The Role of Geodesy – GGOS & Future Trends

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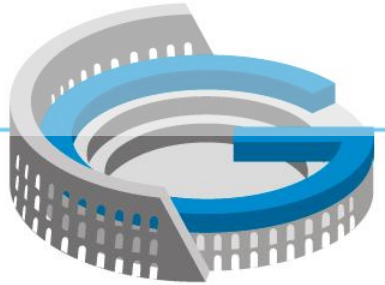
President IAG

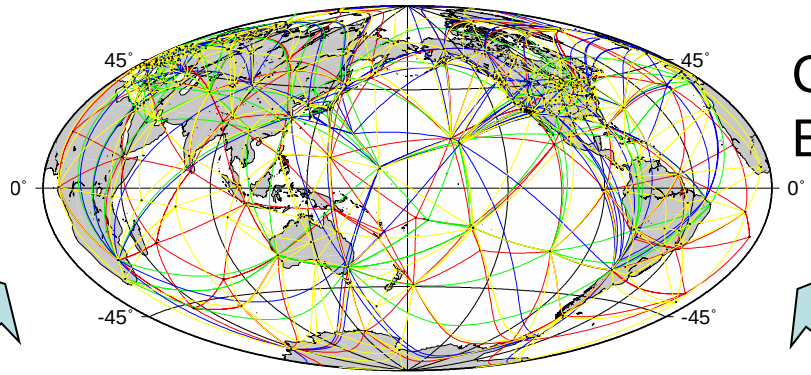
1. The Role of Geodesy

Dual Nature of Geodesy

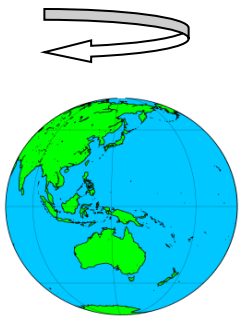
- Geodesy is the *foundation* for the representation of horizontal & vertical position (& its variation) in global or national reference frames, primarily to support societal needs for geospatial data.
- Geodesy is also a *fundamental* ***Geoscience*** that uses a wide range of earth observation & space technologies (satellite, aerial, vehicle, terrestrial platforms) that contribute to our understanding of the "System Earth", *and in particular its dynamics and geometry/gravity interactions*.



The Classical "Pillars" of Geodesy

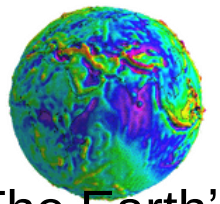


Geometry of the Earth's Surface(s)



Earth Rotation and Polar Motion (EOP)

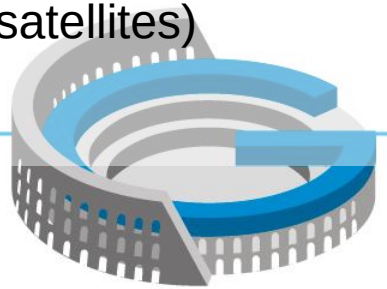
Reference Frames (Terrestrial and Celestial Geometry and Gravity Position and Time)



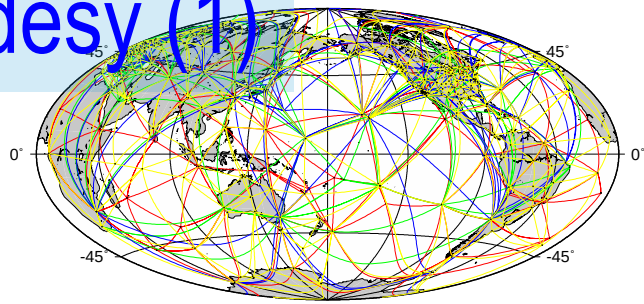
The Earth's Gravity Field

Classical Geodesy Roles

- *Positioning*
  - Global & national horizontal & vertical datums
  - Precise positioning technologies & procedures
  - Precise geodetic network computations
  - Bathymetry & mapping
- *Earth Orientation*
  - Length of Day
  - Transformation between Terrestrial & Celestial Reference Frames
  - Momentum of Inertia (mass transport) studies
- *Gravity Field*
  - Geoid model
  - Gravity measurements, gravity anomalies (ground, aircraft & satellites)
  - Earth tides studies & GEMs



The Classical Challenges of Geodesy (1)



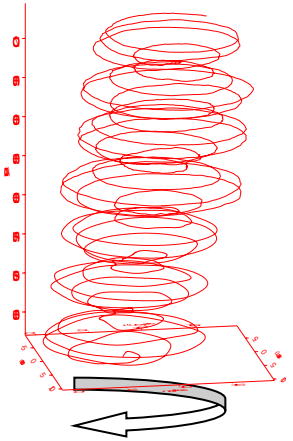
Geometry of the Earth's Surface(s)

- National geodetic control networks
- Precise angle & distance measurement
- Atmospheric refraction
- Ellipsoidal calculations & map projections
- Large geometric system LSE & error theory
- Geodetic survey technology

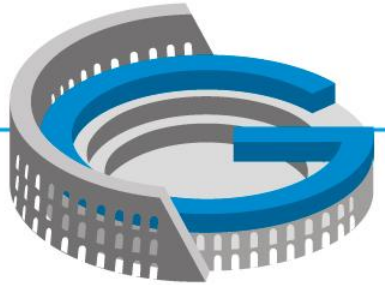
Peter Apian's *Geographia* 1533

The Classical Challenges of Geodesy (2)

