NASA's Next Generation Space Geodesy Network

ABSTRACT: NASA's Space Geodesy Project (SGP) is developing a prototype core site for a next generation Space Geodetic Network (SGN). Each of the sites in this planned network consist of state-of-the-art co-located stations from all four space geodetic techniques, GNSS, SLR, VLBI, and DORIS, with the goal of achieving modern requirements for the International Terrestrial Reference Frame (ITRF). In particular, the driving ITRF requirements for this network are 1.0 mm in accuracy and 0.1 mm/yr in stability, a factor of 10-20 beyond current capabilities. Development of the prototype core site, located at NASA's Geophysical and Astronomical Observatory at the Goddard Space Flight Center, started in 2011 and will be completed by the end of 2013. In January 2012 two operational GNSS stations, GODS and GODN, were established at the prototype site within 100 m of each other. Both stations are being proposed for inclusion into the IGS network. In addition, work is underway for the inclusion of next generation SLR and VLBI stations as well as a modern DORIS station. An automated survey system is being developed to measure inter-technique vector ties, and network design studies are being performed to define the appropriate number and distribution of these next generation space geodetic core sites that are required to achieve the driving ITRF requirements. We present the status of this prototype next generation space geodetic core site, results from the analysis of data from the established geodetic stations, and results from the ongoing network design studies.

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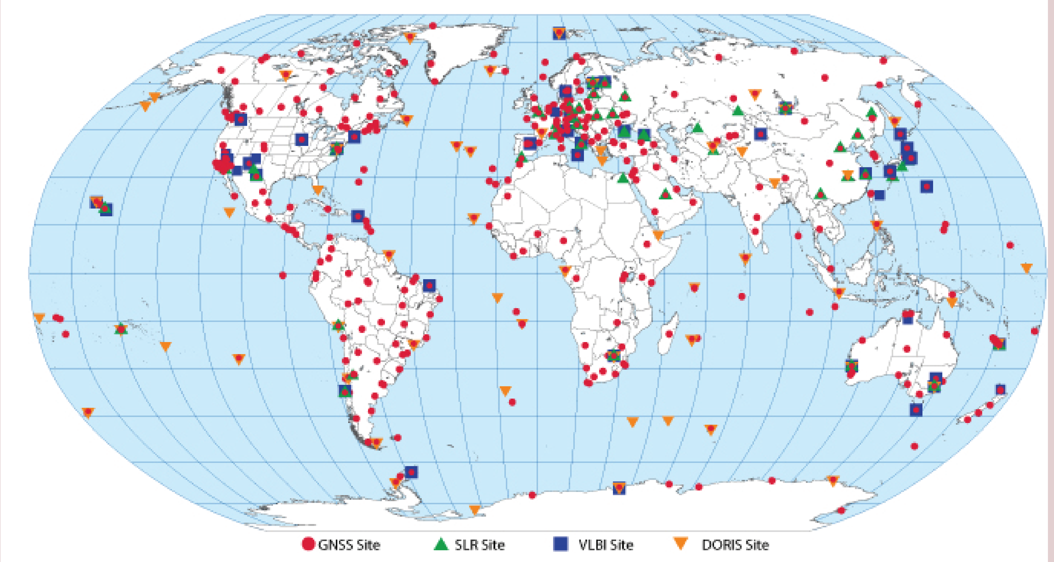
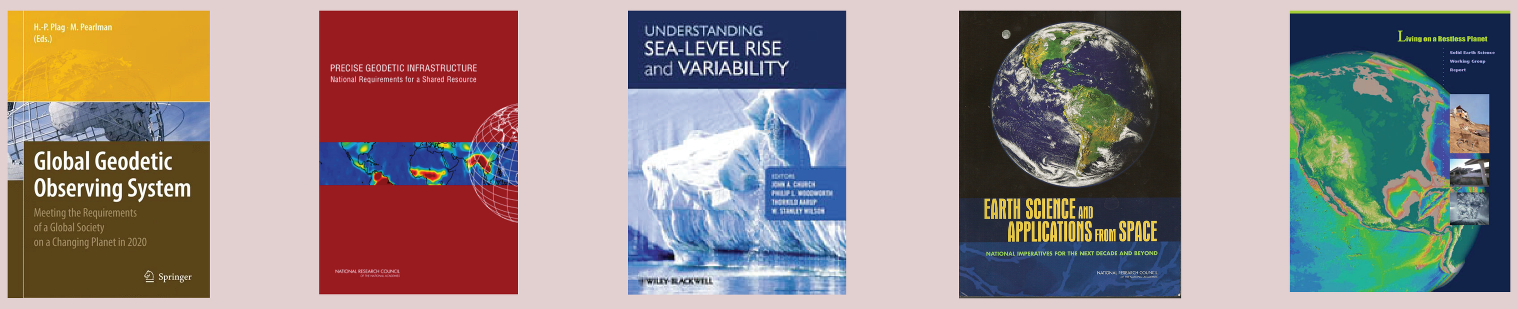
SUPPORTING FUTURE REQUIREMENTS – MOTIVATION FOR NASA SPACE GEODESY PROJECT

