

The International GNSS Service (IGS): Creation, Development, and Achievements in the «Early» Years

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IGS Symposium and Workshop 2024

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Preamble

- This report is based on facts & events captured in
 - many **IGS Annual Reports**,
 - the proceedings of many dedicated **IGS workshops**,
 - many **scientific papers**,
 - and on **personal memories**
- The history of many institutions and individuals are closely linked to the development of the IGS.
- **Quite a few** of these **institutions and individuals** **are** represented **here** in Bern, the individuals **as "veterans"**.
- It is a great honor for me to present this overview on behalf of all "veterans".

What is the IGS?

- **The IGS is ...**
 - the outcome of the IGS **Campaign Oversight Committee** (1991–1993) and the **1992 IGS test campaigns**,
 - an official IAG (International Association of Geodesy) Service since 1994,
 - based on the IGS Network equipped with GNSS receivers,
 - today an interdisciplinary service providing the geodetic geometry products (coordinates of ground stations, orbits of satellites, Earth Orientation and Rotation Parameters), Clock Products, and Atmosphere Products (related to the Earth's Ionosphere and Troposphere).
- Official operations started in 1994 as the **International GPS Service for Geodesy and Geodynamics** to be renamed as the **International GNSS Service** in 2005. The essential steps of the transition were;
 - **IGEX**(1998): 3–months GLONASS Test Campaign,
 - **IGLOS** Test Service (2000–2005).
 - The European Galileo, the Chinese BeiDou, the Japanese QZSS, ... became issues after 2010
 - **MGEX**: Multi–GNSS–products. "Multi" meaning "> 2" started in 2012.

The IGS is **also** Based on ...

- A **rapidly growing constellation**, from 4–6 GPS satellites in 1982 to about 24 in 1995.
- The **strong support from the U.S. Dept. of Defense**, Defense Mapping Agency, **U.S. Dept. of Commerce**, National Oceanic and Atmospheric Administration, organizing, e.g., the **International Symposia Series on Precise Positioning with the GPS**.
- A **rapidly developing Internet** for IGS data collection and exchange of scientific results.
- The **International Association of Geodesy** hosting long-lasting "Services" (prototype: International Latitude Service (ILS), est. 1899), with products easily accessible to the scientific community, e.g., in the field of geodesy and geodynamics.
- The preparatory work of **pioneers** like e.g., Gerald (Gerry) Mader from the U.S. National Geodetic Survey, initiating coordination in the field of global GPS applications.
- The dedication of IAG and GPS leaders, in particular Ivan Mueller (Ohio State University), Georges Balmino (French Space Agency), Chris Reigber (DGFI Munich), Bill Melbourne (JPL), etc., ...

Motivation for the IGS in 1989



Ivan I. Mueller 1930–2023

- 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.

IGS colleagues of the **first** and **later** generations!

- The founders: **Gerry Mader** (CIGNET), **William Melbourne**, **Bernard Minster** (Geophysics perspective), **Ivan Mueller** (Chief ideologist), **Ruth Neilan** (Ms Casa Uno, Dos, Tres, ..., and head of IGS Central Bureau)
- IGS Infrastructure & Standards: **Angie Moore** (network), **Carey Noll** (CDDIS), **Werner Gurtner** (RINEX, IGS Reports/Messages), ... **Markus Bradke** (GFZ) and **Ryan Ruddick** (Geoscience Australia)
- Central Bureau: **Ruth Neilan**, **Angie Moore**, **Steve Fischer**, ..., 2017 **Allison Craddock**, **Mayra Oyola-Merced**, **Léo Martire**, ...
- Analysis Center Coordination: **Clyde Goad**, **Jan Kouba**, **Tim Springer**, **Robert Weber**, **Gerd Gendt**, **Jim Ray**, **Jake Griffiths**, **Kevin Choi**, **Tom Herring** and **Michael Moore/Salim Masoumi**, new ACC to take over in 2025

IGS colleagues of the **first** and **later** generations

- **Chair:** Gerhard Beutler, Chris Reigber, John Dow, Urs Hugentobler, Garry Johnston, Félix Perrosanz, Rolf Dach
- **GNSS:** Jim Slater from NIMA (National Imagery and Mapping Agency), Robert Weber, **MGEX:** Oliver Montenbruck
- **The IERS Link:** Martine Feissel, 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, Michael Coleman
- ... and many other friends and colleagues.

