International Laser Ranging Service

SLR Tracking of GNSS Constellations

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UMBC

Motivation

- Several GNSS constellations are rapidly maturing and most of them plan to carry SLR CCR arrays
- SLR has been "starving" for targets in MEO/HEO orbits to complement the LAGEOS & ETALON pairs
- GNSS can benefit from SLR tracking in various areas, from calibration/validation of their orbits to improving their solutions, etc.
- SLR can take advantage of the existence of these new targets to strengthen and expand its product list

Experiments

- Start with the 8 & 16 site SLR networks
  - Same as those used for the SLR & VLBI simulations
- Examine the contribution of SLR tracking to GNSS
  - Can we transfer origin and scale with required accuracy?
- Simulations for 6 and 12 s/c from GPS and Galileo
  - Examined the effect of restricted tracking on orbit quality
  - Force model errors on orbit quality
  - Origin and scale error due to restricted tracking
  - More than 2000 cases of weekly tests, still being examined

Simulation Parameters

Case	GPS or Galileo Constellation Spacecraft				
	Number of Sites	Number of S/C	Elevation Cutoff	Daytime %	Nighttime %
1	8 or 16	All	20	100	100
2	8 or 16	6	20	100	100
3	8 or 16	6	45	50	75
4	8 or 16	6	45	25	50
5	8 or 16	6+6	20	100	100
6	8 or 16	6+6	45	50	75
7	8 or 16	6+6	45	25	50
Force-model Error Change: C_r					
8	16	6+6	45	50	75
9	16	6+6	45	25	50
Force-model Error Change: NO empirical accelerations					
10	16	6+6	45	50	75
11	16	6+6	45	25	50
Force-model Error Change: C_r & NO empirical accelerations					
12	16	6+6	45	50	75
13	16	6+6	45	25	50

Future ITRF Accuracy Goal

- Future ITRF* should exhibit consistently and reliably accuracy and stability at the level of:

<1 mm in epoch position, and

< 0.1 mm/y in secular change

*Current performance: ~ 10 mm and ~ 1 mm/y

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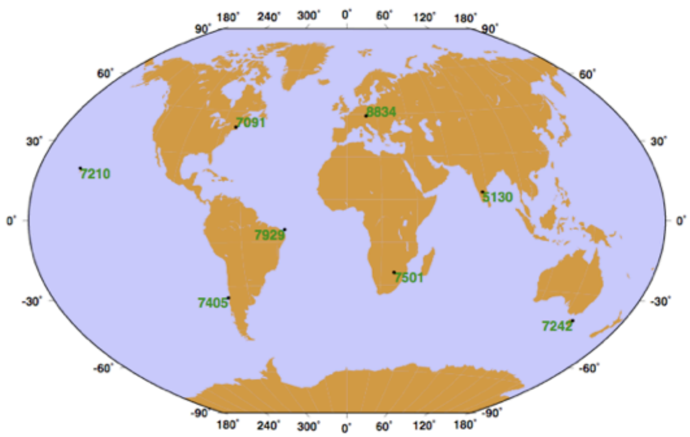
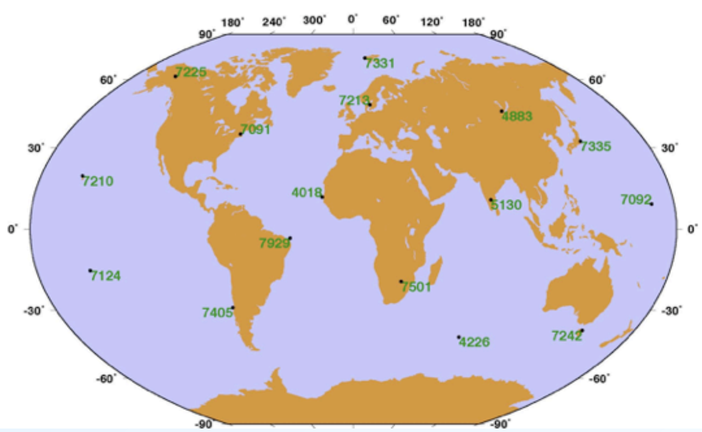
Next Generation NASA Networks 08 sites



Next Generation NASA Networks 16 sites



- Two SLR networks of NGSLR systems (24/7 operational capability)
- All stations track all s/c of either the GPS or the Galileo Constellations as reference, then one case of only six s/c, in an alternate case of 12 s/c
- At this stage the errors that were considered were limited to random walk errors at the stations, similar to those we see at contemporary stations and limited orbital mis-modeling of non-conservative forces

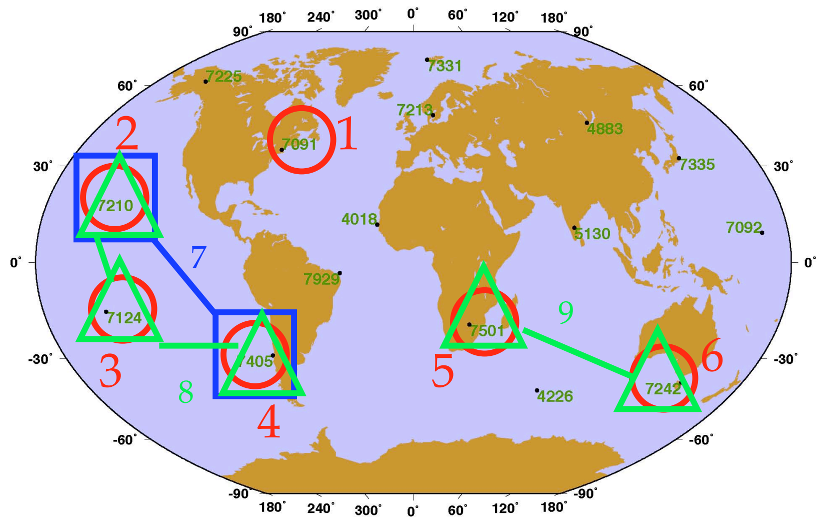
GNSS Tracking with SLR

(All 26 GPS & Only 6)

