ESA's Genesis mission - from an ILRS perspective

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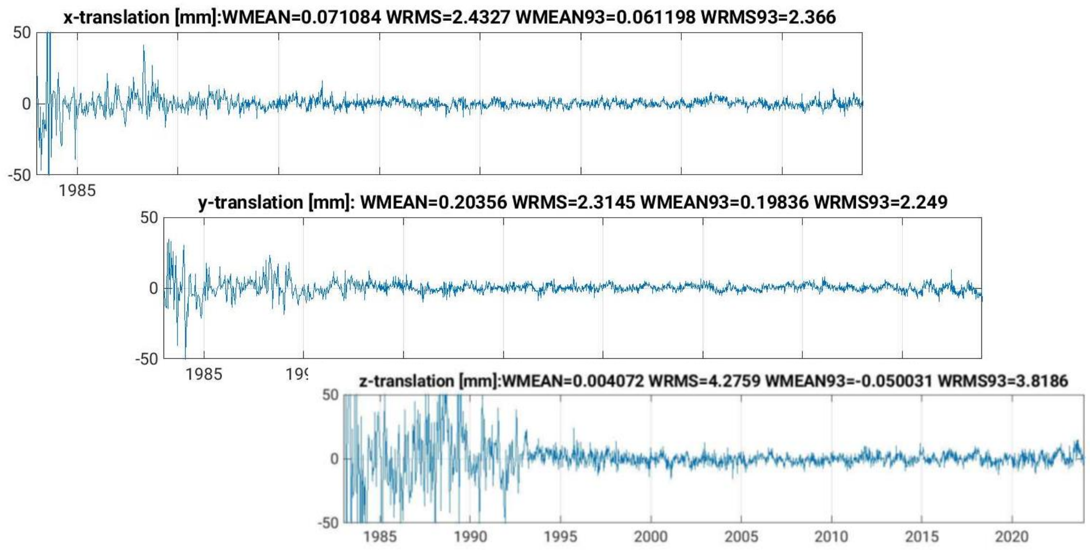
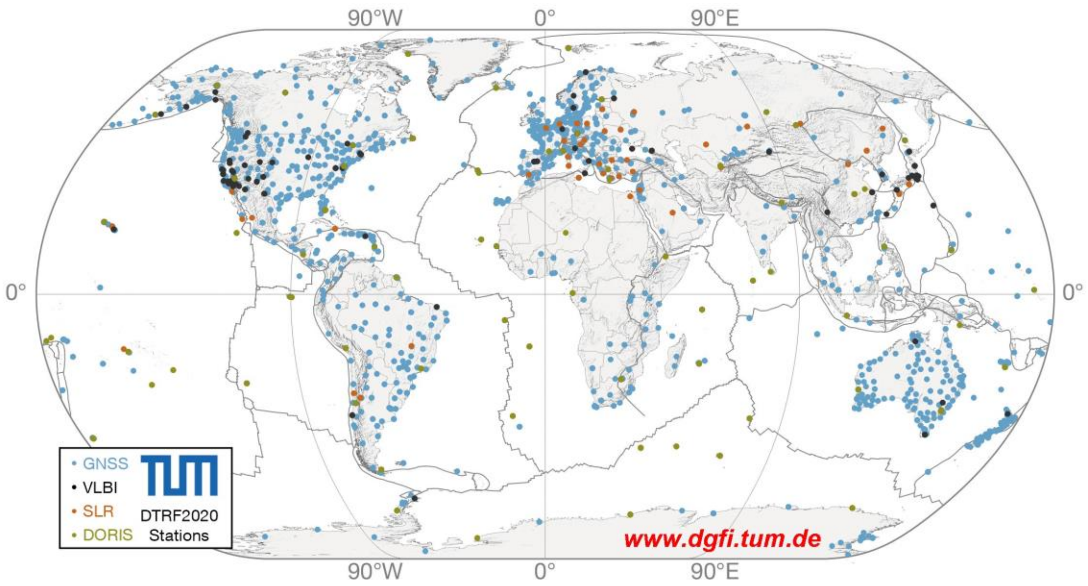
Importance of SLR for TRF realizations (I)

- **SLR uniquely provides access to the Center of Mass** (CM) of the system Earth via observations…
  - to spherical satellites → attitude realization not critical; accurate modelling of solar and Earth's radiation feasible
  - at about 6000 and 20.000 km altitude → modelling of thermospheric drag not required
- Together with VLBI (and GNSS), **SLR also contributes to the scale** realization
- Mix of multiple satellite inclinations (2 LAGEOS + 2 Etalon) → **SLR provides accurate Length-of-Day (LOD)** parameters
- SLR also contributes significantly to the low-degree spherical harmonic coefficients of the Earth's gravity field





Seitz et al., 2023

Importance of SLR for TRF realizations (II)

- BUT:
  - **sparse and inhomogeneous global distribution** of observing stations
- Solution:
  - ILRS network upgrades on their way: **18 currently and future online coming SLR stations**
  - **many simulations are performed to**
    - identify most beneficial new satellite
    - identify most beneficial new station location

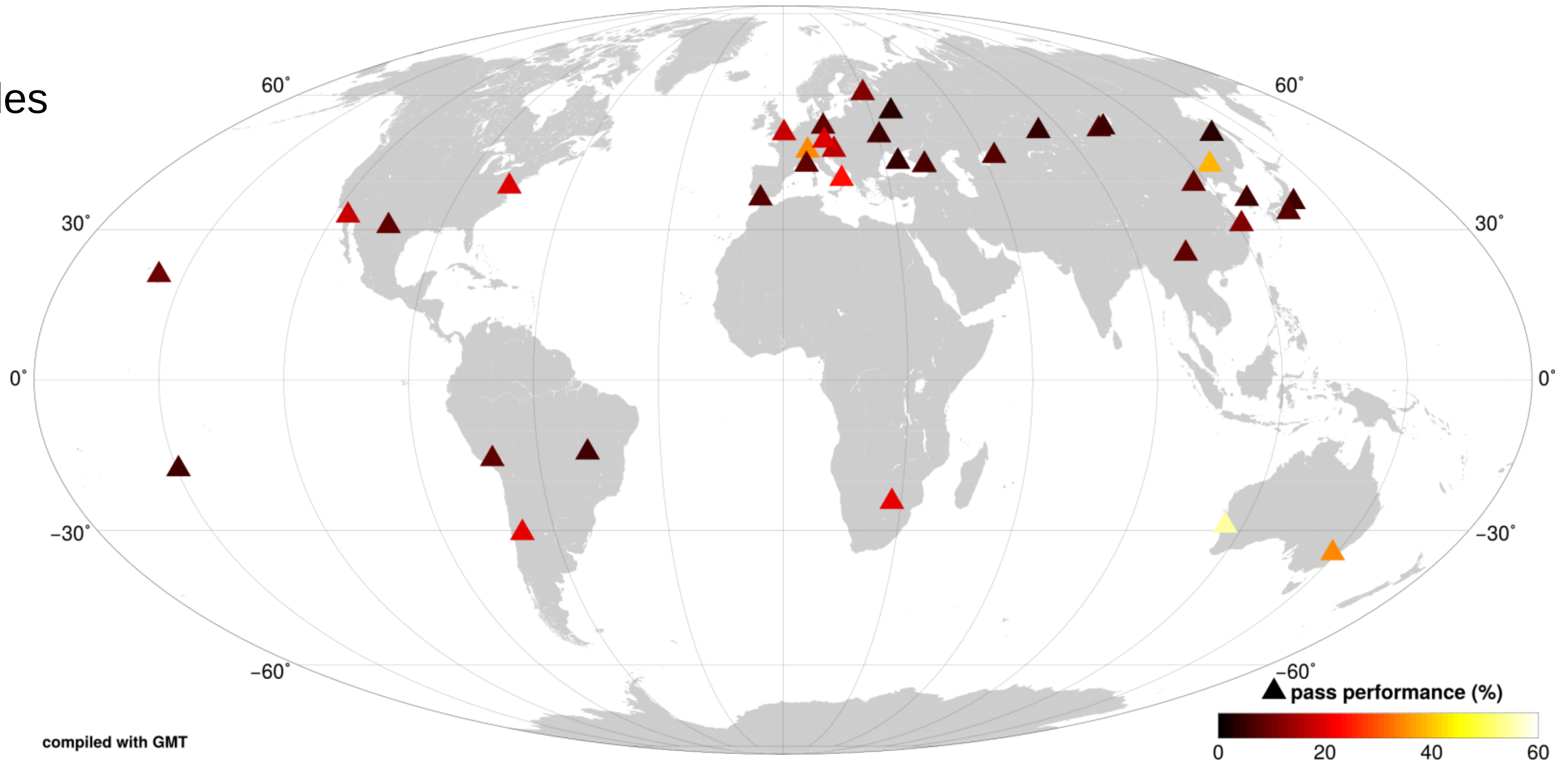
Site Name	Type	Agency	Timeframe
La Plata, Argentina	upgraded core site	BKG, Germany	2024 – 2025
San Juan, Argentina	upgraded SLR system	NAOC, China	2024 – 2025
Metsähovi, Finland	new SLR system	FGI, Finland	2024 – 2025
Greendbelt, MD, USA	Replacement core site	NASA, USA	2026 – 2029
Haleakala, HI, USA	Replacement core site	NASA, USA	2026 – 2029
McDonald, TX, USA	Replacement core site	NASA, USA	2026 – 2029
Ny Ålesund, Norway	new core site	NMA Norway/NASA, USA	2024 – 2025
Ensenada, Mexico	new SLR site	IPIE, Russian Federation*	2024 – 2026
Java, Indonesia	new SLR site	IPIE, Russian Federation*	2024 – 2026
Gran Canaria, Spain	new SLR system at core site	IPIE, Russian Federation*	2024 – 2026
Tahiti, French Polynesia	new SLR system	IPIE, Russian Federation*	2024 – 2026
Mt Abu, India	new SLR site	ISRO, India*	2025 – 2026
Ponmundi, India	new SLR site	ISRO, India*	2025 – 2026
Ishioka, Japan	new SLR site	Hitotsubashi U., NAOJ, U. Tokyo, Japan	2024
Yebes, Spain	new SLR site	IGS, Spain	2024
Irkutsk, Russia	new SLR site	VNIIFTRI, Russia	2025 – 2026
Mendeleevo, Russia	new SLR site	VNIIFTRI, Russia	2025 – 2026
San Fernando, Spain	upgraded SLR system	Real Instituto y Observatorio de la Armada	2025

* situation unclear

Geodesist's handbook, 2024

Importance of SLR for TRF realizations (III)

