UNITED NATIONS GLOBAL GEODETIC CENTRE OF EXCELLENCE

MODERNISING GEOSPATIAL REFERENCE SYSTEM CAPACITY DEVELOPMENT WORKSHOP

Introduction to Geospatial Reference Systems Infrastructure

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HOW

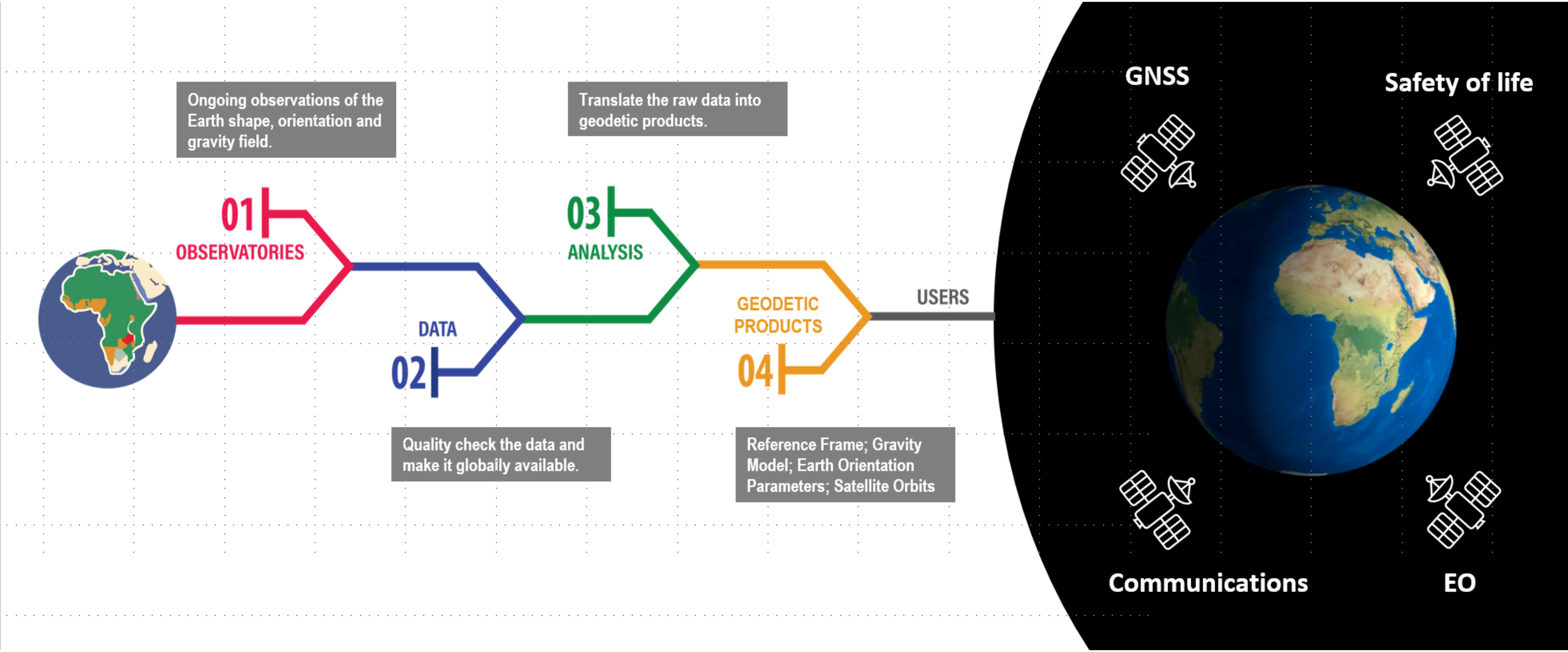
Day 1, Session 2 [1 2 3]

Acknowledgements: Zuheir Altamimi (FRA); Detlef Angerman (TUM); Johannes Bouman (GER); Jan Dostal (UN-GGCE); Richard Gross (NASA); Anna Riddell (AUS); Laura Sanchez (TUM); Jeffrey Verbeurgt (BEL).

Summary

- The Earth is dynamic. We must continuously monitor it because we need to know the 'place in space' of the Earth and satellites and at all times for accurate and reliable satellite services.
- Important geodetic ground infrastructure for reference frame creation includes Very Long Baseline Interferometry, Satellite Laser Ranging, Global Navigation Satellite Systems, DORIS and gravimetry. These techniques are complementary.
- Current geodetic ground infrastructure challenges include a northern hemisphere bias, aging technology and an overreliance on in-kind support.
- Stronger governance systems are needed both internationally and within Member States.

Global Geodesy Supply Chain

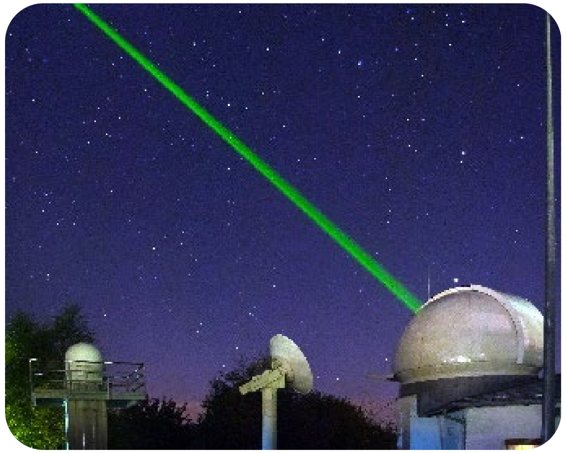


Space geodetic techniques

VLBI

Very Long Baseline Interferometry

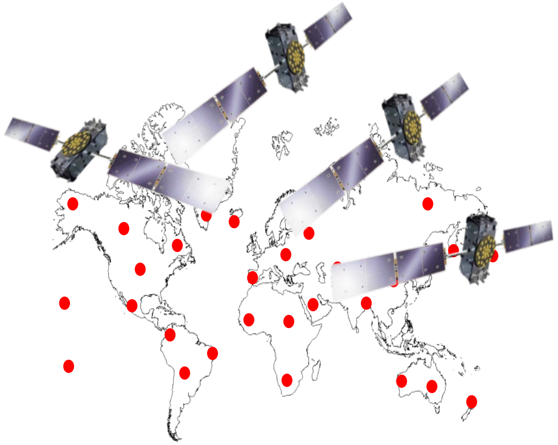
Earth rotation, station coordinates, quasar positions



