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The International GNSS Service (IGS): The Secrets of a Success and the Challenges of the Future

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IGS Workshop 2012

University of Warmia and Mazury in Olsztyn, Poland

July 23, 2012, 9^h:05^m – 9^h25^m

Opening Plenary Session

Plenary Room

Contents

- Chronicle of Events 1989 – today
- The Secrets of the IGS Success
  - Full exploitation of the GNSS signals
  - Full exploitation of internet communication
  - The people
  - Statistical stability
- Challenges of the Future
  - Multi-GNSS
  - LEO Orbit and gravity field determination using GNSS
  - Real-time orbit and clock determination
- Did the IGS learn lessons of interest for GNSS Operators?!

Motivation for the IGS in 1989

- The primary motivation in planning the IGS was the recognition in 1989 that the most demanding users of the GPS satellites, the geophysical community, were purchasing receivers in exceedingly large numbers and using them as more or less black boxes, using software packages which they did not completely understand, mainly for relative positioning.

- The other motivation was the generation of precise ephemerides for the satellites together with by-products such as Earth orientation parameters and GPS clock information.

Planning the IGS 1989-1991

Date	Event
August 1989	IAG Scientific Assembly in Edinburgh. Plans by Mueller, Mader, Melbourne, Minster, and Neilan
March 1990	IAG Executive Committee Meeting in Paris decides to establish a Working Group to explore the feasibility of an IGS under IAG auspices. I.I. Mueller was elected as chairman.
April 1990	The Working Group is redesignated as *IAG Planning Committee for the IGS* in Paris
September 1990	Planning Committee Meeting in Ottawa. Preparation of the *Call for Participation*
February 1991	CFP mailed. Letters of Intent due 1 April 1991
April 1991	CFP Attachments mailed to those whose letters of intent were received
May 1991	Proposals due
June 1991	Proposals evaluated and accepted in Columbus, Ohio
August 1991	Planning Committee reorganized and renamed as *IGS Campaign Oversight Committee* at the 20th IUGG General Assembly in Vienna
October 1991	First IGS Campaign Oversight Committee Meeting in Greenbelt

Proof of Concept Phase

Date	Event
March 1992	2nd IGS OSC Meeting at OSU, Columbus, Ohio
May 1992	Communication test
May 1992	Establishment of IGS Mailbox at University of Bern
June 21, 1992	Start of IGS Test Campaign 1992
July 1992	First results!
July 27, 1992	Start of Epoch'92 campaign, lasting for two weeks
September 23, 1992	Official end of the campaign, continuation on best effort basis
November 1992	Start of IGS Pilot Service
March 1993	1st IGS Workshop in Bern, IGS Terms of Reference drafted
May 1993	Meeting of the OSC in Baltimore
August 1993	IAG Approval for IGS at IAG Scientific Meeting in Beijing
October 1993	IGS Analysis Center Workshop
October 1993	IGS Network Operations Workshop and First Governing Board Meeting
December 1993	2nd Governing Board Meeting in San Francisco

The Official IAG Service 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 since 2004

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

The IGS people of the first generation!

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The founders: Gerry Mader (CIGNET), Ivan Mueller (Chief ideologist), Bernard Minster (Geophysics perspective), Ruth Neilan (Ms Casa Uno, Dos, Tres, …)

Sine qua non: Carey Noll (CDDIS), Werner Gurtner (RINEX, IGS Reports/Messages), …

Analysis Center Coordinators: Clyde Goad, Jan Kouba (Left-over from Doppler/Transit), Tim Springer, Robert Weber, Gerd Gendt, Jim Ray (the Warrior), Jake Griffiths

Chairmen: Gerhard Beutler (sleepless in Bern), Chris Reigber, John Dow, Urs Hugentobler

Mr GLONASS: Jim Slater from NIMA (National Imaging and Mapping Agency)!

All IGS (Associate) Analysis Center, Data Center and Network representatives!