Examined Cases	8 sites	16 sites	16 sites R_b=10 mm	16 sites R_b=10 mm (random)
Scale [ppb]	-0.22 ± 0.5	-0.08 ± 0.4	1.25 ± 0.4	0.94 ± 0.4
Origin 3-D [mm]	3.0 ± 2.5	1.5 ± 1.3	3.6 ± 2.5	2.5 ± 2.1
Scale [ppb]	0.16 ± 0.6	0.19 ± 0.7	1.50 ± 0.7	2.09 ± 0.7
Origin 3-D [mm]	1.6 ± 2.9	2.3 ± 2.4	4.3 ± 3.4	5.2 ± 4.3

16-site SLR Network Variations

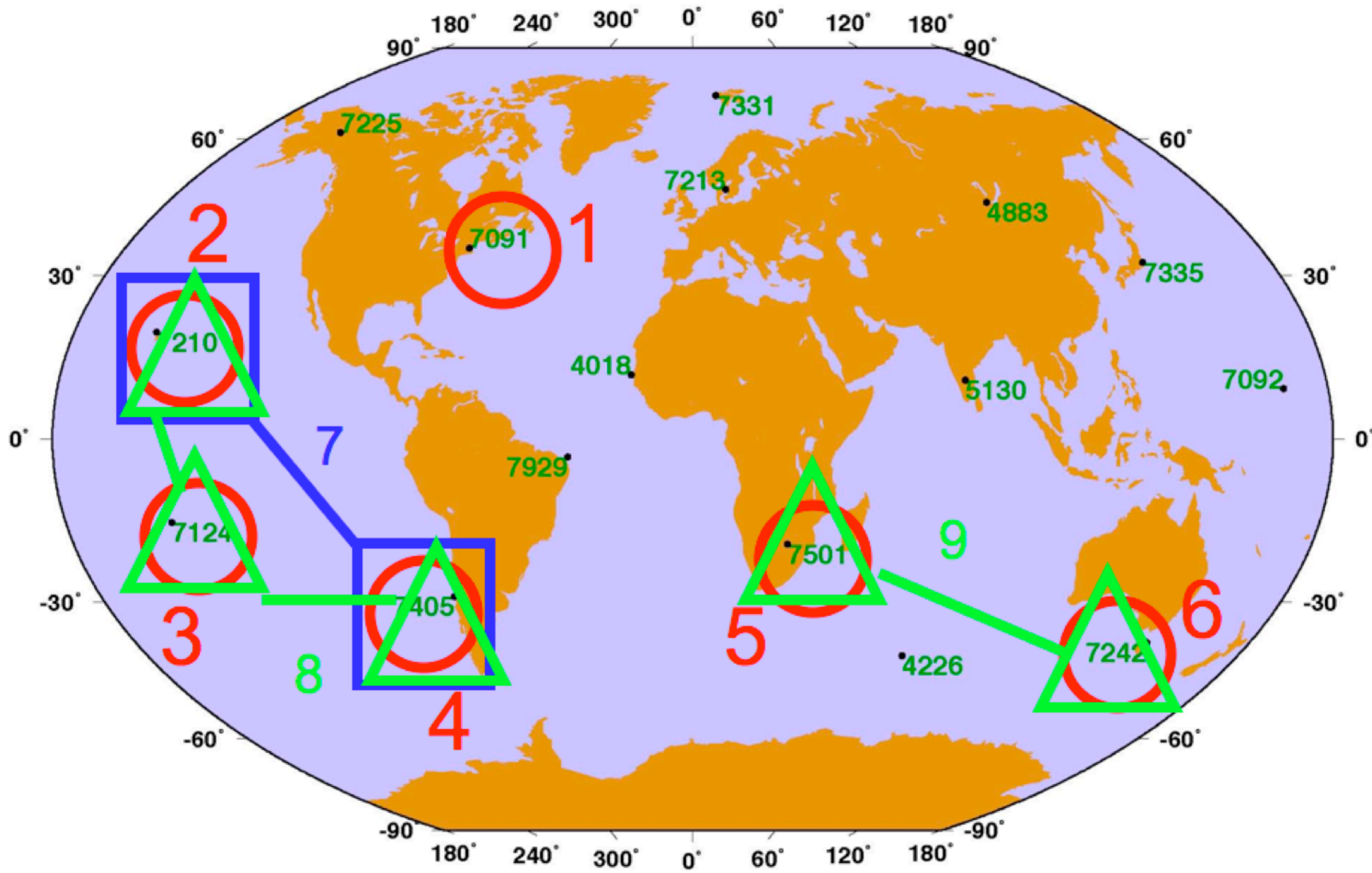
Next Generation NASA Networks 16 sites



Although the sites named at right are not at the exact locations shown above, they are close enough (proxies) to be considered sites representative of that area.

- Starting with the 16-site SLR network we generated simulated results for 10 variants, each with one or more of the NASA (or NASA-equipped) sites removed
- The removed sites are:
  1. **GGAO**
  2. **Hawaii**
  3. **Tahiti**
  4. **Arequipa**
  5. **South Africa**
  6. **Australia**
  7. **Hawaii & Arequipa**
  8. **Hawaii, Arequipa & Tahiti**
  9. **South Africa & Australia**
  10. **All six sites**