- Space geodetic networks provide the measurements that are needed to define and maintain the International Terrestrial Reference Frame (ITRF)
- Requirements for the ITRF have increased dramatically since the 1980's
  - Most stringent requirement 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
- Simulations show the required ITRF is best realized from a combination solution using data from a global network of ~30 integrated stations having all available techniques with next generation measurement capabilities
  - Current network cannot meet this requirement, even if it could be maintained over time (which it cannot)



Current IGS, ILRS, IVS, and DORIS network site locations

- National Research Council's 2010 report, "Precise Geodetic Infrastructure: National Requirements for a Shared Resource" stated: "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."
- Current core NASA network is deteriorating and inadequate; NASA's Space Geodesy Project is addressing this need

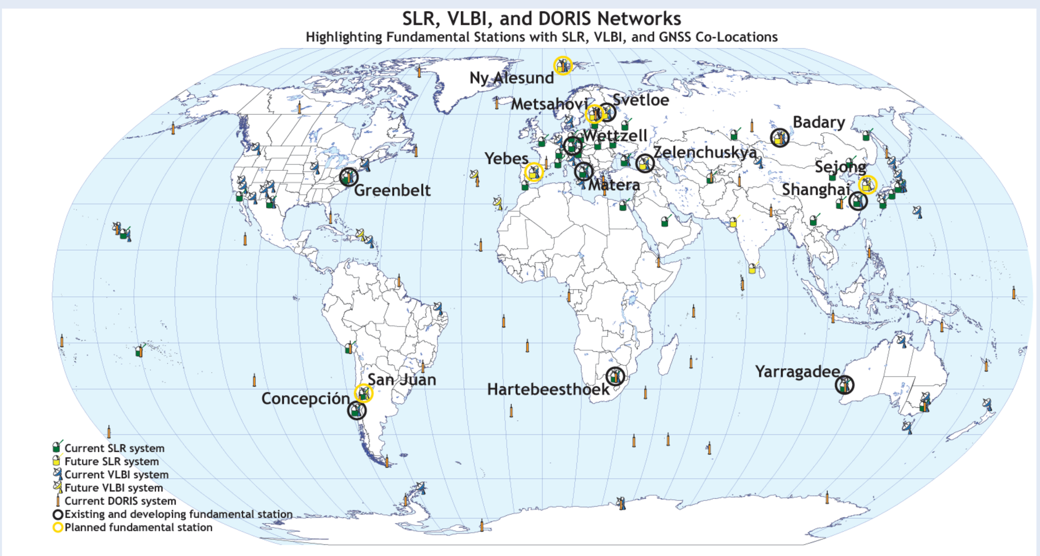


NRC RECOMMENDATIONS

- Deploy the next generation of automated high-repetition rate SLR tracking systems at the four current U.S. tracking sites in Hawaii, California, Texas, and Maryland
- Install the next-generation VLBI systems at the four U.S. VLBI sites in Maryland, Alaska, Hawaii and Texas
- Deploy additional stations to complement and increase the density of the international geodetic network, in a cooperative effort with its international partners, with a goal of reaching a global geodetic network of fundamental stations
- Establish and maintain a high precision GNSS/GPS national network constructed to scientific specifications, capable of streaming high rate data in real time
- Make a long-term commitment to maintain the International Terrestrial Reference Frame (ITRF) to ensure its continuity and stability
- Continue to support the activities of the GGOS
- Make a long term commitment to the maintenance of ITRF
- The current core NASA network is deteriorating and inadequate. NASA's Space Geodesy Project is addressing this need