SLR

Satellite Laser Ranging

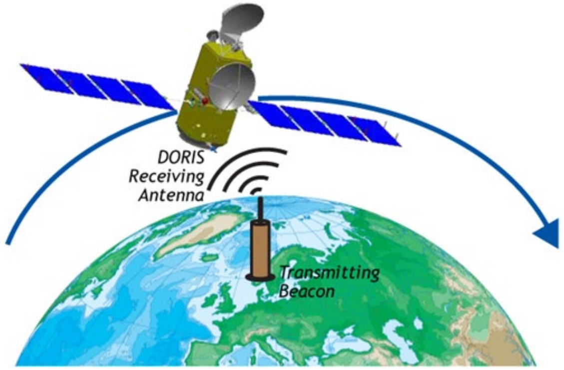
Satellite orbits, station coordinates, Earth rotation, centre of mass of the Earth



GNSS

Global Navigation Satellite Systems
(GPS, GLONASS,
Galileo, Beidou)

Station coordinates, Earth rotation, Geodynamics

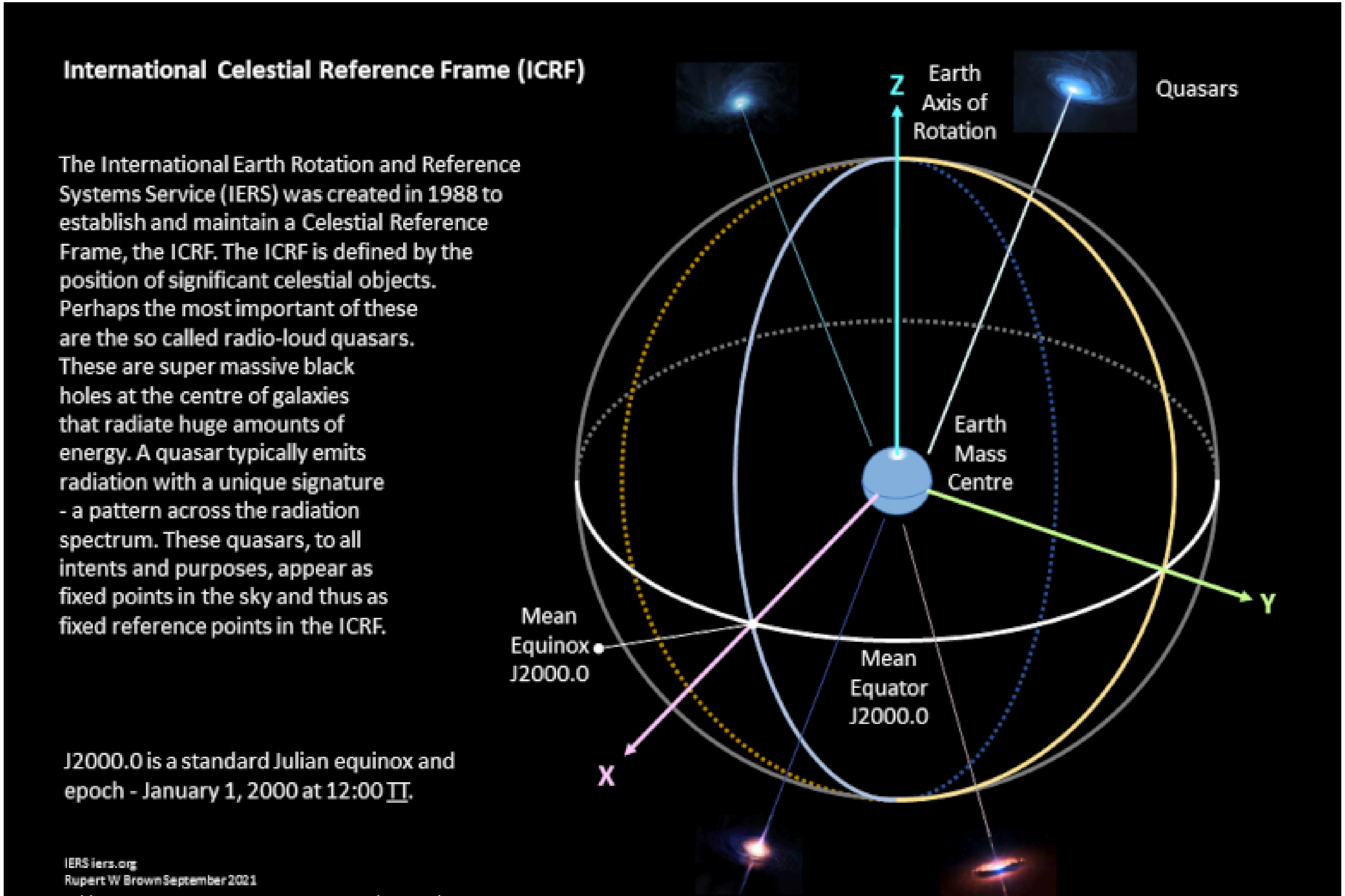


DORIS

Doppler Orbitography and Radiopositioning Integrated by Satellite

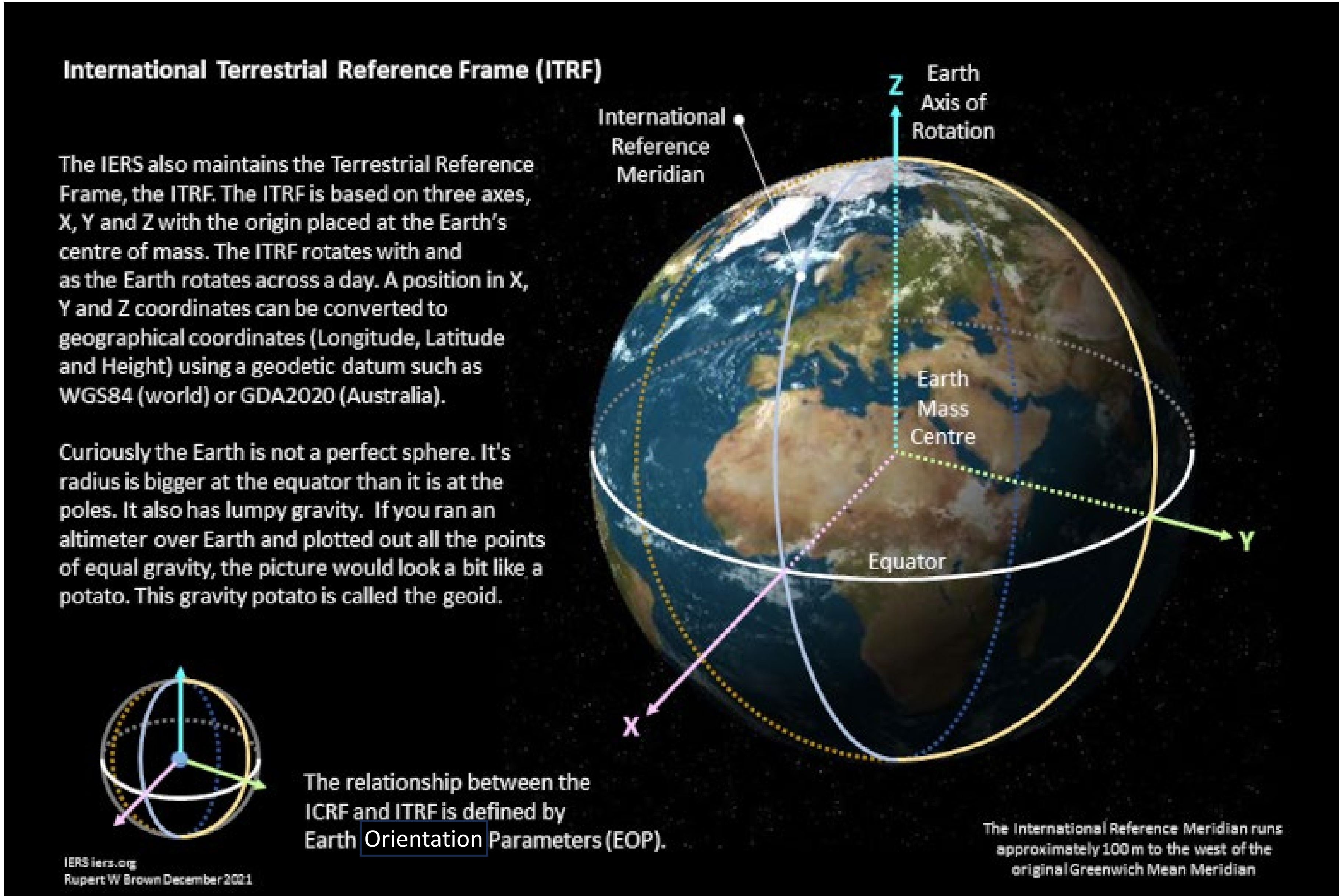
Satellite orbits, Station coordinates, Earth rotation, gravity field

