РОСКОСМОС

ГЛОБАЛЬНАЯ НАВИГАЦИОННАЯ СПУТНИКОВАЯ СИСТЕМА ГЛОНАСС

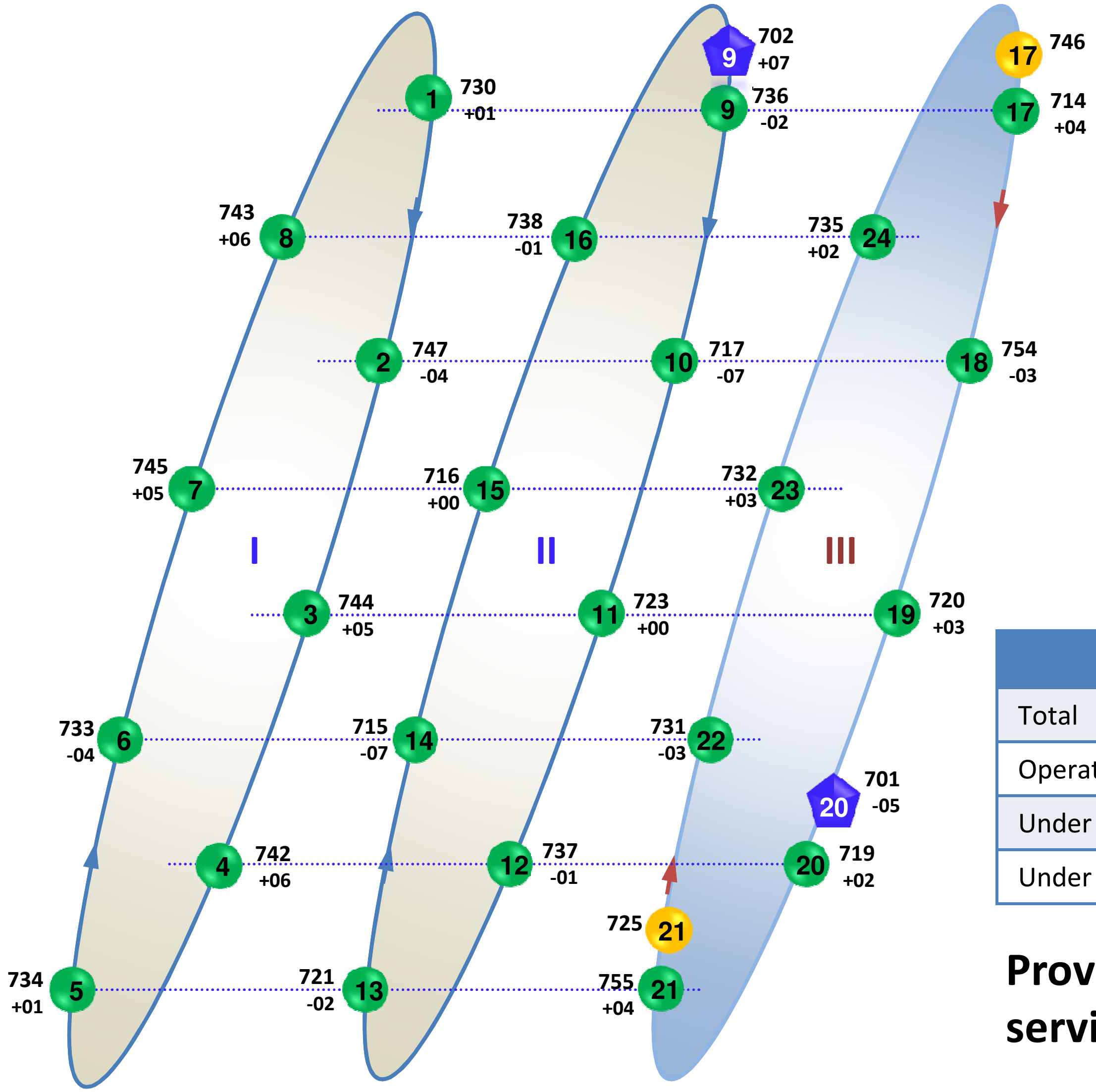
РЕШЕТНЕВ
А О «И С С»