The IGS Campaign Oversight Committee

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 <i>IAG Planning Committee for the IGS</i> in Paris
September 1990	Planning Committee Meeting in Ottawa. Preparation of the <i>Call for Participation</i>
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 <i>IGS Campaign Oversight Committee</i> at the 20 th IUGG General Assembly in Vienna
October 1991	First IGS Campaign Oversight Committee Meeting in Greenbelt

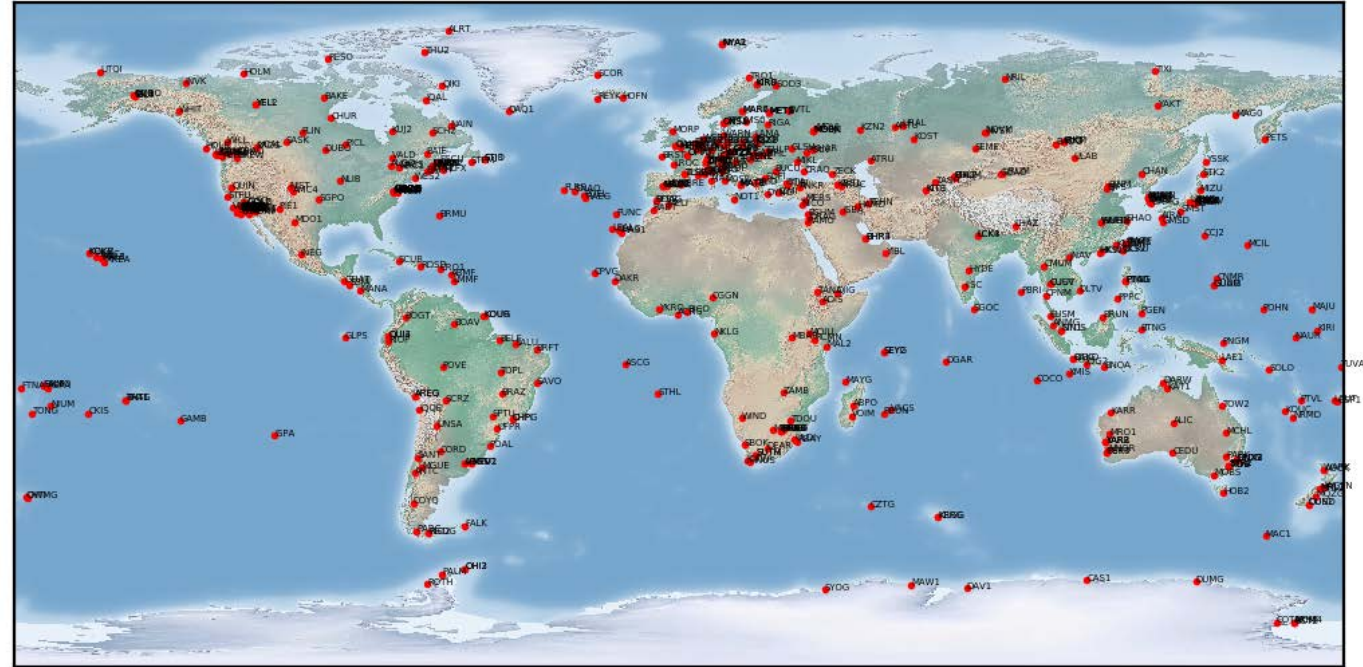
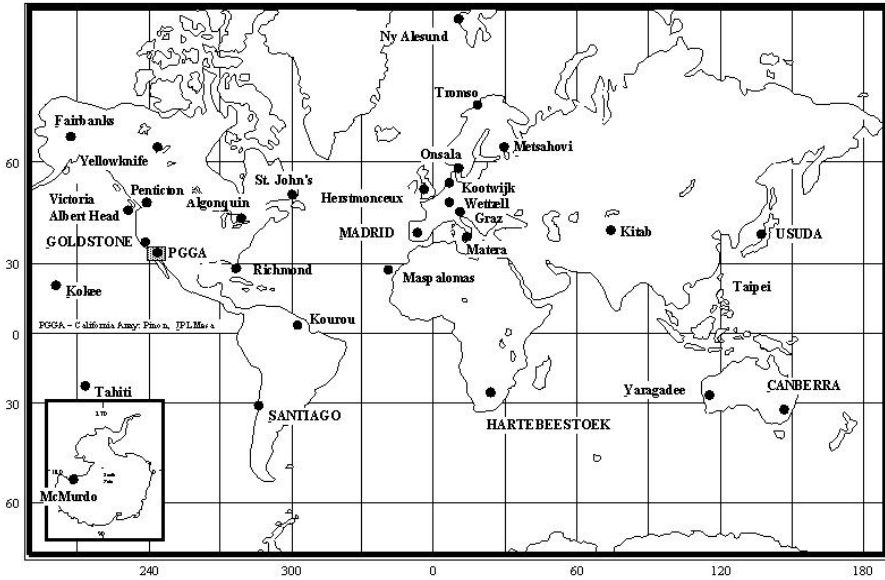
The IGS Campaign Oversight Committee

