Geodetic Reference Antenna in Space (GRASP):

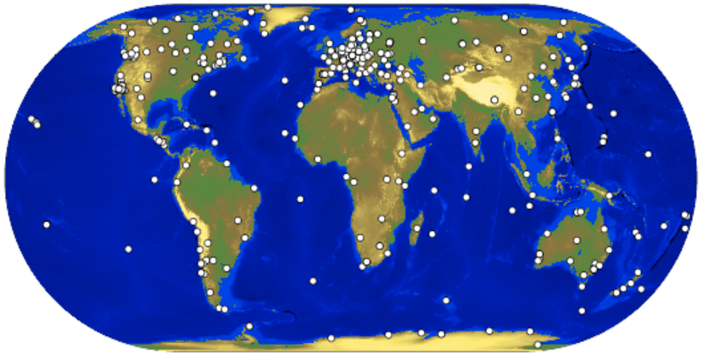
A Mission to Enhance GNSS and the Terrestrial Reference Frame

Yoaz Bar-Sever, Willy Bertiger, Shailen Desai, Richard Gross, Bruce Haines, Sien Wu, *JPL*

Steve Nerem, *University of Colorado , Boulder*

GRASP Mission Goals

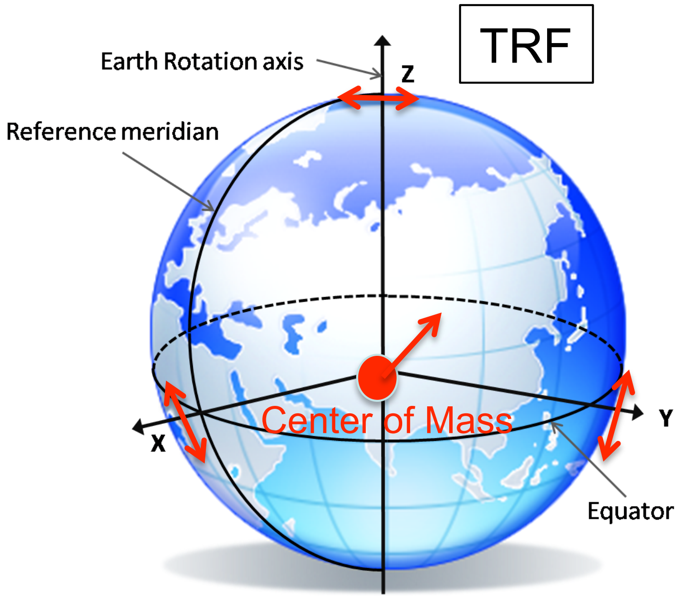
With thousands of tracking sites globally, GNSS is the primary technique for *densifying, transferring, and accessing* the Terrestrial Reference Frame (TRF)

