Satellite Orbit Determination

at the

Astronomical Institute of the University of Bern (AIUB)

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on behalf of the AIUB team

University of Bern

Astronomical Institute

Satellite Geodesy **Optical Astronomy**

Zimmerwald

Satellite orbit determination activities

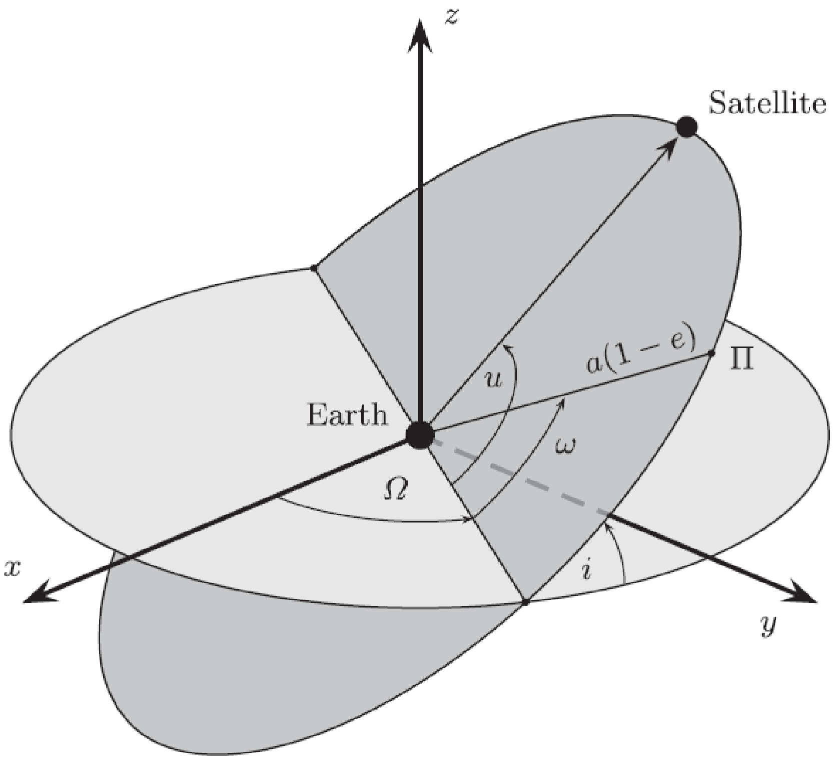
This presentation

Overview Talk

T. Schildknecht

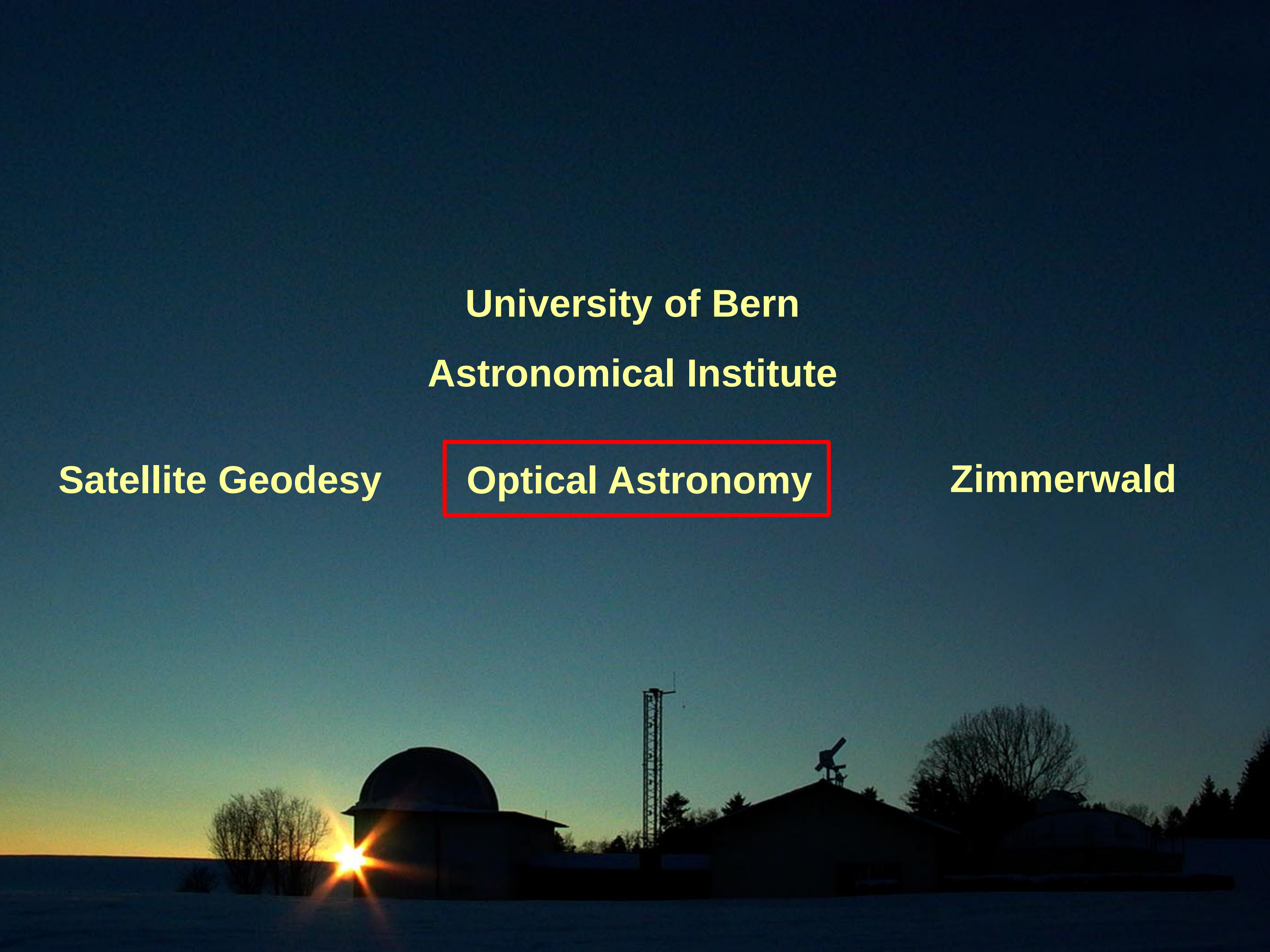
Orbit Determination (OD)

Common to all OD problems: Initial osculating elements estimated at time t_0



a: semi–major axis
e: numerical eccentricity
i: inclination
Ω: right ascension of the ascending node
ω: argument of perigee
u_0: argument of latitude at time t_0

