The Future of GNSS Remote Sensing

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Fourth FORMOSAT-3/COSMIC Data Users Workshop
UCAR Boulder, CO
October 27-29, 2009
Earth Surface and Interior Focus Area

ESI Strategic Goals-

1. What is the nature of deformation at plate boundaries and what are the implications for earthquake hazards?
2. How do tectonics and climate interact to shape the Earth's surface and create natural hazards?
3. What are the interactions among ice masses, oceans, and the solid Earth and their implications for sea level change?
4. How do magmatic systems evolve and under what conditions do volcanoes erupt?
5. What are the dynamics of the mantle and crust and how does the Earth's surface respond?
6. What are the dynamics of the Earth's magnetic field and its interactions with the Earth system?

ESI Achievements

- GRACE:1st Time Variable Gravity & Mass Flux
- Earthquake Forecasting
  - SRTM: 1st Uniform Global Topography
  - 17 of 19 Earthquakes

ESI Component Programs

- Natural Hazards
  - Predictive Models
  - Remote Sensing
  - Natural Laboratories
- Space Geodesy
  - Celestial Ref Frame
  - Terrestrial Ref Frame
  - Earth Rotation
  - Crustal Dynamics
- Planetary Interior
  - Geomagnetic Models
  - Gravity Models
  - Geodynamic Models

ESI Strategic Priorities

- Develop Geodetic Imaging Approach: Restless Planet Initiative, DESDynl, ICESat-II, LIST
- Renew Global Geodetic Network Approach: Support GGOS:
- Expand Geopotential Field Exploration Approach: Technology Development & Partnerships (International, DoD, Focus Areas) GRACE II

Overview of ESI Focus Area
The Future of GNSS Remote Sensing

**Goals: Atmospheric Physics, Weather, Climate**

**Resolution:** Spatial and Temporal distribution of refractivity and ionization
Tomographic imaging of Atmosphere and Ionosphere

**Accuracy and Stability:**
- Time- $1 \times 10^{-13}$ (Presently ~$1 \times 10^{-9}$)
- Distance-$1 \times 10^{-10}$ (Presently ~$1 \times 10^{-8.5}$)

**Strategy**
- Multi-Disciplinary Support
- Analogy to Seismology
- Technology Development

**Programmatic Vehicles:**
- GNSS Development Programs
- NRC Decadal Study (*Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond, NRC, 2007*)

**Time Horizon:**
- 2015 is the target (5 year development period required)
The NRC Decadal Study

- Tier 1 Missions: SMAP, ICESat II, DESDynI, CLARREO launch dates 2015+
- Principal Scientific Challenges
  - Climate Change
    - Sea level Change
  - Extreme Events
    - Geohazards
    - Severe Storms
  - Land Surface Change
- NOAA to launch a GPSRO Constellation
- NASA to place GPSRO receivers on all Satellites
The geodetic infrastructure needed to enhance, or even to maintain the terrestrial reference frame is in danger of collapse (cf. Chapter 1). Improvements in both accuracy and economic efficiency are needed. Investing resources to assure the improvement and the continued operation of this geodetic infrastructure is a requirement of virtually all the missions for 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 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 inter-related for robust, long-term monitoring of global change. A precise reference frame is also essential to interplanetary navigation and diverse national strategic needs.”
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The Global Geodetic Observing System
(SLR, VLBI, GNSS, DORIS)

ITRF Development Goal: 1 mm Accuracy and 0.1 mm/yr Stability
Presently $1 \times 10^{-8.5}$ Goal: $1 \times 10^{-10}$

- Aging Instrumentation
- Unbalanced geographic distribution
- Inadequate co-location of instruments
- Aging and inadequate analysis software
- Changing GNSS Constellations, Signals, Technology
- Declining NASA (US) network contribution and leadership
- NASA resources leveraged 2.5:1
GNSS Challenge: 60 to 90 High Precision Radio Sources Within the Decade (+ QZSS & GAGAN)

- GPS
- Galileo
- GLONASS
- Beidou
GNSS Frequency Allocations

2015: Estimated time of full deployment
2020: Codeless Operation will cease to be supported by GPS
TriG: The NextGen GNSS Remote Sensing Receiver

- TriG: Based on the NASA/JPL BlackJack / IGOR + GPS receiver utilizing demonstrated successes and lessons learned with current flight instruments

- Improved Radiation Tolerance (~50K RAD)

- 8+ antenna inputs with digital beam steering

- Compact PCI chassis design provides implementation flexibility for varied applications

- Modular Design allows for a variety of mission support including:
  - Smaller more accurate POD only instruments
  - High Gain multi-GNSS refraction measurements
  - Development of GNSS Reflections for tomographic imaging
  - Near real time precision orbit determination for autonomous operation and onboard data reduction
GNSS-R Requires the New GNSS signals, Large Apertures and Beam Steering

NASA’s Aquarius, SMAP, and DESDynI utilize large aperture reflectors suitable for GNSS-R

NASA’s SIR-C measured the first high angle GNSS-R reflections from space- (SNR=120)
Seismic Analog Should be Studied to Improve GNSS Remote Sensing Resolution

Marine Multichannel Seismic Technique

Layering and Interval Velocities
Multichannel analog for GNSS-Remote Sensing requires formation flight

- GRACE, Tandem-X and Tandem-L all could provide useful platforms for multi-receiver GNSS-Remote Sensing

- Initial Deployment of COSMIC may have produced a useful data base
GNSS Remote Sensing Has Come a Short Way Down a Very Long and Productive Path for Climate Change and Natural Hazards Research and Applications