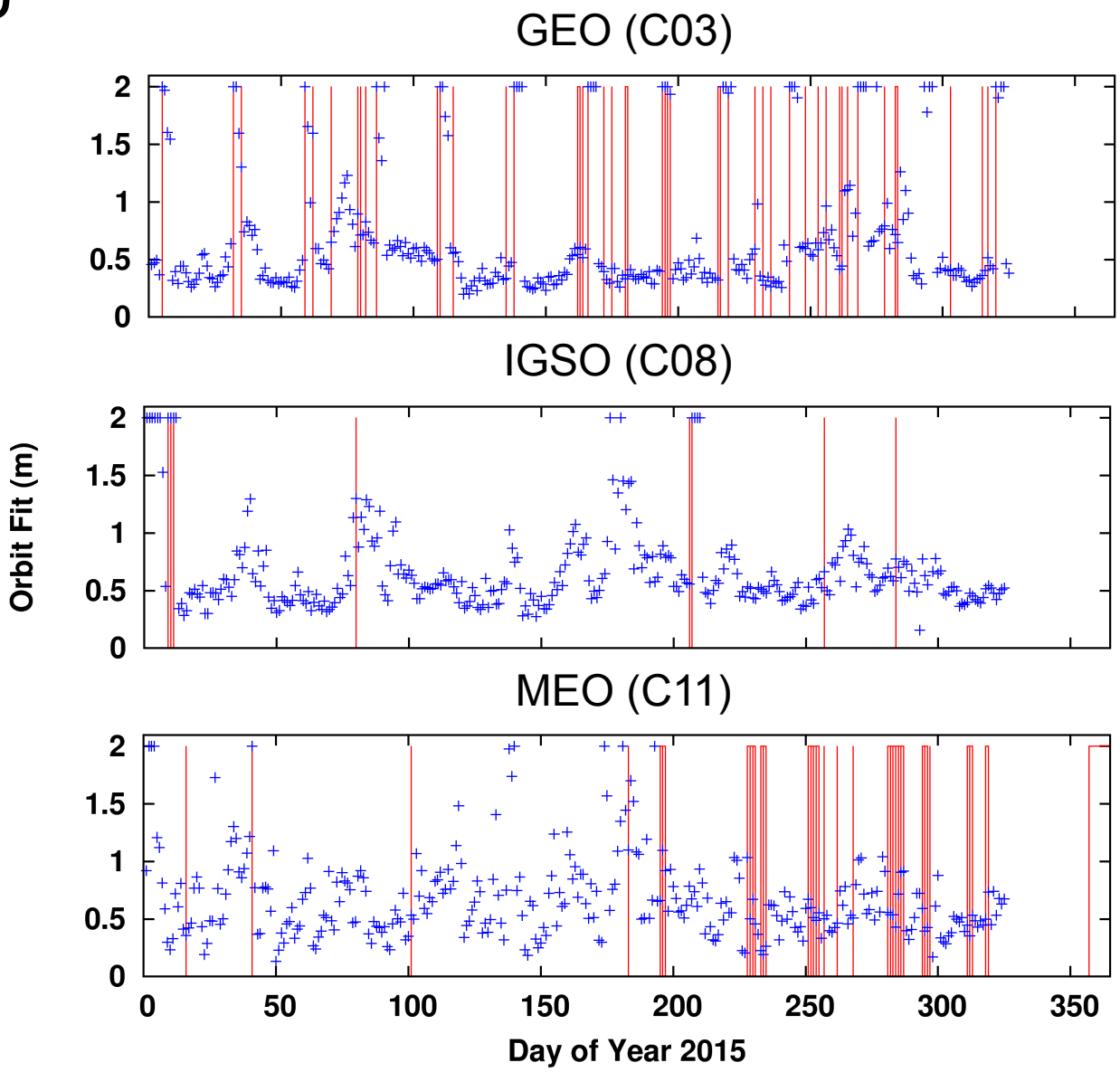


Antenna Offset Estimates

	ID	X_{ESA}	Y_{ESA}	Z_{ESA}	X_{JPL}	Y_{JPL}	Z_{JPL}	
	GEO	0.600	0.000	1.100	0.600	0.000	1.100	nominal
IGSO	C06	0.549	"	3.049	0.622	"	2.297	
IGSO	C07	"	"	3.237	"	"	2.607	
IGSO	C08	"	"	3.843	"	"	3.294	
IGSO	C09	"	"	3.974	"	"	2.615	
IGSO	C10	"	"	3.882	"	"	3.767	
MEO	C11	"	"	2.070	0.604	"	1.928	
MEO	C12	"	"	2.314	"	"	"	
MEO	C13	"	"	2.202	"	"	"	
MEO	C14	"	"	2.312	"	"	"	