Different to all OD problems:
- Additional parameters (from a few ones to 100k's)
- Arc–lengths (from days to weeks)
- Observations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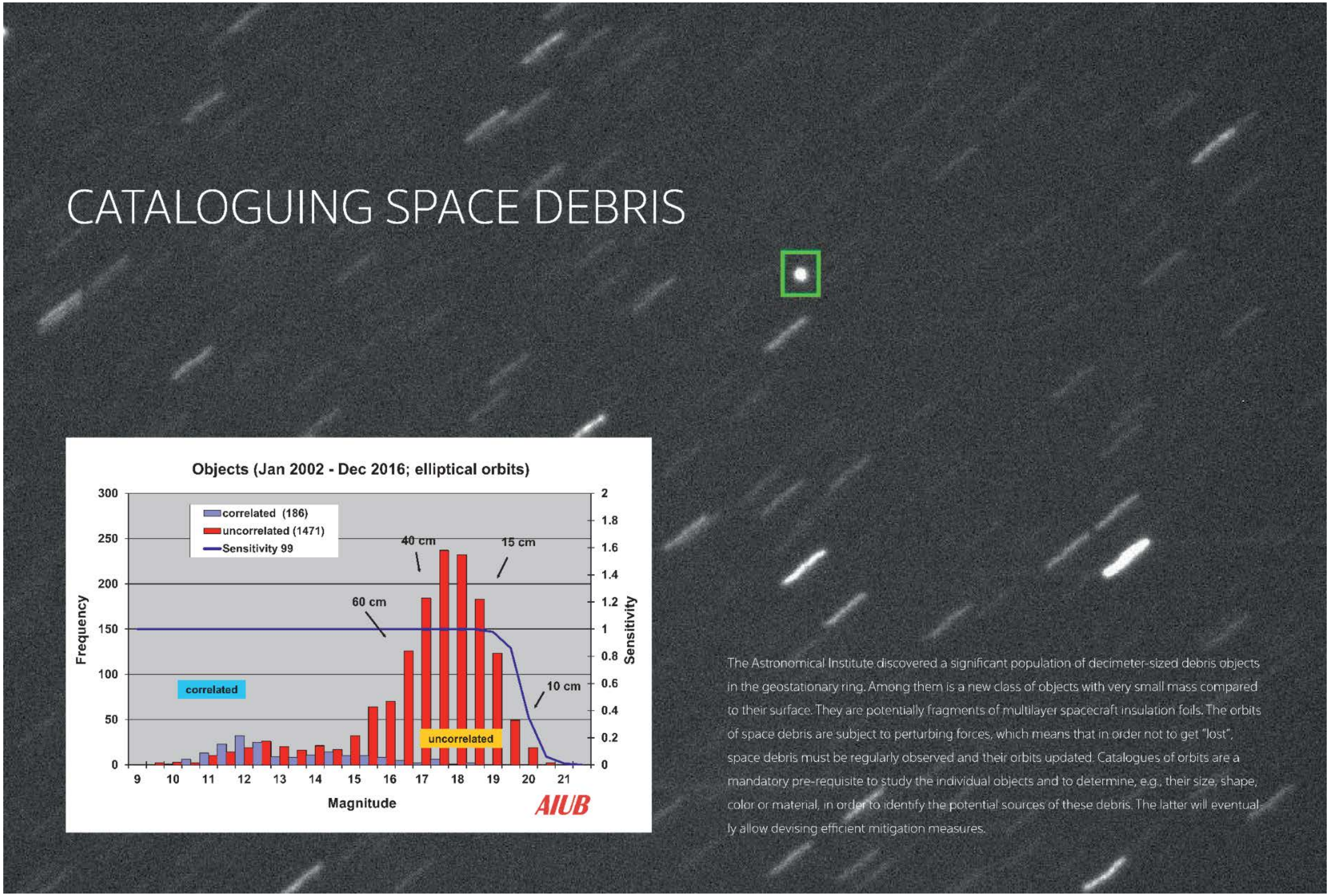
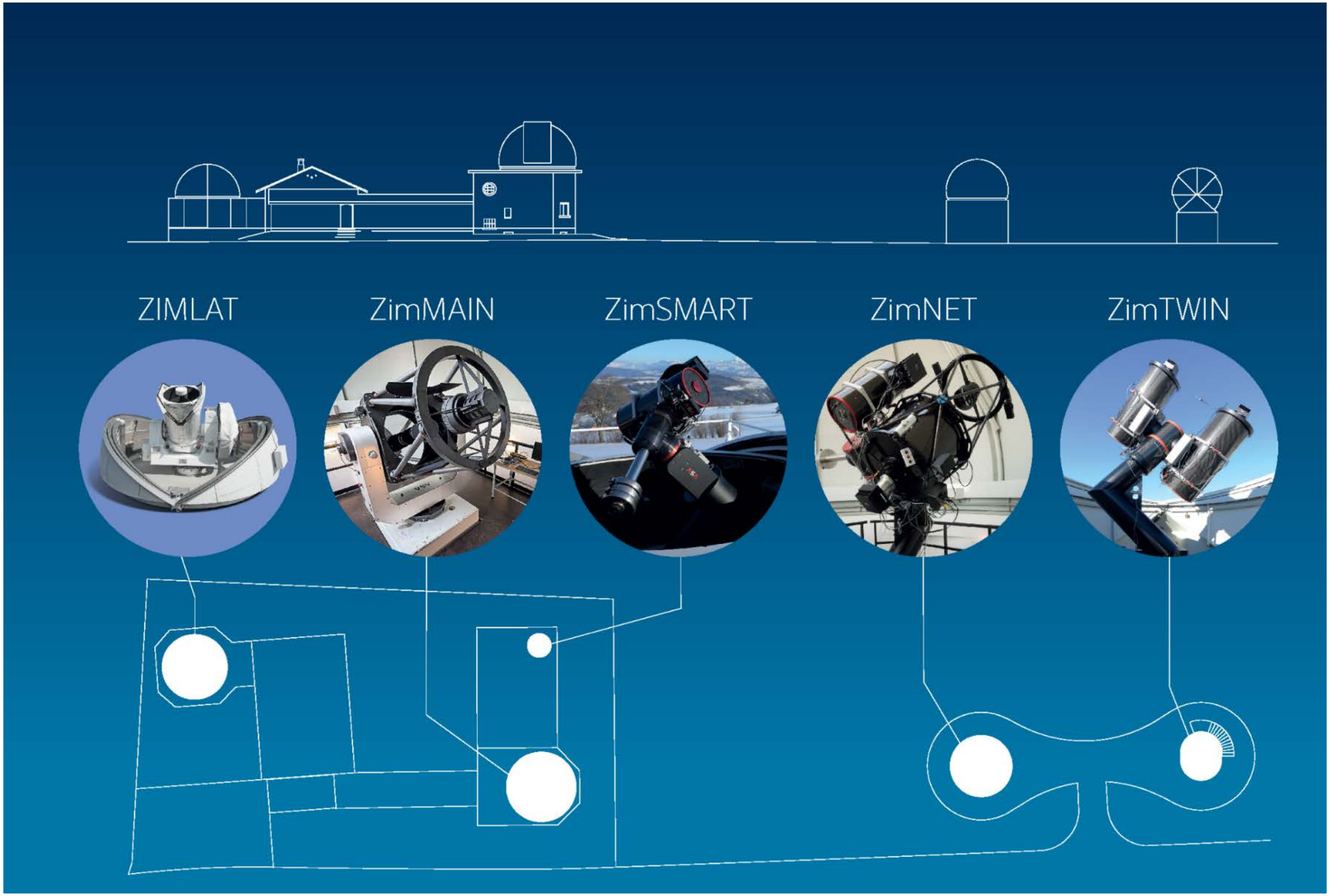
Optical Astronomy at Zimmerwald



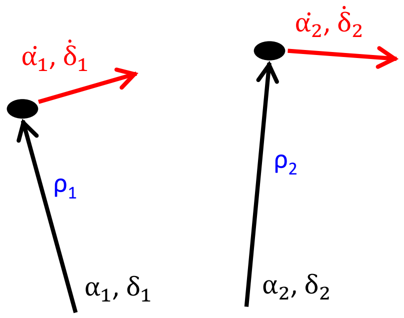
Optical Sensors at Zimmerwald



Initial OD using optical observations

- Series of angular observations (α_i, δ_i, i=1, … , n) from optical surveys: tracklets
- Challenge:
  - few and sparse observations
  - tracklets with e.g. 3 obs. in 1 min.
  - 2 or more tracklets separated by hours or days
  - hundreds of objects
- Goal: find out which tracklets belong to the same object.
- Methodology: Optimized Boundary Value Initial Orbit Determination with Shooting Method
- The angular rates are obtained by performing a linear fit on the angular positions.

- Hypothesis on ρ_1, ρ_2
- Compute hypothetical orbit (Lambert)
- If hypothetical $\dot{\alpha}$, $\dot{\delta}$ = observed $\dot{\alpha}$, $\dot{\delta}$ => same object!



(Mann et al., 2020)

Initial OD using optical observations

- Two tracklets are tested at a time. They are separated by a few hours or multiple revolutions for the geostationary orbit regime.
- The table shows that the method correlates all the tracklets for the scenarios considered here (even for the high AMR objects and multiple revolutions).

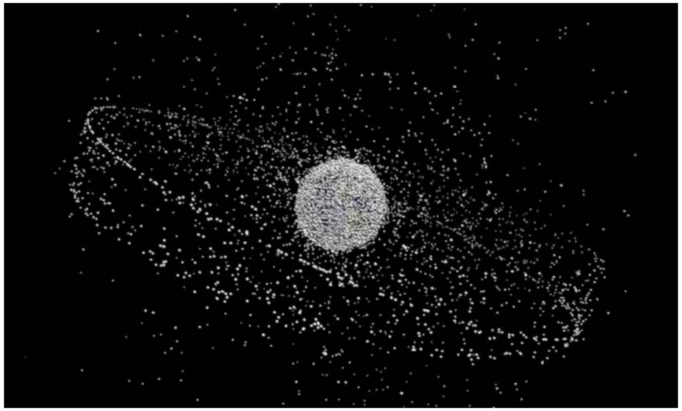
Separation between the tracklets	Area to mass ratio of the object (m^2/kg)	Number of true correlations	Number of false correlations	Number of missed correlations	Number of tracklets tested
3-4 hours	0.01	11	0	0	22
	0.1	11	0	0	22
	1.0	10	0	0	20
1 revolution	0.01	11	0	0	22
	0.1	11	0	0	22
	1.0	10	0	0	20
2 revolutions	0.01	11	0	0	22
	0.1	11	0	0	22
	1.0	10	-	0	20
3 revolutions	10.0	12	-	0	24

