Multi-GNSS and other science issues in the IGS

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based on material provided by
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300 N Harbor Drive
California, Cal 90277
USA

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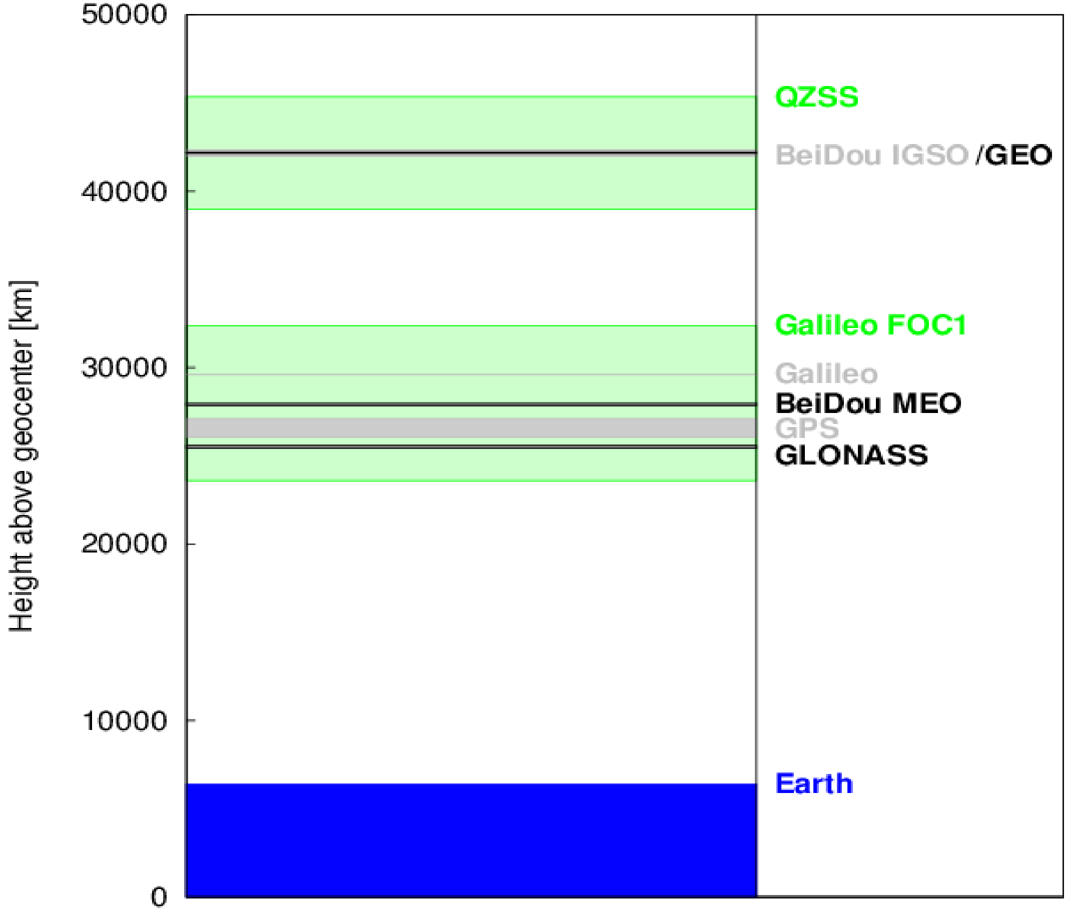
- Status of GNSS, November 2017: Approaching the state of 3+ fully deployed systems
- Endorsement of IGS activities by PNT and the IGS White Paper on GNSS metadata.
- Effect of metadata on orbit quality
- [Earth Rotation Parameters (ERPs) from GPS and GLONASS and from GLONASS-like GPS-sub-systems]

GNSS Status, November 2017



83 GNSS & RNSS satellites (w/o GEOs) are routinely analyzed at CODE and other IGS ACs.

The satellites have different characteristics (semi-major axes *a*, eccentricities *e*, inclinations *i*) and different signals, tracking modes.