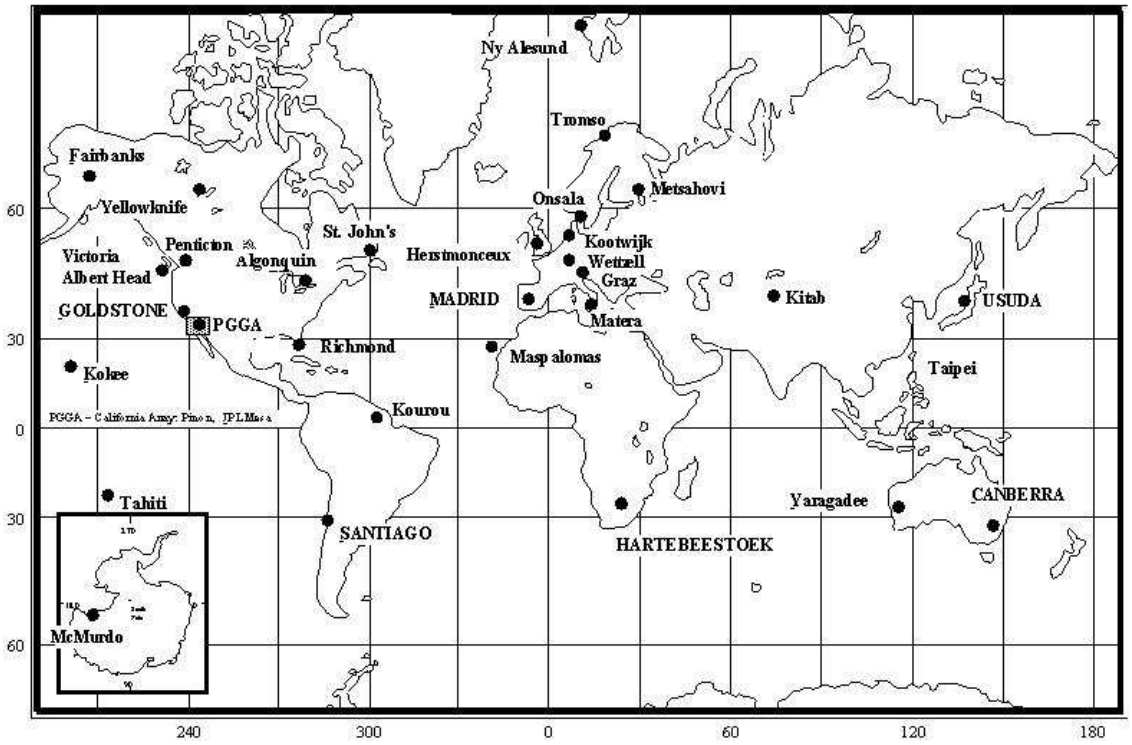
…

The IERS Link (the French Connection): Martine Feissel (Master of the leap second and the IERS Central Bureau), Claude Boucher (to some extent …), Bernd Richter, Chopo Ma, Pascal Willis, Zuheir Altamimi, …

The time keepers: Dennis McCarthy, Jim Ray, Gérard Petit, Félicitas Arias, Ken Senior