Date	Event
March 1992	2 nd 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	1 st 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	2 nd Governing Board Meeting in San Francisco

It was probably the most important **decision** for the IGS *not* to interrupt tracking and analysis on September 23, 1992, but **to continue operations on a "best effort basis" after the test campaign.**

The terms were drafted in my office at the University of Bern with Ivan breathing down my neck; they were discussed and accepted by the Campaign Oversight Committee in the meeting room of the faculty of Natural Sciences of the University of Bern.

The IGS Tracking Network



From about 20+ receivers (mainly ROGUEs) in 1992 to 500+ receivers, more than 300 of them Multi-GNSS in 2024.

The IAG Service 1994 – 2004



Ruth E Neilan



Jim Slater 1947–2018

Date	Event
January 1994	Start of official service on January 1, G. Beutler founding chair
November 1994	Workshop on the <i>Densification of the ITRF</i> at JPL, Pasadena
May 1995	IGS Workshop on <i>Special Topics and New Directions</i> 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
October 1998	Start of IGEX, 3-month GLONASS Test Campaign
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 Availability 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

Orbit Validation / Combination

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Combining the orbits of the IGS Analysis Centers

Gerhard Beutler¹, Jan Kouba², and Tim Springer³

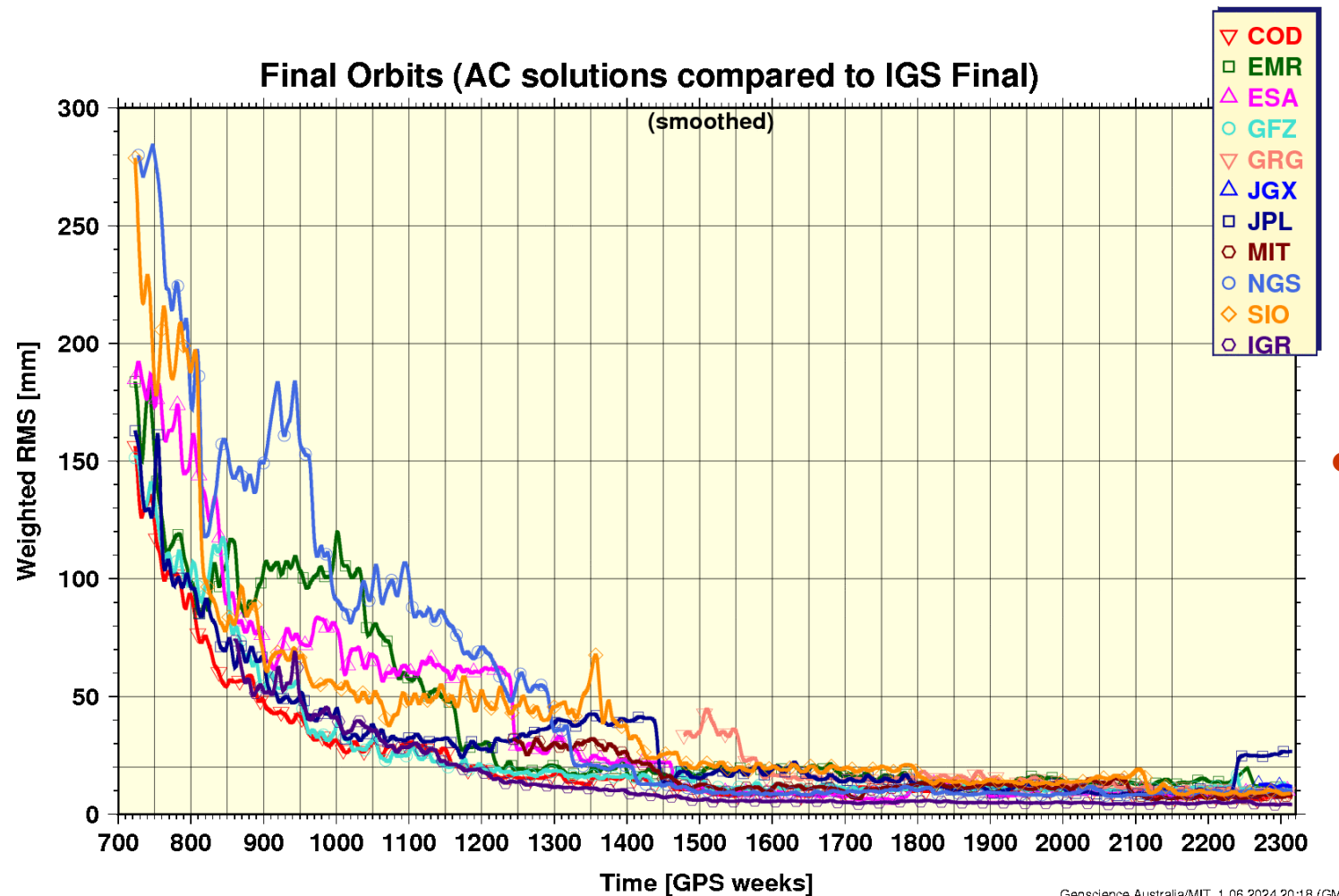
¹ Astronomical Institute, University of Bern, Bern, Switzerland

² Geodetic Survey of Canada, SMRRS, NRCan, Ottawa, Canada

³ Delft University of Technology, Delft, The Netherlands

- Principles of orbit combination – basically still in use today.
- Quote from Jan Kouba when the IGS Combination was accepted by the IGS GB:
- Oh, Gerhard, they really bought that!

Orbit Validation / Combination



- **Consistency** of Analysis Center Contributions to the combined IGS final orbits (from January 1994 to June 2024) is of the order of 1 cm today.

The IGS as an Interdisciplinary Service



Pergamon

