National Research Institute for Physical-Technical and Radio Engineering Measurements

GLONASS Orbit/Clock Combination in VNIIFTRI

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1. INTRODUCTION

Some Analysis Centers in Russian Federation such as Information-Analytical centre of positioning, navigation, and timing (IAC PNT) TSNIIMASH, Mission Control Centre (MCC), High-precision ephemeris and time correction estimation system (HETCES/SVOEVP) as well as a number of Analysis Centers of the International GPS Service for Geodynamics (IGS) are producing daily precise orbits and time corrections of GLONASS satellites. These individual products are based on measurement data received from GLONASS globally distributed ground stations and available at several IGS Data Centers (e.g. CDDIS, IGN, etc.). For the reason that the application models as well as software systems and the data sets used by individual Centers are not identical the satellite orbit/clock solutions represented by individual Centers can differ a little from each other.

On the one hand, due to the absence of priori information regarding exact satellite orbit/clock solutions the preference can't be given to orbits of any of the Centers. On the other hand, the increasing role of GLONASS satellite orbit/clock products used in many applications of space geodesy necessitates having such combined products created by the authorized Russian organization which could serve as official data over the whole Russian Federation territory.

A general scheme of combined orbits producing by the Coordinating Center on the base of information provided by the Analysis Centers is given in Fig. 1.

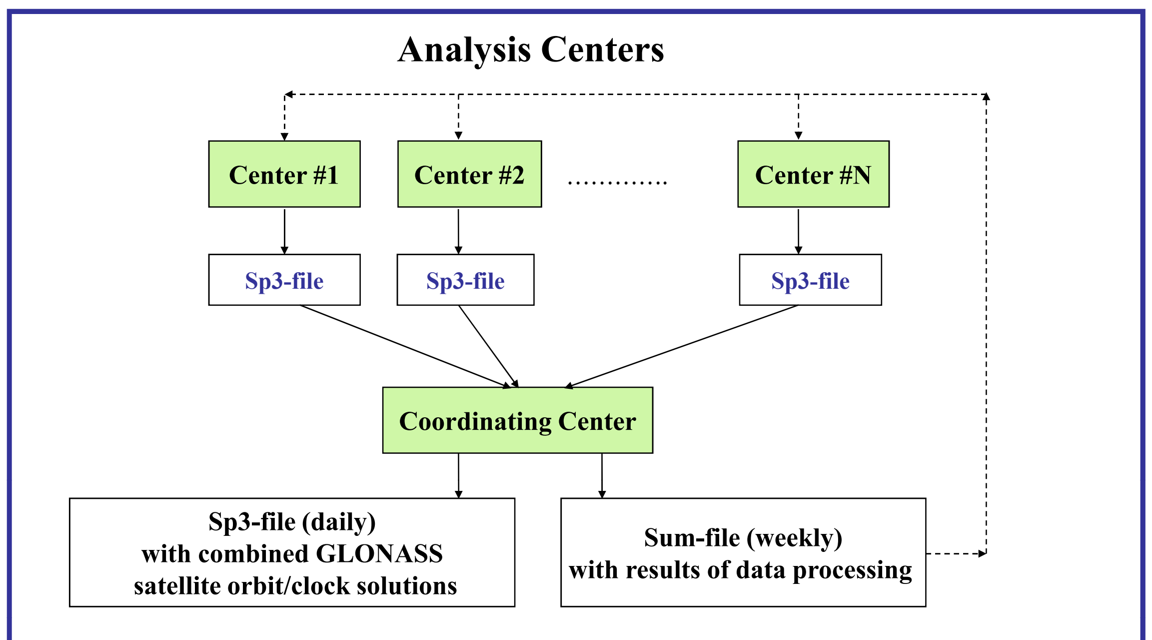

Fig. 1. A general scheme of combined orbits producing

An idea of the weighted average orbit/clock combination for GPS and GLONASS satellite constellations by mathematical processing of calculation results obtained by individual Analytic Centers goes back to IGS. Since 1993 and to the present IGS issues Sp3-files with official values of coordinates and clock corrections of GPS satellites. Since 2004 up to now the combined orbits and clock corrections of GLONASS satellites are formed under the auspices of IGS by the Data-processing center of National administration of oceanic and atmospheric researches and National geodetic service of the USA (NOAA/NGS).

