The Space Geodesy Project

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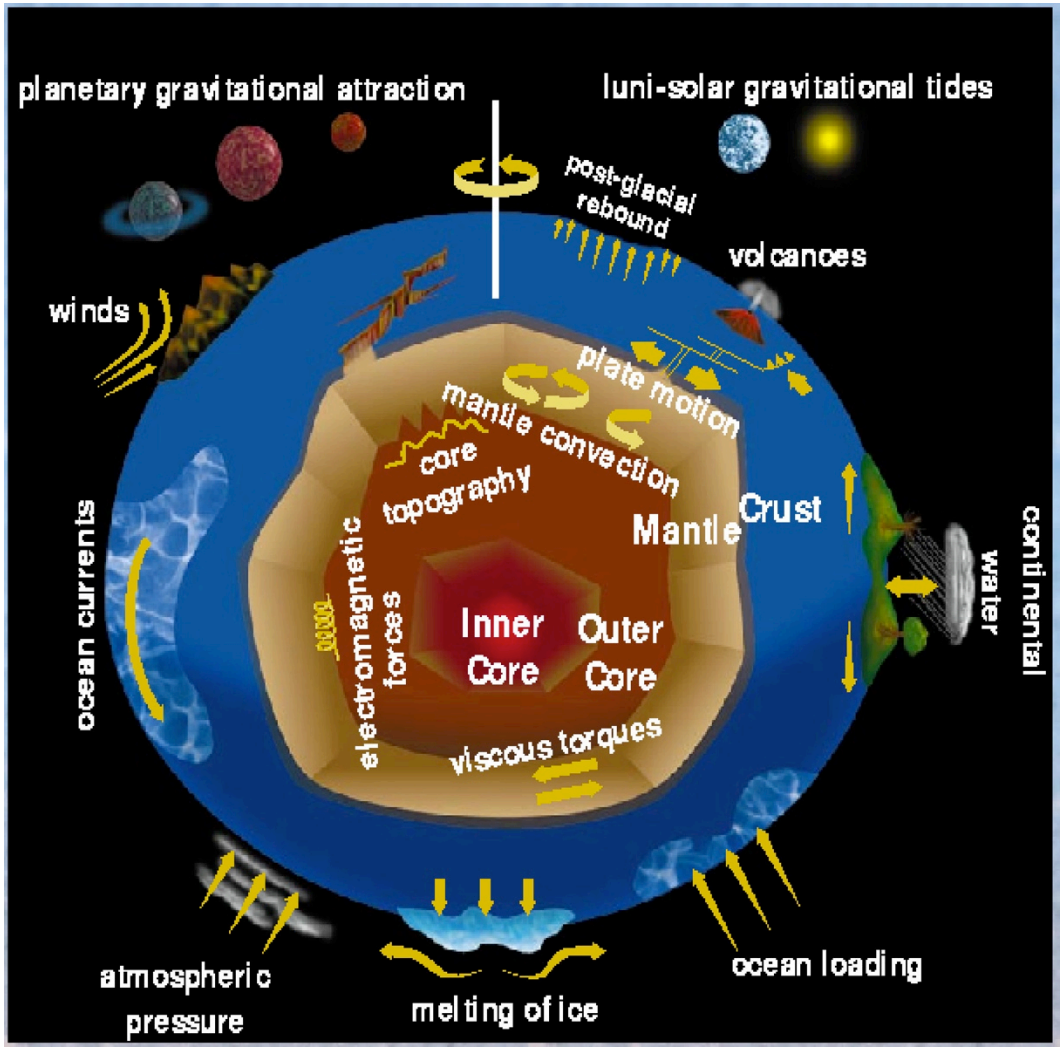
Code 690.2

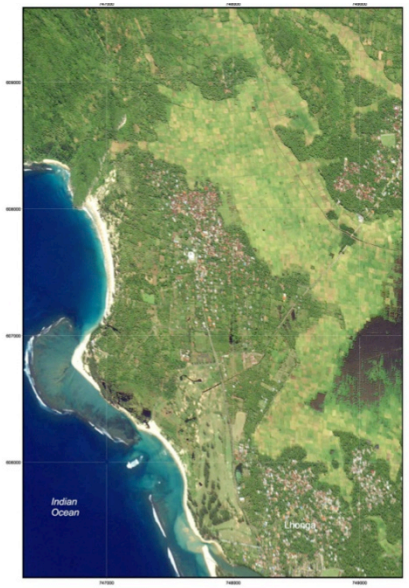
Solar System Exploration Seminar for the Director of Science and Exploration

