



GGOS and the Role of SLR in GGOS

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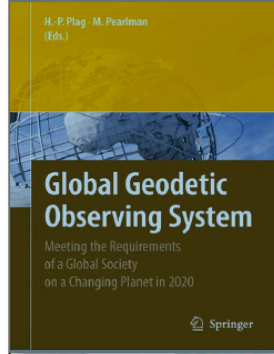
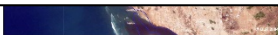
Overview

- **Introduction to GGOS and present developments**
- **Combination of the Space Geodetic Techniques**
- **The Strengths of SLR (compared to other techniques)**
- **Contribution to the Focus Areas of GGOS**
- **Conclusions**

Introduction to GGOS and present developments

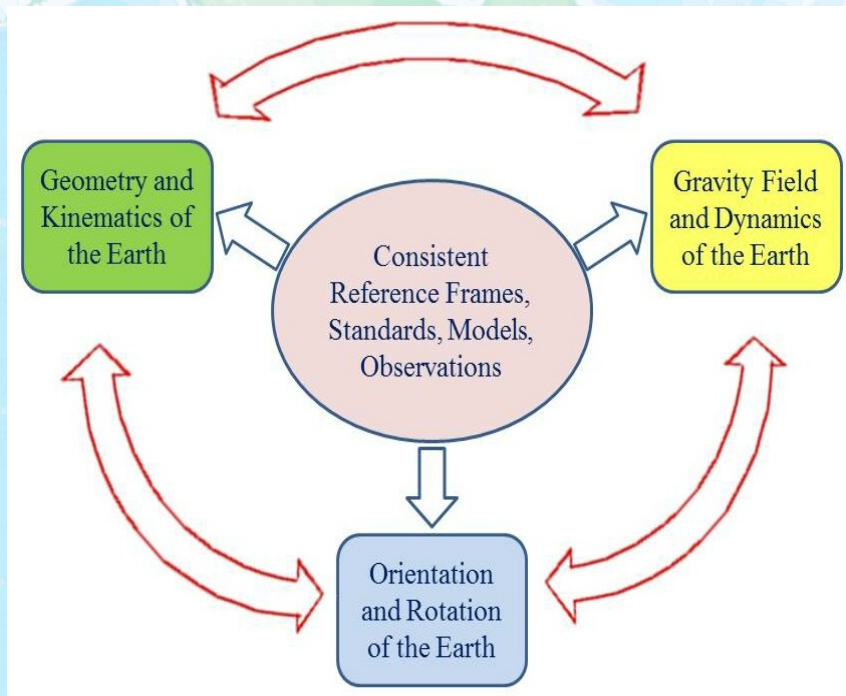
Global Geodetic Observing System (GGOS)

- **Established by the IAG in 2004 to be its Observing System**
- **Vision: Advancing our understanding of the dynamic Earth system by quantifying our planet's changes in space and time to:**
 - **Advance Earth Science (Earth, oceans, ice, atmosphere, etc)**
 - **Help us better understand the processes**
 - **Help us make intelligent societal decisions**
- **Mode of Operation: Works with the IAG components (IGS, ILRS, IVS, IDS, IGFS, IERS, IAG commissions, etc.) to provide the geodetic infrastructure necessary for monitoring the Earth System and Global Change:**
 - **observations needed to monitor, map, and understand changes in the Earth's shape, rotation, and mass distribution;**
 - **the TERRESTRIAL REFERENCE FRAME and CELESTIAL REFERENCE FRAME for measuring and consistently interpreting key global change processes;**
 - **Other data products that require integration among measuring techniques: Unified height systems, Unified sea level model, Natural hazard warning tools, etc**



The study, understanding and modelling of the effects of global change require:

- precise, consistent and stable reference frames,
- standards and models for the three geodetic parameter groups:
 - Earth geometry and kinematics,
 - Earth gravity field and dynamics,
 - Earth orientation and rotation.