Network Size Variations



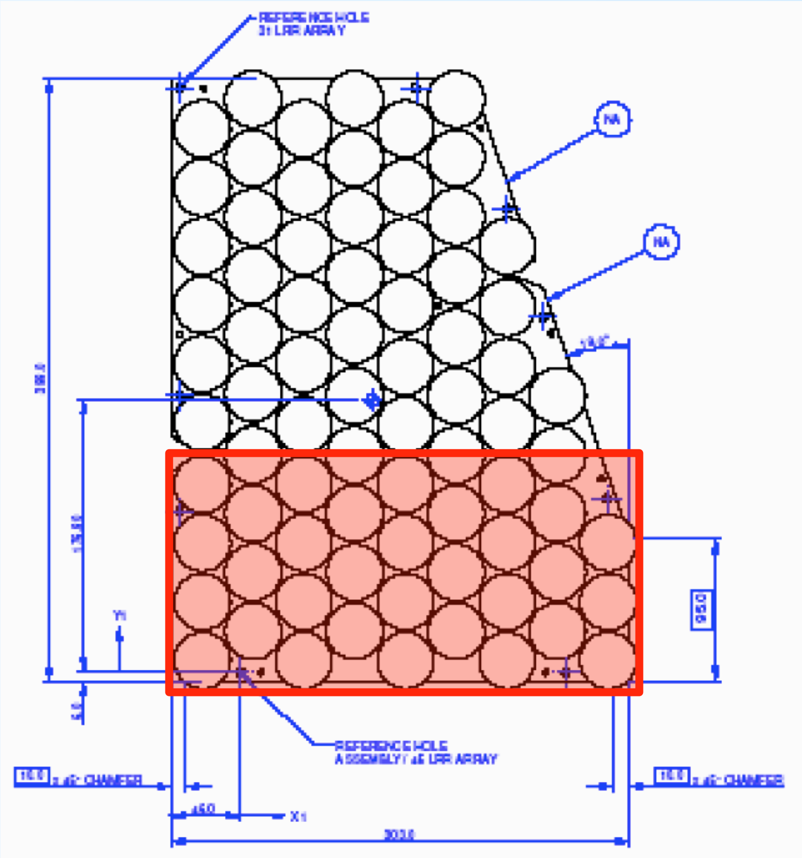
Summary of Network Variations' Cases

Case	Removed site	Origin error (3D in: mm - %)		Scale error (in: ppb - mm - %)		
Standard 16	Reference network	---	---	---	---	---
1*	GGAO (NA)	3.2 mm	40 %	0.08 ppb	0.51 mm	-59 %
2	Hawaii	3.2	41	0.16	1.02	-16
3	Tahiti	3.1	34	0.18	1.15	-5
4	Arequipa (SA)	3.1	36	0.10	0.64	-48
5	S. Africa	3.2	40	0.13	0.83	-32
6	Australia	2.8	22	0.15	0.96	-21
7	Hawaii & Arequipa	4.2	83	0.06	0.38	-69
8	Hawaii, Arequipa & Tahiti	5.7	149	-0.02	-0.13	-112
9	S. Africa & Australia	3.2	40	0.15	0.96	-21
10	All 6 NASA sites	8.1	252	-0.55	-3.52	-394