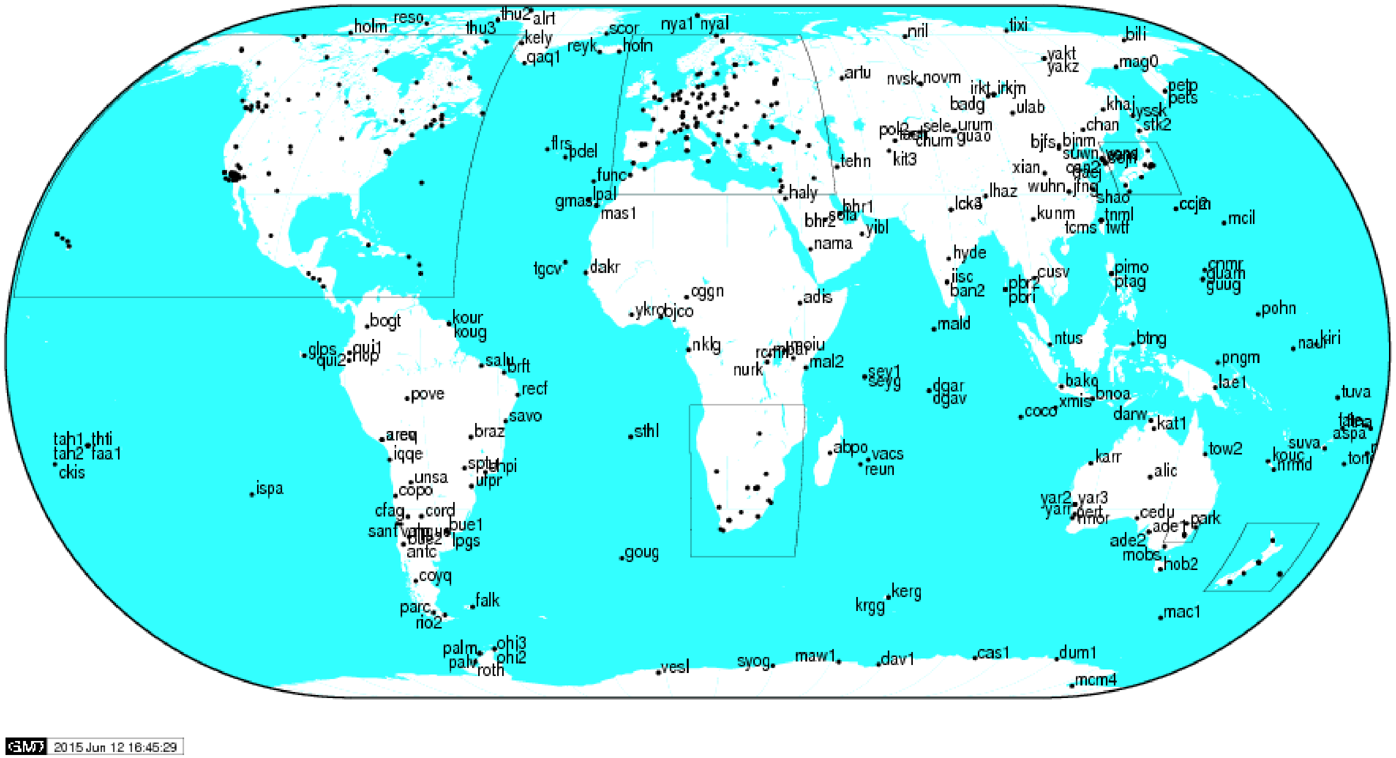
QZS-1,-2,-4 and Galileo FOC-1,-2 satellites are in elliptical orbits ($e \approx 0.075$, $e \approx 0.16$, respectively)

Currently, there are 31 satellites in the GPS constellation, 24 in GLONASS, 17 in Galileo, 9 in Beidou-2 (3+6*), 2 in QZSS.

***) plus five GEOs, + 7 sats in Beidou-3**

Galileo approaches full constellation in 2018/19 time frame, 2 more satellites in QZSS become available soon.

IGS: Monitoring the Earth with GNSS



The IGS network: The International Terrestrial Reference Frame (ITRF) is based on hundreds of permanent GNSS sites and on tens of SLR and VLBI sites (positions within 1 cm, velocities within 1 mm/year).

The IGS currently tracks all GNSS.

IGS Endorsement by PNT

On June 29, 2017, at its 19th meeting, the Advisory Board adopted the following endorsement:

- ***The PNT Advisory Board takes note of the IGS White Paper on 'Satellite and Operation information for the Generation of Precise GNSS Orbit and Clock Products' and endorses it as a minimum set of information required for the highest accuracy of GNSS applications, and encourages the open sharing of technical information on GNSS important to the international scientific community consistent with national security and intellectual property constraints.***

On behalf of the IGS I would like to thank the PNT advisory board for this endorsement of IGS activities.