Earth Rotation and Polar Motion



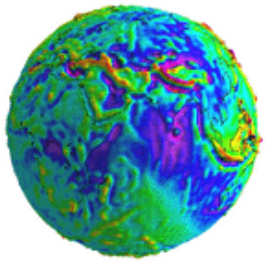
- Positional astronomy
- Earth/mass/inertia & SEMs
- Reference frame transformations
- Ocean-atmosphere-solid earth coupling
- Astronomical & space geodesy technology

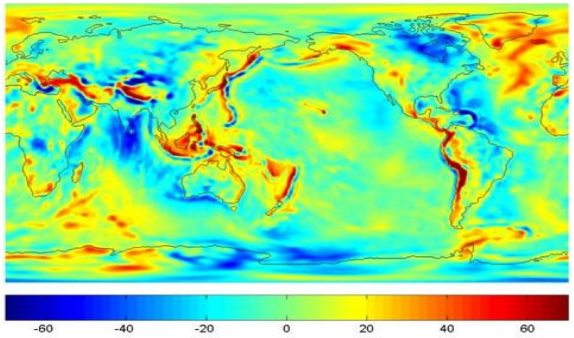


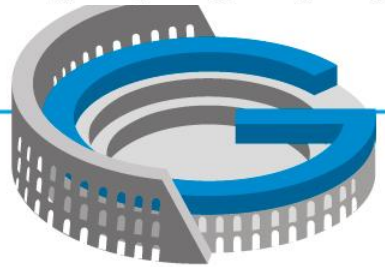
The Classical Challenges of Geodesy (3)

- GBVP & potential theory
- Gravity anomalies & DoV
- Unification of geometry & gravimetry
- Surface gravity data limitations
- Height datums
- Satellite GFMs
- Astronomical & space geodesy technology
- Satellite altimetry
- Absolute & relative gravimetry

The Earth's Gravity Field







Yet...

The Beginnings of a Geodetic Renaissance

- Geodesy joins the ranks of "big science"… e.g. *satellite missions*
- Big, expensive observatories… *SLR, VLBI, etc.*
- Exotic data types… *analysis centres, services, value-added products, etc.*
- Accuracy far greater than required for National Mapping... *"Geodetic science"*
- "Globalisation" of geodesy, e.g. WGS84, ITRF, GEMs
- *Widespread availability of low-cost geodesy tools... GPS geodesy*

Modern Geodesy

Geodesy now defined in terms of the following *capabilities*:

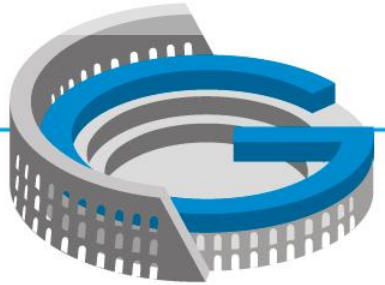
1. Determination of precise global, regional & local 3-D (static or kinematic) *positions on or above the Earth's surface.*
2. Mapping of *land, sea & ice surface geometry*.
3. Determination of the Earth's (time & spatially) *variable gravity field.*
4. Measurement of *dynamical phenomena*:

   - *Solid Earth (incl. cryosphere)*: surface deformation, crustal motion, GIA, polar motion, earth rotation, tides, water cycle, mass transport, etc.
   - *Atmosphere*: refractive index, T/P/H profiles, TEC, circulation, etc.
   - *Ocean*: sea level, sea state, circulation, etc.

Geodesy Drivers

Complexity *of the "System Earth" requires increasingly sophisticated and integrated observing systems & modelling, in order to detect the "fingerprints" of* ***Global Change*** *and* ***Earth dynamics****.*

Helplessness *in the face of* ***natural disasters*** *reminds us that our knowledge of the Earth's complex system is* ***rather limited*** *and we have* ***low predictive capability****.*



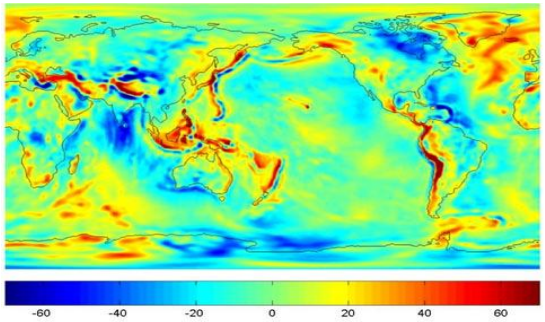
IAG/FIG Commission 5/ICG Technical Seminar

Reference Frame in Practice

Rome, Italy 4–5 May 2012

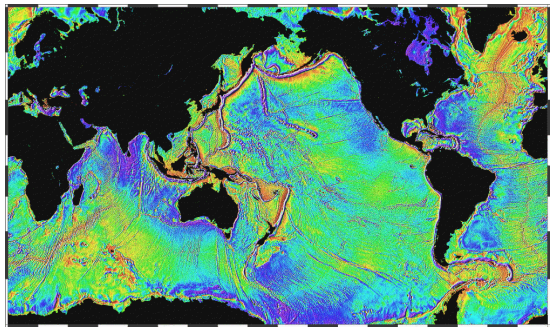
Climate Change:

- How much is sea level changing here?
- How is the atmospheric circulation changing?
- How is the Water Cycle changing?
- How do the Earth, Atmosphere and Oceans exchange energy?