2. INTERNATIONAL GLONASS PILOT PROJECT (IGLOS-PP)

Originally the combined orbits of GLONASS were formed in the framework of the international IGLOS-PP. IGLOS-PP was a Pilot Project initiated in 2000 to track and analyze data from the Russian GLONASS satellite constellation. It also served as an important demonstration of integrating new constellations and signals into the IGS framework. The IGLOS-PP was terminated at the request of the Project Chair at the end of 2005, because GLONASS data and products had been successfully integrated into the standard operations of the IGS.

Now 9 Centers are involved in the activities on production of the combined GLONASS orbits (see Fig. 2).

The Coordinating Center of the IGLOS project on orbits/clock combination of GLONASS satellites :

IGL	IGLOS Combine Orbits, NOAA/NGS Operational Data Center, USA

The centers participating in the IGLOS project on orbits/clock combination of GLONASS satellites:

BKG	Bundesamt fuer Kartographie und Geodaesie, Germany
COD	Center for Orbit Determination in Europe, AIUB, Switzerland
COF	Center for Orbit Determination in Europe, AIUB, Switzerland
EMR	Natural Resources Canada
ESA	European Space Agency, Germany
GFZ	GeoForschungsZentrum Potsdam, Germany
GRG	Groupe de Recherche en Geodesie Spatiale /CNES, France
IAC	Information-Analytical Centre, RF
MCC	Mission Control Centre , RF

The time diagram of participation of the Centers in the IGLOS project since 2004 up to date.

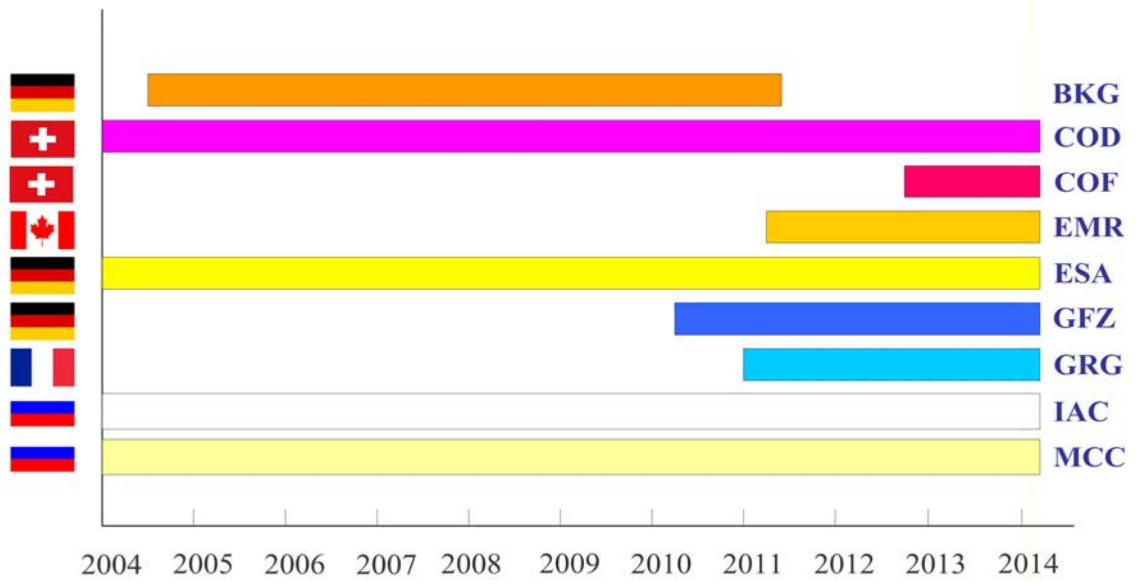

Fig. 2. The time diagram of participation of different Centers in GLONASS orbit/clock combination.

