Impact of SLR Tracking of GNSS Constellations on Science

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Purpose of Position Paper

- The purpose of this position paper is to examine the scientific benefits from the tracking of GNSS constellations with SLR

- Direct impact of SLR tracking on the GNSS constellations was already presented in the corresponding Position Papers

- Herein we will focus on the areas where the improved products will likely have significant implications and the new opportunities presented to the SLR community with the large number of Laser Retro-reflector Arrays (LRA) that will be very soon launched in orbit.

Introduction

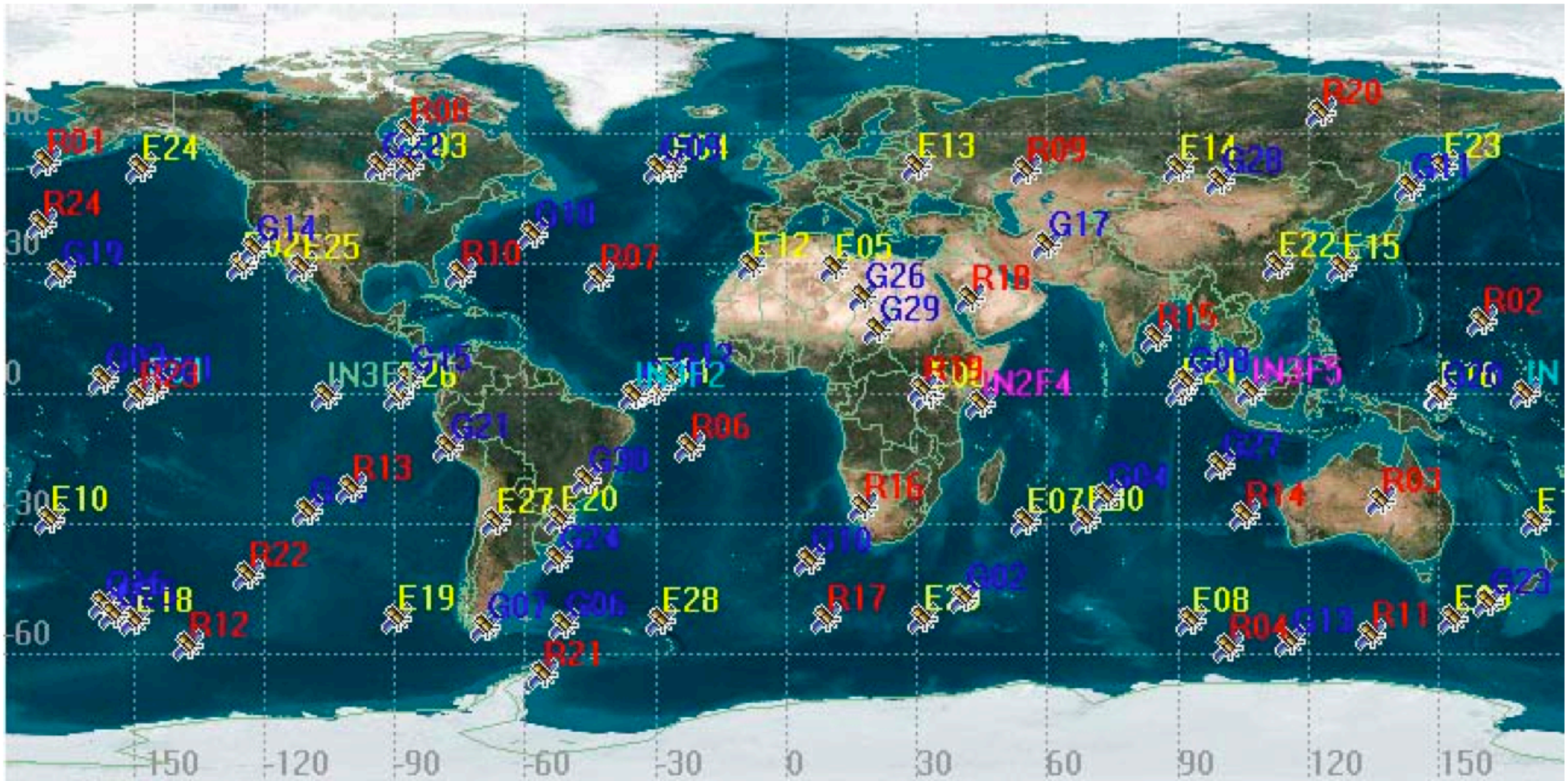
- GNSS now a typical utility service expected readily available worldwide
- From very early GPS users from very diverse areas attempted to extract highly accurate results, well before the system became fully operational
- Scientists very quickly realized the potential of such technology and were some of the first and most demanding users
- The need for high accuracy for geodetic applications drove the development of sophisticated receiving equipment at a very rapid pace

