

Kinematic and Dynamic Precise Orbit Determination using GPS

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 - Orbit Types Computed at TUM
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Introduction

- More and more LEO satellites are equipped with **geodetic GPS receivers**.
 - More and more missions are designed with a **constellation of several LEOs** (COSMIC, ACE+, SWARM, . . .).
 - **Three layers** in future:
 1. **GNSS Layer:** Layer of GNSS satellites in MEO (Medium Earth Orbits) or GEO (GEostationary Orbits) (GPS, GLONASS, GALILEO, . . .)
 2. **LEO Layer:** Layer of LEO satellites at different altitudes and with various orbit characteristics, forming a LEO constellation
 3. **Ground Layer:** Global network of tracking stations for GNSS and LEOs with different observation techniques (GPS, SLR, DORIS, . . .)
 - **Combination of all three layers** to improve various global parameters (orbits, Earth rotation, gravity field, atmospheric parameters, station coordinates, . . .)
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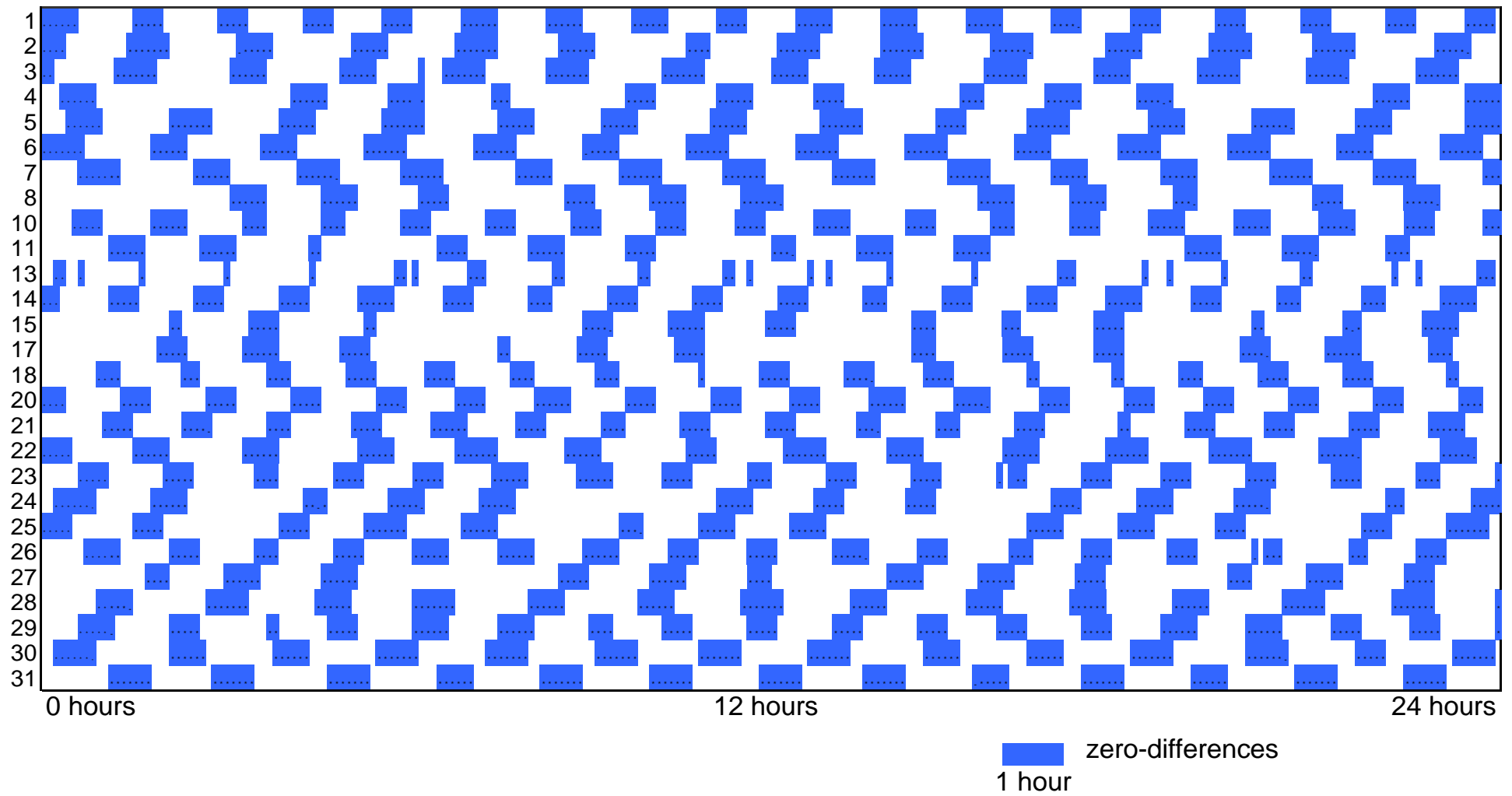
LEO Satellites With Onboard Geodetic GPS Receiver

LEO	Mission Goals	Launch	# Sat.
TOPEX/Poseidon	Altimetry	08/1992	1
GPS/MET	Atmosphere sounding	04/1995	1
ØERSTED	Magnetic field	01/1999	1
CHAMP	Gravity, magn. field, sounding	07/2000	1
SAC-C	Atmosphere, magnetic field	11/2000	1
JASON-1	Altimetry	12/2001	1
GRACE (A + B)	Gravity, atmosphere sounding	03/2002	2
ICESAT	Laser altimetry	exp. 2002	1
COSMIC	Atmosphere sounding	exp. 2005	6
METOP	Meteorology	exp. 2005	3
GOCE	Gravity	exp. 2006	1
ACE+	Atmosphere sounding	exp. 2008 ?	4
SWARM	Atmosphere, magnetic field	exp. 2008 ?	4