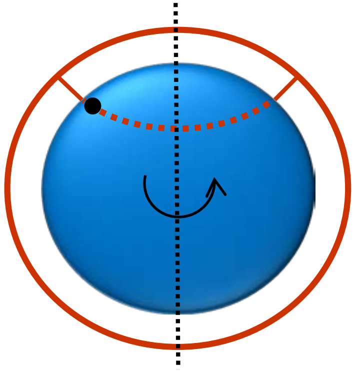
(Mann et al., 2020)

Space object orbit database build-up

Problem:

- Constantly increasing number of objects in LEO (future: megaconstellations)
- A single radar station can observe an object in LEO usually twice per day
- Find observations originating from the same object within a large number of observations





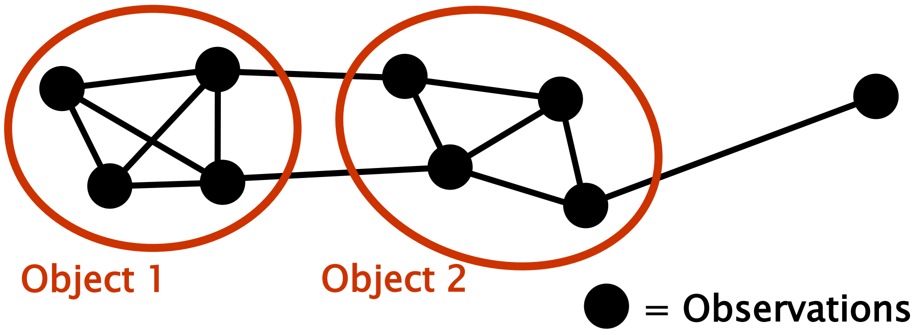
Method:

- Test pairs of observations whether they originate from the same object
- Includes an initial orbit determination with simplified perturbations

Space object orbit database build-up

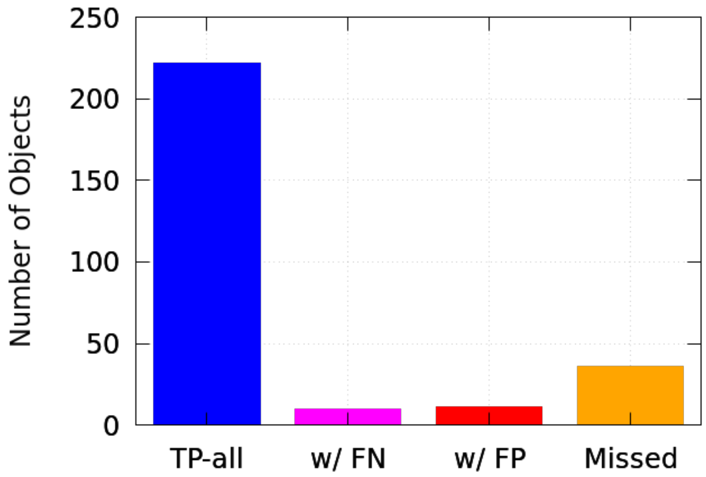
Post-processing of pairwise associations:

- Remove false associations
- Create a graph structure
- Search for clusters
- Additional constraints using orbital elements

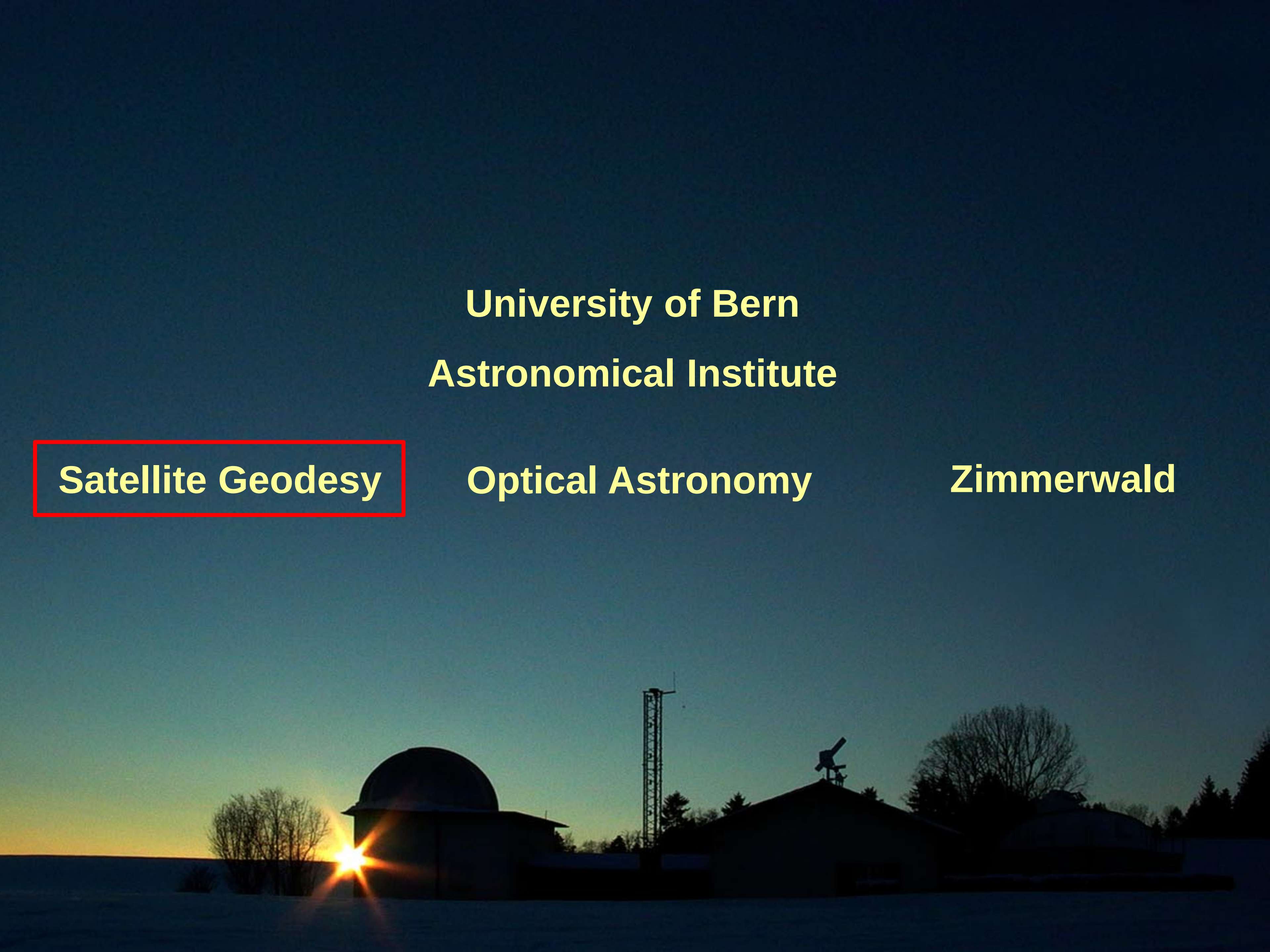


Results using real radar data:

- Identification of more than 80% of objects from 5 days of measurements



(Reihs et al., 2020a, 2020b)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Some important activities / collaborations

- AIUB develops the Bernese GNSS Software, a state-of-the-art software package which is used today by more than 700 institutions worldwide.

- AIUB hosts the Center for Orbit Determination in Europe (CODE), one of the global analysis centers of the IGS.

- AIUB contributes to long-term collaborations, e.g., to establish the Galileo Terrestrial Reference Frame (GTRF).