3. ORBIT/CLOCK COMBINATION STRATEGY

The principles of orbits/clock combination were proposed by Beutler G., Springer T., Kouba J., Mireault Y., Lahaye F. It is based on iterative process of creation of satellite orbital systems.

First orbital system.

- **Each Center's ephemeris is rotated to establish a common orientation to account for possible systematic pole offsets between individual Analysis Center solution and to make the GLONASS combined orbits compatible with the IERS EOP.**
- **Calculation of averages (over all Centers) values of coordinates of all satellites.**

Second orbital system.

- **Align of all Center's ephemeris to the 1-st orbital system.**
- **Calculation of weights of both the Centers and the satellites.**
- **Calculation of the average values of coordinates of satellites taking into account weights of all Centers.**

Combined orbital system.

- **Align of all Center's ephemeris to the 1-st orbital system taking into account satellite's weights.**
- **Calculation of the average values of satellite positions taking into account weights of all Centers.**

4. MATHEMATICAL TOOLS TECHNIQUE USED IN ORBIT/CLOCK COMBINATION

Helmert transformation H_P :

$$\mathbf{x}' = (1+\mu)\cdot \mathbf{R}_Z(\gamma)\mathbf{R}_Y(\beta)\mathbf{R}_X(\alpha)(\mathbf{x}+\mathbf{x}_0) = \mathbf{H}_P\,\mathbf{x}$$

where $\mathbf{p} = (x_0, y_0, z_0, \alpha, \beta, \gamma, \mu)$ **– transformation parameters used in adjusting one orbital system C1 to another C2:**

$$F_P = \sum_{j,k} \left\| H_P \mathbf{x}_{2,k}^j - \mathbf{x}_{1,k}^j \right\|^2 \xrightarrow[P]{} \min \quad \text{(without satellite's weights)}$$

$$F_P = \sum_{j,k} \left\| H_P \mathbf{x}_{2,k}^j - \mathbf{x}_{1,k}^j \right\|^2 \cdot W^j \xrightarrow[P]{} \min \quad \text{(with satellite's weights)}$$

$\|\cdot\|$ **– Euclidean norm in** R^3 **and** $\mathbf{x}_{1,k}^j\ \mathbf{x}_{2,k}^j$ **– known vectors.**

The principle of clock combination is based on alignment of time scales for different time data sets in L1-norm

$$G_{\alpha,\beta} = \sum_{j,k} \left| \Delta t_{2,k}^j + \alpha + \beta\cdot t - \Delta t_{1,k}^j \right| \xrightarrow[\alpha,\beta]{} \min$$

α, β - shift and drift parameters

5. GLONASS ORBIT/CLOCK COMBINATION ACTIVITY IN MAIN METROLOGICAL CENTRE OF THE STATE SERVICE FOR TIME AND FREQUENCY (MMC SSTF), VNIIFTRI

By now an algorithm and software were developed in MMC SSTF for production of the combined orbits and clock corrections for GLONASS satellites. Main functions of the software are as follows:

Production of combined GLONASS orbits and clock corrections on base of data sets provided by individual Centers

Outliers detection in satellite orbit/clock data sets as they determined by each Center and elimination if needed appropriate epochs for each satellite and for each Center from further combination process

The detection and elimination of "bad" satellites from combination process

Application orbital dynamics with calculation of long arc (1,3,5,7 days) orbits to obtain some statistical characteristics of combined orbits

Producing report files of two types:
1) Sp3-files with combined orbits and clock corrections for GLONASS satellites (daily)
2) Sum-files of reports for the 8th day period with transformation parameters, statistical, accuracy and orbital characteristics for each satellites and each Center (weekly)