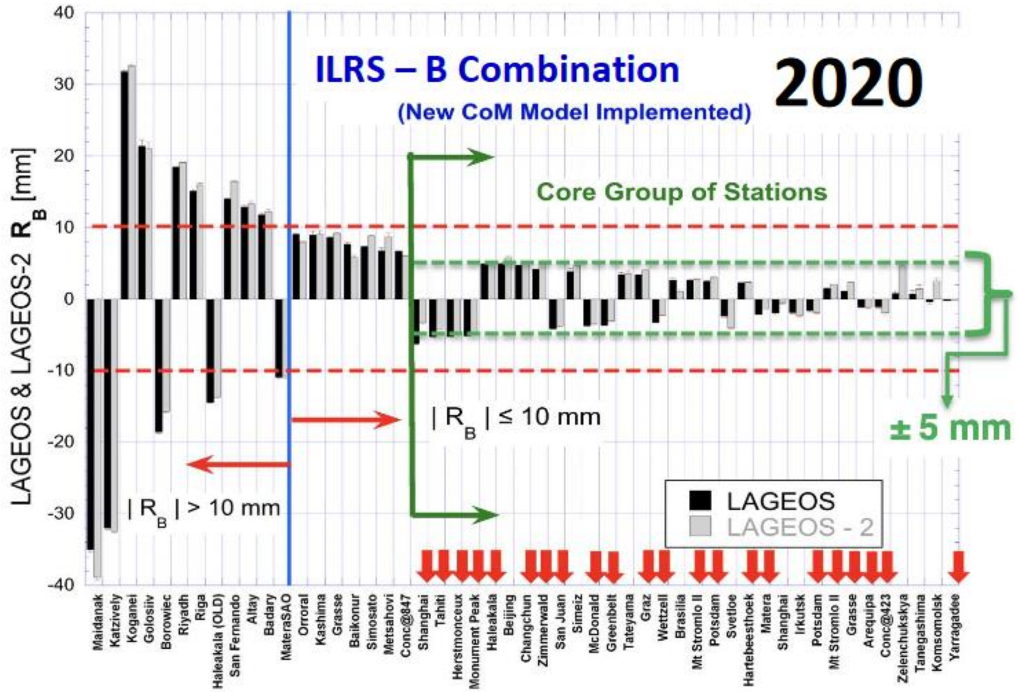
- BUT:
  - **very different performance of stations** due to numerous reasons → only ~ 15-20 stations significantly contribute to TRF
- Solution:
  - **advertisement of technological improvements**, etc. by the ILRS Governing Board (GB) and Central Bureau (CB)
  - **many simulations are performed to**
    - quantify potential of performance upgrades
    - cf., e.g., GGOS PLATO WG reports!

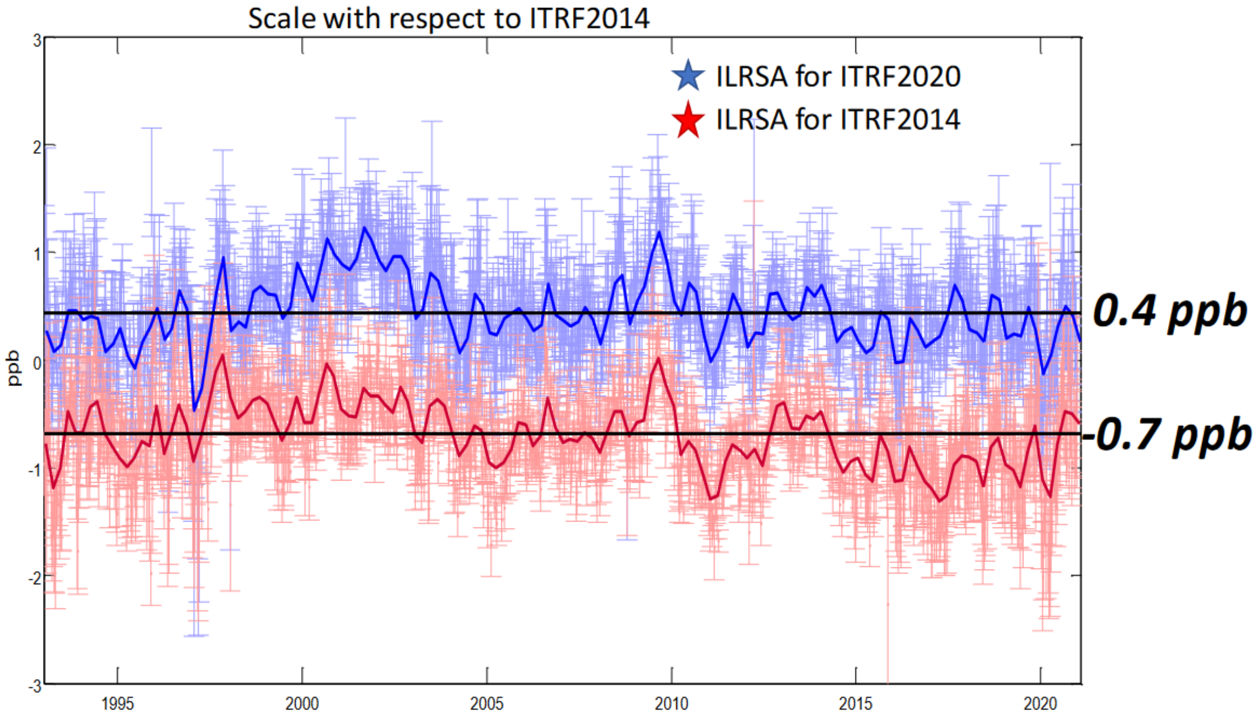


Kehm, 2022

Importance of SLR for TRF realizations (IV)

- BUT:
  - **measurement biases** systematically affect the SLR observations
- Solution:
  - development of refined **target signature model** + determination of **system-dependent long-term mean range biases**

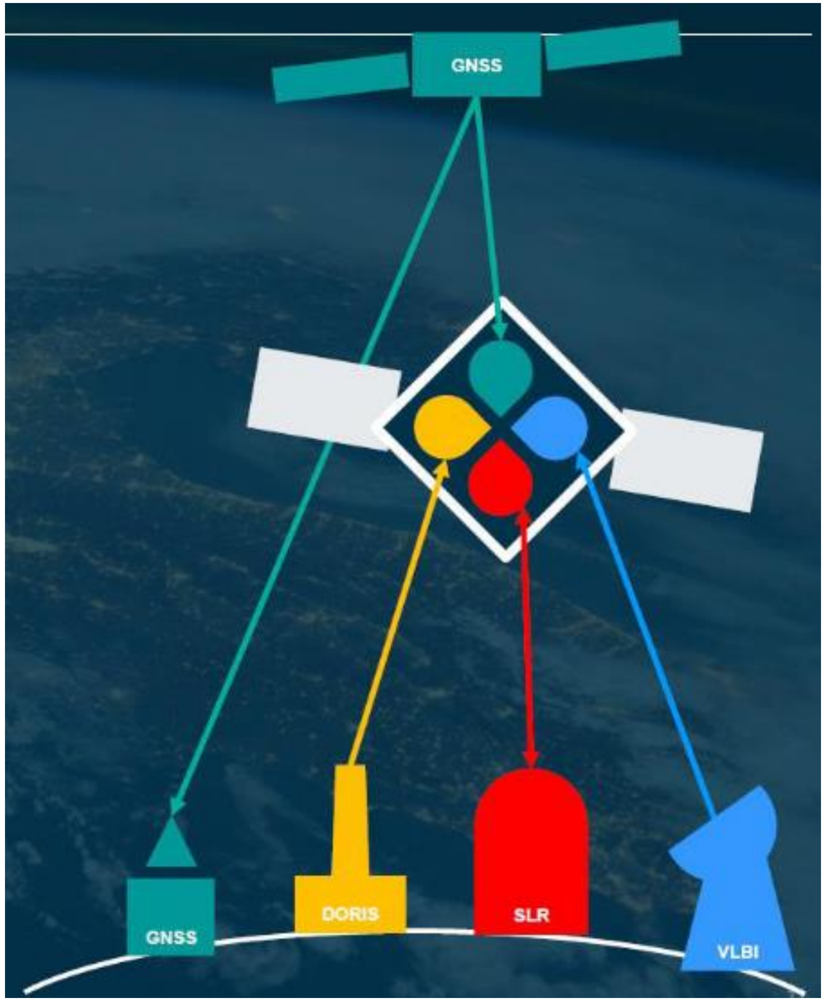




Luceri et al., 2022

The Genesis satellite and mission

- To overcome these shortcomings, a fundamental station in space would be beneficial
- Genesis satellite:
  - ~ 250-300kg, ~ 6000 km altitude, ~95° inclination (currently planned)
    → **good visibility by all SLR stations?** (cf. next slides)
  - 4 co-located instruments, launch planned in 2028
- Genesis mission objectives:
  - contribute to **improve ITRF accuracy and stability** by providing **in-orbit colocation and necessary combined processing** for the four space-based geodetic techniques
  - contribute to **improve the link between the ITRF and the ICRF**, thanks to the increased consistency of the Earth Orientation Parameters (EOP)
- Advantages of the SLR technique on-board:
  - **passive retro-reflector**

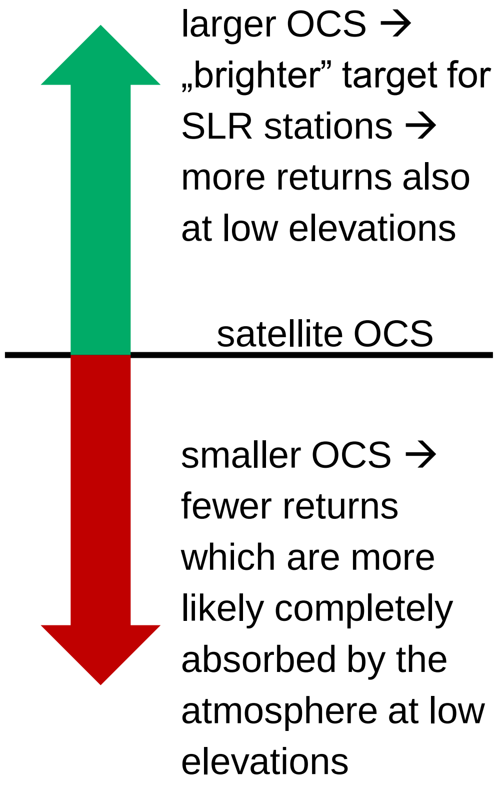


ESA, 2024

Genesis’ optical cross section (as planned today)

- The optical cross section (OCS) of an artificial near-Earth satellite directly impacts the expected return rate of photons (i.e. normal points – NPs) from the reflector
  - a smaller OCS will have a major impact on the return rate, i.e. a smaller OCS will not allow to get low elevation returns (since the few reflected photons are absorbed by the atmosphere)
  - with lower satellite altitude, the OCS needed to obtain laser echoes can be much lower
  - low elevation observations are required for the decorrelation of range biases and station height estimates

- For LAGEOS-1/2, the OCS is about $1.5*10^7$ m^2
- Requirements by ESA to Genesis (status: October 2024; same as in March 2023?)
  - minimum effective cross section of $3*10^6$ m^2 at apogee for laser wavelength of 532 nm
  - this is about 20% of the return rate from the ILRS standard target LAGEOS

