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

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International Association of Geodesy

A Constituent Association of the IUGG

... advancing geodesy ...

"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."

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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…*

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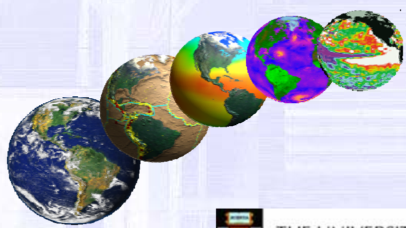
FIG Working Week, Commission 5, Stockholm, Sweden, 14-19 June 2008

What has changed?…

Modern Geodesy is concerned with defining frameworks & using a variety of technologies to monitor *CHANGE…*



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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.

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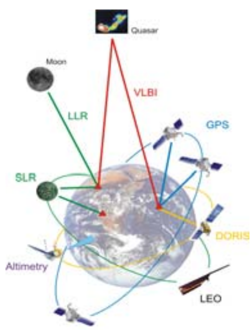
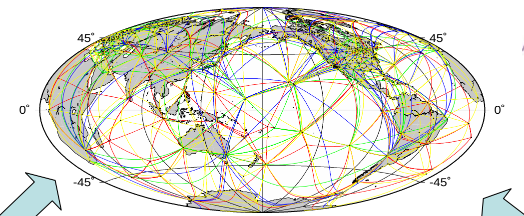
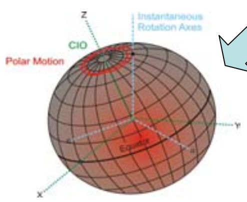
The "Pillars" of Geodesy



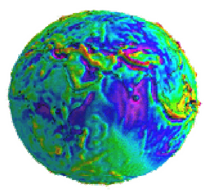
(1) Geometry of the Earth's Surface(s) and their time variation



Reference Frames



(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)

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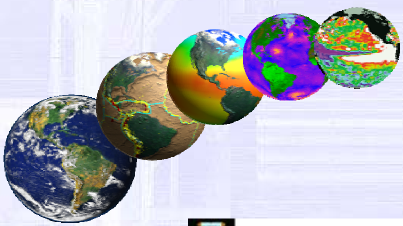
Geodesy's Contribution (2)

- 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



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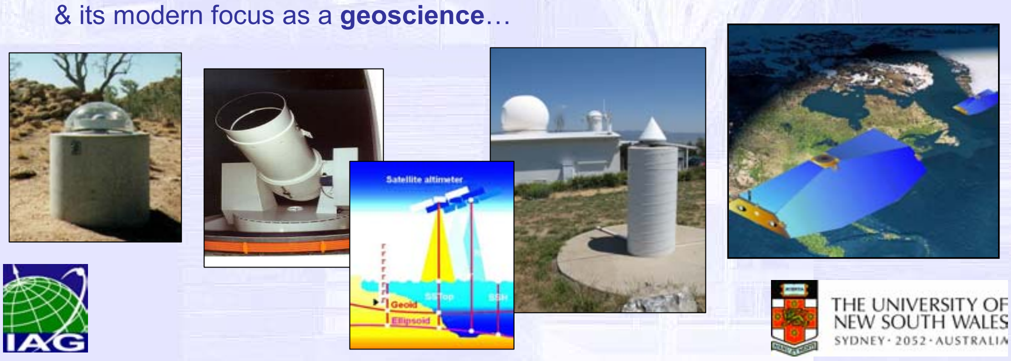
Modern Geodesy's Tools…

- 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**…



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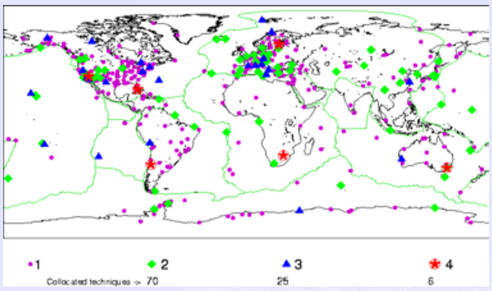
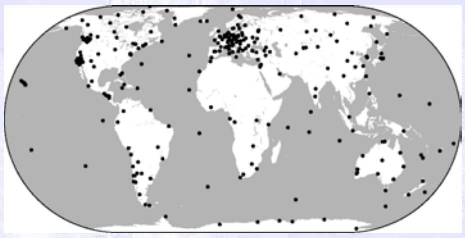
(1) Permanent Space Geodetic Networks