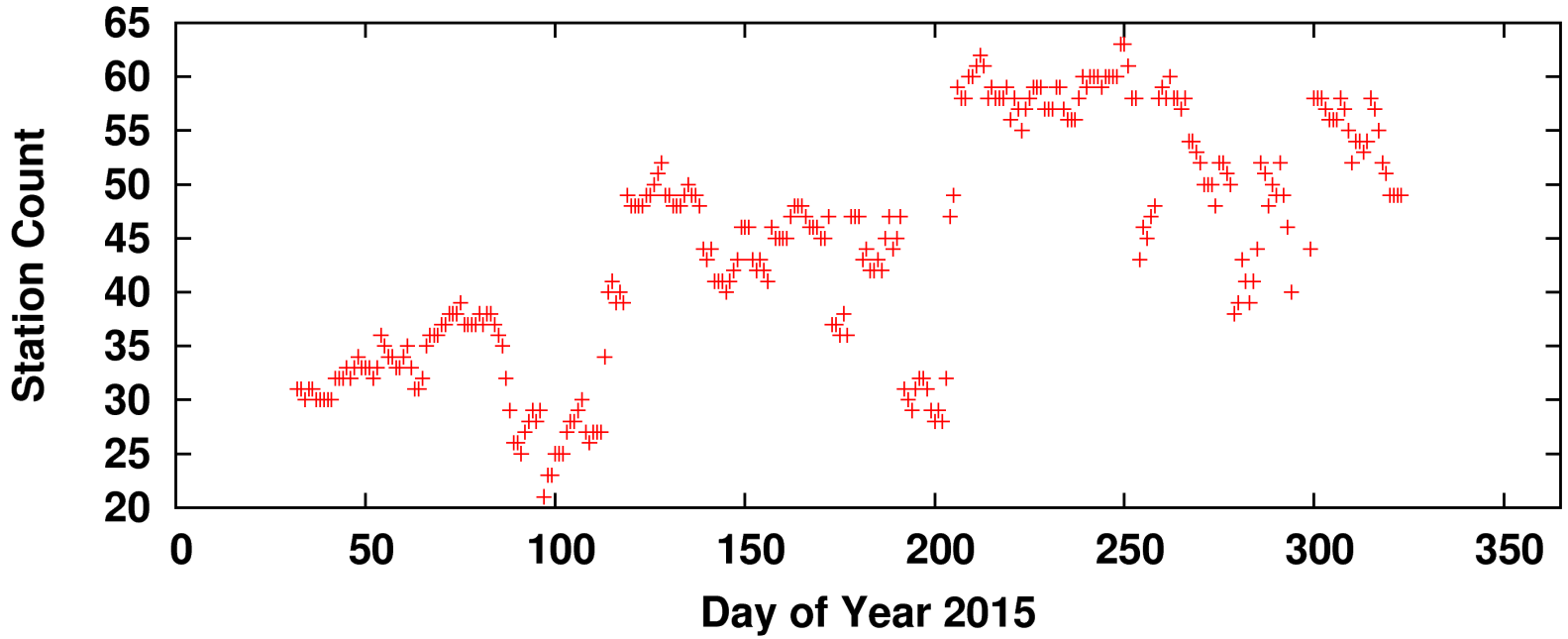
$[XYZ]_{ESA}$ values from "Estimation of Satellite Antenna Phase Center Corrections for BeiDou", Dilssner et al., IGS Workshop, 2014

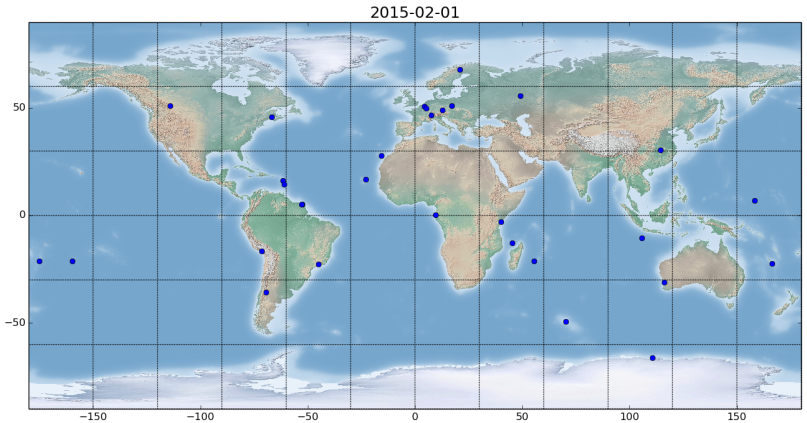
"NABU"

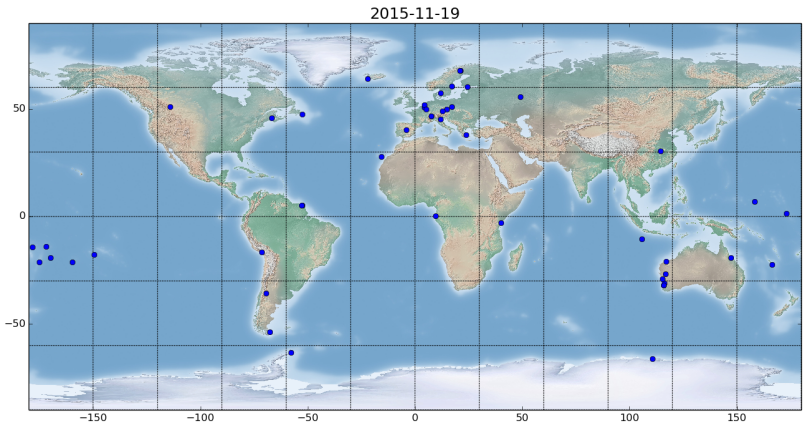

GEO (C03)
IGSO (C08)
MEO (C11)
Orbit Fit (m)
Day of Year 2015
0
0.5
1
1.5
2
0
50
100
150
200
250
300
350

Post-Processed
(Filter/Smoothed)