IGS White Paper on GNSS

The IGS White Paper on

Satellite and Operations Information for the Generation of Precise GNSS Orbit and Clock Products

by Oliver Montenbruck

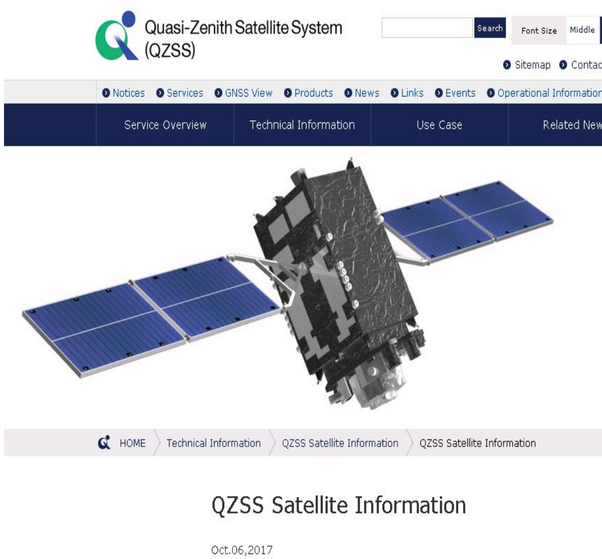
is now available in the IGS knowledge base under

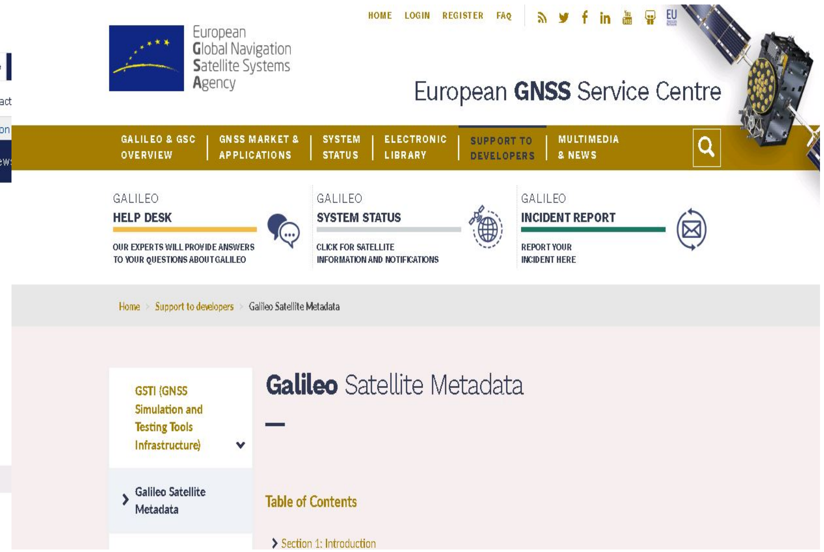
http://kb.igs.org/hc/en-us/articles/115000802772

- The paper is a living document. Its most recent version documents the latest release of metadata for QZSS and Galileo.

Impact of satellite metadata on POD

Missing satellite metadata is a limiting factor for accuracy of estimated orbits and clocks, therefore the disclosure of …





Galileo IOV (Dec. 2016) and FOC (Oct. 2017) metadata by the GSA

QZS-1 and QZS-2 information by JAXA in several steps in 2017

… is very much appreciated!

Impact of satellite meta data on POD

Test	Galileo					QZS-1		
Name	Al-bedo	Ant. Thr.	Atti-tude	Pulses	Median SLR [cm]	Albedo	AntThr. (244 W)	Median SLR [cm]
OPER	-	-	-	-	-3.8 (-+4.5)	-	-	-7.8
ALB1	x	-	-	-	-2.0	m= 1800 kg	-	-2.6
AAT1	x	260 W	-	-	+0.6	m= 1800 kg	m= 1800 kg	+0.3
AAT2	x	130 W	-	-	-0.7	m= 3600 kg	m= 3600 kg	-3.7
EAT	x	200 W	x	-	0.0	m= 1950 kg	m= 1950 kg	-0.3
EATP	x	200 W	x	R, S, W; 12h	+0.6	m= 1950 kg	m= 1950 kg	-0.3
EATU (upd...)	x	I: 130 W F:200 W	X	-	-0.2 (-+4.6)	m= 2000 kg	m= 2000 kg	-1.8
EATUP (…BW)	x	I: 130 W F:200 W	X	R, S, W; 12h	+0.5 (-+3.5)	m= 2000 kg	m= 2000 kg	-1.6 (w. PLS)