GNSS CCR Arrays

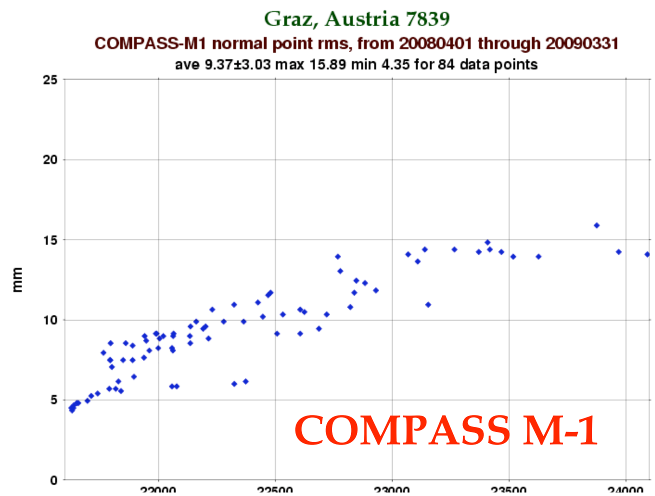
GPS 35 & 36 Array

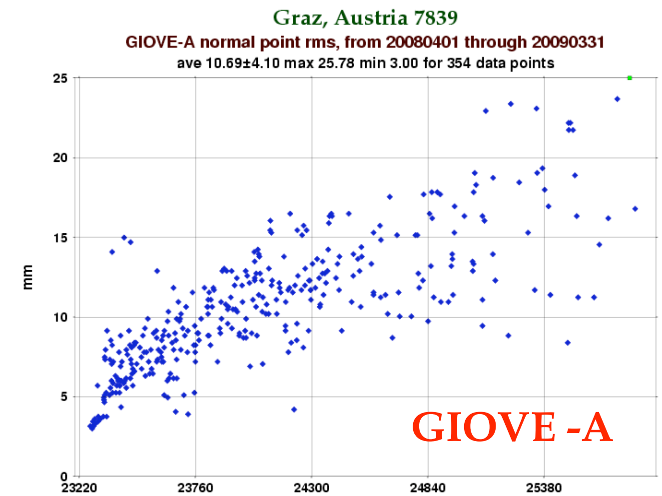
GIOVE – A Array



Signal Strength vs. CCR Array Size

Graz





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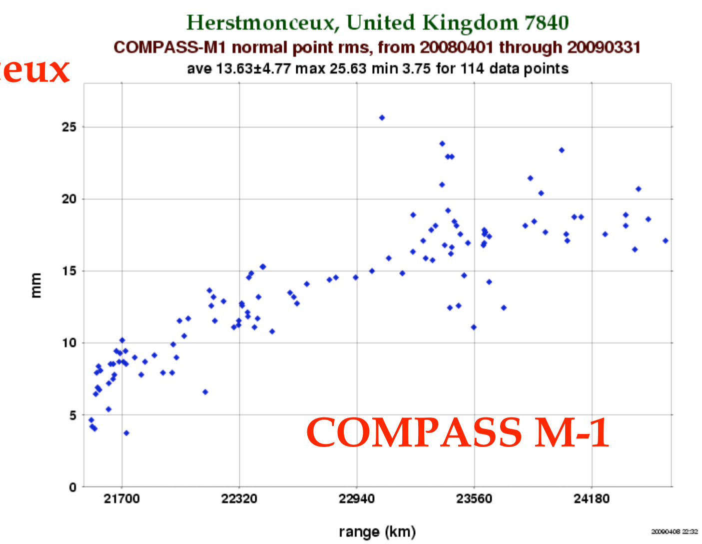
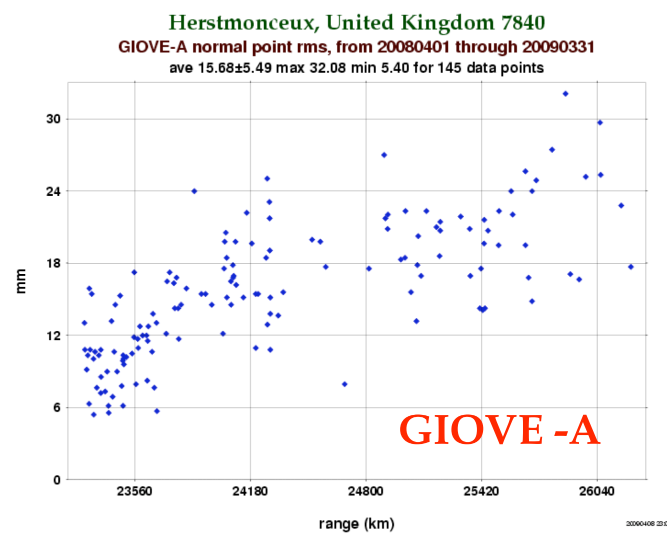
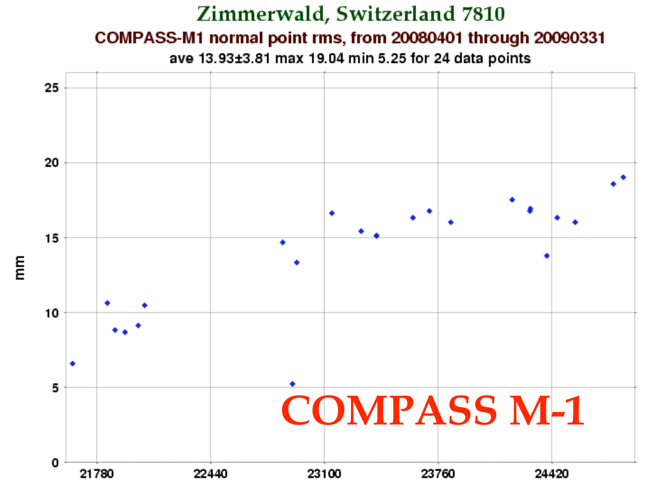
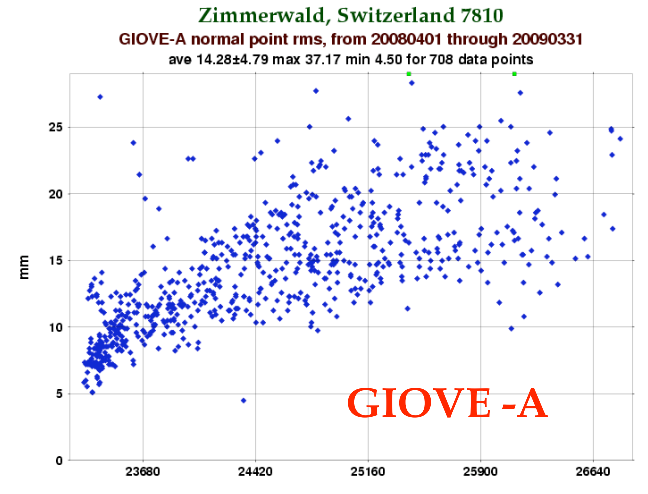