GNSS Today

- Today we have available a multitude of GNSS constellations:
  - that are operational (GPS),
  - or nearly so (*GLONASS, COMPASS/Beidou, Galileo*),
  - while there are yet more in the process of development (QZSS)
- GNSS has evolved as the prime system for a number of geodetic applications, some of which are:
  - precise positioning,
  - monitoring of deformation fields,
  - Earth rotation monitoring,
  - Precise Orbit Determination (POD) of LEO missions,
  - development of the International Terrestrial Reference Frame (ITRF), etc.

GNSS in Near Future

GPS+GLONASS+GALILEO*



*From Drazen Svehla Institute of Astronomical and Physical GeodesyTechnischeUniversitätMünchen, Germany

Summary of Direct Benefits to GNSS

- SLR, an independent technique, insensitive to the ionosphere and with very small dependence on atmospheric water vapor (refraction delay), will aid their calibration and validation of GNSS orbits

- SLR observations will aid in modeling the onboard clocks, a key part of GNSS techniques

- SLR measurements are independent of the GNSS station positions and onboard clocks, thus the effect of any mis-modeling of the GNSS clocks can be separated from orbit errors, leading to improved understanding of clock behavior in space

Other Areas of Benefit

- Other areas that will benefit directly are:
  - the tracking support in the initial phases of deployment of new constellations (ESA's GIOVE-A & B),
  - Constellations with tracking network in its infancy (COMPASS),
  - the improvement and validation of spacecraft dynamics (albedo),
  - the alignment of the GNSS intrinsic reference frames to ITRF,
  - To enable the interoperability of GNSS systems through a common, independent measurement technique

Additional, Indirect Benefits

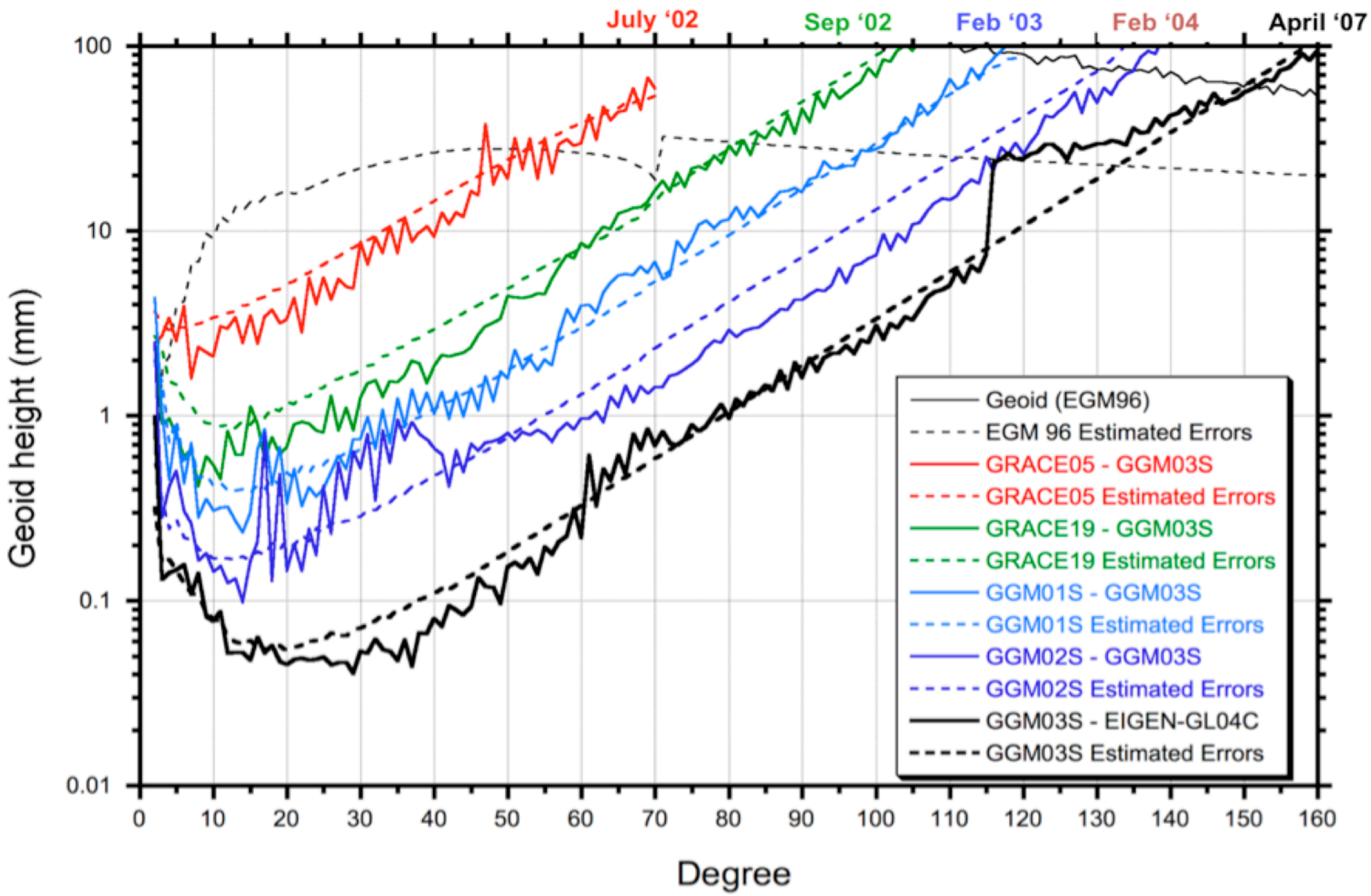
- Improved positioning and navigation of instrumented platforms, on the ground, seaborne, airborne, or on spacecraft
- Precise Point Positioning (PPP) for users who do not demand the highest accuracy and rely on precise orbits available through IGS or other individual institutions and agencies
- GNSS tracking for POD will produce a more accurate orbit and higher consistency with the ITRF, leading to better geolocated products and most likely a quicker turn-around of products, sometimes a critical factor