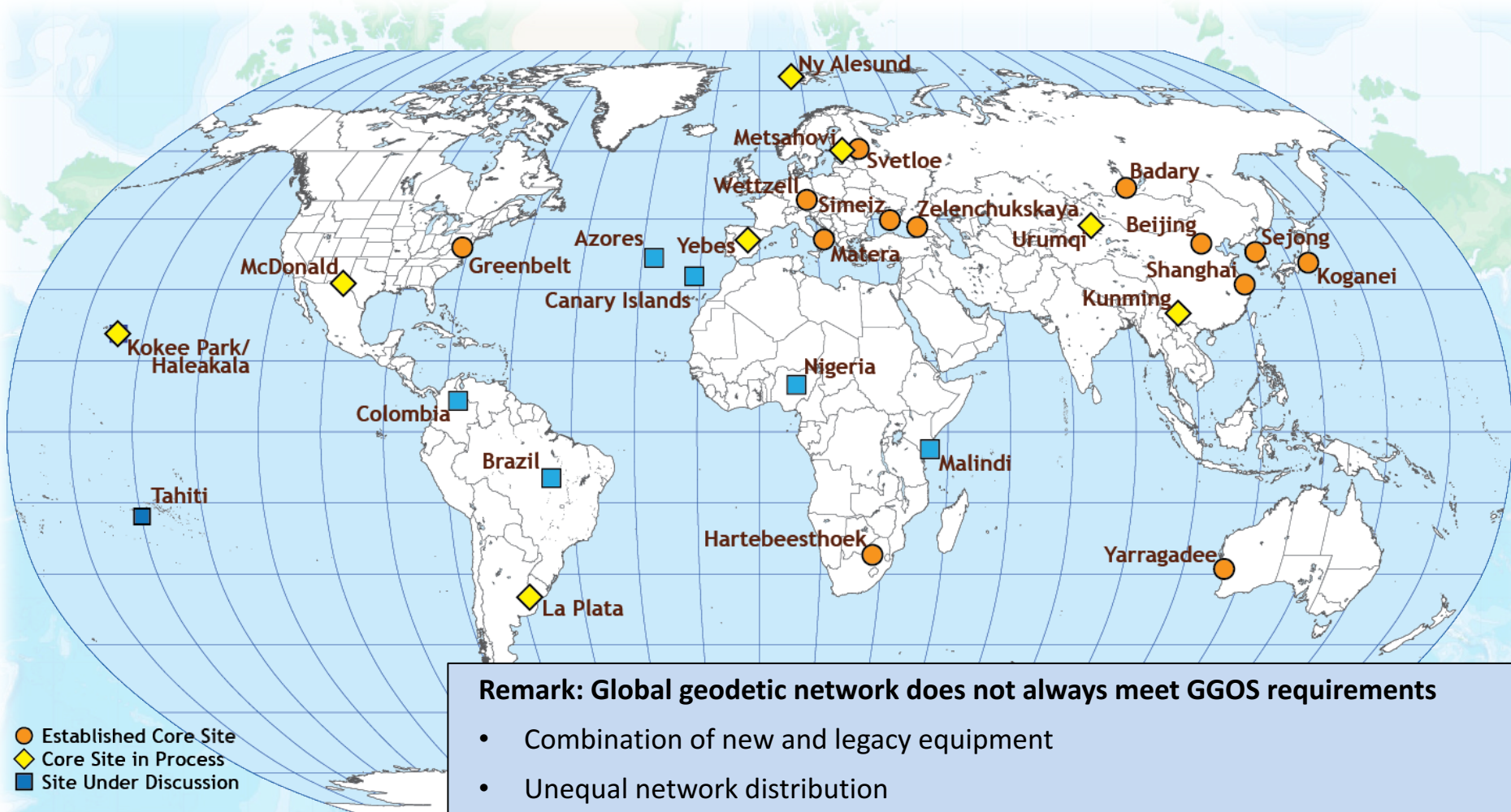


The reference frame is the basis upon which we measure change over space, time, and evolving technology.

It must fulfill the following conditions:

- One order more precise than the magnitude of the phenomena to be analysed;
- Globally consistent and reliable (high precision at any place of the Earth's surface);
- Stable over long periods (high precision at any time).

