GNSS for Positioning, Navigation, Timing, and Science

Gerhard Beutler
Astronomical Institute, University of Bern, Switzerland

19th International Workshop on Laser Ranging

October 27-31, 2014

Session 03: Science through Missions
Monday, October 27, 14^h10^m-14^h30^m
Governor Calvert House
Annapolis
USA

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- What can GNSS do for SLR?
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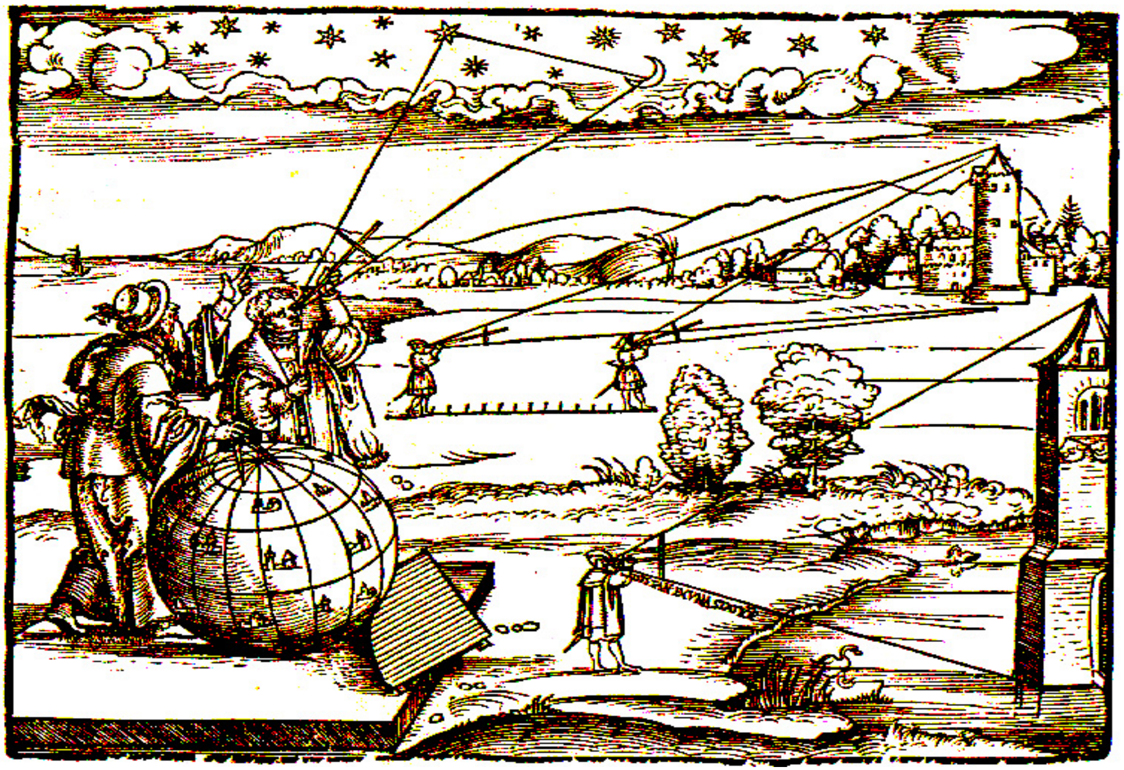
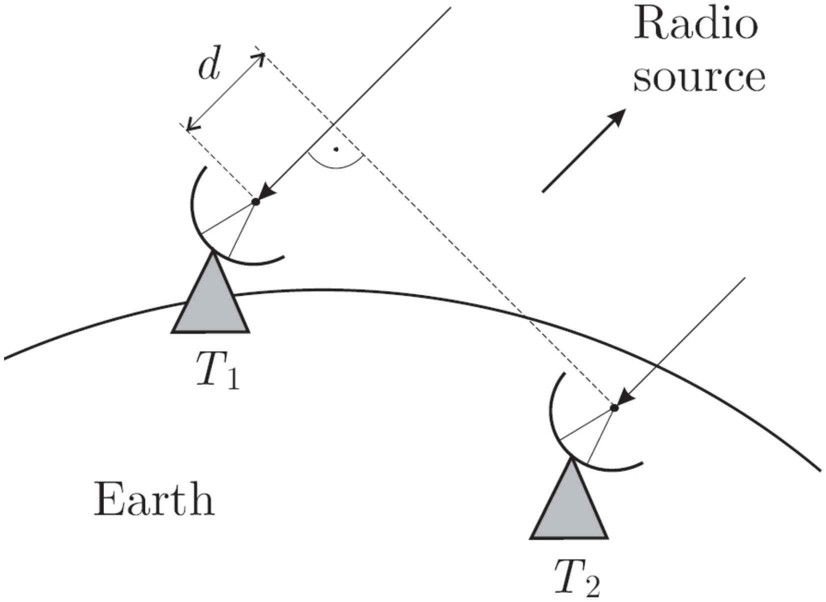
Positioning, Navigation, and Timing



