Geodetic Infrastructure and GNSS Development - Basic Facts for Surveying Engineering and Policy Makers

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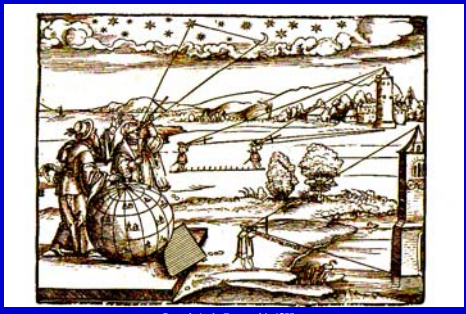
Table of Contents

Astronomy, Geodesy, Surveying and Navigation



Peter Apian's *Geographia* 1533

• The tools were, to a great extent, the same. The measurement of angles was *the* central issue.

Astronomy, Geodesy, Surveying, Navigation & Policy

- The ***principles*** of navigation, surveying and geodesy remained *in essence* the same since Apian's times till 1950.
- The celestial and global terrestrial reference systems and were established.
- Our field of science was always relevant for socity & policy. Remember, e.g., that ...
- the English Parliament issued in 1714 the *Longitude Act* to determine longitude on sea to 0.5° (2 Min), resp. 0.66° (3 Min) resp. 1° (4 Min).

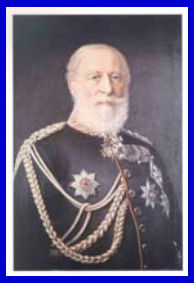
Basic Thoughts

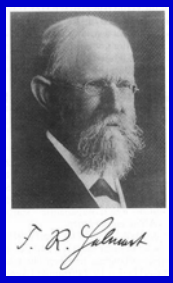
- Geodesy, surveying, fundamental astronomy, and navigation are closely related.
- The impact of our science on application, which is relevant for practice, is *significant*.
- The *Global Geodetic Infrastructure* plays a key role in geodesy since IAG's foundation.
- In the "good old days" the states took the initiative & responsibility for its preservation!

Foundation of IAG
From Baeyer's 1861 Memo to the King of Prussia

- " … one could compute about 10 meridian arcs at different longitudes ...;
- ... there is a wide field for scientific investigations ... which will lead to interesting and important results.
- If Central Europe is willing to unite and use its resources for the solution of this task, it will create an important and magnificent enterprise."

Development of IAG
(International Association of Geodesy)





• IAG was founded in 1861, when General J.J. Baeyer (left) proposed Central European Arc Measurements.

•F.R. Helmert was the second Director of the IAG Central Bureau 1886-1917 in Potsdam.

• In 1899 the Int. Latitude Service (ILS) became IAG's first service.

• After the first World War IAG became an Association of IUGG.

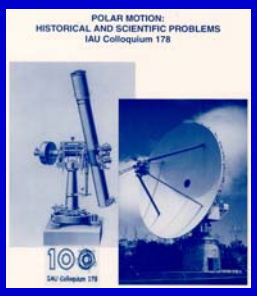
IAG: Home of Earth Rotation Monitoring since 1899!

•The IAG Central Bureau was initially located at the Geodetic Institute of Potsdam, then in Japan and Italy.

• The Institute also acted as CB for the ILS with ***C.T. Albrecht*** as head.

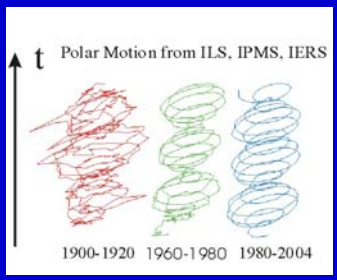
•Important geodetic infrastructure since foundation!

ILS, IPMS, IERS: A Case Study



- The cover of the proceedings of the IAU Colloquium 178 symbolizes the radical change of instrumentation used for polar motion between 1899 and 1999.
- The IERS might have been set up in a similar way as the ILS!

