GIOVE Orbit and Clock Determination Based on the CONGO Network

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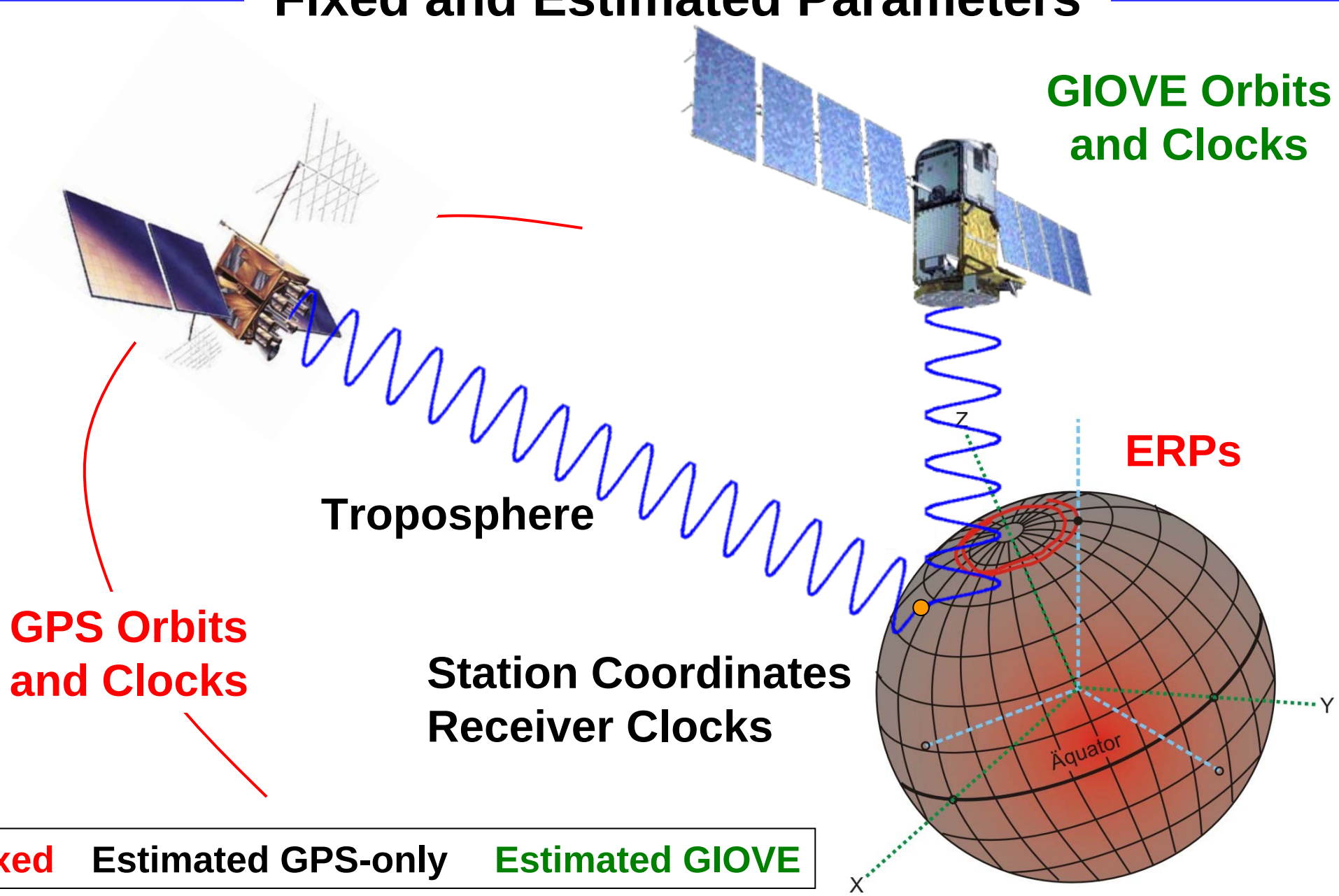
Outline

- Modified version of the Bernese GPS Software
- Processing strategy
- Parameterization and modeling
- Operational CONGO Processing
- Results:
  - Station coordinates
  - Code bias parameters
  - Satellite orbits
  - Satellite clocks

Modified Version of the Bernese GPS Software

- Based on the official version 5.0
- Processing of 2 pre-selected frequencies
- Full functionality of the Bernese GPS Software, i.e. estimation of
  - Station coordinates
  - Satellite orbit parameters
  - Satellite and receiver clock parameters
  - Troposphere zenith delays and gradients
  - Antenna offsets and phase center variations
  - Auxiliary parameter: ambiguities, code biases, …
- Developed in the framework of the BayPAF project by TUM and GFZ Potsdam for EADS/Astrium

Fixed and Estimated Parameters



Fixed	Estimated GPS-only	Estimated GIOVE

Estimated Parameters

Step 1: GPS-only Precise Point Positioning

- **Station coordinates**: one set per day
- **Troposphere zenith delays**: 2 h parameter spacing
- **Troposphere gradients**: 24 h parameter spacing
- **Receiver clock** corrections: per epoch

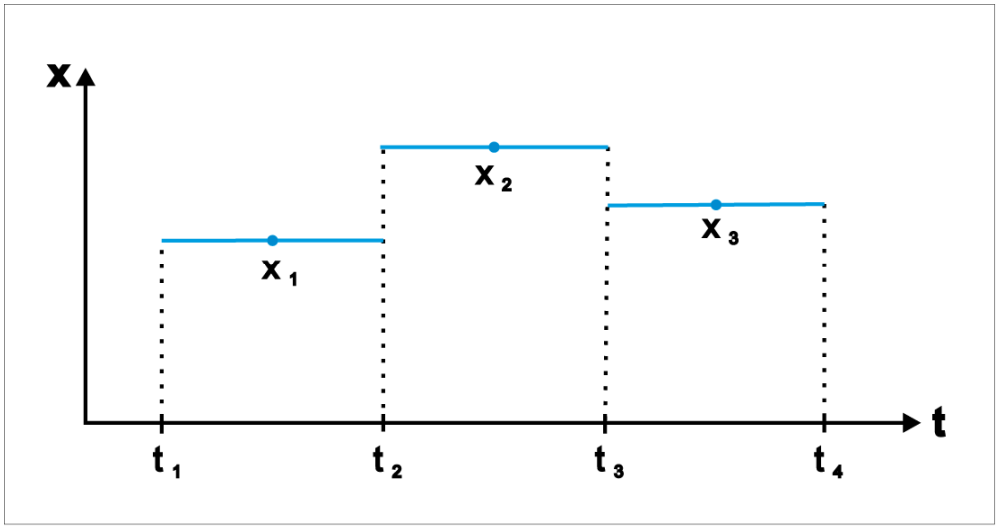
Step 2: GPS-only results fixed, GIOVE zero difference solution

- **Orbital elements**: 6 Keplerian elements per satellite
- **Radiation pressure** parameters: 5 or 9 per satellite
- **Satellite clock** corrections: 1 per epoch and satellite
- **Interfrequency/Intersystem bias**: 1 per station (except for one)

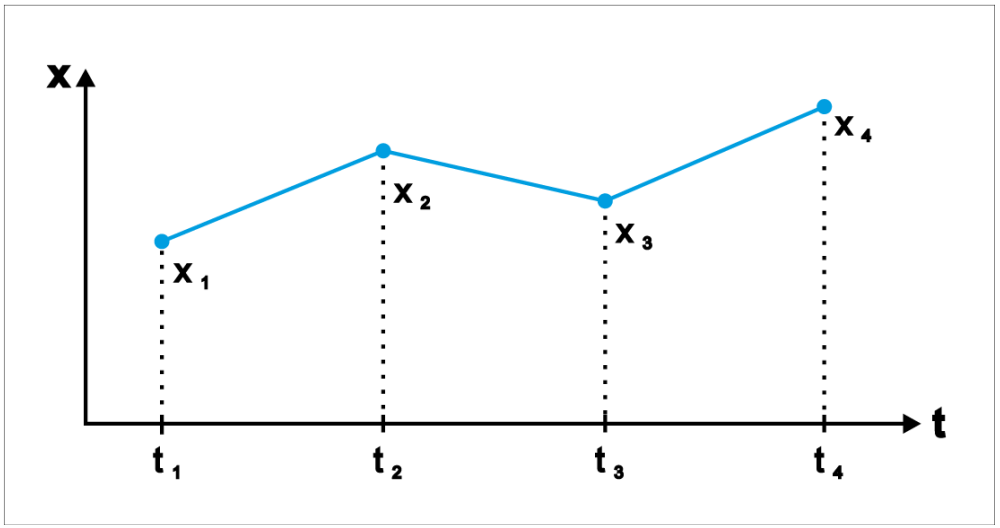
Parameterization

- **Constant offsets**, e.g., station coordinates
- **Epoch parameters**, e.g., satellite clocks
- **Piecewise linear function**, e.g., troposphere parameters

Constant offsets



Piecewise linear function



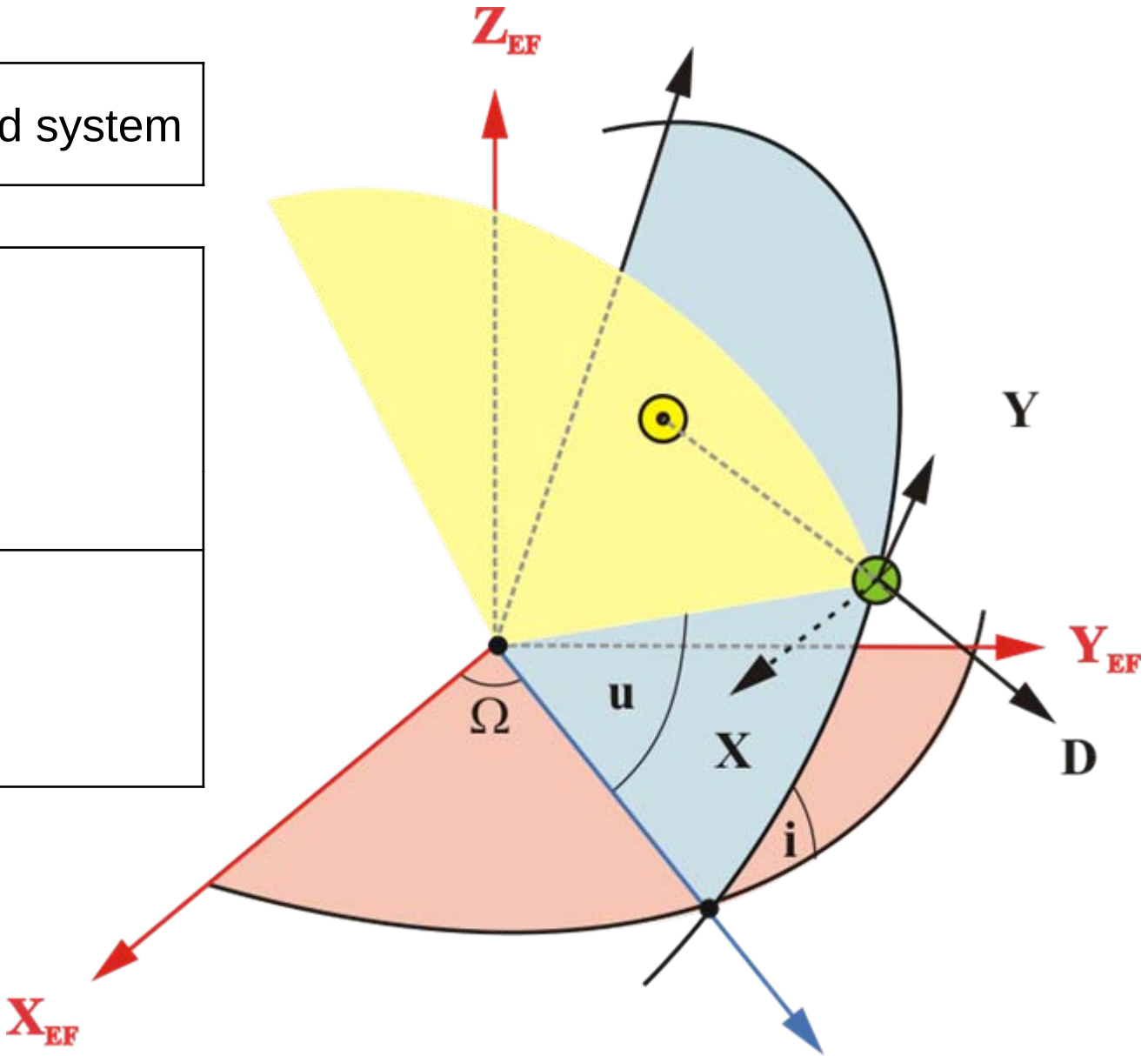
Radiation Pressure Modeling (1)