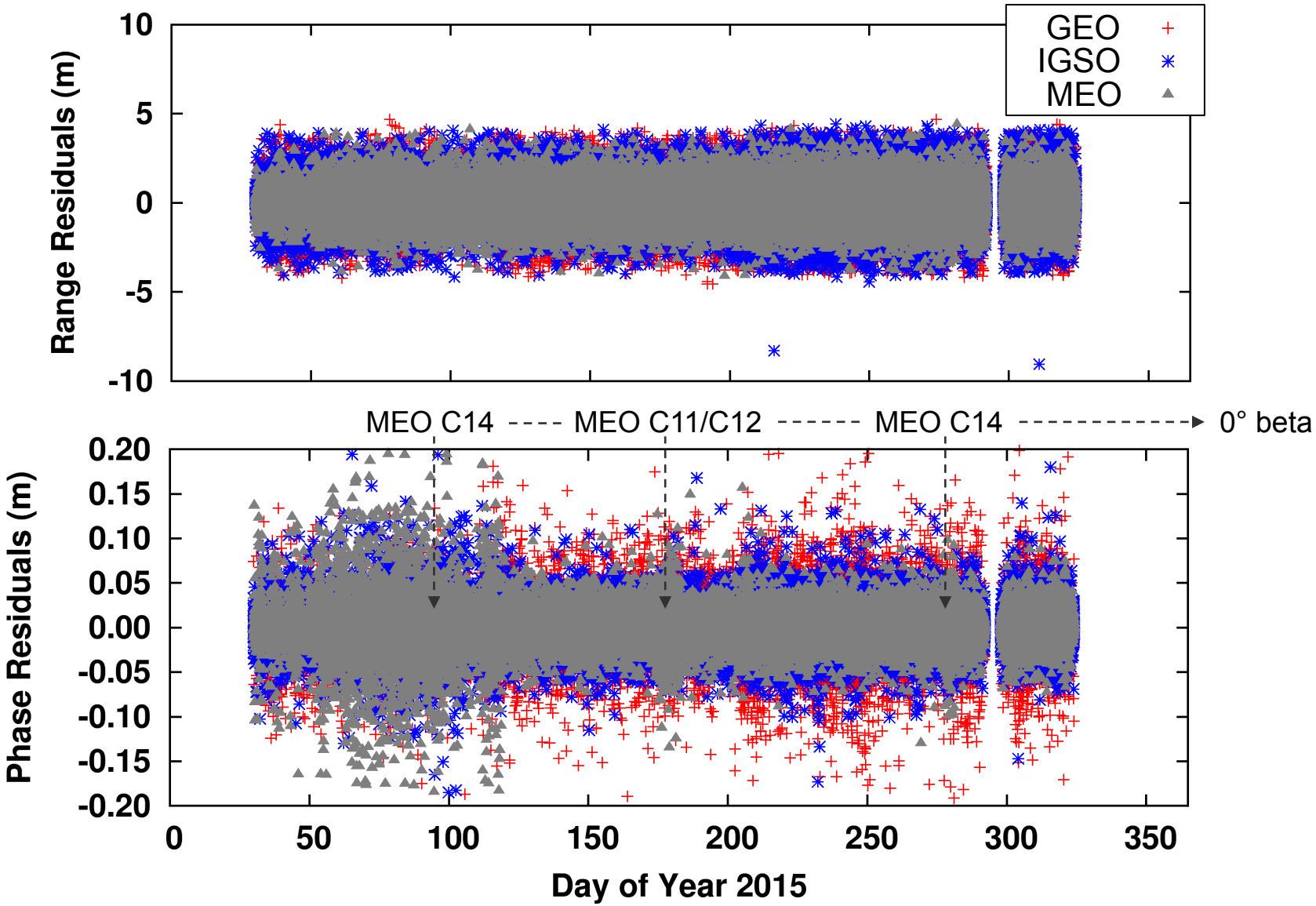
Stations


Station Count
65
60
55
50
45
40
35
30
25
20
0
50
100
150
200
250
300
350
Day of Year 2015