International Celestial Reference Frame (ICRF)



https://geoscienceaustralia.github.io/ginan/theory.html

International Terrestrial Reference Frame (ITRF)



https://geoscienceaustralia.github.io/ginan/theory.html

Geodetic techniques

Gravimetry

Earth’s shape
Gravity field
Zero value for height
Mass Transport
Water cycle
Climate monitoring

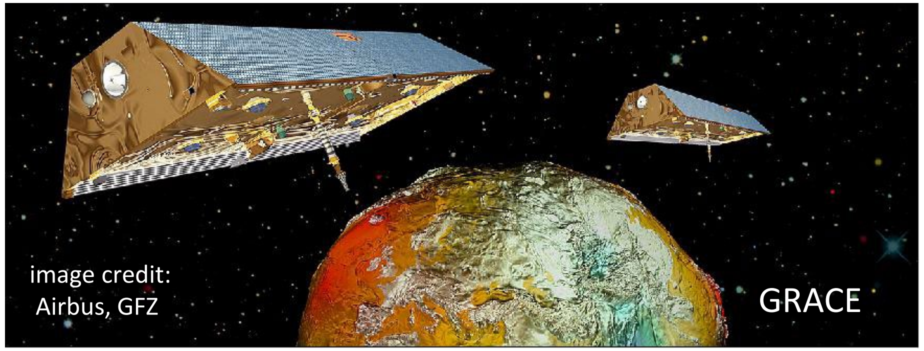
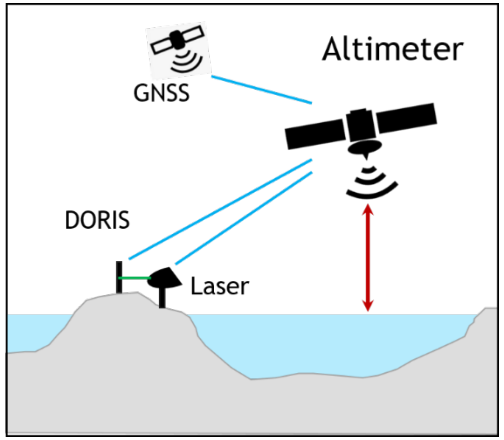
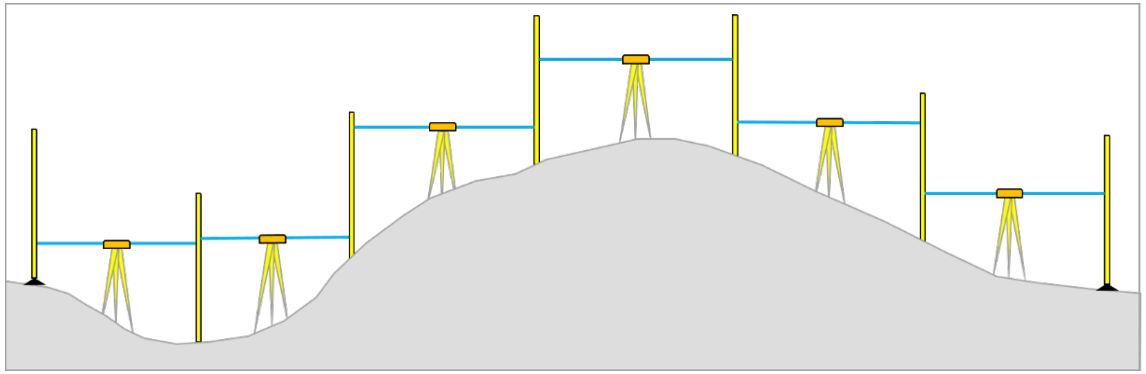