VLBI

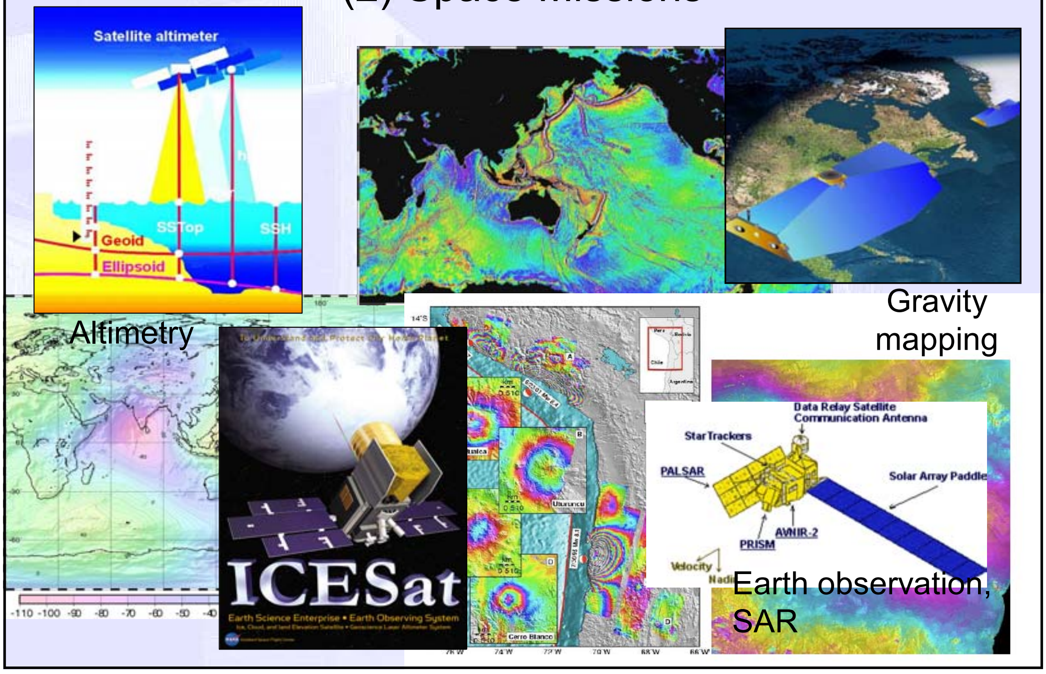
SLR





GPS

(2) Space Missions



Future Geodetic Observations

Missions & Technologies over the next 5-10 years

Observations

Observations	Missions & Technologies
Position, Rotation	GPS,VLBI,SLR,DORIS — GPS III,Galileo,VLBI,SLR... — dense networks
Land Surface	SRTM — TerraSAR-X — ARES — EnMAP — hyperspectral imaging
Topo Ocean, Ice	ENVISAT, JASON-1, ICESAT, CRYOSAT-2 — GPS reflections — JASON-2
Deformation	Envisat — TerraSAR-X — LEO-InSAR — TanDEM-X — LEO clusters
Gravity	CHAMP — GRACE — GOCE — laser interferometer mission
Magnetism	ØRSTED, CHAMP — SWARM — constellations
Seismometry	denser networks, ocean bottom — space technologies, INSAR...

2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013

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FIG

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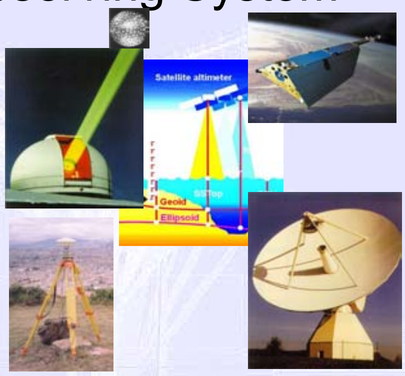
IAG's Global Geodetic Observing System

- 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.



GGOS

The BIG challenge for mm-geodesy!