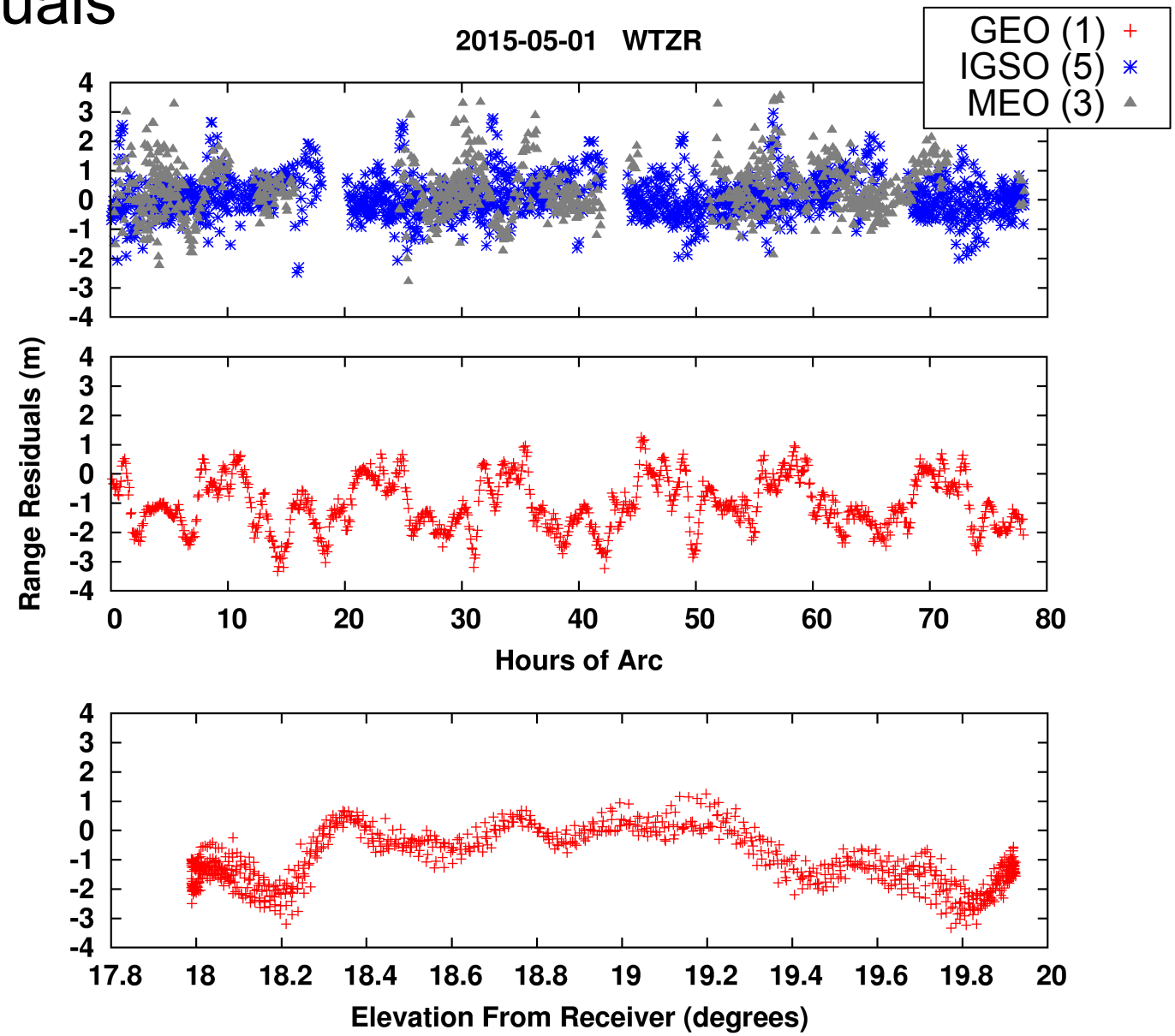

2015-02-01
50
0
−50
−150
−100
−50
0
50
100
150


2015-11-19
50
0
−50
−150
−100
−50
0
50
100
150

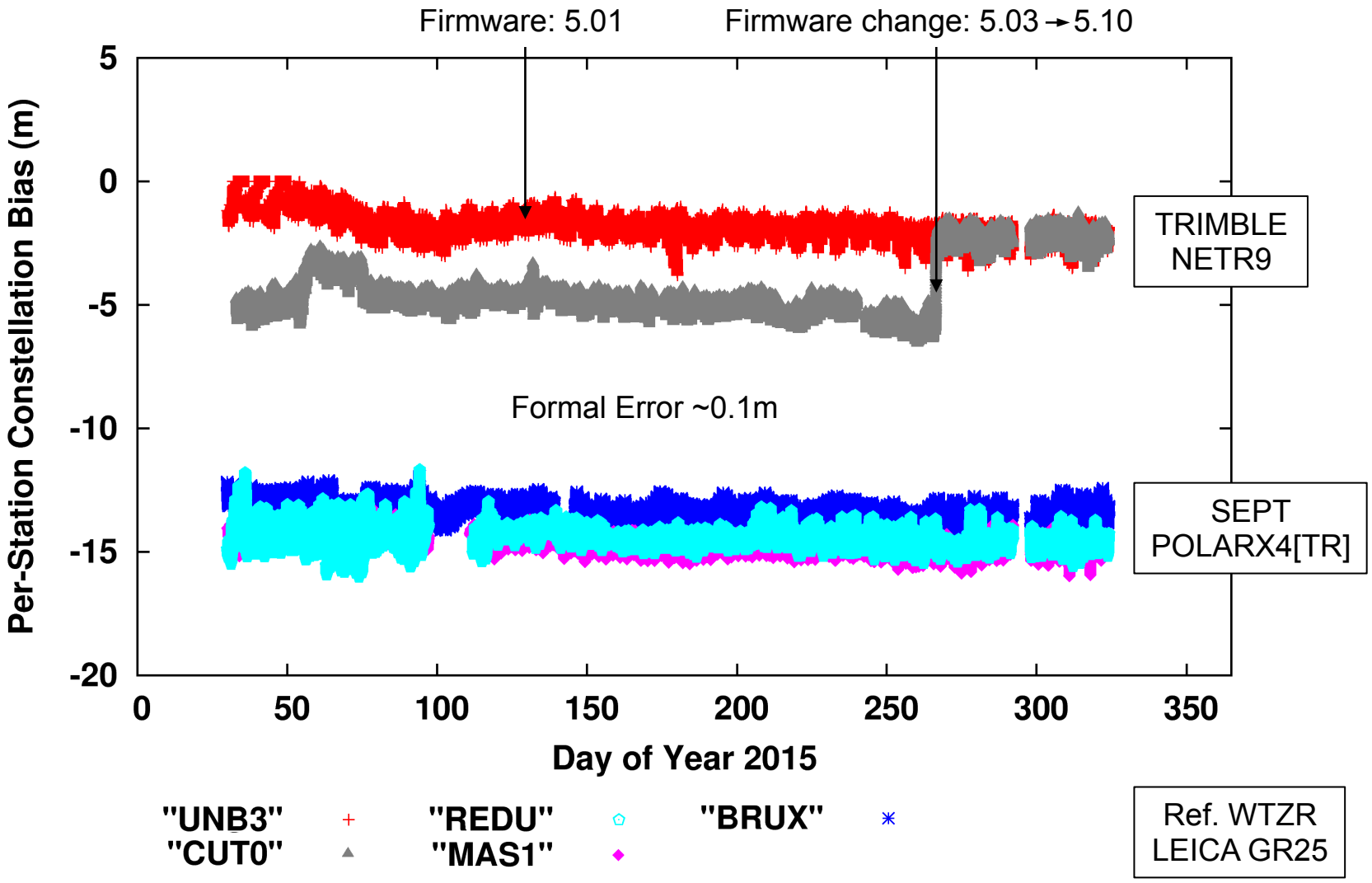
Residuals


GEO
IGSO
MEO
Range Residuals (m)
10
5
0
-5
-10
MEO C14
MEO C11/C12
MEO C14
0° beta