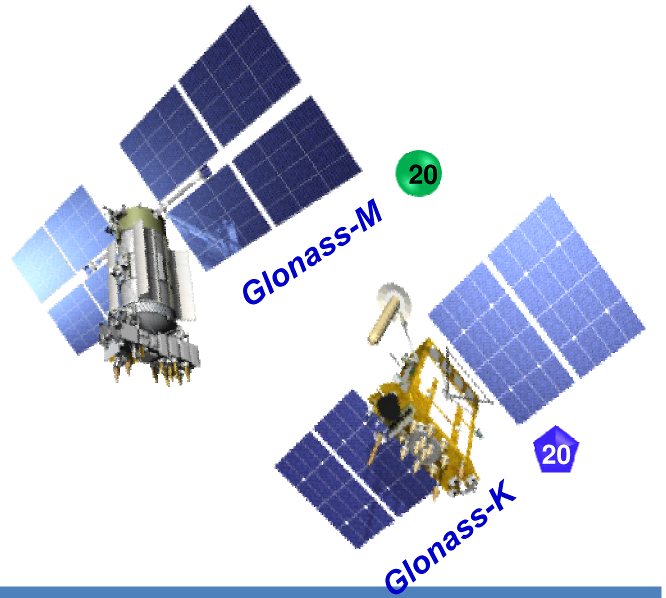
GLONASS-M Satellite Geometry and Attitude Models for Precise GNSS Data Processing

2015 ILRS Technical Workshop

РЕШЕТНЕВ
АО «ИСС»

