Modern Geodesy, GNSS Surveying, and their Contribution to a Greater Understanding of “System Earth”

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“There has always been a well-defined relationship between geodesy and surveying…with the former providing the foundation/framework for the latter.”

“However, while geodesy's traditional role is being expanded to address the observational and analysis requirements for Global Change studies… GNSS technology allows for more nuanced links between geoscience, operational geodesy and surveying.”
GNSS has revolutionised Geodesy and Surveying...

As a result there has been unprecedented collaboration between geodetic agencies, lands departments and surveyors... the IAG and FIG are now partners on several fronts... though each still have distinct roles & priorities...

What has changed?...

Modern Geodesy is concerned with defining frameworks & using a variety of technologies to monitor CHANGE...
What is Geodesy?

- Geodesy is “the branch of science concerned with:
  - the determination of the size and shape of the Earth
  - the exact position of points on, above or within the Earth, &
  - a description of its variable gravity field.” (Classical defn.)
- Geodesy is also a geoscience that contributes to our understanding of the solid Earth, Atmosphere & Oceans.

The “Pillars” of Geodesy

1. Geometry of the Earth’s Surface(s) and their time variation
2. Earth Rotation and Polar Motion
3. The Earth’s Gravity Field and its time variation
Geodesy’s Contribution (1)

- **Fundamental Spatial Infrastructure**
  - Reference surfaces and reference frames for mapping, surveying, and spatial data: “Digital Earth”, SDI

- **National Reference Datums**
  - 3D & 2D Cartesian coords: mapping & scientific
  - Heights above MSL: height datum
  - Geoid-MSL geometry: height above geoid

- **Global Terrestrial Reference Frames**
  - 3D coords: International Terrestrial Reference Frame - ITRF200x
  - Sea Level height: sea level surface from satellite altimetry
  - Global Gravity Model: static & variable gravity field

- **Global Celestial Reference Frames**
  - International Celestial Reference Frame (ICRF)
  - Polar motion & earth spin rate (EOPs)

Geodesy’s Contribution (2)

- **Point kinematics:**
  - Plate tectonics *global scales*
  - Local deformation *due to faults, landslip, volcanos, subsidence*
  - Structural monitoring *local scales*

- **Surface monitoring:**
  - Differential InSAR *on land*
  - Satellite altimetry *in ocean areas*

- **Gravity field (& Geoid) & its variations**
  - Global, regional & local scales
  - Mass transport studies

- **Earth rotation:**
  - ITRF-ICRF transformation models
  - Scientific studies
Modern Geodesy's Tools…

- Geometric techniques: VLBI, SLR, GNSS, DORIS
- Ocean/ice mapping: satellite radar & laser altimetry
- Topographic mapping: SAR & earth observation missions
- Gravity mapping: CHAMP, GRACE, GOCE missions

All contribute (directly or indirectly) to BOTH the classical function of geodesy & its modern focus as a geoscience…

(1) Permanent Space Geodetic Networks

VLBI

SLR

GPS
(2) Space Missions

**Gravity Mapping**
- **Altimetry**
- **Earth observation, SAR**

**Future Geodetic Observations**

*Missions & Technologies over the next 5-10 years*

**Observations**
- Position, Rotation
- Land Surface
- Topo Ocean, Ice
- Deformation
- Gravity
- Magnetism
- Seismometry

<table>
<thead>
<tr>
<th>Year</th>
<th>Mission/Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>GPS, VLBI, SLR, DORIS</td>
</tr>
<tr>
<td>2004</td>
<td>GPS III, Galileo, VLBI, SLR... dense networks</td>
</tr>
<tr>
<td>2005</td>
<td>SRTM TerraSAR-X</td>
</tr>
<tr>
<td>2006</td>
<td>ARES EnMAP hyperspectral imaging</td>
</tr>
<tr>
<td>2007</td>
<td>ENVISAT, JASON-1, ICESAT, CRYOSAT-2 GPS reflections JASON-2</td>
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<td>2008</td>
<td>CHAMP GRACE</td>
</tr>
<tr>
<td>2009</td>
<td>GOCE laser interferometer mission</td>
</tr>
<tr>
<td>2010</td>
<td>ØRSTED, CHAMP</td>
</tr>
<tr>
<td>2011</td>
<td>SWARM constellations</td>
</tr>
<tr>
<td>2012</td>
<td>denser networks, ocean bottom</td>
</tr>
<tr>
<td>2013</td>
<td>space technologies, INSAR...</td>
</tr>
</tbody>
</table>
Future Geodetic Observations

