The Global Geodetic Observing System (GGOS): The IAG's Contribution to a Greater Understanding of "System Earth"

Chris Rizos
Vice President, International Association of Geodesy
School of Surveying & Spatial Information Systems,
University of New South Wales, Sydney, Australia.

International Association of Geodesy ... advancing geodesy ...

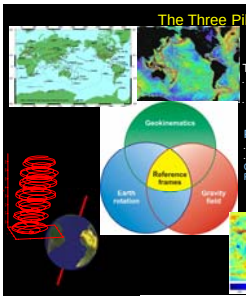
The Global Geodetic Observing System (GGOS): The IAG's Contribution to a Greater Understanding of "System Earth"

- Introduction: the three "pillars" of geodesy
- GGOS: the organisation, the system, the observations
- Some examples of geodesy's contributions to Global Change studies…
  - o GNSS and Geokinematics
  - o Mass Transport and Geodesy
  - o Monitoring the Global Water Cycle
  - o Geodetic Monitoring of Sea Level
- Where to from here for GGOS?

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 the *foundation* for the spatial representation of 3D position, and its variation, in Terrestrial or Celestial reference frames, and supports societal needs in surveying & mapping.
- Geodesy is also a *geoscience* that contributes to our understanding of the solid Earth, Atmosphere & Oceans, *and in particular their dynamics*.

The Three Pillars of Geodesy



The three "pillars":
- Earth Shape (solid & sea/ice surface)
- Earth Gravity Field
- Earth Rotation

Products/Services:
- Reference Frames
- Observations of the Shape/ Geometry, Gravitational Field and Rotation/Orientation of the Earth

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Modern Geodesy's Role as an EO Technique and a Geoscience

Global Change Studies: the changing Earth, Atmosphere and Oceans

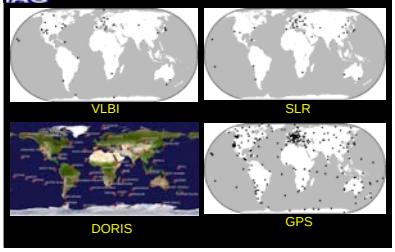
- Climate/global change:
  - Is sea level changing?
  - Is the atmosphere circulation changing?
  - How is Water Cycle changing?
  - How do the Earth, Atmosphere and Oceans interact?
- Geohazards:
  - Is stress building on a fault?
  - Has a tsunami wave been detected?
  - Is there an impending volcanic explosion?
- Environmental:
  - What is the mesoscale ocean circulation?
  - What is the pattern of the atmospheric water vapour?
  - What is the volume of ice being lost in the Antarctic?

"The International Association of Geodesy (IAG) is the oldest of the international scientific bodies, having its origins in the late 19thC… it is part of the IUGG… Modern Geodesy is reaffirming the importance of geodesy to the other geosciences through its IAG Services."

IAG Services

Geometry	IERS:	International Earth Rotation and Reference Systems Service
	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 *(2003)*
	BGI:	Bureau Gravimetrique International
	IGeS:	International Geoid Service
	ICET:	International Centre for Earth Tides
	ICGEM:	International Centre for Global Earth Models
	IDEMS:	International Digital Elevation Models Service
Ocean	PSMSL:	Permanent Service for Mean Sea Level *(1933)*
	IAS:	International Altimetry Service *(in planning)*
Std	BIPM:	Bureau International des Poids et Mesures (Time *1875*)
	IBS:	IAG Bibliographic Service

Permanent Space Geodetic Networks



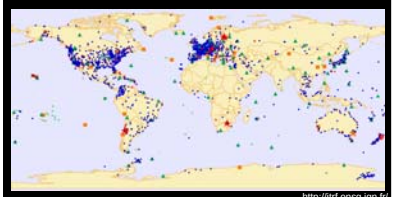
Modern Geodesy's Tools

- 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 to the modern focus of geodesy as a ***geoscience****…*

Fundamental IAG Product of the IERS

International Terrestrial Reference Frame (ITRF)



http://itrf.ensg.ign.fr/

Collocated sites

"IAG is establishing the Global Geodetic Observing System (GGOS) as a response to the challenge of providing the tools & products to monitor & model 'System Earth' dynamics associated with 'Global Change'."