NASA RESPONSE TO THE NRC REPORT – THE SPACE GEODESY PROJECT

- Contribute to building a new global network of integrated next generation SLR, VLBI, and GNSS 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
- Next Generation SLR and VLBI technology pathways known and under development

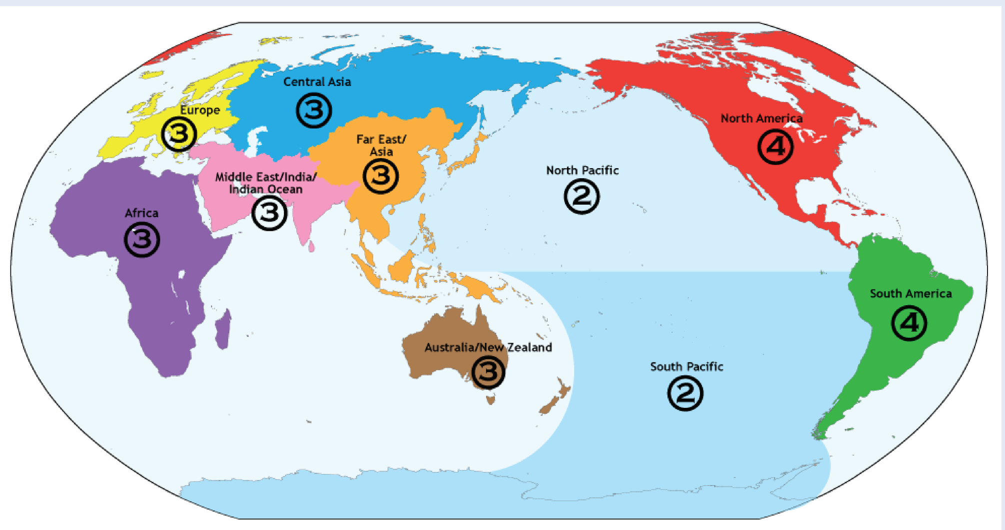


NASA'S SPACE GEODESY PROJECT

- New initiative started at the end of FY11
- Part of the Earth Science Decadal and the National Research Council study "Precise Geodetic Infrastructure"
- GSFC/JPL partnership with participation from Smithsonian Astrophysical Observatory and the University of Maryland
- Goals:
  - Establish and operate a prototype next generation space geodetic site 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

PROJECT STATUS SUMMARY

- Performed simulation studies to scope the network
- Simulations show that the global network requires:
  - ~30 globally distributed, well positioned, co-location Core Sites with proper conditions
  - 16 of these Core Sites must track GNSS satellites with SLR to calibrate the GNSS orbits
- Prototype station currently on track for completion in 2013.
- Implementation plan currently under development to upgrade current NASA sites and establish new sites with our international partners.
- Evaluate current NASA Sites as candidate Core Sites;
  - Current year: GSFC, Monument Peak, Mt. Haleakala, Kokee Park, McDonald, Arequipa, Yarragadee, Hartebeesthoek, Tahiti, Fortaleza
- On-going discussions with existing and potential international partners
- If additional systems are built, they could be deployed as a full station or perhaps as a system contribution in a partnership



- *Simulations show that approximately 30 globally distributed co-locations sites are required*
- *Current focus:*
  - *Sensitivity of data products to the accuracy of the inter-system vectors at co-location sites*
  - *Benefit of having co--locaXon using a multi-technique, satellite-based target Geodetic Reference Antenna in Space (GRASP)*

- Contributed to development of GGOS Site Requirements document that defines a fundamental station and details ideal site conditions for these stations

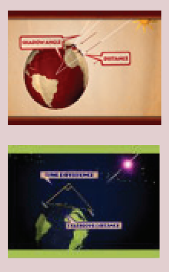
FOR FURTHER INFORMATION

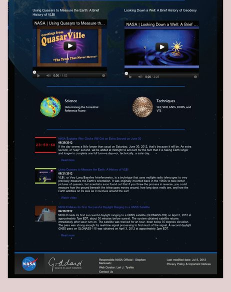
Additional Reading:

- NASA's Next Generation Space Geodesy Project: http://space-geodesy.gsfc.nasa.gov/reports/SGP_GGOS.pdf
- Site Requirements for GGOS Core Sites: http://cddis.gsfc.nasa.gov/docs/GGOS_SiteReqDoc.pdf
- "NASA's Next Generation Space Geodesy Program", M. R. Pearlman, H. V. Frey, R. S. Gross, F. G. Lemoine, J. L. Long, C. Ma, J. F. McGarry, S. M. Merkowitz, C. E. Noll, E. C. Pavlis, D. A. Stowers, F. H. Webb, and T. W. Zagwodski, Abstract EGU2012-6608 presented at 2012 EGU General Assembly, Vienna Austria, April 23-27, 2012. http://space-geodesy.gsfc.nasa.gov/docs/2012/SGP_EGU_2012.pdf
- "GGOS Network Simulation Studies", E. Pavlis http://space-geodesy.gsfc.nasa.gov/docs/2012/NetworkSlidesGGOS_BNC_EGU2012.pdf

SGP Website: http://space-geodesy.gsfc.nasa.gov/

- A history of geodesy video: http://space-geodesy.gsfc.nasa.gov/multimedia/geodesyHistoryVideo.html
- A history of VLBI video: http://space-geodesy.gsfc.nasa.gov/multimedia/VLBIHistoryVideo.html





NEXT GENERATION SYSTEM IMPLEMENTATION AT GGAO

GGAO

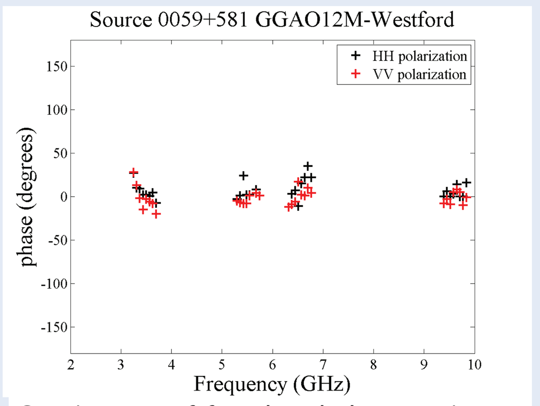
- Goddard Geophysical and Astronomical Observatory is located 5 km from Goddard Space Flight Center
- GGAO is one of the few sites in the world to have all four geodetic techniques co-located at a single location
- GGAO is the site of the SGP's state-of-the-art prototype station development: NGSLR and VLBI2010
- Also under development is a vector tie capability that will link together the four measurement techniques

MODERN GNSS ANTENNA RECEIVER PAIRS

- Pair of multi-constellation (GPS, GLONASS, Galileo) antenna receiver pairs (GODN and GODS) were installed with deep drilled brace monuments and are collecting data since 2012-01-18.
  - JAVAD TRE_G3TH DELTA receiver
  - TPSCR.G3/SCIS antenna/radome
- Data publicly available from CDDIS
- Applications to join IGS network in process
- Existing GPS (GODE) and GPS+GLONASS (GODZ)

VLBI2010

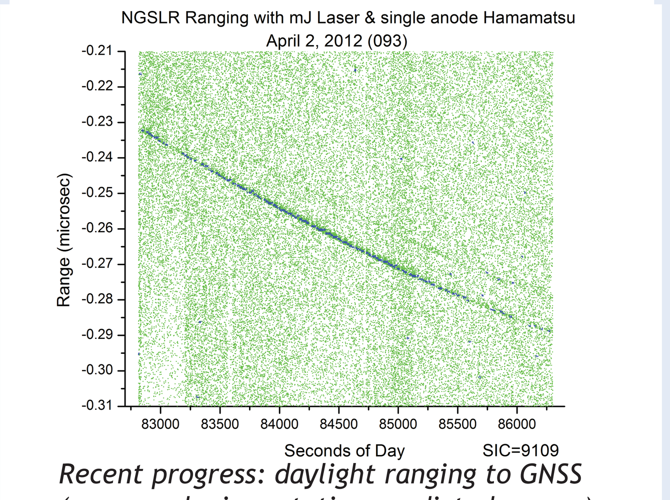
- VLBI2010: an enabling technology upgrade to the existing global geodetic VLBI network developed within the International VLBI Service for Geodesy and Astrometry (IVS)
- Technical development of the front end and back end electronics continues at Goddard and MIT Haystack Observatory
- Specifications (NASA Implementation):
  - Smaller antennas (~12m), fast moving, operating unattended, mechanically reliable, economically replicable – more observations for troposphere and geometry (Cobham/Patriot antenna)
  - Broad continuous frequency range (~2-12 GHz) using multiple bands – smaller observation error and interference avoidance (QRFH feed)
  - Higher speed recording, increased sensitivity (RDBE backend, Mark 5C recorder)
  - Transfer data with combination of high speed networks & high rate disk systems
- System Features:
  - Fast antenna plus high data rate enables improved troposphere sampling with acceptable SNR for observation by worldwide VLBI network
  - Standardization and commercial-off-the-shelf availability of many key components will lead to lower operation and replication costs
  - Selectable RF band placement will better tolerate radio frequency interference and allow compatibility with legacy S/X systems
  - Improvement in group delay will enable ~1mm position determination when the VLBI2010 technology is incorporated in the expanded global network
- Achievements & Status:
  - Demonstrated 60% aperture efficiency.
  - Demonstrated 5 deg/sec azimuth slew rate.
  - Westford 18m antenna implemented with the same electronics but a prototype feed; demonstrated broadband data collection at a rate of 8 Gbps and a 4 ps group delay uncertainty for the GGAO-Haystack baseline.
  - 12m antenna implemented with the full VLBI2010 signal chain.
  - RMS delay difference between the independent polarizations less than 1 picosecond over an hour.
  - Six hours of geodetic data were taken at 3.5, 5.5, 6.6 and 9.6 GHz. All bands produced good observations.