X_{EF}, Y_{EF}, Z_{EF}	Earth-fixed system

Ω	Right ascension of the ascending node
u	argument of latitude
i	Inclination
D	Sun – Satellite
Y	Along solar panel axis
X	Y x D

Sun

Satellite



Radiation Pressure Modeling (2)

$$\mathbf{a}_{RPR} = D(u) \cdot \mathbf{e}_D + Y(u) \cdot \mathbf{e}_Y + X(u) \cdot \mathbf{e}_X$$

$$\begin{aligned} D(u) &= D_0 + D_C \cdot \cos u + D_S \cdot \sin u \\ Y(u) &= Y_0 + Y_C \cdot \cos u + Y_S \cdot \sin u \\ X(u) &= X_0 + X_C \cdot \cos u + X_S \cdot \sin u \end{aligned}$$

u	Argument of latitude
e_D	Unit vector Sun-satellite
e_Y	Unit vector along the solar panel axis
e_X	$e_Y \times e_D$
$D(u), Y(u), X(u)$	Accelerations due to radiation pressure in the directions e_D, e_Y und e_X

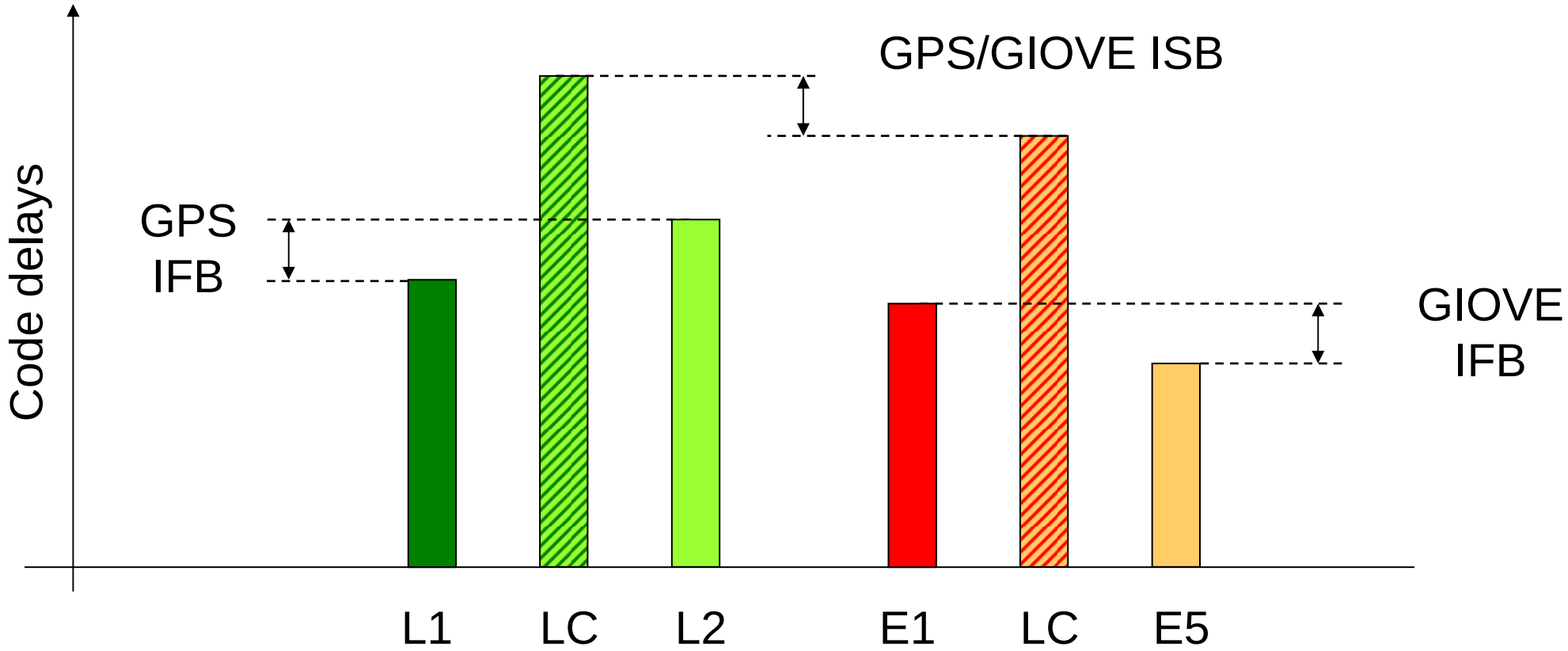
Troposphere Modeling

$$ZTD(z, A) = f_d(z) \cdot ZD_{apr} + f_w(z) \cdot ZD_{est} +$$
$$+ N \frac{\partial f_w}{\partial z} \cos A + E \frac{\partial f_w}{\partial z} \sin A$$

ZTD	Zenith total delay
ZD_{apr}	A priori zenith delay
f_d	Hydrostatic mapping funktion: Niell Mapping Function
ZD_{est}	Estimated wet delay, 2^h parameter spacing
f_w	Wet mapping funktion: Niell Mapping Function
N,E	Troposphere gradients, 24^h parameter spacing
z	Zenith distance of the satellite
A	Azimuth of the satellite

Interfrequency and Intersystem Biases

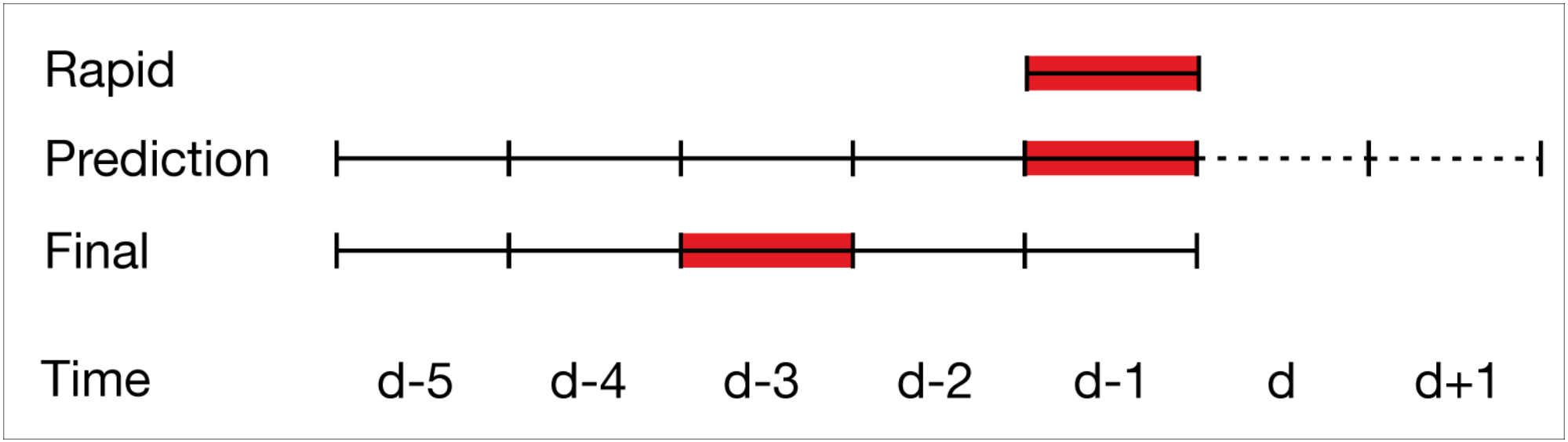
Interfrequency Bias: **IFB** Intersystem Bias: **ISB**
Ionosphere Linear Combination: **LC**