Earth Observing Mission Support

- Oceanographic missions like OST/Jason-2 for example will be able to release sea surface height maps in near real-time with much higher accuracy than it is possible today, leading to various oceanographic applications not possible at present

- GRACE & GOCE products will benefit from the higher quality of the GPS orbits to the extent that they can make better use of that tracking data for the resolution of the very low-degree harmonics that are now typically substituted from SLR-based solutions

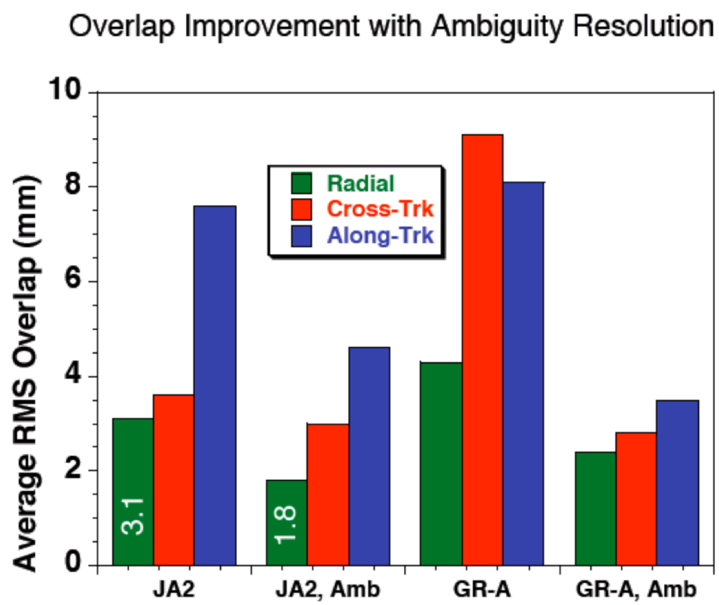
GRACE-derived Geoid Error Spectrum



Potential LEO Orbit Improvement*

Data Processing/Ambiguity Resolution

- **Single Receiver Ambiguity Resolution**
  - Not fixing, finite weight on double-differences
- **Global GPS Orbit and Clock Process (JPL FLINN, QL,…)**
  - For each arc saves – Transmitter name, receiver name, widelane average/standard deviation, phase bias (wlpb file)
- **Single receiver uses orbit/ clock and wlpb information and tries to resolve all possible double differences**
  - Widelanes, narrow lanes, iterative improvement
  - Parameter adjustment allows for non-normal error distributions