GLONASS Constellation Status

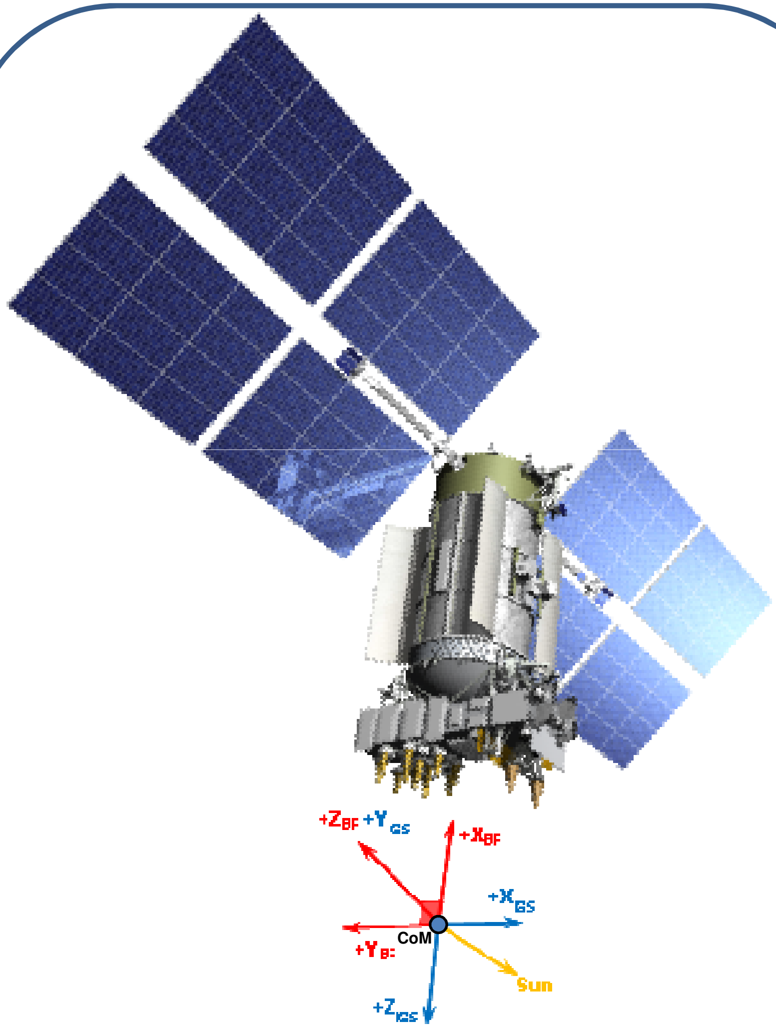


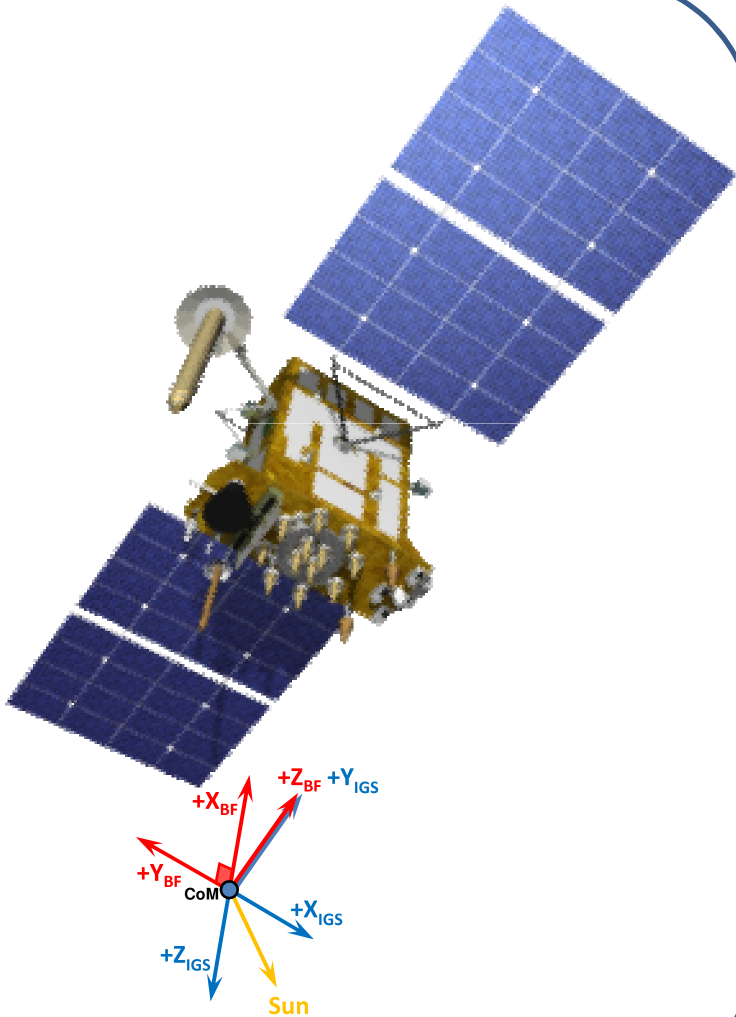


Status as of Oct. 24, 2015.	
Total	28 S/Cs
Operational (Glonass-M)	23 S/Cs
Under flight test (Glonass-K1)	2 S/Cs
Under investigation (Glonass-M)	3 S/Cs

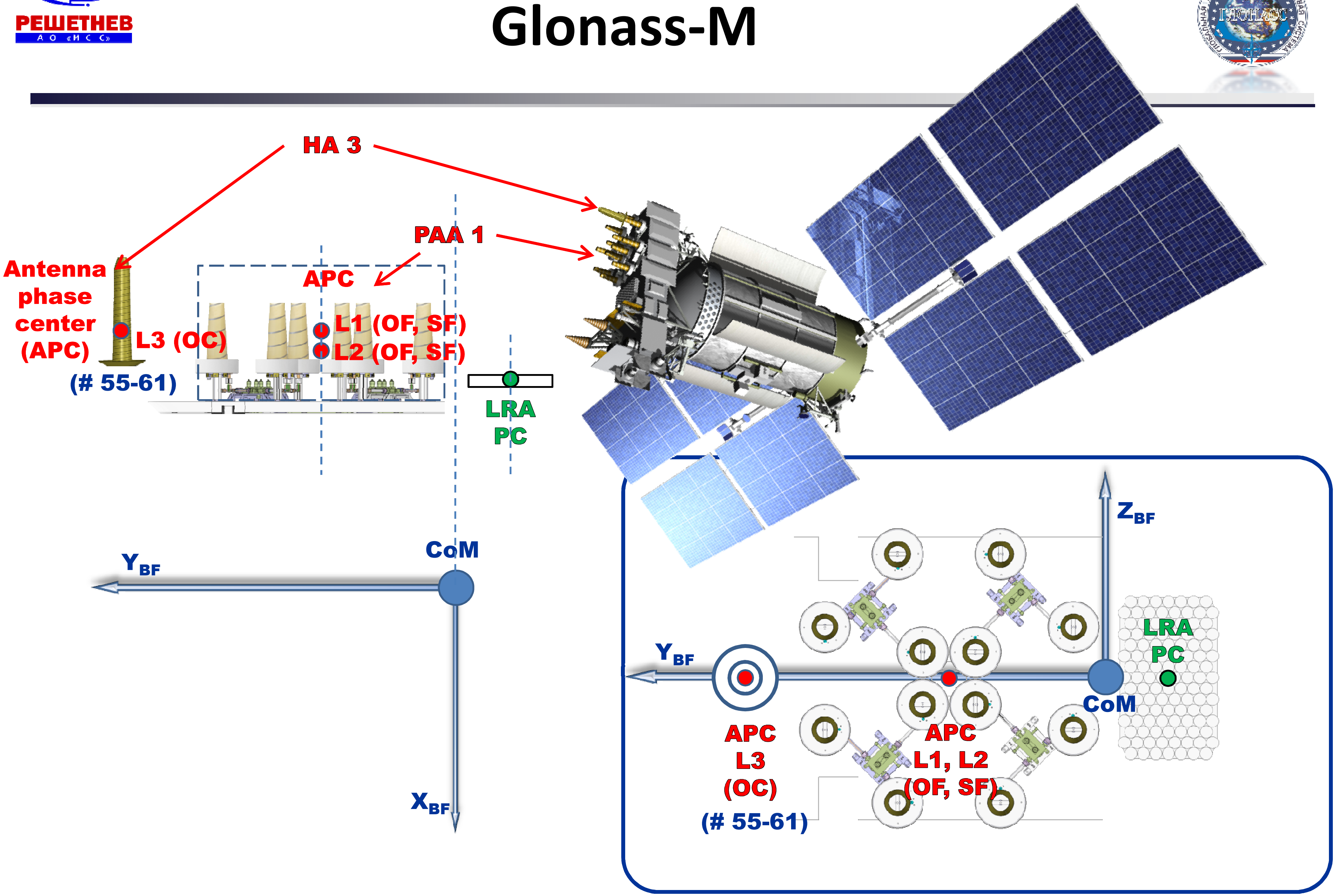
Provides L1 and L2 FDMA open access service