Phase Residuals (m)
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
0
50
100
150
200
250
300
350
Day of Year 2015

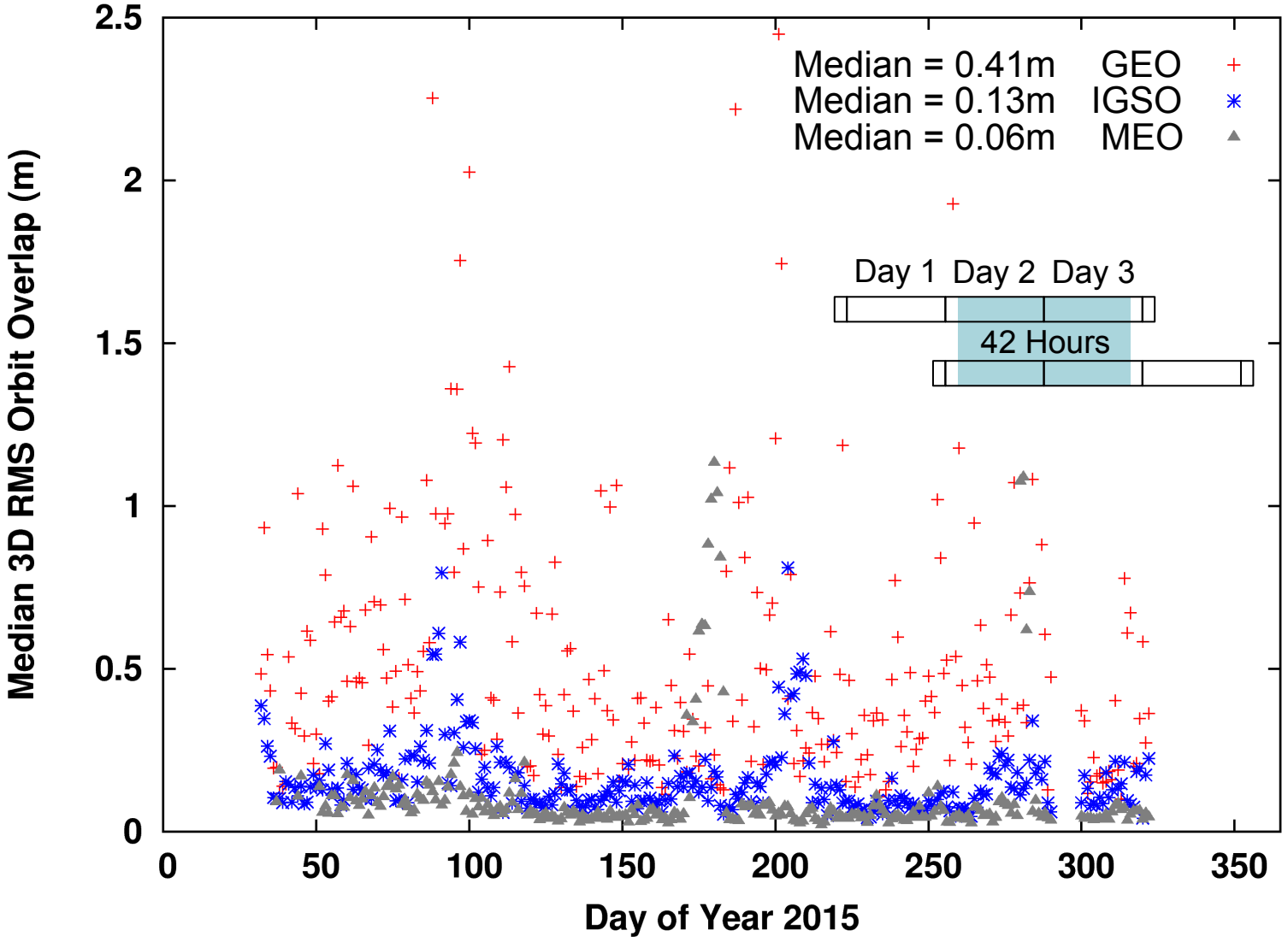
Residuals


2015-05-01 WTZR
GEO (1)
IGSO (5)
MEO (3)
Range Residuals (m)
Hours of Arc
Elevation From Receiver (degrees)