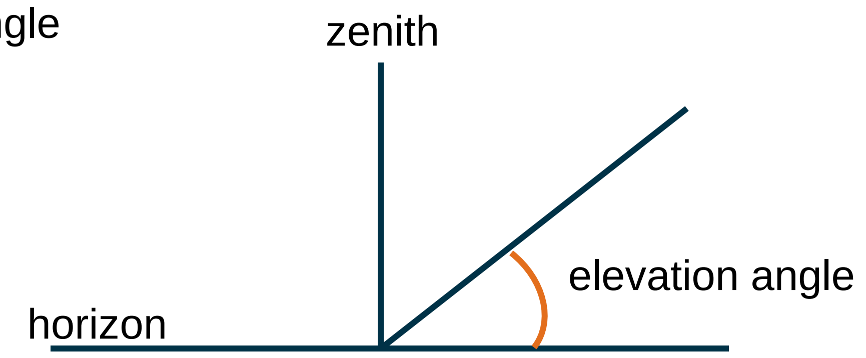


Genesis' optical cross section (as planned today)

- Is this sufficient for Genesis?
- This questions is assessed by discussing the impact of the LAGEOS and LARES OCS on the current tracking performance of the existing SLR station network between 2012 and 2024
  - LAGEOS has 426 retros (~ 6000 km altitude)
  - "optimistic" scenario what performance we can expect from Genesis

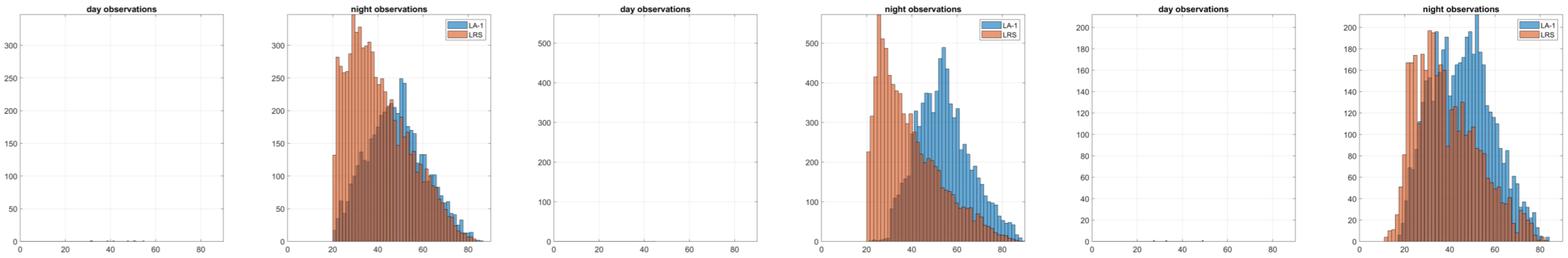
  - LARES is a smaller sphere with 92 retros (~ 1450 km altitude)
  - lower altitude means shorter way through atmosphere → better tracking of LARES by SLR network?

- Histograms of LA-1 and LRS observations are plotted w.r.t. the elevation angle



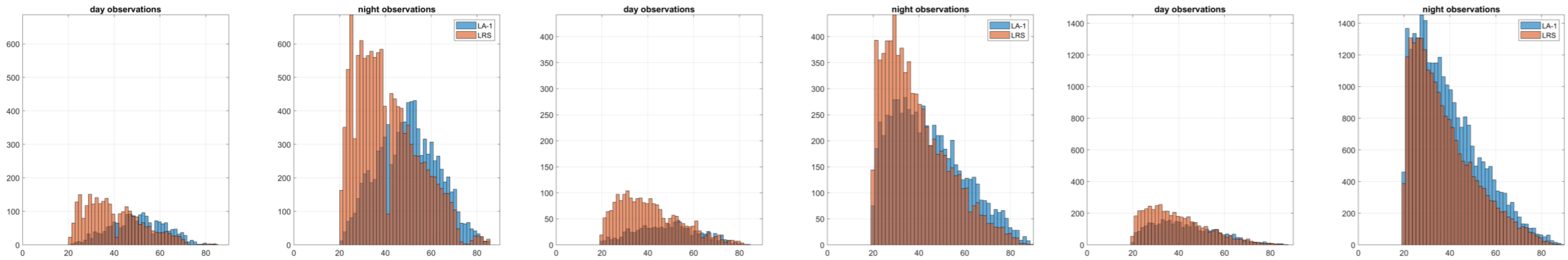
Real data analysis (I)

- In total, 50 different stations tracked LAGEOS (LA-1) and LARES (LRS) during the past 12 years
- 17 stations do not observe LA-1 or LRS during daytime at all
  - for these stations, much more LRS NPs are obtained at low elevations which proves that these stations already have problems tracking LA-1 at low elevations
  - conclusion: these stations will have problems to track Genesis (with a smaller OCS than LA-1) during daytime
  - some of these stations will have problems acquiring sufficient NPs to Genesis even during nighttime (due to few low elevation returns)!
  - examples:



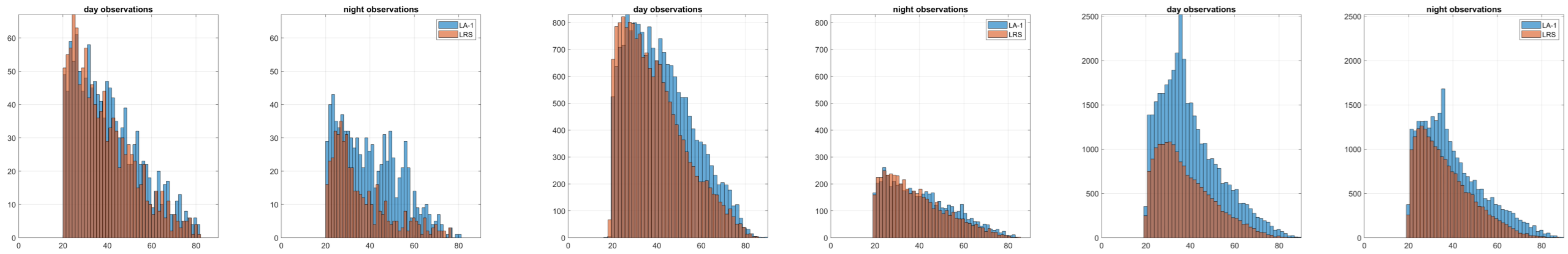
Real data analysis (II)

- In total, 50 different stations tracked LAGEOS (LA-1) and LARES (LRS) during the past 12 years
- 17 stations do not observe LA-1 or LRS during daytime at all
- 12 stations provide only very few daytime NPs
  - a small number of daytime NPs to LA-1 indicate these stations might not to be able to acquire Genesis NPs during daytime
  - during nighttime, the situation is diverse; for some stations situation is clearly non-optimal as before, for others its better
  - examples:



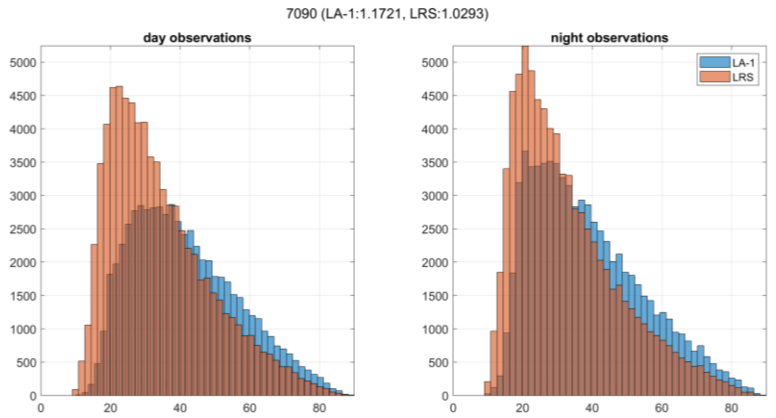
Real data analysis (III)

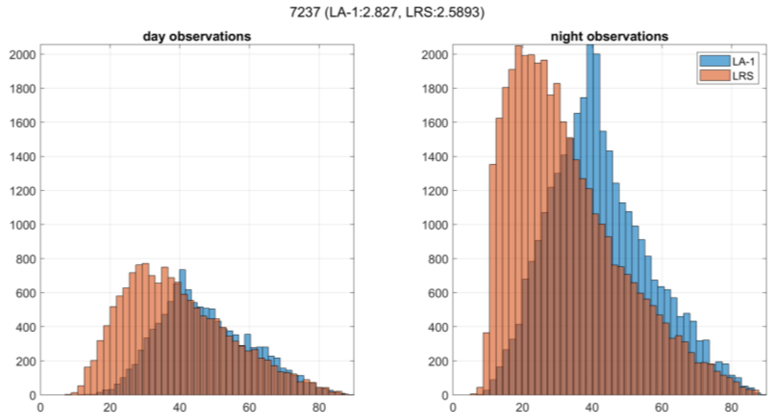
- In total, 50 different stations tracked LAGEOS (LA-1) and LARES (LRS) during the past 12 years
- 17 stations do not observe LA-1 or LRS during daytime at all
- 12 stations provide only very few daytime observations
- 21 stations provide a reliable amount of day- and nighttime NPs
  - only 6 stations perform well (day- and nighttime NPs; no clear drop in low elevations, both satellites show similar statistics, etc.)
  - examples:

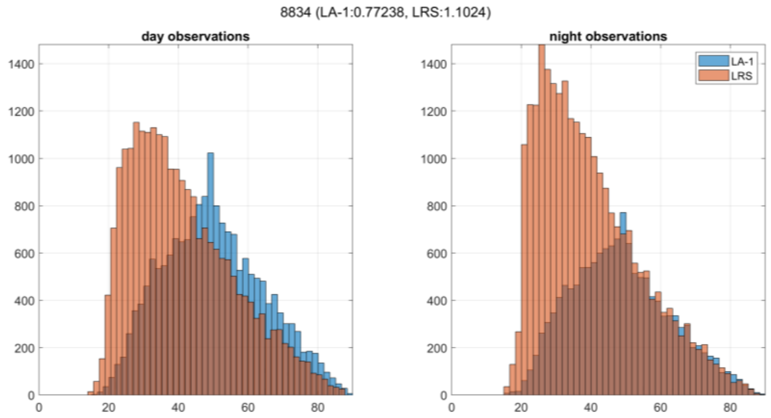


Real data analysis (IV)

- ♦ In total, 50 different stations tracked LAGEOS (LA-1) and LARES (LRS) during the past 12 years
- ♦ 17 stations do not observe LA-1 or LRS during daytime at all
- ♦ 12 stations provide only very few daytime observations
- ♦ 21 stations provide a reliable amount of day- and nighttime NPs
  - – only 6 stations perform well (day- and nighttime NPs; no clear drop in low elevations, both satellites show similar statistics, etc.)
  - – 15 stations have problems with LA-1 observations at low elevations → smaller OCS will cause problems (maximum will be much smaller and move towards higher elevations)!