Satellite body-fixed coordinate system





Glonass-M


HA 3
PAA 1
Antenna phase center (APC)
L3 (OC)
(# 55-61)
APC
L1 (OF, SF)
L2 (OF, SF)
LRA PC
CoM
Y_{BF}
X_{BF}
Z_{BF}
Y_{BF}
LRA PC
CoM
APC L3 (OC)
(# 55-61)
APC L1, L2 (OF, SF)

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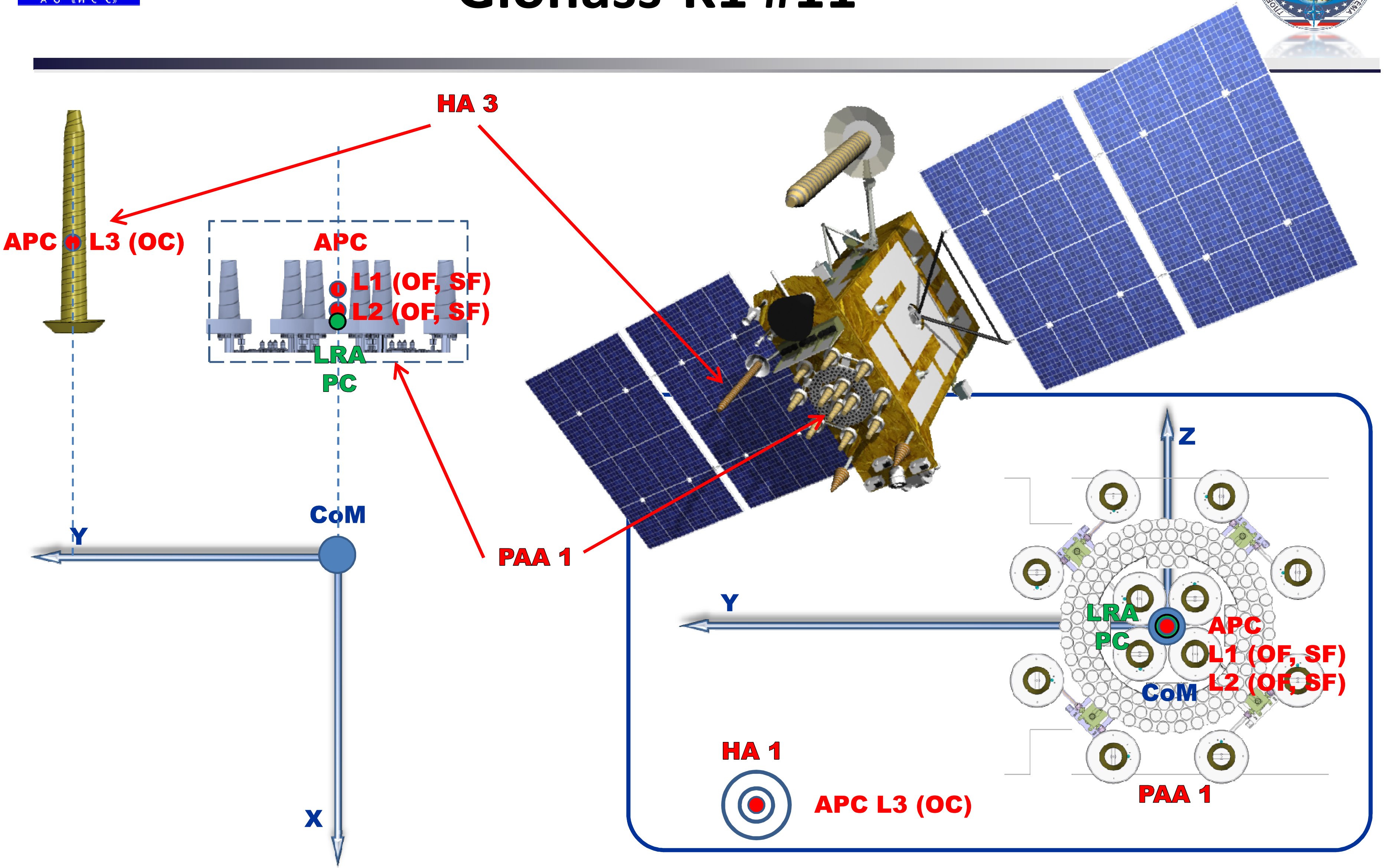
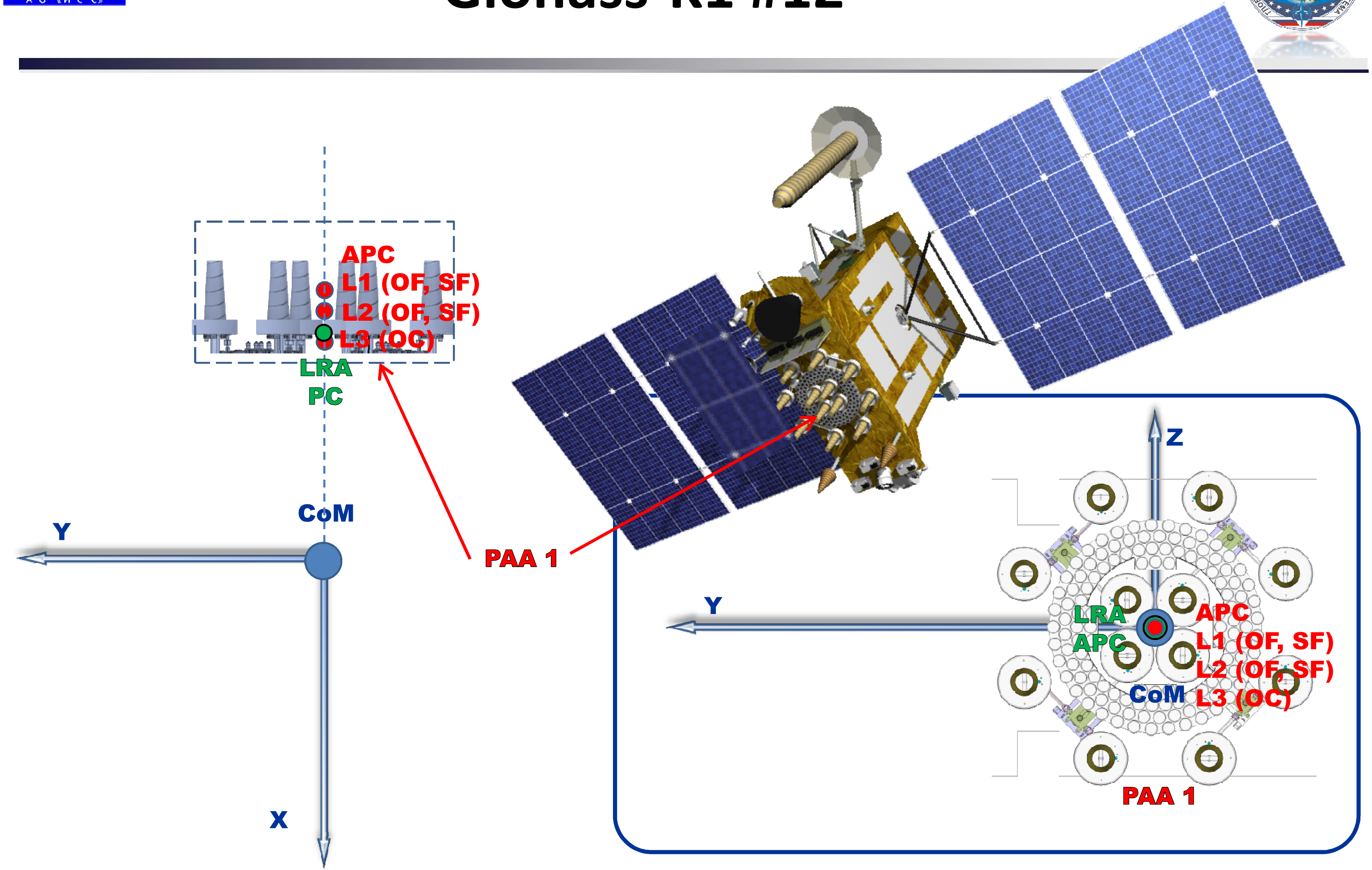
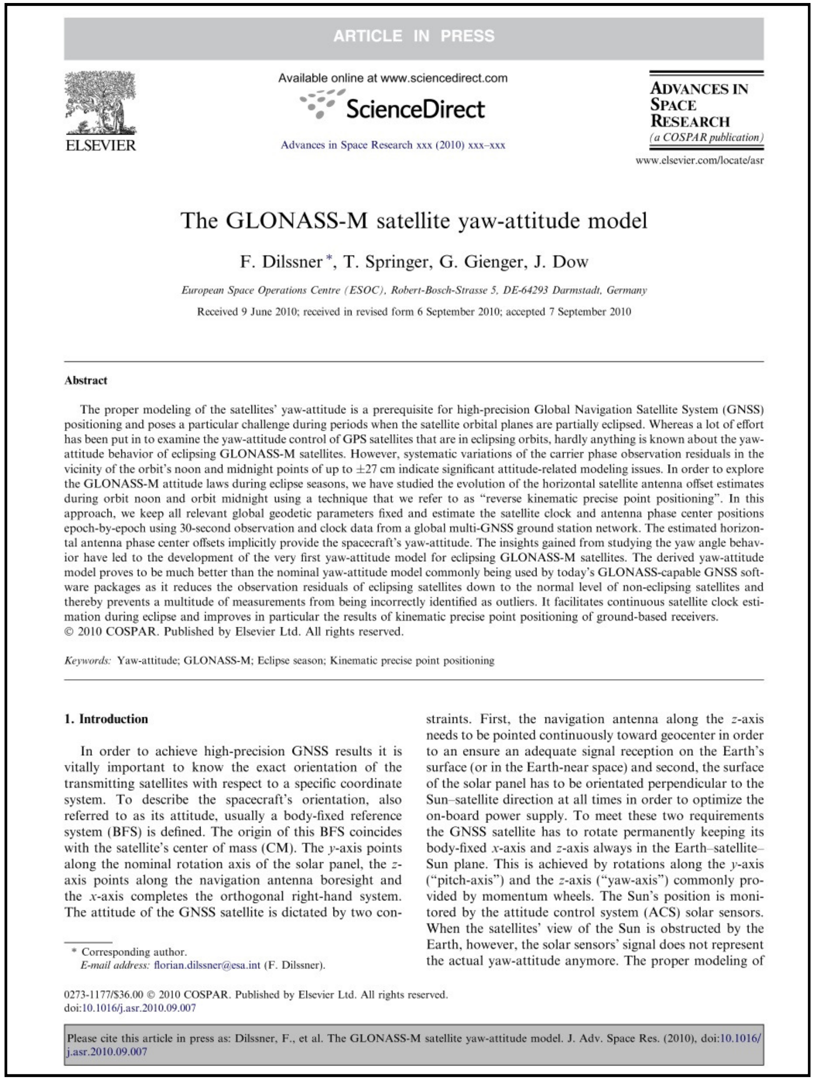
Glonass-K1 #11