Impact of satellite meta data on POD

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AAT1	x	260 W	-	-	+0.6	m= 1800 kg	m= 1800 kg	+0.3
AAT2	x	13			-0.7	m=	m=	-3.7
EAT	x	200 W	x	-	0.0			-0.3
EATP	x	200 W	x	R, S, W; 12h	+0.6			-0.3
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Impact albedo: +1.8 cm

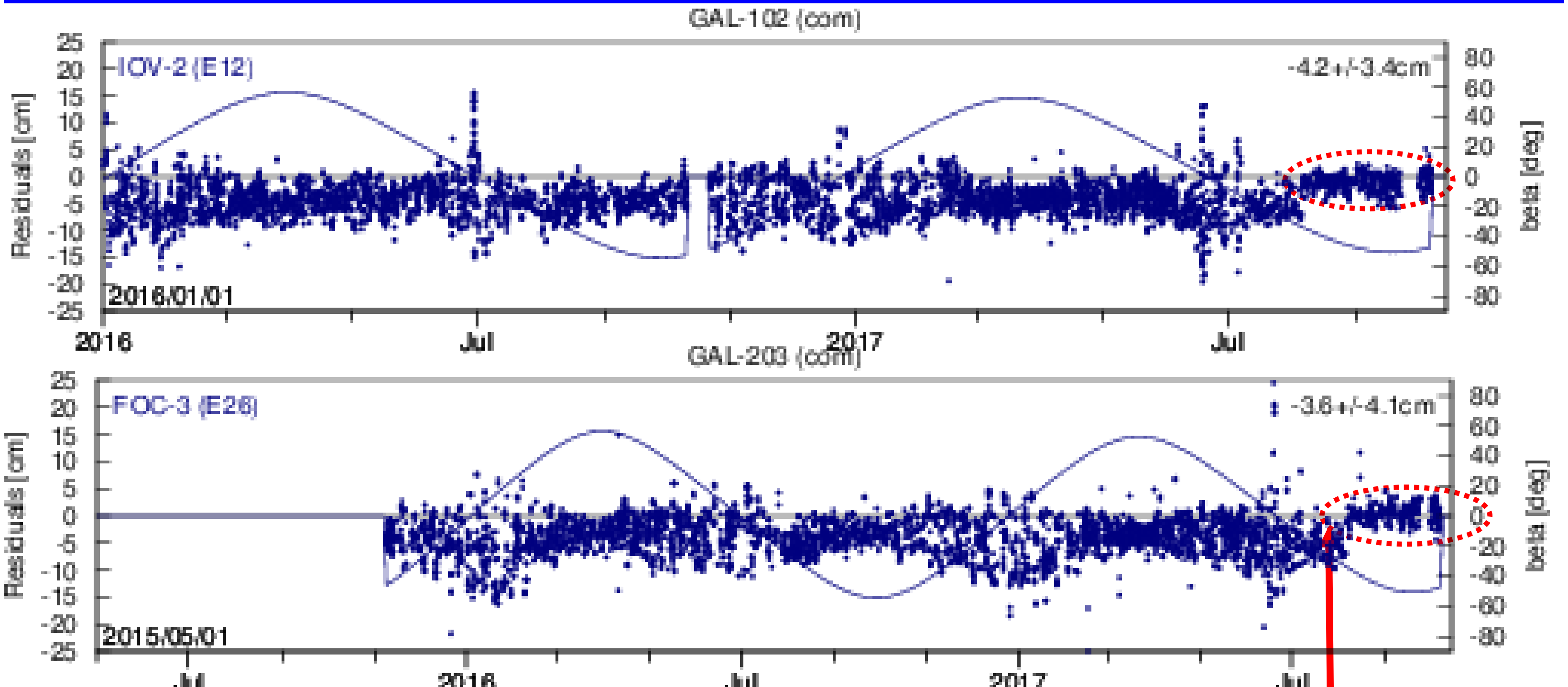
Impact antenna thrust: 1 cm/100 W

Impact SC mass: 2.2 cm/1000 kg

(macro model over-scaled)