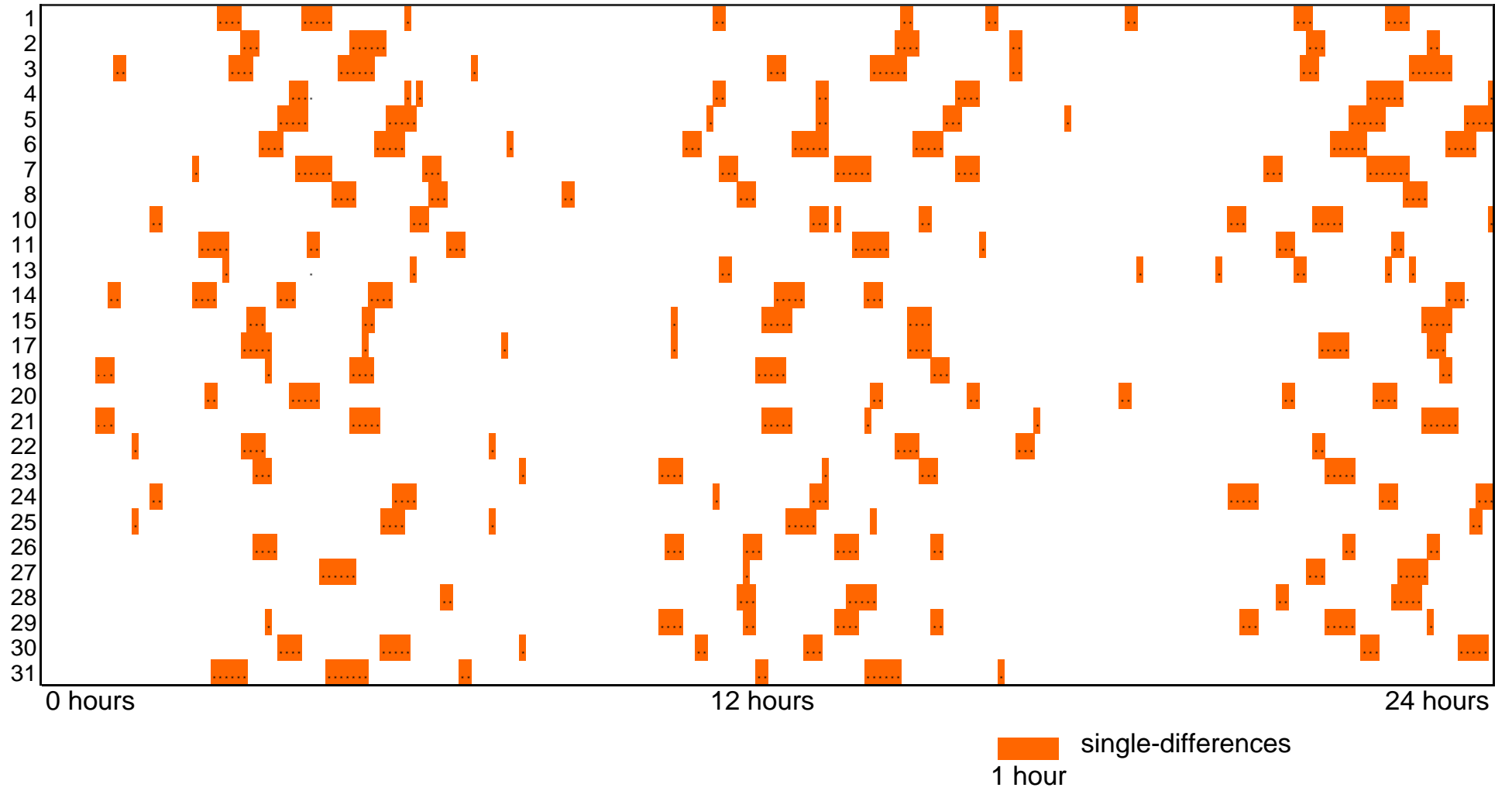
LEOs presently in orbit: \approx **8**

LEOs in orbit in 2008: \approx **26**

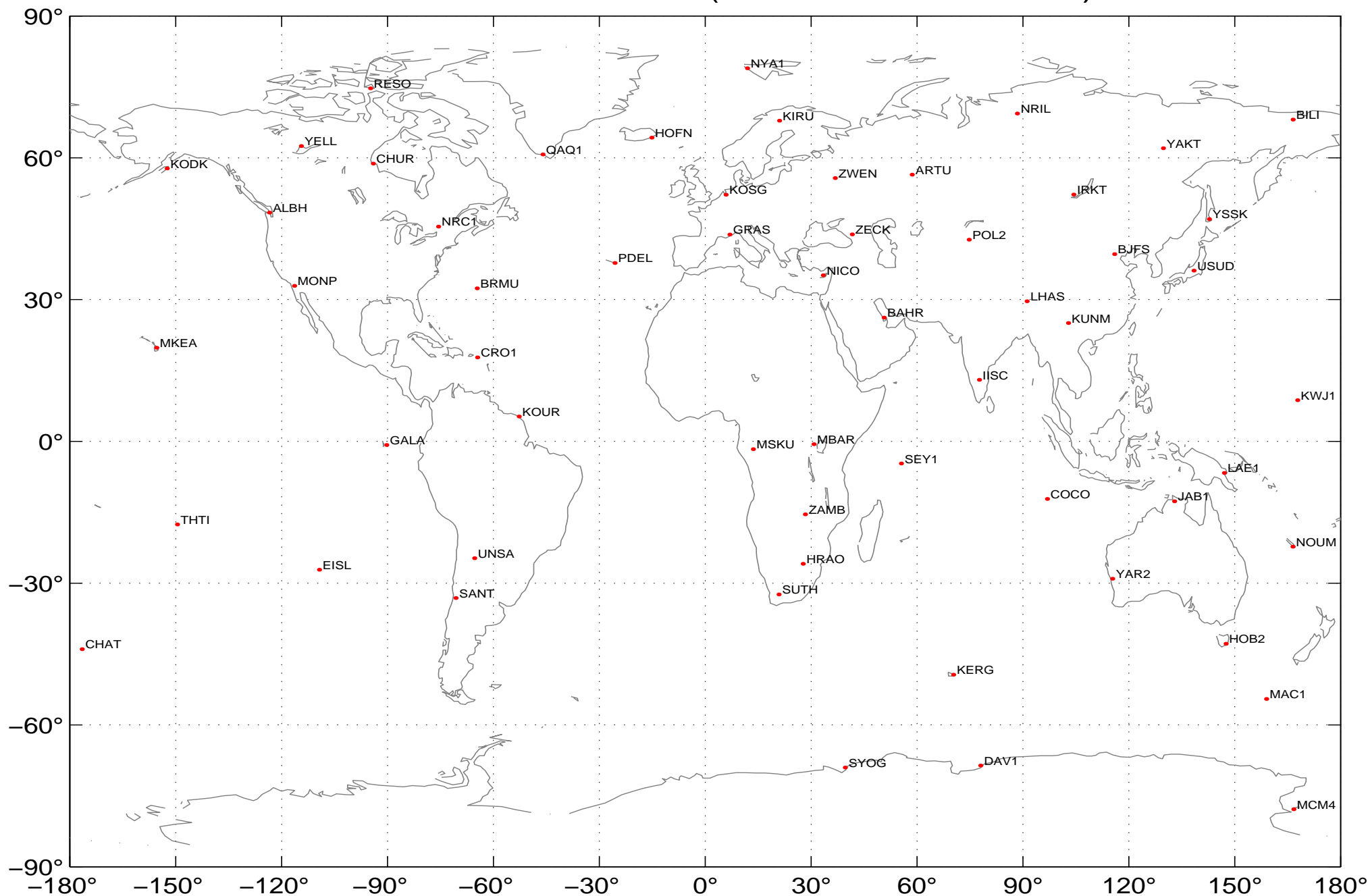
GPS visibility from CHAMP (day 200/2002)



Baseline CHAMP-JASON



IGS Ground Network (58 Stations Selected)



KINEMATIC & DYNAMIC POD

LEO GPS RECEIVER
Phase/Code
LEO

STAR SENSOR
Attitude
LEO

GPS Orbits
IGS

ERP
IGS

IGS Network
Phase/Code
IGS

GPS Sat.
Clocks
IGS

ZD
PROCESSING

DD and TD
PROCESSING

IGS Network
coordinates
IGS

Troposphere
zenith delays
IGS

LEO
Clock

Kinematic orbit
Dynamic orbit

Kinematic orbit
Dynamic orbit

LEO Dynamic POD

- Mathematical model: least-squares adjustment with variational equations
 - Gravity model: EIGEN1S
 - Air drag: NRLMSISE-00 + Horizontal Wind Model (HWM93)
 - Other forces: Sun, Moon, planets, solid & ocean tides, GR, ...
 - Parameterizations
 - 6 initial conditions (Keplerian elements)
 - 9 solar radiation pressure/air drag
 - 1 air drag bias
 - pseudo-stochastic pulses every 9-15 min. (radial, along track, cross track)
 - Orbit arc length: 24 hours.
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LEO Kinematic POD