The International Association of Geodesy

The Global Geodetic Observing System

July 2003: Decision of the International Association of Geodesy (IAG) to **establish** a Global Geodetic Observing System (GGOS)

April 2004: IAG/GGOS becomes Participating Organisation of the Group on Earth Observation (GEO) with the goal to contribute to the Global Earth Observing System of Systems (GEOSS)

May 2006: GGOS becomes Member of the Integrated Global Observation Strategy Partnership (IGOS-P)

July 2007: GGOS becomes an **component** of the IAG: *the observing system of the IAG*

July 2009: Publication of the GGOS 2020 Reference & Science Strategy documents

July 2011: "Official" launch of GGOS… *IUGG G.A. 2011*

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The Global Geodetic Observing System

Goals of GGOS

- Promote the data and products of the Services and become the *collective voice for IAG*;
- Collect and archive, through the Services, geodetic observations, products, and models and ensure their consistency, reliability and accessibility;
- Ensure the stability and monitoring of the three fundamental fields of geodesy: *geometry, Earth rotation*, and *gravity field*;
- Identify a consistent set of geodetic products generated by the Services and establish the requirements concerning the products' accuracy, time resolution, and consistency;
- Identify IAG service gaps and develop strategies to close them;
- Stimulate close cooperation between IAG Services;
- Achieve maximum benefit for the scientific community and society in general.

Motivation for Understanding Key GC Processes

Some GC processes are sudden, some are very slow… *most can be destructive if communities are vulnerable…*

Motivation

- **Helplessness** in the face of **natural disasters** demonstrates that our **knowledge** of the Earth's complex system is **rather limited.**
- **Deeper insight** into the processes and interactions within this system is one of the most urgent challenges for our society.
- To monitor changes in the Earth system and the GC processes responsible for natural disasters a **global Earth Observing System** needs to be established… a *GEOSS*.
- Space geodetic techniques, altimetry, InSAR, gravity missions, in-situ measurements, etc., will permit the monitoring of the Earth system with an **unprecedented accuracy**.

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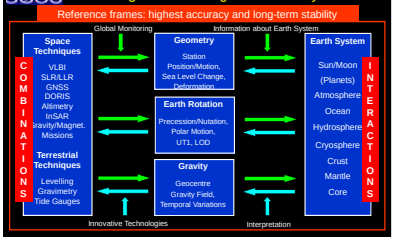
Monitoring and Modelling the Earth's System



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The Global Geodetic Observing System

Processing, Analysis, Combination

- Fully automated processing in near real-time, *or even in real-time*
- Full reprocessing capabilities for all data available, *long consistent time series for long-term trends*
- Combination of all data types at the observation level
- Combination with LEO data, *collocation, gravity, geocentre, atmosphere,…*
- Combination with satellite altimetry data, *and with InSAR*
- Combination with terrestrial data, *e.g. gravity field, levelling,…*
- Combination of different analysis centres, *redundancy, reliability, accuracy,…*

Improvements in modelling, parameterisation, conventions, computing, visualisation, service provision…

GGOS implies…

- *Continued provision of the most accurate and stable geodetic reference frames possible*
- Upgraded ground infrastructure
- Multi-technique "core network" of "super sites"
- Continuous, long-term observations
- "Operationalisation" of geodetic infrastructure & missions
- Global collaboration
- Regional elements, e.g. densification
- Integrated analysis & interpretation
- Reliable products & services of the highest quality
- "One-stop-shop" for geoscientific users
- Addressing user requirements

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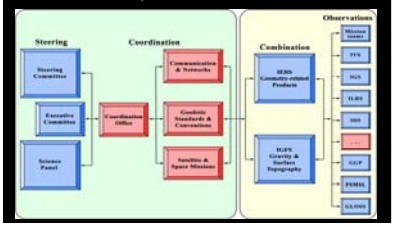
The Global Geodetic Observing System

The Organisation: Integrating IAG Services & other components…



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The System has many technical components…

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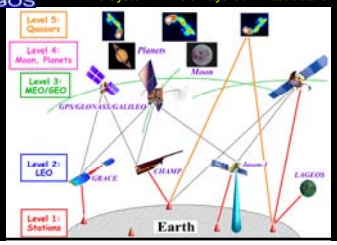
The System: A Multi-Layered Infrastructure



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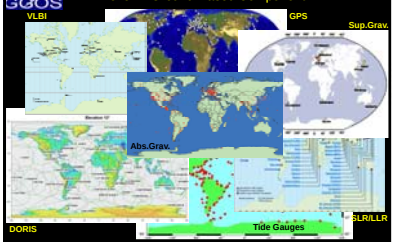
Level 1: Ground-Based Component

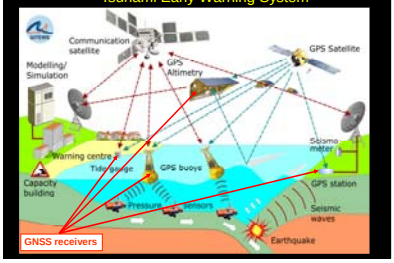


Level 2: Satellite Mission Component

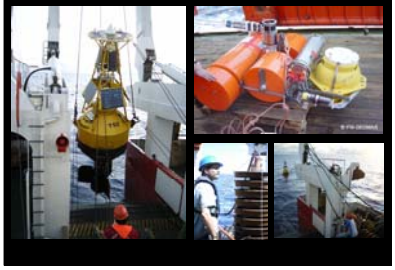
"Because GC signatures are often very small, the technological challenges of GGOS can be summarised very simply… to deliver on the commitment to improve the accuracy, reliability & timeliness of geodetic products by an order of magnitude in the coming decade… towards what we may refer to as ppb or 'millimetre-geodesy'."*