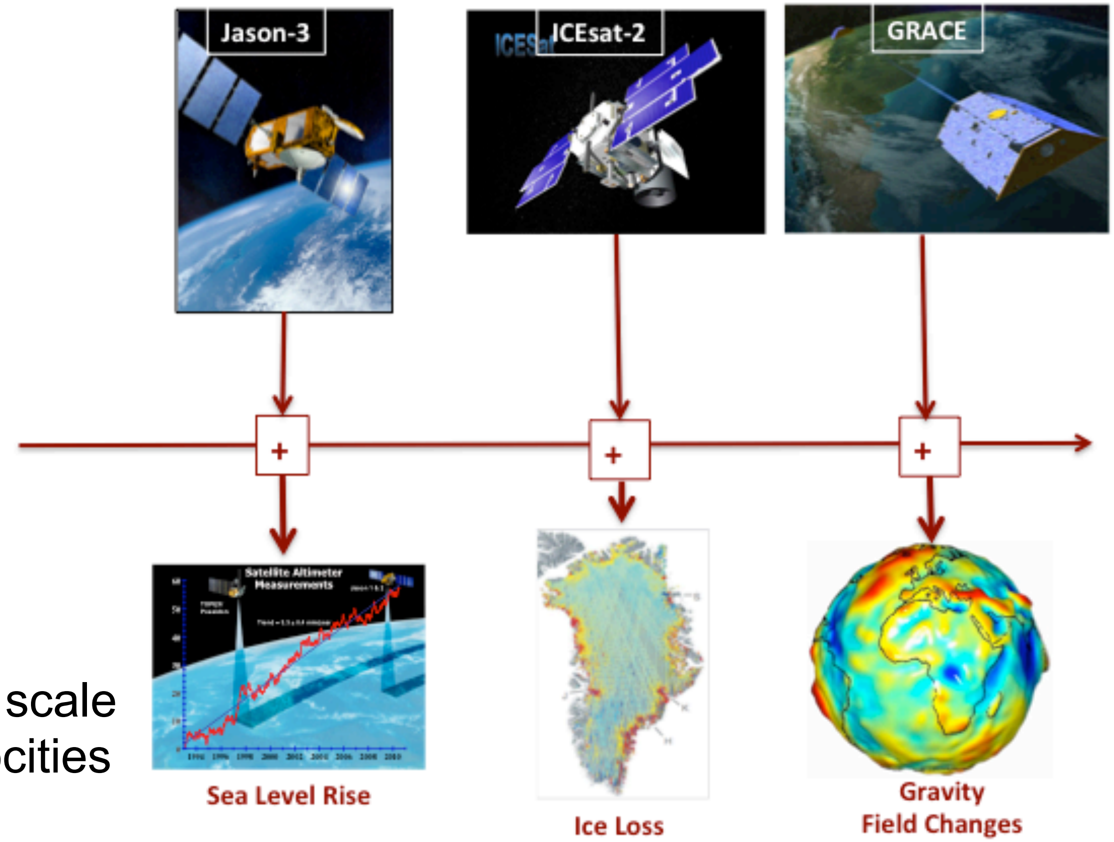


The GRASP mission concept is designed to address the following problems:

- Establishing precise and stable ties between the geodetic techniques used to define and disseminate the TRF
- Consistently calibrate the myriad antennas used to transmit and receive GNSS signals, in ground and space applications
- Enhance the contribution of GNSS to the TRF, and further improve the accuracy and stability of the TRF
- Improve the overall accuracy of GNSS orbit and clock states, benefiting all precision GNSS applications
- And more…

The Terrestrial Reference Frame is the Foundation for all Metric Observations of the Earth





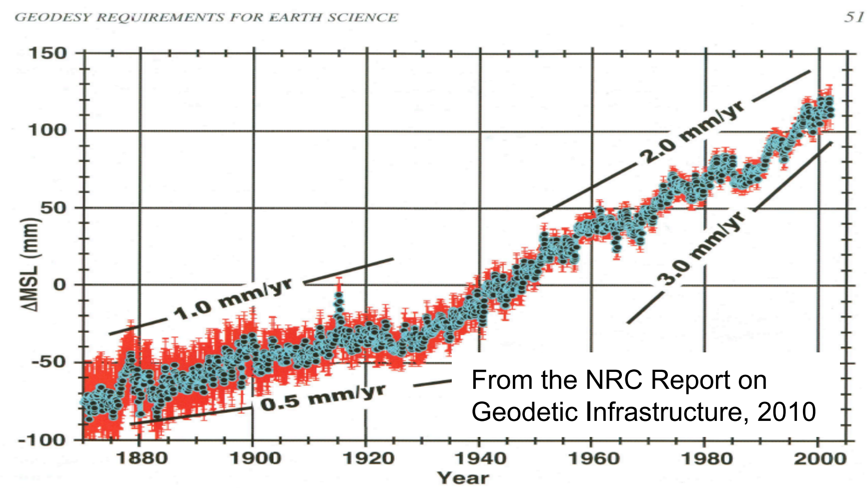
Definition: geocenter, coordinates, scale
Realization: site positions and velocities

The TRF is currently determined by 4 space-ground geodetic techniques: SLR, VLBI, GPS/GNSS, and DORIS

TRF accuracy and stability currently limited by inter-technique ties, and GNSS antenna phase center uncertainties

Venture EV-2 Mission Concepts

The TRF is a significant Error Source in Measuring and Understanding Changes in the Earth System



Is sea level accelerating?