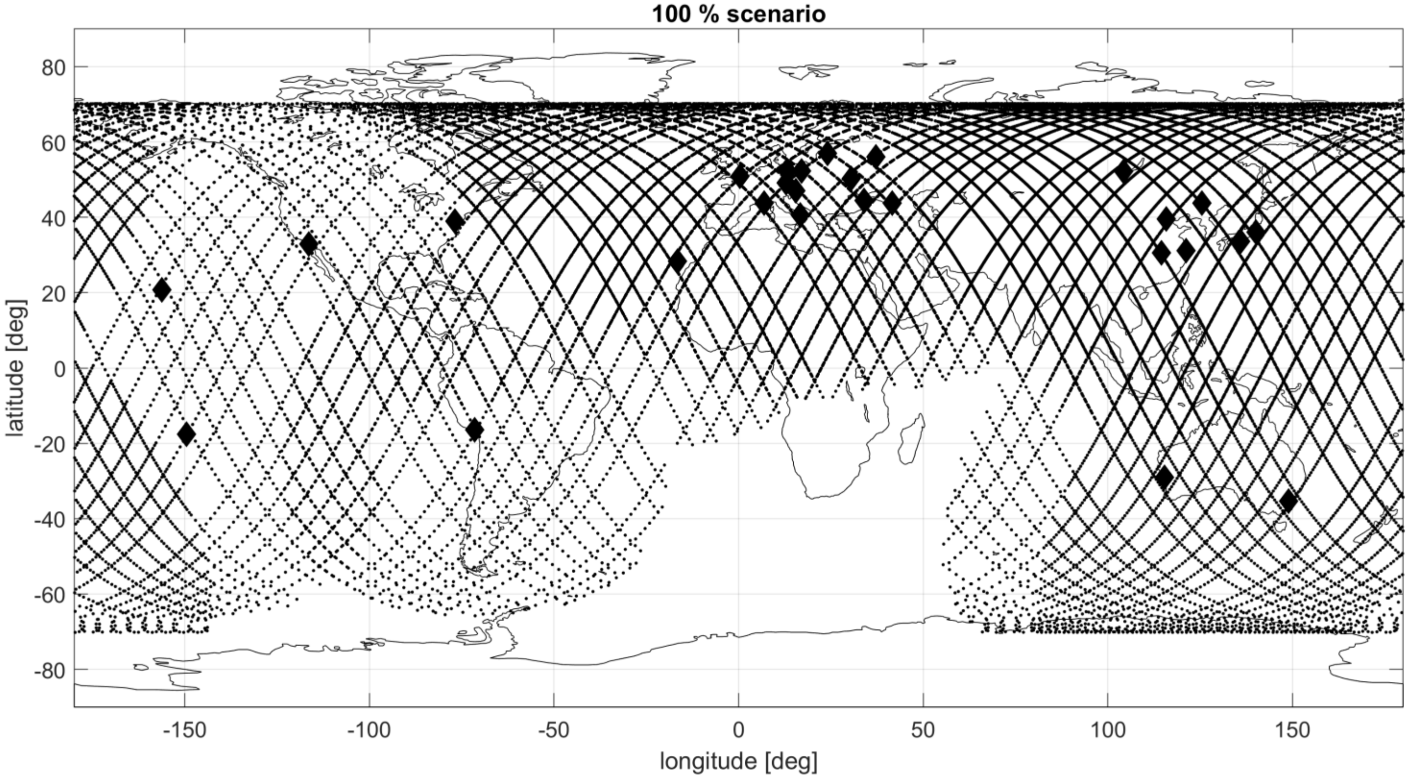




Real data analysis vs. simulation

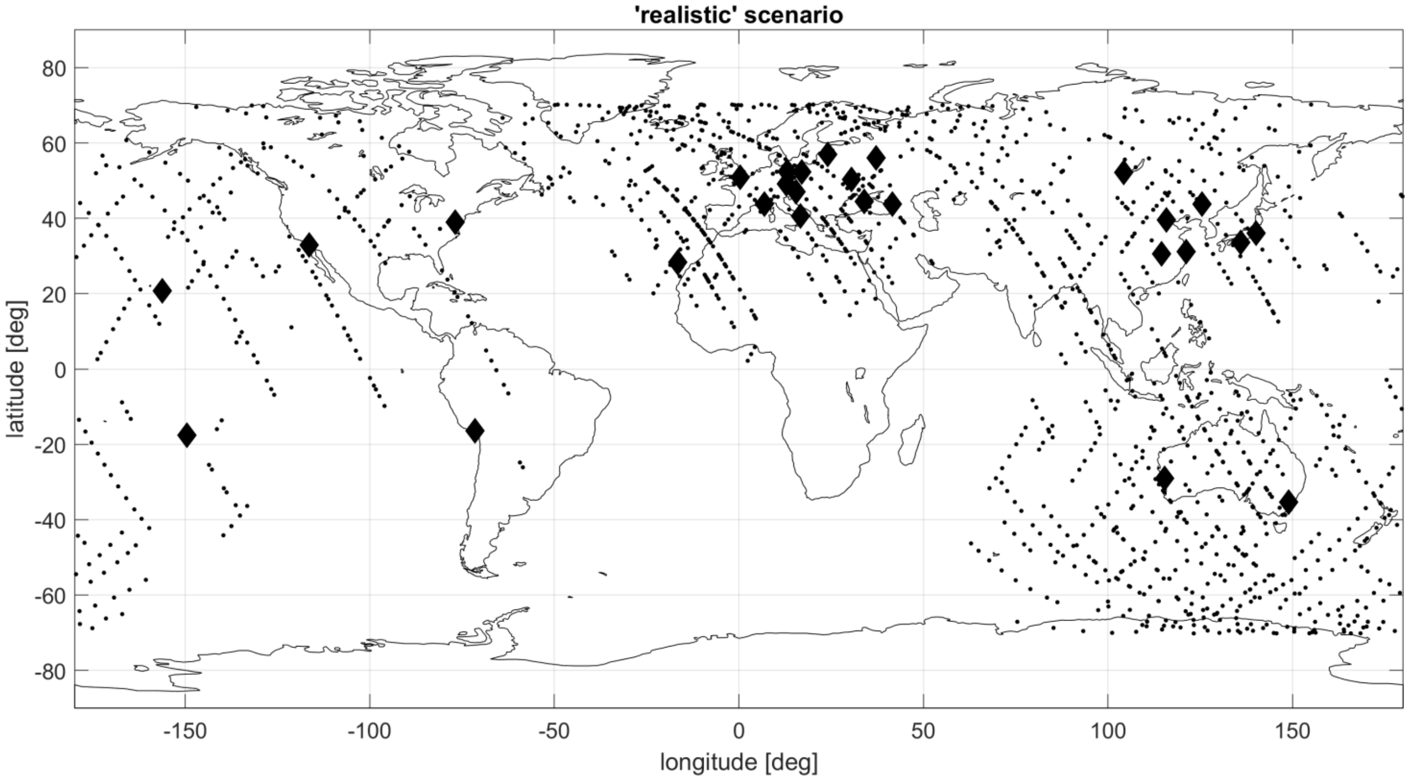
- Simulation scenario: 7-day LA-1 arc (GPSweek 2333), 100% pass performance (unrealistic!)

  (important: only stations really observed in that week simulated)



Real data analysis vs. simulation

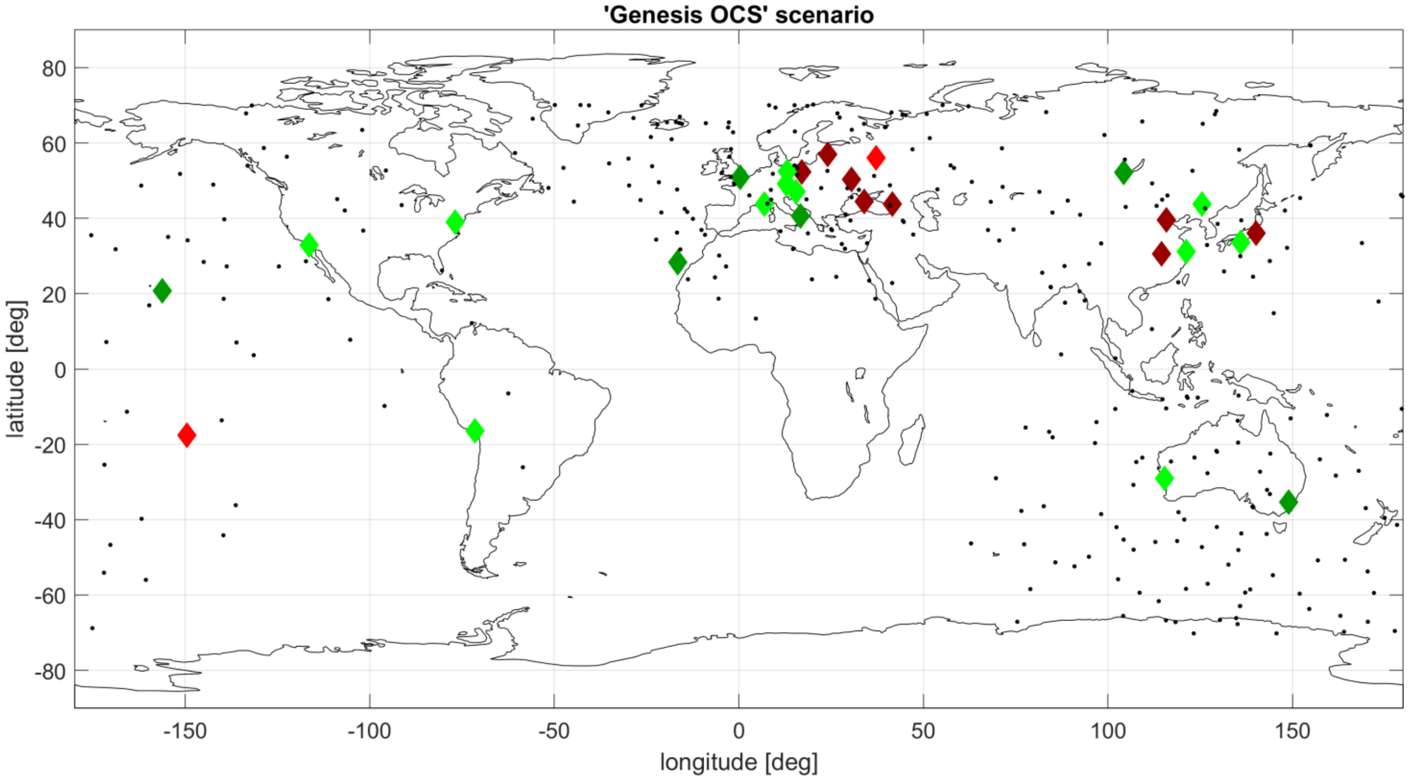
- Simulation scenario: 7-day LA-1 arc (GPSweek 2333), realistic (true obs. epochs) pass performance
  - global mean SLR network performance ~ 14% (due to many reasons as weather conditions, staff, technical level, etc.)