image credit:
Airbus, GFZ



Levelling, Altimetry, Tide Gauges

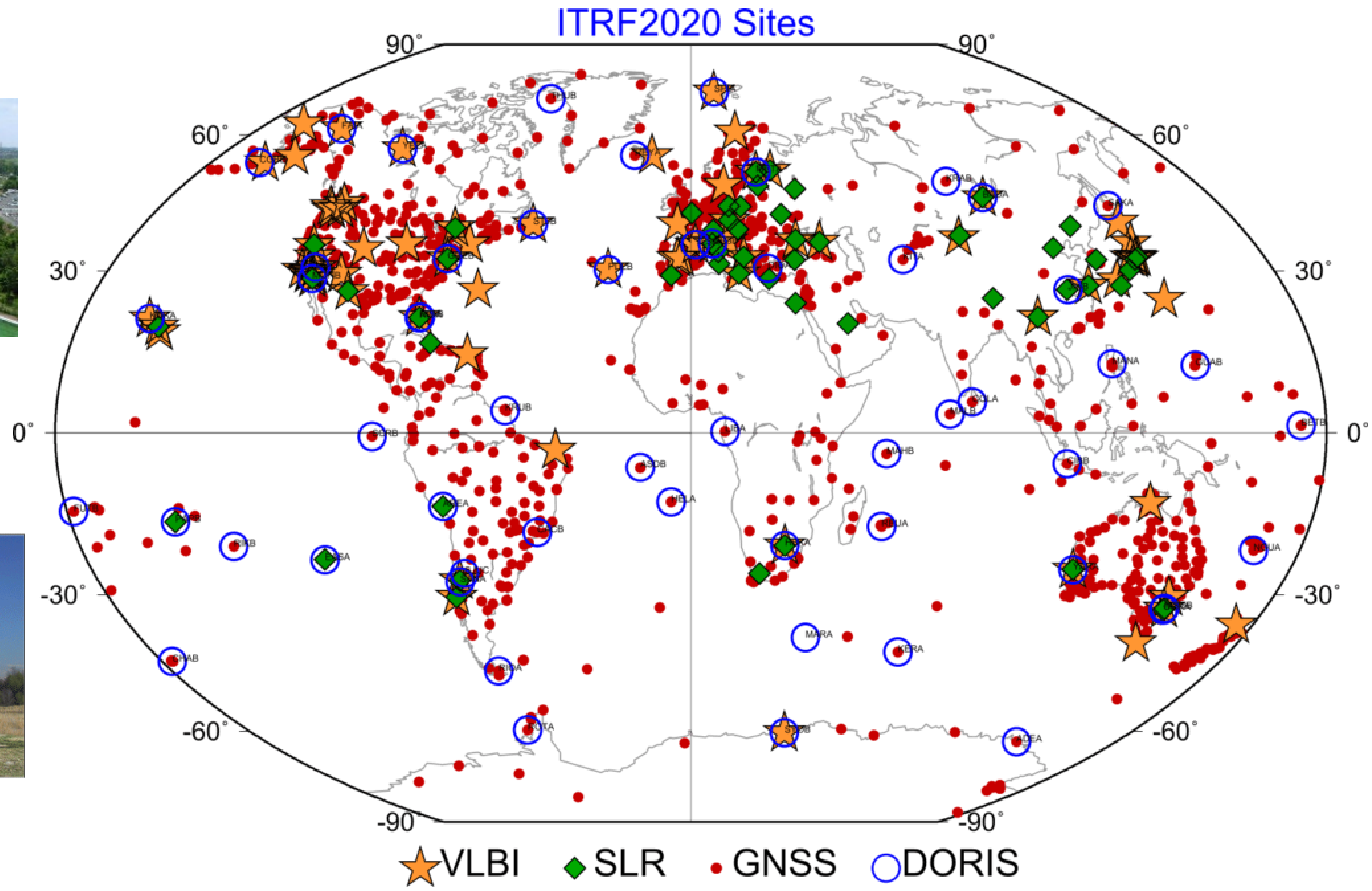
Vertical reference system
Height component
Sea level