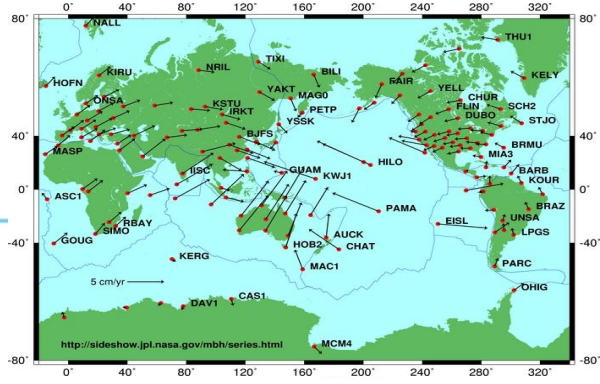
Geohazards:

- Is stress building on this fault?
- Has a tsunami wave been detected?
- Is there an impending volcanic explosion?
- What is the ground & structural deformation?



Environmental:

- What is the mesoscale ocean circulation?
- What is the pattern of the atmospheric water vapour?
- How is the pattern of ground water & soil moisture changing?
- What is the volume of ice being lost in the Arctic/Antarctic?



Sponsors:

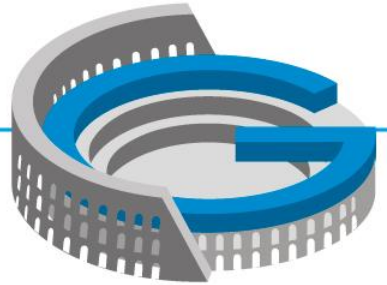
esri Trimble CIPAG

Geospatial Drivers

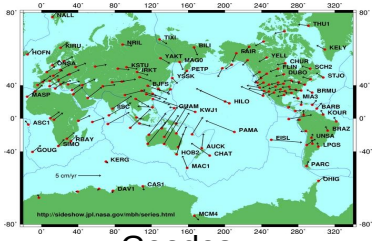
*There is an insatiable demand for **geospatial data** driving development of new mapping technologies...*

*There is an ever increasing need for accurate, reliable and available **positioning capability** to support many functions in modern societies...*

GNSS is the technology that has revolutionised navigation, surveying & geodesy...



Building Construction



Geodesy

PP GNSS Apps

- Surveying & mapping
- Precise kinematic apps, such as machine guidance/control
- Define/monitor datum, geodesy apps, etc.
- Precise georeferencing of airborne or terrestrial scanning/imaging sensors

Monitoring

Rapid Mobile Mapping

Port Operations

Land Surveying

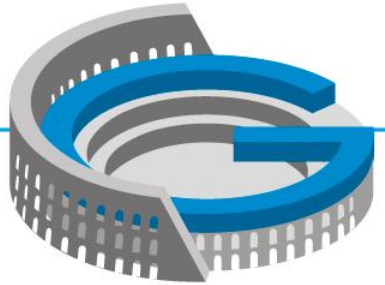
Machine Guidance

Precision Agriculture

GNSS has made Geodesy more accessible & more relevant than ever before...

Society wants reliable, rapid, real-time, high accuracy, cost-effective, positioning capability, in well-defined datum, with minimum constraints...

GNSS Geodesy seeks to address this goal.



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   - *Ocean*: sea level, sea state, circulation, etc.

Modern Geodesy...reinterpreted via GNSS

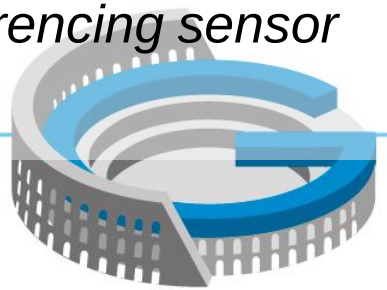
Modern Geodesy... *its debt to GNSS*

Geodesy can now be defined in terms of the following *capabilities*:

1. Precise GNSS positioning *on or above the Earth's surface.*
2. Precise imaging/scanning sensor georeferencing.
3. Precise gravity sensor georeferencing.
4. Sensor georeferencing, coordinate change monitoring & GNSS measurement modelling/analysis.

The Value of Geodesy & GNSS to Society

- **Fundamental geoscience**… *solid earth geophysics, atmospheric, cryospheric & oceanographic processes, hydrology*.
- **Global Change studies**… *climate change, water cycle & mass transport, sea level rise, mesoscale circulation, GIA, polar*… long-term monitoring.
- **Geohazard research & disaster response**… *seismic, volcanic, landslip, storms, flooding, tsunami, space weather*… early warning systems.
- **Geodetic reference frames**… *ITRF, national datums, SDI, gravity, timing*.
- **Engineering**… *PNT, atmospheric remote sensing, georeferencing sensor platforms, POD...* operational & engineering geodesy.



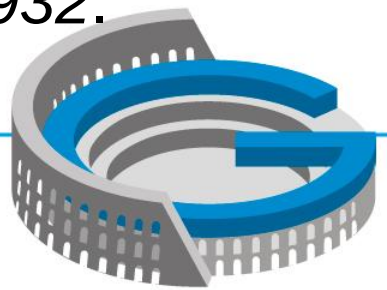
2. Geodesy: The International Structure

150th Anniversary

1862-2012

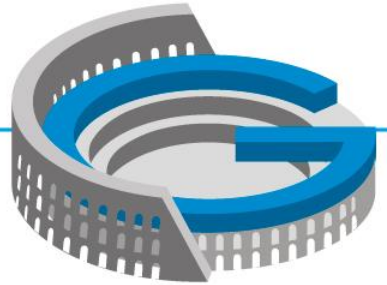
Founding of the IAG

- The International Association of Geodesy (IAG) is one of the oldest of the international scientific bodies, dating from 1862... *the "Mitteleuropäischen Gradmessung"*.
- Fruitful period ("golden era") under Baeyer (died 1865) and then Helmert (died 1917), with Central Bureau at Potsdam, Germany.
- The IAG fundamentally changed after WWI... *International Union of Geodesy & Geophysics (IUGG) founded 1919, IAG joins few years later, current name agreed to in 1932*.