August 22, 2012

Dynamic Earth



Motivation: Monitoring the Earth System

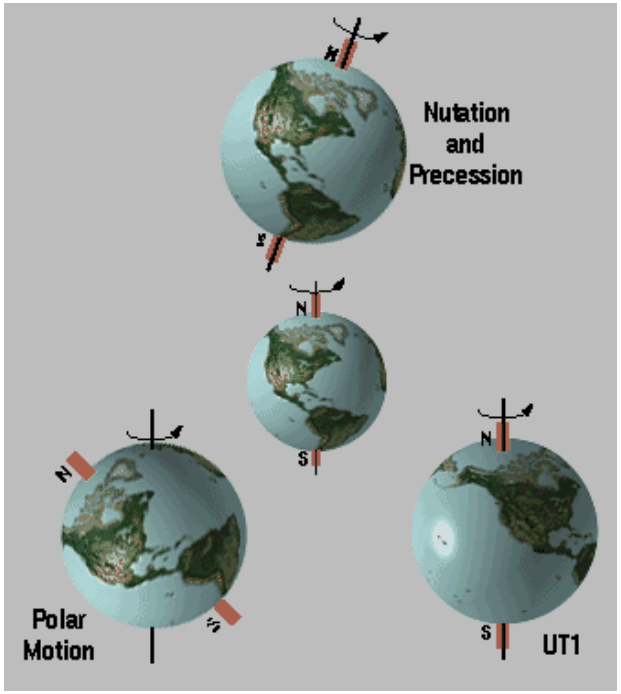


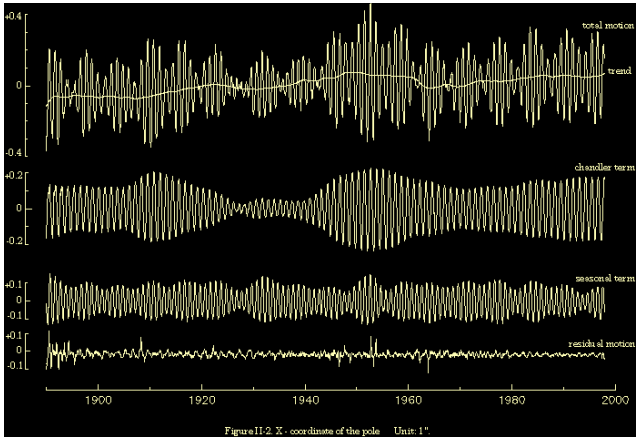
Pillar 1: Geometry and Deformation of the Earth

- Problem and fascination of measuring the Earth:
  - Everything is moving !
- Examples:
  - Plate motions
  - Solid Earth tides (caused by Sun and Moon)
  - Loading phenomena (ice, ocean, atmosph.)
  - Earthquakes …
- Continuous monitoring is absolutely crucial.

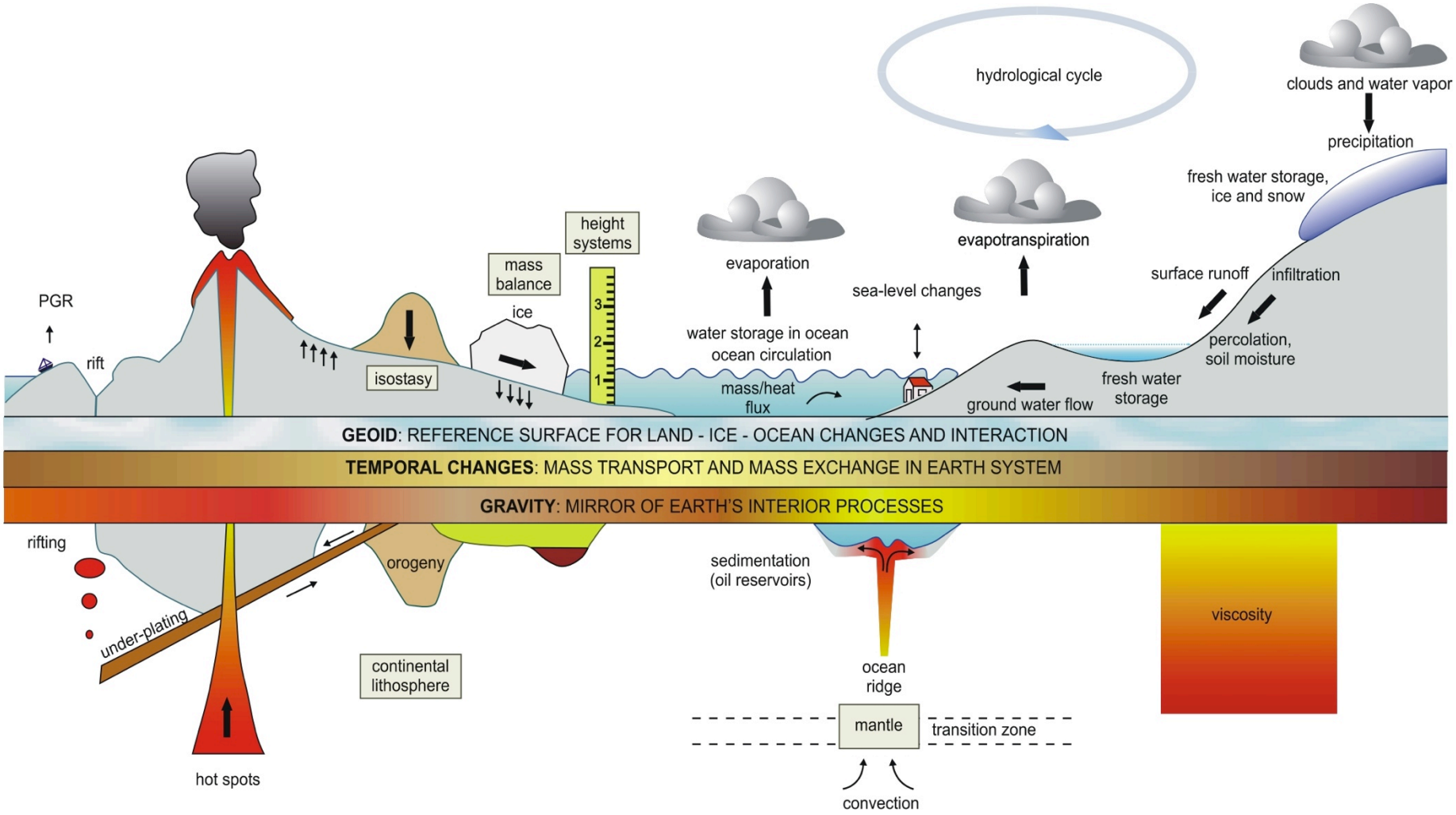
Pillar 2: Earth Rotation

- Earth orientation parameters (EOP) describe the irregularities of the earth's rotation and are required for any positioning and navigation:
  - Universal time
  - Coordinates of the pole (Polar Motion).
  - Celestial pole offsets (Precession and Nutation)