- Mathematical model: least-squares adjustment
 - Parameterization:
 - zero-differences (LEO+GPS)
 - * LEO kinematic positions
 - * LEO clock
 - * zero-difference ambiguities
 - double-differences (ground network+LEO+GPS)
 - * LEO kinematic positions
 - * double-difference ambiguities
 - Orbit arc length: 24 hours (any)
 - Gravity free-method, free of all forces.
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LEO Orbit Types Computed at TU Munich

- **10 different orbit types** using GPS phase observations:
 - Zero-differences:
 - * kinematic POD
 - * dynamic POD
 - Double-differences:
 - * kinematic POD - ambiguity-float
 - * kinematic POD - ambiguity-fixed
 - * dynamic POD - ambiguity-float
 - * dynamic POD - ambiguity-fixed
 - LEO Constellation
 - * LEO kinematic network (ambiguity-float/fixed)
 - * LEO dynamic network (ambiguity-float/fixed)
 - Combined ground IGS and LEO kinematic network (ambiguity-float/fixed)
 - Combined ground IGS and LEO dynamic network (ambiguity-float/fixed).
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Ambiguity Resolution Strategy

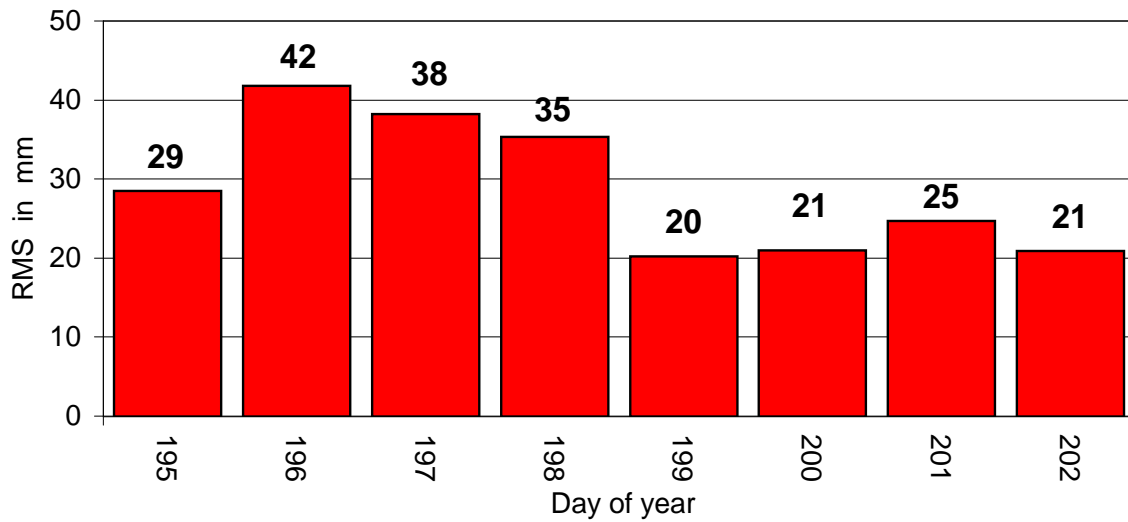
- **Wide-Lane Ambiguities:**

- Melbourne-Wübbena linear combination of code and phase observations.
- The effects of ionosphere, geometry, clocks and troposphere are eliminated.
- P-code measurements on L1 and L2 with a very good quality are indispensable (LEO and ground network).
- Differential code biases (C1-P1 biases).
- Baseline-wise ambiguity resolution (CHAMP-station).
- 24-hour files processed over 11 days DOY140-150/2001.

- **Narrow-Lane Ambiguities:**

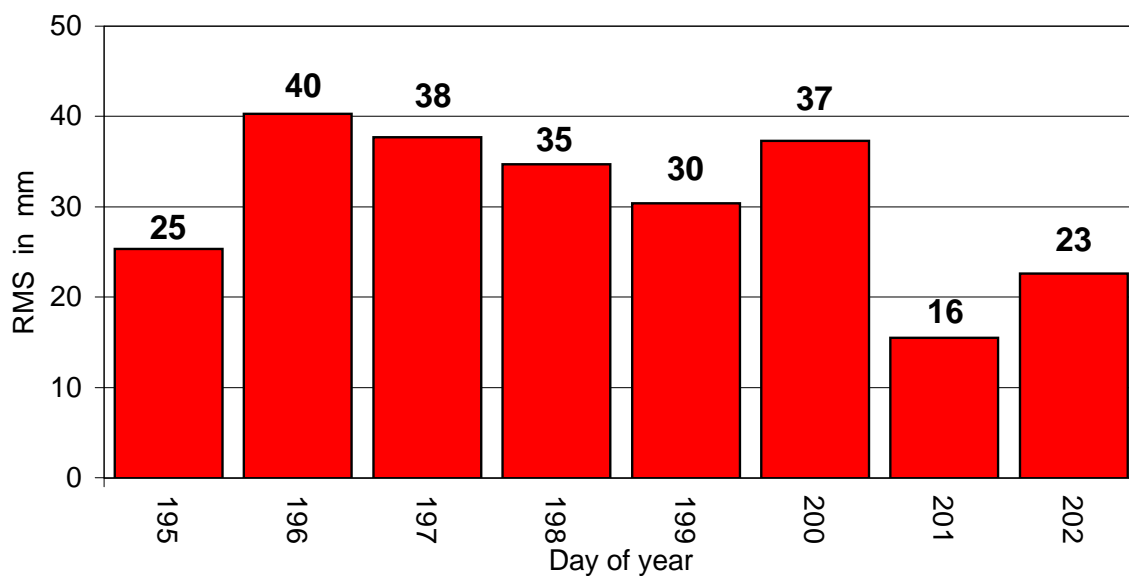
- When wide-lane ambiguities are known, ionosphere-free LC can be used to resolve narrow-lane ambiguities.
 - Troposphere biases can be eliminated using IGS troposphere zenith delays (gradients).
 - Station coordinates fixed to the weekly IGS solutions.
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SLR Residuals for CHAMP
Zero-diff. Kinematic Orbit (days 195-202/2002)