Peter Apian's *Geographia* 1533

The problem is not really new …

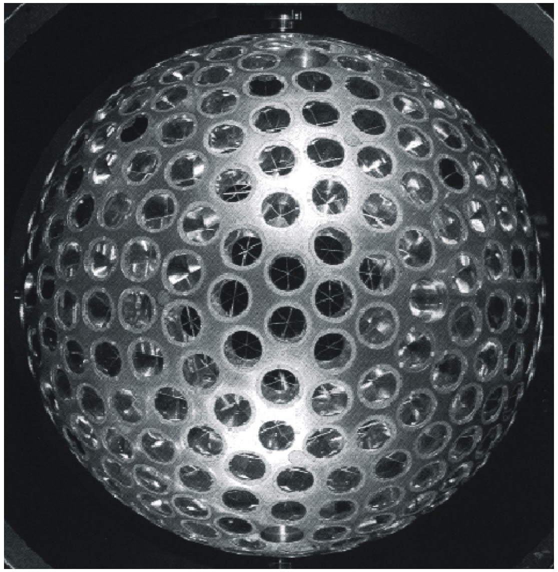
Space Geodesy: VLBI



Celestial reference frame is established by VLBI.

VLBI provides in addition precession, nutation *and UT1,* and contributes to the scale of the terrestrial network.

Space Geodesy: Laser Ranging



... SLR provides the origin of the terrestrial system, it contributes to the scale, Earth rotation, calibrates/validates GNSS orbits.

The ILRS (International Laser Ranging Service) provides measurements and products

Space Geodesy: GNSS

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GNSS = Global Navigation Satellite System

GNSS are the **working horses of space geodesy**

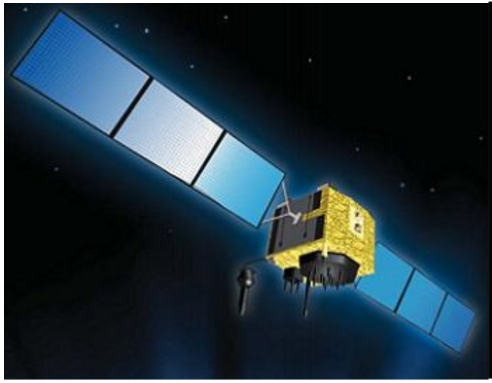
General perception:

- GNSS people should *densify* the global terrestrial *network* of stations provided by VLBI and SLR
- *but please do not try to get involved in science!*
- GNSS people do not even plan their own missions – they are abusing system designed for "real" use: *horribile dictu*!

GNSS today: the Satellites

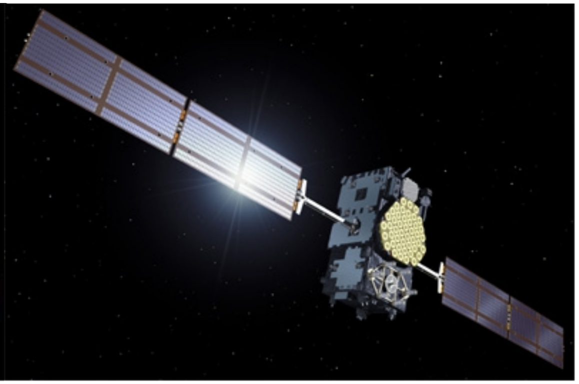
The GNSS satellites

- **Weight** ~ 1 ton
- **Size** ~ 2 x 2 x 2 meters
- **Panels' span** ~ 10 meters



GPS (Block IIF)

GLONASS (K)



Galileo (IOV)

Constellation Status (2014)