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THE INTERNATIONAL GPS SERVICE (IGS): AN INTERDISCIPLINARY SERVICE IN SUPPORT OF EARTH SCIENCES

G. Beutler¹, M. Rothacher¹, S. Schaer¹, T.A. Springer¹, J. Kouba², R.E. Neilan³



The International GNSS Service 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 - 2008
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 - 2013
June 2014	IGS Workshop and celebration of 20 years of services in Pasadena, predecessor of today's event

Multi-GNSS Processing in the IGS



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Review

The Multi-GNSS Experiment (MGEX) of the International GNSS Service (IGS) – Achievements, prospects and challenges

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Multi-GNSS Analysis was initiated in 1998 by IGEX (Chair Jim Slater), continued afterwards in IGLOS (Chair J. Slater), was then coordinated 2003–2012 by the GNSS Working Group (Chair Robert Weber). From 2012 onwards the IGS Multi-GNSS working group took care of the Multi-GNSS Experiment (MGEX) with Oliver Montenbruck as Chair.

The “True Value” of the IGS Network

- The IGS maintains today a list of 500+ sites/receivers in its network.
- The IGS network is heterogeneous (virtually all high precision receiver types), many of them multi-GNSS.
- This IGS site list, together with the protocols of the IGS ACs, allowed it, e.g., to analyze the GLONASS April 1–2 incident in 2014 in some depth:
 - There were three classes of receivers, those tracking all satellites normally, those tracking GPS normally, and those failing to track GPS and GLONASS.
 - The incident was caused by bad GLONASS Broadcast Messages transmitted for some time from 9h p.m. onwards.
 - The positions from the bad broadcast messages showed a consistent rotation of about 0.5 deg around the x-axis of the inertial equatorial coordinate system.
 - The IGS data sets (in particular the concatenated Broadcast Messages) were of paramount importance to analyze the effect.
 - For more information consult:
(<https://www.gps.gov/governance/advisory/meetings/2014-06/beutler1.pdf>)
- The IGS is in a position to perform an integrity monitoring of all GNSS included.