mean SLR RMS= **29** mm

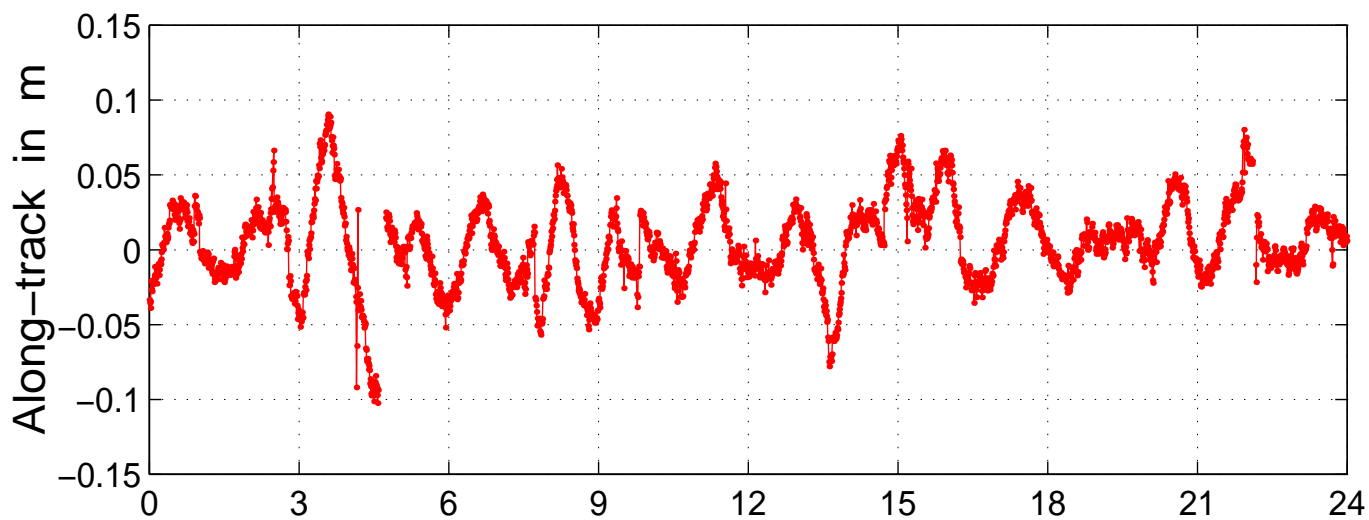
SLR Residuals for CHAMP
Zero-diff. Dynamic Orbit (days 195-202/2002)