ITRF Observation Techniques

VLBI

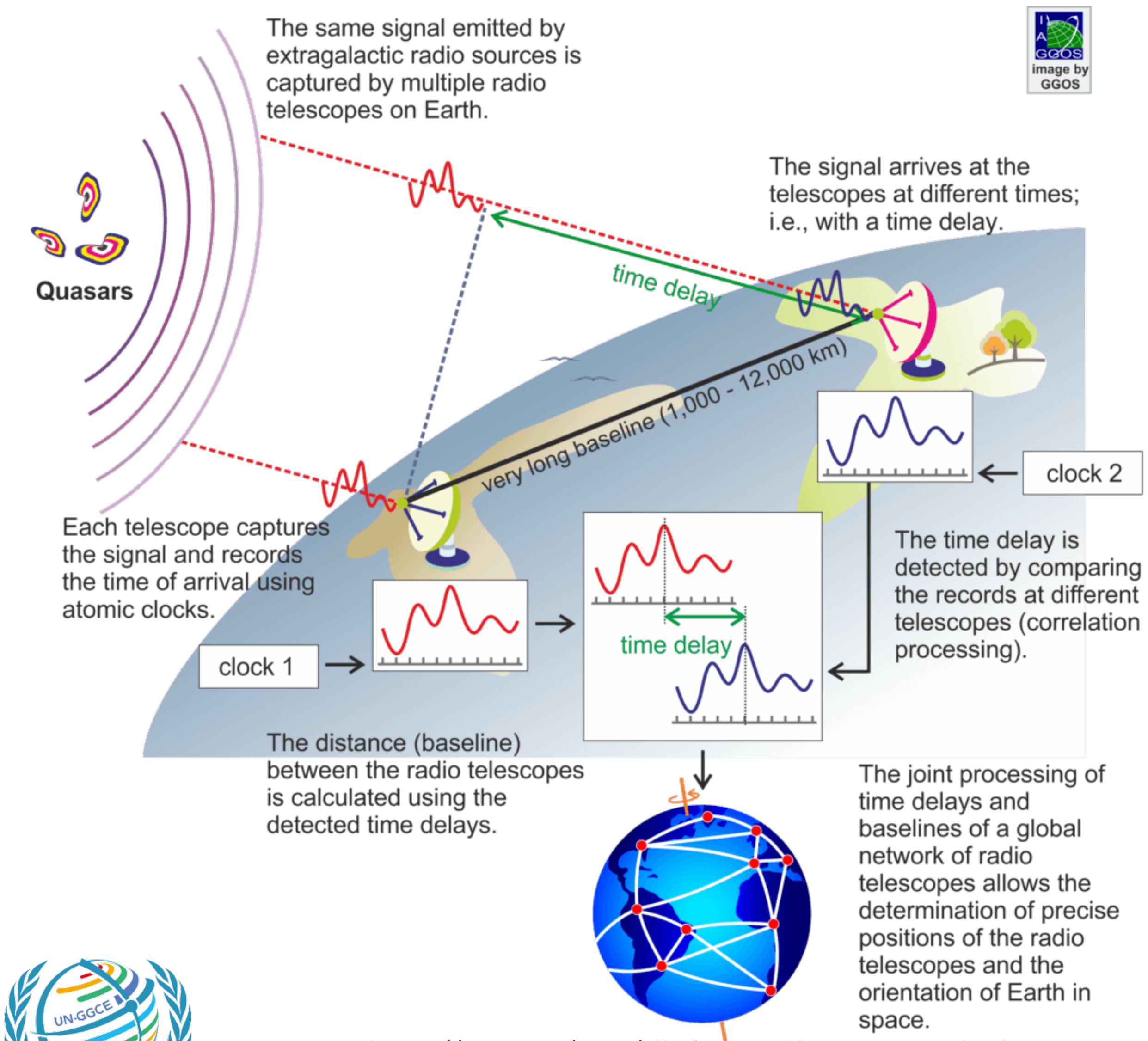
SLR



GNSS

DORIS

Very Long Baseline Interferometry (VLBI)



https://ggos.org/item/vlbi (created by Laura Sanchez)

Recording of electromagnetic radiation from very distant objects in space (quasars) in the microwave frequency range

Interferometric method: At least two telescopes required, highest time requirements (atomic clocks required)

Determination of the exact travel time difference by correlating the recorded data after measurement at a correlator

Calculation of the baselines between the VLBI stations

Based on the times recorded at different locations, it is possible to determine the **orientation** of the Earth, **spin-rate** of the Earth and the **distance between the antennas** (which can be 1000s of km apart) with millimeter precision.