Pulses might shift the SLR offset

Impact of satellite metadata on POD



(SLR validation provided by the IGS MGEX: http://mgex.igs.org)

Model changes active in CODE MGEX solution since GPSWEEK 1962

Orbit improvement confirmed by external validation

IGS White Paper on GNSS

Item	Type	Used for	Desired properties	Relevance	Availability of provider information
Mass	S/C	Modeling of non-gravitational forces (radiation pressure, Earth radiation pressure, antenna thrust)	Accuracy 0.1-1.0% (1-10kg)	High	GAL,QZS
	OPS		Variation over time	Low	GAL,(QZS)
Center-of-mass (in s/c frame)	S/C	Modeling of antenna and laser reflector coordinates relative to the reference point of all orbit products	0.1-1.0 cm in all axes	High	GLO,GAL,QZS,(BDS)
	OPS		Variation over time	Low	GAL,(QZS)
Laser reflector position in (s/c frame)	S/C	Modeling of satellite laser ranging observations	0.1-1.0 cm	High	GLO,BDS,GAL,QZS,IRS
GNSS antenna phase center location (in s/c frame)	S/C	Modeling of the effective point of signal emission	1 cm; to be supplied for each individual antenna and signal frequency	High	(GPS),(GLO),GAL,QZS
			Direction dependent phase center variations (1 mm)	Medium	(GPS),GAL,QZS
Panel model	S/C	Modeling of solar and Earth radiation pressure	Dimension of solar panels (1-10%) Dimensions of satellite body (six surfaces, 1-10%) Optical properties (absorption, specular and diffuse reflection; 1-5%) Distance of panels from body (for BeiDou and QZSS)	High	GAL,QZS
			CAD model (coarse; for complex structures with relevant shading)	Low/ Medium	-
Radiated antenna power	S/C	Modelling of antenna thrust	Accuracy 20W	Low	(QZS)
	OPS		Variation over time	Low	-
Attitude	S/C	Modelling of antenna offset, phase wind-up and radiation pressure	Nominal attitude law outside eclipses (1-2 deg)	High	GPS,GLO,BDS, GAL,QZS,IRS
	S/C, OPS		Attitude during noon and midnight turns in the eclipse season	High	(GPS),(GLO),GAL
	OPS		Epochs of mode transition (yaw steering vs normal mode; for BeiDou and QZSS)	High	(QZS)
Orbit maneuvers	OPS	Modeling of orbit discontinuities	Time (5s) and Delta-V (0.1-1cm/s)	High (BDS) Medium (others)	(QZS)

GPS is currently "gold standard" in science. To maintain this position, official values concerning antenna phase center (frequency dependent) & panel model are necessary from the GPS, as well. Official confirmation of mass and attitude models matters, as well.

Summary

Metadata for Galileo and QZSS improve orbits (and most likely the quality of other parameters).

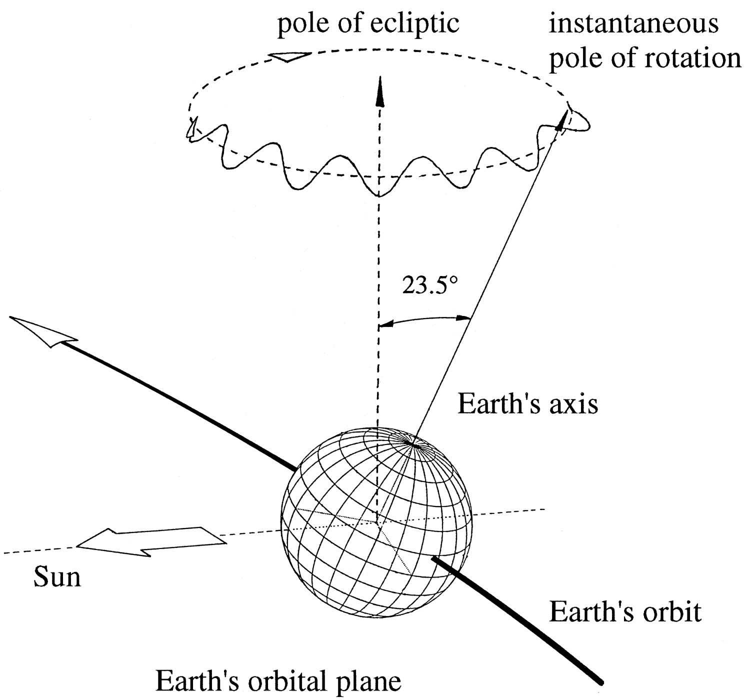
→ Metadata are not a luxury, but a "must" for scientific GNSS application.