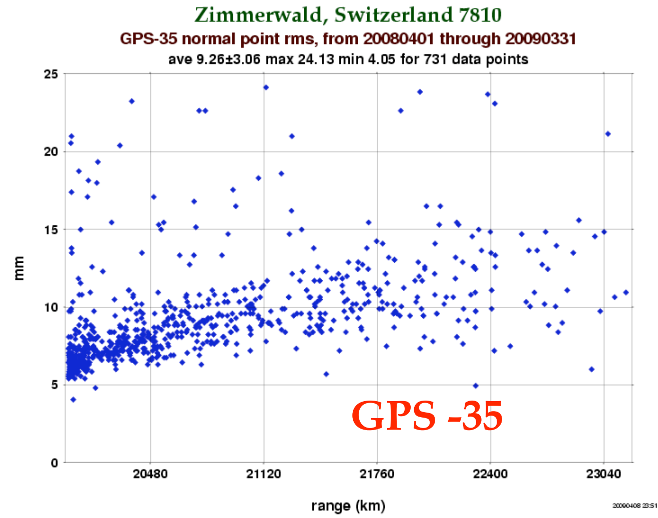


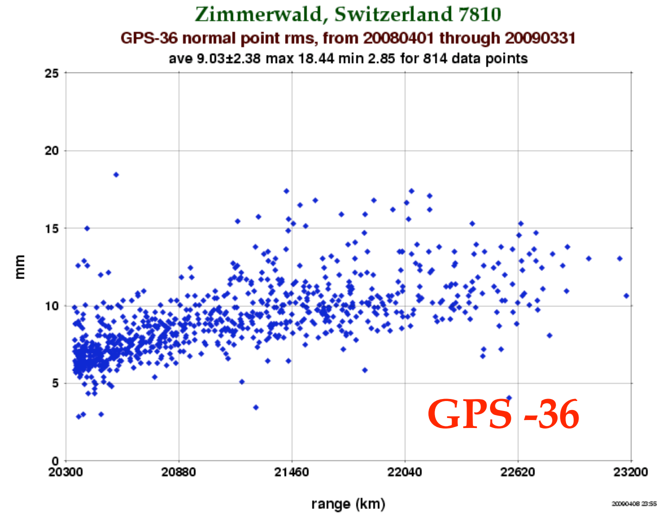
Signal Strength vs. CCR Array Size

Zimmerwald

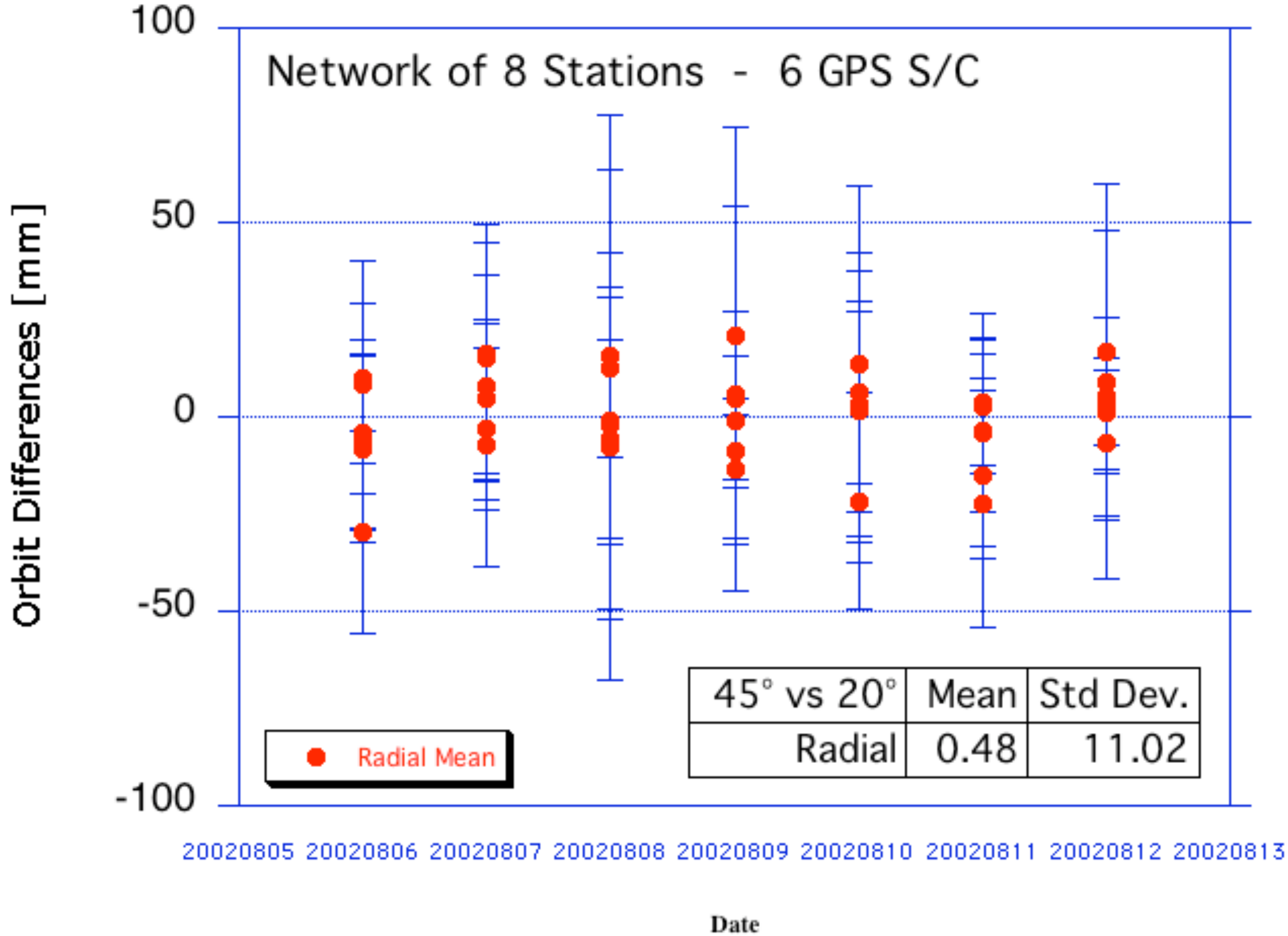






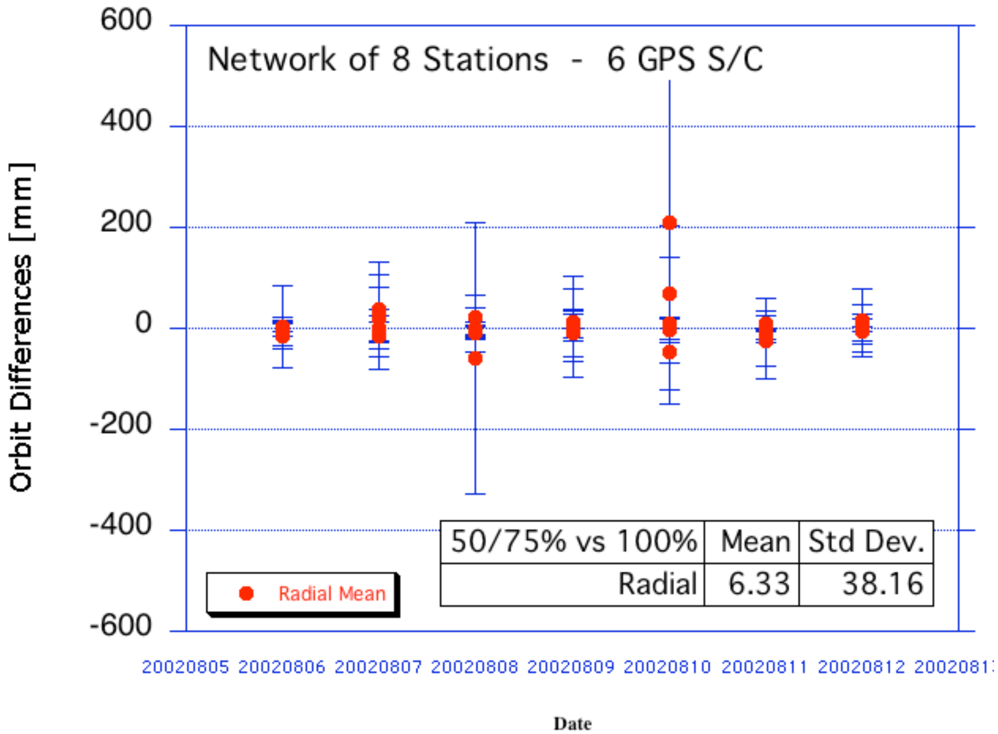


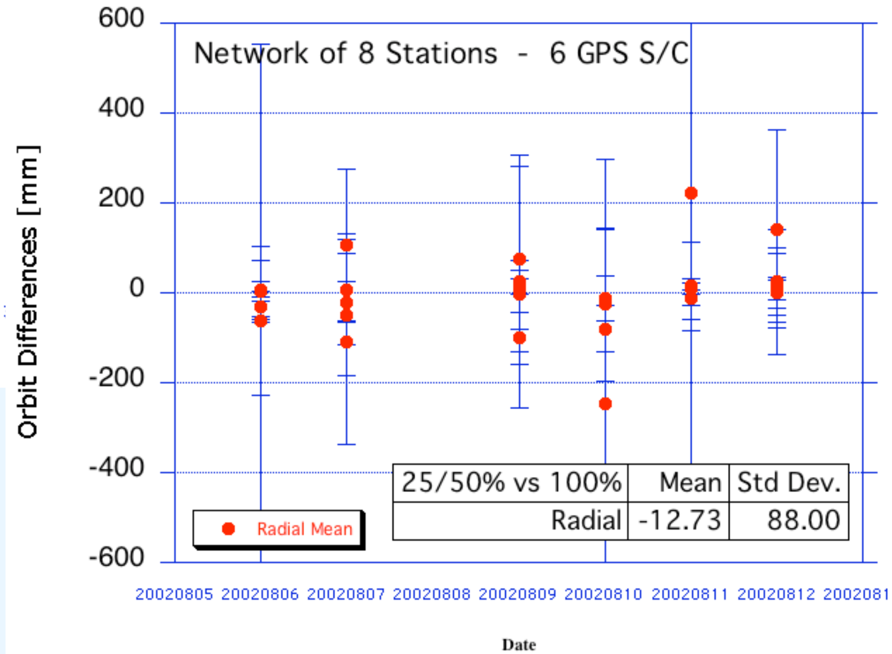