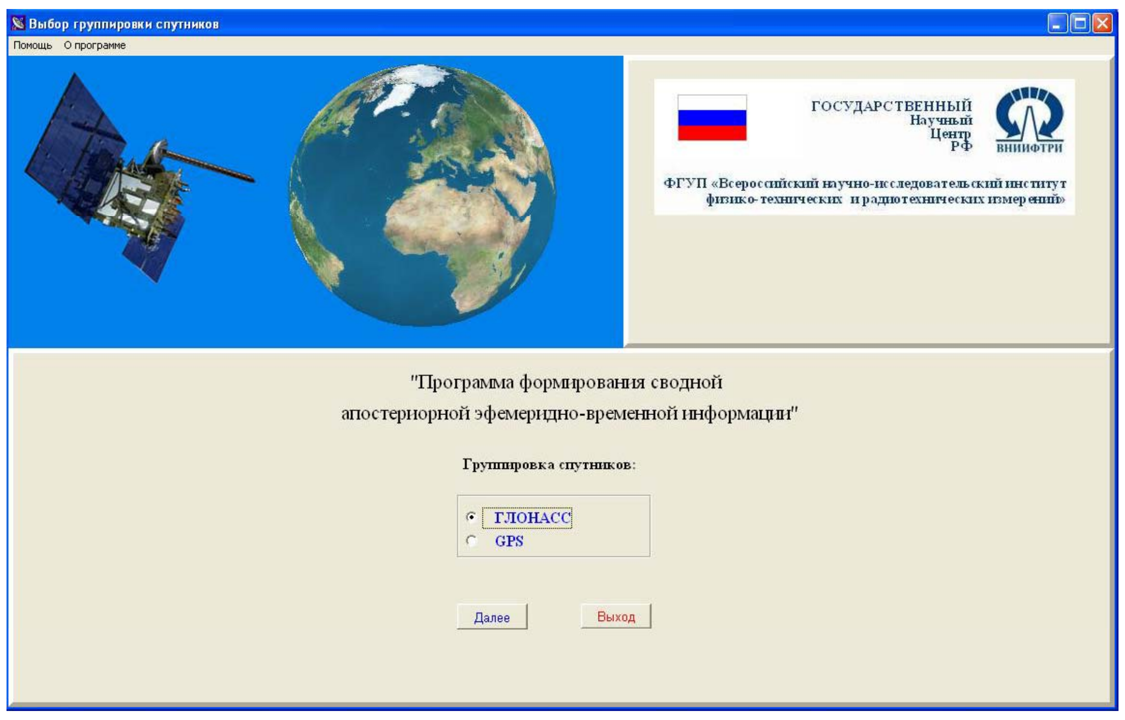

Fig. 3. Main dialog window of the software for producing GLONASS satellite combined orbits and clock corrections

Comparison results of GLONASS orbits defined by the Centers with the IGL combined orbits for the period from 2011.01.29 to 2011.02.05 are presented on Fig. 4.