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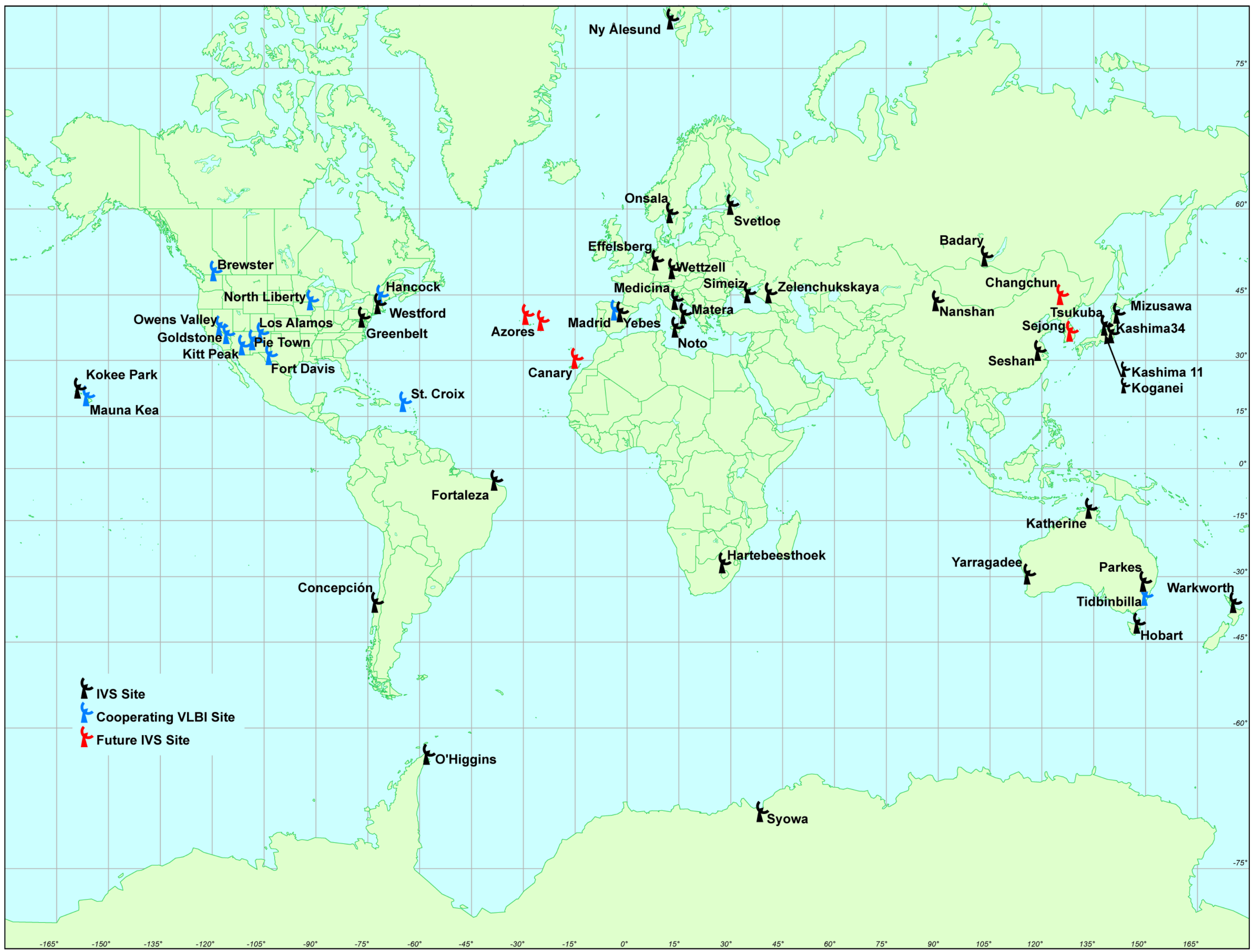
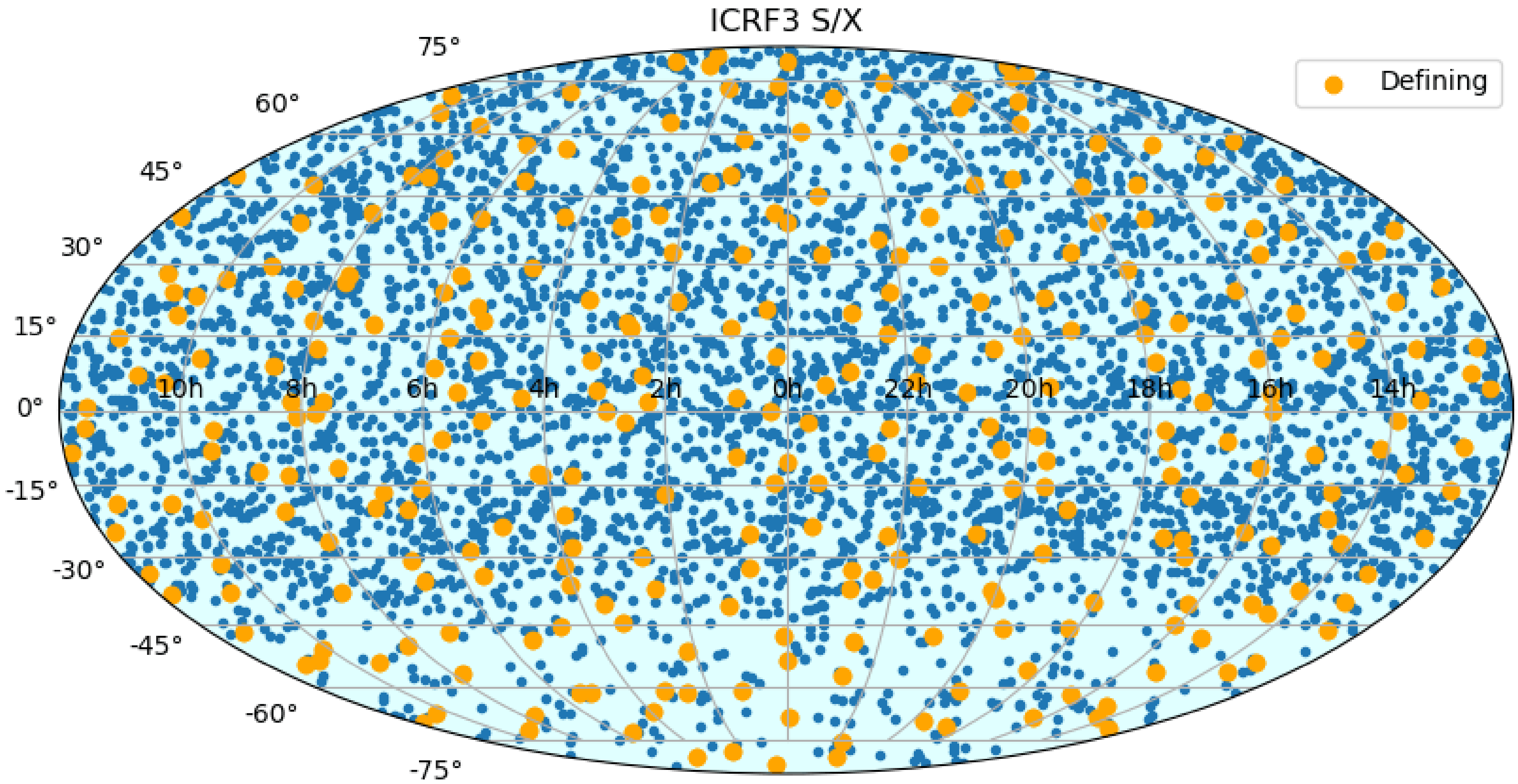
International VLBI Service for Geodesy and Astrometry



(source: ivscc.gsfc.nasa.gov)

Very Long Baseline Interferometry (VLBI)



https://ggos.org/item/celestial-reference-frame/

(Charlot P. et al, (2020) The third realization of the International Celestial Reference Frame by very long baseline interferometry. Astronomy and Astrophysics, Vol. 644, A159, 28 p., DOI: https://doi.org/10.1051/0004-6361/202038368)

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Radio telescopes operated by BKG

20 m RTW (Wettzell)

13 m TWIN-Teleskope (Wettzell)

6 m Radioteleskop AGGO
(La Plata)