GPS Cases - I



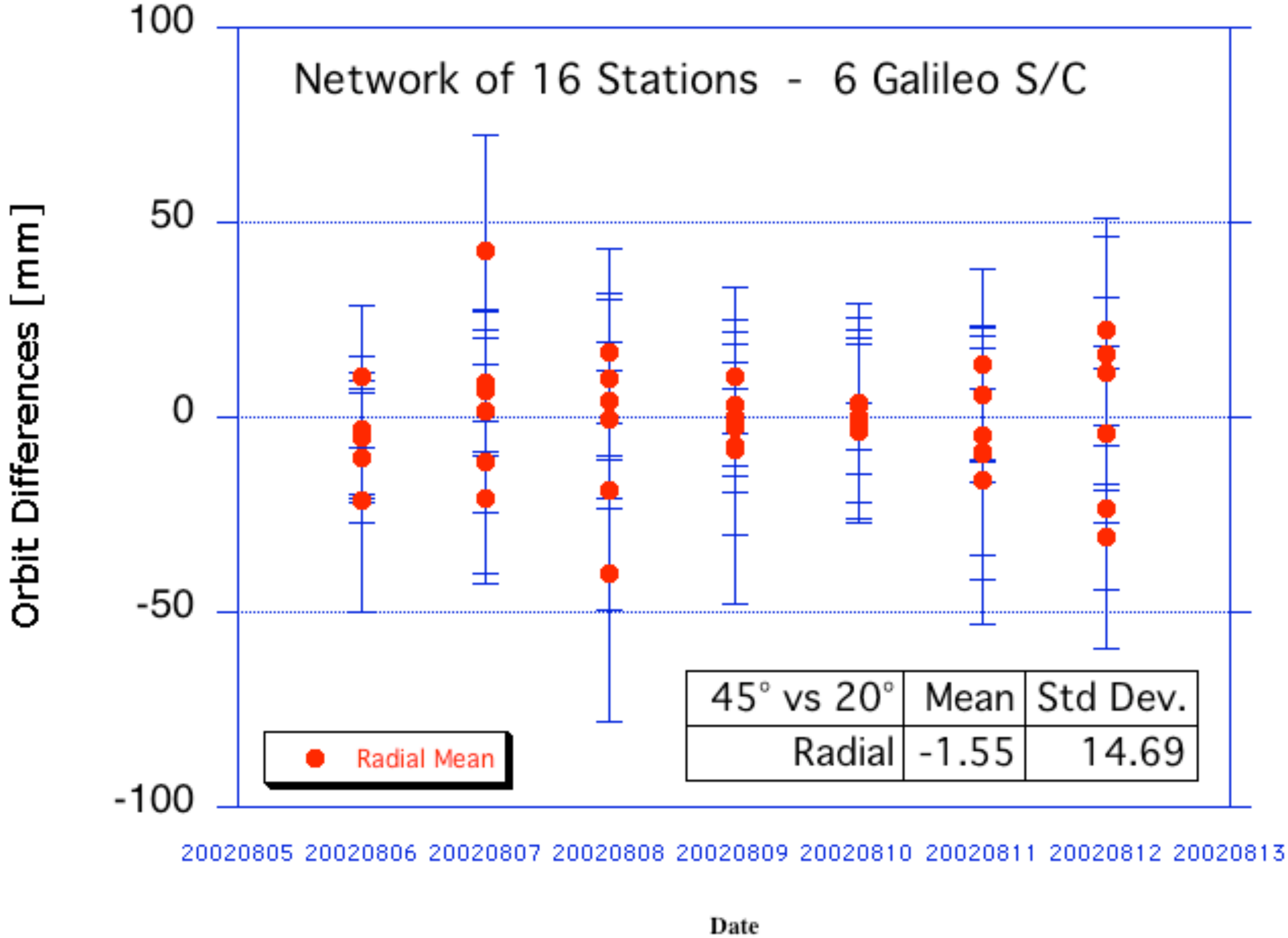
Network of 8 Stations - 6 GPS S/C
Orbit Differences [mm]
100
50
0
-50
-100
Radial Mean
45° vs 20°
Mean
Std Dev.
Radial
0.48
11.02
20020805 20020806 20020807 20020808 20020809 20020810 20020811 20020812 20020813
Date

