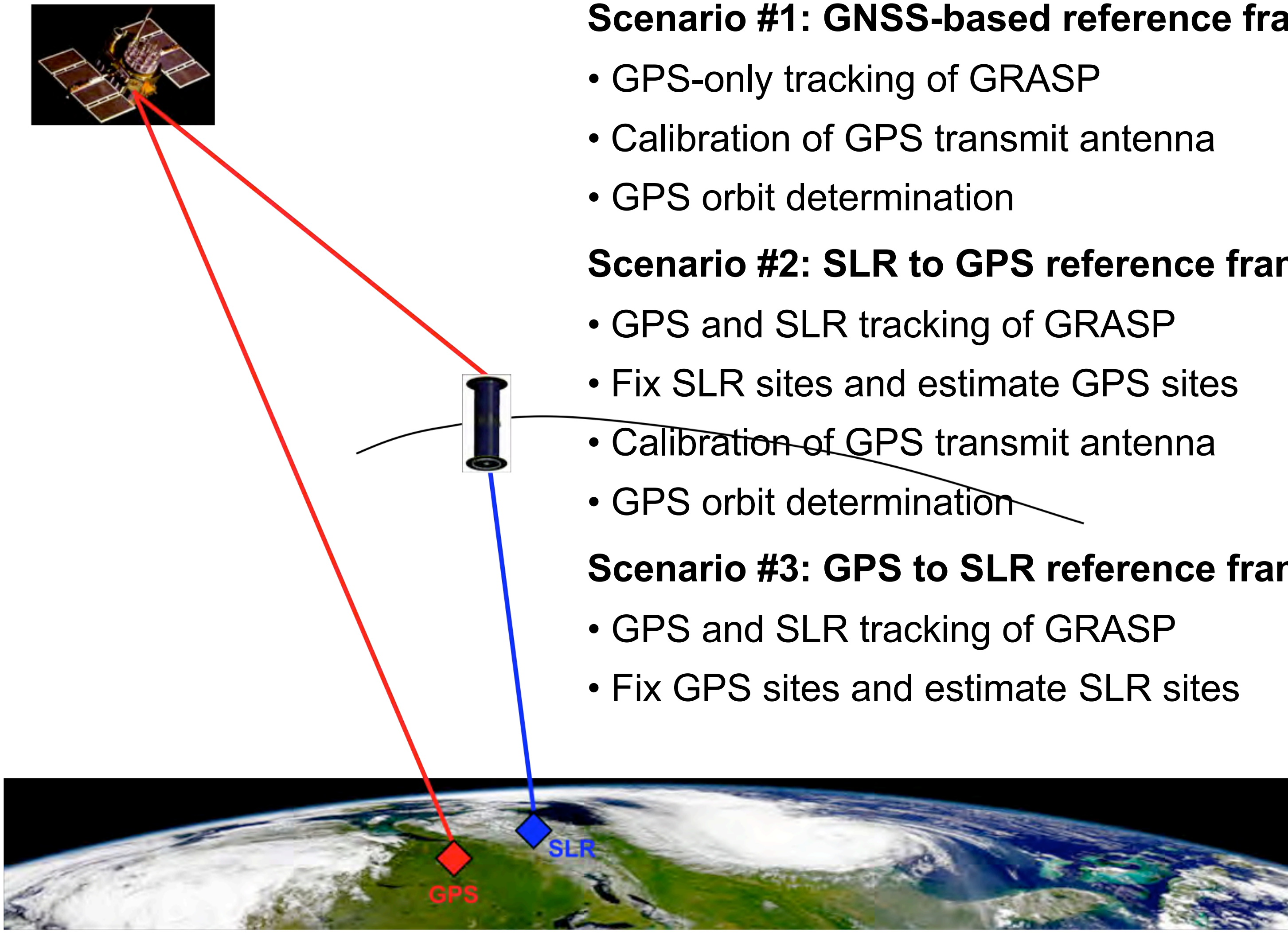
GRASP Simulations
(SLR can serve as proxy for VLBI)

