GNSS processing in Institute of Applied Astronomy RAS

Vladimir Suvorkin, Sergey Kurdubov and Iskander Gayazov
Institute of Applied Astronomy RAS

GPS processing in Institute of Applied Astronomy RAS runs from year 2000. For many years it has been based on the software package GRAPE which processed triple differenced GPS observations. At February 2014 GRAPE was replaced by a newly developed software for processing zero-differenced observations of GLONASS and GPS.

Processing strategy

Data preprocessing: Melbourne-Wubbena combinations of code and phase measurements for cycle slip detection, outliers removing and forming satellite passes.

Basic Observables: Zero-differenced phase and code ionosphere-free combinations of global GNSS network stations, corrected by P1-C1 satellite code biases (cc2noncc), daily observations with 30 seconds sampling rate

Sites coordinates: IGb08 reference frame coordinates and velocities

Displacements: solid tides, ocean loading, pole tide loading (IERS 2010)

Geometric model: Receivers antennas eccentricities, absolute receiver and satellite (to CoM) antennas phase centers, elevation-dependent and azimuth-dependent corrections with accordance to absolute model IGS08.atx; wind-up effect (Wu et al., 1993)

Signal propagation: Troposphere: GMF (IERS , Boehm et al.2006) mapping function, horizontal north and east gradients

Relativistic: path range effect (Shapiro delay) and satellite clock corrections.

Solar system bodies ephemeris: DE421

Terrestrial to Celestial frame transformations: IAU 2000A model, subdaily polar motion libration

Orbit modelling:

- EGM2008 Geopotential model (truncated to degree and order 12) and corrections with accordance to IERS 2010: conventional, solid and ocean tides corrections, solid and ocean pole tides corrections to geopotential coefficients
- Modelling for GPS, GLONASS and SLR satellites
- IAU 2000A precession-nutation model
- Post-Newtonian relativistic corrections (Schwarzschild metric)
- Solar radiation pressure: empirical model (Gayazov, 2002): Apriori + 3 estimated parameters
- Numerical integration: DINCH integrator (single-step correction-prediction integration with Chebyshev approximation)

Configuration of parameters to be estimated:

Configuration descriptions of parameters defines a design of a model matrix and program working regime. For every estimated parameter there are corresponding partials computation routines. Values for non-estimated parameters must be preliminarily available as input data or modelled within the program code.

For every parameter description in XML format:

```
{   type : " parameter's type "
    timeDependency : "parameter's time
dependency"
    polynomialDegree : "parameter's
polynomial degree"
    name : " parameter's name" }
```

type values:
- station (coordinates, clock biases, trop. zpd…)
- satellite (coordinates, velocities, SRP, clock biases…)
- common (phase amb., EOP …)

timeDependency – daily (one per day - global parameters)
- everyMoment: – for every epoch of observations (local parameters)

polynomialDegree – for global parameters, degree of the orthogonal polynomial

name – identification name of parameter (corresponding to derivatives routine in the program)

Examples of working regimes:
1. Fixed sites positions, estimation of all the possible parameters – EOP Service mode
2. Static PPP (Precise point positioning) – estimation of receiver position only
3. Extended static PPP (station positions, troposphere, clock biases, etc.)