Real data analysis vs. simulation

- Simulation scenario: 7-day LA-1 arc (GPSweek 2333), ‘Genesis OCS’ expected pass performance

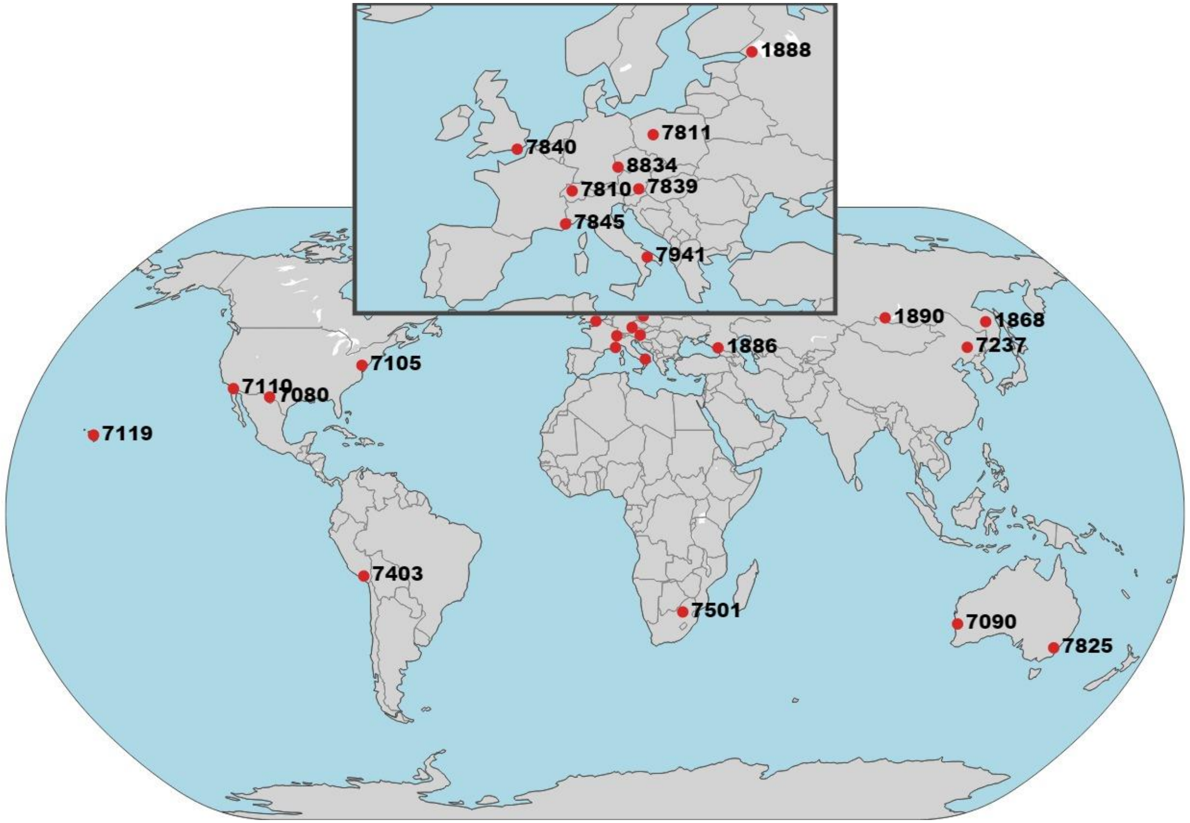
stations with… ♦ no daytime obs. at all, ♦ few daytime obs. only,
♦ daytime obs. but very few low-elevation obs., ♦ daytime obs. and enough low-elevation obs.



Simulation study (I)

- Simulation study performed by Tomasz Kur and others from Wroclaw University (Poland)
  - simulation of a weekly arc with ‘realistic’ LA-1 performance for each station

Simulation scenarios	Acronym for results
LAGEOS 1 + LAGEOS 2 + LARES 1 + Genesis	LAG 1/2 + LAR 1 + GEN
LAGEOS 1 + LAGEOS 2 + LARES 1 + Genesis with a priori GNSS-based orbit	LAG 1/2 + LAR 1 + GEN_{GNSS}
LAGEOS 1 + LAGEOS 2 + LARES 1 + LARES 2 + Genesis	LAG 1/2 + LAR 1/2 + GEN
LAGEOS 1 + LAGEOS 2 + LARES 1 + LARES 2 + Genesis with a priori GNSS-based orbit	LAG 1/2 + LAR 1/2 + GEN_{GNSS}



Simulation study (II)

- Polar orbits beneficial for high-lat. stations, lower inclinations beneficial for low-lat. stations
- Virtually identical results for prograde and retrograde orbits of equal tilt w.r.t. the equator
- Not discussed in this simulation: need for a larger Genesis OCS!

#observations

station	30.0°	35.0°	40.0°	45.0°	50.0°	55.0°	60.0°	65.0°	70.0°	75.0°	80.0°	85.0°	90.0°	95.0°	100.0°	105.0°	110.0°	115.0°	120.0°	125.0°	130.0°	135.0°	140.0°	145.0°	150.0°	Latitude [°]
1888	1,650	2,247	2,800	3,330	3,725	4,126	4,545	4,936	5,330	5,760	6,415	6,743	6,826	6,744	6,413	5,740	5,327	4,922	4,534	4,155	3,699	3,259	2,786	2,245	1,639	60.53°
7811	2,603	3,036	3,409	3,712	4,070	4,338	4,602	4,830	5,039	5,231	5,410	5,665	5,956	5,660	5,431	5,232	5,033	4,826	4,590	4,298	4,048	3,746	3,408	3,029	2,588	52.28°
1890	2,659	3,076	3,432	3,706	4,054	4,343	4,596	4,822	5,025	5,213	5,386	5,597	5,883	5,588	5,380	5,217	5,025	4,815	4,592	4,395	4,072	3,768	3,440	3,059	2,641	51.77°
7840	2,744	3,145	3,499	3,839	4,119	4,367	4,599	4,823	5,007	5,165	5,316	5,478	5,728	5,457	5,325	5,174	4,998	4,810	4,606	4,335	4,100	3,816	3,497	3,145	2,739	50.87°
1868	2,761	3,162	3,524	3,871	4,111	4,378	4,610	4,808	5,005	5,158	5,314	5,457	5,700	5,460	5,305	5,145	4,991	4,813	4,610	4,339	4,104	3,829	3,506	3,164	2,746	50.69°
8834	2,909	3,290	3,608	3,873	4,179	4,396	4,610	4,797	4,953	5,066	5,183	5,280	5,342	5,258	5,192	5,075	4,936	4,796	4,606	4,419	4,162	3,887	3,599	3,282	2,901	49.14°
7839	3,101	3,445	3,739	3,991	4,234	4,437	4,618	4,775	4,878	4,982	5,022	5,015	4,816	5,009	5,028	4,981	4,897	4,781	4,604	4,473	4,208	3,990	3,731	3,441	3,108	47.07°
7810	3,121	3,465	3,748	4,008	4,234	4,426	4,617	4,772	4,874	4,974	5,019	5,000	4,792	4,993	5,016	4,960	4,861	4,760	4,619	4,433	4,232	4,004	3,746	3,461	3,121	46.88°
7237	3,413	3,701	3,939	4,126	4,335	4,492	4,614	4,721	4,787	4,799	4,769	4,513	4,362	4,534	4,766	4,783	4,798	4,731	4,609	4,452	4,322	4,124	3,921	3,679	3,404	43.79°
7845	3,410	3,698	3,930	4,154	4,305	4,474	4,603	4,710	4,781	4,814	4,757	4,506	4,365	4,524	4,763	4,818	4,771	4,723	4,629	4,446	4,319	4,127	3,936	3,683	3,423	43.75°
1886	3,422	3,710	3,938	4,159	4,328	4,475	4,617	4,721	4,776	4,792	4,762	4,487	4,344	4,498	4,755	4,776	4,771	4,723	4,636	4,470	4,311	4,132	3,930	3,698	3,409	43.65°
7941	3,687	3,920	4,096	4,303	4,395	4,523	4,605	4,671	4,675	4,626	4,470	4,131	4,059	4,124	4,488	4,627	4,688	4,674	4,622	4,498	4,402	4,255	4,094	3,913	3,674	40.65°
7105	3,822	4,015	4,170	4,296	4,434	4,530	4,599	4,631	4,615	4,525	4,244	3,976	3,919	3,993	4,255	4,524	4,632	4,649	4,579	4,593	4,438	4,315	4,183	4,018	3,824	39.02°
7110	4,308	4,395	4,476	4,501	4,548	4,584	4,542	4,481	4,303	3,929	3,666	3,560	3,525	3,568	3,666	3,915	4,327	4,472	4,532	4,643	4,548	4,529	4,465	4,394	4,309	32.89°
7080	4,468	4,521	4,555	4,578	4,568	4,541	4,502	4,390	4,154	3,740	3,536	3,461	3,428	3,447	3,548	3,728	4,165	4,390	4,508	4,608	4,579	4,578	4,568	4,530	4,484	30.68°
7119	5,220	5,061	4,934	4,716	4,639	4,439	4,140	3,659	3,412	3,263	3,156	3,108	3,089	3,112	3,164	3,251	3,406	3,669	4,140	4,447	4,651	4,810	4,933	5,070	5,226	20.71°
																										equator
7403	5,570	5,292	5,072	4,884	4,625	4,261	3,762	3,467	3,280	3,152	3,060	3,017	2,993	3,019	3,072	3,154	3,289	3,467	3,747	4,340	4,619	4,858	5,068	5,301	5,554	-16.47°
7501	4,830	4,793	4,762	4,725	4,643	4,560	4,391	4,120	3,687	3,454	3,330	3,260	3,242	3,269	3,323	3,436	3,687	4,143	4,371	4,603	4,636	4,707	4,772	4,804	4,845	-25.89°
7090	4,611	4,611	4,634	4,606	4,650	4,562	4,462	4,314	3,970	3,626	3,476	3,389	3,351	3,380	3,474	3,657	3,984	4,324	4,465	4,544	4,618	4,648	4,643	4,622	4,599	-29.05°
7825	4,121	4,243	4,355	4,445	4,529	4,572	4,557	4,526	4,447	4,225	3,846	3,711	3,670	3,714	3,854	4,248	4,452	4,535	4,566	4,574	4,520	4,455	4,359	4,249	4,121	-35.32°
Total	72,430	76,826	80,620	83,823	86,725	88,824	90,191	90,974	90,998	90,494	90,137	89,354	89,390	89,351	90,218	90,441	91,038	91,023	90,165	89,065	86,588	83,837	80,585	76,787	72,355	