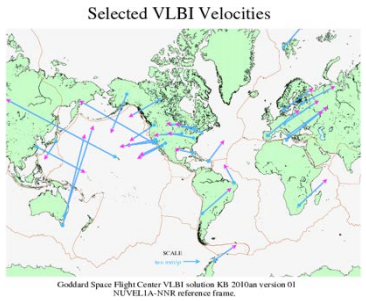


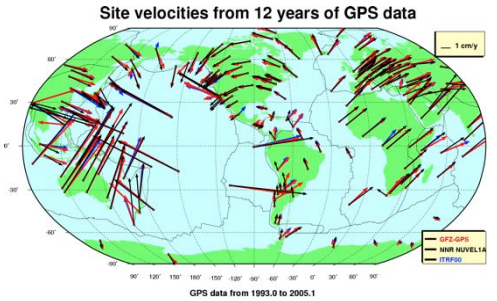
Pillar 3: Gravity Field, Mass Transport

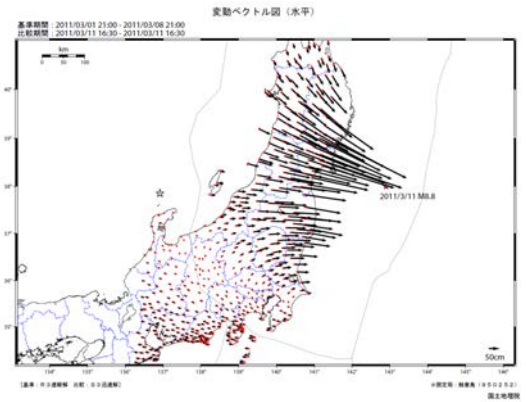


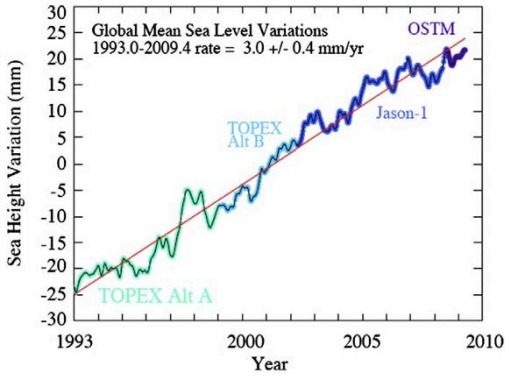
Space Geodesy Applications

- Data from space geodesy measurements archive are utilized for direct science observations and geodetic studies, e.g., plate motion, gravity field, earthquake displacements, Earth orientation, atmospheric angular momentum, etc.
- Real-time data is used for natural hazards monitoring and early warning.
- Data also contribute to the determination of the Terrestrial Reference Frame (TRF), an accurate set of positions and velocities.
- Data used for Precise Orbit Determination (POD).
- Additional products include atmosphere measurements to aid in weather forecasting, etc.
- Measurements provide critical information for accurate deep space navigation.
- GSFC maintains the archival and distribution of the worldwide space geodetic data using the Crustal Dynamics Data Information System (CDDIS).