Development and Establishment of the IGS **in Hindsight**

Development and establishment of the IGS was a **fantastic experience!**

- **Satellite–geodetic observation techniques** based on high–orbiting navigation satellite systems, applied to continental, even global scales, were "**firsts**".
- Precise Orbit Determination (**cm–level POD**) and **gravity field** determination **of the Earth** based on navigation satellites were "**firsts**".
- The **willingness** of the international geodetic community **to join forces around 1990 for science** was remarkable – to say the least.

The **challenges** are **different today**: The IGS provides well–established and indispensable **contributions to**

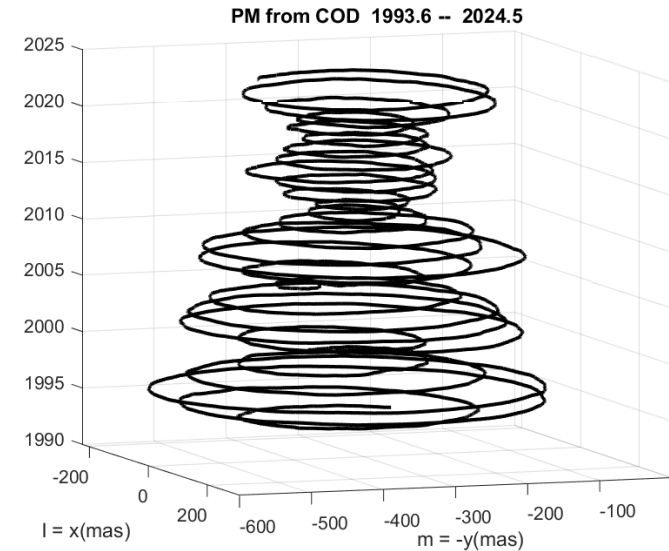
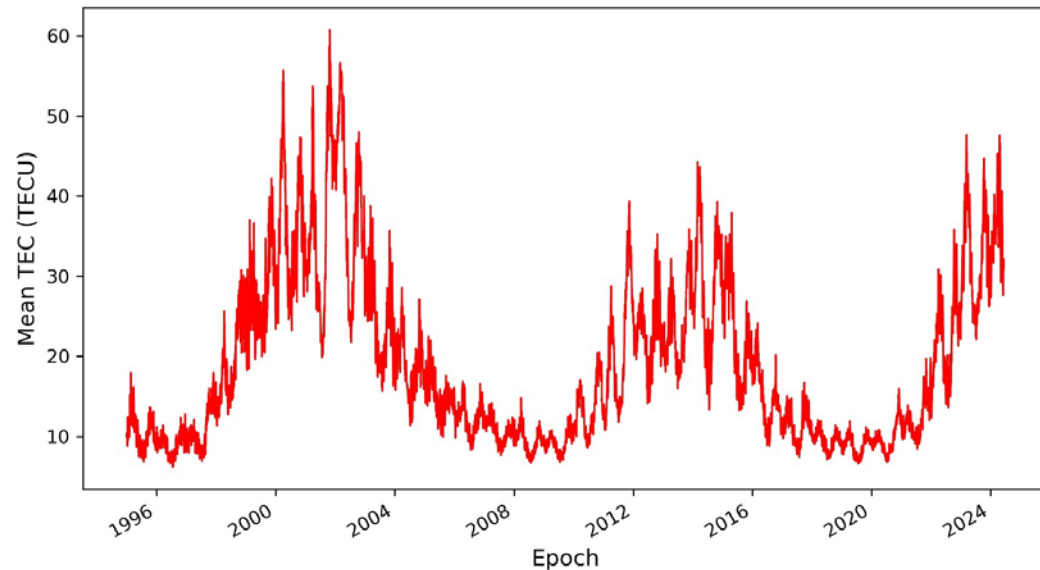
- **the ITRF**, the International Global Terrestrial Reference Frame,
- **LEO orbit determination** with GNSS, starting with the CHAMP, GRACE, GOCE missions.