*From: [Bertiger et al., 2009]

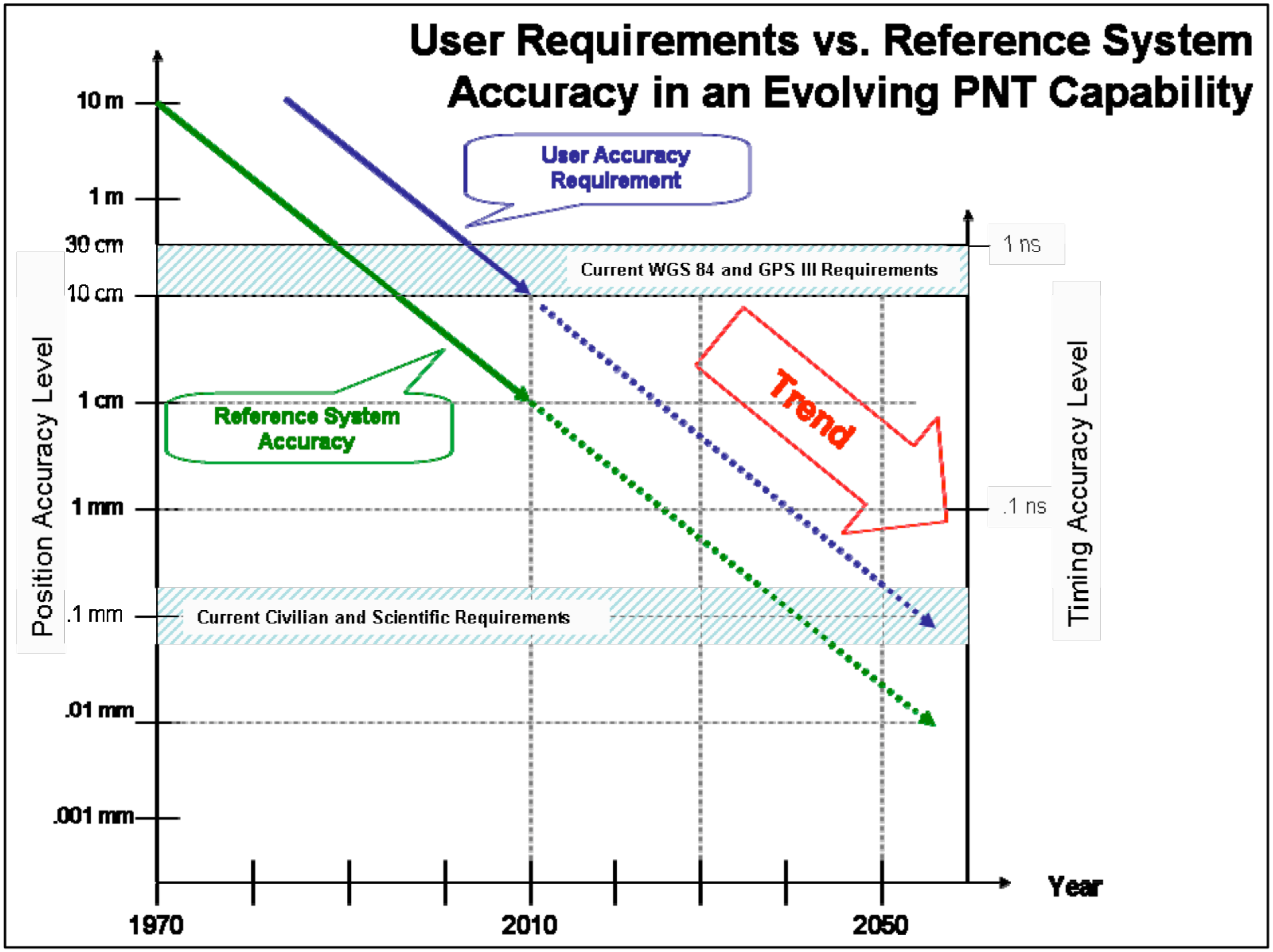
International Laser Ranging Service

Science Objective	Mission	Category/Sponsor	Geodesy Requirement
Atmospheric Science Climate Change	CLARREO (NASA portion) 2010-2013	Decadal Survey - NASA	precise orbit determination
Atmospheric Science Hydrologic Science	SMAP 2010-2013	Decadal Survey - NASA	geo-referencing
Cryospheric Science Climate Change	ICESat-II 2010-2013	Decadal Survey - NASA	precise orbit determination
Solid Earth Science Cryospheric Science Natural Hazards Climate Change	DESDynI 2010-2013	Decadal Survey - NASA	precise orbit determination
Solid Earth Science	HyspIRI 2013-2016	Decadal Survey - NASA	geo-referencing
Ocean Science Hydrologic Science Natural Hazards	SWOT 2013-2016	Decadal Survey - NASA	precise orbit determination
Solid Earth Science Hydrologic Science	LIST 2016-2020	Decadal Survey - NASA	precise orbit determination
Solid Earth Science Hydrologic Science Ocean Science	GRACE-II 2016-2020	Decadal Survey - NASA	precise orbit determination
Cryospheric Science Hydrologic Science	SCLP 2016-2020	Decadal Survey - NASA	geo-referencing
Atmospheric Science Climate Change	CLARREO (NOAA portion) 2010-2013	Decadal Survey - NOAA	precise orbit determination
Atmospheric Science Climate Change	GPSRO 2010-2013	Decadal Survey - NOAA	precise orbit determination
Ocean Science Natural Hazards	Jason-3 2013 launch	Future ocean altimetry	precise orbit determination
Ocean Science Natural Hazards	Sentinel-3A 2013 launch	Future ocean altimetry	precise orbit determination
Cryospheric Science Ocean Science Natural Hazards	CRYOSAT-2 2009 launch	Future ocean altimetry	precise orbit determination
Ocean Science Natural Hazards	SARAL 2010 launch	Future ocean altimetry	precise orbit determination
Ocean Science Natural Hazards	HY-2A 2010/11 launch	Future ocean altimetry	precise orbit determination

US Support for SLR Tracking GPS

- US Federal Organizations (NASA, NGA, NOAA, USGS, NRL, USNO) have recommended to the ***Interagency Forum on Operation Requirements*** (IFOR) that a very important step toward the GGOS accuracy target of 1 mm accuracy and 0.1 mm/y stability is:
  - to provide systematic co-location in space through the precision orbit determination of GPS satellites via the global network of laser ranging stations supported by these agencies and GGOS
- The required improvements in the ITRF are approximately 10-20 times its current accuracy