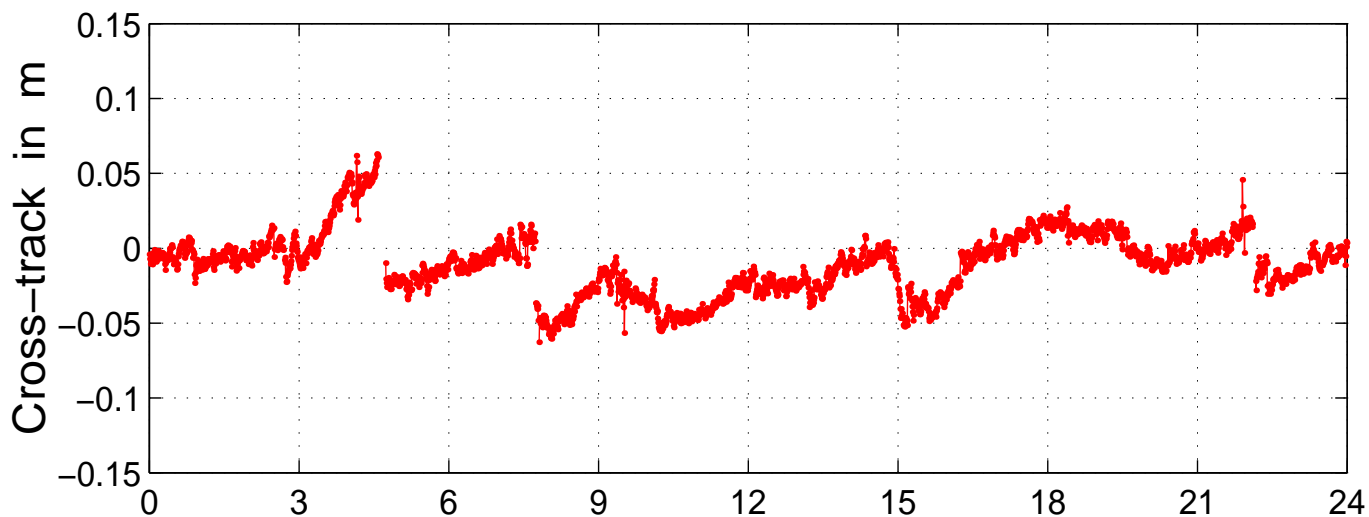
mean SLR RMS= **30** mm

CHAMP Zero-difference Kinematic – Zero-difference Dynamic Orbit day 200/2002

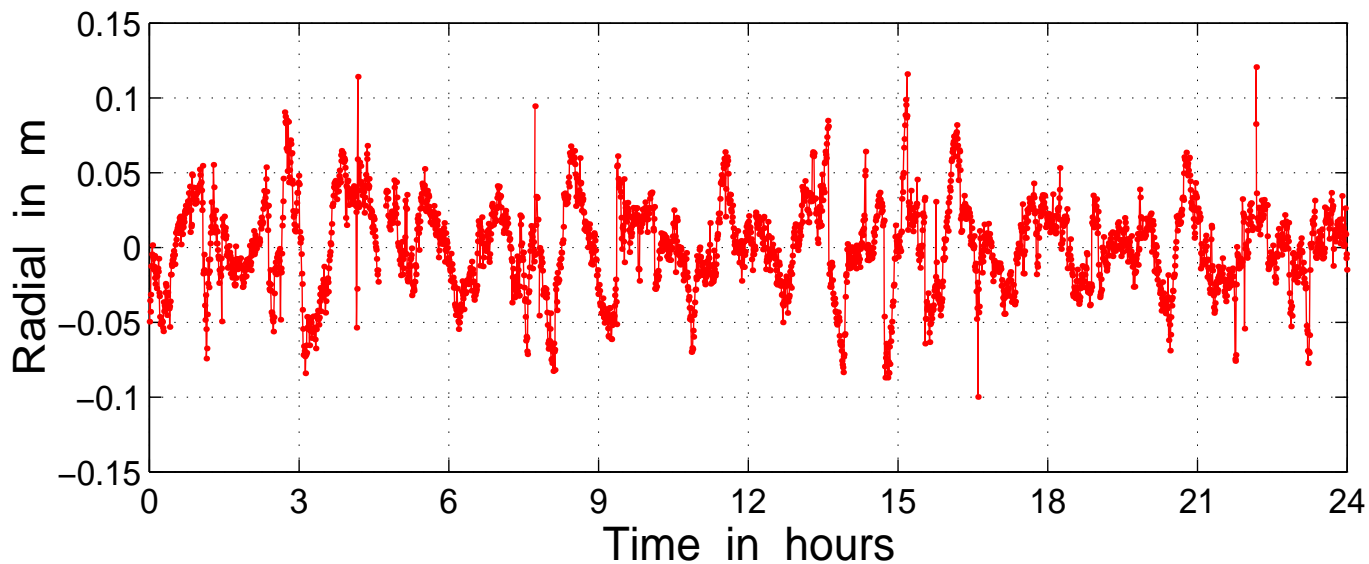
RMS=2.8 cm



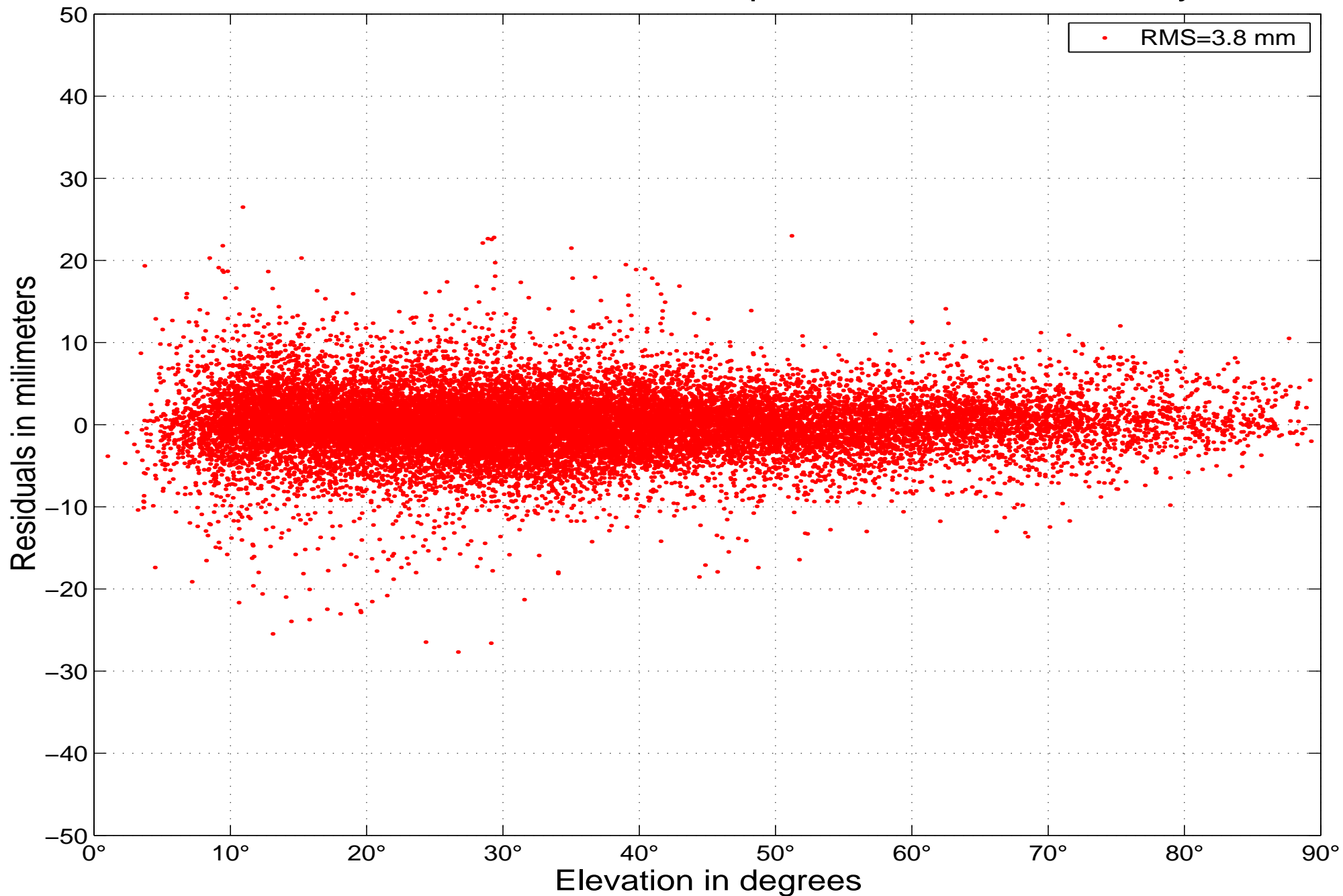
RMS=2.3 cm