Present and Projected CORE Network (all 4 techniques)



Remark: Global geodetic network does not always meet GGOS requirements

- Combination of new and legacy equipment
- Unequal network distribution
- Local ties of techniques
- Still systematic observational errors
- Need for ~10 times improvement in measurement accuracy

UN Establishes a Subcommittee on Geodesy

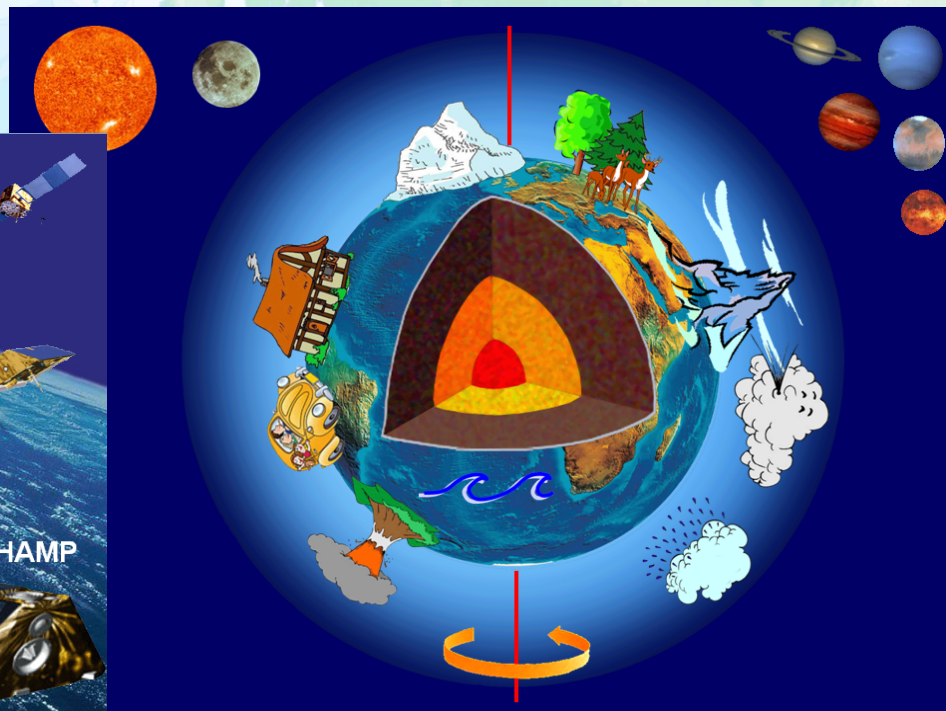
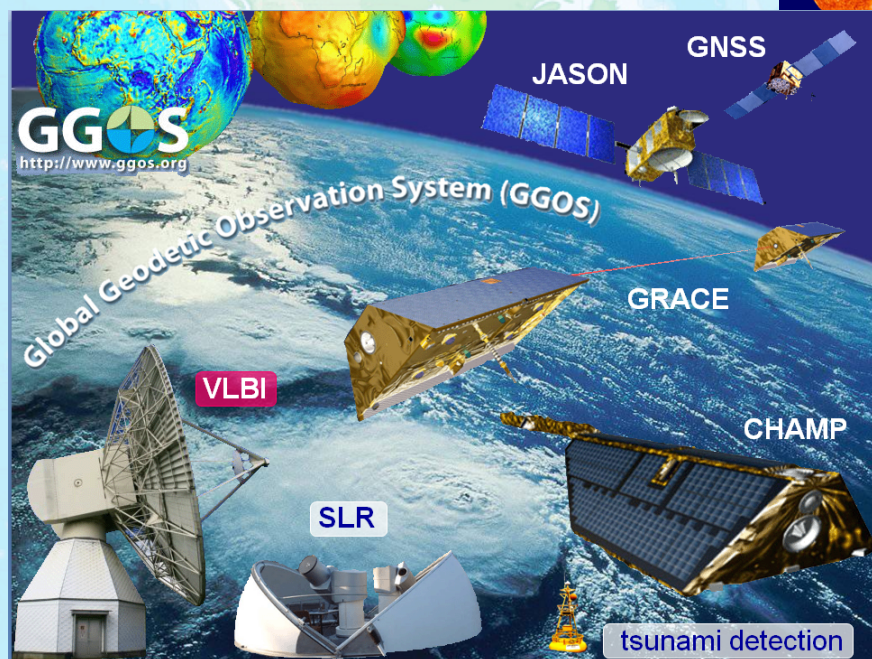
- At the Seventh Session of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) Meeting in New York City during the first week of August, the membership endorsed the formal establishment and composition of a **UN Subcommittee on Geodesy**;
- Based on "Global Geodetic Reference Frame (ITRF and ICRF combination) for Sustainable Development (GGRF);
- Recognizes the importance of a globally coordinated approach to geodesy – the discipline focused on accurately measuring the shape, rotation and gravitational field of planet Earth, and stresses the value of ground-based observations and remote satellite sensing when tracking changes in populations, ice caps, oceans and the atmosphere over time.