*ppb = parts per billion

Example (Monitoring Point Displacement):
Tsunami Early Warning System

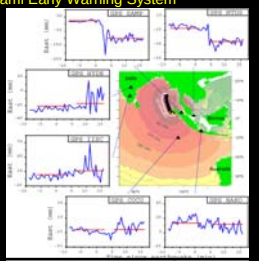


Tsunami Buoy: GPS / OBPU / Seismometer



Example (Monitoring Geokinematics):
Tsunami Early Warning System

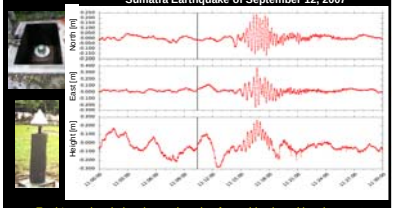
Near-real time determination of ground displacement at permanent sites using GPS



Blewitt et al., 2006

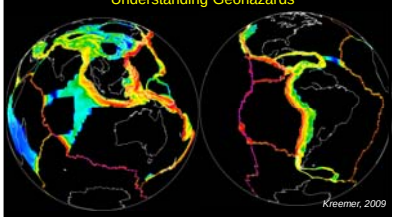
Example (Analysis): Combination of GPS / Seismology

Sumatra Earthquake of September 12, 2007



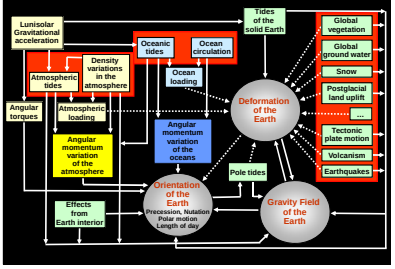
- Earth's motion during the earthquake → combination with seismometers
- Deformation due to the earthquake (magnitude determination, rupture process)

Example (Crustal Dynamics Interpretation): Understanding Geohazards

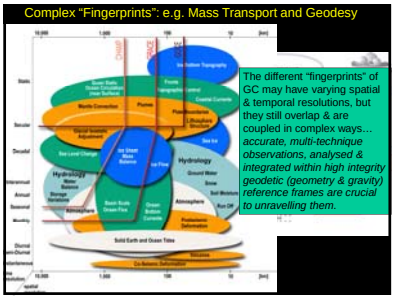


Global Strain Rate Field Derived from Surface Velocities

However, Earth System Modelling is Complex…

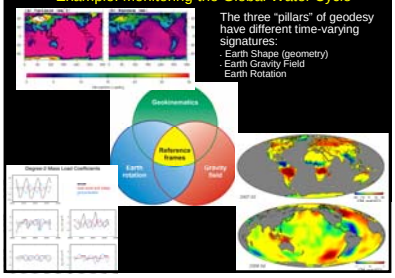


Complex "Fingerprints": e.g. Mass Transport and Geodesy



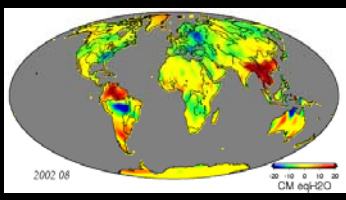
The different "fingerprints" of GC may have varying spatial & temporal resolutions, but they still overlap & are coupled in complex ways… *accurate, multi-technique observations, analysed & integrated within high integrity geodetic (geometry & gravity) reference frames are crucial to unravelling them.*

Example: Monitoring the Global Water Cycle



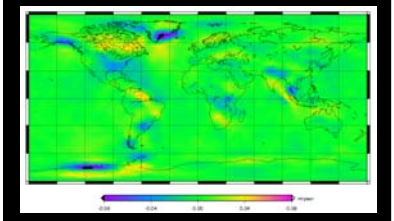
The three "pillars" of geodesy have different time-varying signatures:
- Earth Shape (geometry)
- Earth Gravity Field
- Earth Rotation

Monitoring the Global Water Cycle



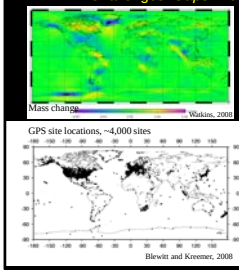
http://grace.jpl.nasa.gov/information/

Monitoring *Trends* in the Global Water Cycle, *due to CC?*



JPL MASCON, secular trends 2003-2007, Watkins, 2008

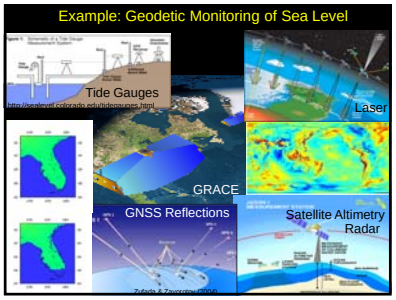
Challenges: *Gaps in coverage…*



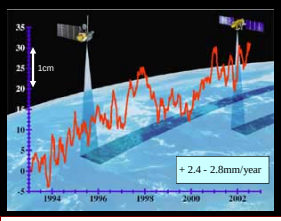
Spatial gaps hamper integration of gravity (left) and ground displacement at GNSS sites (below).