IAG... *balancing its priorities*

- Coordinating & advancing geodetic practice across central europe (later globally), and to address scientific challenges in geodetic/earth science... *hence has always had both government/pragmatic and scientific/academic agendas*.
- The “balance” between practical outcomes (including mapping datums) and an emphasis on scientific studies (and “geodetic theory”) has always been a delicate one.
- *In the last few decades the establishment of IAG Services harks back to the origins of the IAG*.



IAG Services

Geometry

IERS: International Earth Rotation and Reference Systems Service
(ILS in 1899, BIH in 1912, IPMS in 1962, IERS in 1987)

IGS: International GNSS Service *(1994)*

IVS: International VLBI Service *(1999)*

ILRS: International Laser Ranging Service *(1998)*

IDS: International DORIS Service *(2003)*

Gravimetry

IGFS: International Gravity Field Service *(2004)*

BGI: Bureau Gravimetrique International *(1951)*

IGeS: International Geoid Service *(1992)*

ICET: International Centre for Earth Tides *(1956)*

ICGEM: International Centre for Global Earth Models *(2003)*

IDEMS: International Digital Elevation Models Service *(1999)*

Ocean

PSMSL: Permanent Service for Mean Sea Level *(1933)*

IAS: International Altimetry Service *(2008)*

Std

BIPM: Bureau International des Poids et Mesures *(Time 1875*)

IBS: IAG Bibliographic Service *(1889)*

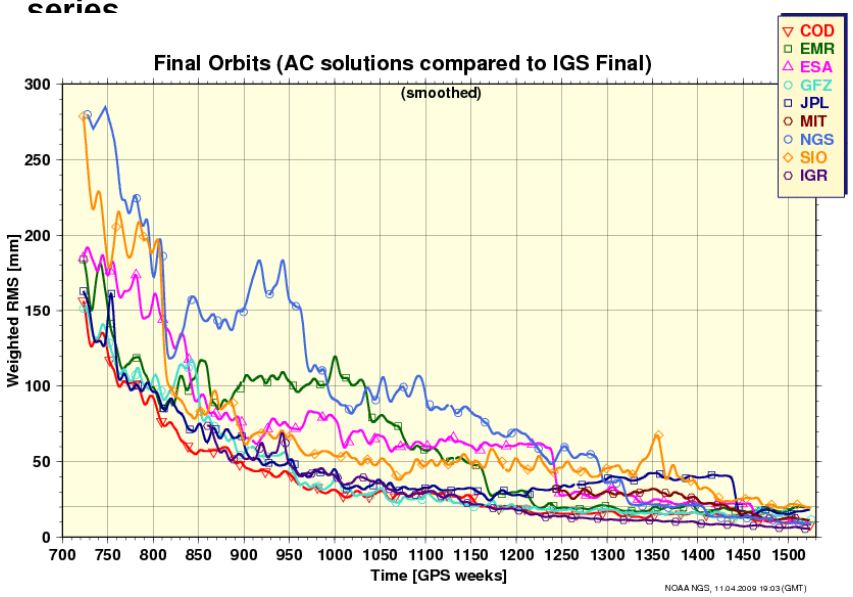
What the IGS Pioneered…
& why the IAG is so proud of it

- **Products**… *highly professional, operational service with performance far better than any other GPS service provider… trailblazer for other IAG services*.
- **Democratisation**… *of geodetic technologies & knowhow… involving organisations & agencies from many countries.*
- **Dense global coverage**… *engaging with station operators around the world, promoting IAG ideals*.
- **Adaptability**… *ability to extend & maintain tracking network… experiment & develop new products… with inbuilt "self-improvement" mechanism.*
- **Engagement**… *scientific & professional organisations… respected "brand" with unrivalled GNSS expertise… encouraging open & inclusive "culture" across the geodetic community.*

International GNSS Service

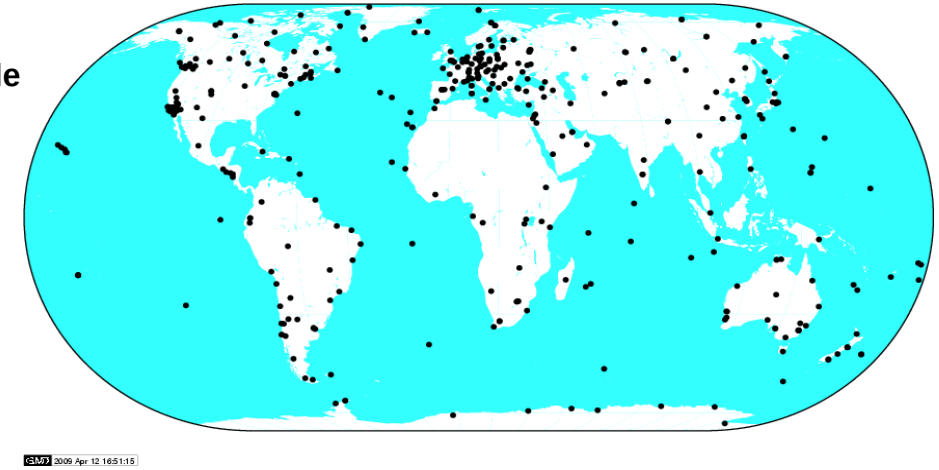
The IGS is a voluntary federation of more than 200 worldwide agencies in more than 90 countries that pool resources and permanent GPS station data to generate precise GPS products.