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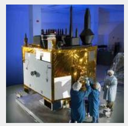
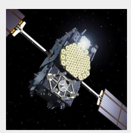
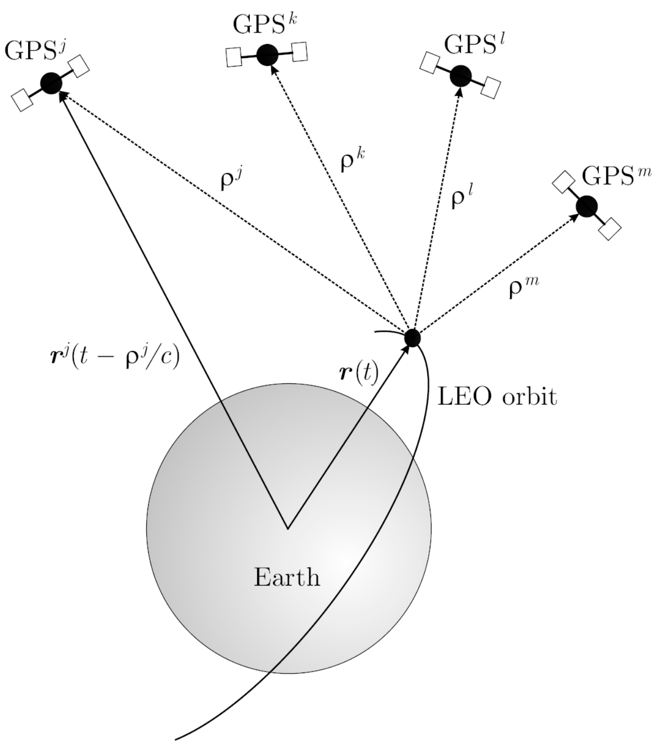
System	Blocks	Signals	Sats*)
GPS 	IIA	L1 C/A, L1/L2 P(Y)	8
	IIR-A/B	Same	12
	IIR-M	+L2C	7
	IIF	+L5	4(+1)
GLONASS 	M	L1/L2 C/A + P	24
	K	+L3	(1)
BeiDou 	GEO	B1, B2, B3	5
	IGSO	same	5
	MEO	same	4
Galileo 	IOV	E1, (E6), E5a/b/ab	(4)
QZSS 	IGSO	L1 C/A, L1C, SAIF L2C, E6 LEX, L5	1
IRNSS 	IGSO	L5, S	(2)

*) not yet declared healthy/operational

Positioning and Timing with GNSS



GNSS have been designed for use on the Earth's surface or in the Earth-near space.

Each satellite is equipped with a stable oscillator generating at least two coherent carriers. Code info is modulated on the carrier.

The travelling time of signals (and its changes in time) between the GPS satellite and the receiver are the basic measurements.

➔ With the speed of light *c* the distances ρ (and their time evolution) between satellite and receiver may be reconstructed.

The actual measurement is the pseudo-range:

Positioning: $c\,(t_r - t^s) = \rho + c\,(\Delta t_r - \Delta t^s) + \Delta\rho_I(\lambda) + \Delta\rho_t$

Science: $c\,(t_r - t^s) = \rho + c\,(\Delta t_r - \Delta t^s) + \Delta\rho_I(\lambda) + \Delta\rho_t$

For normal users (as opposed to scientists) the grey terms are assumed known

- $\rho = |r(t^s) - R(t_r)|$ is used to determine the **position** of the receiver $R(t)$ and the orbit $r(t)$ of the GNSS satellite.
- $c\,(\Delta t_r - \Delta t^s)$ for **synchronization** of space and ground clocks.
- $\Delta\rho_I(\lambda)$, the ionospheric delay, is used for **ionosphere modeling (space weather)**.
- $\Delta\rho_t$, the tropspheric delay, is used in **meteorology** (to determine the water vapor content of the atmosphere).

GNSS for everybody

$c\,(t_r - t^s) = p_r^s = \rho(x,y,z) + c\,\Delta t_r$

→

take (at least) four satellites, solve for

$x, y, z, \Delta t_r$

When trying to find addresses in foreign cities, a GNSS-based navigation system may save your life or *at least your marriage*.