9 m Radioteleskop O'Higgins

Image Credits: BKG

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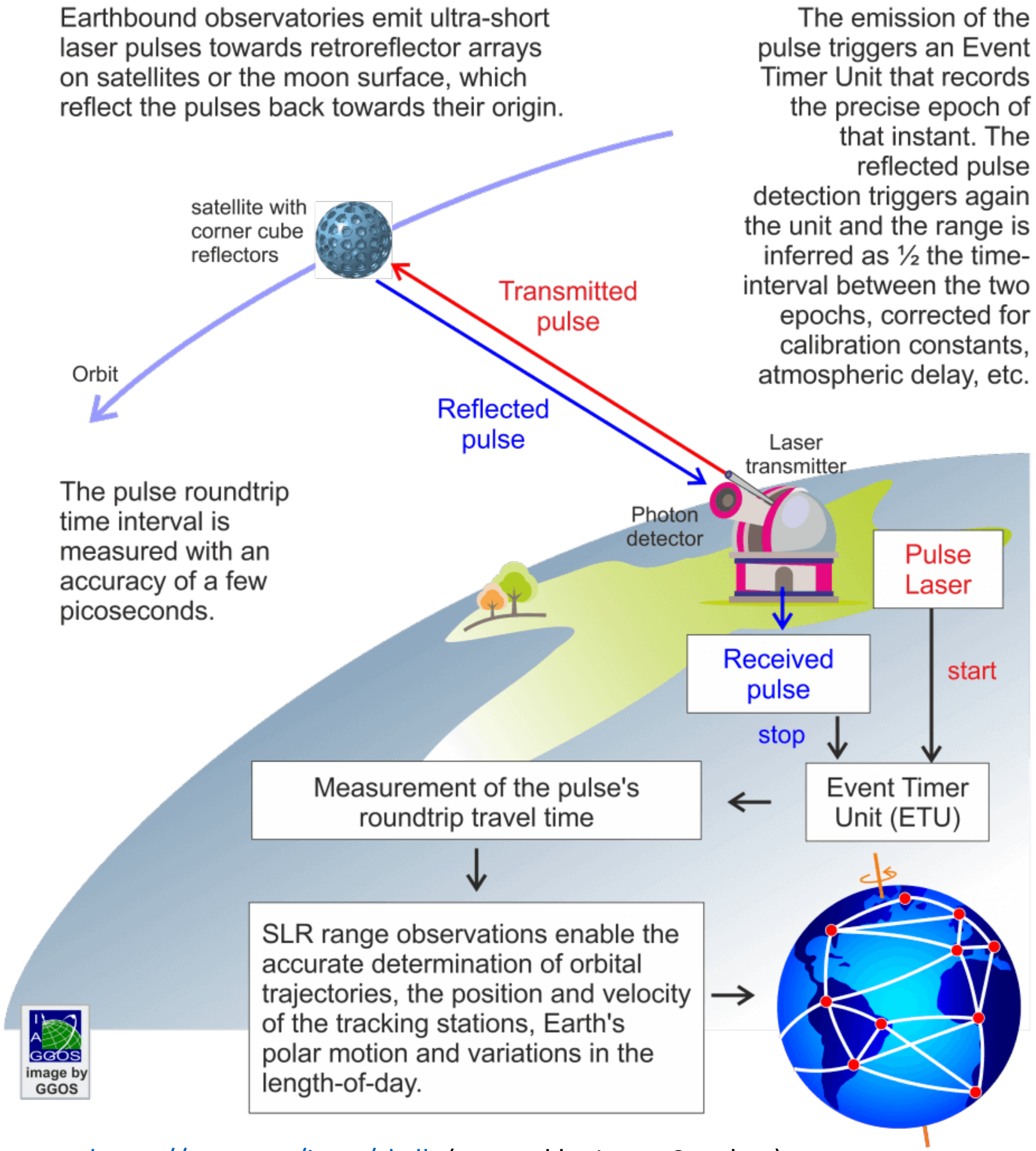
Satellite Laser Ranging (SLR/LLR)



https://ggos.org/item/slr-llr (created by Laura Sanchez)

Satellite Laser Ranging operators fire lasers from ground observatories at satellites and measure the time it takes for the laser light to return.

Based on the time delay, geodesists can monitor the orbits of satellites with centimeter accuracy.

For some satellite applications, it is important to know precisely where a satellite was when it transmitted a signal to ensure accuracy and reliability (e.g. GNSS).

Satellite Laser Ranging is also used to define the diameter of the Earth, strength of the gravity field, centre of the mass of the Earth (the point satellites orbit around), and the centre of the global coordinate reference frame.