Many satellite missions, earth science missions and multidisciplinary applications, rely upon the openly available IGS products such as ephemerides and coordinate time series



IGS products are formed by combining independent results from each of several Analysis Centres. Improvements in signals and computations have brought the centres' consistency in the Final GPS satellite orbit calculation to ~ 2cm.

Graph courtesy Analysis Coordinator J. Ray, NOAA, NGS



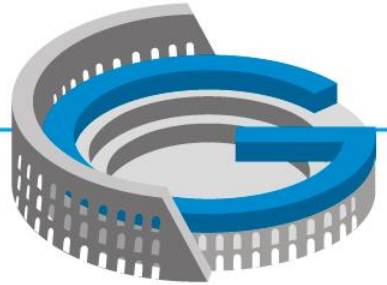
Over 400 permanent tracking stations operated by more than 100 worldwide agencies comprise the IGS network. Currently the IGS supports two GNSS: GPS and the Russian GLONASS. IGS plans to include Galileo, Compass ad QZSS once available.

GPS Applications in IGS Projects & Working Groups

- IGS Reference Frame
- Timing and Precise Clocks
- Ionosphere WG
- Antenna Calibration WG
- Bias and Calibration WG
- LEO WG
- Troposphere WG
- Sea Level - TIGA Project
- Real-Time WG
- Data Center WG
- GNSS WG

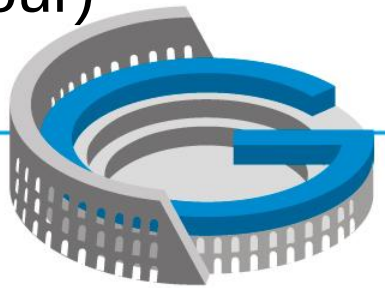
http://igs.org

- By the late 1980's, the potential of GPS for geodesy & geodynamics was realised by many organisations:
  - Announcement of Opportunity 1991: *International GPS Service for Geodynamics* (until 1999, then simply IGS)
  - Start of 3 month Test Campaign 21 June 1992
  - IGS became an official service of the IAG in January 1994
  - Became the **International *GNSS* Service** March 2005
- Key to approach: sharing investments and operational costs by pooling the resources of many organisations to establish an independent ground segment and generate high accuracy products... ***operates on "best efforts" basis, reliability through redundancy, with all products freely available to all users***.



Current IGS Products

- Precise GNSS orbits (post-processed & predicted):
  - GPS (3-5 cm, 3Dwrms), predictions (<5-10 cm)
  - GLONASS (~5-10 cm, 3Dwrms)
- GNSS clock corrections (satellite & stn: sub-ns)
- Earth orientation parameters (polar motion, PM rate, LOD)
- Ground positioning (sub-cm), definition & *access* to ITRF
- Ionospheric delay mapping
- Tropospheric parameters (integrated water vapour)
- *Tracking data from IGS stations (RINEX files)*