Grand network solution with 66 GPS sites, 11 SLR sites, 29 GPS sats, 1 GRASP; 7 day arc



Scenario #1: GNSS-based reference frame enhancements

- GPS-only tracking of GRASP
- Calibration of GPS transmit antenna
- GPS orbit determination

Scenario #2: SLR to GPS reference frame transfer

- GPS and SLR tracking of GRASP
- Fix SLR sites and estimate GPS sites
- Calibration of GPS transmit antenna
- GPS orbit determination

Scenario #3: GPS to SLR reference frame transfer

- GPS and SLR tracking of GRASP
- Fix GPS sites and estimate SLR sites

Sample Detailed Simulation Setup (GIPSY)

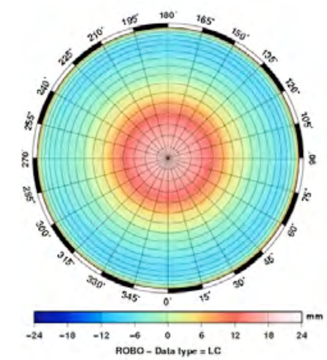
Constellation: 29 GPS satellites

MEO: 2500-km polar orbit

SLR Stations: 11 stations

GPS Stations: 66 stations

Data Types: To GPS stations: ion-removed GPS pseudorange (40 cm) & carrier phase (5 mm) + Robot APV maps for LC (& x100 for PC)
To GRASP: ion-removed GPS pseudorange (10 cm) & carrier phase (2.5 mm)
SLR to/from GRASP: (1 cm)



Data Span: 7 days

Data Sampling: once every 5 minutes

Estimated Geodetic Parameters:

GPS transmitting antenna phase centers (10 cm each component)

GPS tracking station location (20 cm each component) —SLR stations fixed
(or) SLR station location (20 cm each component) —GPS stations fixed
(or) geocenter (1 km) — all stations fixed

Other Estimated Parameters:

GRASP and GPS epoch states (1km; 1m/sec)

GRASP process-noise force (0.1nm/sec^2 each direction)

GPS X & Z solar scales as process noise (1%)

GPS Y force as process noise (0.01nm/sec^2)

GPS and ground clocks as white noise

GPS tracking site zenith troposhere delays as random walk

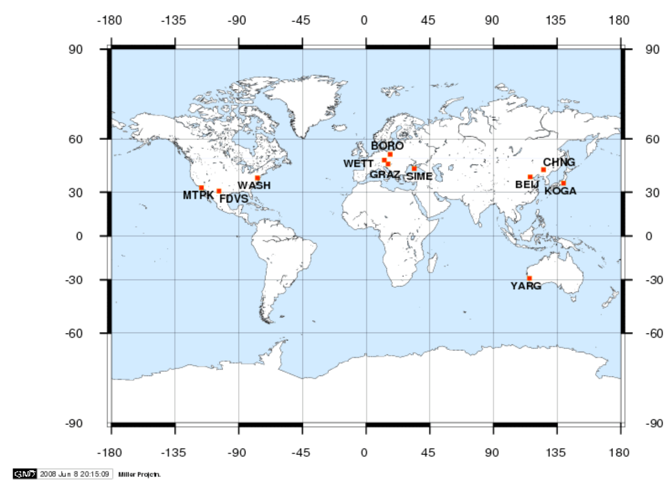
Phase biases

7-Parameter Transformation:

with stacov for GPS stations —SLR stations fixed

(or) with stacov for SLR stations —GPS stations fixed

SLR Ground Network



Simulation Results
(Combined Random and Systematic Errors)