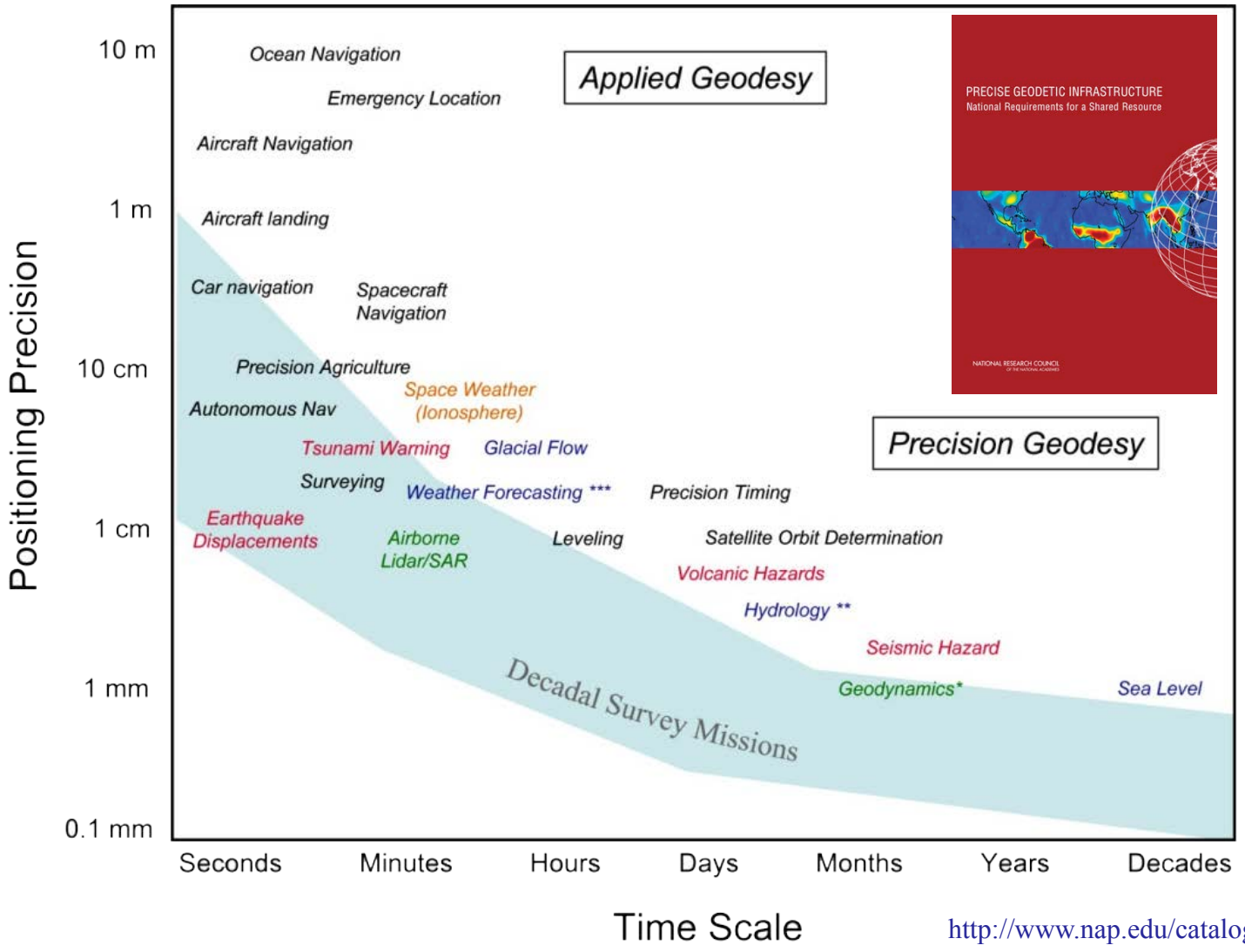








Space Geodesy Provides Positioning, Navigation, and Timing Reference Frames and Earth System Observations



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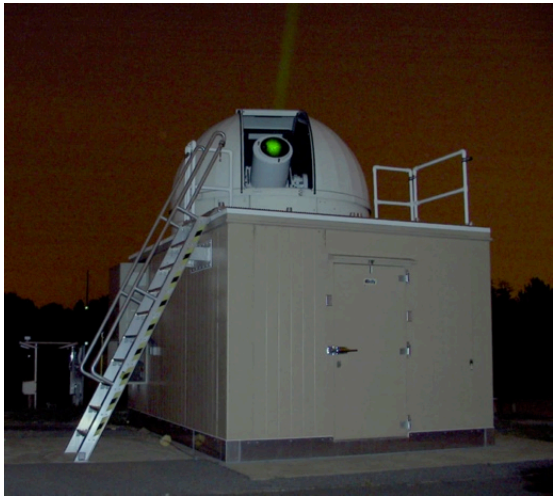
Space Geodetic Systems

Very Long Baseline Interferometry (VLBI)



Satellite Laser Ranging (SLR)

Global Navigation Satellite System (GNSS)

Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)

Satellite Laser Ranging (SLR)

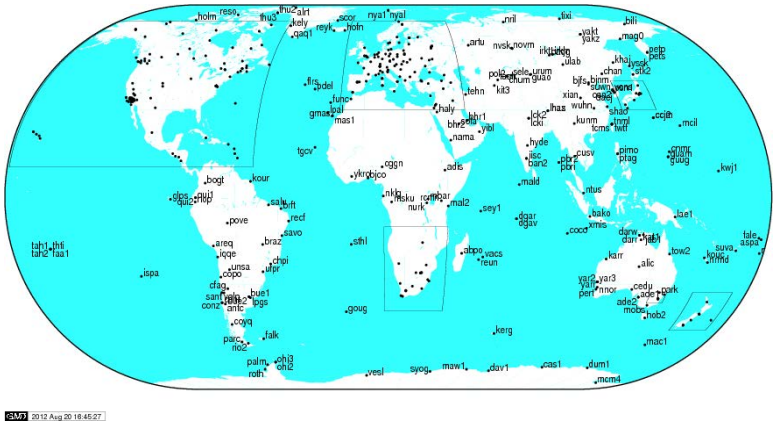
- Currently 23 operational stations worldwide acquiring data daily.
- GSFC operates five SLR stations:
  - GGAO, Greenbelt, Maryland,
  - McDonald Observatory, Fort Davis, Texas (Univ. of Texas at Austin),
  - Monument Peak, Mount Laguna, California,
  - Haleakala, Maui, Hawaii (Univ. of Hawaii, Institute for Astronomy),
  - Arequipa, Peru (Universidad Nacional de San Agustin (UNSA)).
- GSFC supports three partner stations:
  - Tahiti, French Polynesia (CNES, Univ. of French Polynesia),
  - Hartebeesthoek, South Africa (NRF, Hartebeesthoek Radio Observatory),
  - Yarragadee, Australia (Geoscience Australia).
- GSFC provides the Central Bureau of the International Laser Ranging Service (ILRS) that coordinates the worldwide SLR network, observing, data processing and analysis.
- GSFC maintains the archival and distribution of the worldwide SLR data using the Crustal Dynamics Data Information System (CDDIS).