Genesis orbit inclination

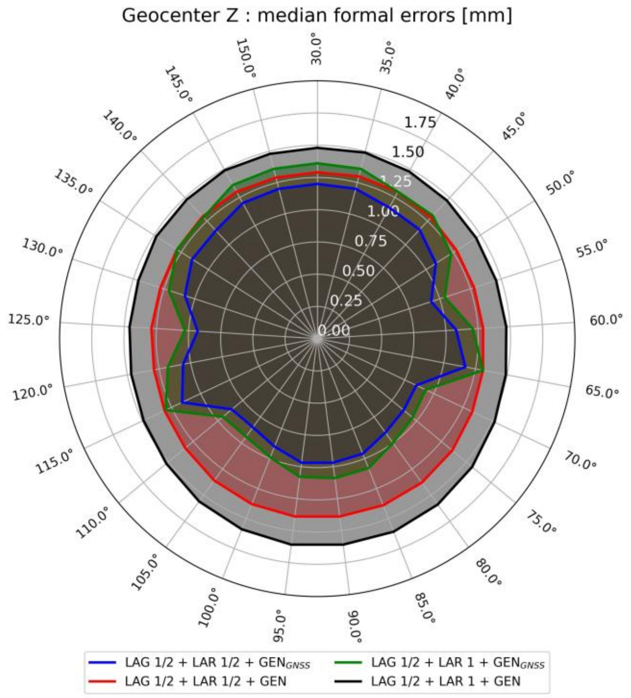
well-performing stations regarding OCS

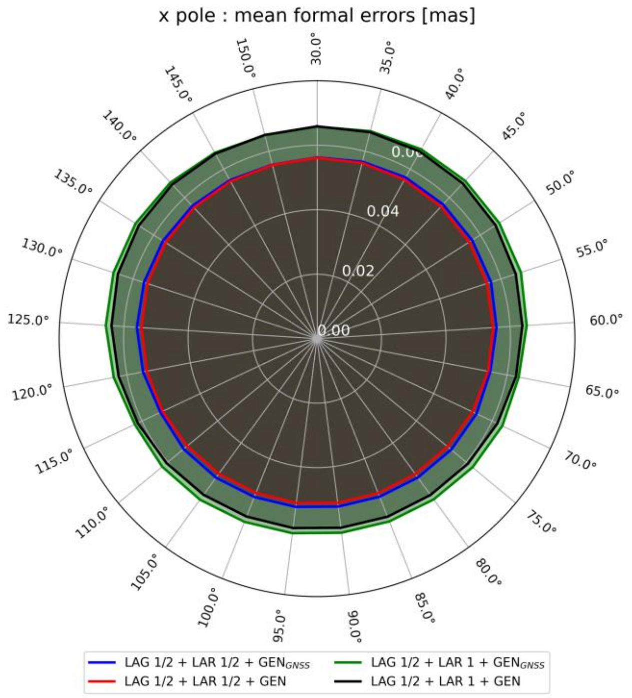
drop in low elevation NPs → reduced number of Genesis NPs expected

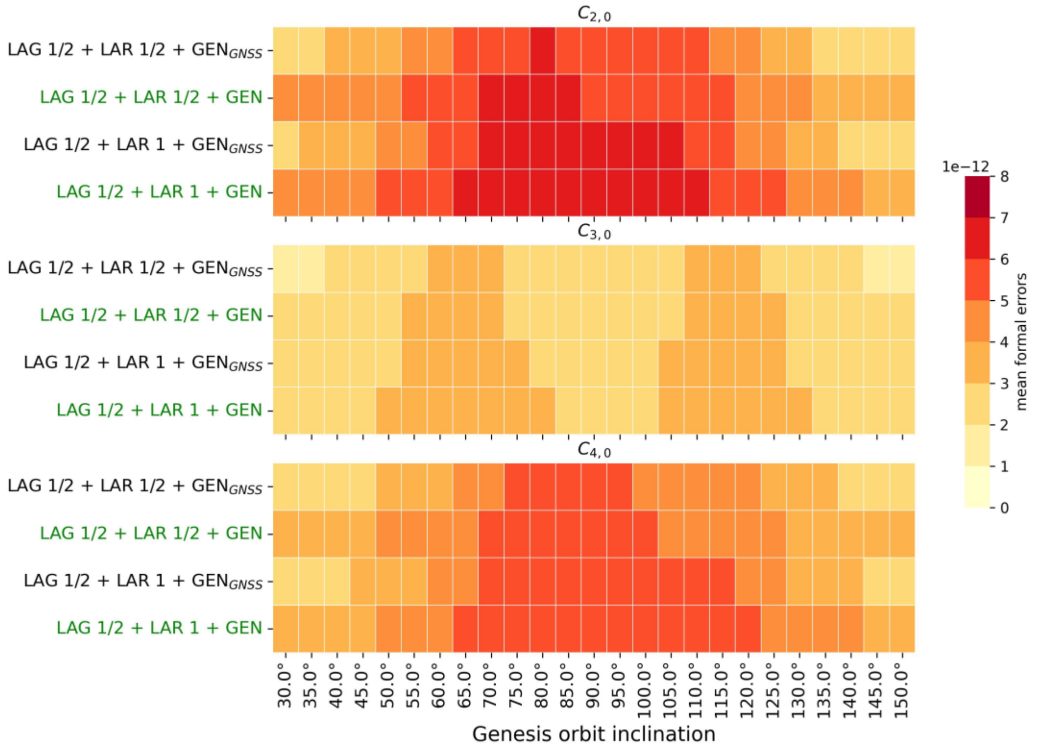
no or very few daylight NPs → problems with Genesis OCS expected

Simulation study (III)

- Mean formal errors of z-geocenter indicate an inclination between 70° and 110° to be the best option ←→ gravity field coefficients have the highest formal errors in that regime…

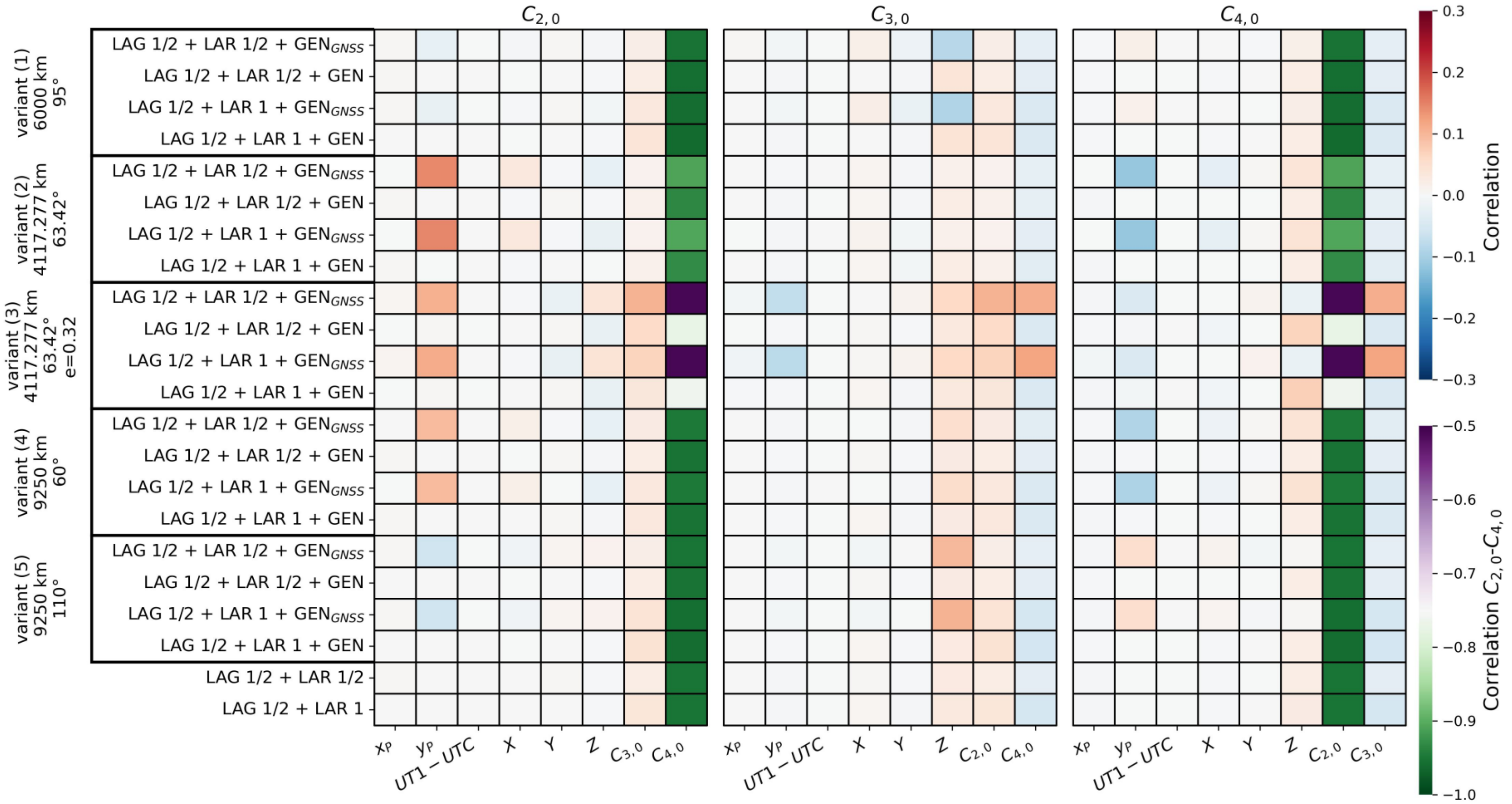






Simulation study (IV)

♦ Decorrelation of C_{20} and C_{40} can be achieved with an eccentric orbit at low altitude



Conclusions

Real data analysis

- If the OCS requirement for Genesis is not changed (at least to LA-1 OCS; RRA design on Genesis already fixed?)
  - many SLR stations won’t be able to sufficiently track Genesis at low elevations → degradation of height and range bias determination?
  - for nearly half of the SLR network it seems to be very difficult to obtain daytime NPs of Genesis

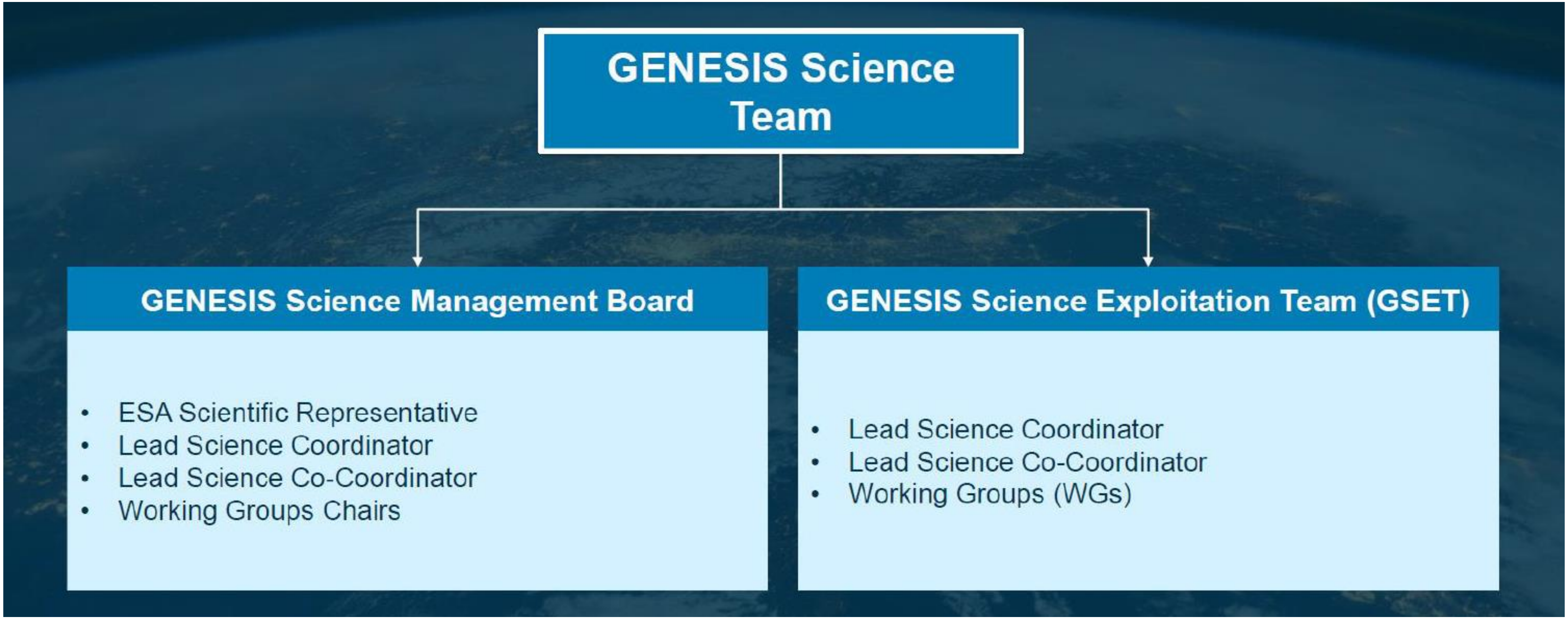
Simulations

- 6000 km altitude and inclinations between 70° and 110° result in smallest mean formal error for z geocenter
- Eccentric orbit at low altitude is most beneficial for gravity field recovery