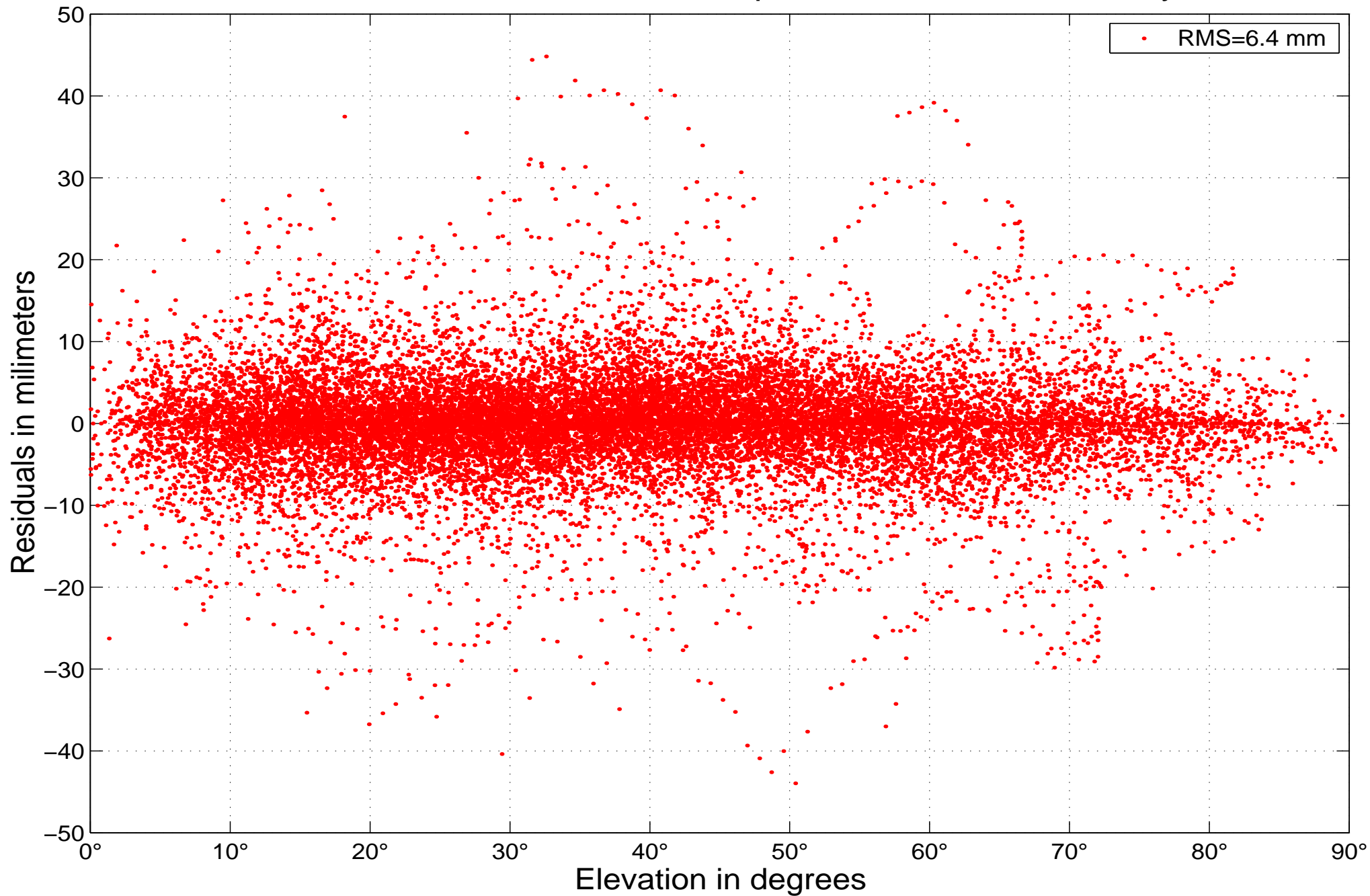
RMS=3.0 cm



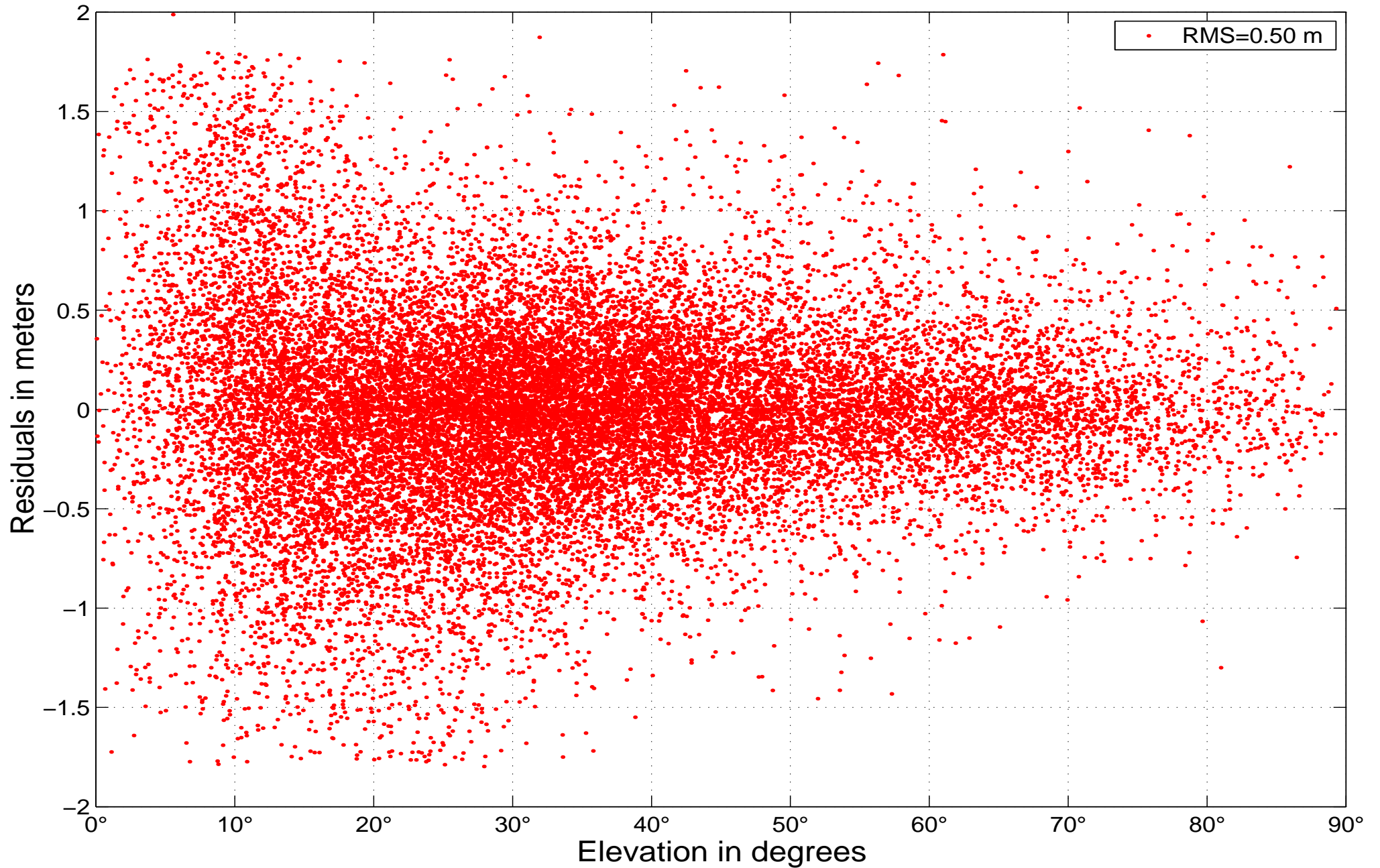
CHAMP Zero-diff. Kinematic Orbit: Ionosphere-free Residuals, day 200/2002



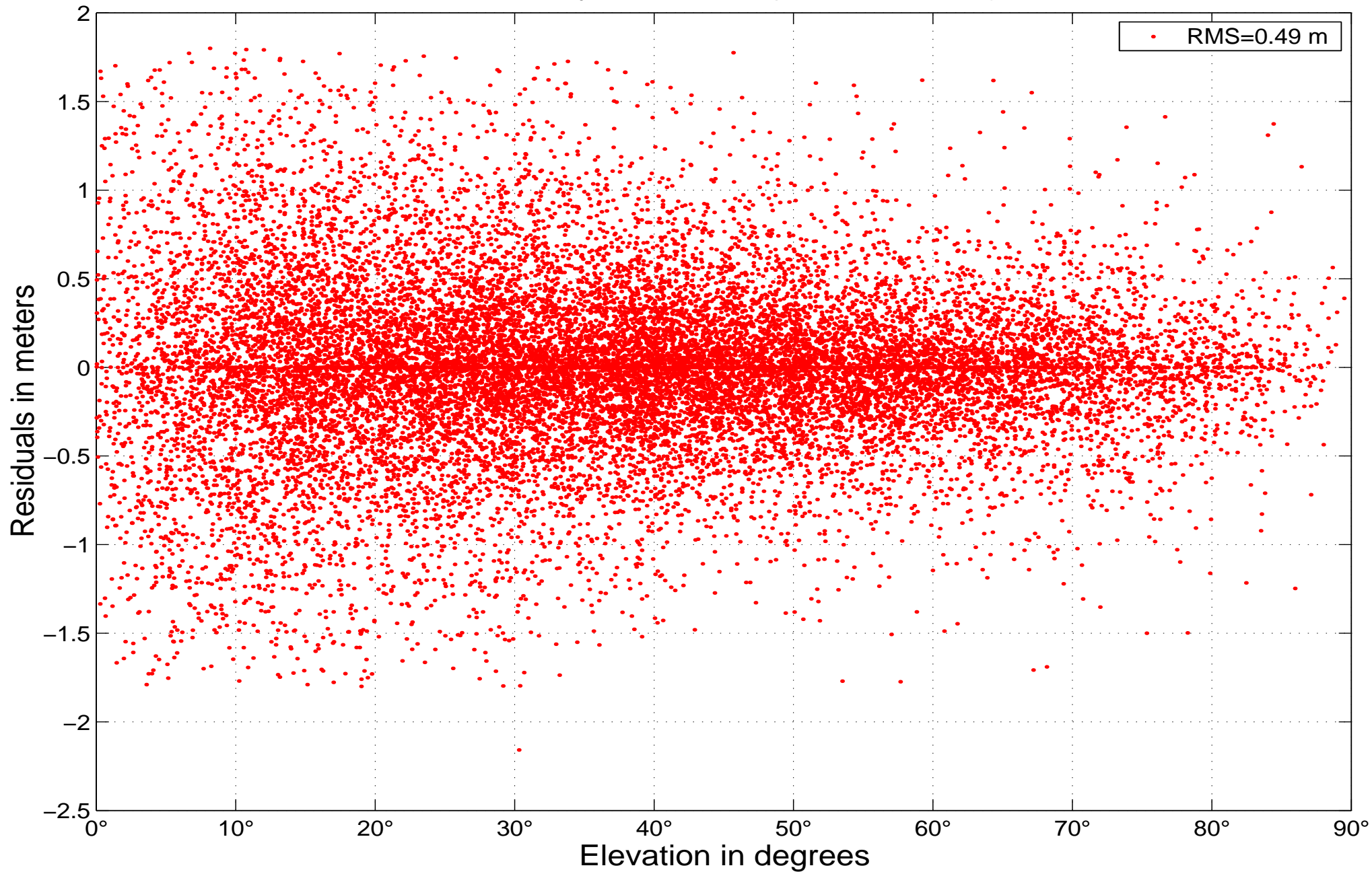
JASON Zero-diff. Kinematic Orbit: Ionosphere-free Residuals, day 200/2002