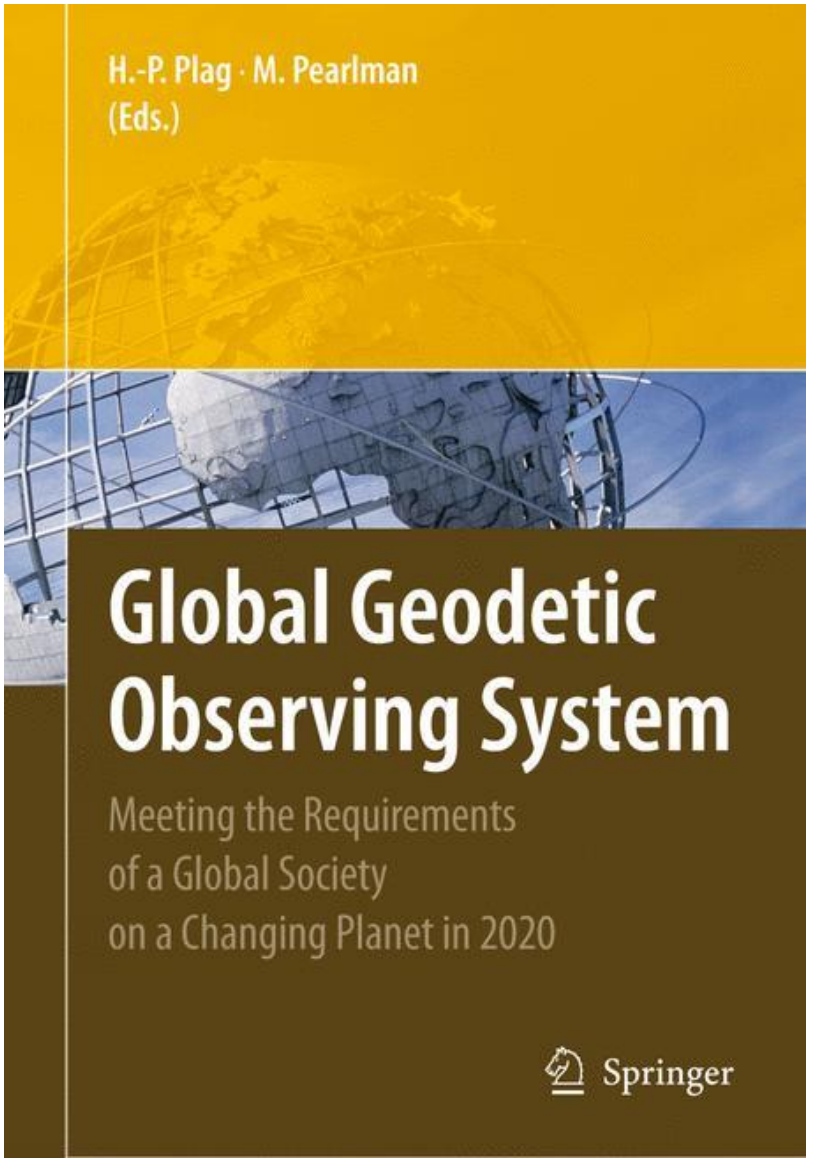
Global Geodetic Observing Sy

- GGOS uses the technologies, method… *Modern Geodesy* to study the "S… spatial and temporal resolution, ac…
- Addresses challenge… …ynamics.
- Possible bec… …ce far in *excess* of geospati…
- R… …on and integration.
- … …ents in space technology, global scientific s… …onal cooperation.
- Ta… …age of IAG's services, *to build a synoptic geo-monitoring serv…*

GNSS(IGS) is critical to delivering on the GGOS vision

GGOS 2020 Plan

- Published by Springer in Summer 2009
- Editors: H.P. Plag & M. Pearlman; many co-authors
- ISBN: 978-3-642-02686-7
- 332 pages, 129.95 €!
  (I have an e-copy)
- Reference book for all GGOS-related activities and planning
- *Excellent resource on Modern Geodesy; its techniques & capabilities*



3. Geodesy: Trends & Challenges

Geodesy Trends

- **Increasing global cooperation...** *vital to addressing GGOS goals*.
- **Scientific geodesy guided by GGOS2020 user requirements**.
- **Order-of-magnitude improvement in accuracy...** *reference frame stability*.
- **Improvements in performance...** *spatial/temporal resolution, timeliness, etc*.
- **Continued reliance on GNSS...** *the ultimate geodetic tool*.
- **Convergence of global geodesy goals/trends with regional & national goals...** *especially wrt datums, GNSS infrastructure, "unified geodesy agendas", etc*.
- **Increasing recognition of geodesy as an „earth observing science" ...** *focus on „change detection" (4D), „geodetic imaging", etc*.

What is GGOS?

continuous

The goal of GGOS can be summarised: improve the accuracy, resolution, reliability & timeliness of geodetic products by an order of magnitude in the coming decade -- 1mm accuracy reference frame & stability of 0.1mm/yr…

by operationalising 'millimetre-geodesy' in order to monitor faint System Earth dynamic effects.

shop" for advanced geodetic products…

http://www.ggos.org

IAG Services

Geometry

IERS: International Earth Rotation and Reference Systems Service

IGS: International GNSS Service

IVS: International VLBI Service

ILRS: International Laser Ranging Service

IDS: International DORIS S

IGFS:

Gravimetry

BGI:

IGeS: I

ICET: I

ICGEM: In Earth Models

IDEMS: International Digital Elevation Models Service

Ocean

PSMSL: Permanent Service for Mean Sea Level

IAS: International Altimetry Service

Std

BIPM: Bureau International des Poids et Mesures

IBS: IAG Bibliographic Service

GGOS...