**Missions & Technologies over the next 5-10 years**

- **Observations**
  - Position, Rotation
  - Land Surface: SRTM, TerraSAR-X, ARES, EnMAP
  - Topo Ocean, Ice: ENVISAT, JASON-1, ICESAT, CRYOSAT-2
  - Deformation: GPS, VLBI, SLR, DORIS, GPS III, Galileo, VLBI, SLR...
  - Gravity: dense networks, GPS reflections, JASON-2
  - Magnetism: ØRSTED, CHAMP
  - Seismology: GRACE, GOCE, laser interferometer mission, LEO clusters
  - Topo Ocean, Ice: TerraSAR-X, ARES, EnMAP

**IAG's Global Geodetic Observing System**

- GGOS integrates different geodetic techniques, different models, different approaches in order to achieve the required long-term consistency, reliability and understanding of the geodetic, geodynamic and global change processes of "System Earth".
- Currently drafting implementation plans.

The BIG challenge for mm-geodesy!
Measuring and Modelling "System Earth"

Space Geodetic Techniques
- VLBI
- SLR/LLR
- GNSS
- DORIS
- Altimetry
- InSAR
- Gravity Missions

Terrestrial Techniques
- Levelling
- Abs./Rel.
- Gravimetry
- Tide Gauges
- Air-/Shipborne

Observation Modelling
- Geometry
  - Station Position/Motion,
  - Sea Level Change,
  - Deformation
- Gravity
  - Geocentre
  - Gravity Field,
  - Temporal Variations
- Earth Rotation
  - Precession/Nutation,
  - Polar Motion,
  - UT1, LOD

Influence / Modelling

System Earth
- Sun/Moon
  - (Planets)
- Atmosphere
- Ocean
- Hydrosphere
- Cryosphere
- Core
- Mantle
- Crust

FIG Working Week, Commission 5, Stockholm, Sweden, 14-19 June 2008

The Global Geodetic Observing System (GGOS)

http://www.ggos.org
GNSS: The Versatile Geodetic Tool

- GPS has progressively taken on ever-increasing importance for all three "pillars" of geodesy.
- Current applications: **POD, point kinematics, atmospheric remote sensing, deformation monitoring**…
- These roles (& more) will increase with multi-constellation GNSS and increases in sophistication of CORS infrastructure.
- *The International GNSS Service (IGS) must evolve in order to address the increased demands of GGOS…*
- *The GNSS CORS infrastructure is a critical IGS component…*

Challenge 1: *From GPS to GNSS*…

2013: 4x no. of satellites, 6x no. of signals!
Challenge 2: From PP to RT…

IGS RT-PP: Objectives

- Manage & maintain a global IGS real-time GNSS tracking network.
- Enhance & improve selected IGS products.
- Generate new real-time products.
- Investigate standards & formats for real-time data collection, data dissemination & delivery of derived products.
- Monitor the integrity of IGS predicted orbits & GNSS status.
- Distribute real-time observations & derived products to users.

http://www.rtigs.net

The IGS: IAG’s First Operational Service

- By the late 1980's, the potential of GPS for geodesy and geodynamics was realised by many organisations:
  - 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 (now ca. 200) organisations to establish an independent ground segment generating high accuracy products … “best efforts” basis, reliability through redundancy, freely available to all users.