Glonass-K1 #12





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The GLONASS-M satellite yaw-attitude model

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Abstract

The proper modeling of the satellites' yaw-attitude is a prerequisite for high-precision Global Navigation Satellite System (GNSS) positioning and poses a particular challenge during periods when the satellite orbital planes are partially eclipsed. Whereas a lot of effort has been put in to examine the yaw-attitude control of GPS satellites that are in eclipsing orbits, hardly anything is known about the yaw-attitude behavior of eclipsing GLONASS-M satellites. However, systematic variations of the carrier phase observation residuals in the vicinity of the orbit's noon and midnight points of up to ±27 cm indicate significant attitude-related modeling issues. In order to explore the GLONASS-M attitude laws during eclipse seasons, we have studied the evolution of the horizontal satellite antenna offset estimates during orbit noon and orbit midnight using a technique that we refer to as "reverse kinematic precise point positioning". In this approach, we keep all relevant global geodetic parameters fixed and estimate the satellite clock and antenna phase center positions epoch-by-epoch using 30-second observation and clock data from a global multi-GNSS ground station network. The estimated horizontal antenna phase center offsets implicitly provide the spacecraft's yaw-attitude. The insights gained from studying the yaw angle behavior have led to the development of the very first yaw-attitude model for eclipsing GLONASS-M satellites. The derived yaw-attitude model proves to be much better than the nominal yaw-attitude model commonly being used by today's GLONASS-capable GNSS software packages as it reduces the observation residuals of eclipsing satellites down to the normal level of non-eclipsing satellites and thereby prevents a multitude of measurements from being incorrectly identified as outliers. It facilitates continuous satellite clock estimation during eclipse and improves in particular the results of kinematic precise point positioning of ground-based receivers.