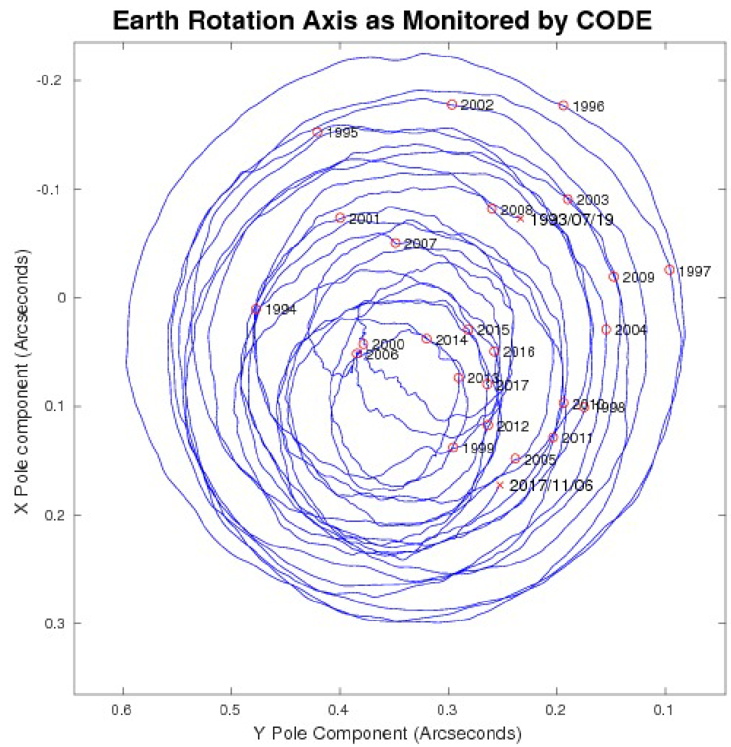
Laser reflectors are badly needed, as well, in particular for validating orbit quality, ERP quality, etc.

Currently 80+ satellites are routinely tracked by the IGS-MGEX.

Earth Rotation Parameters (ERPs)

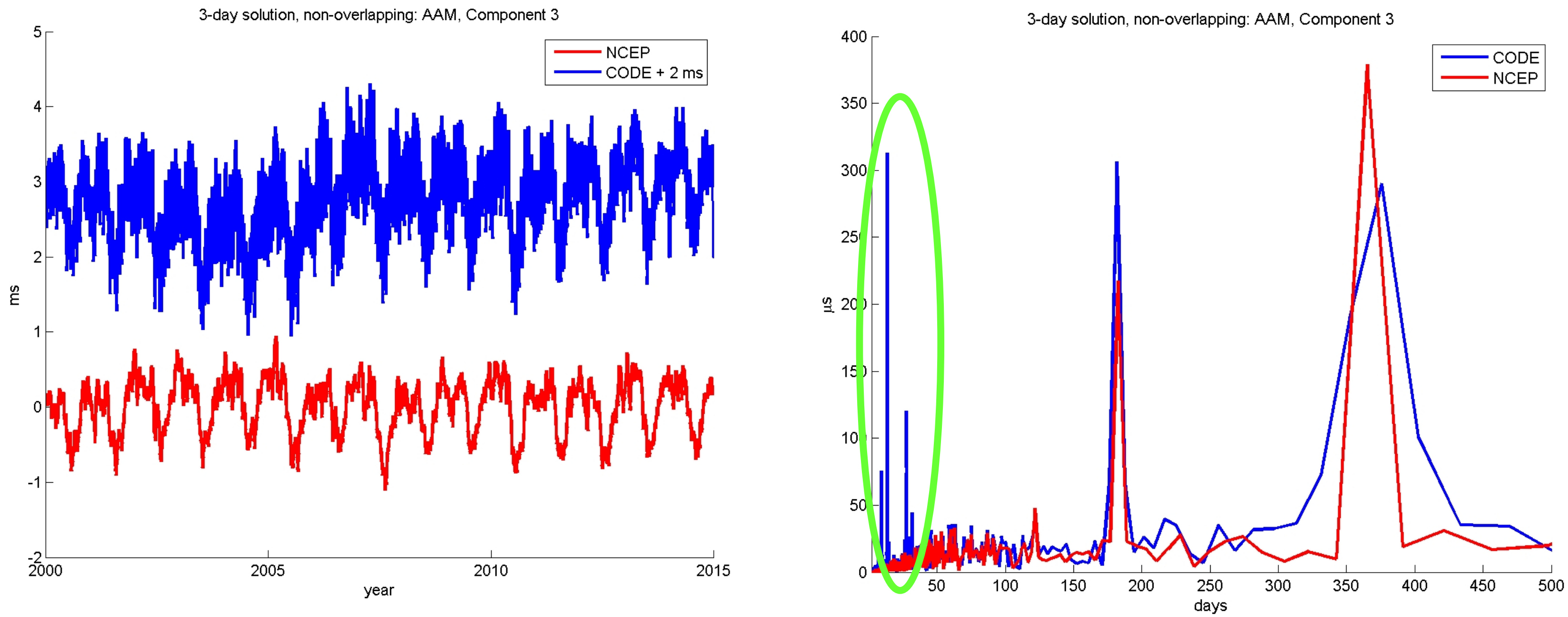
The Earth's rotation axis in inertial space