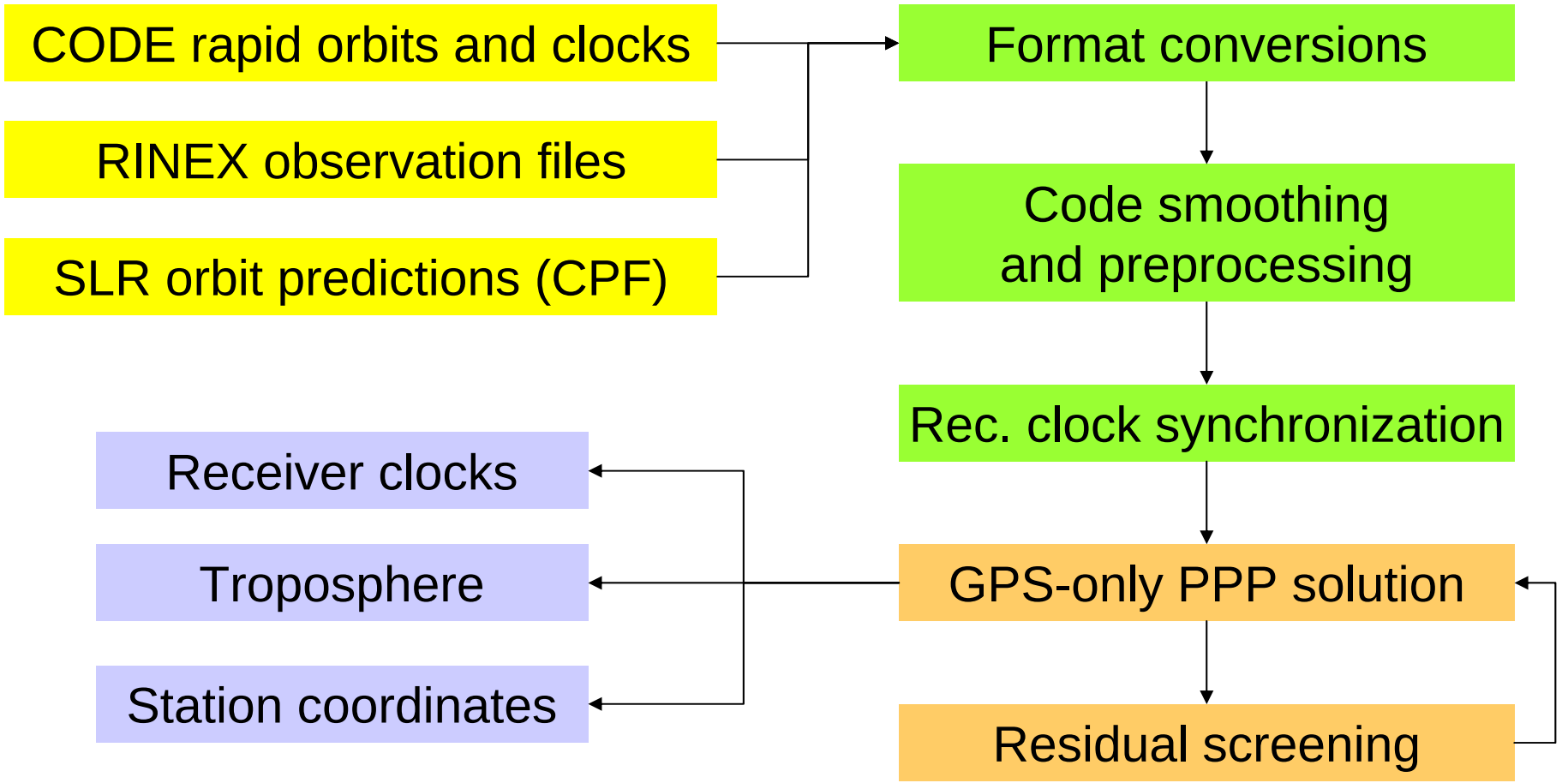
Code delays for: GPS signals GIOVE signals

Operational CONGO Processing

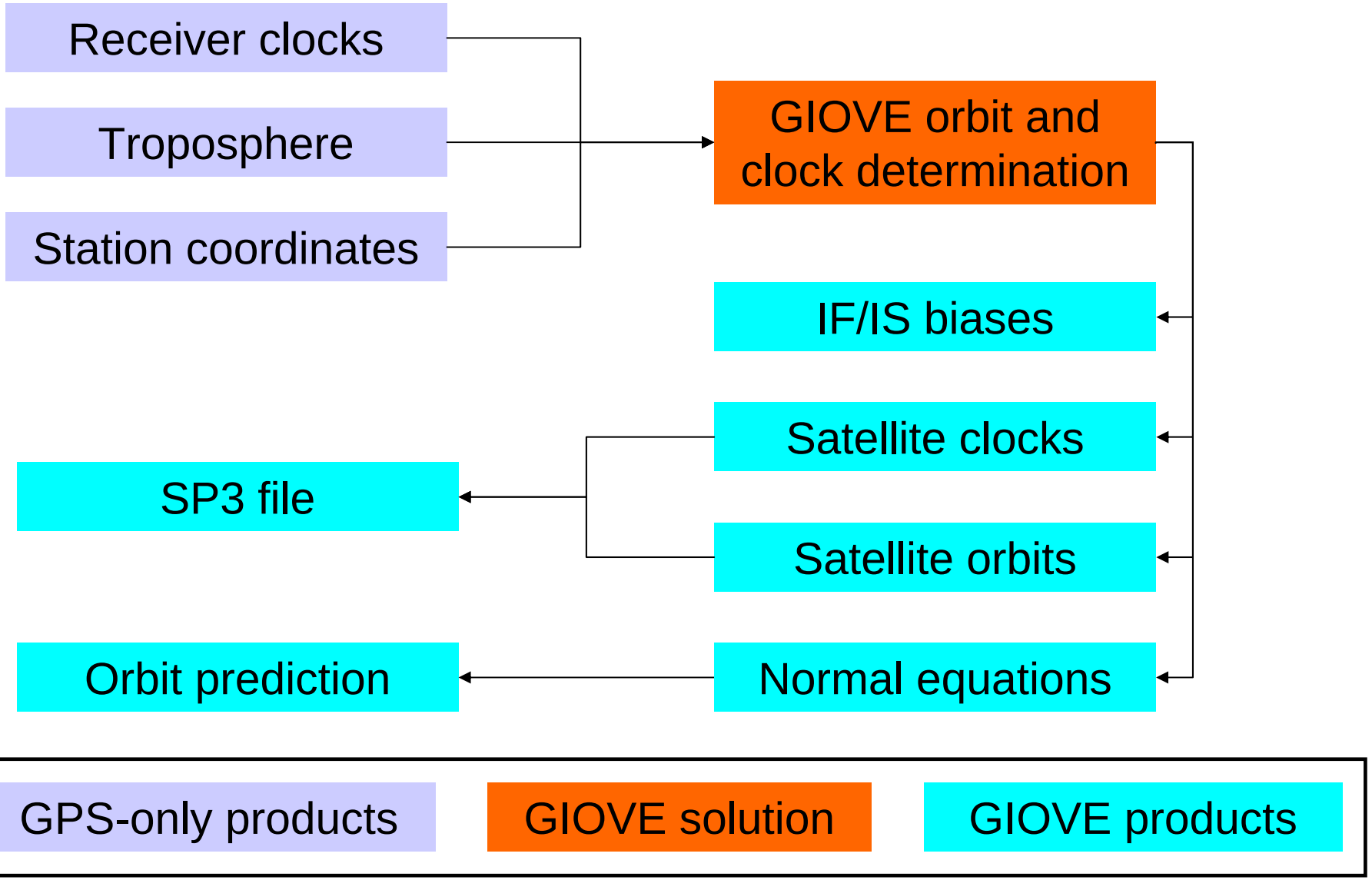
- **Rapid solution**
  - 1-day solution: NEQs
  - 5-day solution: 2-day orbit prediction
- **Final solution**
  - Orbit: middle day of a 5-day solution
  - Orbit fixed for the final clock solution
  - SLR residuals



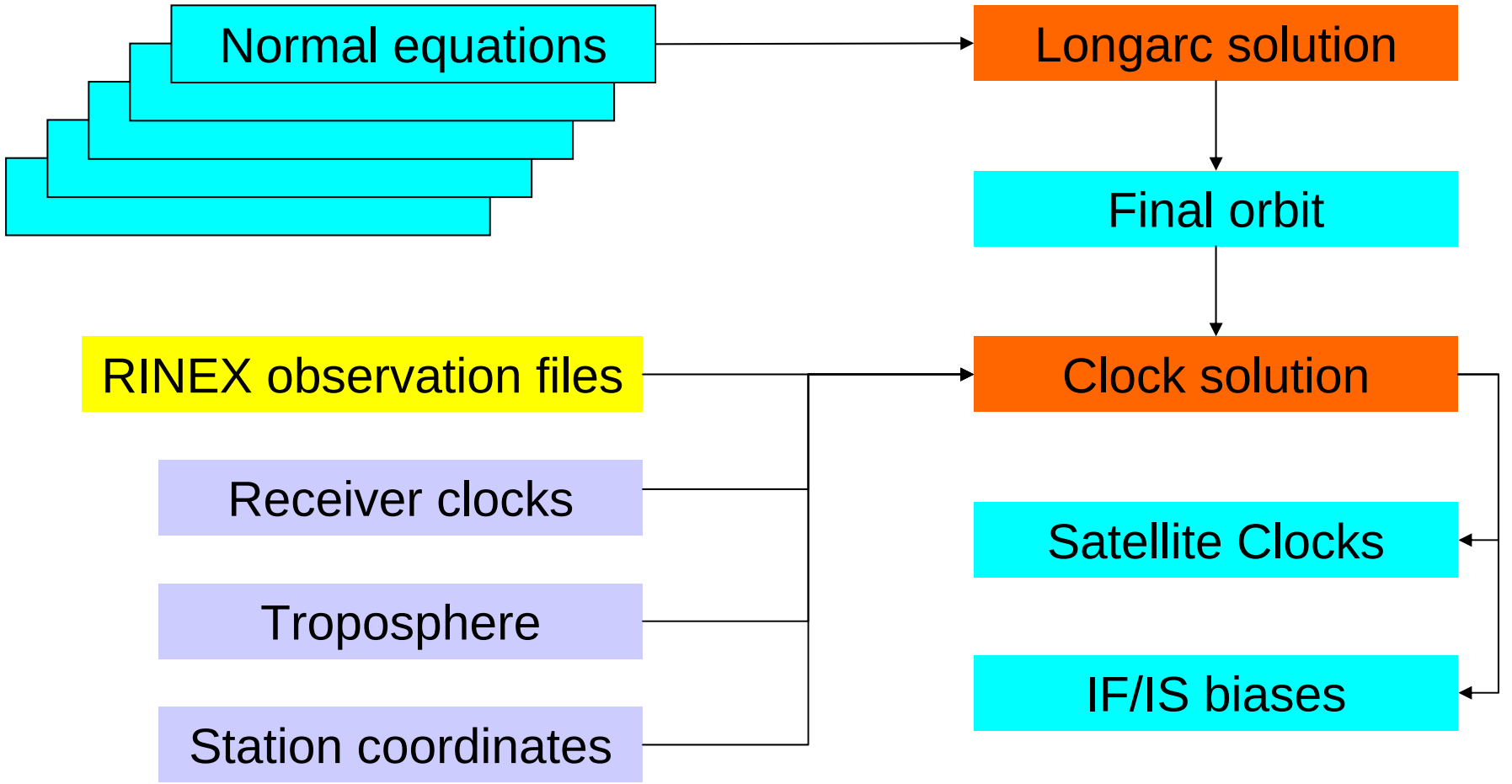
Operational Rapid Solution (1)



Operational Rapid Solution (2)