Impact of TRF Error on Global Mean Sea Level (GMSL) Record from Spaceborne Altimetry:[2]

Altimeter Global Mean Sea Level Measurement Error Budget	
Glacial isostatic adjustment (affects volume of ocean basins)	0.1 mm/y
Altimeter drift error (predominantly radiometer drift)	0.4 mm/y
Altimeter bias errors (the ability to link overlapping missions)	0.4 mm/y
Reference frame origin error (affects the satellite orbits)	0.2 mm/y
Systematic vertical motion error (affects the altimeter calibration)	0.4 mm/y
Total error (root-sum-squared)	**0.6 mm/y**

RSS = 0.45 mm/yr

Impact of TRF on GMSL Record from Tide Gauges*:* competing approaches for TRF realization yield estimates for sea-level rise ranging from 1.2 to 1.6 mm/yr.[3]

Desired accuracy for measuring global mean sea level (GMSL) rise is 0.1 mm/yr.[1]

1 Cazenave *et al.*, “Sea Level Rise – Regional and Global Trends”, Oceanobs 2009 Plenary Paper, Venice, September 2009.
2 NRC report on Precise Geodetic Infrastructure (2010)
3 Collilieux, X., and G. Wöppelmann, Global sea-level rise and its relation to the terrestrial reference frame, *J. Geod*. 85:9–22 2011.

Uncertainty in GPS Antenna Phase Variations is a Limiting Error Source in GPS-Geodesy

Venture EV-2

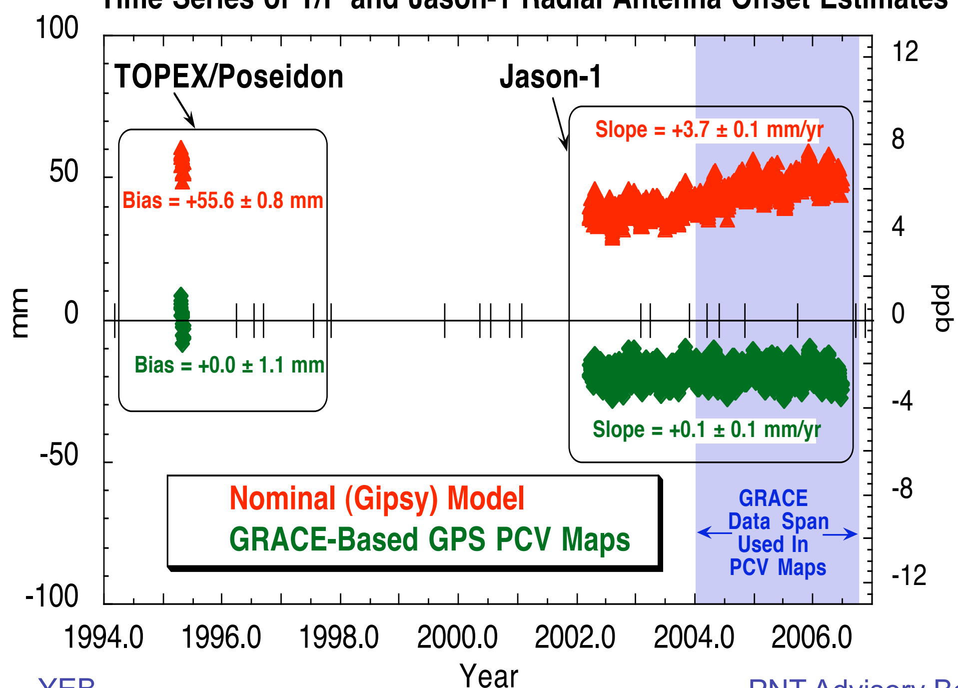
Mission Concepts

Evidence of a problem:

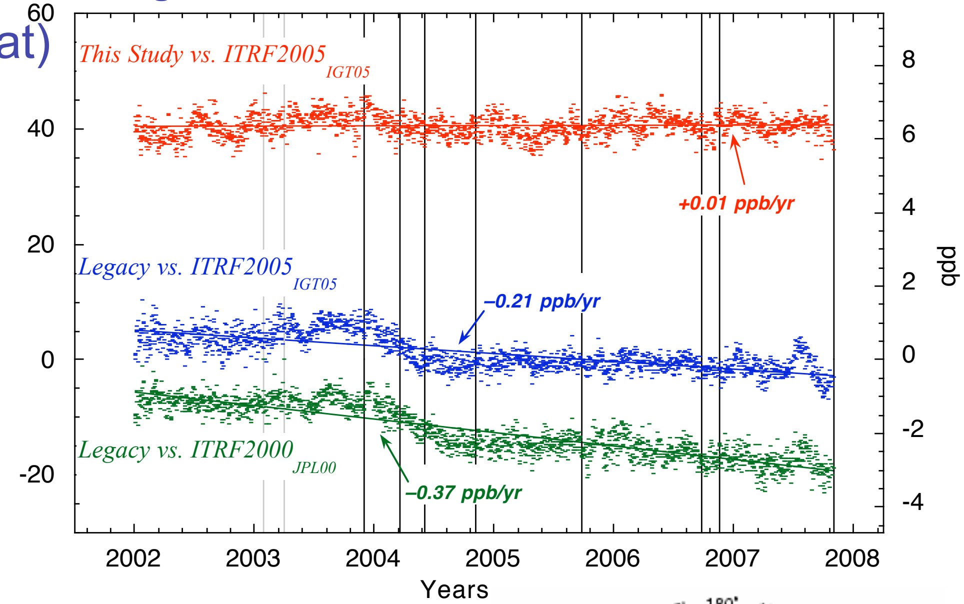
- High post-fit residuals for GPS43 (1st IIR sat)
- Bias in Topex GPS antenna position
- Drift in Jason GPS antenna position
- Drift in GPS realization of TRF Scale