GNSS for (almost) everybody

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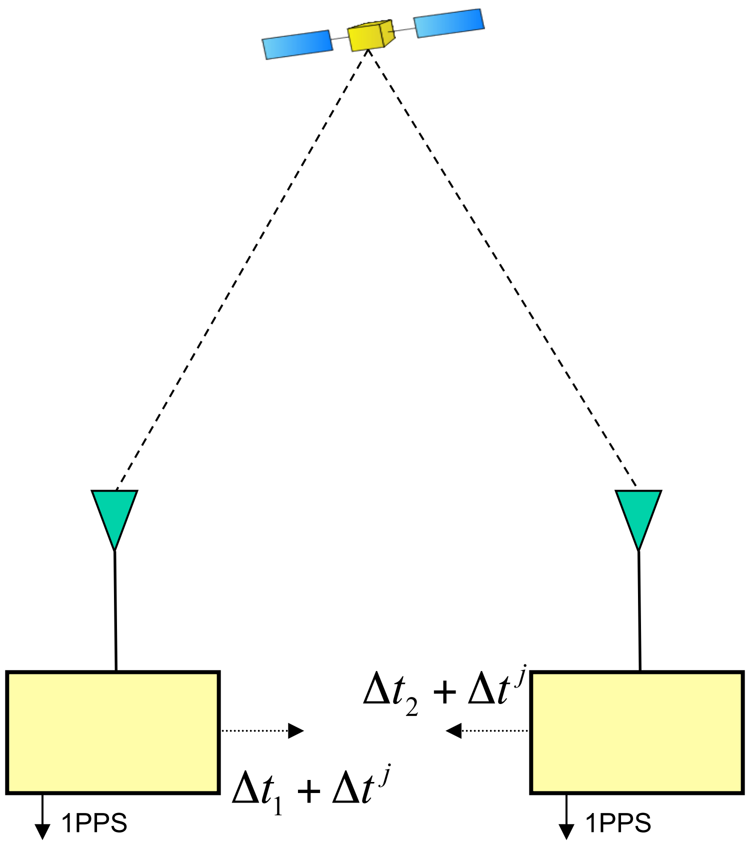


$$\Delta t_i + \Delta t^j = \frac{1}{c}\left(p_i^j - \rho_i^j\right)$$

$$\Delta t_1 - \Delta t_2 = \frac{1}{c}\left(p_1^j - \rho_1^j\right) - \frac{1}{c}\left(p_2^j - \rho_2^j\right)$$

"traditional method“ = *Common view*

quasi-simultaneous observations of one satellite by two receivers (simultaneous in s/c time scale)

broadcast or IGS ephemeris (assumed known)

dual frequency → ionosphere correction

receiver *i* computes its clock offset using satellite *j*

1PPS output/input synchronized to receiver clock

Stories about problems above the 1ns-level in GNSS time transfer are fairy tales! (remember the CERN ←→ Gran Sasso neutrino experiment)

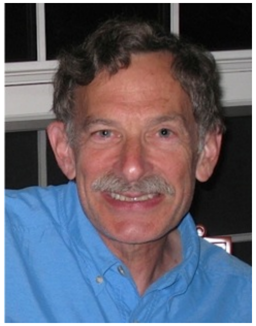
GNSS for Science

What has been achieved in science with GNSS?

- **GNSS orbit accuracy < 5cm → enables, e.g., LEO POD!**
- **Terrestrial Reference Frame 400 sites < 1cm, < 1mm/ year**
- **Polar Motion: < 1 mm (about 20mas), one day resolution**
- **length of day: few ten *ms* (could be done better)**
- **Clock synchronization: Conventional: 1ns, science: few 10 ps consistency with orbits, < 1ns absolute**