Scenarios \ Performance Metrics	GPS Orbit mm	GPS Ant Z Offset mm	GRASP Orbit mm	Geo-center mm	GPS Site Position mm	SLR Site Position mm	Helmert Trans. mm
0) Ground GPS Data Only (No GRASP): Fixed ground sites, estimate GPS orbits, phase offsets, geocenter	20.7 H 13.5 C 22.2 L	113.6	N/A	2.9 X 2.6 Y 59.4 Z	N/A	N/A	N/A
1) GPS Data Only from Ground and GRASP: Fixed ground sites, estimate GPS orbits, phase offsets, geocenter	7.4 H 7.2 C 7.4 L	30.9	0.9 H 0.6 C 2.4 L	2.2 X 0.9 Y 5.6 Z	N/A	N/A	N/A
2) SLR -> GPS Ref. Transfer: GPS and SLR Data, fixed SLR sites, estimate GPS orbits, phase offsets, and GPS sites	8.4 H 8.7 C 7.9 L	14.1	0.7 H 0.7 C 1.9 L	2.7 X 1.3 Y 1.4 Z	2.9 X 3.7 Y 0.9 Z	N/A	0.4 Ry 2.0 Tz 4.5 Sc
3) GPS -> SLR Ref. Transfer: GPS and SLR Data, fixed GPS sites, estimate GPS orbits, and SLR sites	8.3 H 7.1 C 7.4 L	N/A	0.7 H 0.6 C 2.0 L	0.8 X 0.8 Y 0.7 Z	N/A	0.1 X 0.2 Y 0.1 Z	0.4 Ry 0.4 Tz 0.3 Sc

Broad GNSS Benefits

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

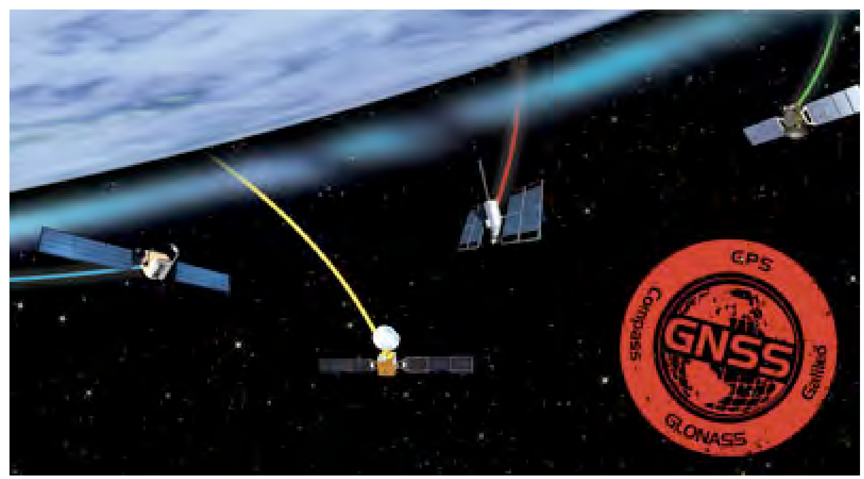
- **Factor of 3.5** improvement is determination of GPS antenna radial offset with GPS data alone; **factor of 8** improvement with SLR data
- Acutely needed as GNSS antennas, frequencies, and signals proliferate
- Broad GNSS system-wide improvements due to better antenna models
- GNSS satellite APV sampling fully consistent with high LEO missions, such as Jason, and will improve GNSS-based orbit determination of LEOs

GRASP directly improves GNSS orbit determination and ground positioning due to exquisite dynamics (10 times better than Jason) and outstanding observation geometry