Very Long Baseline Interferometry (VLBI)

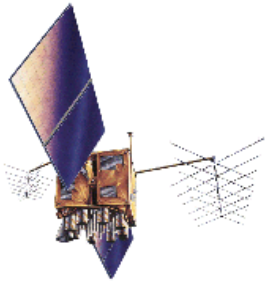
- 40 stations worldwide acquiring data, some daily.
- GSFC operates 3 VLBI stations:
  - GGAO, Greenbelt, Maryland,
  - Westford, Massachusetts (MIT, Haystack Observatory),
  - Kokee Park, Hawaii.
- GSFC provides support for 3 partner stations:
  - Svalbard, Norway (Norwegian Mapping Authority),
  - Fortaleza, Brazil (Mackenzie University),
  - Hobart, Australia (University of Tasmania).
- GSFC provides oversight and training to VLBI partners.
- GSFC provides the Coordinating Center and an Analysis Center of the International VLBI Service for Geodesy and Astrometry (IVS) that schedule all international geodetic VLBI networks and observing, oversee data correlation and distribution to the global archive, and perform VLBI data processing and analysis.
- GSFC maintains the archival and distribution of the worldwide VLBI geodetic data using the Crustal Dynamics Data Information System (CDDIS).

Global Navigation Satellite Systems (GNSS)

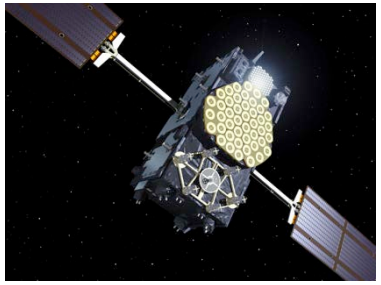
- This decade will see an explosion of new GNSS.
- 440 GNSS tracking stations within the International GNSS Service (IGS) network.
- 189 stations participating in the Real Time Pilot Project
- Many more stations within other networks.



GPS



Galileo



GLONASS

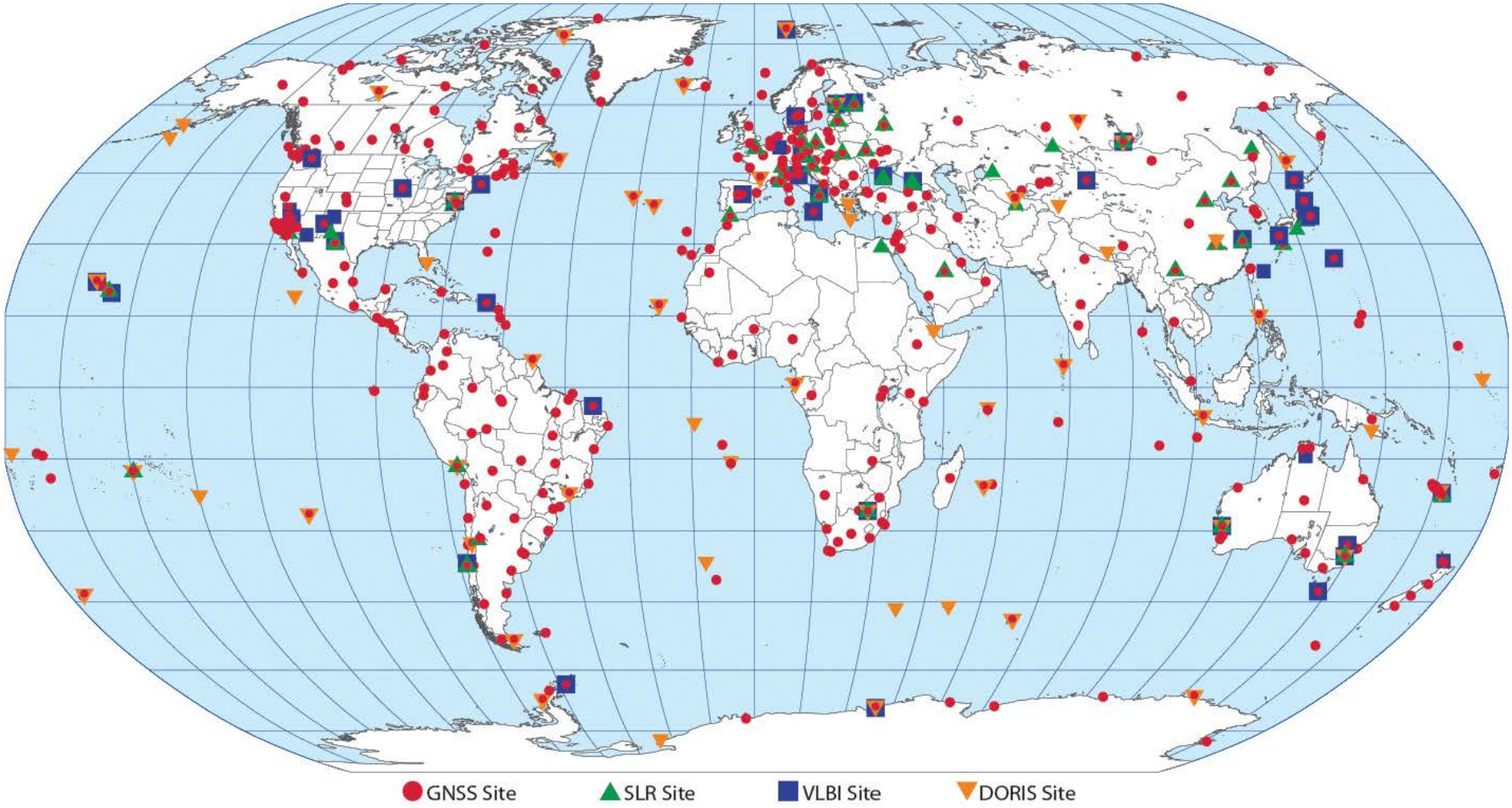
GPS Laser Retroreflector Array Project

- Systematic co-location in space through the precision orbit determination of GPS satellites via SLR will contribute significantly towards improving the accuracy and stability of the ITRF.
- GPS will then provide a means to accurately and uniformly distribute this new accuracy to all systems utilizing GPS.
- NASA-DoD partnership to support laser ranging of next generation GPS satellites.
  - GSFC led instrument.
  - Partnering with the Naval Research Lab on Formulation, including the development and testing of a flight model.
- First unit on GPS III SV9 scheduled for launch in 2019 to 2021 time frame.
- Baseline delivery of at least 27 arrays.

Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)

- GGAO DORIS beacon is part of a global network of ~57 stations since June 2000.
- DORIS receivers are used on altimeter (TOPEX, Jason1, Jason2, ENVISAT, Cryosat-2) and remote sensing (SPOT) satellites; Future Missions: Jason-3, SWOT & SENTINEL-3.
- GSFC maintains the archival and distribution of the worldwide DORIS geodetic data using the Crustal Dynamics Data Information System (CDDIS).

Global Geodetic Network



Global Geodetic Observing System (GGOS) Services & Products

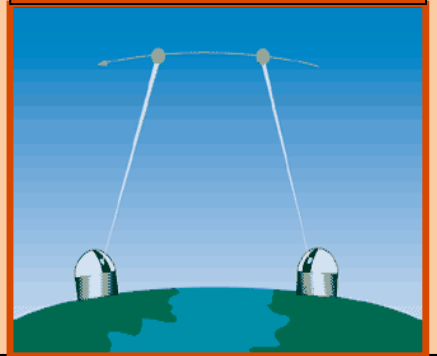
International Terrestrial Reference Frame (ITRF)
(Accurately positioned points with respect to the Earth's Center of Mass and the fixed background of Quasars)

International Earth Rotation and Reference Systems Service (IERS)

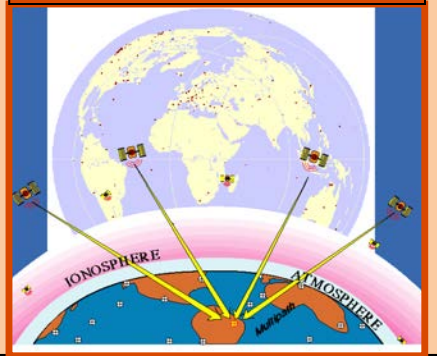
Precision GPS Orbits and Clocks, Earth Rotation Parameters, Station Positions

Very Long Baseline Interferometry (IVS)

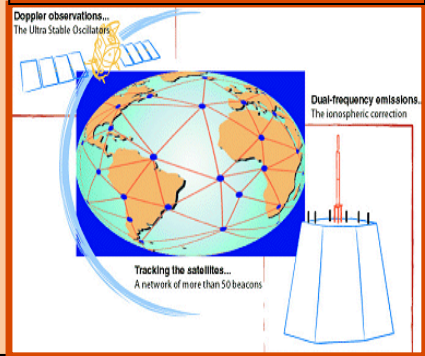
Satellite Laser Ranging (ILRS)



Global Navigation Satellite Systems (IGS)



Doppler Orbit Determination and Radiopositioning Integrated on Satellite (IDS)

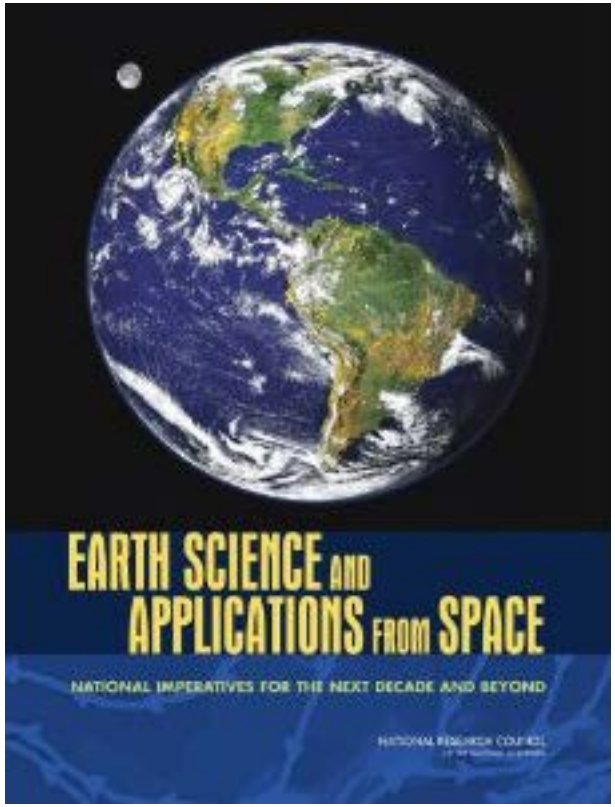


“Collapsing” Infrastructure

“Requirement for precise measurement and maintenance of the terrestrial reference frame.

The geodetic infrastructure needed to enhance or even to maintain the terrestrial reference frame is in danger of collapse (see Chapter 1). Improvements in accuracy and economic efficiency are needed. Investing resources to ensure the improvement and continued operation of the geodetic infrastructure is a requirement of virtually all the missions proposed by every panel in this study.

The terrestrial reference frame is realized through integration of the high-precision networks of the Global Positioning System (GPS), Very Long Baseline Interferometry (VLBI), and satellite laser ranging (SLR). It provides the foundation for virtually all space-based and ground-based observations in Earth science and studies of global change, including remote monitoring of sea level, sea-surface topography, plate motions, crustal deformation, the geoid, and time-varying gravity from space. It is through this reference frame that all measurements can be interrelated for robust, long-term monitoring of global change. A precise reference frame is also essential for interplanetary navigation and diverse national strategic needs.”