Some important activities / collaborations

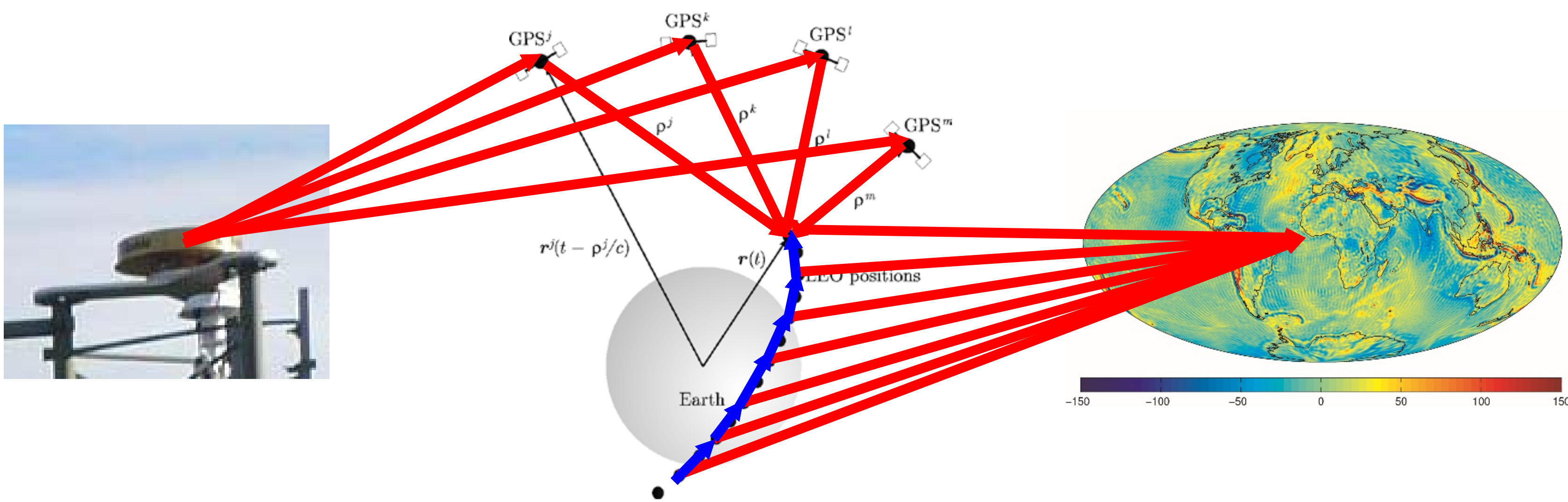
- AIUB coordinated the H2020 project EGSIEM 2015-2017

- Parts of EGSIEM are continued as a new IAG service: Combination Service for Time-variable Gravity Field Models (COST-G)

- AIUB contributes to ESA Quality Working Groups (QWGs), e.g. the QWG of the Copernicus POD Service

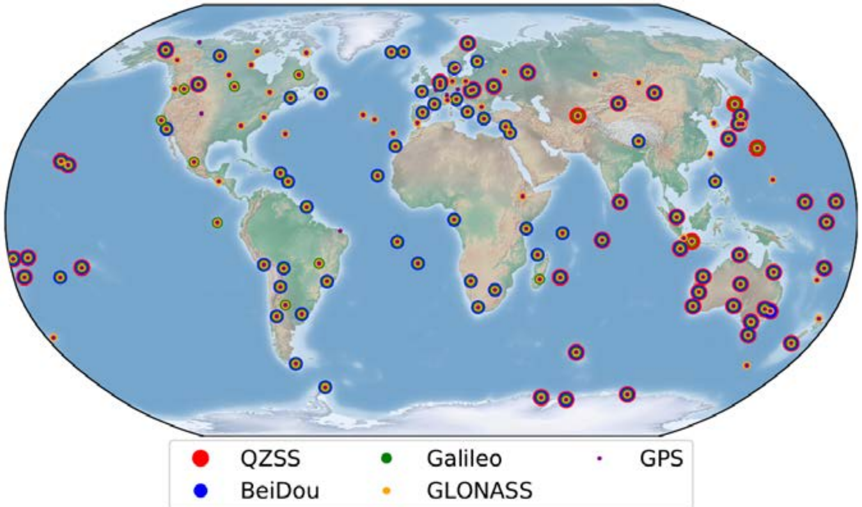
Generalized orbit determination

Original measurements	Intermediate Products, additional measurements	Final Products

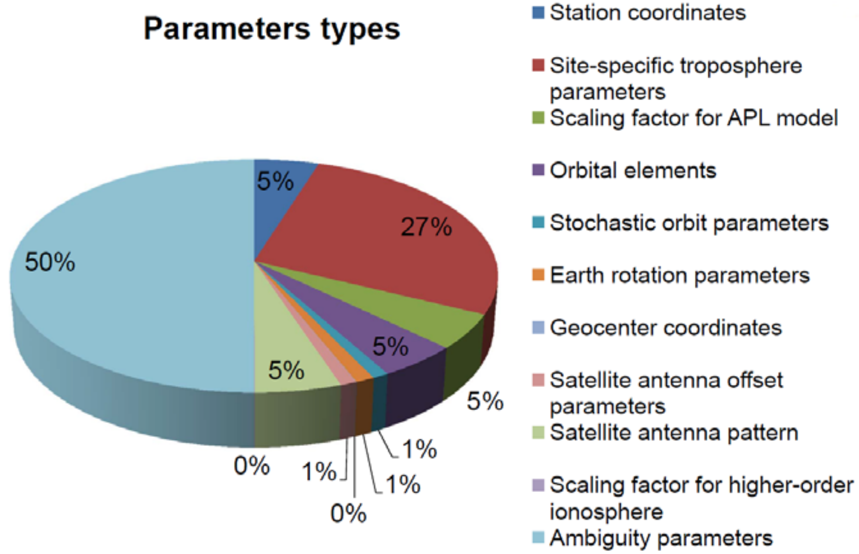


- Satellite orbits are important intermediary products to derive parameters of geodetic and geophysical interest.
- Ideally they are simultaneously solved together with the orbit parameters.

Global GNSS Solutions



Network used for CODE's MGEX solution

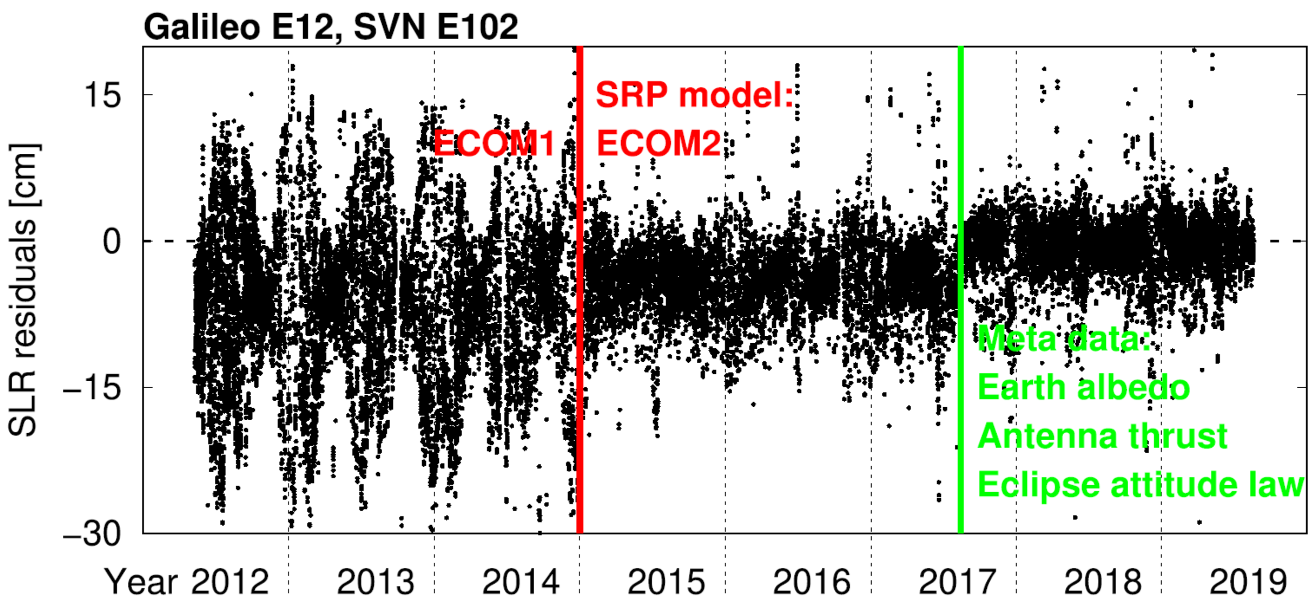


- **A large number of parameters is simultaneously adjusted in global GNSS solutions. Orbit parameters typically constitute only a few percent of the total number.**

(Dach et al., 2019)

MGEX solution

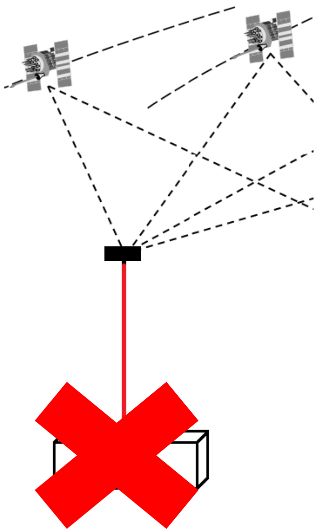
- Galileo observations are processed at AIUB since 2012 in the frame of the IGS MGEX project.
- Many orbit modeling improvements have been achieved:

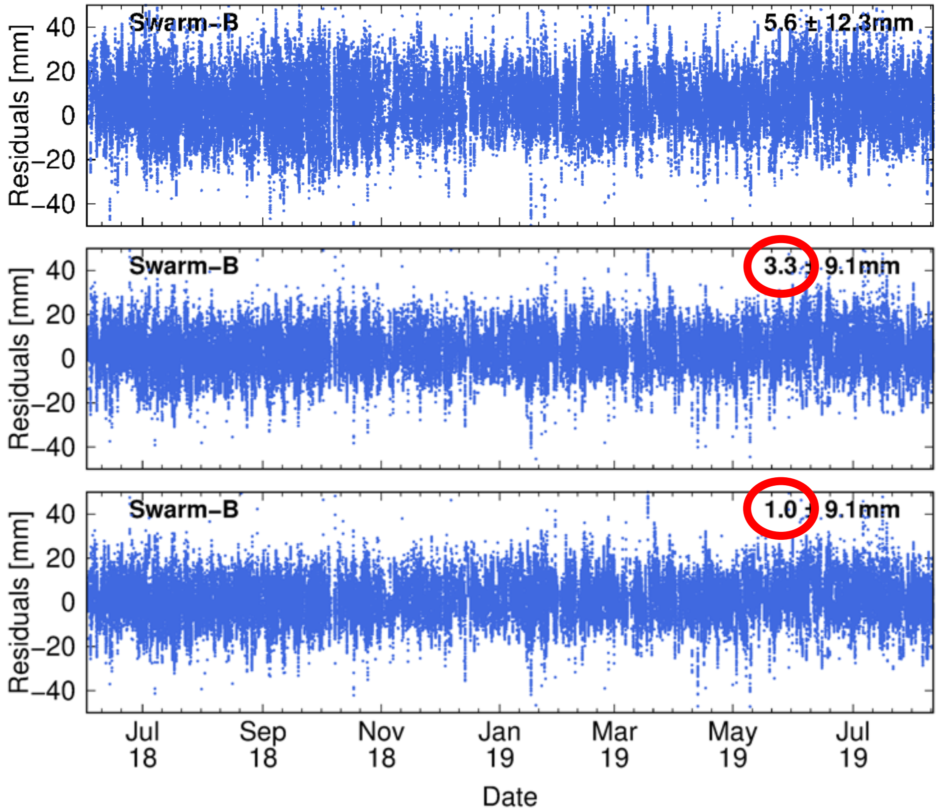


- SLR validation is an invaluable tool to independently assess the orbit quality.

(Prange et al., 2020)

SLR validation of LEO orbits





Ambiguity–float, no non–grav. modeling

Ambiguity–fixed, no non–grav. modeling

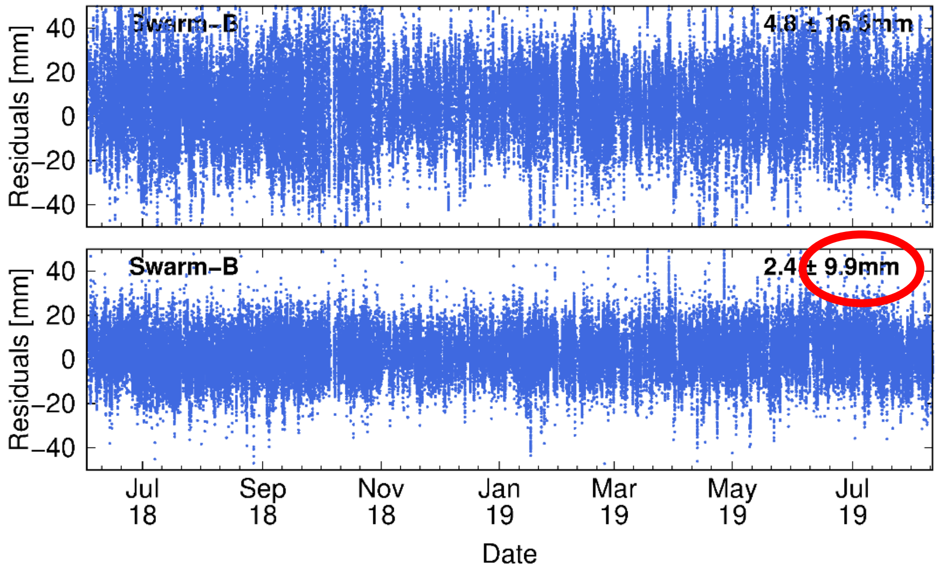
Ambiguity–fixed, with non–grav. modeling

SLR observations of 14 high–performance SLR stations, 20 cm outlier threshold, 10° elevation cutoff. SLRF2014 station coordinates used. No parameters estimated.

(Arnold et al., 2019; Mao et al., 2020)

Kinematic LEO orbits

Kinematic positions are purely geometrically derived from the GPS observations and fully independent on the force models used for LEO orbit determination.

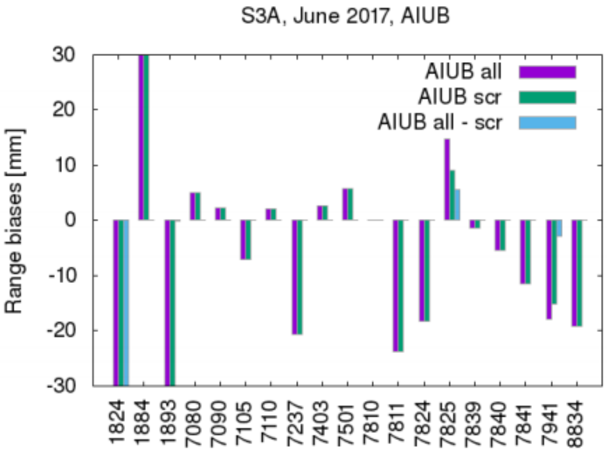


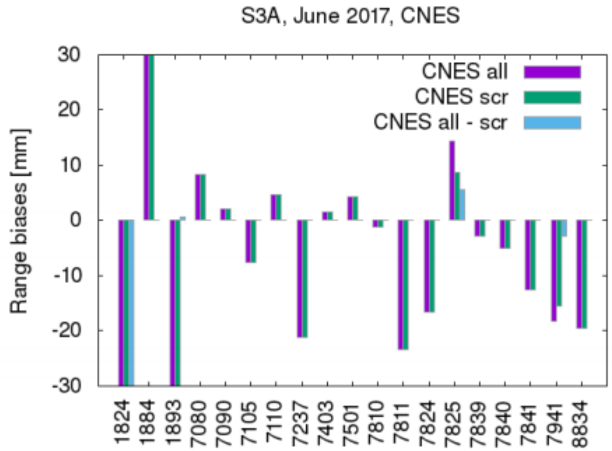
Ambiguity-float

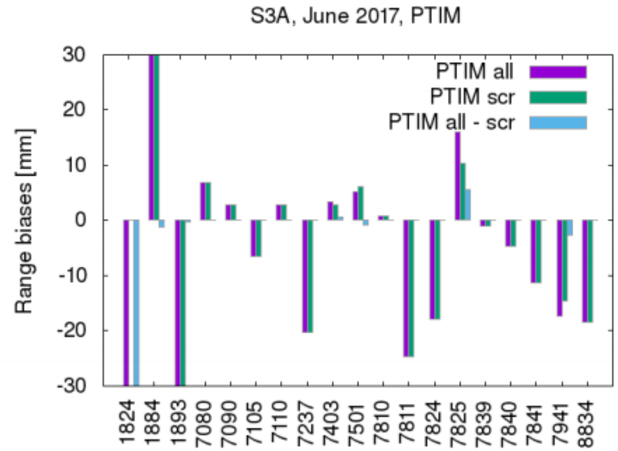
Ambiguity-fixed

- The SLR STD of ambiguity-fixed kinematic orbits (9.9mm) is only marginally worse than for the ambiguity-fixed dynamic orbits (9.1mm, see previous slide).
- This nicely illustrates the limitation of SLR to “distinguish” between the orbits.
- Comparisons to ambiguity-fixed kinematic orbits should be regularly performed to detect inconsistencies, e.g., related to wrong GPS antenna phase center offsets.