Error is phase center => error is position

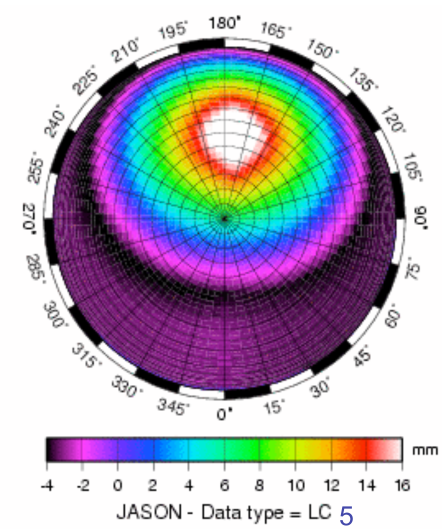
Time Series of T/P and Jason-1 Radial Antenna Offset Estimates



TRF Scale from GPS Alone (2002–2007): Agreement with ITRF2005



Jason APV map before correction for GPS transmit APV

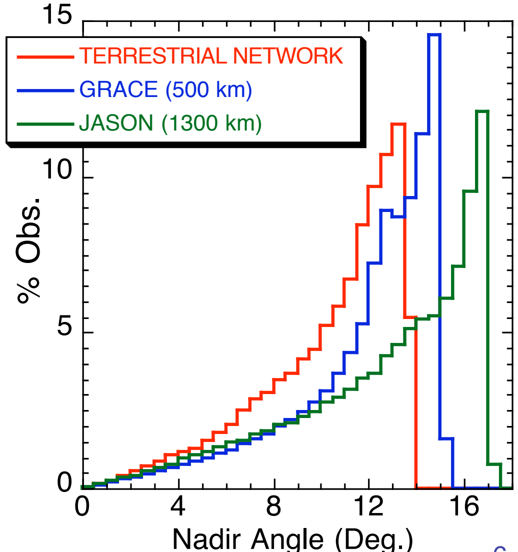


Problems with Ground-Based Determination of the GPS Satellites Antenna Phase Variations

Estimation of GPS transmit APV from ground observations is problematic:

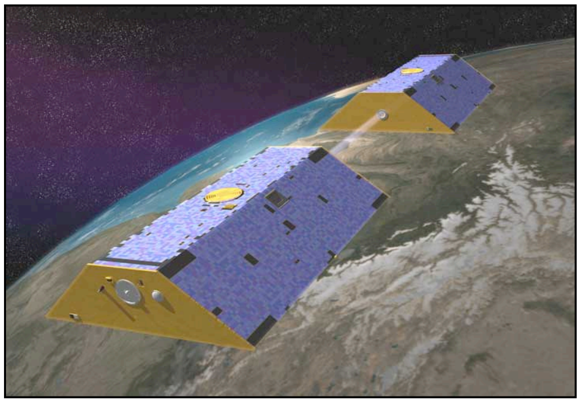
- Sensitivity to tropospheric delay biases
- High correlation with receiver APV, which are uncertain due to local multipath and diversity of hardware
  - Robot- or anechoic chamber-based antenna calibrations do not capture the conditions in-situ
  - High likelihood of global systematic error because of common monument types
- Dependent on the TRF; IGS selected antenna offset to maintain the TRF Scale
- Narrow field of view limits utility for space applications