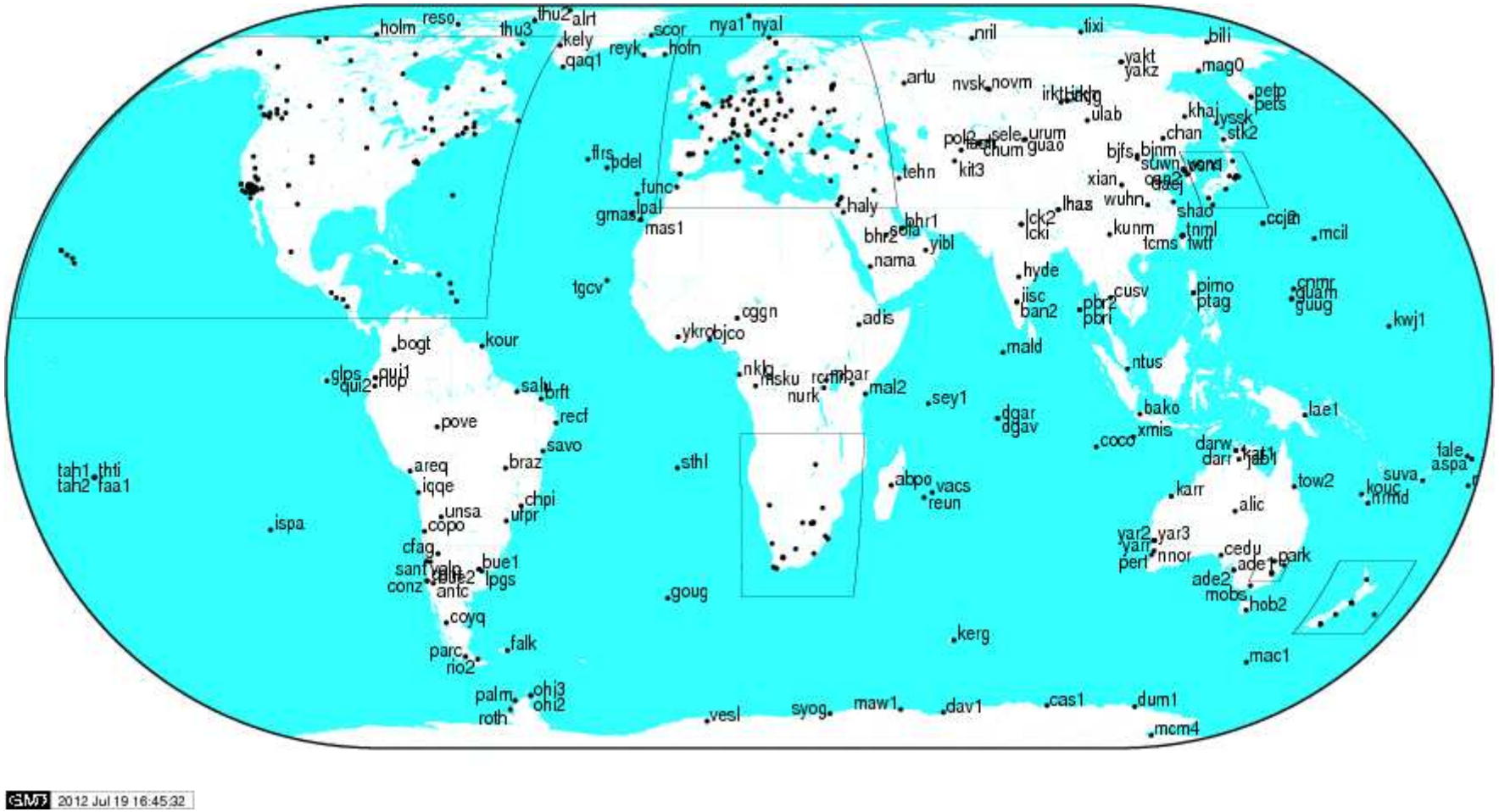
… and many, many other dear friends and colleagues.

IGS Tracking Network in 1992



About 20 useable receivers (mainly ROGUE).

IGS Tracking Network in July 2012



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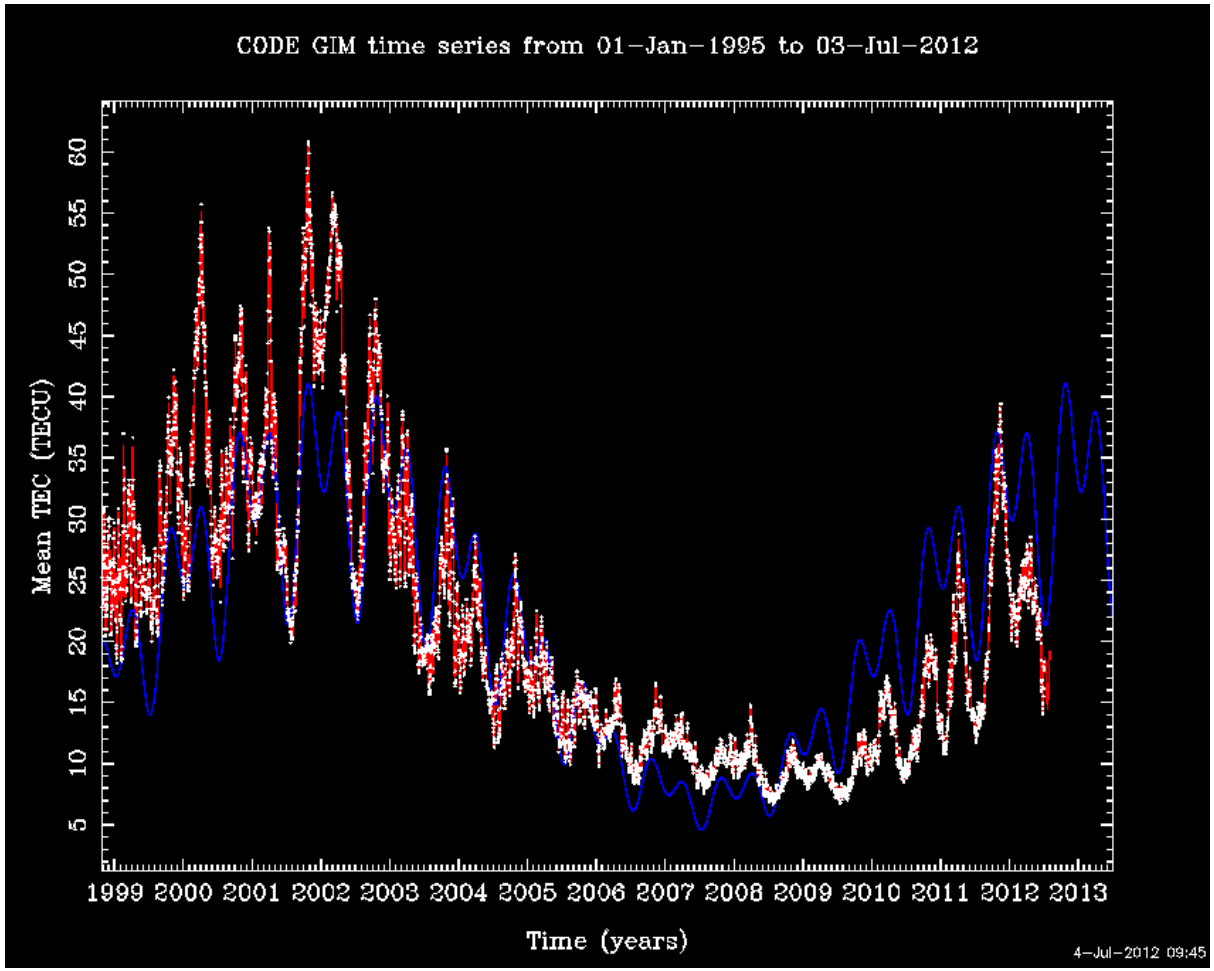
The IGS: Exploitation of GNSS signals