Left: motion of the Earth' pole in inertial space
Right: polar motion on Earth's surface (1994.25-2017.83); 1" ≈ 30 m

Earth Rotation Parameters (ERPs)



Left: Length of day differences w.r.t. mean sidereal day, derived from GNSS (blue) and from meteorological data (red). Right: corresponding spectra.

Annual, semi-annual, 1/3-annual lines due to momentum exchange between solid Earth and Atmosphere, 14- and 27-day lines in GNSS spectrum due to tidal effects.

→ Periodic motion due to well-defined forces. So far so good …

Earth Rotation Parameters (ERPs)

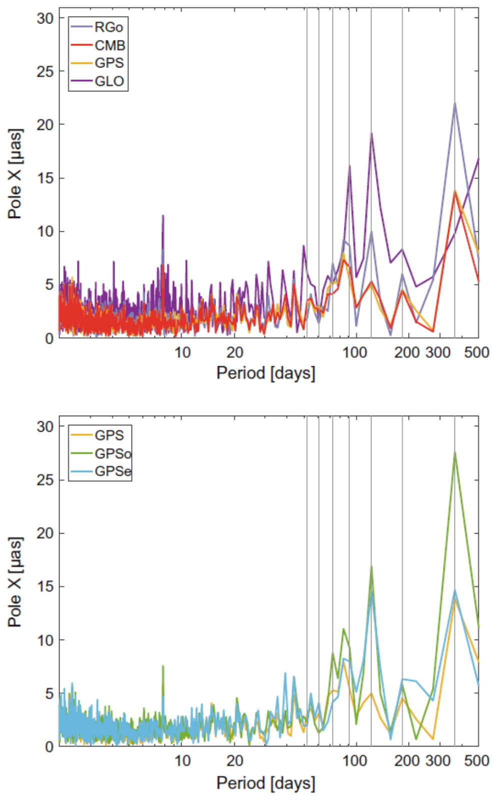


Fig. 10 Amplitude spectra of the differences of the pole x-coordinate to the corresponding IERS 08 C04 series from GPS, GLONASS, the combined solution and RGo (*top*) and from GPS, GPSo and GPSe (*bottom*)