Combination of Space Geodetic Techniques

Approaches of GGOS

- Combination and integration of all available observations, methods, ...
- Combine physical measurements and geometric techniques
- Improve our understanding of the interactions in "System Earth"



GGOS: Parameter Space for Combination

Parameter Type	VLBI	GPS/ GLON.	DORIS/ PRARE	SLR	LLR	Alti- metry
Quasar Coord. (ICRF)	X					
Nutation	X	(X)		(X)	X	
Polar Motion	X	X	X	X	X	
UT1	X					
Length of Day (LOD)	X	X	X	X	X	
Sub-Daily ERPs	X	X				
ERP Ocean Tide Amplitudes	X	X		X		X
Coord.+Veloc.(ITRF)	X	X	X	X	X	(X)
Geocenter		X	X	X		X
Gravity Field		X	X	X	(X)	X
Orbits		X	X	X	X	X
LEO Orbits		X	X	X		X
Ionosphere	X	X	X			X
Troposphere	X	X	X			X
Time/Freq. Transfer	(X)	X		(X)		

Major SLR Contributions

Strengths of SLR

Solutions and Statistics: Example CONT'02



CONT'02 VLBI Campaign

- DGFI: **VLBI** solutions
- TUM : **GNSS** solutions
- TUM : **SLR** solutions (L1+L2)

October 17-30, 2003, continuous VLBI

SLR: few observations but also few parameters (no clocks, no troposphere, no ambiguities,...)

CONT'02	SLR	VLBI	GNSS
# Obs.	5'195	46'682	5'935'760
# Coord.	81	24	459
# EOP	75	75	75
# Tropos.	0	1'554	26'726
# Orbits	30	0	3'770
# Ambig.	0	0	43'238
# Clocks	0	1'164	---
# Param.	186	2'817	74'268

Wavelength and Water Vapor

SLR is the only technique observing at optical wavelengths:

- SLR is in a **unique situation** concerning atmospheric refraction
- Troposphere **dispersive** for SLR, but not for microwaves
- Two-frequency laser ranging (mainly **validation tool** ?)
- Dry delay can be modeled with pressure data at the site
- Wet delay is very small (max. ~6mm):
68x smaller than for GNSS

$$\frac{\delta\rho_{trp,wet}^{Micro}(z=0)}{\delta\rho_{trp,wet}^{SLR}(z=0)} \approx 68$$

All other techniques (GNSS, VLBI, DORIS, altimetry, InSAR, ...):

- Suffer from the **same tropospheric refraction effects**
- Suffer from **similar ionospheric refraction effects**
- Have tropospheric refraction as the or a **major error source**

Only SLR can help to detect biases (e.g. due to atmosphere mismodeling) common to all other techniques

Clocks and Correlations

Estimation of clock parameters:

- **SLR**: the only technique, where in general **no clock corrections** have to be estimated
- **GNSS**: receiver and satellite clock parameters for every epoch
- **VLBI**: receiver clock corrections about every hour (between stations)
- **DORIS**: clock biases have to be estimated too

Estimation of clock parameters degrades the height quality

Exceptions for SLR:

- Estimation of a **range bias** for an SLR station: corresponds to a **receiver clock correction** in GNSS/VLBI/DORIS
- Estimation of a **time biases** for an SLR station

Occurance of range biases should be avoided to the extent possible

Antennas and Absolute Scale

Characteristics of GNSS receiver and satellite antennas:

- Not accurately known, changing with elevation and azimuth
- GNSS results dependent on **elevation cut-off**
- Systematic effects due to **antenna phase center** (and multipath) errors (receiver and satellite antennas)
- Many changes of GNSS receiver/antenna equipment (jumps in height)
- GNSS is much affected by systematic effects; difficult for accurate **absolute height** and **absolute scale** determination in the global network and for ITRF.