Extension of SLR Validation Concepts







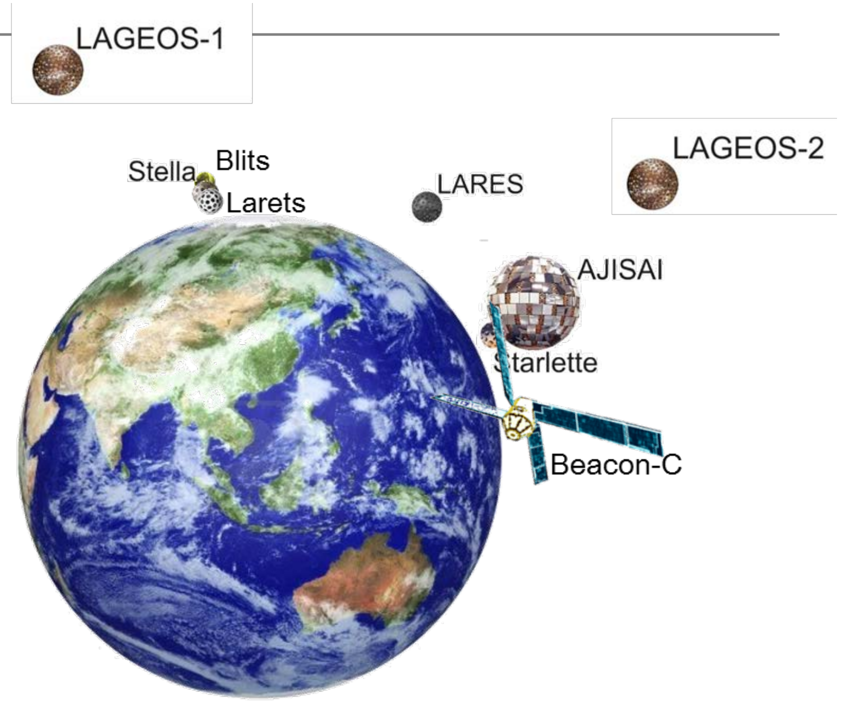
Figures from a multi-agency study initiated at OSTST 2019 by A. Couhert (CNES).

- Especially LEO satellites allow not only for a validation of the orbit quality in the radial direction, but also in the other directions. Using longer data spans, mean SLR biases may also be determined in the other orbital directions.
- But LEO SLR data and GPS-based dynamic LEO orbit modeling will also become more and more interesting to estimate SLR station coordinates and range biases.

Multi-satellite cannonball SLR solutions

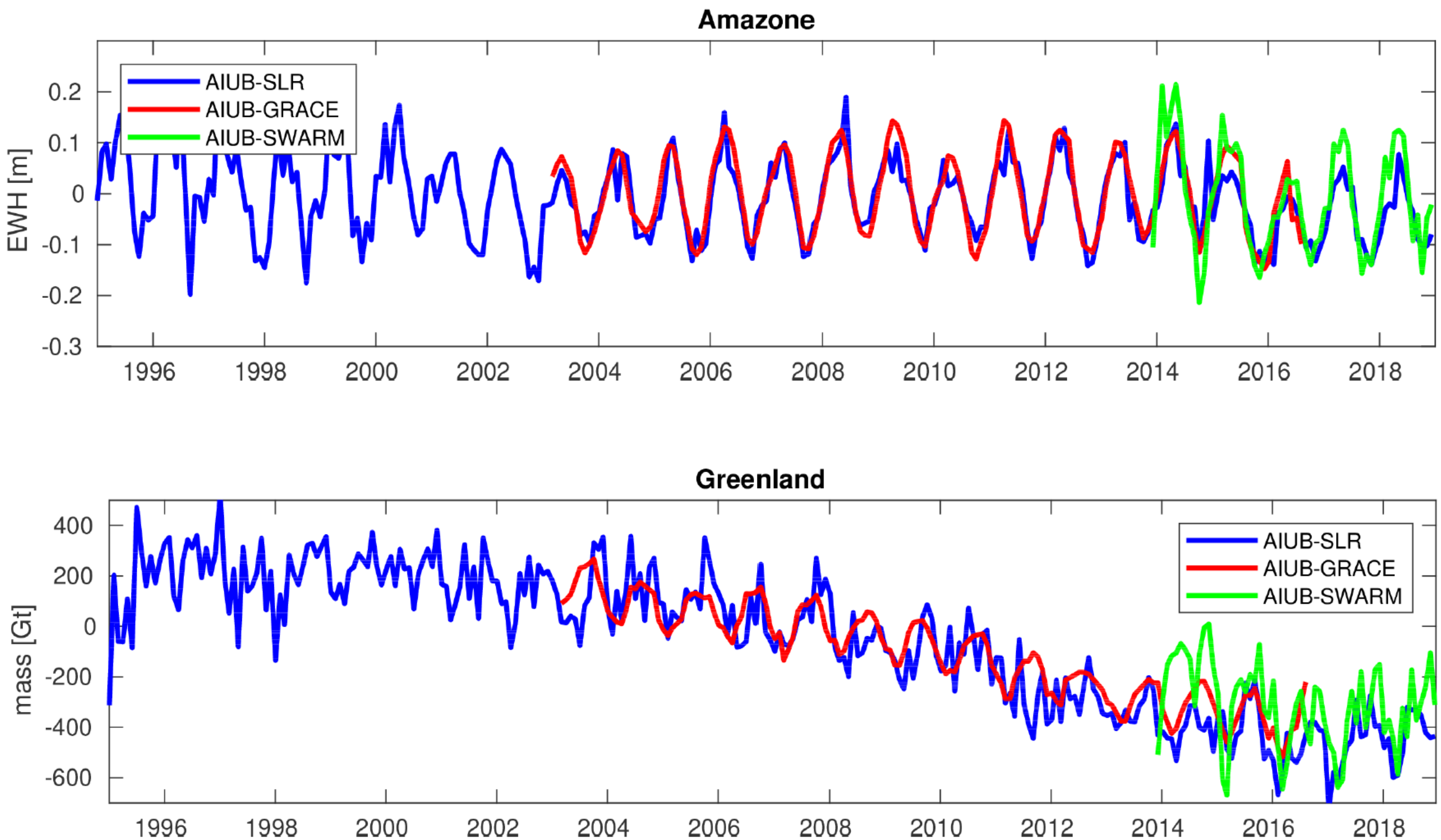
		SLR solutions
Estimated parameters		LAGEOS-1/2, Starlette, Stella, AJISAI, LARES, Blits, Larets, Beacon-C
Orbits	Osculating elements	a, e, i, Ω, ω, u_0 (LAGEOS: 1 set per 10 days, LEO: 1 set per 1 day)
	Dynamical parameters	LAGEOS-1/2 : S_0, S_S, S_C (1 set per 10 days) Sta/Ste/AJI : C_D, S_C, S_S, W_C, W_S (1 set per day)
	Pseudo-stochastic pulses	LAGEOS-1/2 : no pulses Sta/Ste/AJI : once-per-revolution in along-track only
Earth rotation parameters		X_P, Y_P, UT1-UTC (Piecewise linear, 1 set per day)
Geocenter coordinates		1 set per 30 days
Earth gravity field		**Estimated up to d/o 10/10** (1 set per 30 days)
Station coordinates		1 set per 30 days
Other parameters		Range biases for all stations (LEO) and for selected stations (LAGEOS)

(Sośnica et al., 2014a, 2015)



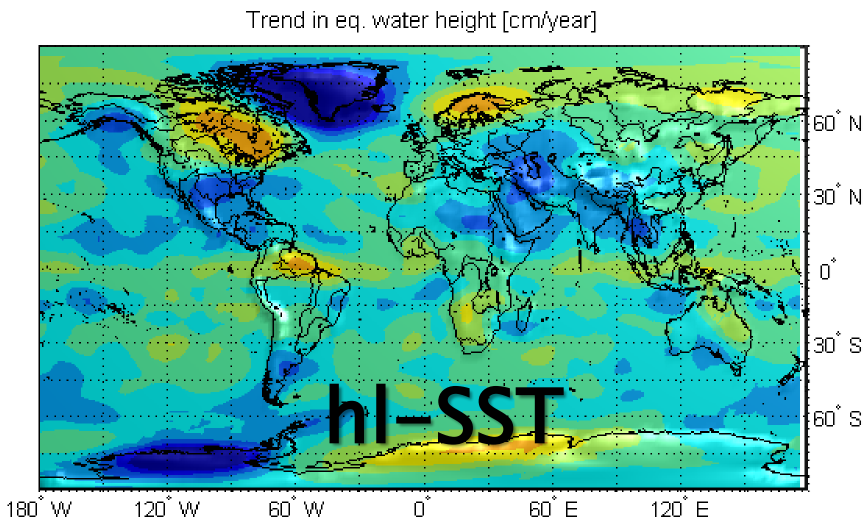
- Up to 9 SLR satellites with different altitudes and different inclinations are used.
- For LAGEOS-1/2: 10-day arcs are generated, for low orbiting satellites: 1-day arcs.
- Different weighting of observations is applied.
- Constraints introduced to regularize the normal equations (on GFC, pulses, EOPs).