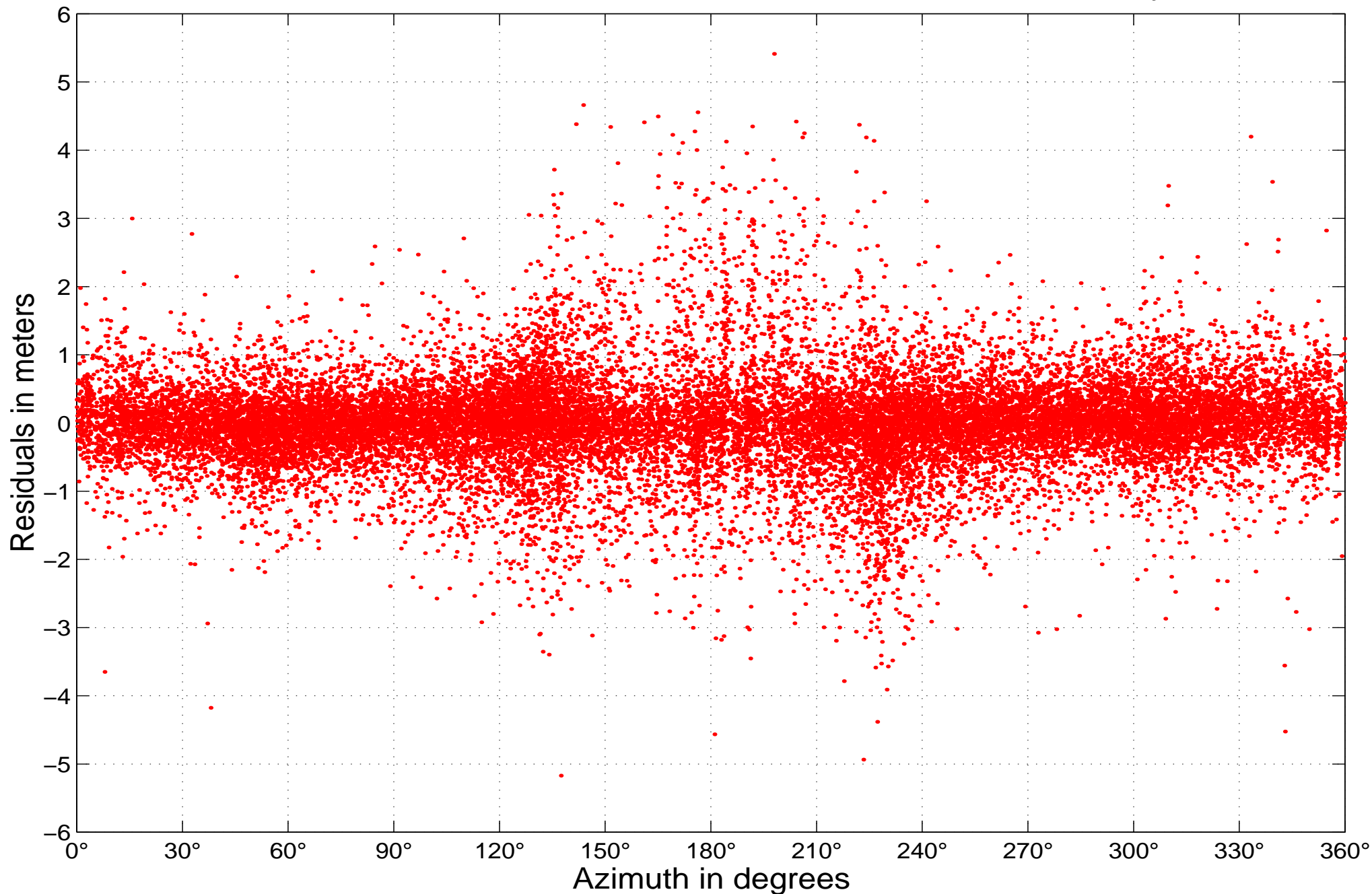
CHAMP Zero-diff. Kinematic Orbit: Code Iono-free Residuals,
day 200/2002 (cut-off 1.8 m)



JASON Zero-diff. Kinematic Orbit: Code Iono-free Residuals,
day 200/2002 (cut-off 1.8 m)



CHAMP Zero-diff. Kinematic Orbit: Code Iono-free Residuals, day 200/2002



CHAMP Multipath



IGS Products

GPS Orbits/Clocks	Accuracy	Latency	Updates	Sample interval
Broadcast	260 cm/7 ns	real time	–	daily
Predicted (Ultra-Rapid)	25 cm/5 ns	real time	twice/day	15 min/15 min
Rapid	5 cm/0.2 ns	17 hours	daily	15 min/5 min
Final	3 cm/0.1 ns	13 days	weekly	15 min/5 min