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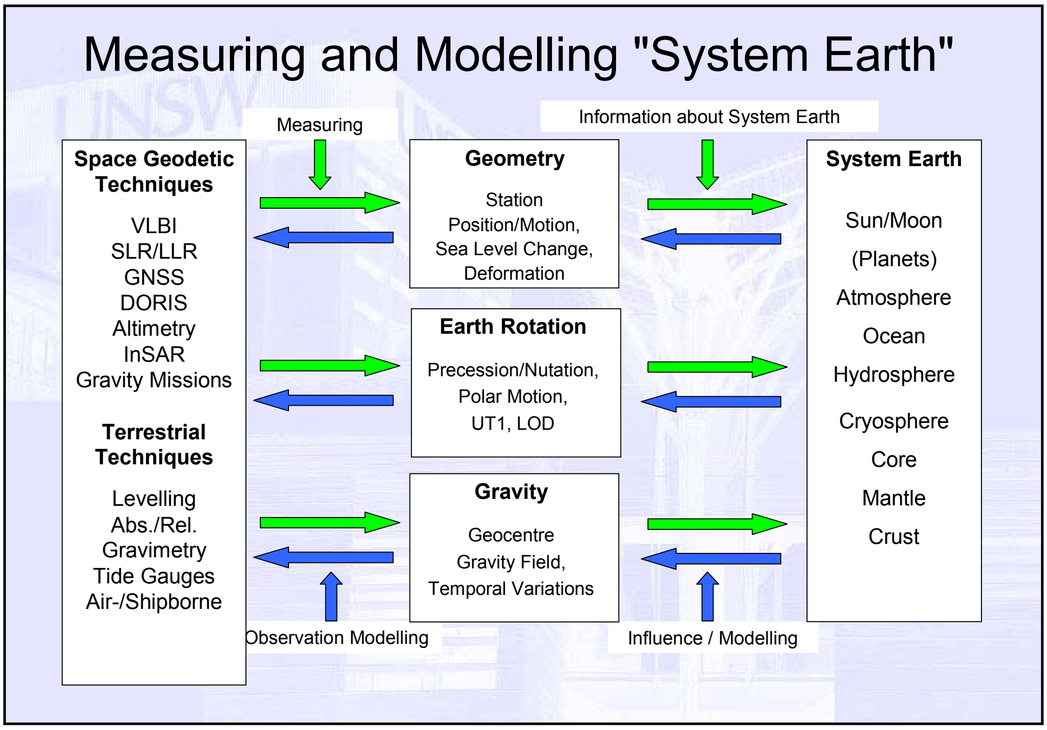
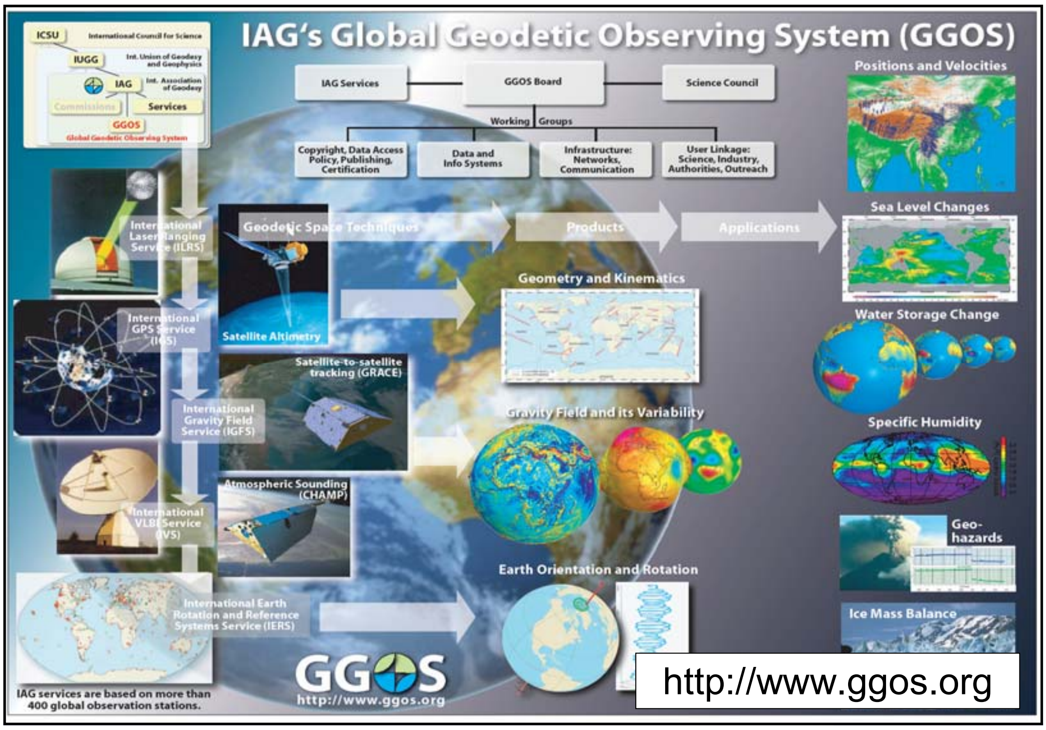