Accuracy Trends, Past and Future



Key Factors for Success

- A requirement for meaningful results from laser ranging to GPS satellites is the very precise knowledge of the location of the effective reflecting plane of the corner-cube retro-reflector (CCR) array with respect to the center of gravity (CoG) of the spacecraft
- The scale of the ITRF is directly related to this "CoG offset" correction that must be applied to the ranges
- For the two LAGEOS satellites we need to be at or below the 1 mm
- Taking into account the size of the GNSS orbits, we estimate that their CoG offset must be known with an accuracy significantly less than 1 cm

Key Factors for Success (cont.)

- High accuracy GNSS orbits and clocks will require the detailed description of the spacecraft geometry and its attitude routine
- Geometry will be crucial in defining an accurate model of non-conservative forces acting on the spacecraft
- Spacecraft attitude and dynamics are also important, so any future use of the GNSS s/c will require a full knowledge of the attitude routine and description of any maneuvers or at least notification of attitude
- It is highly likely that these parameters will vary from spacecraft to spacecraft as well as from block to block. This variability underscores the need to track all satellites over time and to develop spacecraft specific models

Observing System Simulation Experiment

- In a separate presentation we will discuss experiments with SLR tracking of GPS and Galileo spacecraft (6, 12 and all), grading their outcome in terms of the accuracy of various estimated quantities
- The SLR network is assumed to comprise systems of the NGSLR type and performance and be uniformly distributed globally with uniform data yield
- We examine the quality of the resulting orbits for various selections of the system parameters (e.g. data rate, day-night tracking success, size of the onboard CCR array to name a few)

Summary

- GNSS orbits improved with SLR tracking will result in higher accuracy applications of GNSS (e.g. positioning, navigation, time-transfer, POD, etc.)
- For such tracking to be effective, we require that GNSS s/c parameters such as the CoG, size, shape, surface properties, attitude routine, maneuvers, and above all, the CCR array offset from the s/c CoG
- In all cases we require that the GNSS onboard CCR arrays follow at least the minimum requirements set by ILRS, to avoid excessive data loss and poor tracking geometry