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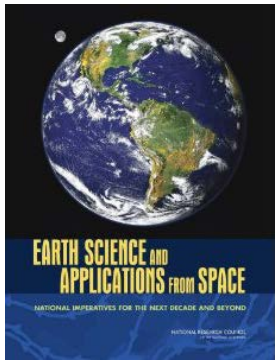
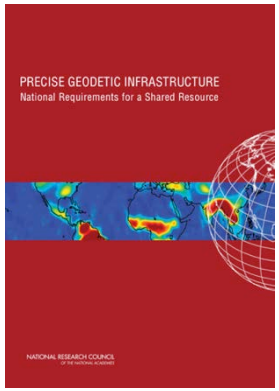
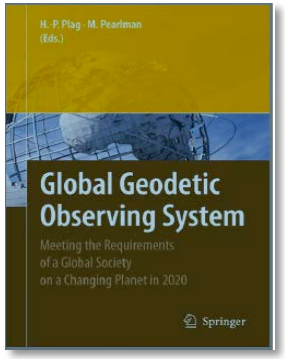
Supporting Future Requirements







- Science Driver:
  - Most stringent requirement on the ITRF comes from sea level studies:
    - "accuracy of 1 mm, and stability at 0.1 mm/year"
    - This is a factor 10-20 beyond current capability.
  - About 30 modern integrated stations are required to meet these requirements.
- NRC Recommendations:
  - Upgrade U.S. stations with modern SLR and VLBI,
  - Work with international partners to deploy additional stations,
  - Establish and maintain a high precision real-time GNSS/GPS national network,
  - Make a long-term commitment to maintaining the ITRF,
  - Continue to support the activities of the GGOS.
- NASA Response
  - Contribute to building a new global network of integrated geodetic stations
  - Network should be there for the coming Decadal Survey missions.
  - NASA proposes to provide 6-10 of these stations if the next generation technology can be demonstrated to function as required.
  - Complete the next generation SLR and VLBI developments.