Constellation Bias

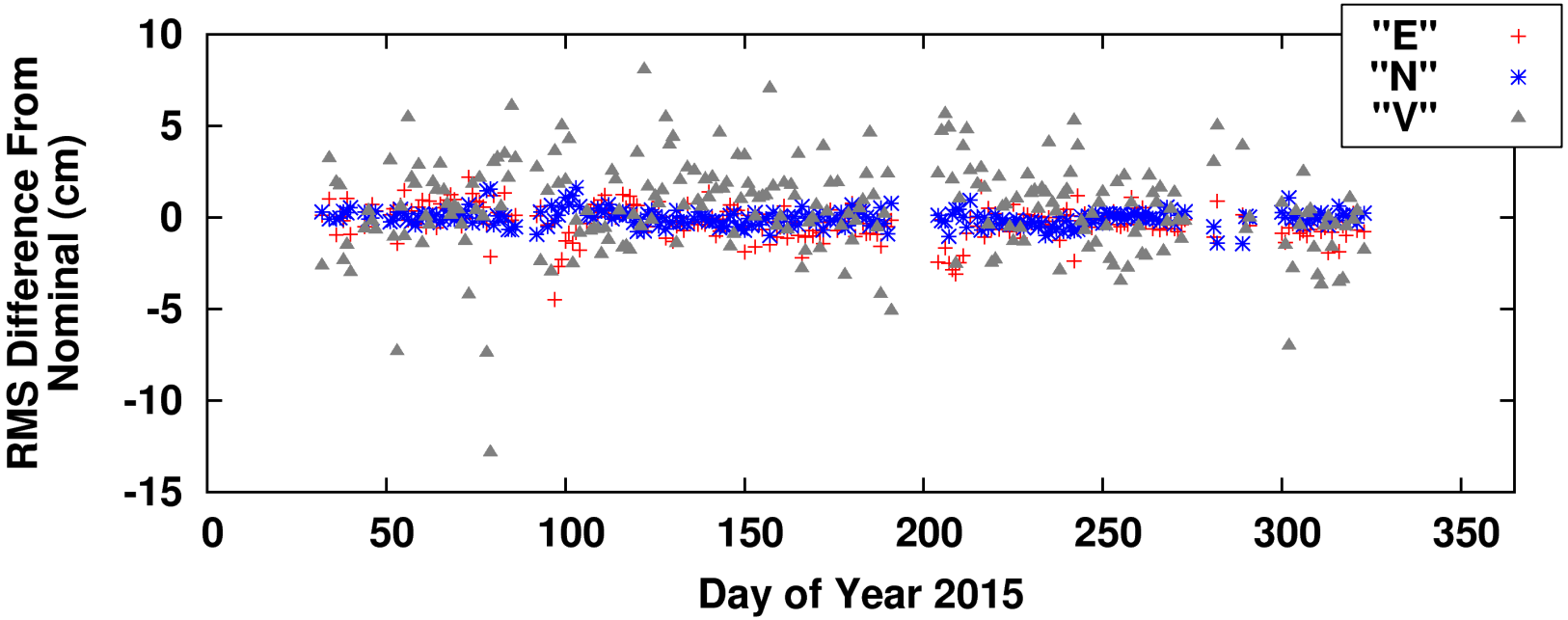


Orbit Overlaps



Point Positioning - static

BeiDou Only – JFNG (China)



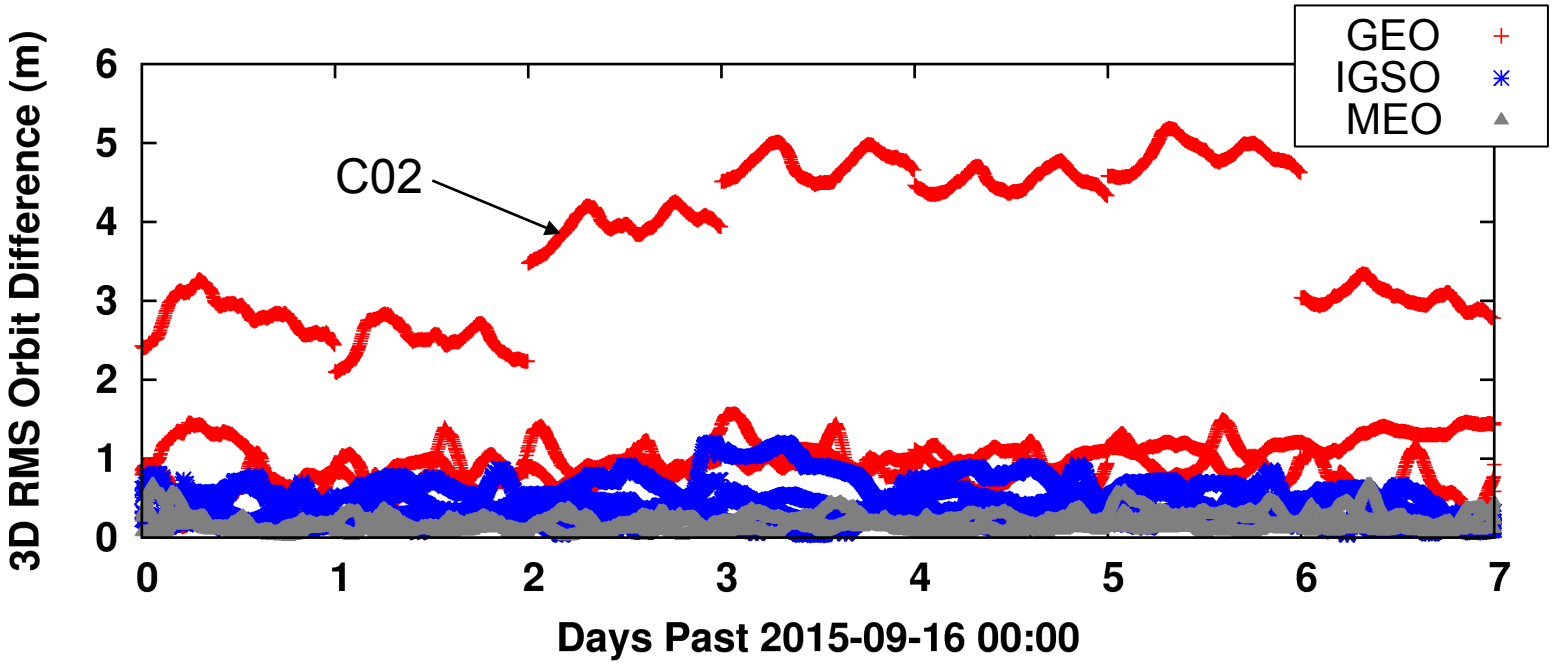
1cm formal error cut removed 12 out of 252 days.