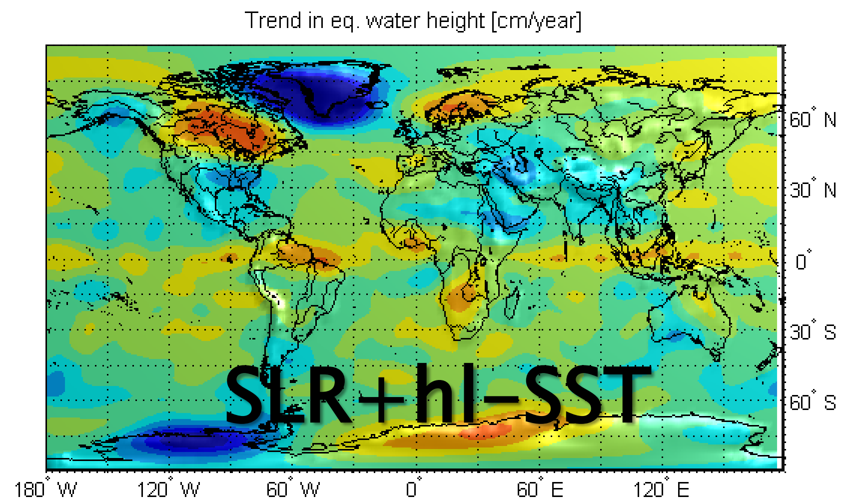
Long-wavelength gravity field recovery

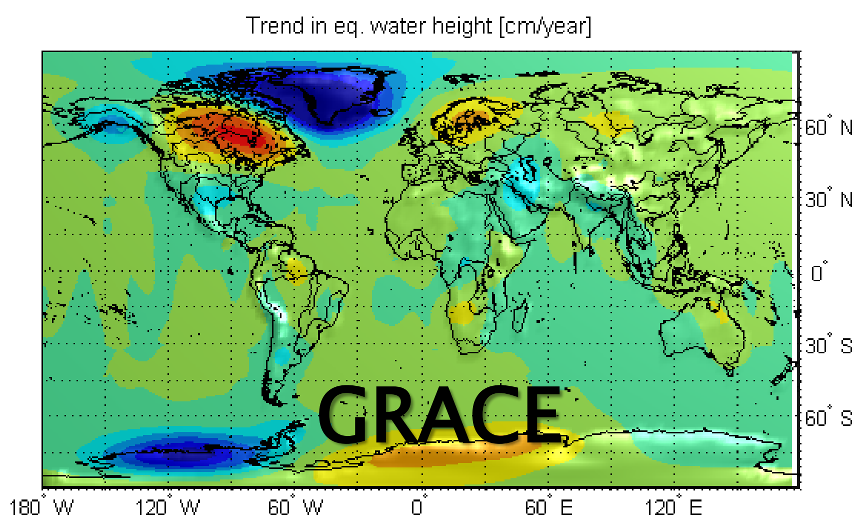


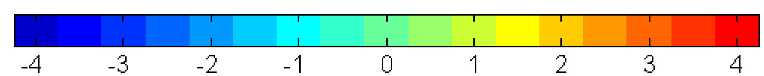
(Meyer et al., 2019)

Long-wavelength gravity field recovery





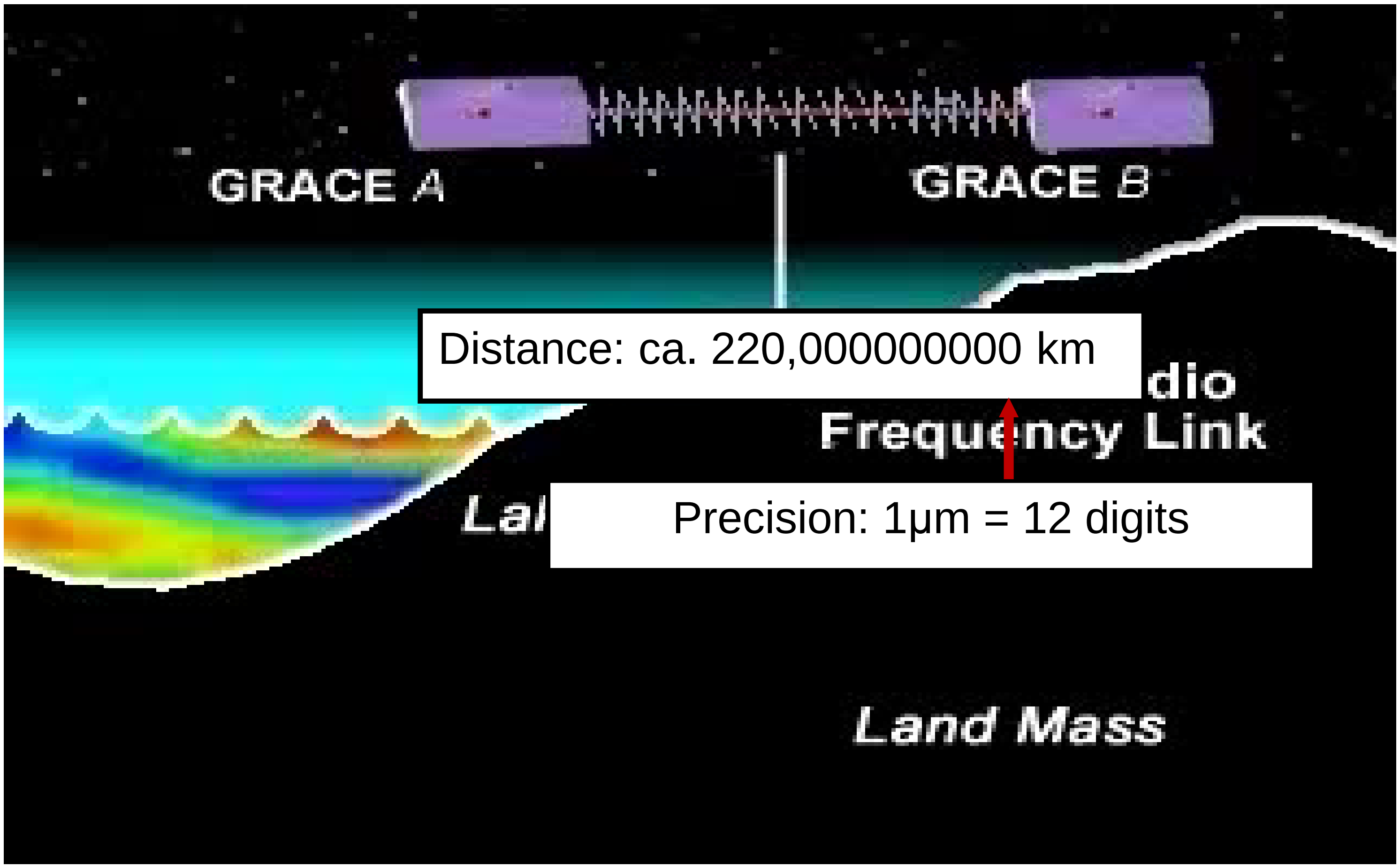




Combination of hl-SST solutions with SLR reduces the variations over oceans and some spurious signals. But only the long-wavelength part of the Earth's gravity field is accessible.

(Sośnica et al., 2014b)