VLBI telescopes:

- VLBI telescopes are huge and heavy structures
- VLBI **telescope deformation** (temperature, sag) may bias results

SLR: no such antenna problems (deformation should be small, no phase center variations): well-suited to define scale of ITRF; but calibration has to be very accurate and reliable.

Orbits and „Observed-Computed“

Validation of GNSS orbits (GPS, GLONASS, Galileo, Beidou, ...):

- SLR measurements are successfully used to validate GNSS orbits
- **Extremely important for improvements in GNSS orbit modeling; still systematic effects in GNSS orbits up to 10-15 cm**

Validation of Low Earth Orbiter (LEO) orbits:

- Much progress in **precise orbit determination (POD)** of **LEOs** thanks to validation with SLR “observed-computed” (O-C)
- Evaluation of different **strategies** (kinematic, reduced-dynamic, ...) and **software packages** and **parameterizations**
- SLR “O-C” values allow detection of **systematic orbit errors**

SLR observations are extremely valuable for POD studies; POD becomes ever more crucial for GNSS and new satellite missions

Geometry and Gravity

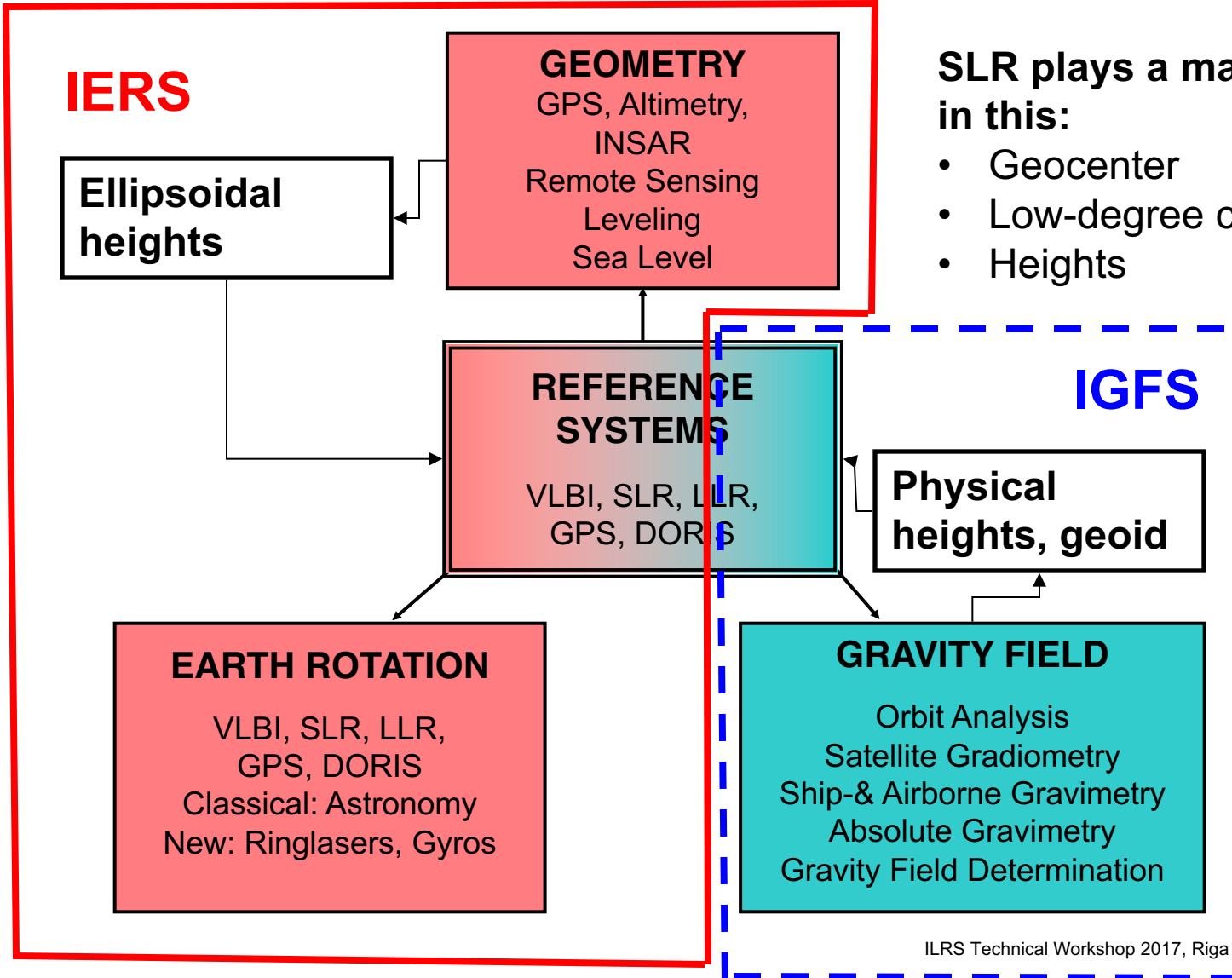
SLR is one of the major techniques to establish a link between geometry, Earth rotation, and gravity (three pillars of geodesy):