Science applications dealt with/enabled by the IGS

The IGS 1994 - 2004

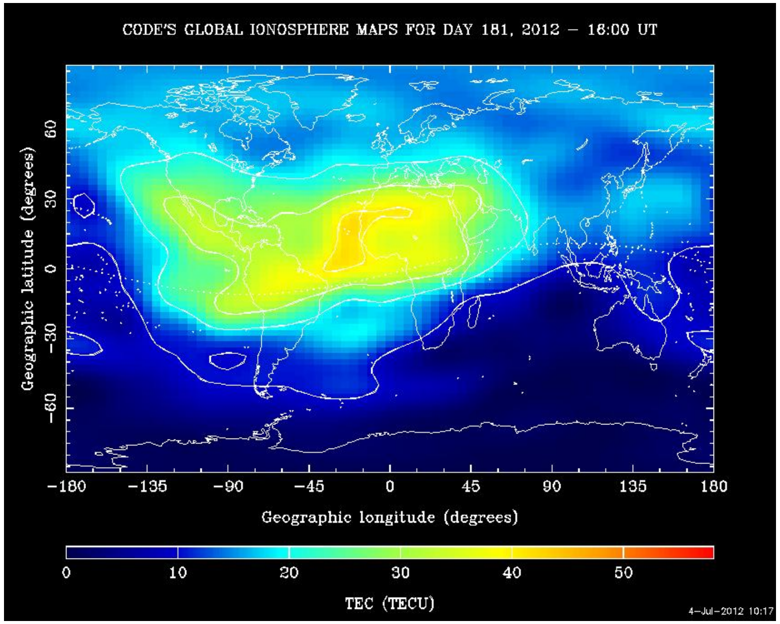


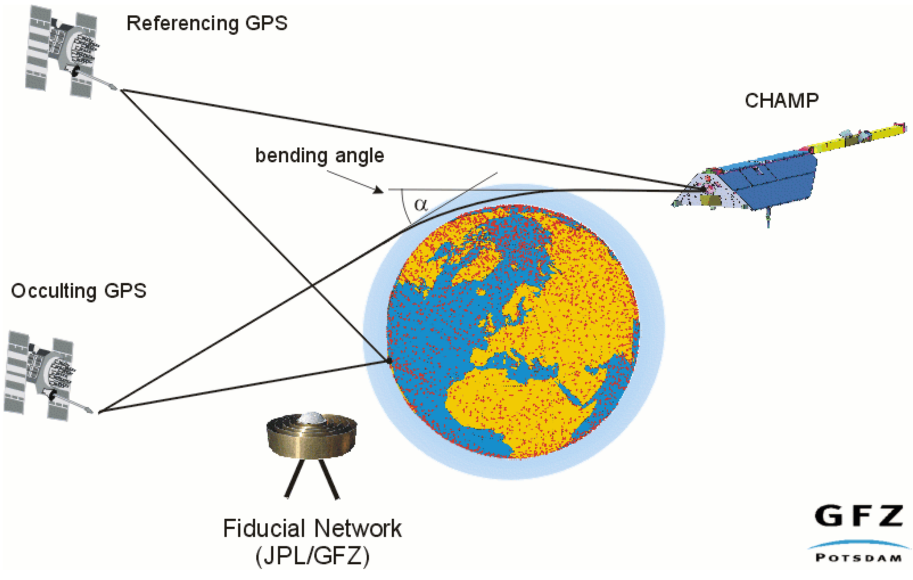
Date	Event
January 1994	Start of official service on January 1
November 1994	Workshop on the *Densification of the ITRF* at JPL, Pasadena
May 1995	IGS Workshop on *Special Topics and New Directions* at GFZ in Potsdam
March 1996	IGS Analysis Center Workshop in Silver Spring, USA
March 1997	IGS Analysis Center Workshop at JPL in Pasadena
December 1997	IGS Retreat in San Francisco
February 1998	IGS Analysis Center Workshop at ESOC in Darmstadt
December 1998	Prof. Christopher Reigber elected as IGS Chairman 1999-2002
March 1999	LEO Workshop, Potsdam, Germany
June 1999	Analysis Center Workshop, La Jolla, California
March 2000	IGS Tutorials in South Africa
May 2, 2000	Selective Availablitiy removed!!
July 2000	IGS Network Workshop
July 15, 2000	CHAMP Launch
September 2000	IGS Analysis Center Workshop at USNO
December 2000	IGS Strategic Planning Meeting
February 2001	LEO Workshop
March 2001	Glonass Service Pilot Project
March 2001	TIGA Project established
April 2002	Ottawa Workshop: Towards Real-time
July 2002	UN Regional GNSS Workshop
December 2002	Prof. John Dow elected as IGS Chairman 2003-2006
April 2003	Ionosphere maps (IONEX) etc. official IGS product
May 2003	First operational combined GPS/GLONASS analysis products
August 2003	Essential improvement of “near-real-time” orbits
March 2004	IGS Analysis Center Workshop and 10 Years Symposium

The IGS 2005-2014

Date	Event
March 2005	IGS renamed International GNSS Service
May 2006	IGS Analysis Workshop in Darmstadt, Germany
December 2007	Combined Space-geodetic analysis workshop in San Francisco, USA
June 2008	IGS Analysis Center Workshop in Miami, USA
2008	IGS Antenna Working Group established
2008 - 2009	First IGS Reprocessing Campaign 1994 - present
2008	IGS Bias and Calibration Working Group
June 2010	IGS Analysis Center Workshop in Newcastle, UK
January 2011	Urs Hugentobler (TU Munich) new IGS Chair
August 2011	IGS-MGEX Call for Participation launched
January 2012	IGS Workshop on GNSS Biases in Bern, Switzerland
July 2012	IGS Analysis Center Workshop in Olsztyn, Poland
2013 - 2014	Second IGS Reprocessing Campaign 1994 - present
June 2014	**IGS Workshop and celebration of 20 years of services**

What else?