Using the „geometry-free“ LC of GNSS signals it is possible to derive maps of 2- or 3-d ionosphere maps.

→The IGS uses the full information content of the GNSS signals.

Really?:

By exploiting the correlations in space and time one might derive, e.g., a GNSS-derived k_p-index of our planet.

A Failure? The IGS/LEO Engagement

• The gravity field missions CHAMP, GRACE, GOCE of the first decade of the third millennium use IGS data, but not all of them make the best possible use of the IGS products (the/my vision was different) – GOCE is the exception/good example.

• The IGS as an organization does not yet make use of LEOs for its products: The vision in 1997 was definitely different!

Key Elements of the IGS Success

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The IGS is based on *user demands* and *needs*.

The IGS has *redundancy* in network, data centers, analysis.

Today, the IGS truly is a GNSS service.

IGS generates combined products ==> *robustness*.

IGS fully (understands and) exploits the GPS signal ==> *Interdisciplinarity*.

Friendly, but tough competition of analysis centers ==> *Stimulating research & development environment*.

IGS is the *Authority for the scientific exploitation of GNSS*.

The IGS could and can rely on dedicated contributors!

In the 1990s "everything the IGS did" was "cutting edge science"!

Is this still true today? Undoubtedly the emphasis has shifted to attractive applications of GNSS (e.g., LEO orbit determination).

How to react?