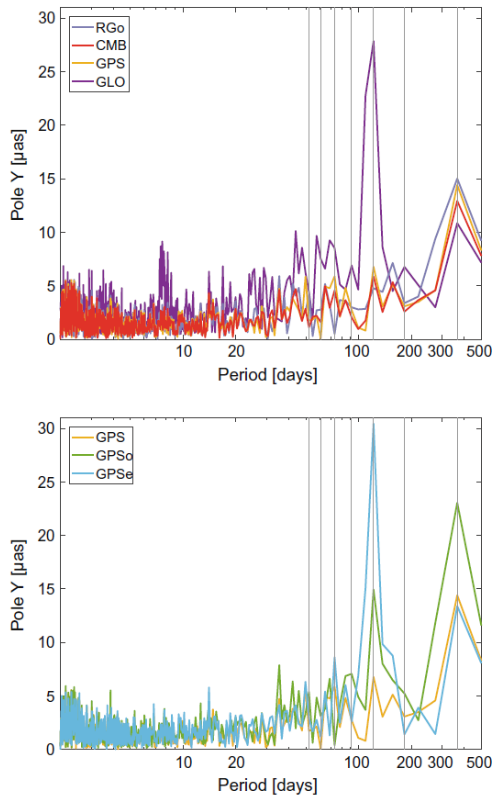


Fig. 11 Amplitude spectra of the differences of the pole y-coordinate to the corresponding IERS 08 C04 series from GPS, GLONASS, the combined solution and RGo (*top*) and from GPS, GPSo and GPSe (*bottom*)

GLONASS spectra of polar motion show spurious spectral lines at 120 days, GPS does not.

When splitting up the GPS constellation into one consisting of the odd (o) and one of the even (e) orbital planes, GPSo and GPSe show similar effects (bottom figures).

Combining two 3-plane systems, e.g., GPSo & GLONASS (=RGo, top Figures), these effects are greatly mitigated.

Constellation matters, multi-GNSS can improve quality of GNSS ERPs.

Summary

Metadata for Galileo and QZSS improve orbits (and most likely quality of other parameters).

→ Metadata are not a luxury, but a "must" for scientific GNSS application.

Laser reflectors are badly needed, as well, in particular for validatng orbit quality, ERP quality, etc.

Galileo probably reaches operational status in 2018/19 time frame. It will be interesting to see Galileo-specific ERPs!

With GPS, Galileo, and GLONASS there will be three fully operational systems, which are capable to monitor independently the geodetic & geophysical parameters accessible to GNSS (ERPs, ITRF, ionosphere).

Currently 80+ satellites are routinely tracked by the IGS-MGEX.

Literature

O. Montenbruck (2017) ***IGS White Paper on Satellite and Operations Information for Generation of Precise GNSS Orbit and Clock Products.*** **IGS knowledge base http://kb.igs.org/hc/en-us/articles/115000802772**

L. Prange, A. Villiger, D. Sidorov, R. Dach, S. Schaer, G. Beutler, A. Susnik, A. Jäggi (2017) ***Impact of new background models on GNSS orbit determination.*** **6th International Colloquium – Scientific and fundamental aspects of GNSS/Galileo, October 2017, Valencia, Spain.**

S. Scaramuzza, R. Dach, G. Beutler, D. Arnold, A. Susnik, A. Jäggi (2017). ***Dependency of GNSS parameters on GNSS constellation.*** **Journal of Geodesy (online)**

The IGS

- The creation of the IGS was **initiated in 1989** with I.I. Mueller, G. Mader, B. Melbourne, and **Ruth Neilan** as protagonists
- The IGS became an **official IAG service** in 1994.
- The IGS first was a pure **GPS Service**, it was renamed as the **International GNSS Service** in 2004.
- Today the IGS is a truly **interdisciplinary, multi-GNSS service in support of Earth Sciences and Society**.
- Since its creation the **IGS Central Bureau** is located in the USA with **Ruth Neilan** as director – who stands for providing **continuity** and **leadership**.

IGS White Paper on GNSS Metadata

IGS White Paper on Satellite and Operations Information for Generation of Precise GNSS Orbit and Clock Products

O. Montenbruck on behalf of the IGS Multi-GNSS Working Group

Abstract

The International GNSS Service (IGS) provides precise orbit and clock solutions for GNSS satellites that support a wide range of science and engineering applications with numerous benefits for society at large. All IGS data and products are made freely available to the scientific community and the general public. To best fulfill its mission, the IGS depends on information from the GNSS providers concerning the characteristics of individual types of satellites as well as their operations. This white paper describes the parameters needed to ensure the highest possible performance of IGS products for all constellations and motivates the need for provision of satellite and operations information by the GNSS providers. All information requested by the IGS is considered to be sufficiently abstract such as to neither interfere with the GNSS providers' safety and security interests nor with intellectual property rights.

Montenbruck et al (2017) IGS White Paper on Metadata asking system providers for information concerning *mass, center of mass, antenna & reflector data, solar panels, radiated power, satellite attitude, and maneuvers*

→ *White paper was endorsed by PNT!*