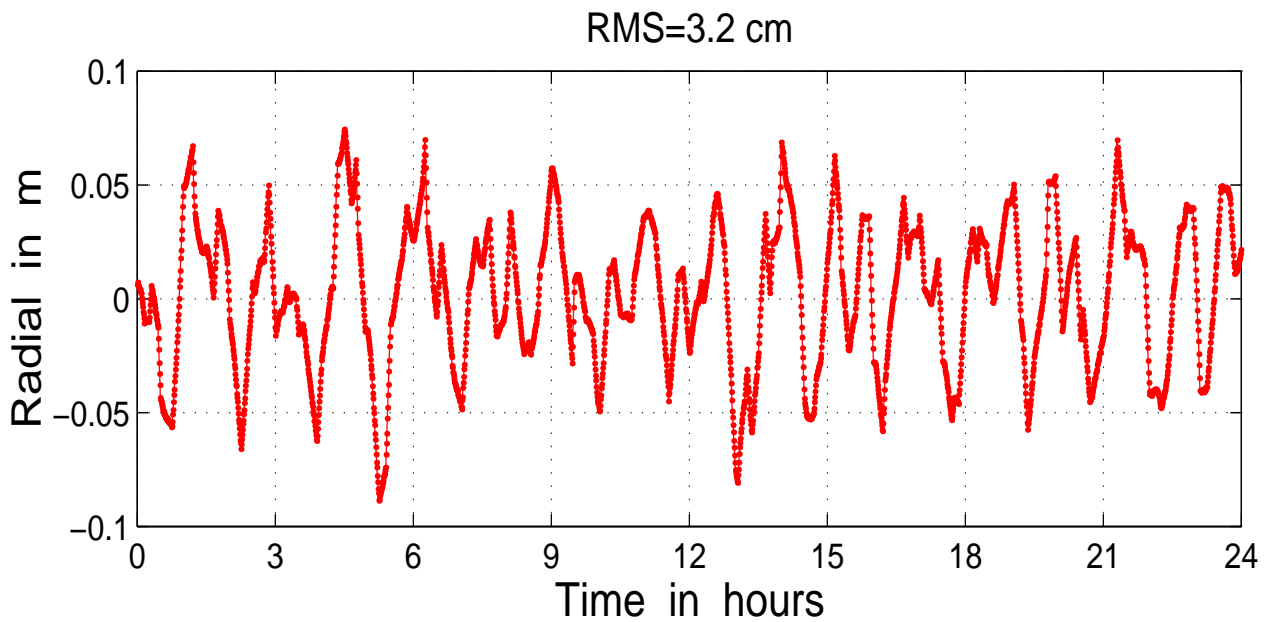
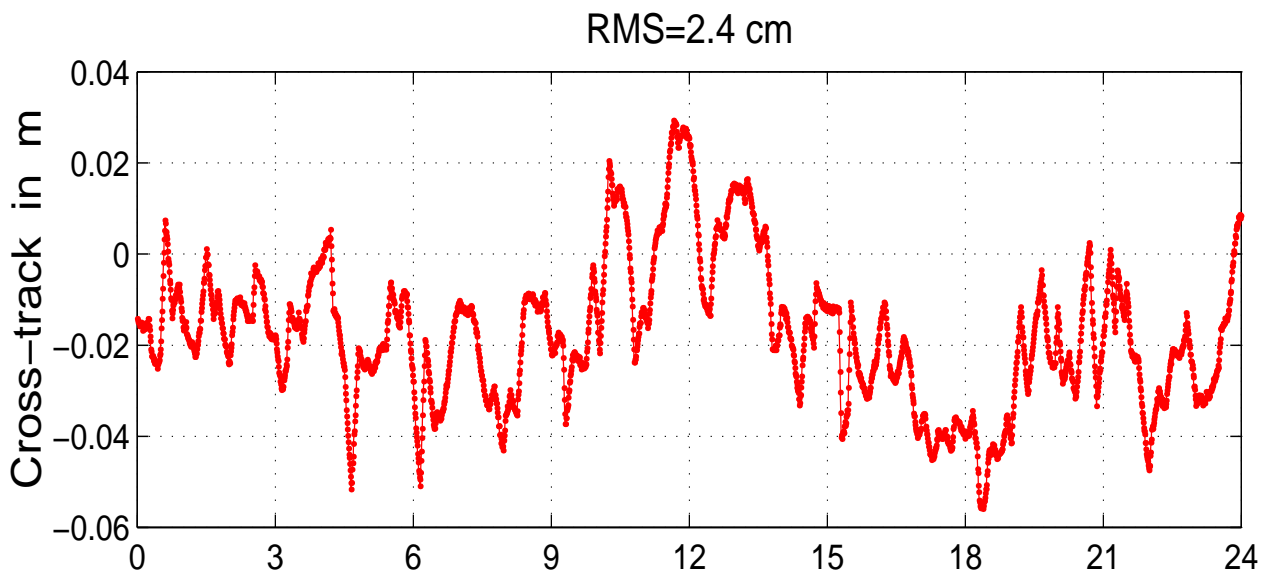
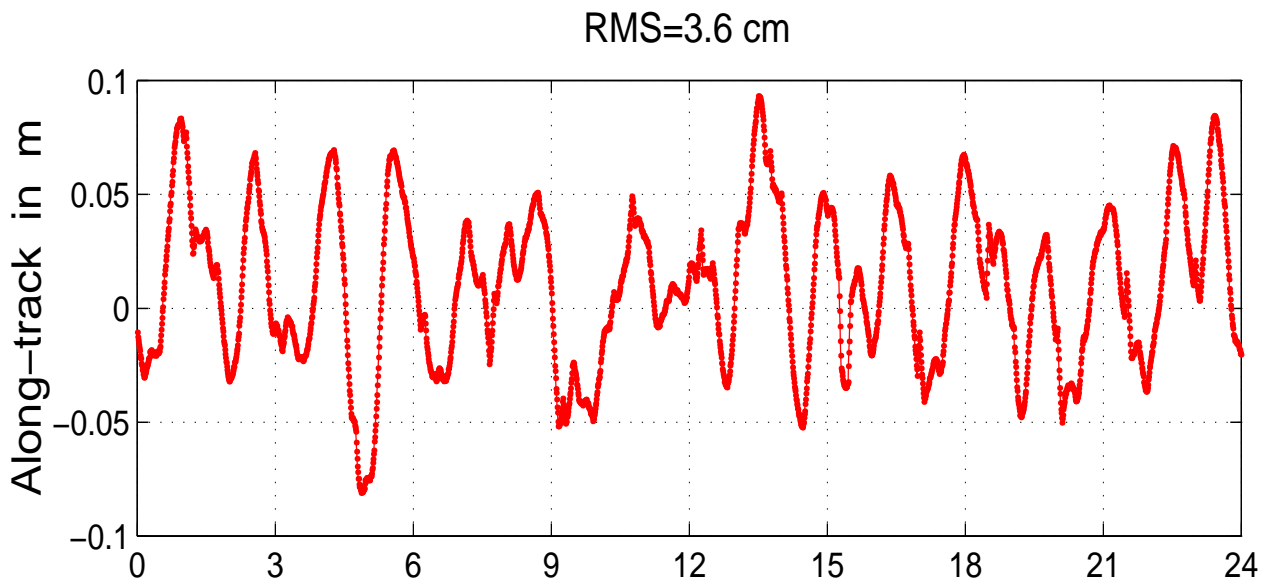
Earth rotation parameters	Accuracy	Latency	Updates	Sample interval
Rapid polar motion/rates	0.2 mas	17 hours	daily	daily
Final polar motion/rates	0.1 mas	13 days	weekly	daily
Rapid Length-of-day (LOD)	0.030 ms	17 hours	daily	daily
Final Length-of-day (LOD)	0.020 ms	13 days	weekly	daily

Troposphere zenith delays	Accuracy	Latency	Updates	Sample interval
Final	4 mm	< 4 weeks	weekly	2 hours
Ultra-rapid	6 mm	2-3 hours	3 hours	1 hour

Active high rate/low latency LEO sites
(15 minute files of 1 second sampling rate)



Rapid CHAMP orbit – Final CHAMP Orbit, day 200/2002 (Rapid GPS Clocks)



Conclusions

- Various kinematic and dynamic POD methods were developed using GPS technique with different accuracy and latency.
 - Kinematic POD can only be done with GPS technique.
 - Kinematic POD is independent of the gravity field and the orbit height.
 - Ambiguity resolution significantly improves the quality of kinematic POD.
 - **Accuracy of the CHAMP kinematic orbits: 28.8 mm**
 - **Accuracy of the CHAMP dynamic orbits: 30.0 mm**
 - POD for LEO constellation can be performed as kinematic or dynamic network consisting of several LEO satellites.
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