Operational Final Solution



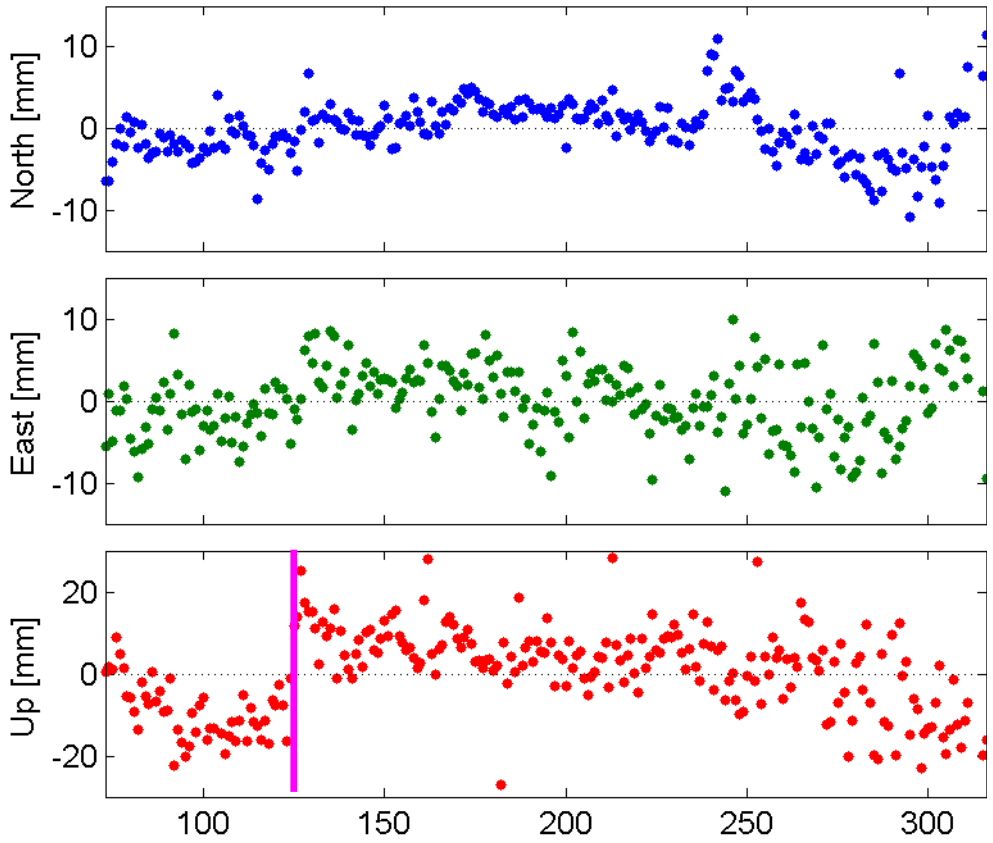
Operational Processing Options

- Phase and code observations
- GIOVE satellite antenna offsets: manufacturer values
- Receiver antenna model: igs05.atx, E5 copied from L2
- Ocean loading: FES2004
- 1 sec code ambiguities corrected for
- IF/IS Bias of New Brunswick fixed to zero