Services in IAG: ILS, IPMS, IERS



• ILS: International Latitude Service (1899-1959)
• IPMS: International Polar Motion Service (1960-1987)
• International Earth Rotation Service (since 1988)

- The ILS monitored Polar Motion with 100 mas accuracy,
- the IPMS did the same with an accuracy of few 10 mas,
- and the IERS monitors Earth rotation with < 0.1 mas acc.
- We see the superposition of the Chandler and the annual signal.

Revolution in Geodesy and Surveying

- The *space age* started with the launch of Sputnik I, on October 4 in 1957. In geodesy the following periods may be distinguished:
  - Optical period (Echo sats., Pageos, Geos, etc)
  - Doppler period using, e.g., the US NNSS
  - ***SLR and LLR*** period (Lageos, Starlette, etc.)
  - ***VLBI period*** based on radio astronomy
  - ***Satellite mission period*** (altimetry, SAR, ***gravity***)
  - ***GNSS period*** (GPS, GLONASS, Galileo)

The Space Age: Impact on Global Geodetic Infrastructure

- Instead of *one method* to establish the global terrestrial and the global celestial reference systems (and the transformation between them), there are now three, namely:
  - ***VLBI*** (Celestial Reference Frame),
  - ***GNSS*** (GPS, GLONASS, GALILEO) (global terrestrial reference frame).
  - ***SLR*** and ***LLR*** for calibration and scale.
- The gravity field is determined with satellite missions (CHAMP, GRACE, GOCE).

The Space Age: Impact on Global Geodetic Infrastructure

- The global geodetic infrastructure is much heavier today than in the pre-space age.
- The achievements are also much better:
  - The reference frames and the transformation between them are far from rigid.
  - ***permanent monitoring*** of the frames and of the transformation between them is a necessity.
  - ***The result is the basis for research in Earth sciences and application (global ref. frame).***

The Space Age: Impact on Global Geodetic Infrastructure

- The results achieved by international scientific collaboration are truly remarkable.
- Unfortunately, the ***funding*** situation is ***not of comparable quality*** because
- the ***funding*** for the new infrastructure ***came out of research and development budgets.***
- It is a ***key issue*** to put the ***funding*** for the Global Geodetic Intrastructure on a solid basis.

The Space Age: Impact on Global Geodetic Infrastructure

- One might think that the problems mentioned are purely a bilateral issue policy <--> IAG.
- This infrastructure is, however, of greatest importance for the entire field of surveying, geodesy, navigation, and fundamental astronomy.
- The infrastructure is in particular highly relevant for IAG *and* FIG!
- The issue shall be illuminated by the achievements of the IGS (International GPS Service).

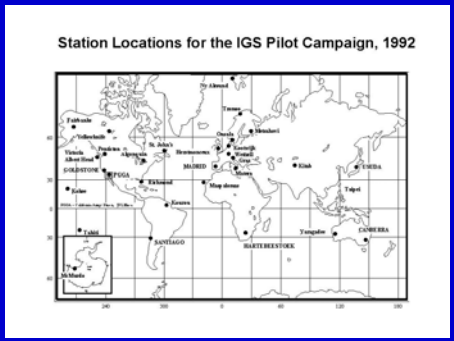
The International GPS Service (IGS)

- The test phase of the GPS in the 1980s proved that the GPS (and potentially other GNSS) would eventually have the potential to revolutionize geodesy *and* surveying.
- Towards the end of the 1980s the orbit quality was the limiting factor for GPS applications.
- Research groups wishing to use the GPS for precise regional or global positioning tasks had to produce “their own” orbits.

The International GPS Service

- The IGS was developed in three steps:
  - Planning phase (1989-91) with I.I. Mueller as chair
  - Proof of concept phase (1991-1993)
  - Official IAG Service since January 1, 1994.
- The IGS was designed as a pure orbit determination service in 1989, it is an ***interdisciplinary service in support of Earth sciences today.***

Global IGS Tracking Network in 1992



- About 20 useable receivers (mainly ROGUE).