The IGS indirectly contributes to:

- **the ICRF**, the International Celestial Reference Frame, by "fixing" the ITRF
- the establishment of **the Earth's Gravity field** by determining low deg/order terms.

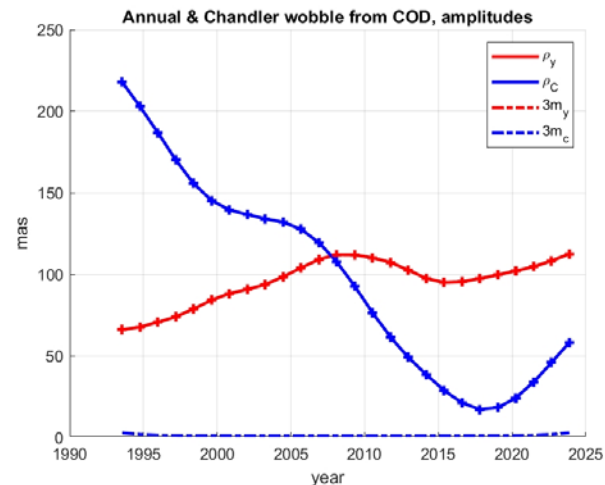
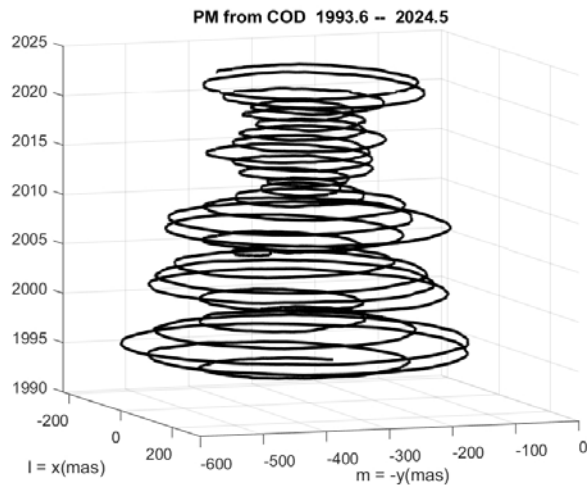
Such contributions ask for an **observational basis spanning decades to centuries.**

IGS Contributions to Science apart from the ITRF



- Left: Mean total electron content (TEC) from high resolution **ionosphere models** based on (at least) dual-band phase observations gathered by the IGS network sites (ask, e.g., Stefan Schaer). The picture illustrates one of the impacts of about three 11-year solar activity cycles on the Earth's ionosphere.
- Right: **Polar motion** monitored by the IGS between 1993.6 and 2024.5; superposition of the Chandler and the annual motion with the beat signal, period of about 6.5 years.

IGS Contributions to Science apart from the ITRF



- **Left: Polar motion (PM)** determined by IGS between 1993.6 and 2024.5, Chandler and annual motion, with a beat period of about 6.5 years.
- **Center: The long-term variability of Chandler amplitude** as reconstructed from IGS daily estimates of PM. Amplitude was close to zero around 2018.3. Amplitude of annual motion (around 100 mas corresponding to 3m on the Earth's surface).
- **Right: S. C. Chandler** (1846–1913) claimed PM to consist of two constituents, with periods of 14 months ("replacing" the Euler period) and one year, respectively. In 1901 he claimed the 14-month signal to actually consist of two constituents similar in size, separated in period by few days leading to a very long beat period (about 90 years) of the Chandler amplitude.

Epilogue

I contacted/bothered many friends and colleagues when preparing this overview to check my memories. Many thanks to all of them. Let me mention in particular:

- Rolf Dach, current Chair of the IGS Governing Board
- Oliver Montenbruck, Chair of the IGS MGEX Working Group since 2012
- Urs Hugentobler, Chair of the IGS Governing Board 2012–2015
- Robert Weber, Chair of the IGS GNSS Working Group 2003–2012
- Stefan Schaer, IGS Bias & Calibration Committee Chair
- Allison B. Craddock, IGS Central Bureau, JPL
- Reiner Rummel, Technical University of Munich
- Richard Langley, University of New Brunswick, Fredericton, Canada