http://igscb.jpl.nasa.gov or http://www.igs.org
IGS Product Summary

- Precise GNSS orbits (3-5 cm), predictions (10-20 cm)
- GNSS clock corrections (satellite, ground: sub-ns)
- Earth orientation parameters (polar motion, length of day)
- Ground positioning (sub-cm)
- Consolidated input to International Terrestrial Reference Frame (ITRF)
- Ionospheric mapping (approaching “near real time”)
- Tropospheric corrections (integrated water vapour)

These products are used by a wide range of users in the scientific & professional disciplines.
IGS Product Summary (2)

<table>
<thead>
<tr>
<th>Earth Rotation Parameters</th>
<th>Accuracy</th>
<th>Latency</th>
<th>Update</th>
<th>Sample Interval</th>
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</thead>
<tbody>
<tr>
<td>Ultra-Rapid (predicted)</td>
<td>PM</td>
<td>0.3 mm</td>
<td>2d</td>
<td>four x daily</td>
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<tr>
<td></td>
<td>IGS</td>
<td>0.3 mm/ky</td>
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<tr>
<td></td>
<td>LOO</td>
<td>0.1 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultra-Rapid (observed)</td>
<td>PM</td>
<td>0.3 mm/ky</td>
<td></td>
<td>four x daily</td>
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<tr>
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<td>LOO</td>
<td>0.1 mm</td>
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<td></td>
</tr>
<tr>
<td>Rapid</td>
<td>PM</td>
<td>&lt;0.2 mm/ky</td>
<td></td>
<td>daily</td>
</tr>
<tr>
<td></td>
<td>IGS</td>
<td>&lt;0.2 mm/ky</td>
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<tr>
<td></td>
<td>LOO</td>
<td>0.01 mm</td>
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</tr>
<tr>
<td>Final</td>
<td>PM</td>
<td>&lt;0.2 mm/ky</td>
<td></td>
<td>weekly</td>
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<tr>
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<td>0.01 mm</td>
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<table>
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<tr>
<th>Atmospheric Parameters</th>
<th>Accuracy</th>
<th>Latency</th>
<th>Update</th>
<th>Sample Interval</th>
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<tbody>
<tr>
<td>Final Ionosphere, South</td>
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<td>&lt; 4 weeks</td>
<td>weekly</td>
<td>2 hours</td>
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<tr>
<td>Path, Daily</td>
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<tr>
<td>Final Ionosphere, North</td>
<td>6 mm</td>
<td>3 hrs</td>
<td>every 3</td>
<td>1 hour</td>
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<tr>
<td>Path, Daily</td>
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<td></td>
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<tr>
<td>Final Ionosphere TEC Grid</td>
<td>2-4 TECU</td>
<td>21 days</td>
<td>weekly</td>
<td>3 hours</td>
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Who funds this? Is this good enough? Many countries & organisations benefit from this collective investment.
IGS Ground Network Challenges

Where does the FIG come in?...

GNSS CORS infrastructure to support surveying, mapping, precise navigation applications...

This is a responsibility of government agencies...

Geodesy needs more (not less) GNSS stations, globally distributed, but also locally with high density...
Why the IGS?

- IAG service, global CORS network, freely available data & products to all users...
- Supports: ITRF, regional densification, GGOS...
- The IGS CORS network is mostly provided by FIG-relevant national agencies.
- The IGS needs an upgraded CORS infrastructure, that is true GNSS-capable, with real-time data streaming...
- Complements (non-IGS) geoscientific networks in U.S., Japan, China...
- New applications need more dense CORS networks, with receiver spacing also suitable for surveying/mapping apps... GNSS geodesy and GNSS surveying side-by-side
Modern Geodesy relies on the contributions of Space Agencies (through space missions), national geodetic/survey organisations (ground infrastructure) and international institutions (providing the framework for collaborative geoscience).

Take home message…

“The FIG through its links to national geodetic/survey agencies is an important ally of the IAG… particularly in ensuring the upgrade and densification of GNSS CORS infrastructure…”