GPS-only Station Coordinates

Hartebeesthoek

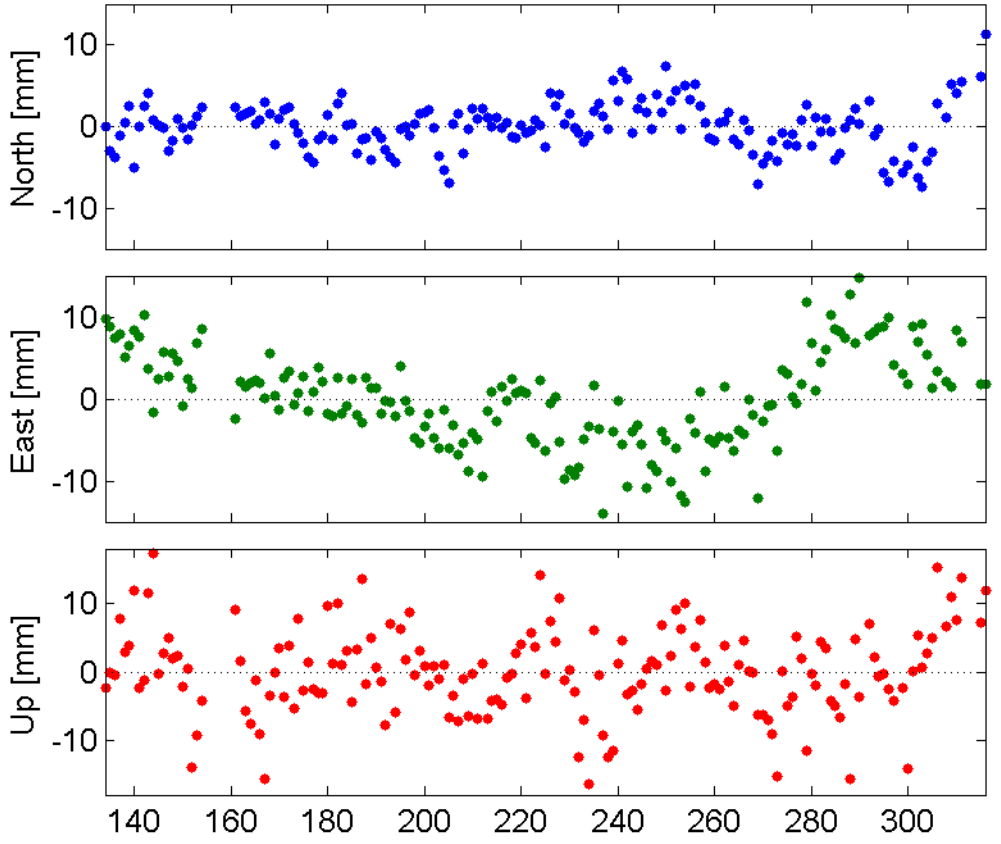
STD_N	3.7 mm	STD_E	4.3 mm	STD_U	10.5 mm



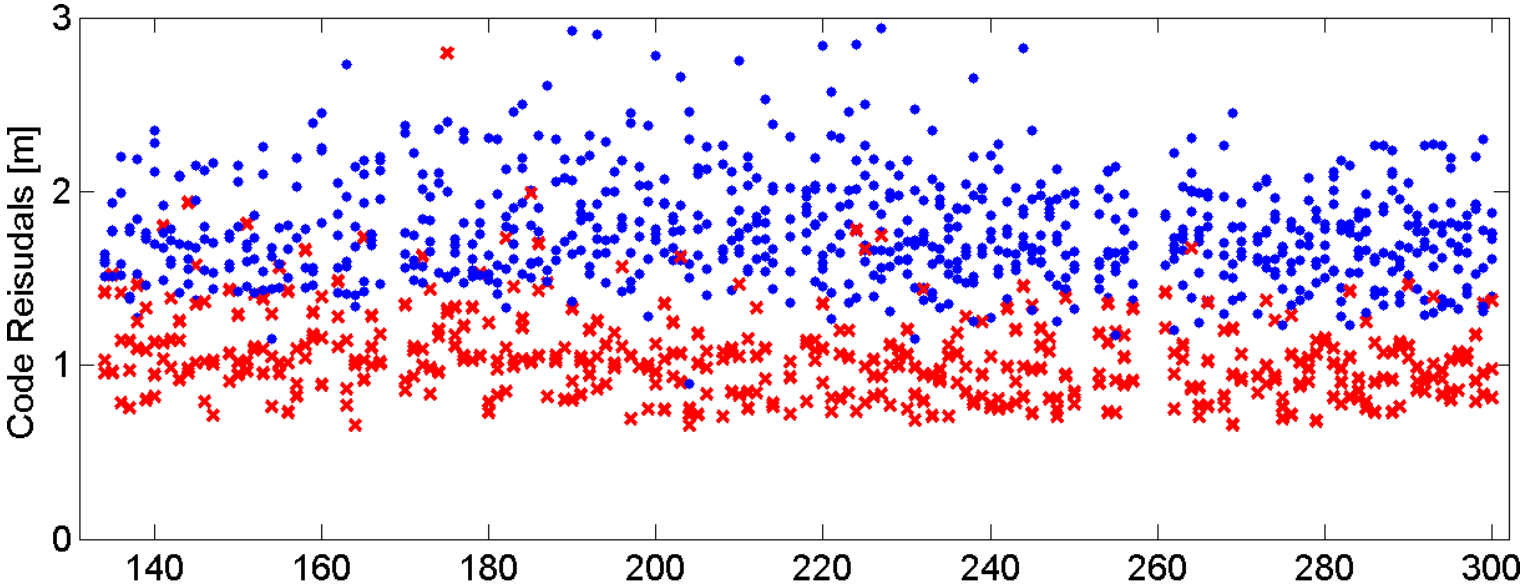
Antenna change

Maui

STD_N	3.0 mm	STD_E	5.7 mm	STD_U	6.3 mm



Code and Phase Residuals GIOVE-B



Daily means

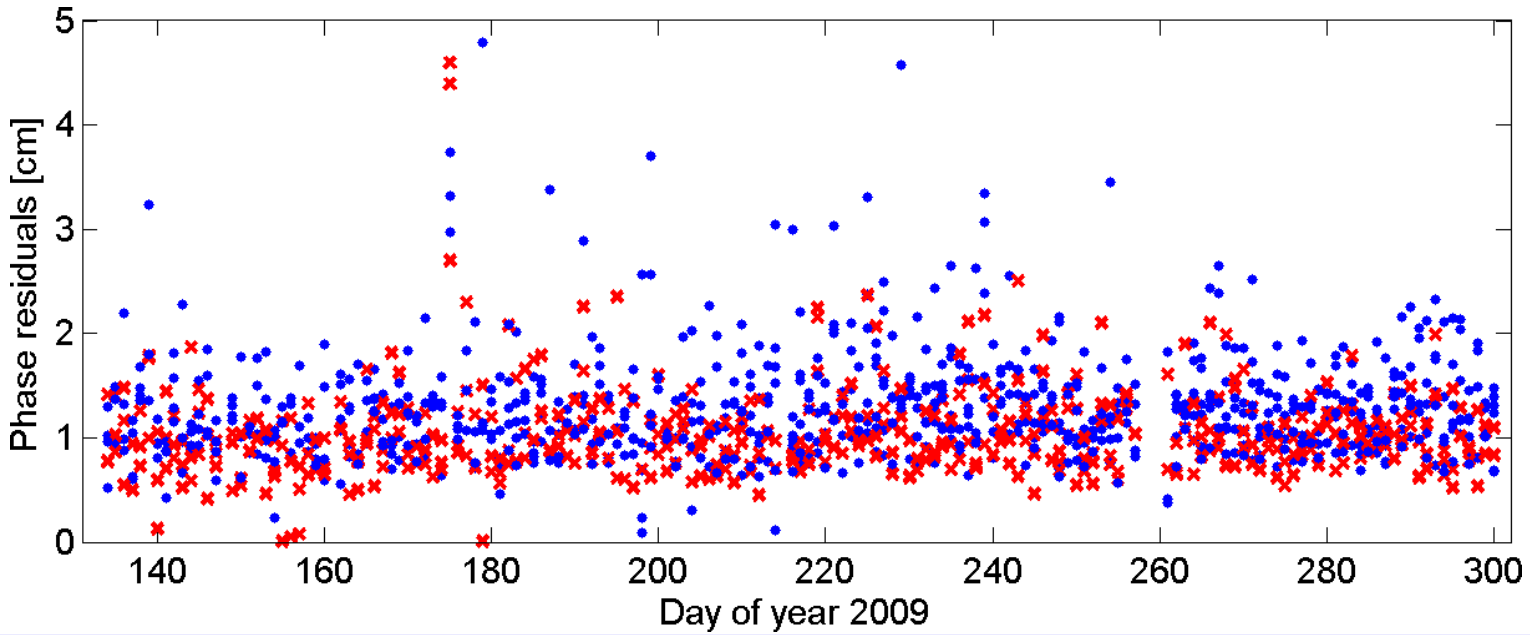
1-day solution

5 RPR param.

30 s sampling

JAVAD

GeNrX



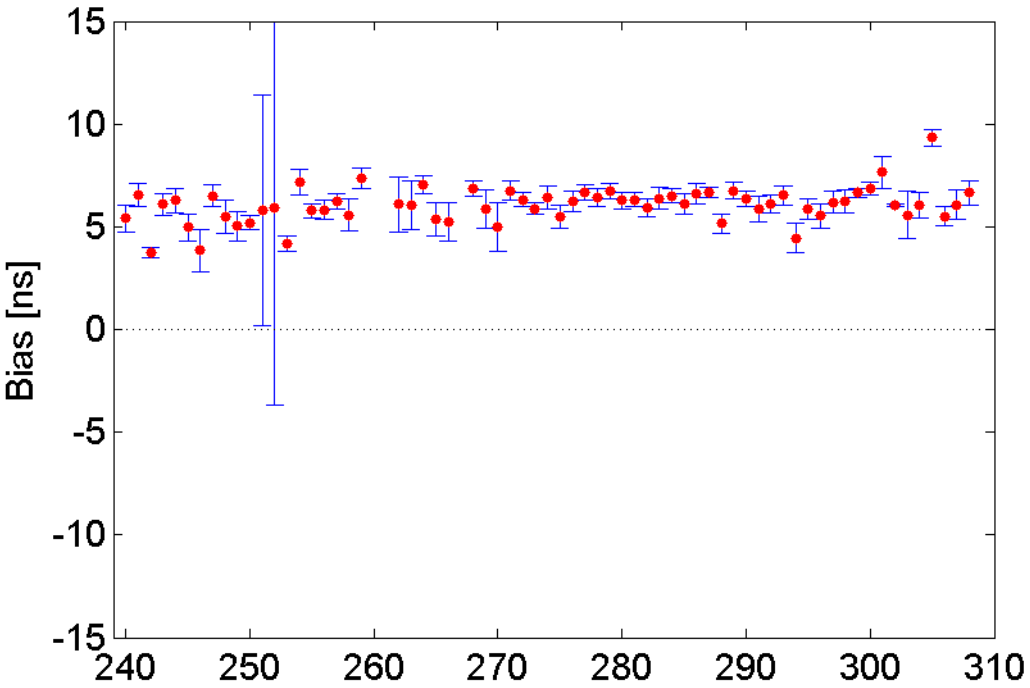
Interfrequency/Intersystem Biases

Javad Receivers at

Hartebeesthoek

Mean 6.1 ns

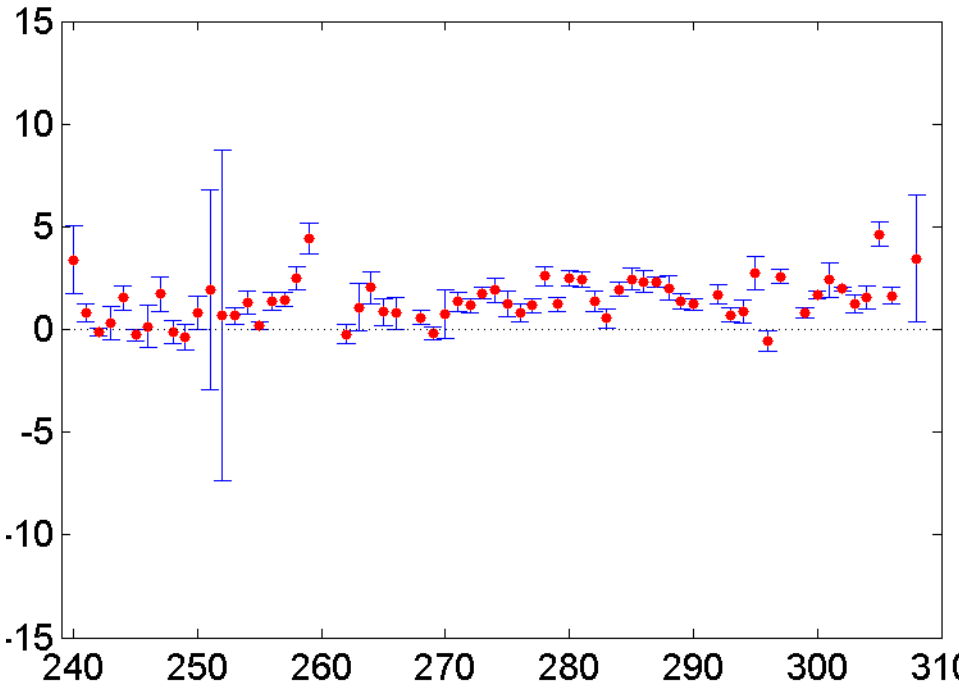
STD 0.9 ns



Maui

Mean 1.4 ns

STD 1.1 ns



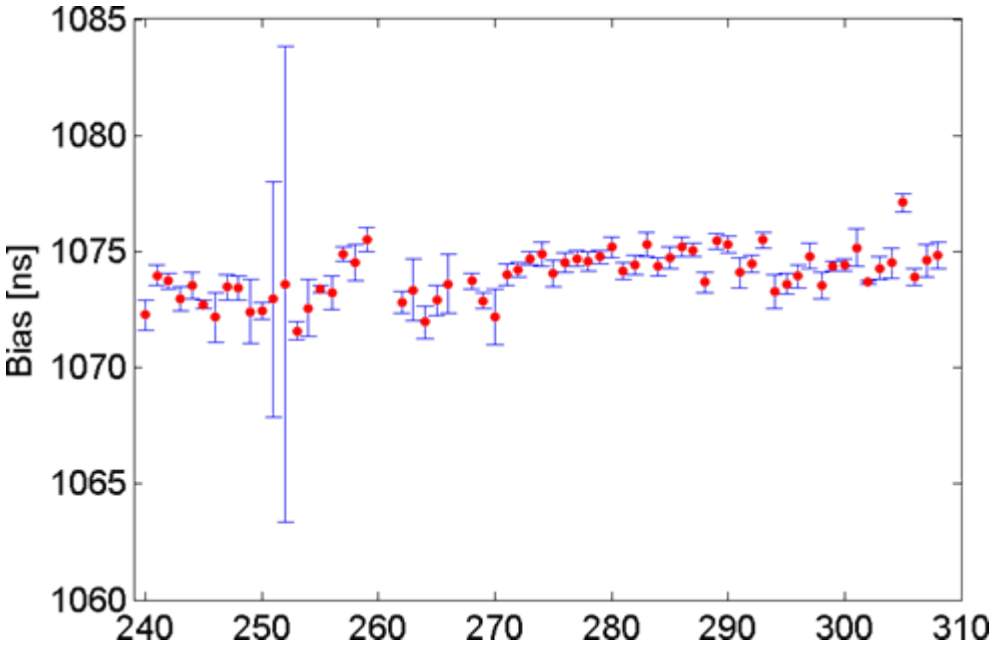
Interfrequency/Intersystem Biases