The IGS as an Official Service

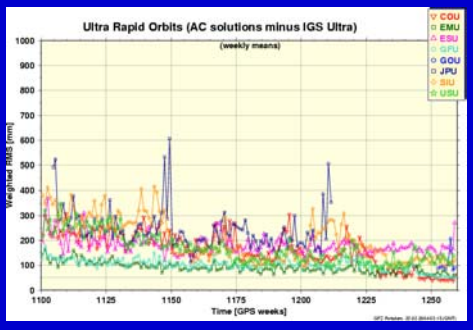
• The IGS Global Network grew from 20-30 in 1993 to well over 300 sites in 2004.

•Adherence to standards is not trivial!

The IGS as an Official Service
Altius, Citius, Fortius

- The number of sites of the IGS grew dramatically.
- The adherence to standards by the IGS ACs was considerably improved.
- Analysis tools became more and more mature.
- Modeling was generalized to include LoD, polar motion drifts, better resolution, etc.
- Delays in data transmission were reduced.
- Rapid and ultra-rapid products were generated.
- All products were systematically compared & combined.

The IGS as an Official Service



• Ultra-rapid orbits (available in real-time) since February 2001. Accuracy today < 10cm.

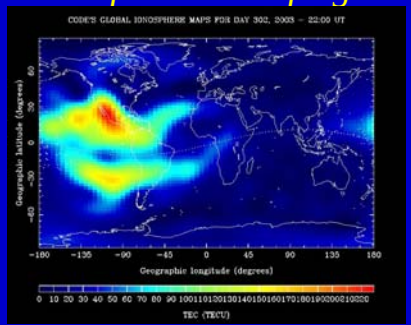
The IGS as an Official Service
Full exploitation of signal

- The (unambiguous) GPS observation equation:
- $c\,(t_r - t^s) = \rho + c\,(\Delta t_r - \Delta t^s) + \Delta\rho_i + \Delta\rho_t$
- The distance ρ is used to determine receiver position, the orbit of the satellite, and ERPs.
- $c\,(\Delta t_r - \Delta t^s)$ is used to synchronize clocks,
- $\Delta\rho_i$, the ionospheric signal delay, is used to derive ionosphere maps, and
- $\Delta\rho_t$, the tropospheric signal delay, is used for GPS meteorology.

The IGS Reference Frame

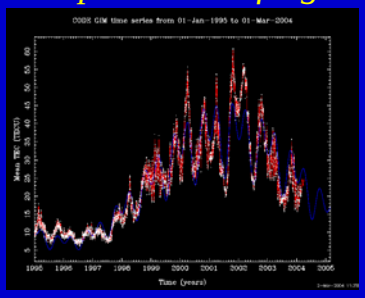
• The IGS monitors *plate tectonics* in "real time". Density of stations and time resolution of station motion are unprecedented.

The IGS as an Official Service
Full exploitation of signal



• Exceptionally high TEC values observed by IGS on October 29, 2003

The IGS as an Official Service
Full exploitation of signal



• Mean TEC was high, but not extraordinary on Oct 29, 2003.

The IGS/GLONASS Network

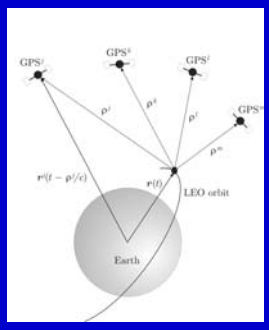
• About 20 IGS stations are equipped with GPS/GLONASS receivers.

• IGEX-98 Campaign in 1998/99, IGLOS-PP since 2001, 5-10 cm GLONASS orbits available in regular IGS products since May 2003.

The IGS as an Official Service

- IGS Achievements 1994-present:
  - *altius, citius, fortius:* the observational basis was improved, the delay between the availability of data and products was reduced, the analysis was substantially improved and made more robust.
  - The GPS *signal is now fully exploited*, leading to new and attractive applications.
  - The service was *generalized* to include *GLONASS* satellites; *Galileo* is being developed.
  - IAG is really good in dealing with GNSS on the scientific level … on the administrative level UN OOSA activities are of vital importance for IAG!