Challenges of the future

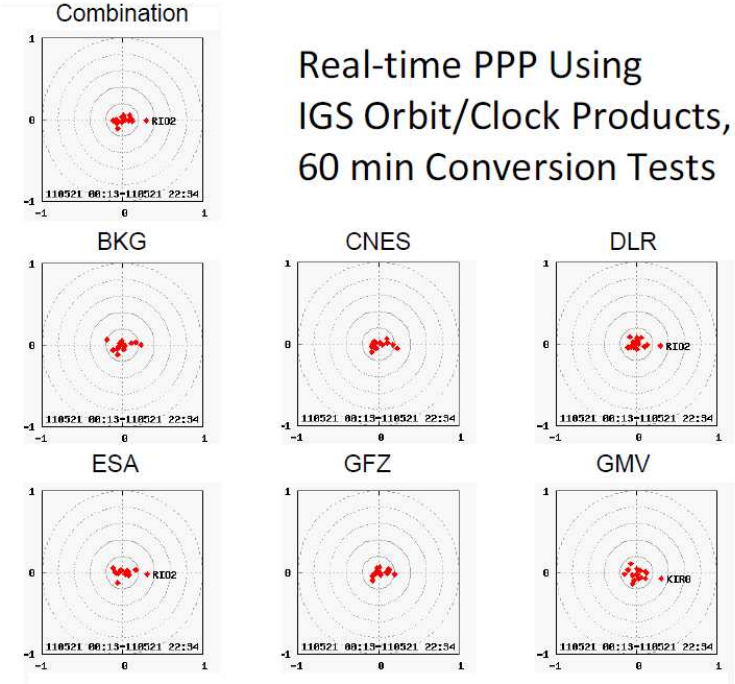

Figure by courtesy of Georg Weber

Radius of target: 1 meter

Consistency approaches the dm level

A product in the true IGS spirit: added value by comparison and combination.

Products are based on a broad participation of traditional and new IGS players.

- **Accurate real time applications are becoming more and more important.**
- **RT Applications have been recognized as a key IGS issue since ist creation.**
- **With the leadership provided by Georg Weber, Mark Caissy, and others the IGS real time project became a remarkable success and a promise for the future.**

Challenges of the future

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The IGS must be/remain the IG(NSS)S

Since 2011 two systems, namely GPS and GNSS, are fully deployed and their data are freely available today.

Positive achievements of the IGS:

- **Creation of bias and calibration working group**
- **Creation of IGS antenna working group**
- **Generationa & Distribution of combined GPS/GLONASS products**

The following questions must be allowed:

- **Should more emphasis be put on a detailed system validation through analysis?**
- **Separate GPS, GLONASS, Galileo, etc. solutions should be made in addition/prior to combination.**

The author believes that these questions should be answered by "yes". The continuation of this talk indicates why!

Challenges of the future

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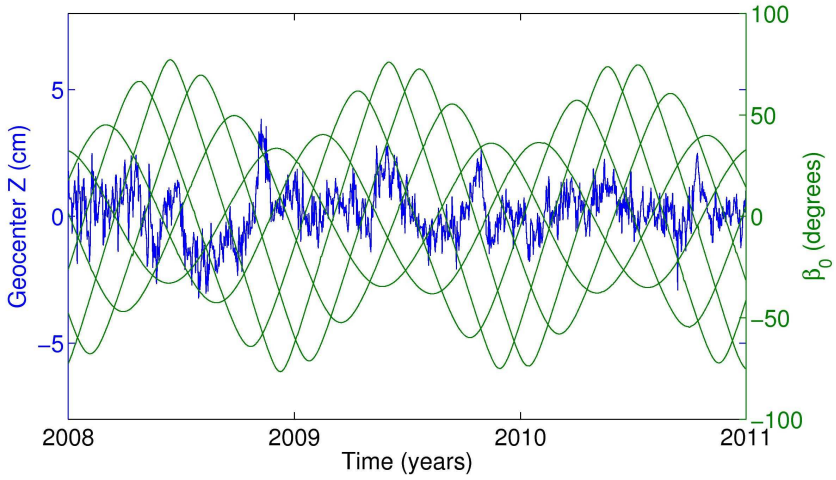
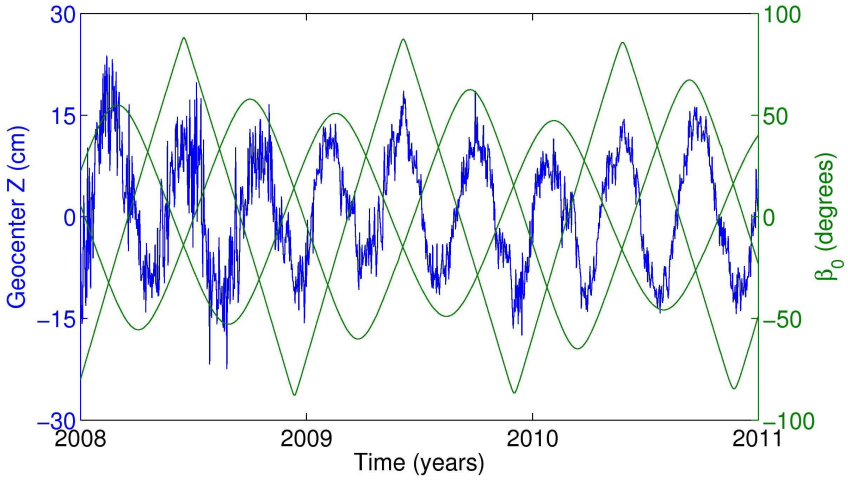
Part of Michael Meindl's PhD Thesis dealt exactly with separate IGS-like GPS and GLONASS solutions.