GeNeRx Receivers at

Wettzell

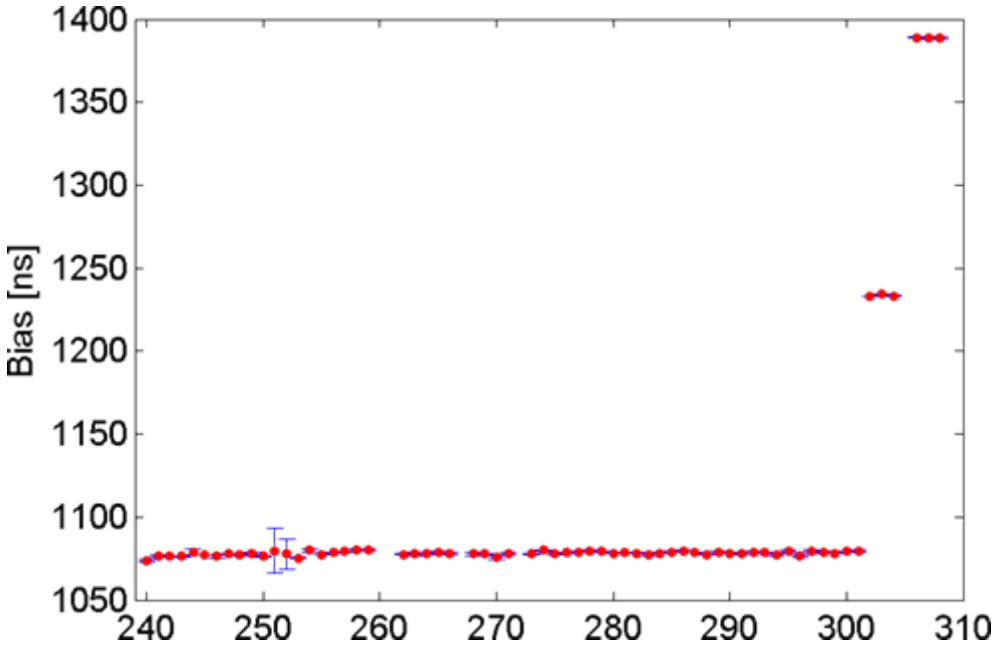
Mean 1074.0 ns

STD 1.0 ns



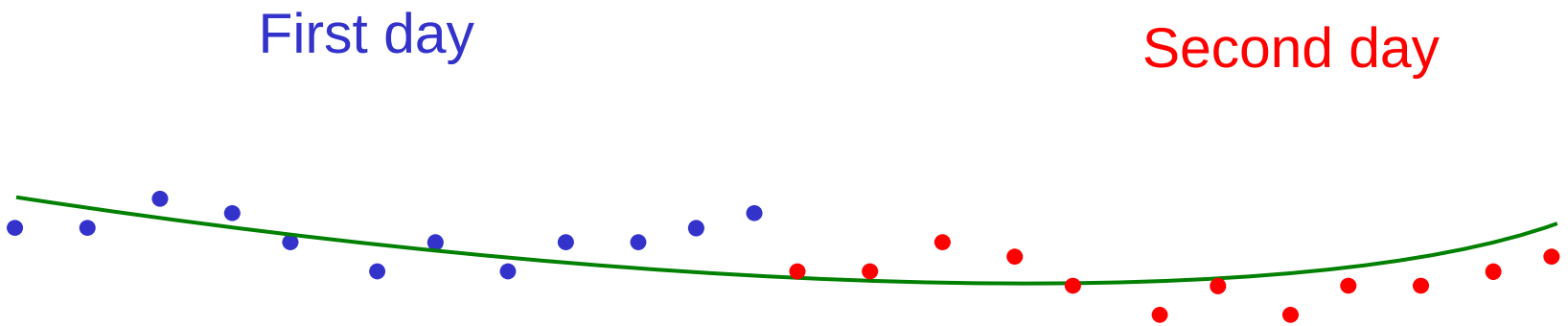
Sydney

Discontinuities of unknown origin



2-Day Orbit Fits

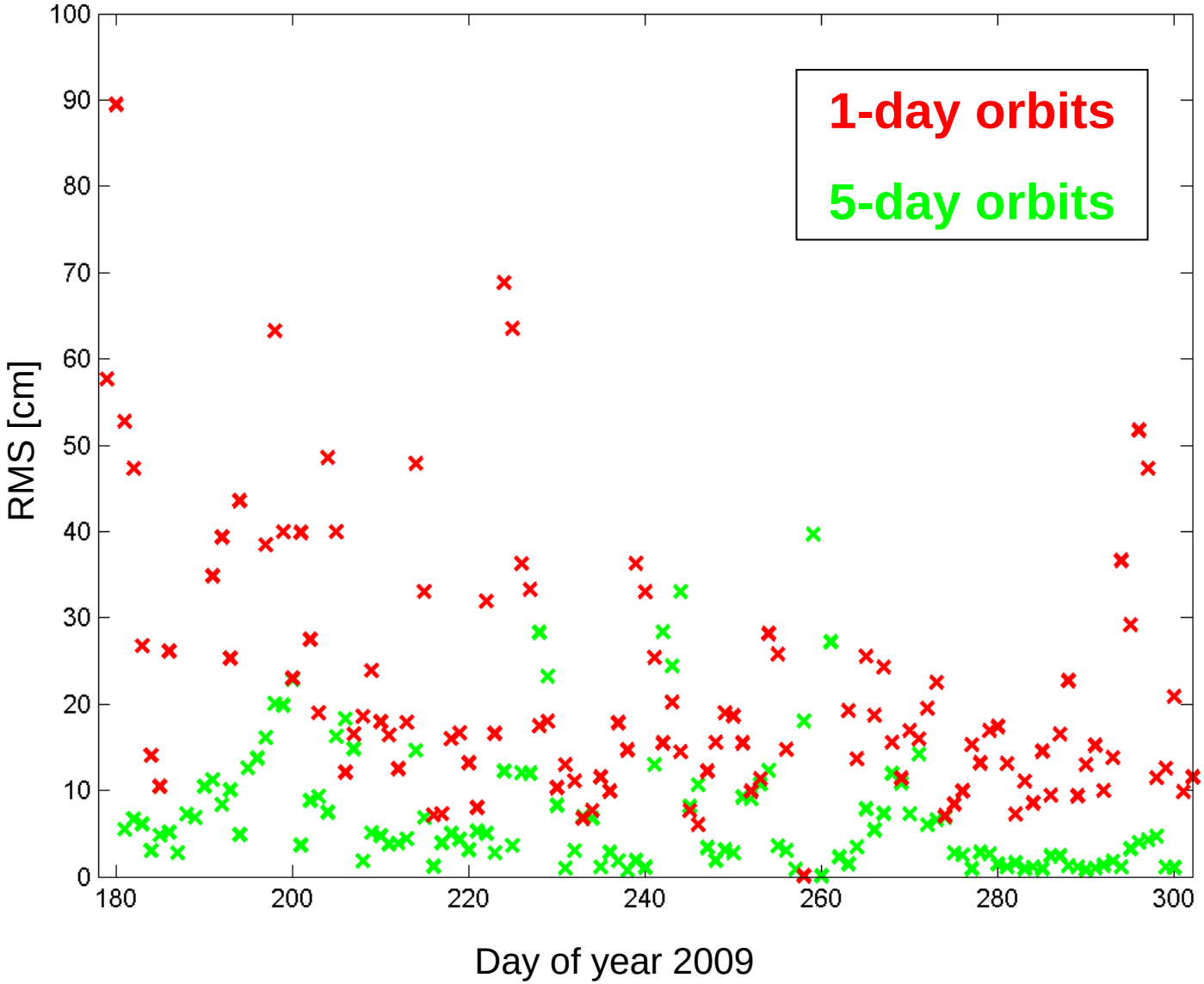
3D cartesian orbit positions (SP3c file) from



Orbit determination: 6 Keplerian elements, 9 radiation pressure parameters

RMS of individual orbit positions w.r.t. 2-day orbital arc

2-Day Orbit Fits



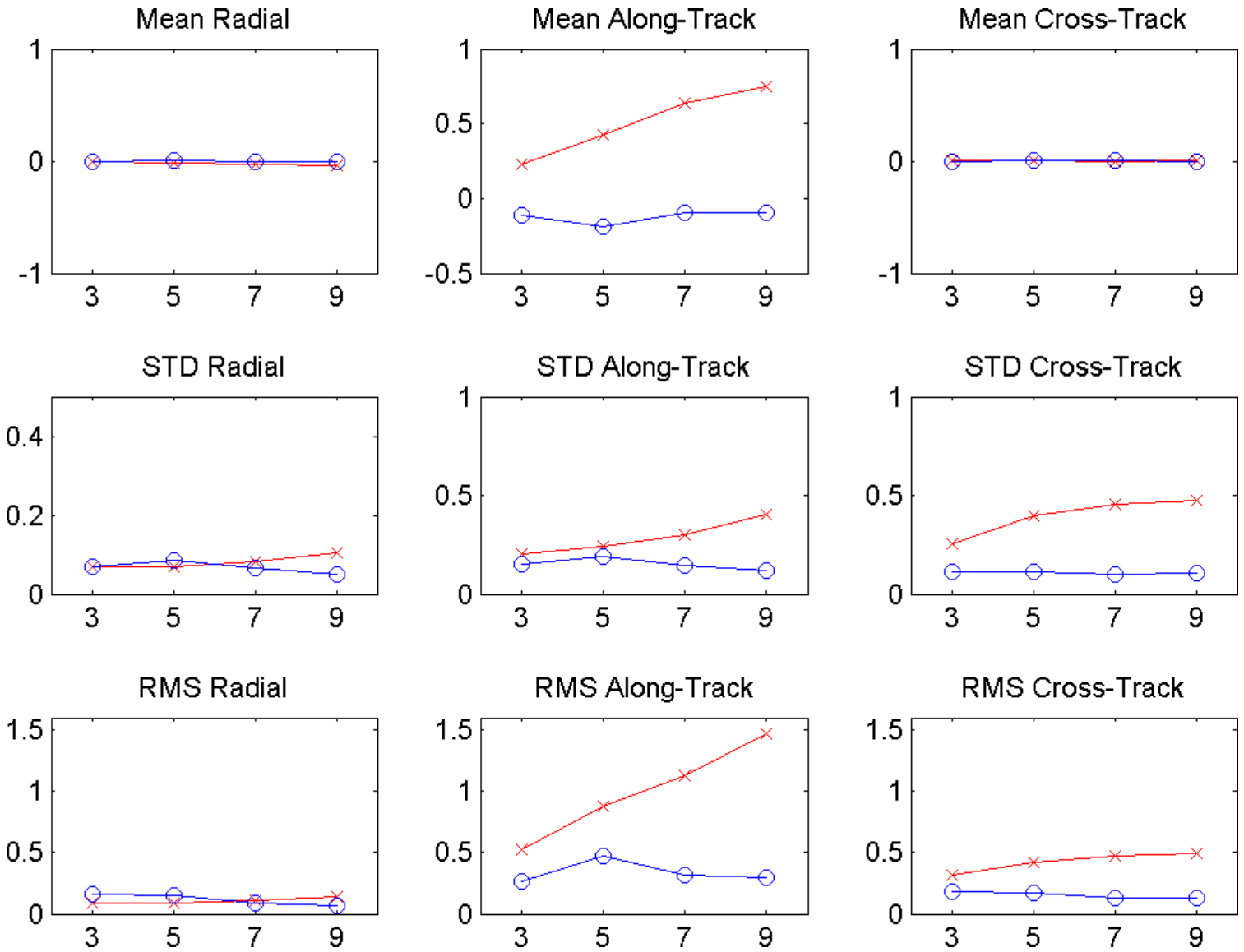
RMS 1-day orbits

21.4 cm

RMS 5-day orbits

7.4 cm

Orbit Differences Middle Day/Last Day



Mean/STD/RMS [m]

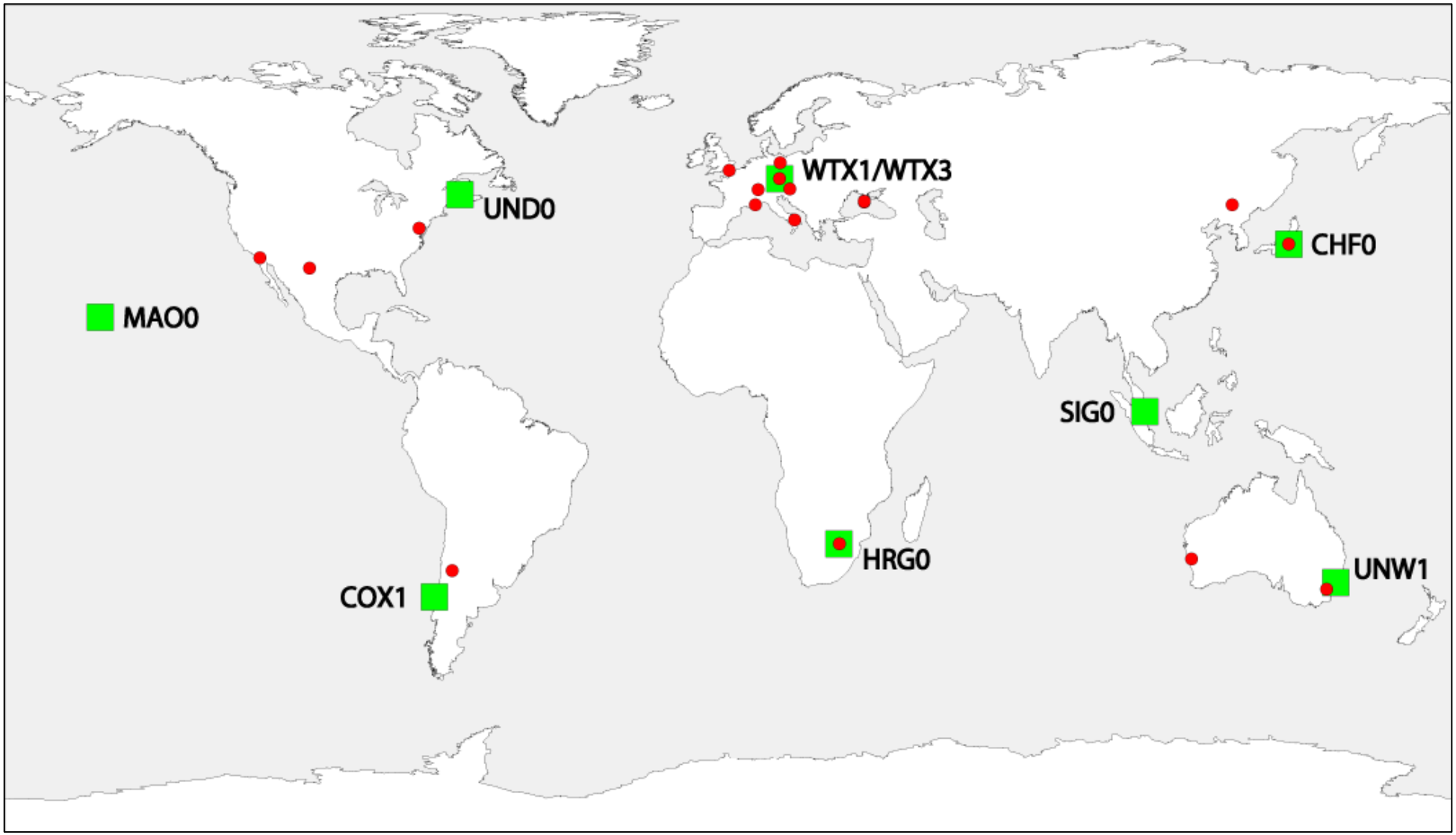
Orbit arc length

Number of RPR parameters:

5 RPR

9 RPR

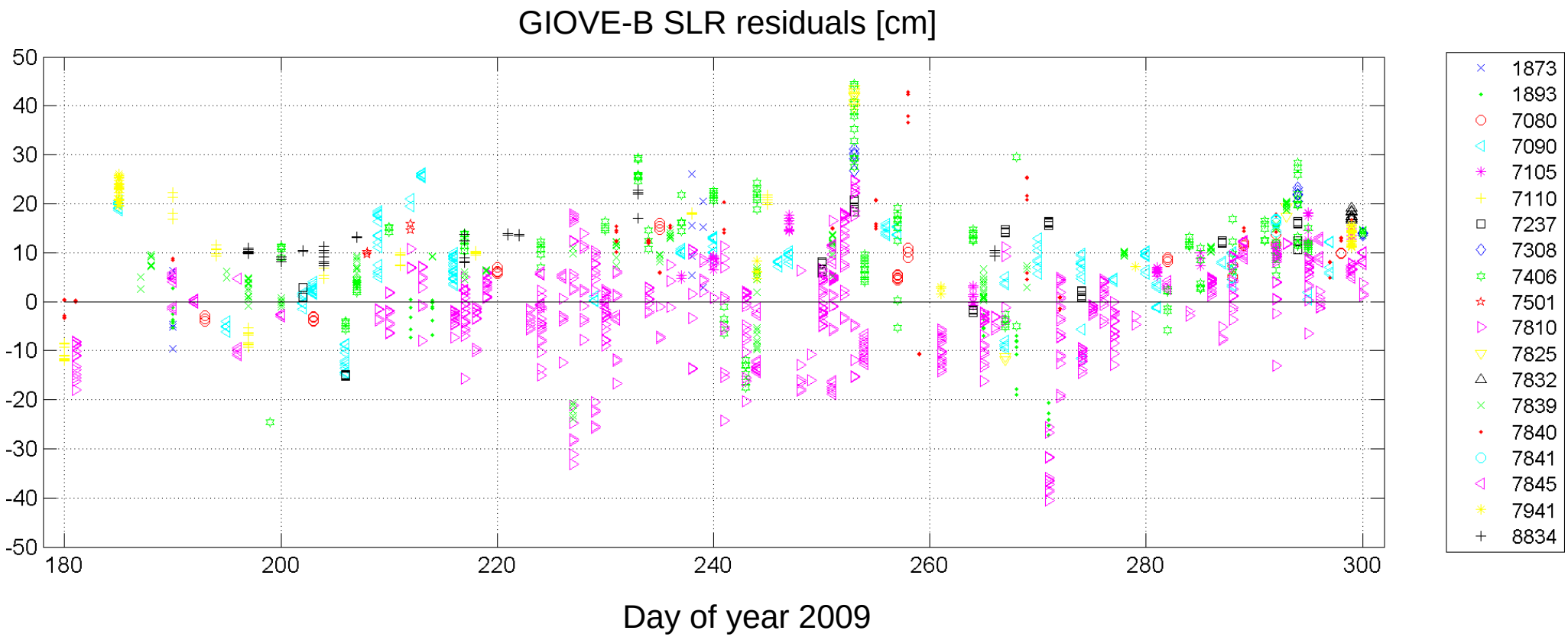
SLR Validation



SLR Residuals for GIOVE-B

CONGO final orbits and SLRF2005 fixed, no parameters estimated, only computation of residuals

Mean: 4.8 cm Standard deviation: 11.9 cm



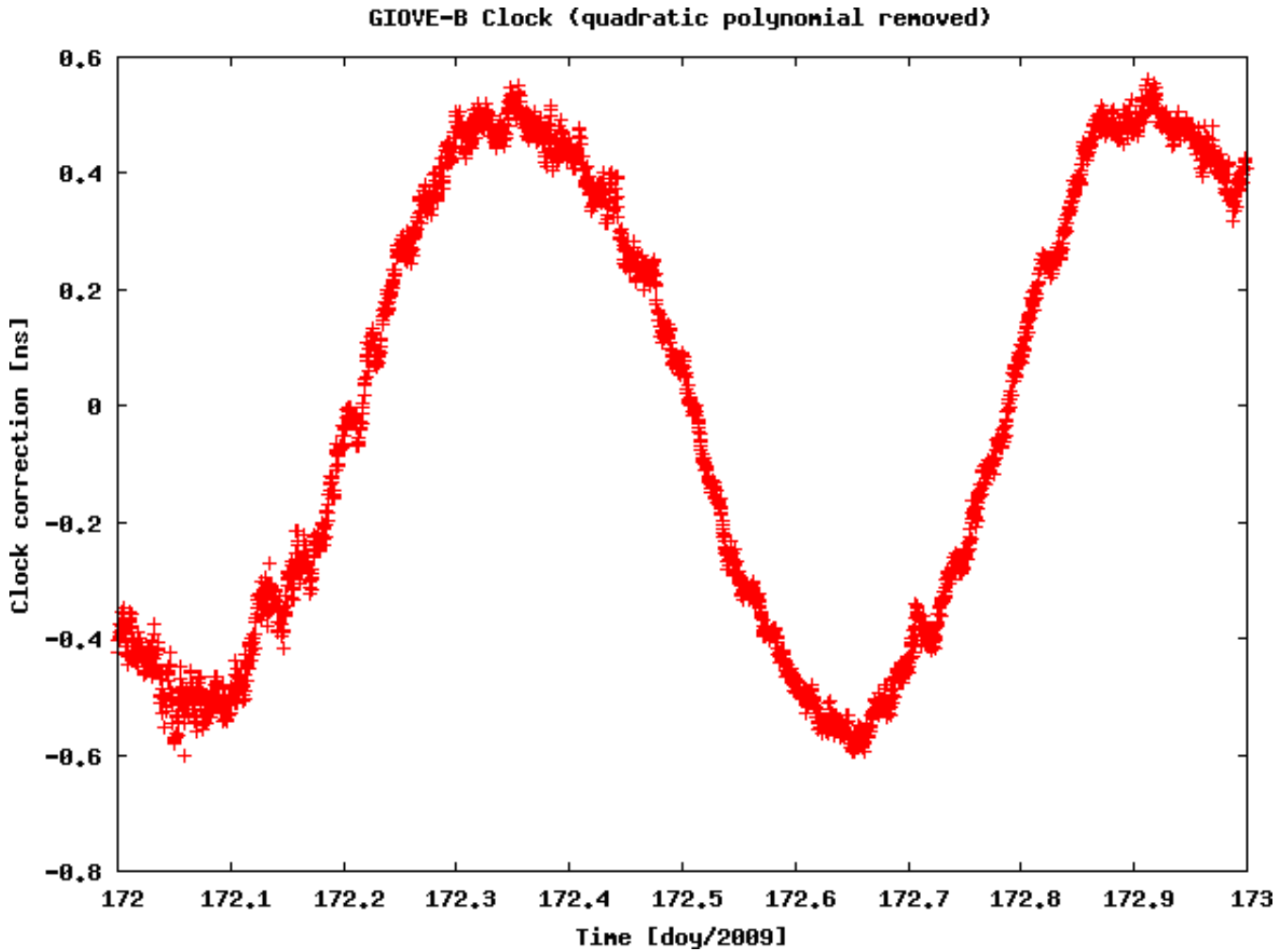
SLR Residuals for GIOVE-B

SLR residual statistics for different arc lenghtes and number of RPR parameters for 180 – 300/2009

Arc length	# RPR	Mean [m]	RMS [m]	Sigma [m]
3	5	0.0461	0.1407	0.1329
	9	0.2013	0.2899	0.2087
5	5	0.0484	0.1284	0.1189
	9	0.1185	0.1868	0.1444
7	5	0.0441	0.1122	0.1032
	9	0.0828	0.1423	0.1158
9	5	0.0510	0.1220	0.1108
	9	0.0639	0.1276	0.1105