Keywords: Yaw-attitude; GLONASS-M; Eclipse season; Kinematic precise point positioning

1. Introduction

In order to achieve high-precision GNSS results it is vitally important to know the exact orientation of the transmitting satellites with respect to a specific coordinate system. To describe the spacecraft's orientation, also referred to as its attitude, usually a body-fixed reference system (BFS) is defined. The origin of this BFS coincides with the satellite's center of mass (CM). The *y*-axis points along the nominal rotation axis of the solar panel, the *z*-axis points along the navigation antenna boresight and the *x*-axis completes the orthogonal right-hand system. The attitude of the GNSS satellite is dictated by two constraints. First, the navigation antenna along the *z*-axis needs to be pointed continuously toward geocenter in order to an ensure an adequate signal reception on the Earth's surface (or in the Earth-near space) and second, the surface of the solar panel has to be orientated perpendicular to the Sun–satellite direction at all times in order to optimize the on-board power supply. To meet these two requirements the GNSS satellite has to rotate permanently keeping its body-fixed *x*-axis and *z*-axis always in the Earth–satellite–Sun plane. This is achieved by rotations along the *y*-axis ("pitch-axis") and the *z*-axis ("yaw-axis") commonly provided by momentum wheels. The Sun's position is monitored by the attitude control system (ACS) solar sensors. When the satellites' view of the Sun is obstructed by the Earth, however, the solar sensors' signal does not represent the actual yaw-attitude anymore. The proper modeling of

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The GLONASS-M satellite yaw-attitude model

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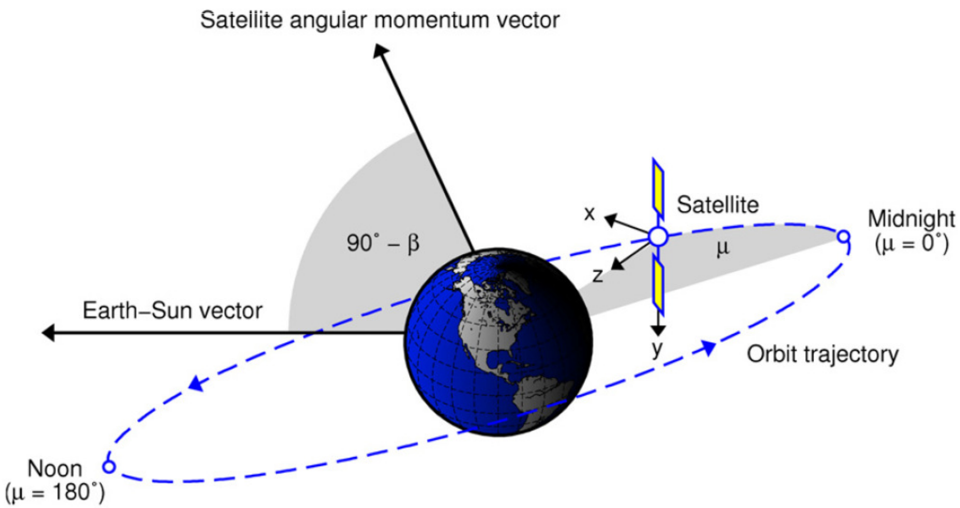

Thank You for your attention!

РЕШЕТНЕВ
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GNSS Satellite Geometry and Attitude Models

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Abstract

This article discusses the attitude modes employed by present Global (and Regional) Navigation Satellite Systems (GNSSs) and the models used to describe them along with definitions of the constellation-specific spacecraft body frames. For use within the International GNSS Service (IGS), a harmonized convention for the labeling of the principal spacecraft axes is introduced, which results in a common formulation of the nominal attitude of all GNSS satellites in yaw-steering mode irrespective of their specific orbit and constellation. The conventions defined within this document provide the basis for the specification of antenna phase center offsets and variations in a multi-GNSS version of the absolute IGS phase center model in the ANTEX (antenna exchange) format. To facilitate the joint analysis of GNSS observations and satellite laser ranging measurements, laser retroreflector array coordinates consistent with the IGS-specific spacecraft frame conventions are provided in addition to representative antenna offset values for all GNSS constellations.