- Geocenter: relation between origin of ITRF and low-degree harmonics coefficient \mathbf{C}_{10} , \mathbf{C}_{11} , \mathbf{S}_{11} of the Earth's gravity field
- Principle axes of inertia tensor: relation between Earth rotation, orientation of the gravity field (\mathbf{C}_{21} , \mathbf{S}_{21} , \mathbf{S}_{22}), and ITRF orientation
- Helps to distinguish between “matter terms” and “motion terms” (gravity “feels” only “matter”, Earth rotation “matter” and “motion”)

SLR as a link between 3 pillars: very important for the GGOS integration concept and for IERS reference frame definitions

Gravity field variations are due to exactly the same Earth processes (e.g., from geophysical fluids) as Earth rotation and deformation (geometry)

Combination of Geometry and Gravity (IERS/IGFS)



SLR plays a major role in this:

- Geocenter
- Low-degree coeff.
- Heights

Contribution of SLR to the GGOS Focus Areas



GGOS Focus Area 1 (FA1): **Unified Height System (Laura Sanchez)**

The Importance of SLR

- Accurate realization of the geocenter and the scale of the ITRF
- Combination of gravity and geometry (physical and ellipsoidal heights)
- Accurate determination of the low-degree gravity field coefficients (better than GRACE and GOCE)
 - contribution to the geoid and unified height systems



GGOS Focus Area 2 (FA2): **Geohazards (John LaBrecque)** The Importance of SLR

SLR Tracking Provides for a Stable and Accurate Reference Frame necessary to the identification and monitoring of geohazards:

Better understanding of long term environmental trends such as:

- Sealevel Change confronting coastal zones
- Land Surface Deformation indicating changes in:
 - crustal stress;
 - landslide creep;
 - aquifer charge.

More accurate instrument positioning for:

- Decadal and annual changes in SAR, Lidar, and Gravity measurements
- Identification of short term and long term errors in GNSS clocks and orbits to
 - Increase the reliability of access to the ITRF;
 - Contribute to improved sensor resolution and accuracy.



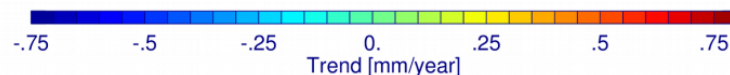
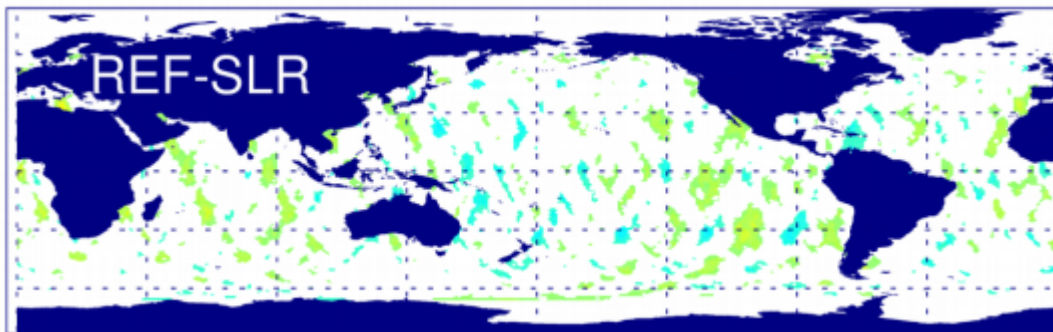
GGOS Focus Area 3 (FA3): Understanding and Forecasting Sea-Level Rise and Variability (Tilo Schoene)

The Importance of SLR

- Demonstration of the value of the GGOS Infrastructure for an integrated Sea Level Monitoring and Forecasting
- Identification of the requirements for a proper understanding of global and regional/local sea-level rise and variability especially in so far as they relate to geodetic monitoring provided by the GGOS infrastructure.