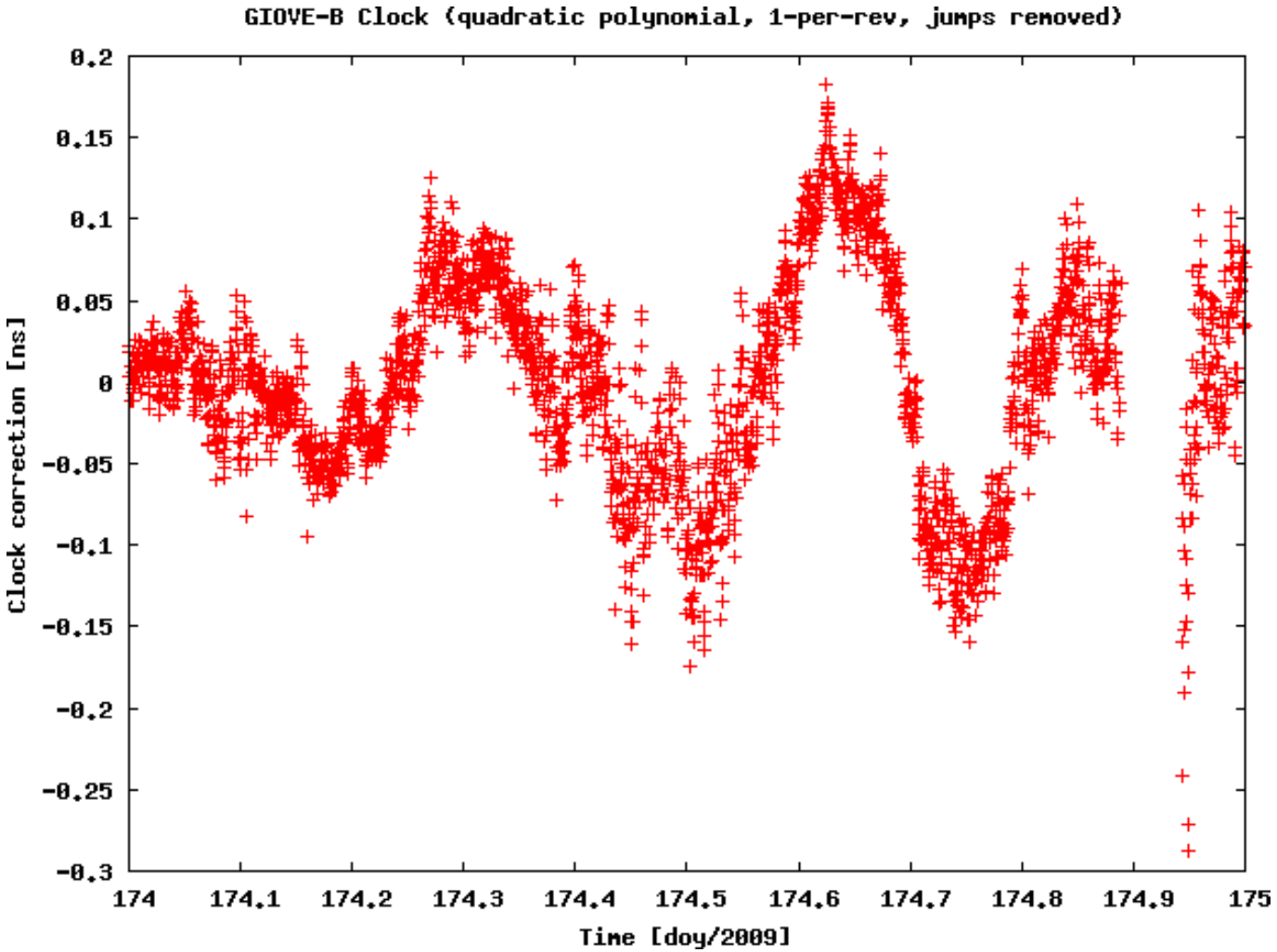
GIOVE-B Satellite Clock

Quadratic polynomial removed: $a_0 + a_1 \cdot t + a_2 \cdot t^2$



GIOVE-B Satellite Clock

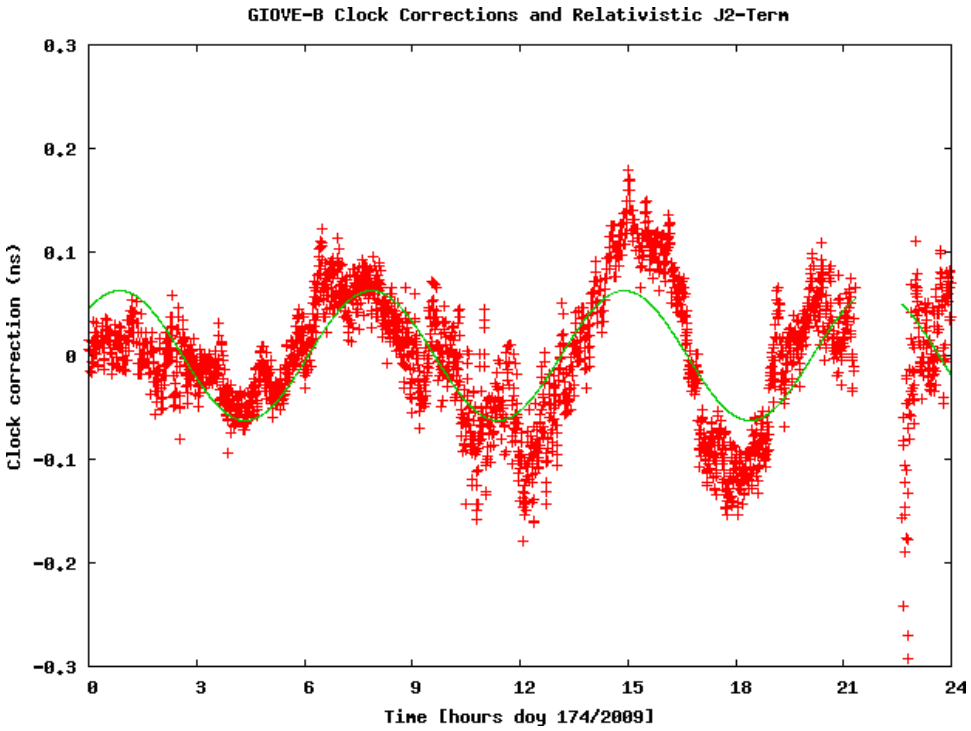
Quadratic polynomial and 1-per-rev removed: $a_0 + a_1 \cdot t + a_2 \cdot t^2 + C \sin(\omega t + \varphi)$

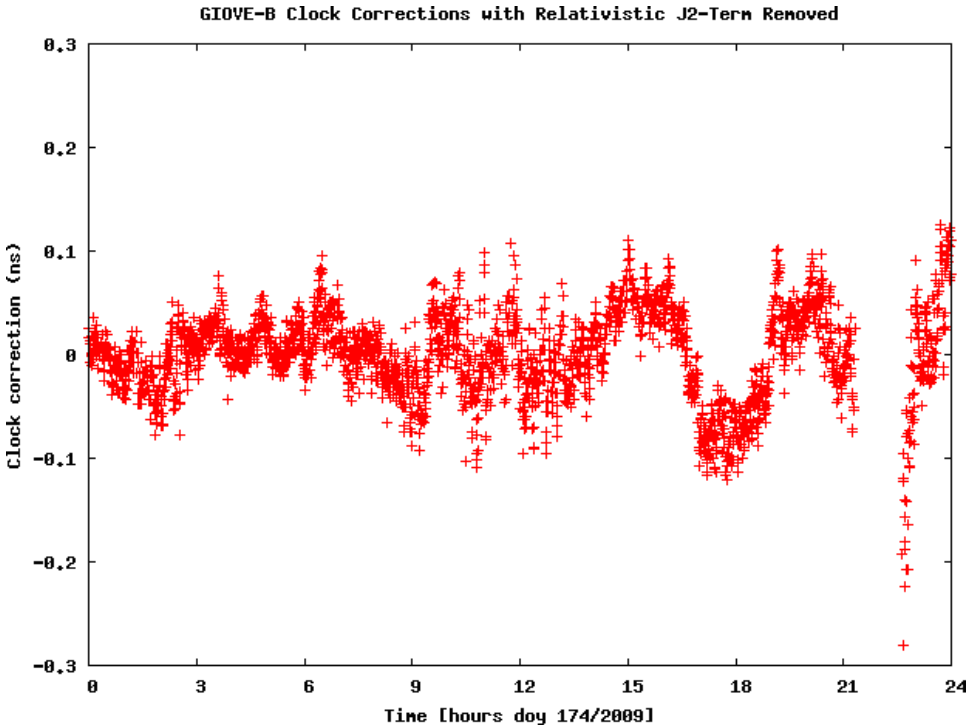


Relativistic J2-Term

The oblateness of the Earth causes an additional term that is not modeled a priori

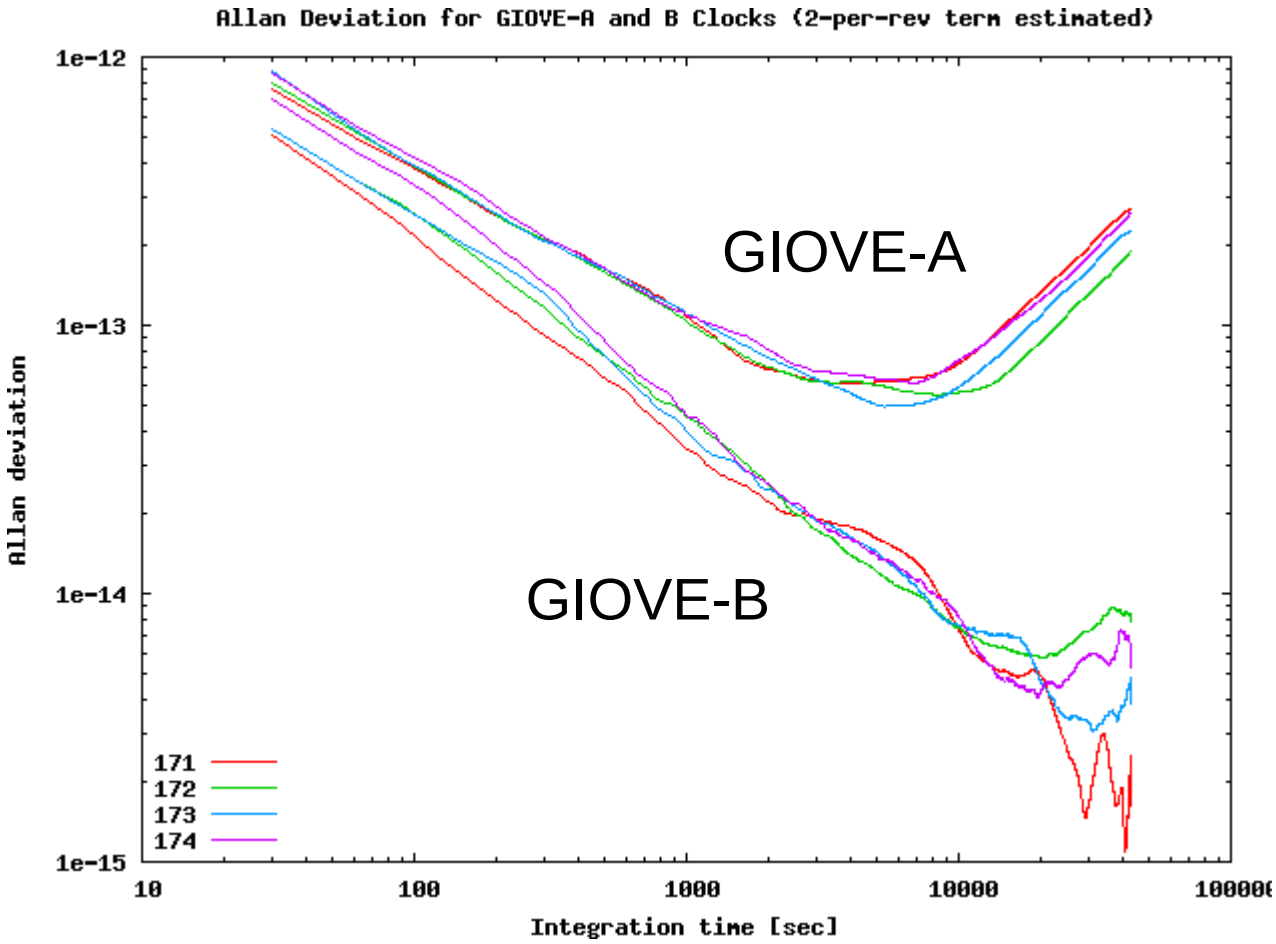
$$\delta t_{rel,2} = -\frac{3a_e^2\sqrt{GMa}J_2}{2a^2c^2}\sin^2 i \sin 2u$$





Allan Deviation GIOVE-A and -B

GIOVE-A: Rubidium clock
GIOVE-B: Passive hydrogen maser



Summary and Outlook

- Orbit determination with dm accuracy possible with the CONGO network
- Passive hydrogen maser show an astonishing accuracy
- Modeling of clock instead of estimating epoch parameters
- Problems with sometimes frequent outages and changing code bias values
- Combination of microwave and optic (SLR) observations
- Estimation of satellite antenna offsets