Sampling of GPS Transmitter Beam Pattern

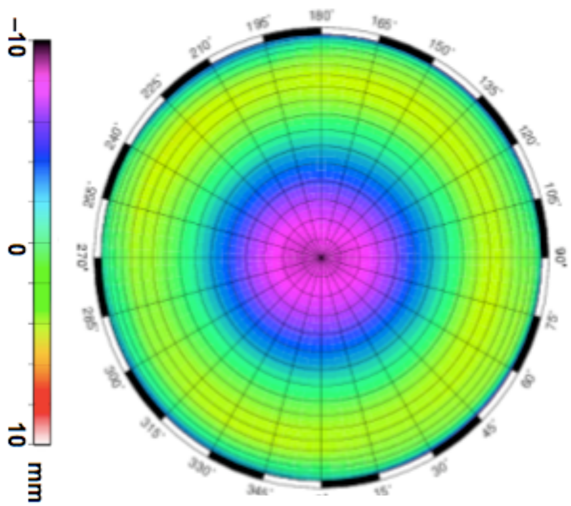


GRACE: GRASP Concept Experiment

GRACE spacecraft (500 km orbit)



GRACE GPS antenna phase (receive)



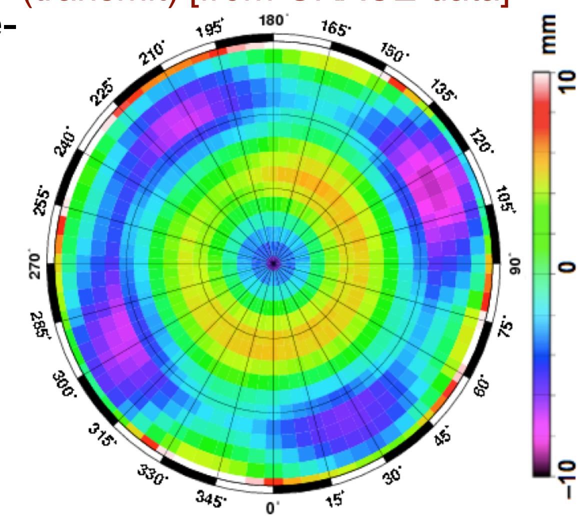
GRACE APV (LC) FROM ANECHOIC MEASUREMENTS

- GRACE acted as the GRASP pathfinder mission
- A priori GRACE antenna model from pre-launch anechoic measurements
- GPS transmit Antenna map estimated iteratively
- *Scale is derived from GM*
- Estimates for all PRNs flying Oct. 2006–Nov. 2009
- Includes group delay (Ionosphere-free pseudorange, *PC*)

- Proof of concept well demonstrated
- But, GRASP is much better suited to this measurement than GRACE:
  - Center of Mass to mm level
  - Better calibrated, and includes PC
  - 1,400 km orbit height (same as altimetry missions: T/P, J-1,2,3)

GPS spacecraft (20,000 km orbit)

GPS spacecraft antenna phase (transmit) [from GRACE data]