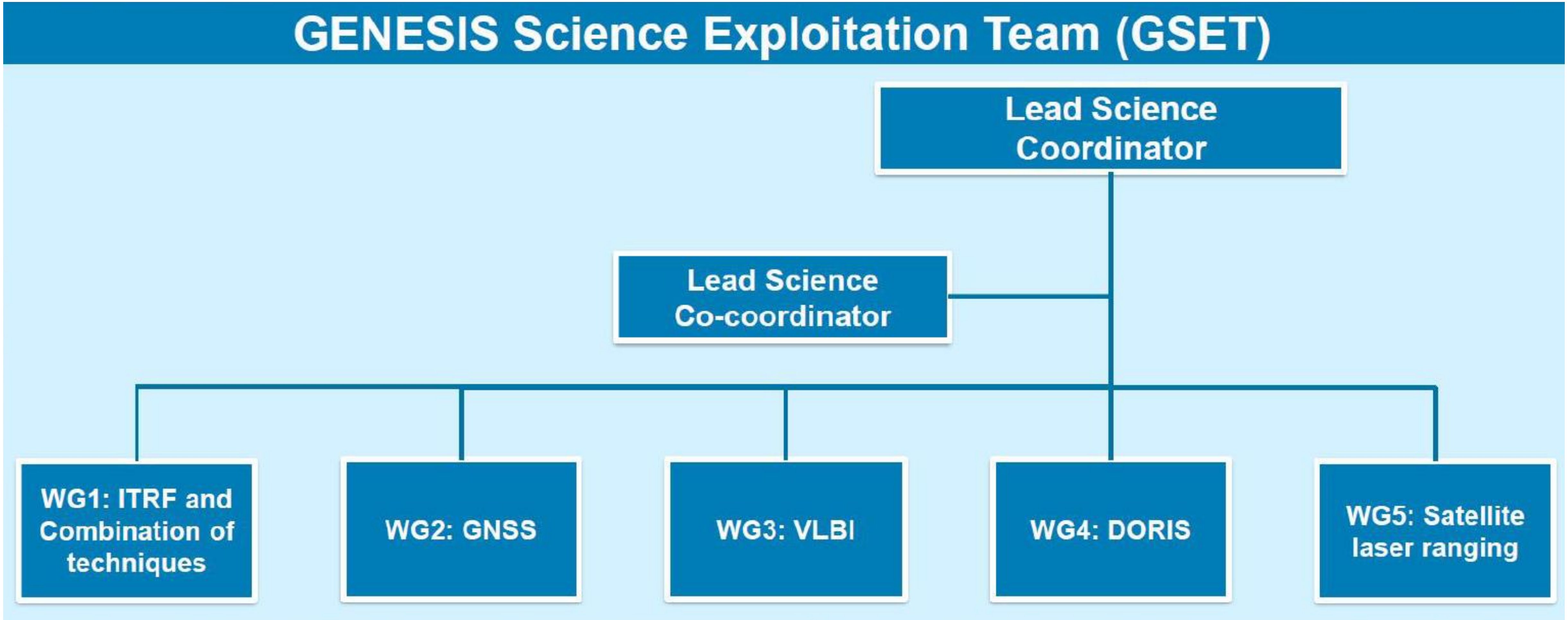
Take-home message

- **Most of the state-of-the-art studies simulate 100% or ‘realistic’ tracking scenarios but do not consider planned OCS for Genesis**
- **Genesis OCS must be changed, otherwise simulations lead to non-optimal conclusions!**

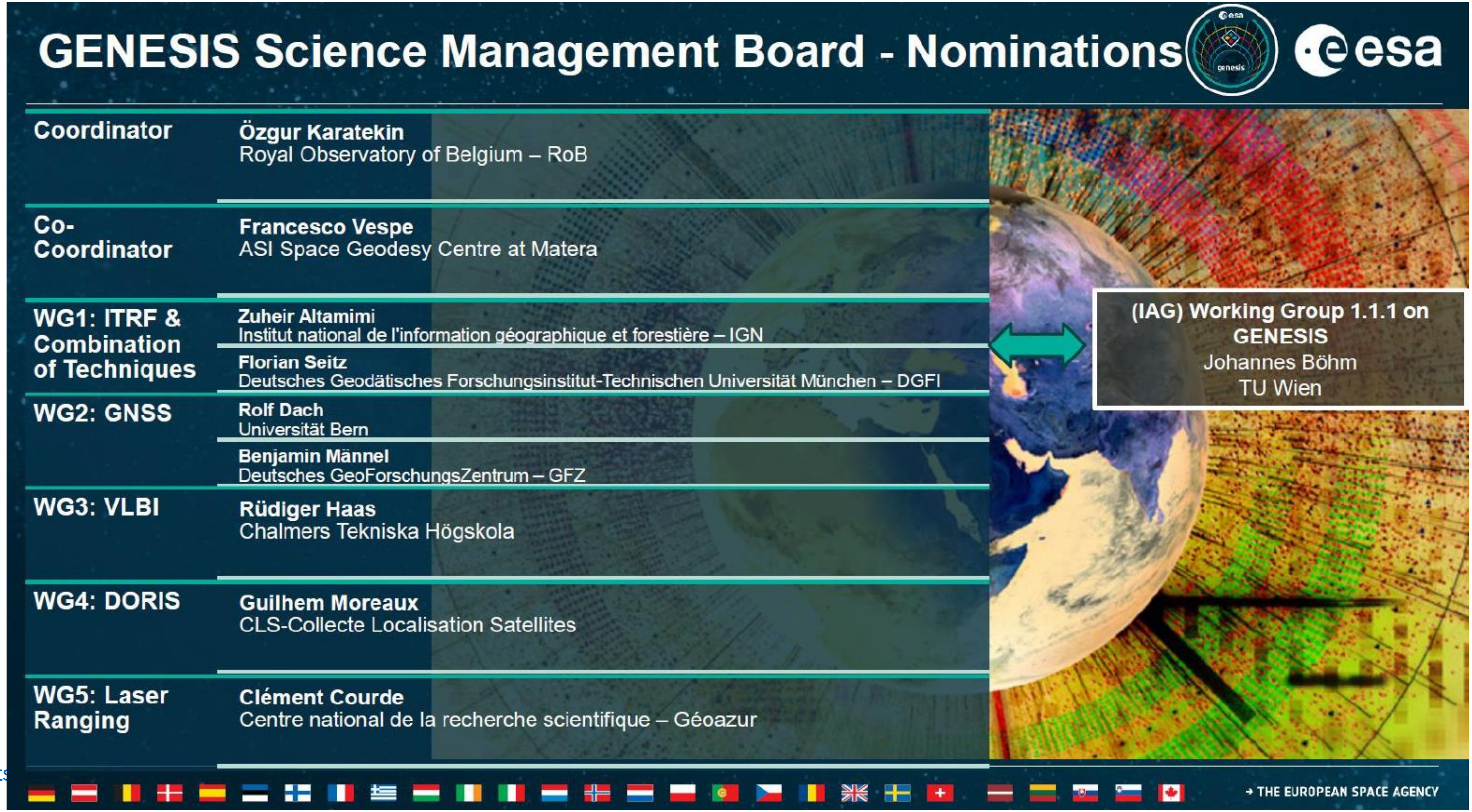
Genesis Science Team setup (I)



Genesis Science Team setup (II)



Genesis Science Team setup (III)



Genesis SLR Working Group (I)

- The Genesis SLR WG acts as an interface to the ILRS and its entities…

IAG WG 1.1.1 „Genesis“
IGS, IVS, IDS, IERS, …

Genesis Science Management Board

Genesis Science Exploitation Team (GSET)

…
Genesis SLR WG

Analysis Standing Committee

Missions Standing Committee

Networks and Engineering Standing Committee

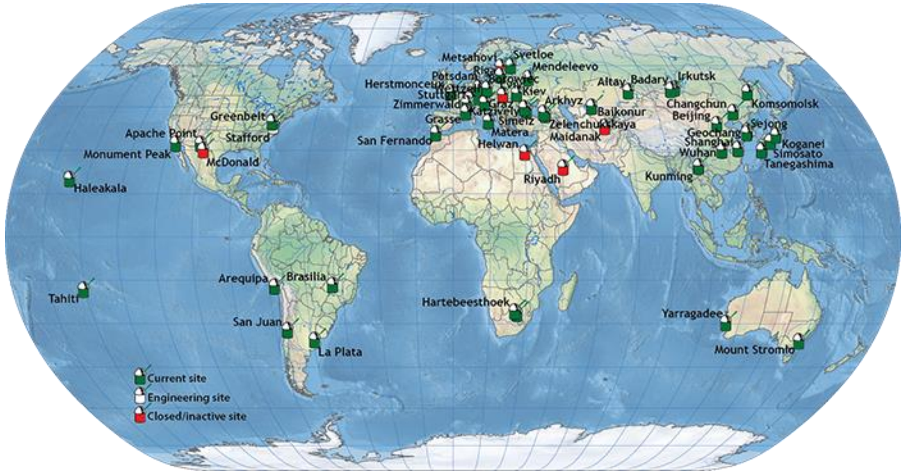
Data Formats and Procedures Standing Committee

Lunar, Interplanetary Ranging & Time Transfer Standing Committee

Space Debris Standing Committee

Governing Board / Central Bureau

Observing Station Network



International Laser Ranging Service

Genesis SLR Working Group (II)

- Kick off: Aug 26th, 2024

- 1st SLR WG meeting: Sep 6th 2024, 1-2 PM, UTC, Zoom
  - establishment of the SLR WG and introduction to Genesis by C. Courde
  - review of the draft ToR and its approval
  - members: Clement Courde (chair), Mathis Bloßfeld (deputy)