GPS Cases - II


Network of 8 Stations - 6 GPS S/C
600
400
200
0
-200
-400
-600
Orbit Differences [mm]
50/75% vs 100% | Mean | Std Dev.
Radial | 6.33 | 38.16
Radial Mean
20020805 20020806 20020807 20020808 20020809 20020810 20020811 20020812
Date

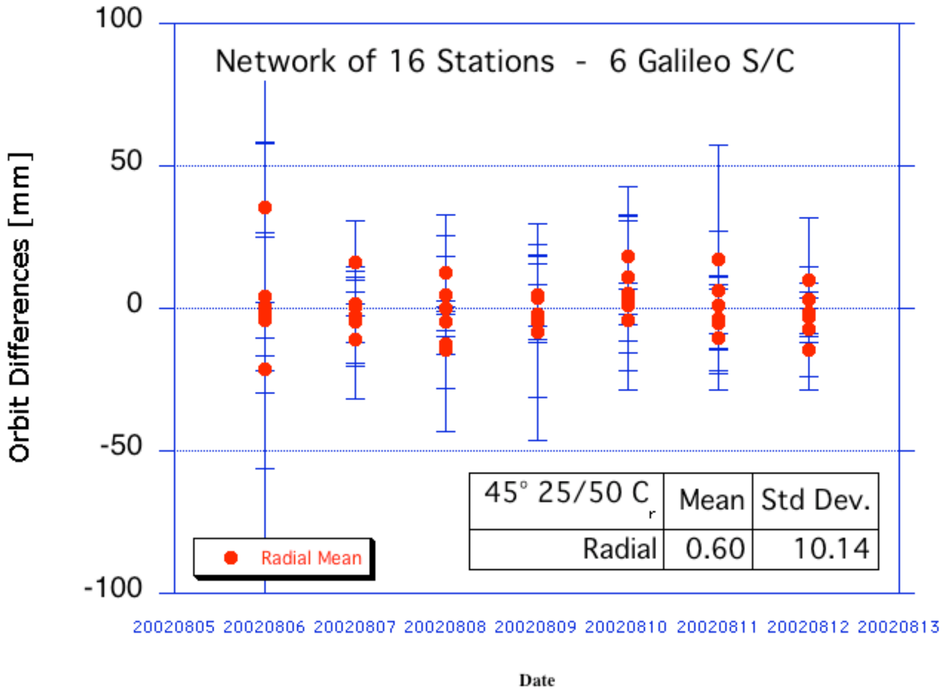

Network of 8 Stations - 6 GPS S/C
600
400
200
0
-200
-400
-600
Orbit Differences [mm]
25/50% vs 100% | Mean | Std Dev.
Radial | -12.73 | 88.00
Radial Mean
20020805 20020806 20020807 20020808 20020809 20020810 20020811 20020812 20020813
Date