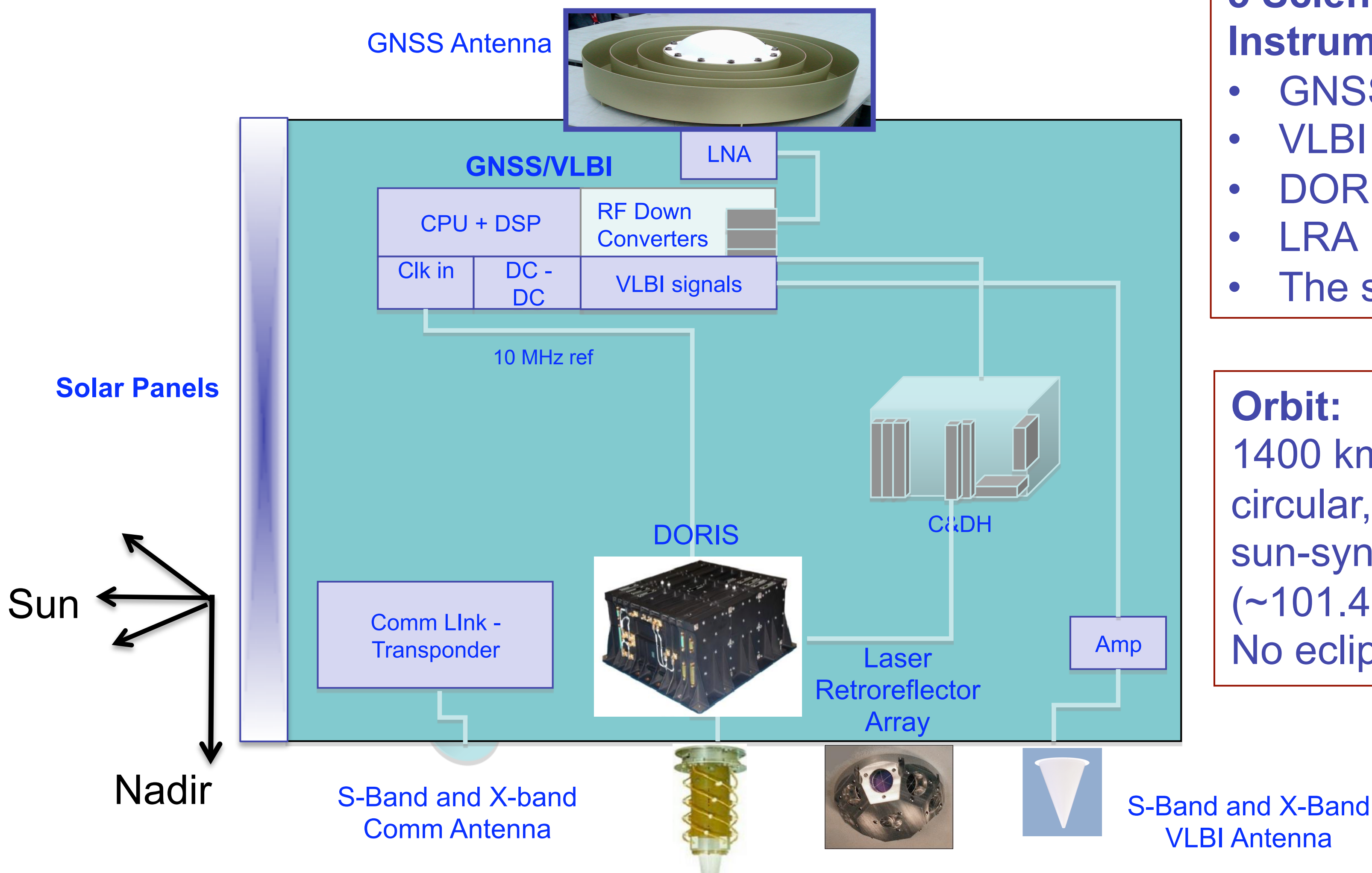
TYPICAL GPS APV (LC) FROM STACKED RESIDUAL APPROACH

GRASP Spacecraft Concept

- Collocate all the geodetic techniques on one spacecraft
- Ground calibrate all sensors to sub-mm
- Design spacecraft and orbit to facilitate sub-mm POD

5 Science Instruments:
- GNSS
- VLBI
- DORIS
- LRA
- The spacecraft

Orbit:
1400 km altitude, circular, sun-synchronous (~101.4°inclination)
No eclipses



GRASP Broad Benefits

- The spacecraft is a flying geodetic super-site:
  - Enables the realization of the TRF with 1 mm accuracy and 0.1 mm/year stability as specified by GGOS
  - Improves the measurement of sea level change and ice/water mass changes being made by satellite altimeter and satellite gravity missions respectively.
  - Essentially an orbiting “measurement lab” that combines the most important geodetic measurements on a single spacecraft.
  - Will complement data being collected by Jason-2/3 and GRACE Follow On.
  - Enhance the global geodetic infrastructure through improved inter-technique ties

- Many of the benefits of GRASP can be extended retroactively to improve the entire ~20 year altimetric sea level record and the decade-long satellite gravity record. Likewise, future altimeter and gravity measurements will benefit from GRASP as well.

- GRASP will enhance the accuracy of precision GNSS applications

- GRASP will promote interoperability of GNSS by providing a common reference

Simulations Demonstrate Broad GNSS Benefits

Absolute reference antenna for consistent calibration of all GNSS antennas, ground and space