GNSS for … studying the ionosphere and the troposphere
… POD (precise orbit determination)
… limb sounding

Modeling GNSS Orbits

- Lageos (LAser GEodetic Satellite); spherical, diameter 60cm, mass 405kg
- GNSS satellite: Body 2 x 2 x 2 m^3, “wings” 20 x 2 m^2, mass 500-1000kg

Modeling GNSS Orbits

Ferraris are built to minimize non-gravitational forces, trucks not really (only "to some extent").

From the p.o.v. of orbitography the Lageos is a Ferrari, the GNSS satellite is a truck.

Modeling GNSS Orbits: GNSS

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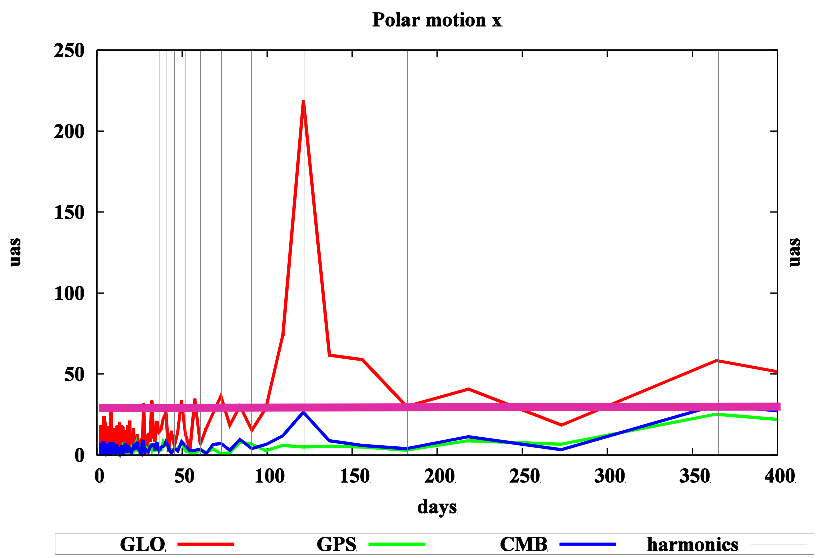
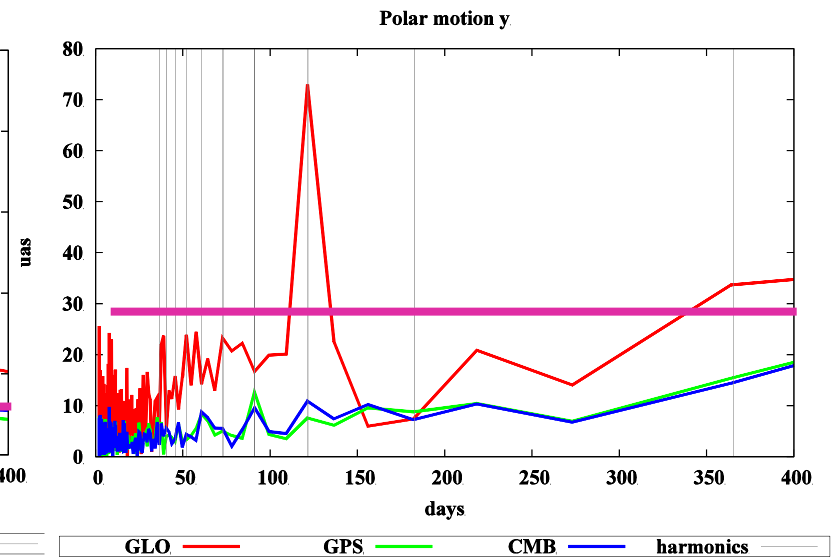
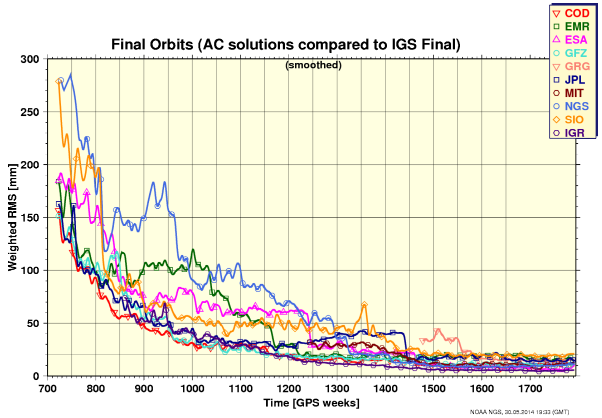