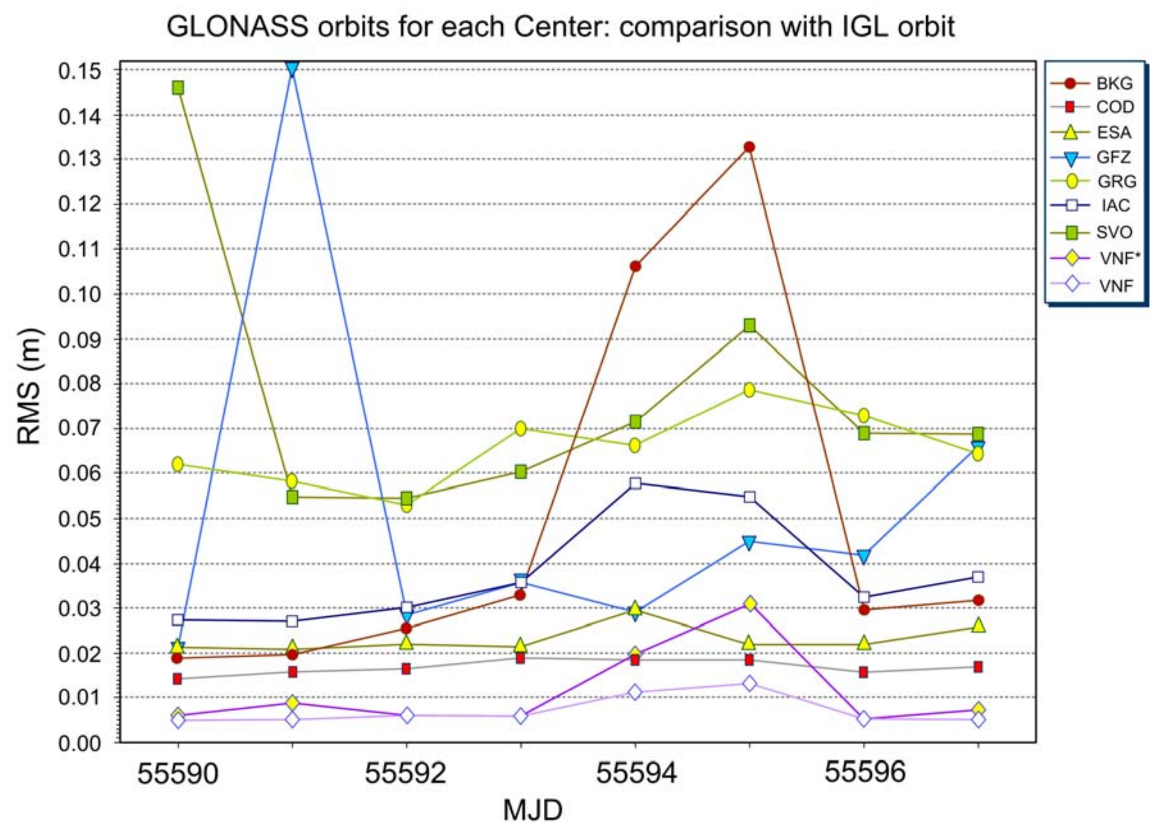

Fig. 4. RMS of GLONASS satellite positions for individual Centers in comparison with IGL combined orbits

Remark: **VNF – final combined orbits of MMC SSTF, VNIIFTRI;**
VNF* – preliminary combined orbits of MMC SSTF, VNIIFTRI (before elimination of "bad" sitellites)
SVO – abbreviature of High-precision ephemeris and time correction estimation system (HETCES/SVOEVP), RF

6. ASYMPTOTIC THEOREM

Denote:

N_{Cent} **– number of Centers,**

N_{Sat} **– number of satellites,**

N_{Epo} **– number of epochs in a day,**

$\mathbf{x}_{i,k,n}^j$ **– position of j-th satellite as it was estimated by i-th Center in k-th day at n-th epoch.**

$\Delta\mathbf{x}_{i,k,n}^j$ **– residual vector:** $\Delta\mathbf{x}_{i,k,n}^j = \mathbf{x}_{exect,k,n}^j - \mathbf{x}_{i,k,n}^j$ **where** $\mathbf{x}_{exect,k,n}^j$ **– exact solution (unknown).**

Theorem.* *Let the following conditions be satisfied

1. RMS calculated for the period in N days for each of the Centers, asymptotically (at N sufficiently large) are equal to each other.

2. In k-th day and n-th epoch the position vector for combined orbit of j-th satellite represents a weighted average (with weights $W_{i,k}$***) of satellite's positions as determined by the Centers:***

$$\mathbf{x}_{comb,k,n}^j = \sum_{i=1}^{N_{Cent}} \mathbf{x}_{i,k,n}^j \cdot W_{i,k}$$

3. The weights $W_{i,k}$ ***are related for each k with residual mean squared*** $RMS_{i,k} = \sqrt{\dfrac{1}{3N_{Epo}N_{Sat}} \sum_{j=1}^{N_{Sat}} \sum_{n=1}^{N_{Epo}} \left\| \Delta\mathbf{x}_{i,k,n}^j \right\|^2}$ ***by monotonely decreasing dependence.***

Then RMS for the combined orbit calculated for the period in N days is no greater then RMS for each of the Centers.