Satellite Laser Ranging (SLR) for Sea Level Research:

1. SLR, among others technologies, is a very precise technique in POD for radar altimetry satellites (for some older such as ERS-1, the only system)
2. SLR provides a prominent technique in the generation of a long-term stable ITRF



<https://doi.org/10.5194/os-2017-51>

Trend difference in sea level rise between a best and SLR-only orbit



GGOS Focus Area 4 (FA4): Geodetic Space Weather

Research (Michael Schmidt)

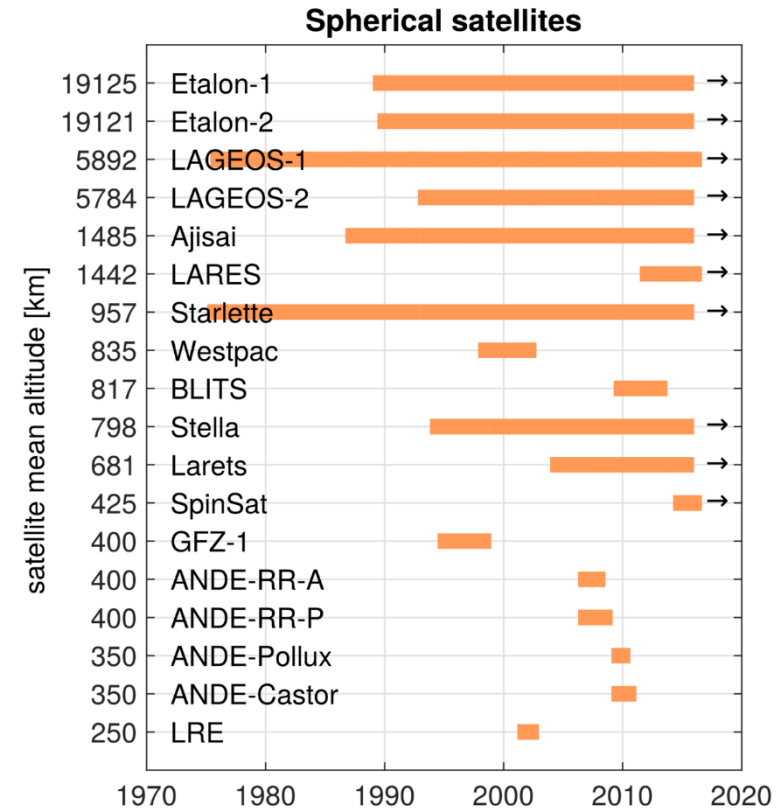
The Importance of SLR

Main objectives of FA4:

1. Improvement in **positioning** and **navigation** by developing high-precision and high-resolution **ionospheric electron density** models
2. Improvement of **precise orbit determination (POD)** of LEO satellites by developing high-precision and high-resolution **thermospheric density** models

Satellite Laser Ranging (SLR) in FA4:

1. SLR is a geodetic **tracking technique** which can be used for the POD of LEO satellites
2. Due to the **high precision** SLR is highly sensitive to any **perturbing acceleration** acting on a satellite
3. Thus, SLR can be used to estimate **thermospheric density** parameters.
4. To increase the accuracy of the estimated thermospheric density, SLR observations to LEOs with a **simple spherical shape** can be used (see table above)
5. These results can be used, e.g. for the **calibration** of physical **thermosphere-ionosphere coupling** models



Mission lifetime and altitudes of spherical satellites usable for SLR applications in FA4.

Conclusions

GGOS:

- GGOS has a challenging program to fulfill with very important science and societal benefits
- Technologies are maturing; new technologies are on the horizon and the core network is growing
- International and political recognition (UN-GGIM) is increasing

SLR:

- As an optical ranging technique SLR has strengths that no other technique has
 - SLR is a unique partner in GGOS and in a rigorous combination of the space geodetic techniques
- **Individual techniques should not try to do everything and to be the best in every discipline but should feel as a part of a larger whole with a common goal**
- **Focus your efforts on your real strengths**