Spectra of polar motion differences w.r.t. IERS 08 C04 from GLONASS-only, GPS-only, and combined GPS/GLONASS Analysis based on years 2012-13. 1-sigma level for IERS 08 C04: Analysis derived from Meindl et al (2013).

Orbit modeling problems for GLONASS do bias virtually all parameters of scientific interest, see Ray, J., Altamimi, Z., Collilieux, X., van Dam, T. (2008)

The IGS in 2014



Orbit modeling in the IGS made great progress in the IGS since 1994.

Orbit validation and combination are of importance.

Consistency of solutions is important – in this context the IGS is in a much better shape today than 10 years ago thanks to the analysis coordination by NOAA/NGS – but …

- Different orbit models (and different para-meterizations) should be allowed
- The arc length should be considered as an important attribute of the solutions!
- GNSS-specific solutions should be made regularly – at least in reprocessing exercises (and be it only for integrity monitoring);
- The three approaches (empirical, box-wing, physical modeling in the Fliegel tradition) must be further developed and validated.
- The parameterization of orbits (e.g., inclusion of low degree spherical harmonics → Sosnica et al., PY10) should be reconsidered – and not only for first degree terms (at least for repro-exercises).

Modeling GNSS Orbits

Orbit modeling problems may show up in all parameters of satellite-geodetic methods.

One detects "spurious" spectral lines at periods which are typical for the modeled perturbing acceleration.

In the case of GNSS solar radiation pressure is the big critical factor.

Rodriguez-Solano, JoG et al. (2014), JoG 88:559–574, showed that the problem may be mitigated by improved SRP models

→ This particular problem will be reduced by about a factor of ten in the near future.

→ Problems of this kind are inherent in satellite geodetic methods.

→ SLR-like satellites, or accelerometers improve the situation.

Modeling GNSS Orbits

J Geod (2014) 88:559–574
DOI 10.1007/s00190-014-0704-1

ORIGINAL ARTICLE

Reducing the draconitic errors in GNSS geodetic products

C. J. Rodriguez-Solano · U. Hugentobler ·
P. Steigenberger · M. Bloßfeld · M. Fritsche

The authors replaced the ECOM by an adjustable box-wing model, where (at maximum) 9 parameters are adjusted for each satellite.

Spurious effects on ERPs and other parameters are significantly reduced in combined GPS/GLONASS solutions.

Modeling GNSS Orbits

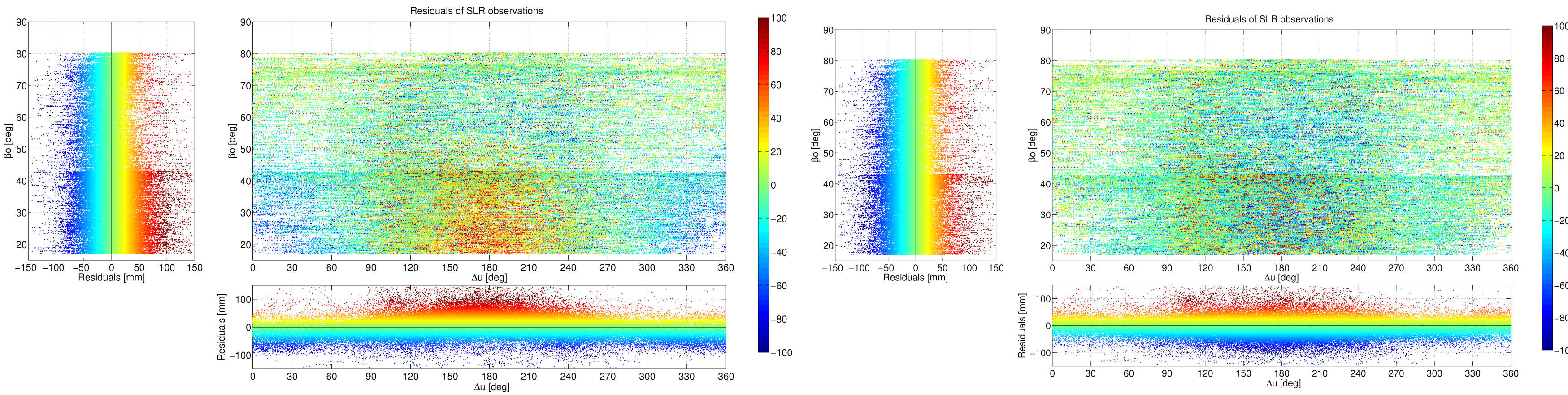
The **major problem** after 2008 was **GLONASS-induced** (blame Jim Slater and Gerhard Beutler!).