RMS difference from nominal over remaining 240 days (cm):

East:	0.94
North:	0.44
Vertical:	2.63

Real-Time
(Filter Only)

Orbit Differences vs Post-Processed

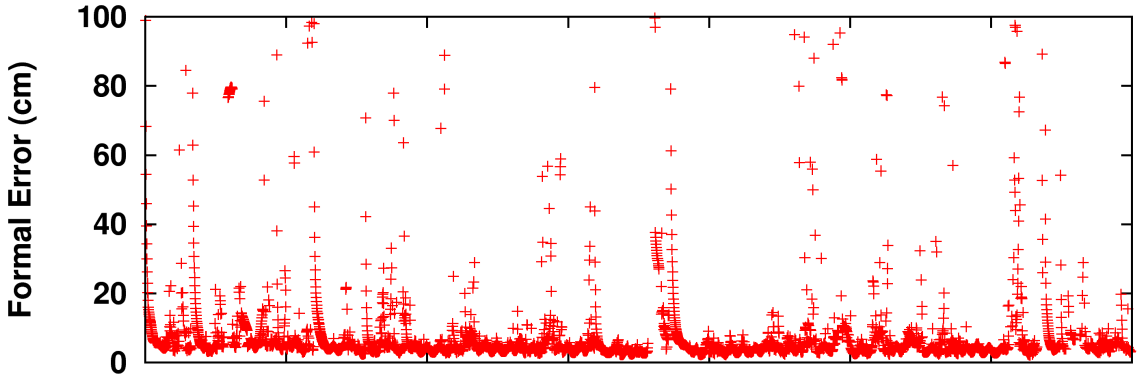


- Continuous two week arc
- One week shown above for clarity
- C03 and C05 removed – unhealthy
- C02?

	3D RMS Across Both Weeks (m)
GEO (-C02)	2.19 (0.99)
IGSO	0.45
MEO	0.23

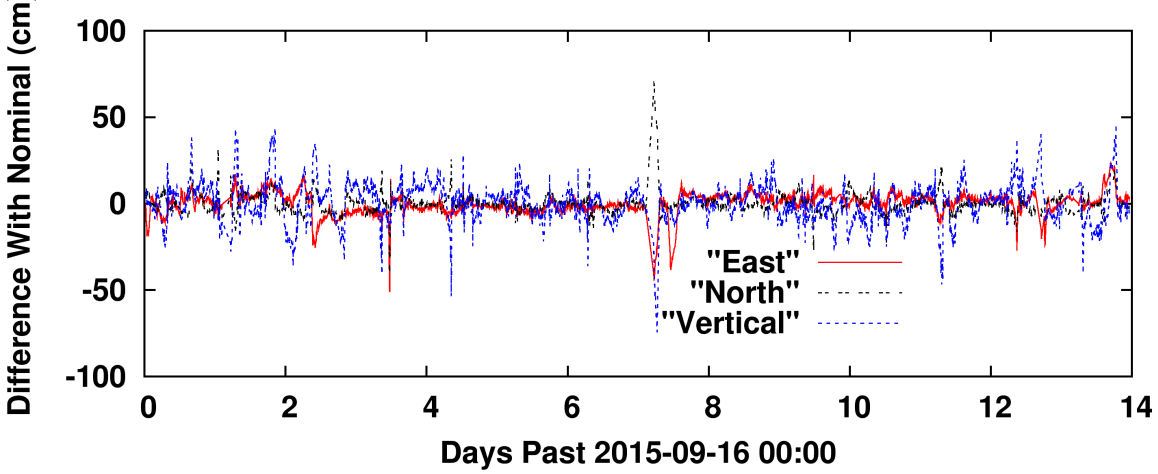
Point Positioning - kinematic

BeiDou Only – SIN1 (Singapore, equatorial)