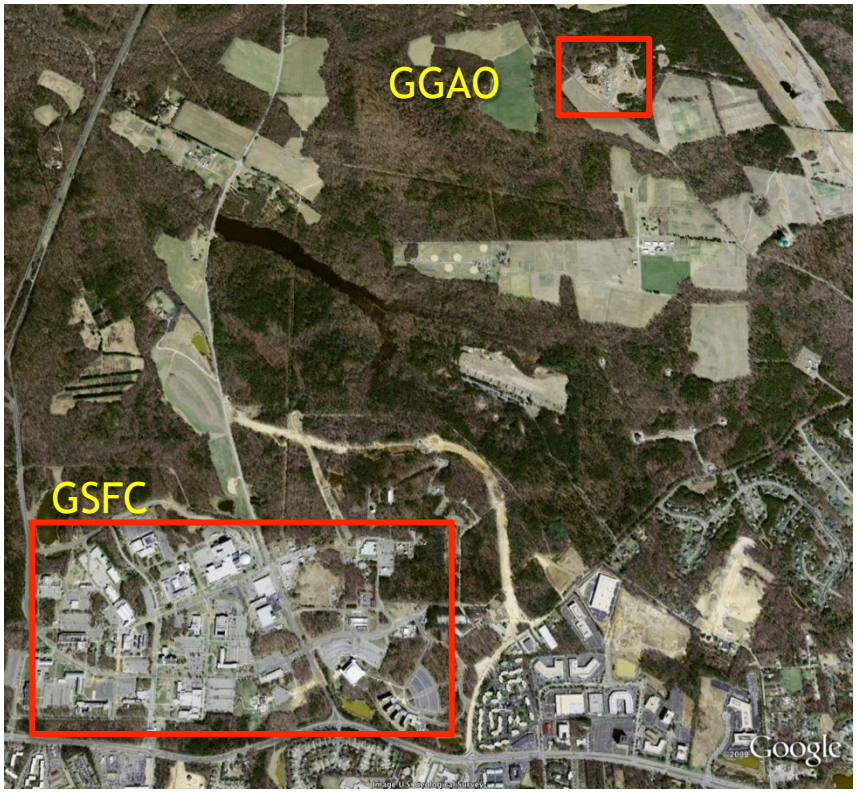
The Space Geodesy Project

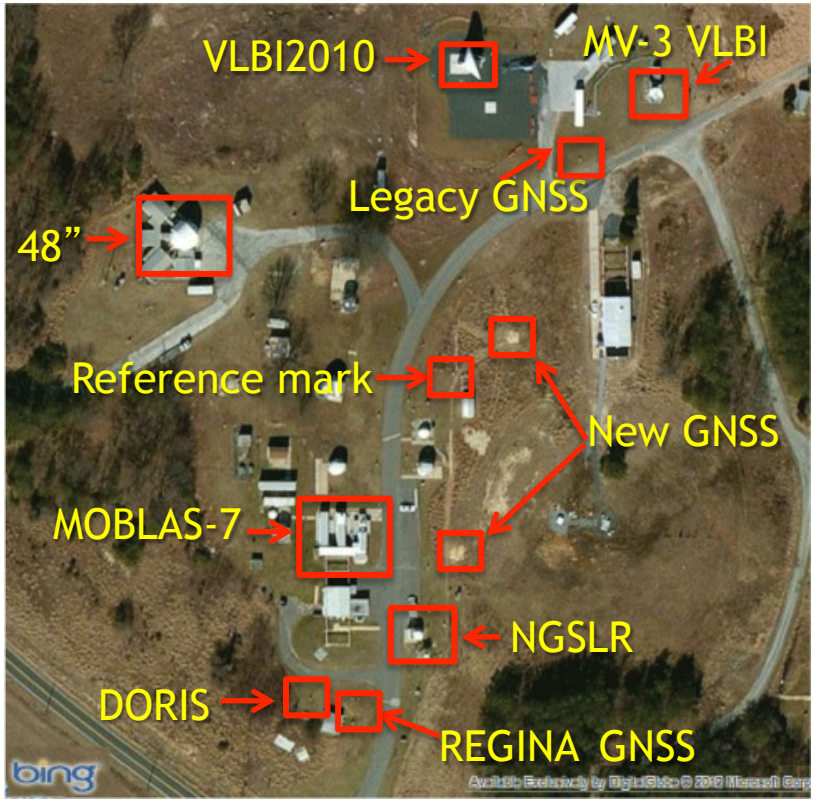
- New initiative started at the end of 2011 in response to the Earth Science Decadal and the National Research Council study "Precise Geodetic Infrastructure." Part of the President's Climate Initiative.
- Goddard led in partnership with JPL and participation from the Smithsonian Astrophysical Observatory and the University of Maryland.
- Goals:
  - Establish and operate a prototype next generation space geodetic station with integrated next generation SLR, VLBI, GNSS (and DORIS) systems, along with a system that provides for accurate vector ties between them.
  - Develop a Project Implementation Plan for the construction, deployment and operation of a NASA network of similar next generation stations that will become the core of a larger global network of modern space geodetic stations.

VLBI	NGSLR	GNSS	Vector Tie
			

Prototype Geodetic Station at GGAO

- Goddard Geophysical and Astronomical Observatory (GGAO) is located 5 km from Goddard Space Flight Center in the middle of the Beltsville Agricultural Research Center. GGAO is one of the few sites in the world to have all four geodetic techniques co-located at a single location.





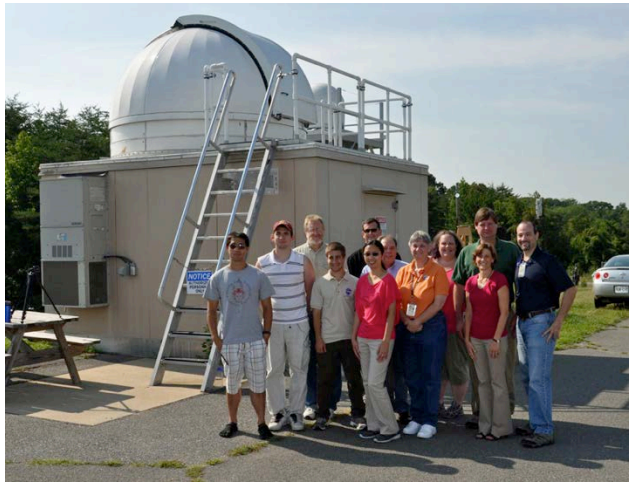
Prototype Station Status Summary

- Prototype station is currently on-schedule for an August 2013 completion.
- NGSLR successfully tracked 20 of out of the 33 current ILRS satellites, including daylight ranging to GNSS (GLONASS-109 & 115).
- NGSLR met a major milestone by completing the development of a new high-power optical bench. Installation at the prototype station is underway.
- Prototype VLBI2010 antenna performed first end-to-end geodetic session on May 16, 2012.
- New GNSS receivers continue to operate well over the past 6 months.

Future Network Development Status

- Completed site assessments of Kokee Park, Haleakala, and Greenbelt. Monument Peak assessment nearly complete. Assessment of other US sites underway.
- Implementation plan under development for an early delivery by the end of the year.
- On-going discussions with existing and potential international partners:
  - Brazil, Instituto Nacional de Pesquisas Espaciais(INPE)
  - Colombia, Instituto Geografico Agustin Codazzi (IGAC)
  - Finland, Finnish Geodetic Institute (FGI)
  - France, Centre National d'Etudes Spatiales (CNES)
  - Korea, Korea Astronomy and Space Science Institute (KASI)
  - Norway, Norwegian Mapping Authority (NMA)
  - Peru, Pedro Paulet Institute of Astronomy and Aeronautics
  - Taiwan, Institute of Earth Sciences Academia Sinica

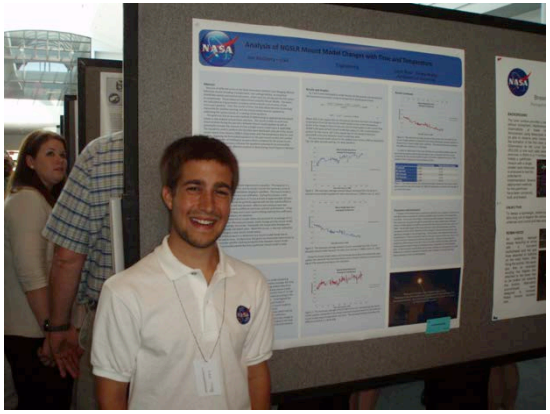
Training the next generation



Six interns worked with the SGP team on tasks ranging from the NGSLR telescope mount, to VLBI radio interference, to analysis of geodetic data.

SGP hosted a summer intern tour of the Goddard prototype station on July 3 for all Goddard summer interns.

The interns also performed surveying tasks at the prototype station.



The summer interns presented their work at the Intern Poster Session on July 25, 2012.