Major **improvements in SRP modeling are about to be implemented** into the products of IGS Analysis Centers.

Spurious spectral lines will not disappear, but they will **be substantially reduced**.

Subsequently we show the SLR-validation of the developments at CODE!

What can SLR do for GNSS?



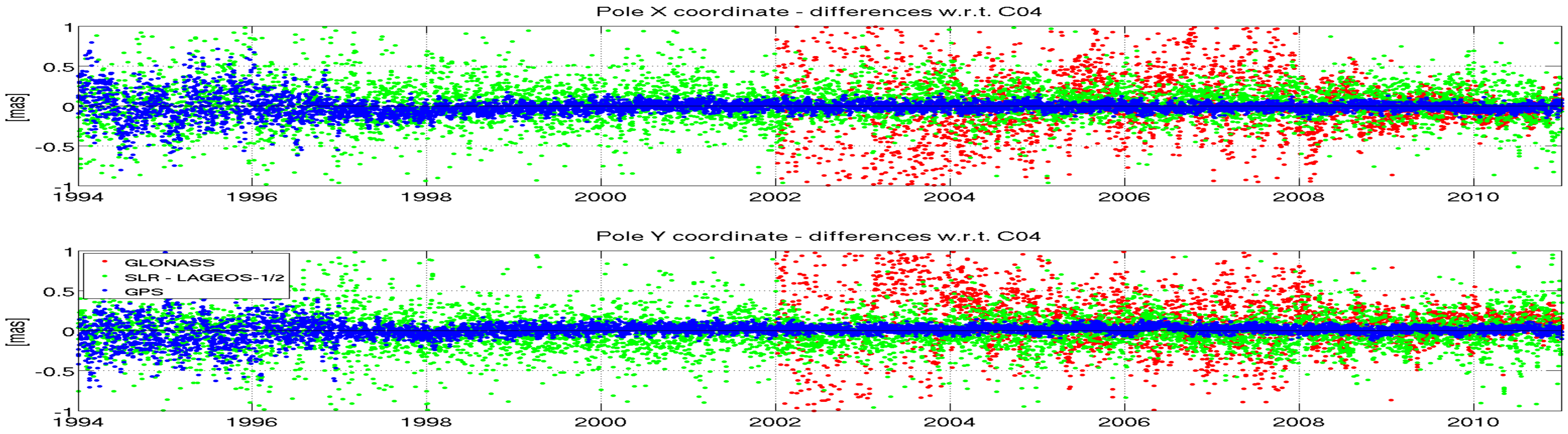
Validation of new CODE SLR models:

SLR-residuals of GLONASS SLR observations in the [*u*-u_s, b]-plane, method introduced to satellite geodesy by Claudia Flohrer/Urschl, before (left) and after (right) model improvement at CODE.

Validation performed by Krzystof Sosnica.

→ Fight for SLR-reflectors on *all* GNSS satellites!

What can GNSS do for SLR?



SLR may may/should make use of the GNSS strength, e.g., in common SLR/ GNSS analysis to get rid of the weakness of the network-induced weakness to determine, e.g., polar motion to even improve the SLR strength in determining the low degree/order terms of the gravity field.

→ Typical GGOS problem! → study the mitigation of amplitudes of spurious lines.

Conclusions

GNSS- and SLR-based geodesy have a lot in common, in particular the problems of

- orbit modeling,
- biasing geophysical parameters by orbit modeling

GNSS and SLR both are sensitive to the low-degree/order terms of the gravity field (including first degree/order terms).

GNSS is basically an interferometric technique, but offering dense worldwide observational coverage – a tremendous advantage!

SLR is an absolute technique – a tremendous advantage – with incomplete observational coverage.

Both techniques need each other!

GNSS in particular needs SLR validation!

→ Get these SLR reflectors on GPS Block III !