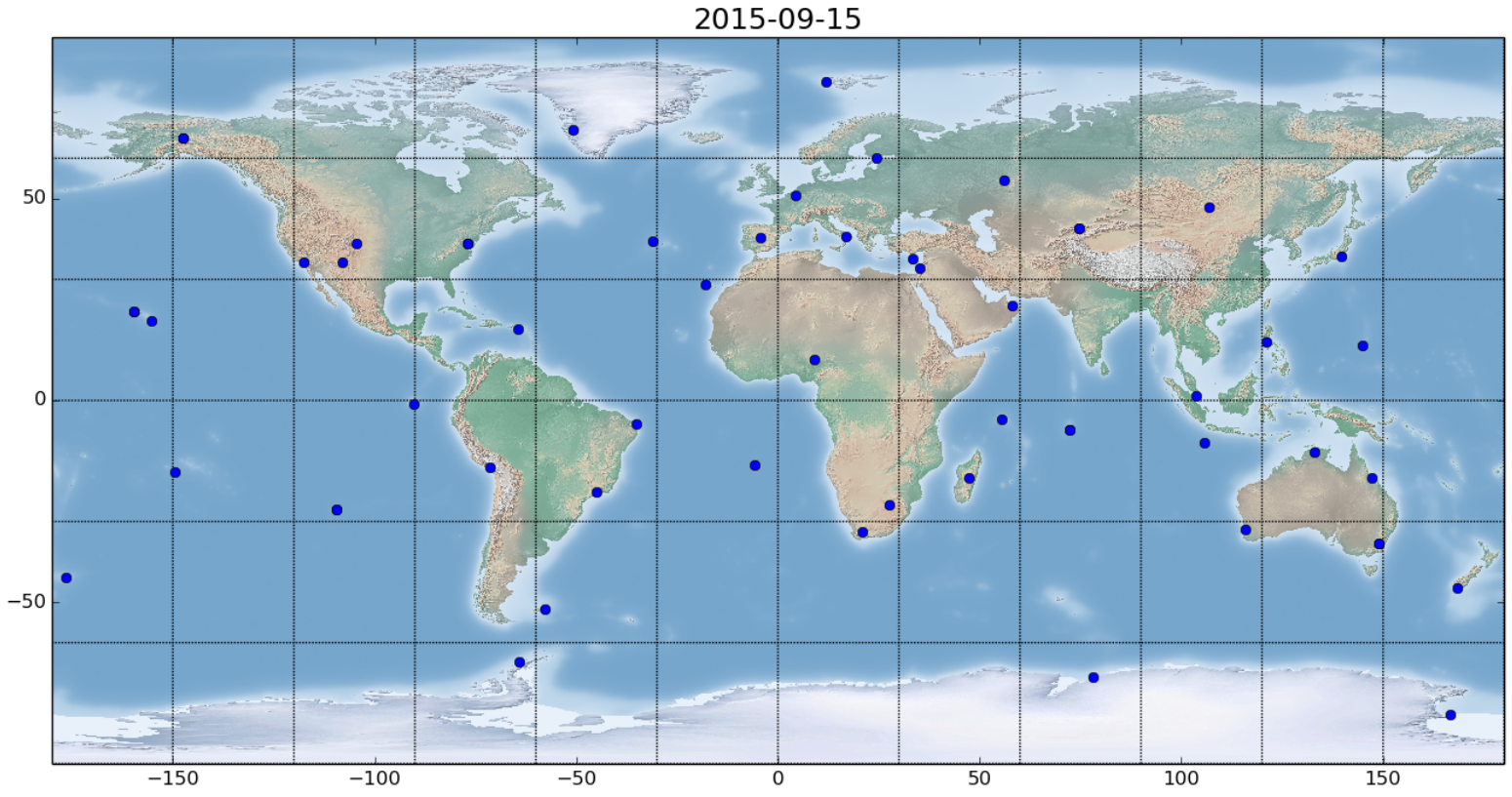


40cm formal error cut removed ~11% of the data.
RMS difference from nominal over two week period (cm):

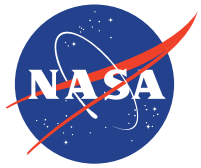
East: 6.29 North: 5.63 Vertical: 11.10



GDGPS Current GPS/BeiDou Real-Time Network



57 stations



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A new GNSS orbit determination and data analysis software called RTGx (evolved from the GIPSY and Real Time GIPSY – RTG software packages) is being used at JPL to produce orbit and clock solutions for GNSS satellites in both real-time and postprocessing modes. We describe the orbit determination approach we currently apply to the growing BeiDou constellation, and its performance as measured by a number of quality metrics, such as residuals, formal errors, overlaps, and various other specialized metrics. Our approach combines GPS with BeiDou dual-frequency measurements to simultaneously estimate all the satellite states, media parameters, and ground station parameters, including a per-station, time-varying constellation clock bias. The ground measurements are based on available data from the combined MGEX and GDGPS tracking networks. We discuss some of the alternative orbit determination approaches we considered and traded.

Our post-processing performance is based on nearly two years of data. We used a portion of these data to estimate satellite antenna offsets and constellation biases. The BeiDou GEO satellites are modeled with an orbit-normal attitude regime, while the IGSO and MEO BDS satellites transition between orbit-normal and a nominal GNSS yaw-steering attitude mode depending upon beta angle. The performance of the products is assessed under both non-eclipsing and eclipsing conditions. These smoothed products then serve as “truth” for a comparison with our real-time filteronly orbit determination products, which are available at a few seconds latency.

ID / PRN

GEO

ID	PRN
C101	01
C103	03
C104	04
C105	05
C106	02

IGSO

ID	PRN
C201	06
C202	07
C203	08
C204	09
C205	10

MEO

ID	PRN
C301	30
C303	11
C304	12
C305	13
C306	14