Simone Dell'Agnello	Mike Pearlman	José Rodríguez Pérez	Matthew Willkinson
Robert Sherwood	Toshimichi Otsubo	Randall Carman	Dariusz Strugarek
Michael Steindorfer	Johann Eckl	David Sarocco	Pierre Exertier
Stephen Merkowitz	Alexandre Belli	Claudia Carabajal	Julien Chabé
Marco Cinelli	Franck Reinquin	Christian Schwatke	Randall Ricklefs

+ further members in the future

- 2nd SLR WG meeting: ASAP… TBD
  - discussion of SLR-related satellite and mission requirements of ESA and compilation of feedback

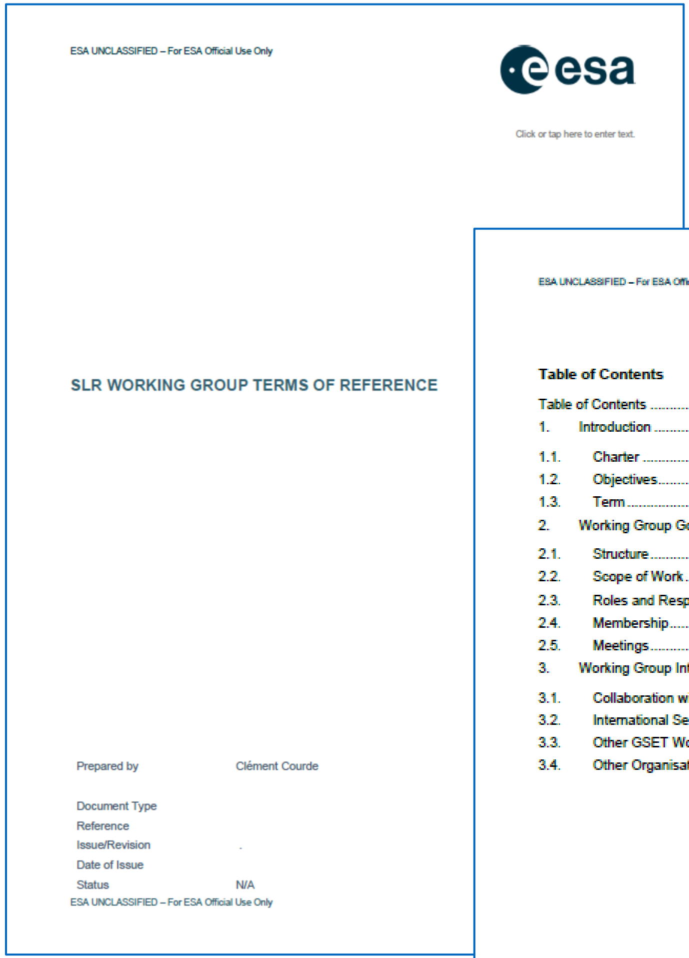
Genesis SLR Working Group (III)

- Main objective:

  The objective of the SLR Working Group (SWG) is to provide **scientific advice and support** to the ESA Genesis Project Team for a **full and effective exploitation** of the SLR observations from the ESA Genesis mission. The SWG should also **request all necessary information from ESA and industry** to properly model the satellite, orbit, and observations.

- Role of the SLR WG:

  The SWG **provides advice and/or makes recommendations** on items referred to it by the ESA Genesis Project Team. Members of the SWG may, however, **raise issues they wish to discuss related to all the SLR aspects** on the ESA Genesis mission



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SLR WORKING GROUP TERMS OF REFERENCE

Prepared by	Clément Courde
Document Type	
Reference	
Issue/Revision	.
Date of Issue	
Status	N/A

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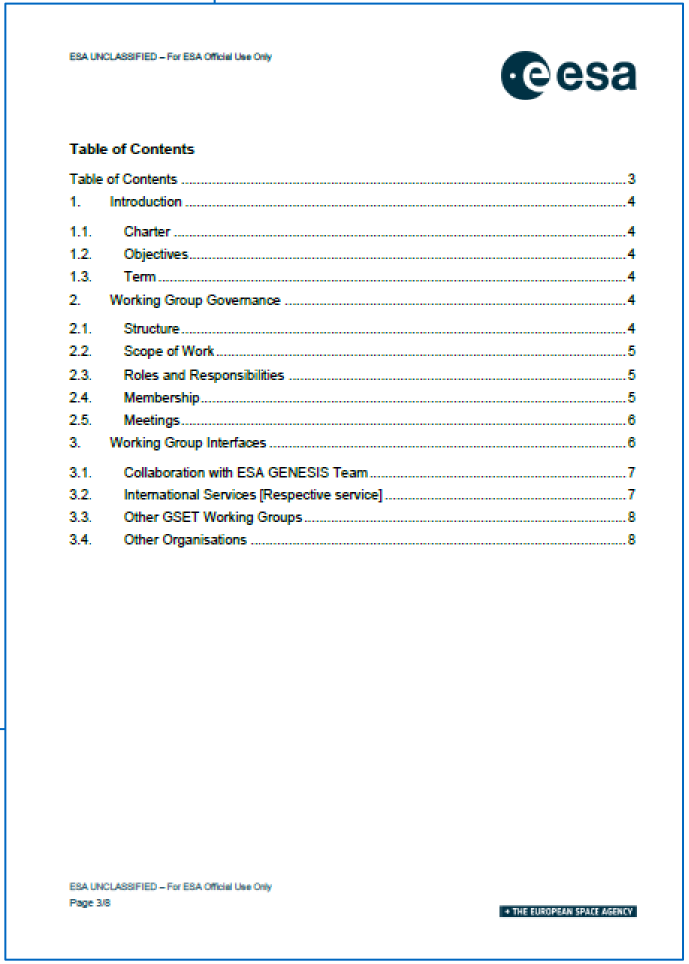

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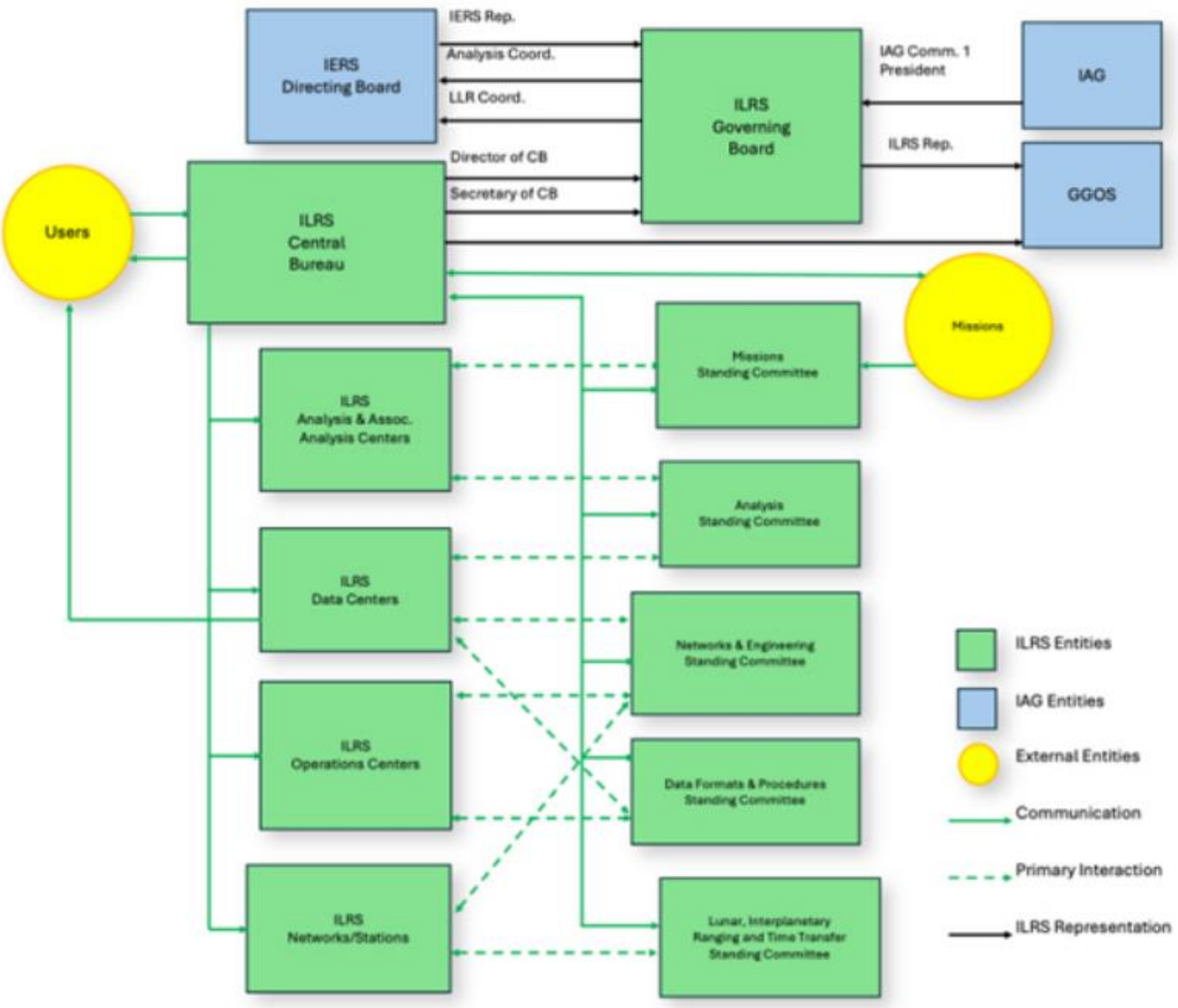
→ THE EUROPEAN SPACE AGENCY

Genesis SLR Working Group (IV)

- Interactions with ILRS Standing Committees
  - support to ESA to **assess the SLR reflector compatibility with ground stations** (Missions Standing Committee)
  - Genesis SLR data: **provide formats for data delivery and data products** (Data Formats and Procedures Standing Committee & Analysis Standing Committee)
  - SLR observation campaign organization: **station recommendations and observation strategy** (Network and Engineering Standing Committee)
  - **support to definition of SLR payload calibration approach** (on the ground and in-orbit; all SCs)



https://ilrs.gsfc.nasa.gov/about/organization, 2024

Genesis requirements… from the ILRS Point of View

- Satellite
  - **Orbit predictions** must be provided in time to allow stations precise telescope pointing
  - **Satellite metadata** (geometric shape, optical surface properties, attitude logs, mass history files, manoeuvres, etc.) must be publicly available
  - **Geometric phase center** offset w.r.t. satellite reference frame must be publicly available
  - **Optical phase center** of reflector must be calibrated on-ground and in-orbit
  - **Reflector compatibility** with ground stations must be ensured (OCS!!)
  - **Nadir-pointing of reflector** is essential
- SLR observations of ground network
  - **Data formats and procedures** must be consistent to ILRS standards
  - **SLR observations** of the ground network are publicly available via the ILRS data portals CDDIS and EDC
  - **SLR observation campaigns** (recommendations and observation strategy) must be coordinated with ILRS entities
- **SLR WG is currently discussing SLR-related Genesis requirements with ILRS SCs (e.g., tracking amount, coordinated tracking with other techniques, cross-section of RRA, data formats, etc.) → answer to ESA provided**