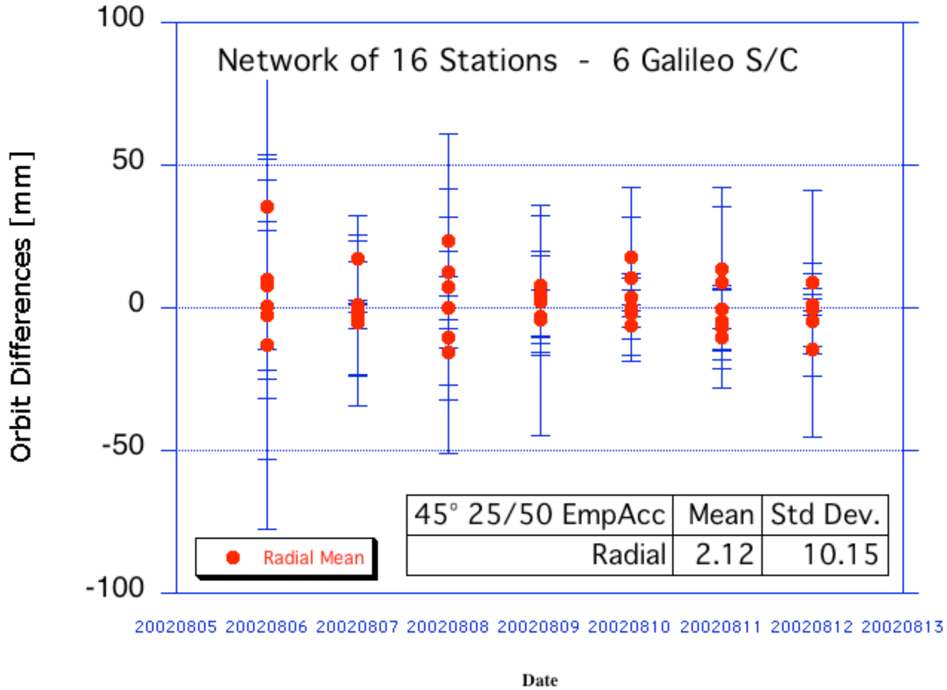
Galileo Cases - I



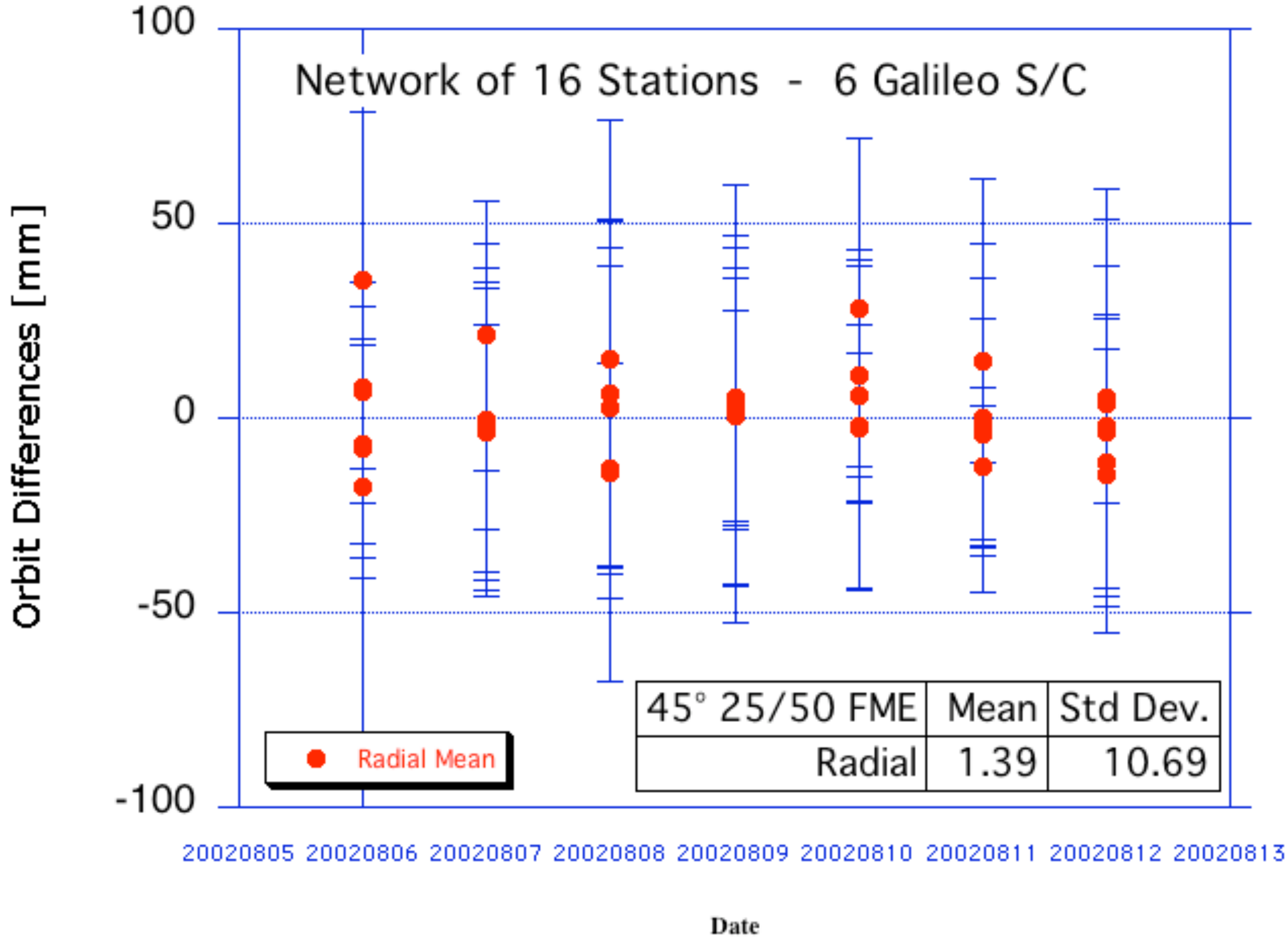
45° vs 20°	Mean	Std Dev.
Radial	-1.55	14.69

Galileo Cases - II





Galileo Cases - III



Summary - I

- SLR tracking of all GPS s/c from a 16-site network meets or exceeds the accuracy/stability goals set by GGOS.
- A variation with reduced tracking of only one quarter of the GPS s/c is nearly as effective.
- When the 16-site network is modified with the removal of key stations, one at a time or in various combinations, we observe that:
  - Single site removals affect the origin definition by 20-40% and the scale from 5 to 60%
  - Based on the few single site removal tests, GGAO carries the highest weight of all tested
  - Removal of pairs of sites results in unacceptable increase in the errors, both in the origin and scale
  - Removal of the three Pacific sites increases the origin errors almost by 150%
  - When all six NASA sites are removed, the error in the origin rises over 250% and the scale error is almost -400%
- Although the removal of a single site results in most cases in acceptable errors, combinations of sites, when removed, have profound consequences on the quality of the resulting TRF. In particular, the Pacific and South American sites seem to be the most important in maintaining the integrity and stability of the TRF.

Summary - II

- Origin and scale quality of SLR can be transferred to GNSS with a tracking network of about a dozen sites globally distributed, tracking six s/c (selected)
- Tracking site drop-outs can cause serious distortions if the sites are located in nearby regions void of other control sites
  - This explains in part the degradation seen in 2003-2006 when 2 NASA sites were shut down in the Pacific area
- Extending the SLR target group to GNSS s/c can bring benefits to both techniques, but it requires careful array design to avoid a waste of resources due to target acquisition difficulties
  - GNSS POD can suffer from low signal strength due to poor tracking geometry and higher rate of loss of returns
  - Arrays smaller than the one on COMPASS will not support better than cm-level radial orbit quality

Future Work

- We are examining the improvement of the TRF from the inclusion of SLR tracking data on GNSS s/c
- Initial results indicate that the EOP will benefit most due to the increased geometry in the space segment
- We will quantify though further simulations the improvement in LEO orbits determined on the basis of GNSS orbits that have been tracked also by SLR