Keywords: GNSS Satellites, Attitude Models, Antenna Offsets, ANTEX, SLR

1. Introduction

The geometry and orientation (or, "attitude") of navigation satellites are critical information for the processing of observations from Global (and Regional) Navigation Satellite Systems (GNSSs) in precise orbit determination and precise point positioning (PPP) applications (Kouba and Héroux, 2001). While orbit information is typically referred to the spacecraft center-of-mass (CoM), the navigation signals emerge from an antenna at a different location. The antenna position relative to the CoM, or, more generally, the phase center offsets (PCOs) and variations (PCVs; Schmid et al., 2005, 2007), are naturally specified in a body-fixed spacecraft coordinate system. Based on the CoM location and the orientation of the body axes relative to a terrestrial or celestial reference frame, the actual antenna position can be described in the required reference frame. The same considerations apply for the location of laser retroreflector arrays (LRAs), which are used on numerous navigation satellites for the purpose of satellite laser ranging (SLR).

Knowledge of the spacecraft attitude is also important to account for the so-called phase wind-up effect (Wu et al., 1993), which describes the variation of the measured carrier-phase range with changes in the relative alignment of the receiver and transmitter antenna. Finally, the spacecraft attitude needs to be known when modeling solar radiation pressure, since the resulting acceleration depends directly on the orientation of the satellite body and the solar panels with respect to the incident radiation (Rodriguez-Solano et al., 2012).

Within the International GNSS Service (IGS; Dow et al., 2009), precise orbit and clock products for the United States' Global Positioning System (GPS) and the Russian Globalnaja Nawigazionnaja Sputnikowaja Sistema (GLONASS) are routinely generated as a basis for a wide range of scientific and engineering applications. For proper use of these products, a consistent description of the spacecraft geometry and attitude is required. Concerning the modeling of satellite antenna PCOs and PCVs, consistency between product generation and application is commonly achieved through standardized values for the antenna parameters (provided in IGS models in the antenna exchange format ANTEX; Rothacher and Schmid, 2010) and the assumption of a nominal body orientation outside the eclipse region. However, a clear attitude definition and reference are likewise critical for phase wind-up corrections when aiming at single-receiver ambiguity fixing in precise point positioning (Teunissen and Khodabandeh, 2015).

In case of GPS and GLONASS, standardization within the IGS has largely been facilitated through the fact that the individual satellites employ similar attitude control laws and enable a harmonized description after aligning the designation of the principal spacecraft axes. With the advent of new GNSSs,

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GNSS Satellite Geometry and Attitude Models

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Recommendation for Committee Decision (WG-D # 23)

Prepared by: Working Group D

Date of Submission: 13 November 2014

Issue Title: Improving the accuracy of multi-GNSS orbits determination by the IGS

Background/Brief Description of the Issue:

Considering
- several global navigation satellite systems (GNSS) exist and that each is continuously expanding and improving,
- the importance of improving the ITRF defining parameters for earth science and positioning applications
- the importance of the GNSS contribution to the ITRF from the IGS,
- the importance of the accuracy of the GNSS orbits determined by the IGS and their impact on the IGS products, and subsequently on the ITRF;
- the necessity of improving the orbit dynamics modelling of GNSS satellites by the IGS

Discussion/Analyses:

The knowledge of GNSS satellite structure, geometry, dimensions, among other satellite data is fundamental to improving orbit modeling and accuracy.

Recommendation of Committee Action:

The ICG WG-D recommends that the GNSS Providers consider the possibility of making available the following list (or a sub-set) of satellite data for better orbit dynamics modeling:

Primary list:
- *Surface geometry and dimensions*
- *Surface optical properties (or material types)*
- *Nominal attitude model*
- *Transmitted power in all signals (and direction if relevant)*
- *Solar panel construction information (thickness, conductivity, power draw)*
- *Position and power output of radiators*
- *Thermal properties of multi-layered insulation*

More detailed list:
- *Structural data/drawings of the satellite, with dimensions (surface only – we don't need the internals)*
- *Optical properties (reflectivity, specularity) of the surface materials*
- *Identification of what is covered in multi-layered insulation (MLI) or 'thermal blankets'*

- *Attitude model of the satellite*
- *Power of all transmitted signals (note we don't need to know anything about function of the signals, only which way they are pointed, and how much power is transmitted)*
- *Construction data of the solar panel (material types, thickness, conductivity, surface properties – reflectivity, specularity, emissivity, power draw from the panel)*

Other necessary information:
- *Centre of mass location*
- *Change of centre of mass over time (manoeuvres)*
- *Location of antenna reference point*
- *Phase centre offset for all frequencies w.r.t. antenna reference point*
- *Phase centre variation as function of azimuth and elevation*
- *Knowledge about the epoch of change of the attitude mode (e.g. for QZSS and BeiDou that switch from Yaw-steering to normal-mode)*
- *Attitude of the satellite as measured/computed on board (i.e. those values used by the attitude control system)*
- *Differential group delays between the different signals (on board of the satellite): can be measured pre-launch*