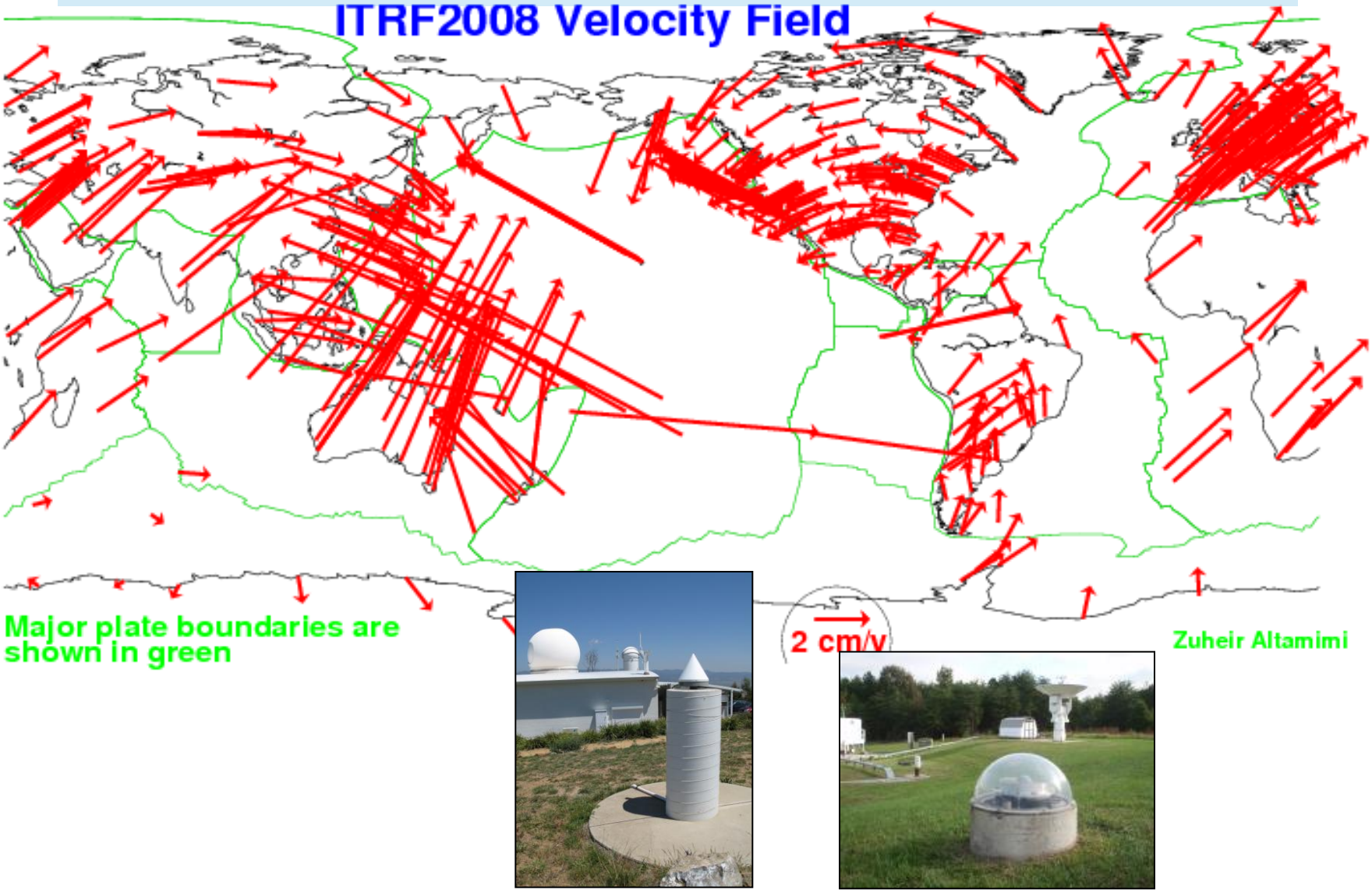
binds them together

Three Themes / Integrated Products

- Theme 1: Global Unified
- Theme 2
- Theme 3

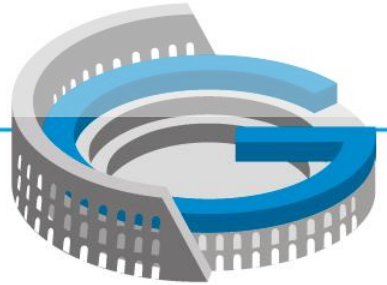
But IAG geodetic services must continue to improve & evolve… independent of GGOS.