Use of Spaceborne GPS Receivers



- Using the IGS products (GPS orbits, clocks, ERPs) kinematic trajectories of LEOs of cm-accuracy can be established with precise point positioning.
- One would have to invent the IGS for this purpose!
- Most LEOs will be equipped with spaceborne GPS receivers in future.

Use of Spaceborne GPS Receivers

• CHAMP, launched in summer 2000, explores gravity field (+ magnetic field and atmosphere) using spaceborne GPS receiver.

•GRACE and GOCE missions are part of "gravity field decade"

The new IAG Structure

- IGS and IERS are to a great extent responsible for the positive image of geodesy in 1990.
- The role of the services is reflected in the 2003-2007 IAG structure:
  - Services are elements of IAG on the same level as the IAG Commissions.
  - 3 representatives of services (Neilan, Rothacher, Schuh) are members of IAG Executive Committee.
  - The ***Global Geodetic Observing System (GGOS)*** should be viewed as geodesy's contribution to Earth sciences and society.

The new IAG Structure

- The success of the services stimulated the creation of the IAG project ***GGOS***:
  - *GGOS* stands for *Global Geodetic Observing System*.
  - *GGOS* is based on IAG services.
  - *GGOS* should be recognized by the "outside world" as geodesy's contribution to Earth sciences.
  - *GGOS* strives for consistency on 10^{-9}-level of geometry, gravity, and ERP.
  - *GGOS* strives for preservation of global geodetic infrastructure and its use for monitoring the Earth.

Relationships of IAG with other Organizations and Projects

- IAG/GGOS shall be related to ***IGOS,*** the *Integrated Global Observing Strategy* working under the auspices of UNESCO, by formulating the *theme* ***Dynamic Earth.***
- IAG became a participating organization in ***GEO***, the Inter-Governmental Group on Earth Observations working on the ministerial level of states. ***GEO*** is co-chaired by the USA, the EC, South Africa, and Japan.

Relationships of IAG with other Organizations and Projects

- The relationships between IAG and FIG (Fédération Internationale des Géomètres) are being intensified, e.g.,
  - by a keynote speech of the IAG president at the FIG working week in Athens,
  - by (originally strong) IAG participation at ***FIG regional conference in Jakarta (October 2004)***,
  - by strong FIG participation in IAG Scientific Assembly in Cairns (August 2005).

Relationships of IAG with other Organizations and Projects

- IAG and FIG are members of the **Joint Board of the Spatial Information Societies (JBSIS)**, the successor of IUSM.
- JBSIS meets annually at one of the meetings of its members (IAG, FIG, ISPRS, ICA, IHO, IMTA).
- Information exchange and a common representation w.r.t. other organizations are key issues.
- The JBSIS met in 2003 in Durban, South Africa, and in July 2004 in Istanbul, Turkey.

Relationships of IAG with other Organizations and Projects

- IAG is working in the ***Action Team on Global Navigation Satellite Systems,*** established under the auspices of the UN Office of Outer Space Affairs in Vienna. ***-->Memo of Understanding?***
- IAG is vitally interested in these activities, since the IGS has the leadership in high-accuracy civil applications of GNSS.
- An ***international committee on global navigation satellite systems***, to work under the auspices of UNO, is proposed by the action team.

Message to Engineering and Policy Makers

- Space age revolutionized geodesy&surveying
- A new ***geodetic infrastructure*** was created
  - providing a unique global reference system
  - promising a unification of geometry and gravity on the 10^{-9}-level.
- This infrastructure is the basis for meaningful research in Earth sciences *and* for application.
- Stability over about thirty years is required!
- Our forefathers creating IAG and FIG set out the good example!

Message to Engineering and Policy Makers

- Stability asks for
  - international coordination on the scientific level
  - close collaboration on the administrative level
  - a political umbrella (GEO?, UNESCO?, ...).
- Scientists and professionals, organized in organizations like IAG, FIG, .., have to work with policy makers to achieve the stability of the geodetic infrastructure for 30 years.