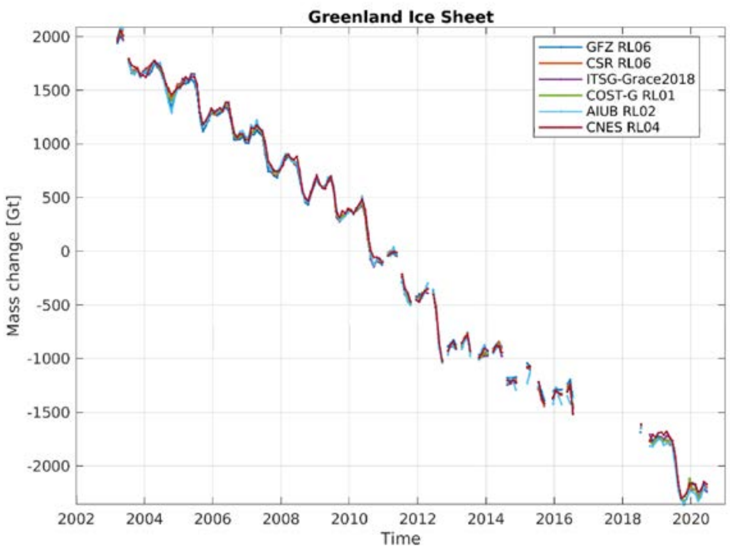
Time-variable gravity field recovery

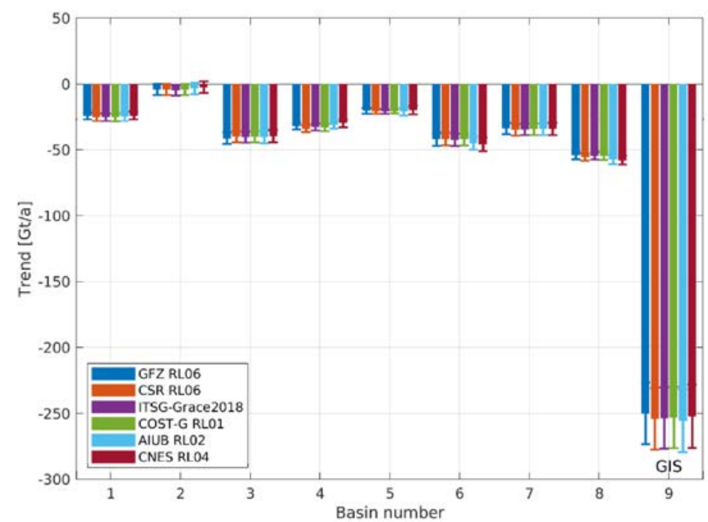


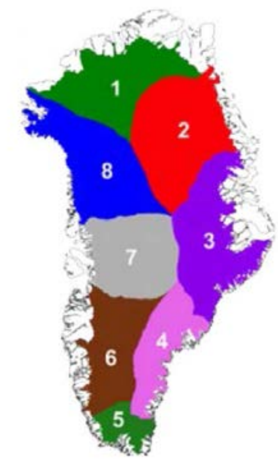
GRACE/GRACE-FO gravity field recovery is a very challenging generalized orbit determination problem due to the ultra precise inter-satellite ranging observables.

Time-variable gravity field recovery

- Monthly gravity fields from GRACE/GRACE-FO are derived at AIUB in the frame of a generalized orbit determination problem (Lasser et al., 2020).
- Monthly gravity fields from various GRACE/GRACE-FO analysis centers are combined at AIUB in the frame of COST-G (Combination Service of Time-variable gravity fields, Jäggi et al., 2020).







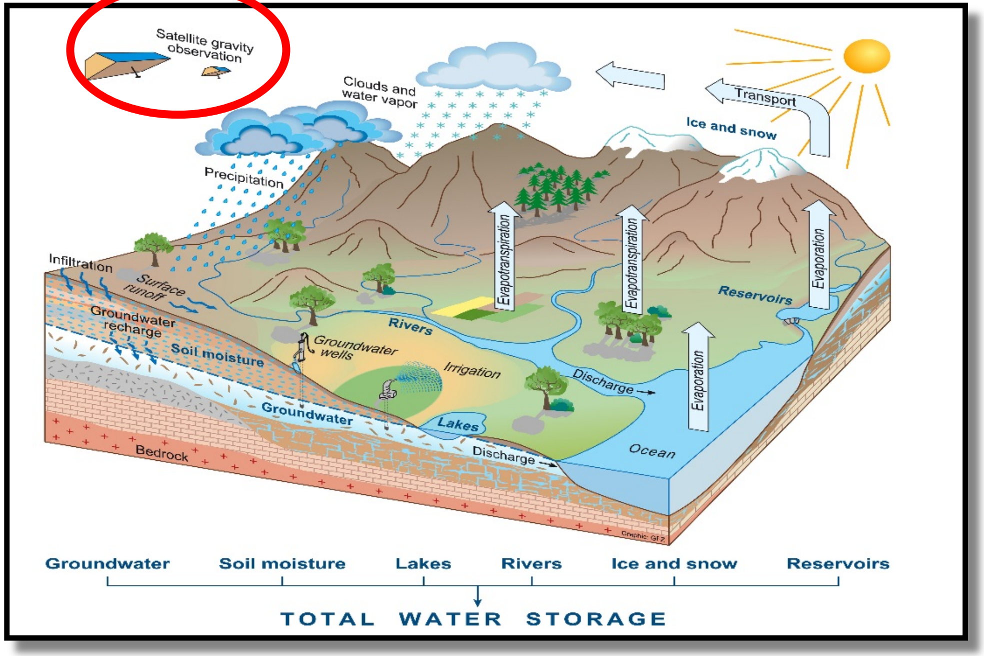
COST-G

(Meyer et al., 2020, Groh et al., 2020)

Outlook – H2020 Project G3P

HORIZON 2020

- Satellite gravimetry with GRACE (2002-2017) and GRACE-FO (2018 -) is the only technique to observe Terrestrial Water Storage (TWS) variations
- Resolving for groundwater storage variations follows a subtraction approach.
- A prototype for a global groundwater product shall be established for the Copernicus Climate Change Service in the frame of a H2020 project G3P.

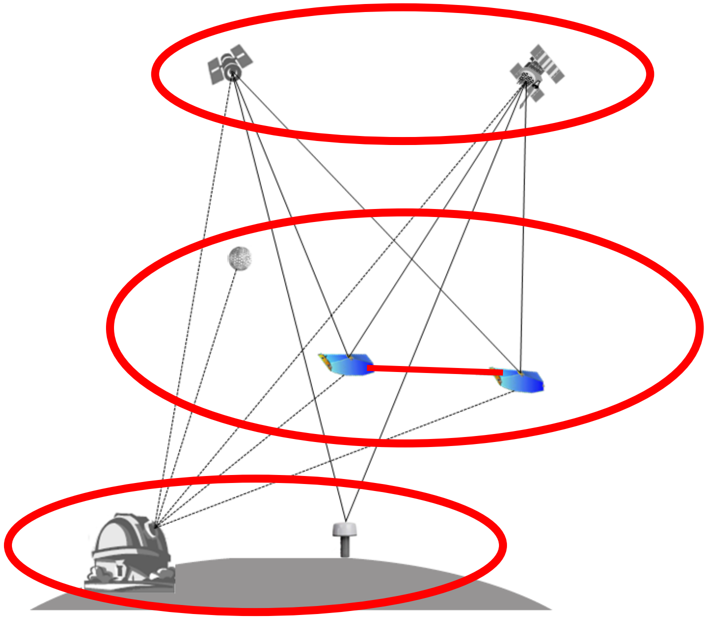


Groundwater = TWS – glaciers – snow – soil moisture – storage in surface water

(Güntner et al., 2020)

Outlook – ERC Project SPACE TIE

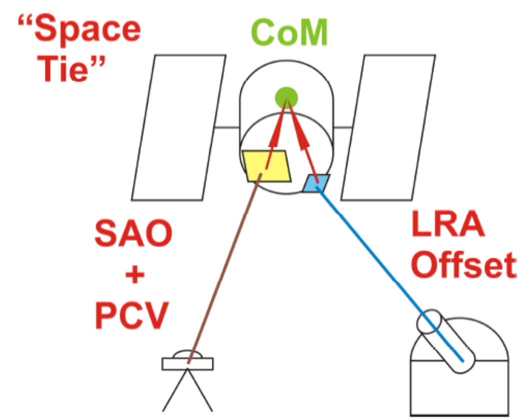
European Research Council
Established by the European Commission



Data Basis

- ~ 80 GNSS satellites
- ~ 20 LEO satellites (**gravity** and **altimetry**)
- GNSS and SLR ground networks

=> A rigorous joint adjustment should be envisaged



Main Idea (in a nutshell)

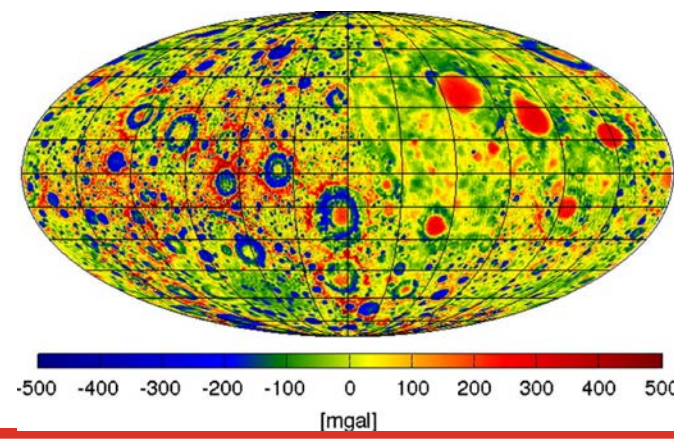
- Use of the Earth's gravity field to act as an additional global tie via satellite orbits
- Exploitation of space co-locations (space ties) on both **GNSS** and **LEO** satellites

=> SPACE TIE has started in 2019 and will run for 5 years

Orbit determination in planetary geodesy

- Based on the heritage of AIUB's GRACE processing, the step into planetary geodesy was initiated a few years ago at AIUB using GRAIL data.

- One-way and two-way Doppler data are processed together with the inter-satellite K-Band data to derive lunar gravity fields up to degree and order 350 in the frame of a generalized orbit determination.



(Arnold et al., 2015; Bertone et al., 2020)

Thanks a lot for your attention

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