Measuring and Modelling "System Earth"
Measuring
Information about System Earth
Space Geodetic Techniques
VLBI
SLR/LLR
GNSS
DORIS
Altimetry
InSAR
Gravity Missions
Terrestrial Techniques
Levelling
Abs./Rel. Gravimetry
Tide Gauges
Air-/Shipborne
Geometry
Station Position/Motion, Sea Level Change, Deformation
Earth Rotation
Precession/Nutation, Polar Motion, UT1, LOD
Gravity
Geocentre Gravity Field, Temporal Variations
System Earth
Sun/Moon
(Planets)
Atmosphere
Ocean
Hydrosphere
Cryosphere
Core
Mantle
Crust
Observation Modelling
Influence / Modelling



IAG's Global Geodetic Observing System (GGOS)
ICSU
International Council for Science
IUGG
IAG
Services
GGOS
IAG Services
GGOS Board
Science Council
Working Groups
Copyright, Data Access Policy, Publishing, Certification
Data and Info Systems
Infrastructure: Networks, Communication
User Linkage: Science, Industry, Authorities, Outreach
Geodetic Space Techniques
Products
Applications
Positions and Velocities
Sea Level Changes
Water Storage Change
Specific Humidity
Geo-hazards
Ice Mass Balance
Geometry and Kinematics
Gravity Field and its Variability
Earth Orientation and Rotation
Satellite Altimetry
Satellite-to-satellite tracking (GRACE)
Atmospheric Sounding (CHAMP)
International GPS Service (IGS)
International Gravity Field Service (IGFS)
International Earth Rotation and Reference Systems Service (IERS)
IAG services are based on more than 400 global observation stations.
GGOS
http://www.ggos.org
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…*

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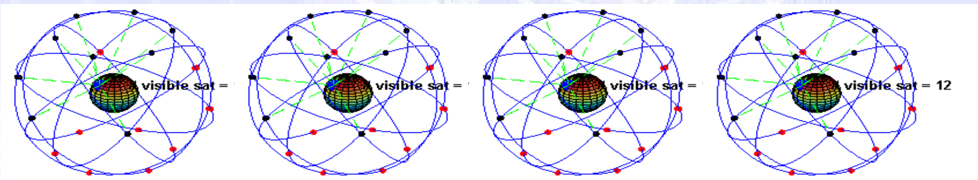
Challenge 1: *From GPS to GNSS…*



GPS III · ГЛОНАСС · GALILEO · COMPASS

2013: 4x no. of satellites,
6x no. of signals!

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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

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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:
  - 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 (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

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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.

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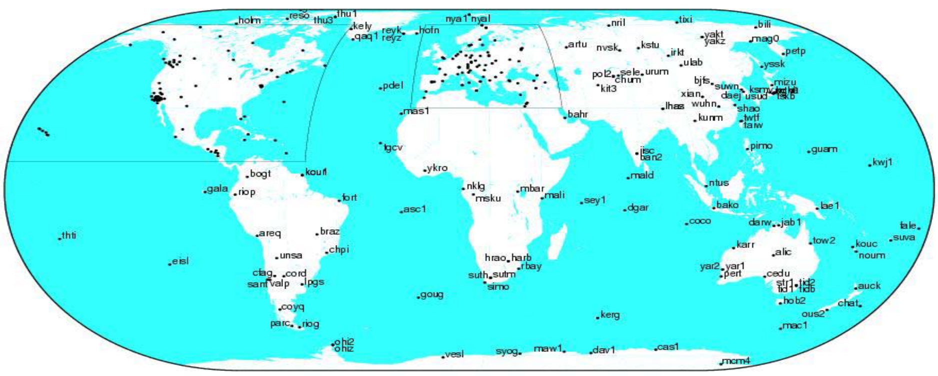
IGS Product Summary (1)