- **Factor of 3** improvement in GPS POD

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



New Perspectives on TRF Definition and Transfer

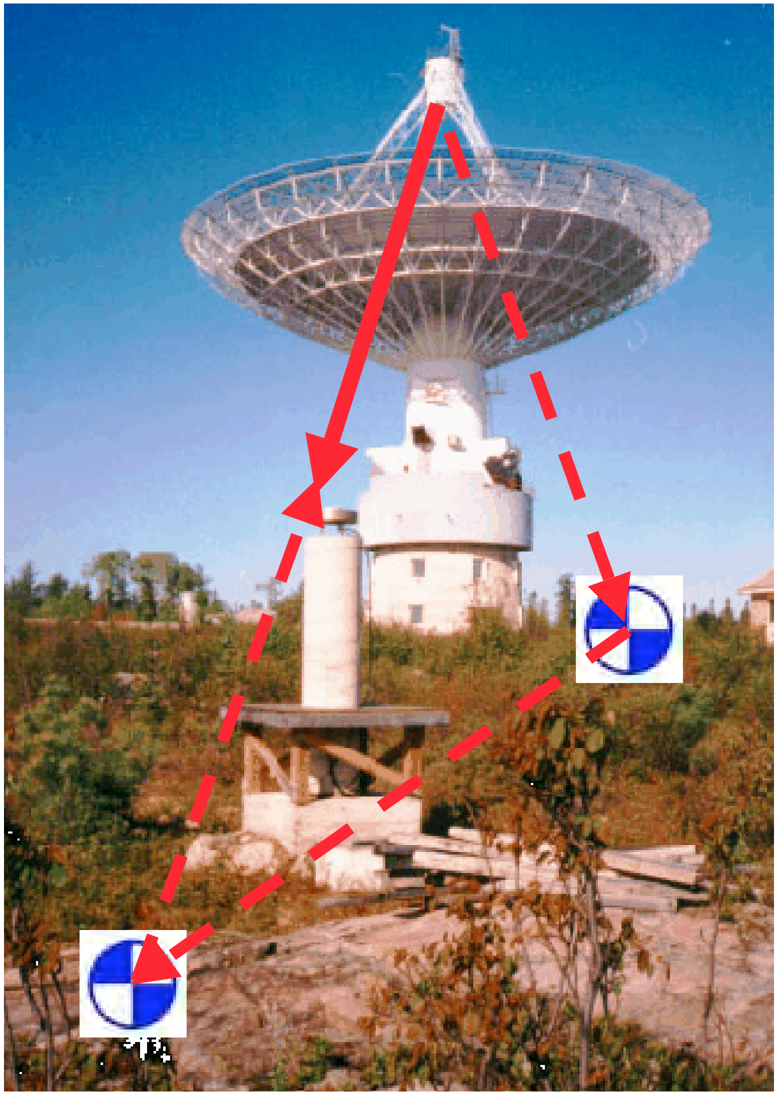
Enables phase-center to phase-center reference frame transfer between the key geodetic techniques

- **Few mm accuracy** in just 7 days
- Reduces or eliminates the need for ground collocation, and for local tie surveys
- Enables **unlimited densification** of the TRF through GNSS
- With local surveying can determine true local eccentricities

Enables more consistent combination of the diverse geodetic techniques

- GRASP provides consistent scale, tied to GM, for all techniques
- Improve the definition of the TRF with increased contributions from GNSS

Stable platform and long-term presence ensures long-term stability of the TRF



New Cross Technique Synergy

Improve positioning of VLBI and Deep Space Network Tracking sites will improve deep space navigation and planetary science

- Enhance TRF-CRF closure tests with VLBI
- Improved deep space navigation by improving DSN antenna locations
- GRASP also offers the ideal target to calibrate DSN range measurements

Broad benefits to DORIS from collocation with all geodetic techniques

Fresh approach to geodesy will bring together the disparate geodetic communities as never before, and energize the unified modeling campaign, consistent with GGOS goals

DSN Navigation Requirements

Tracking Error Source (1 sigma Accuracy)	units	current capability	2005 reqt	2010 reqt	2020 reqt	2030 reqt
Doppler/random (60s)	mm/s	0.03	0.05	0.03	0.03	0.02
Doppler/systematic (60s)	mm/s	0.001	0.05	0.003	0.003	0.002
Range/random	m	0.3	0.8	0.5	0.3	0.1
Range/systematic	m	1.1	0.6	2	2	1
Delta-VLBI	nrad	2.5	5	2	1	0.5
Troposphere zenith delay	cm	0.8	1	0.5	0.5	0.3
Ionosphere	TECU	5	5	5	3	2
Earth orientation (real-time)	cm	7	30	5	3	2
Earth orientation (after update)	cm	5	5	3	2	0.5
Station locations (geocentric)	cm	3	3	2	2	1
Quasar coordinates	nrad	1	1	1	1	0.5
Mars ephemeris	nrad	2	-	3	2	1