Many results simply followed the sqrt(n) law, n = # satellites.

The geocenter and the subdaily EOPs/ERPs did not!



GPS Z-component of geocenter



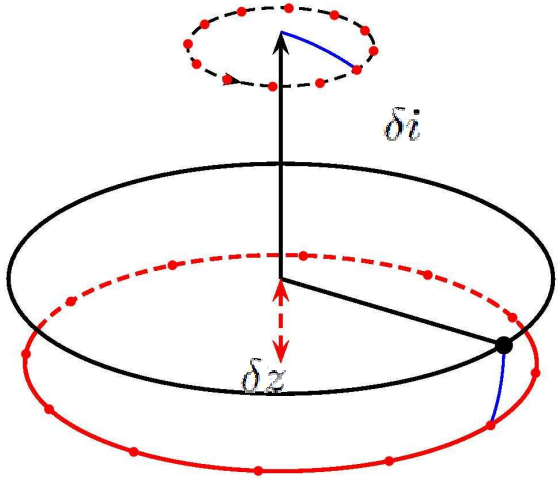
GLONASS Z-component of geocenter

Challenges of the future

From perturbation theory

- **Constant W-component causes a tilting of the orbital plane**

Satellite seemingly moves on a plane in parallel to the original one



$$\delta i = W/n^2 a$$

$$\delta z = W/n^2$$

$$\delta i(t) = \frac{W}{n^2 a} \sin u$$

$$\delta \Omega(t) = \frac{W}{n^2 a \sin i} \cos u$$

$$\delta u(t) = \frac{W}{n^2 a \tan i} \sin u$$

Challenges of the future

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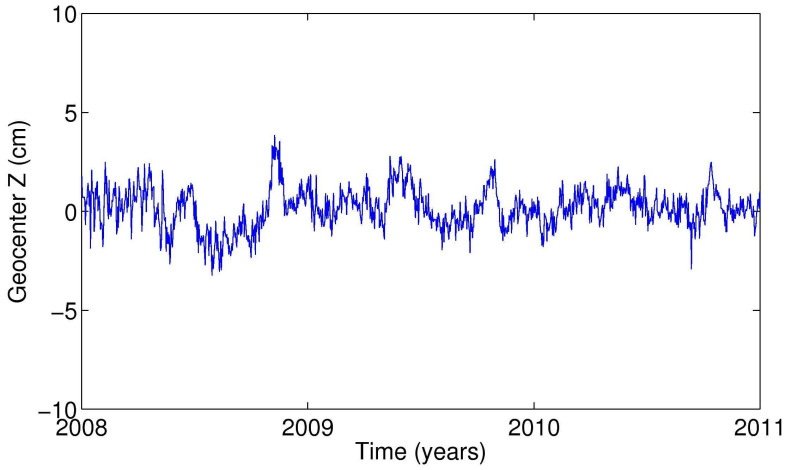
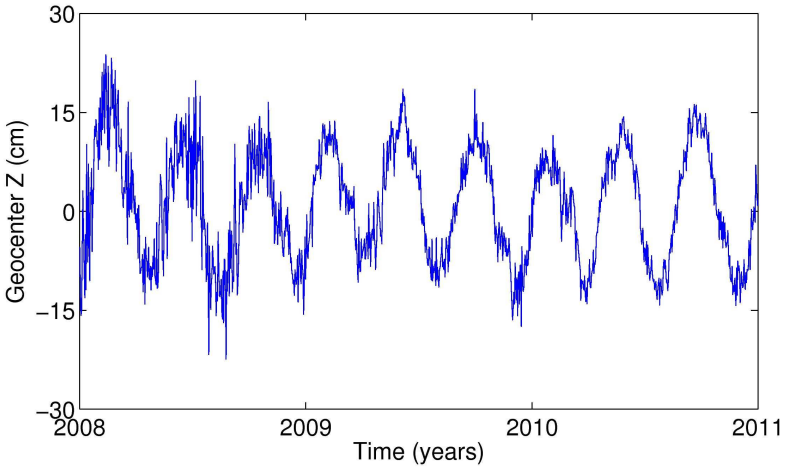
GCC Z-component: estimated