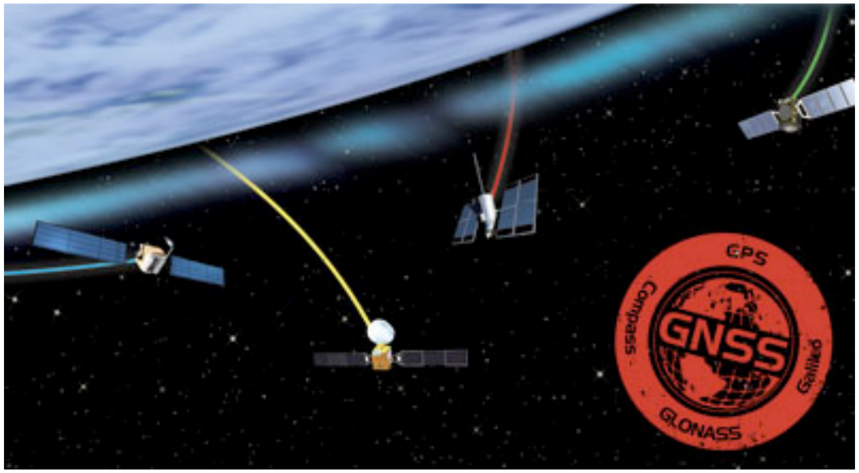
- **Factor of 3.5** improvement is determination of GPS antenna radial offset with GPS data alone; **factor of 8** improvement with SLR data
- GNSS satellite APV sampling fully consistent with high LEO missions, such as Jason, and will improve GNSS-based orbit determination of LEOs

Factor of 3 improvement in GPS POD

Factor of 10 improvement in Geocenter determination with GPS data alone

Enhances GNSS contributions to the TRF through geocenter and scale (GNSS-based scale determination not shown here**)**

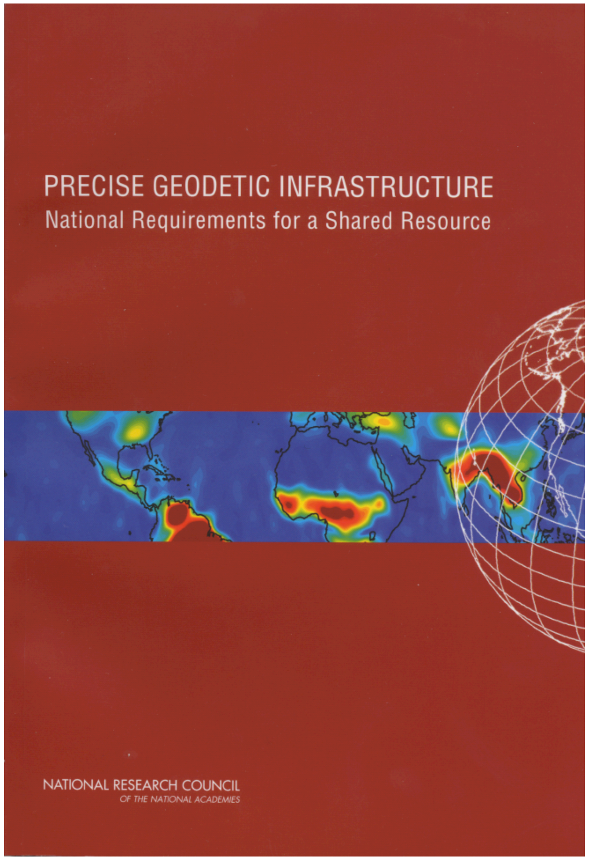
- **Factor of 10** improvement in Geocenter determination with GPS data alone



Strong Scientific Community Support for GRASP as an Innovative Solution to a Critical Problem

Decadal Survey statement about the geodetic infrastructure: "*provides the foundation for virtually all space-based and ground-based observations in Earth science and global change,… It is through this reference frame that all measurements can be inter-related for robust, long-term monitoring of global change.*"

NRC Committee on geodetic infrastructure: "*Although terrestrial techniques might be limited by the uncertainty of measuring instruments' internal offsets, **dedicated space missions could provide a prime opportunity for future innovation in this domain. One such space mission currently being proposed by NASA's Jet Propulsion Laboratory (JPL) is GRASP**"*



GRASP Programmatics

- NASA draft Venture AO released (on time) in February 2011
  - $150M cap, Earth-science focused mission
- Final AO release due June 17, proposals due 3 months later
- Passed JPL Ventures review in March, 2011; now in full mission proposal mode
  - PI: Prof. Steve Nerem, University of Colorado, Boulder
  - *Targeted launch: 2016/2017; 3 years in orbit*
- This is a mission *by* and *for* the geodetic community – all data will be available to the public immediately
- Secured broad endorsements from the geodetic community: GGOS, IGS, ILRS, IDS, and IVS
- GRASP is a dual-use mission – seeking DoD endorsements and support
  - Secured endorsements from GPS Directorate and USNO