Consistency of four-band phases using phase calibration and estimating ionosphere. Residual phases for each 32 MHz channel in the four 512-MHz bands, mean removed. Scan length was 30 seconds. Ionosphere difference between stations is estimated simultaneously. RMS scatter of 10 degrees is about 3 times the formal error. Delay uncertainty is 3 picoseconds in each polarization. These polarizations will be combined with cross-hands (VH and HV) for final estimate of delay.

NGSLR

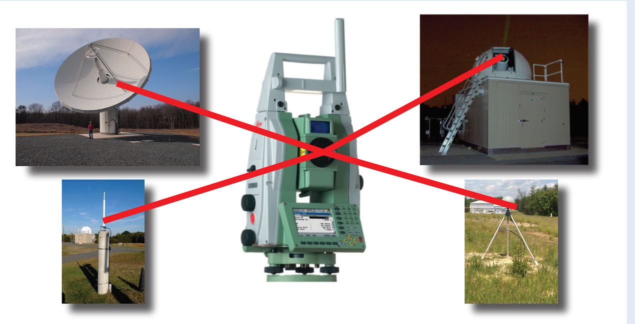
- NGSLR: a high repetition rate single photon detection laser ranging system capable of tracking cube corner reflector equipped satellites in Earth orbit
- System has demonstrated tracking of Earth orbit satellites with altitudes from 300 km to 20000 km
- System Features:
  - 1 to 2 arcsecond pointing/tracking accuracy
  - Multi-kilohertz laser fire rate with single photon detection
  - Able to track CCR equipped satellites up to GNSS altitudes day and night
  - Semi automated tracking features support 24/7 operation
  - Reduced chemical & electrical hazards
  - Small, compact, low maintenance, increased reliability
  - Lower operating/replication costs
- Achievements & Status:
  - Successfully tracked most of ILRS satellites
  - LEO, LAGEOS-1 & -2, and GNSS have all been successfully tracked in both daylight and night
  - System shows good stability in preliminary simultaneous ranging with MOBLAS-7
  - Assembling new optical bench to support automation and make use of a higher power, narrower pulse laser



Recent progress: daylight ranging to GNSS (measured minus station predicted ranges)

CO-LOCATION VECTOR MONITORING

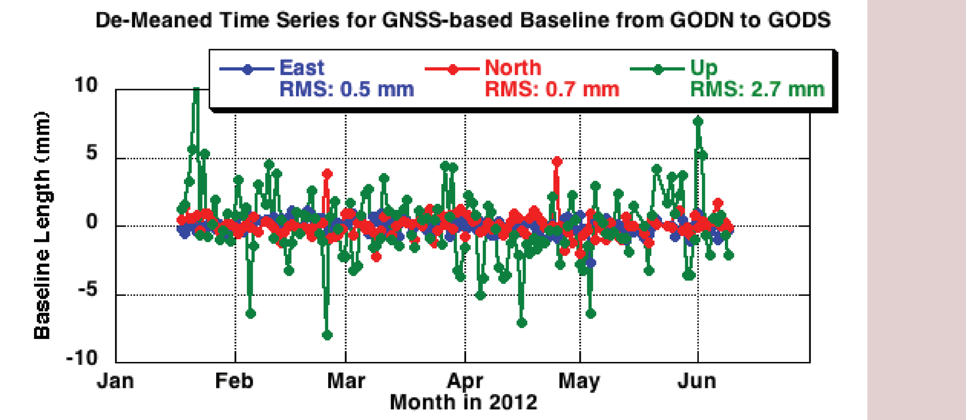
- Automated measurement of inter-instrument vectors is an essential aspect of an integrated space geodesy station
- Measurements provide closure between terrestrial reference frames derived from different space geodetic techniques
- Tests of technologies and currently available systems underway at GGAO
- BIG CHALLENGE: How do we extrapolate measurements to the "electronic or optical" reference point on each instrument?