E.g. Recognition of ITRF as a Fundamental Basis for all Geospatial Applications



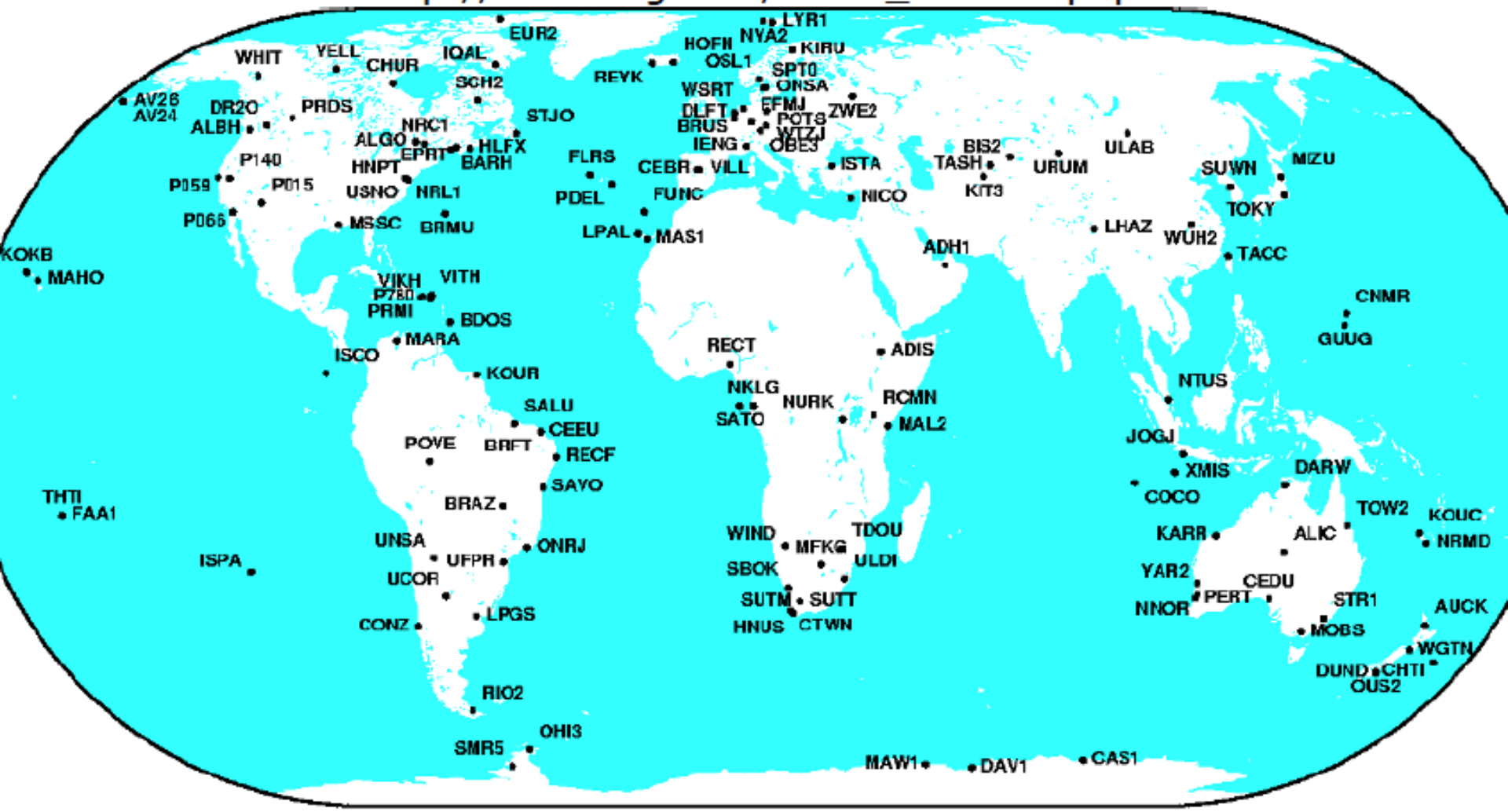
Sorting Out Global Reference Frames

- **ITRF, Height, Gravity, etc...** adoption of fundamental reference frames.
- **Recognition by international standards setting/promotion organisations.**
- **National datums defined/aligned with best global reference frames**.
- **Managing 4D coordinates...** pragmatic solutions for users.
- **Implies embedding geodetic concepts & products into national processes & infrastructure**.
- ***GNSS has special role to play***.



GNSS Tracking Network
Current RT Tracking Network

http://www.rtigs.net/nrcan_monitor.php



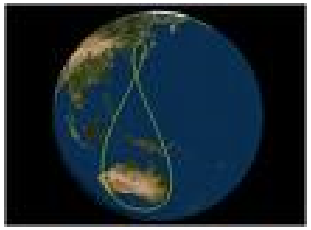
Product Performance Summary

- Accuracy (compared to IGS Rapids)
  - Orbit: 2-5 cm 1-D RMS
  - [illegible]
  - [illegible]
  - [illegible]ation: 20 – 25 sec
- PPP Performance
  - 2-D RMS of 4-5 cm after convergence

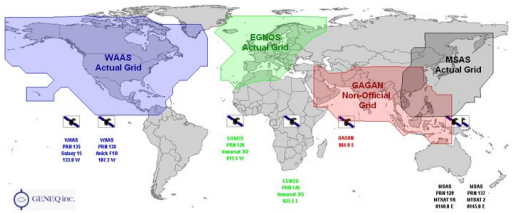
RT-IGS…

Coming in 2012…implications for Precise Positioning as yet unclear

Multi-Constellation GNSS



- Global Constellations:
  - GPS (32)
  - GLONASS (30?)
  - Galileo (30)
  - Beidou (35)
- Regional Constellations:
  - QZSS (3-5+)
  - IRNSS (7)
- SBAS:
  - WAAS (3)
  - MSAS (2)
  - EGNOS (3)
  - GAGAN (2)
  - SDCM (2)

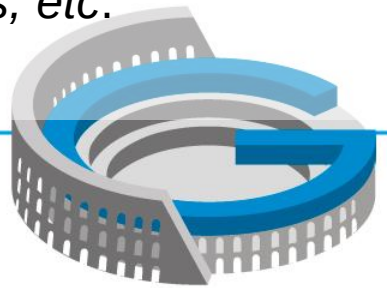


GNSS/IGS Challenges

- **Multi-GNSS era...** *new signals, new obs modelling, new capabilities, new SOPs, new CORS infrastructure*.
- **Increasing demands on CORS infrastructure...** *national & global, geodesy vs "other"*.
- **Implications of PPP**... *datum issues? lowered CORS investment? etc*.
- **Commercial PP...** *how is RT-IGS complementary to commercial alternatives?*
- **Industry standards...** *hardware, data/product formats & protocols, etc*.
- **Geodesy challenges...** *vital to monitor (& possibly influence) GNSS developments*.

Geodesy Challenges

- **Modernisation of the IGS...** *new network stations, new analysis systems, new products, etc*.
- **Managed upgrade of geodetic technology & infrastructure...** *without jeopardising time series continuity, i.e. reference frame integrity*.
- **Embracing GGOS mission & goals**... *ambitious increase in performance*.
- **Increased international collaboration...** *data sharing, commitment, etc*.
- **Continued space agency support...** *satellite missions*.
- **Continued government support...** *ground infrastructure, analysis, etc*.



From Classical to Modern Geodesy...

- From 3D points and terrain, *to 4D mapping of land, sea & ice surfaces*.
- Increased *time* resolution of geodetic measurements & products, *from <10Hz position, to sub-daily EOP, to monthly gravity field models, to annual ice sheet mapping*.
- Increased *spatial* resolution of geodetic products, *from GNSS points, to dm for Lidar, to 1m for SAR, to 100km for gravity features.*
- Increased *accuracy*, *across variety of time scales*.
- Increased variety of satellite missions with geodetic relevance.
- Increased reliance on infrastructure, services & cooperation.