Need increased observations (surface displacements, gravity, mass balance) in areas with large mass changes, in particular:
- Greenland & Svalbard;
- South & S.E. Asia;
- Africa;
- Antarctica & South America.

Example: Geodetic Monitoring of Sea Level

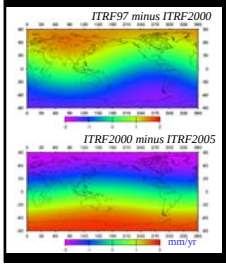


Example: Geodetic Monitoring of Sea Level



How? POD & satellite altimetry, with stable ITRF

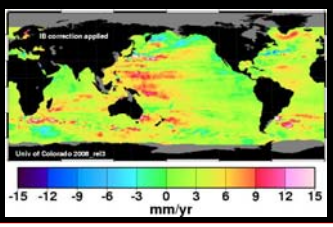
ITRF and Sea Level: Some Challenges



Requirement for global sea level:
- stability of 0.1 mm/yr.

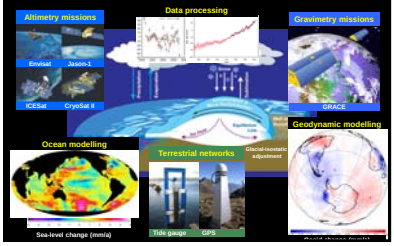
Local vertical land motion:
- Observed vertical rate:
  * typical errors 0.1 – 0.3 mm/yr;
  * uncertainty in reference frame ±2 mm/yr.

Geodetic Monitoring of Sea Level…*interpretation?*



How to separate rise due to thermal expansion from ice melt?

Example (Interpretation & Modelling): Sea Level Change & Ice-Mass Balances



Concluding Remarks

Geodetic observations capture the "fingerprints" of global change phenomena in all three "pillars" (geometry, gravity, rotation).
Integration of the three pillars will give most accurate/reliable results.

Need higher spatial resolution as large spatial gaps hampers full integration. Need long-term, continuous time series of observations to detect trends and signatures.
Major effort to build a stable, long-term core geodetic infrastructure.

Modern geodesy is critically reliant on state-of-the-art space missions.
We need strong geodetic space/satellite programs.

Need to operationalise geodesy and to integrate the solid Earth into "System Earth" models. *We need a major community effort focusing on solid Earth modelling comparable to the efforts on climate modelling.*

GGOS needs…

- Upgraded ground infrastructure, well distributed globally as well as densified in areas of interest
- Global collaboration
- "Core network" of "super sites"
- Space missions to support GGOS
- Continuous, long-term observations
- "Operationalisation" of geodetic infrastructure & missions
- Integrated analysis & interpretation
- Reliable products & services of the highest quality
- Delivered to geoscientific users in a form capable of assimilation into more sophisticated models

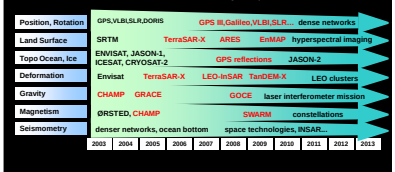
Global Geodetic Core Network… *wishlist*

Core Network (~ 40 Stations with collocated techniques):

- 2-3 VLBI telescopes for continuous observations
- SLR/LLR telescope for tracking of all major satellites
- At least 3 GNSS antennas and receivers
- DORIS beacon
- Ultra-stable oscillator for time and frequency keeping and transfer
- Terrestrial survey instruments for permanent/automated local tie monitoring
- Superconducting and absolute gravimeters
- Meteorological sensors
- Seismometer for combination with deformation from space geodesy and GNSS seismology
- Additional sensors: water vapour radiometer, tiltmeters, gyroscopes, ground water sensors, …

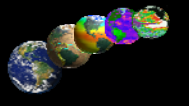
Strong Earth Observation Program…

Satellite Missions & Technologies over the next 5-10 years are fundamental for understanding GC processes



Take Home Message…

"GGOS will continue to rely on the contributions of Space Agencies (through space missions), national geodetic organisations (ground infrastructure) and international institutions (providing the framework for collaborative geoscience)."

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Thank You!