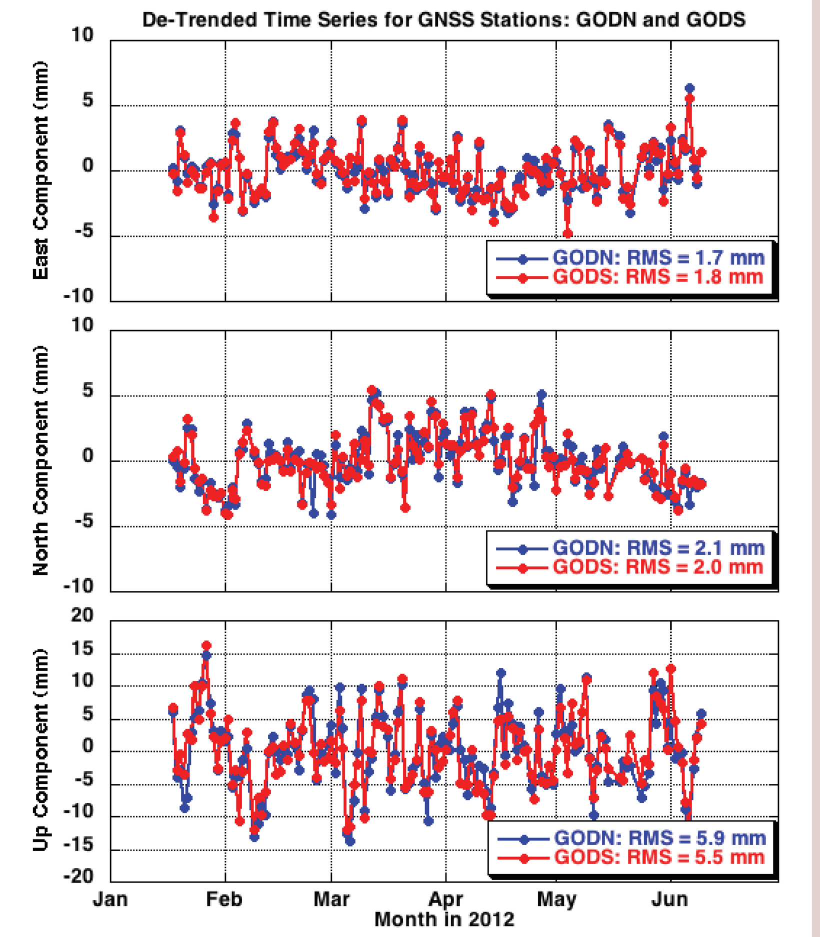
SGP GNSS RESULTS

GPS-BASED CO-LOCATION VECTOR

- Processed ~6 months of GPS data from GODN and GODE (2012-01-18 to 2012-06-09)
  - Independent daily static precise point positioning with single-receiver ambiguity resolution using JPL's GIPSY/OASIS software
- De-trended time series of independently determined station positions in figure below right.
  - Highly correlated station position solutions at GODN and GODS
  - Common mode geophysical signals and systematic errors due to short baseline
- Time series of GODN/GODS baselines computed from independently determined positions. (Baseline length: 76.025 m)
  - East: -19.830 m, North: -73.383 m, Up: 1.224 m
- De-meaned time series of baselines in figure below.
  - Standard deviations of 0.5, 0.7, and 2.7 mm in East, North, Up
- Future work:
  - Expect factor of 2-3 reduction in standard deviation of GODN/GODS baselines by simultaneously using L1-only data from both stations
  - Evaluate GPS-based baselines against in-situ surveys



De-meaned time series of baselines.



De-trended time series of independently determined station positions