GPS



GLONASS

Challenges of the future

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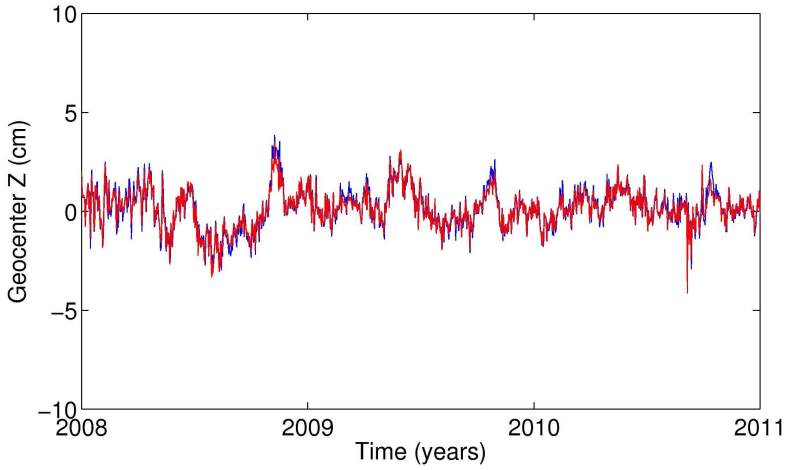
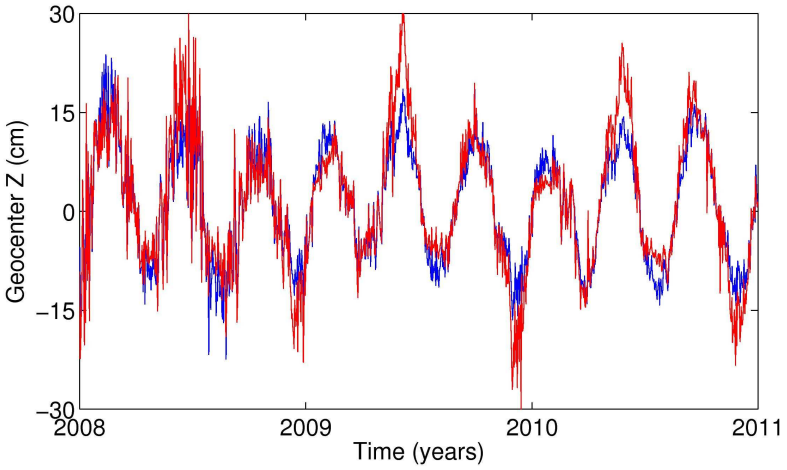
GCC Z-component: estimated, theory



GPS



GLONASS

Challenges of the future

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Quinta Essentia of experiments by Meindl et al (personal view):

- **GNSS-specific peculiarities should be studied in the IGS.**
- **Two issues have been identified in the context of the Ph.D. Thesis of Michael Meindl:**
  - **Geocenter determination**
  - **Determination of ERPs with subdaily (e.g., hourly) time resolution**
- **A regular analysis would undoubtedly reveal more issues.**
- **Radiation pressure is the key issue introducing spurious signals into all kinds of time series (coordinates, e.t.c.) →**
  - **Improve physical models (box-wing).**
  - **Improve empirical models (replace argument of latitude *u* by a more meaningful angular argument).**
  - **Study the impact of every model constituent on the orbital plane.**

Challenges of the future

The IGS should make public GNSS-specific lessons learned.

These lessons include:

- **Calibration and Bias issues (IGS WG)**
- **Antenna issues (IGS WG)**
- **Signal issues (IGS WG)**

Subtle analysis issues should be studied, as well:

- **Radiation pressure is extremely delicate to model (empirical or deterministic). →**
  - **Ask for SLR on next generation GNSS satellites.**
  - **Ask for accelerometry on future generation GNSS satellites.**
- **Constellation issue: The more orbital planes, the better the sampling of radiation pressure at each epoch. Ideally, there should be one orbital plane per satellite!**

Challenges of the future

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- **The IGS must remain the *authority for the scientific exploitation of GNSS*.**
- **The IGS has become an important player in the real time business.**
- **The IGS position in the real-time business should be consolidated.**
- **Every aspect of multi-GNSS should be studied (in the frame of MGEX).**
- **System-relevant differences should be made public/brought to the attention of GNSS operators.**
- **The IGS should become a player in the LEO business. It should in particular use LEOs for its core business, the generation of IGS products.**
- **Regular reprocessing campaigns are "a must"!**