		Accuracy	Latency	Updates	Sample Interval
GPS Satellite Ephemerides / Satellite & Station Clocks					
Broadcast	orbits	~160cm	real time	--	daily
	Sat. clks	~7ns			
Ultra-Rapid (predicted half)	orbits	~10cm	real time	four x daily	15 min
	Sat. clks	~5ns			
Ultra-Rapid (observed half)	orbits	<5cm	3 hours	four x daily	15 min
	Sat. clks	~0.2ns			
Rapid	orbits	<5cm	17 hours	daily	15 min
	Sat. & Stn. clks	0.1ns			5 min
Final	orbits	<5cm	~13 days	weekly	15 min
	Sat. & Stn. clks	<0.1ns			5 min
GLONASS Satellite Ephemerides					
Final		15cm	2 weeks	weekly	15 min
Geocentric Coordinates of IGS Tracking Stations (>130 sites)					
Final positions	horizontal	3mm	12 days	weekly	weekly
	vertical	6mm			
Final velocities	horizontal	2mm/yr	12 days	weekly	weekly
	vertical	3mm/yr			

IGS Product Summary (2)

		Accuracy	Latency	Updates	Sample Interval
Earth Rotation Parameters					
Ultra-Rapid (predicted half)	PM	0.3mas	real time	four x daily	four x daily (00,06,12,18 UTC)
	PM rate	0.5mas/day			
	LOD	0.06ms			
Ultra-Rapid (observed half)	PM	0.1mas	3 hours	four x daily	four x daily (00,06,12,18 UTC)
	PM rate	0.3mas/day			
	LOD	0.03ms			
Rapid	PM	<0.1mas	17 hours	daily	daily (12 UTC)
	PM rate	<0.2mas/day			
	LOD	0.03ms			
Final	PM	0.05mas	~13 days	weekly	daily (12 UTC)
	PM rate	<0.2mas/day			
	LOD	0.02ms			
Atmospheric Parameters					
Final tropospheric zenith path delay		4mm	< 4 weeks	weekly	2 hours
Ultra-Rapid tropospheric zenith path delay		6mm	2-3 hours	every 3 hours	1 hour
Final Ionospheric TEC grid		2-8 TECU	~11 days	weekly	2 hours; 5 deg (lon) x 2.5 deg (lat)
Rapid Ionospheric TEC grid		2-9 TECU	<24 hours	daily	2 hours; 5 deg (lon) x 2.5 deg (lat)

IGS Ground Network



GMT Jun 25 16:10:01 2002

Who funds this? Is this good enough?

Many countries & organisations benefit from this collective investment

IGS Ground Network Challenges

RT-IGS

GPS+Glonass

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...*

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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***

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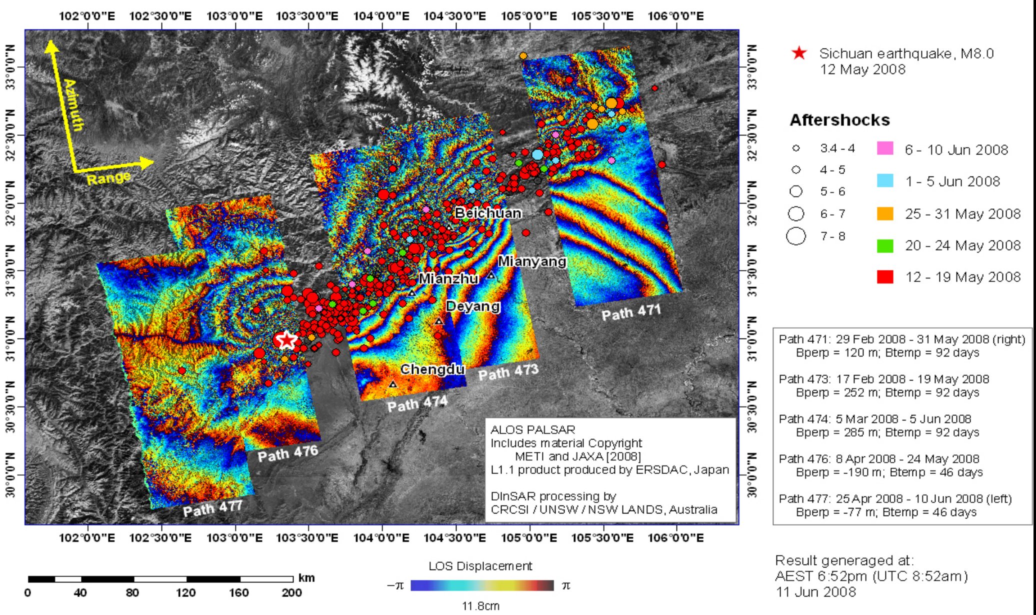

Take home message…

"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)."

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…