GNSS EOP Service scheme:
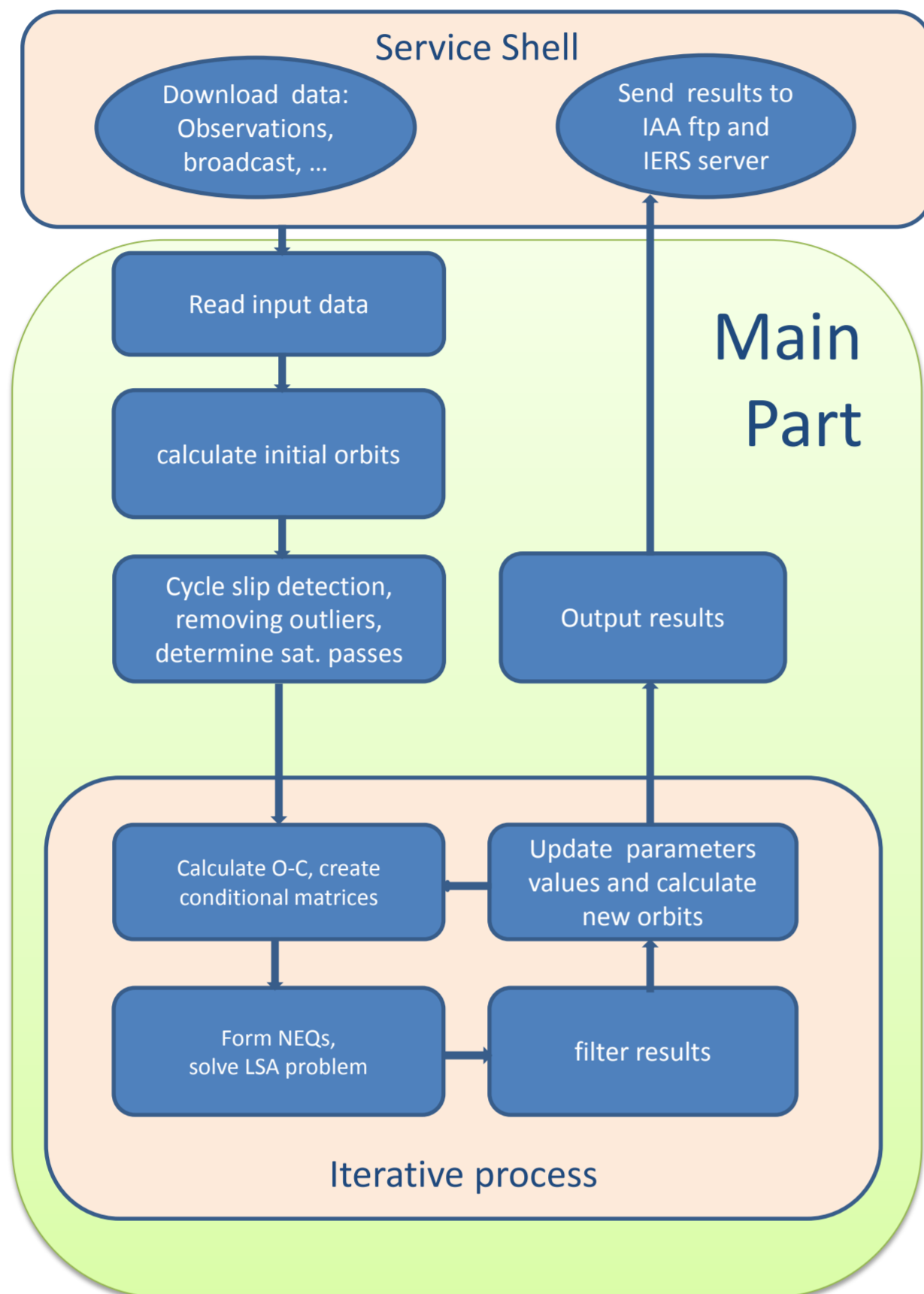
Service shell:
Data download scripts (observation files, broadcast messages, sp3-orbits (for comparison)), UT1-UTC
Launch processing
Sending results to IERS

GNSS EOP Service processing:
- ~50 stations within IGS Network
- weighted multi-group least-squares algorithm
- 2 segments: daily parameters and every moment (30s sampling)
- no a priory and continuity constraints
- clock alignment to broadcast GPS-time
- 30s sampling rate
- At first iterations we estimate float phase ambiguities and clock biases with fixed a priory satellite parameters. At the second iteration we add troposphere to estimation.
- Then other parameters (orbital, EOP, horizontal gradients)

Model matrix design

Parameters vectors	x	y_1	y_2	y_3	…	y_k	z
Conditional matrices (partial derivatives):	A_1	B_1					Z_1
	A_2		B_2				Z_2
	A_3			B_3			Z_3
	…				…		…
	A_k					B_k	Z_k

A_i – matrices of daily parameters
B_i – matrices of 'everymonent' parameters
Z_i – O-C vector
i – epochs of day

Development software and performance:
Python3 for shell, C++ and Fortran for data processing and computation
Intel C compiler, LAPACK and BLAS for vector and matrix operations, system solving
32 Satellite, 50 Stations solution, 30s sample: 60 - 130seconds for each iteration (Intel Corei7 4770k, 32Gb DDR3 RAM)

Products of GNSS EOP Service:
Daily for previous day:
- daily Xp, Yp, Xrate, Yrate, LOD
- Troposphere (as 12-degree orthogonal polynomial or for every 30s parameters set)
- Atmospheric gradients - 2 daily parameters (per North and East)
- Satellite orbits (initial coordinates, velocities, 3 parameters of SRP model)
- Every moment satellite and sites clock biases (aligned to broadcast GPS-time)

Under development and testing:

- Improved SRP 9+6 model: 3 coefficients for each of 3 coordinates in satellite fixed frame, 3 components of stochastic pulse acceleration per every revolution.
- Albedo
- Yaw attitudes for satellites
- 2nd order Ionosphere for signal propagation
- Atmospheric loading for site displacements
- SINEX output for further combinations
- SLR measurements processing
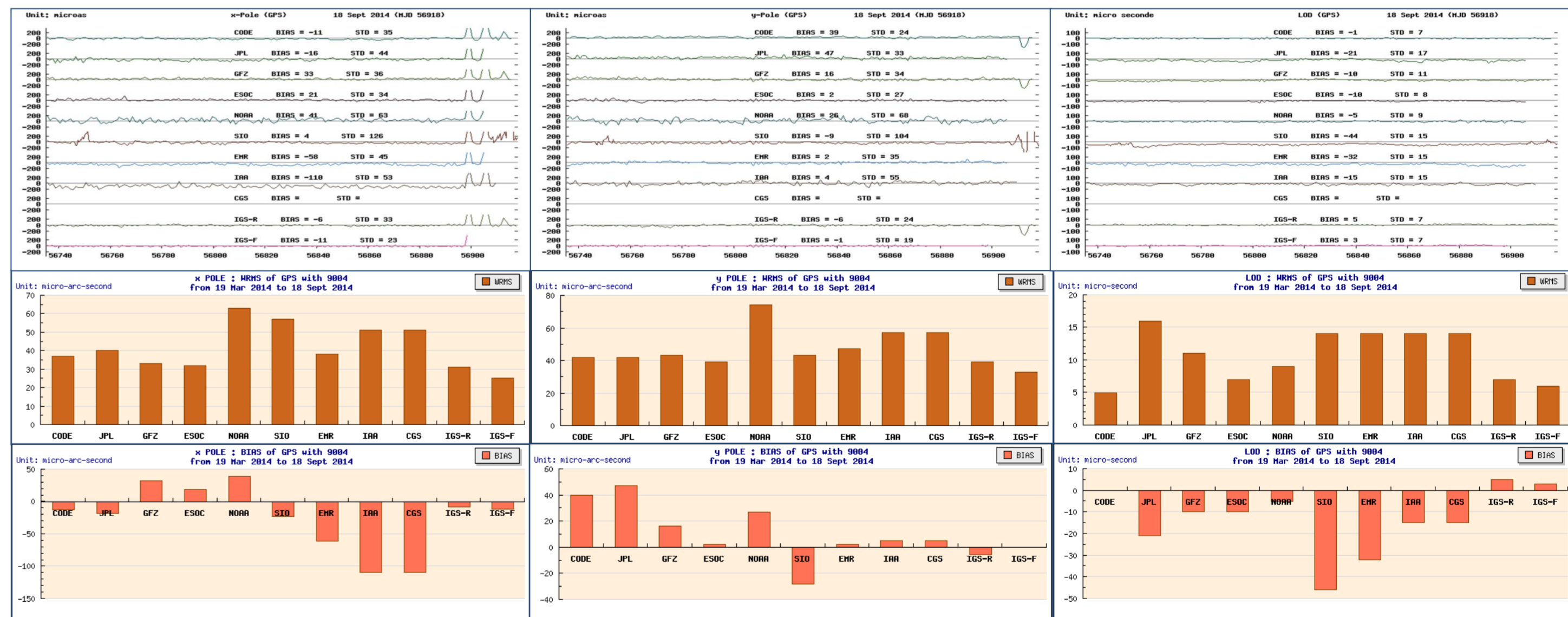
Data span, MJD	Xp, μas	Yp, μas	LOD, μs
accuracy	**39**	**48**	**10**
	4	4	0
56690.50 to 56716.50	**59**	**59**	**16**
	4	5	0
56718.50 to 56747.50	**60**	**62**	**14**
	4	5	0
56749.50 to 56777.50	**50**	**50**	**15**
	4	4	0
56779.50 to 56808.50	**57**	**50**	**9**
	4	4	0
56810.50 to 56838.50	**42**	**48**	**17**
	4	5	0
56840.50 to 56869.50	**38**	**55**	**11**
	4	5	0

Product quality:
- **Satellite orbits**: 25-60mm 3D-rms (compared to ultra rapid IGS SP3)
- **Troposphere**: st. dev. 1.3mm compared to IGS
- **Clock biases**: st. dev. 26 ps compared to IGS
- **EOP**: Mean formal uncertainty and Weighted RMS agreement with IERS Bulletin B, 313-319, see table and graphs

References:
I. S. Gayazov 'Parameterization of the Solar Radiation Pressure model for GPS satellites', IAA Transactions, No. 8, 2002
I. S. Gayazov, V. V. Suvorkin, S. L. Kurdubov, V.S. Pshenkin, 'A new version of software package GRAPE for GNSS phase measurements processing, , IAA Transactions, No. 27, "Celestial Mechanics", 2013