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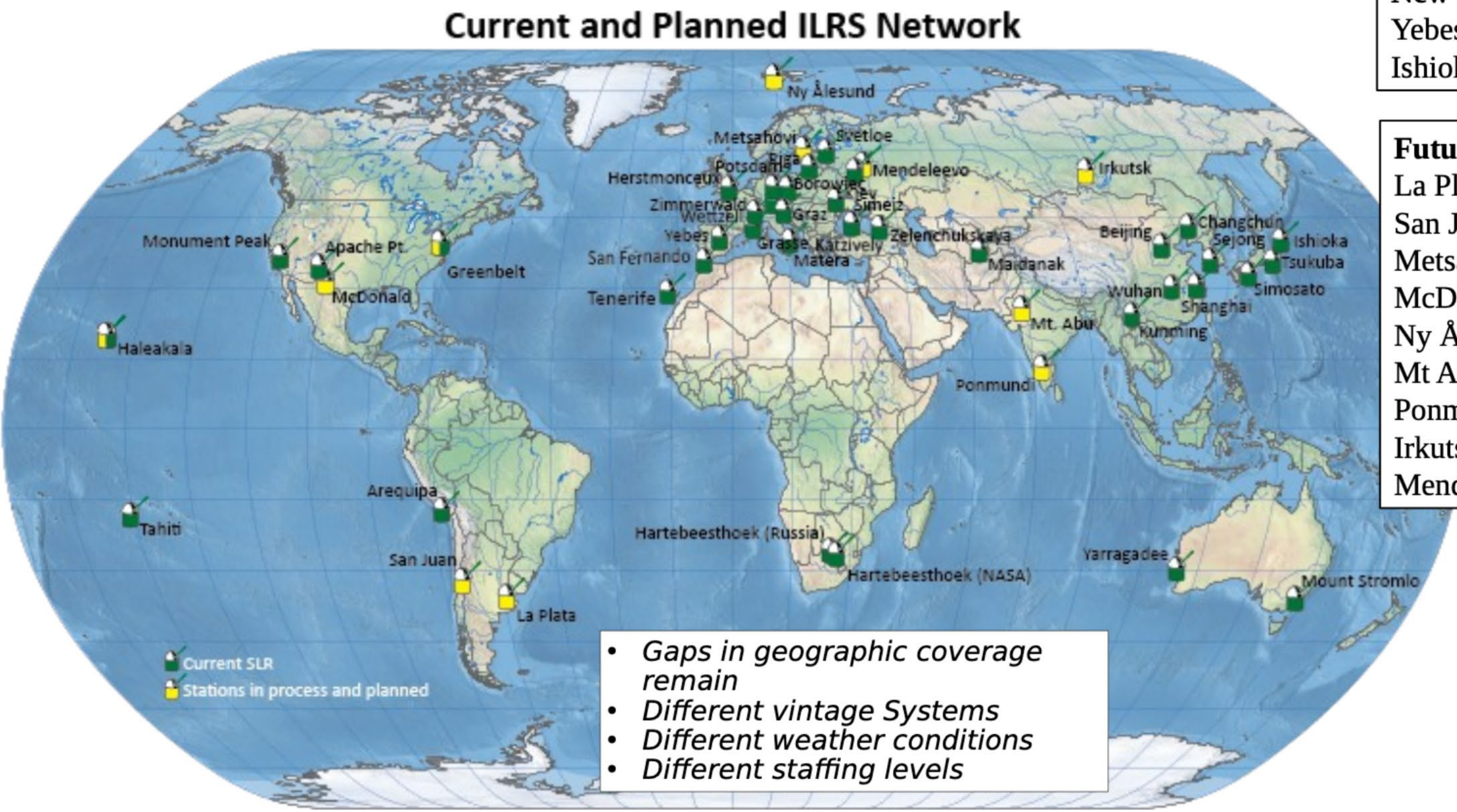
International Laser Ranging Service



- *Gaps in geographic coverage remain*
- *Different vintage Systems*
- *Different weather conditions*
- *Different staffing levels*

New Stations (2023-2024)
Yebes, Spain
Ishioka, Japan

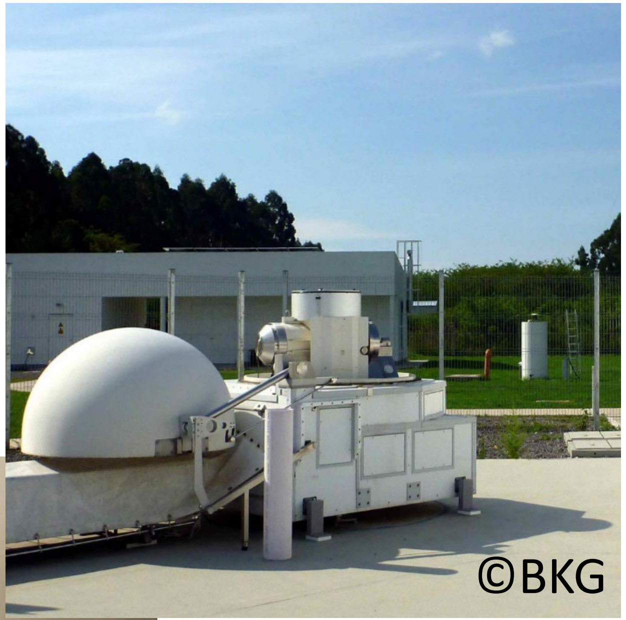
Future Stations (2024-2027)
La Plata, Argentina
San Juan, Argentina
Metsähovi, Finland
McDonald, TX, USA
Ny Ålesund, Norway
Mt Abu, India
Ponmundi, India
Irkutsk (Tochka), Russia
Mendeleevo (Tochka), Russia

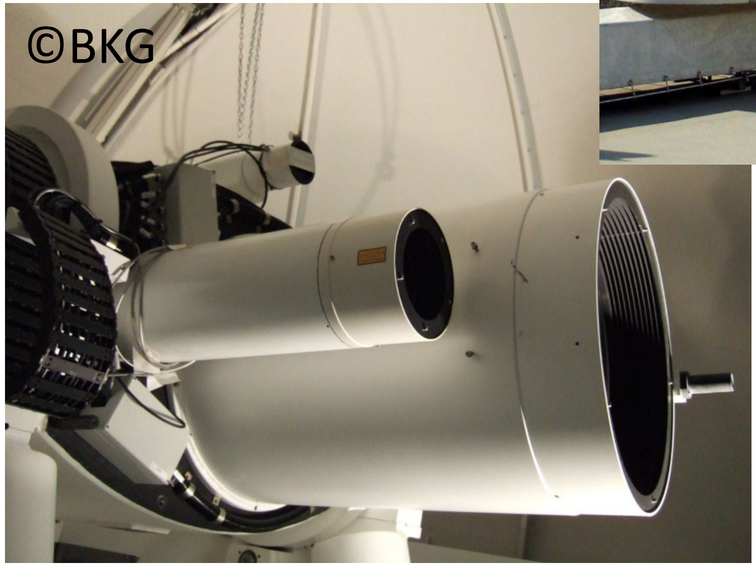
source: ilrs.gsfc.nasa.gov

Laser Ranging Systems of BKG

WLRS (Wettzell), 75 cm Teleskop, monostatisch

AGGO-SLR (La Plata),
50 cm Teleskop, monostatisch





SOSW (Wettzell)
50 cm Empfangsteleskop
16 cm Sendeteleskop

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Global Navigation Satellite Systems

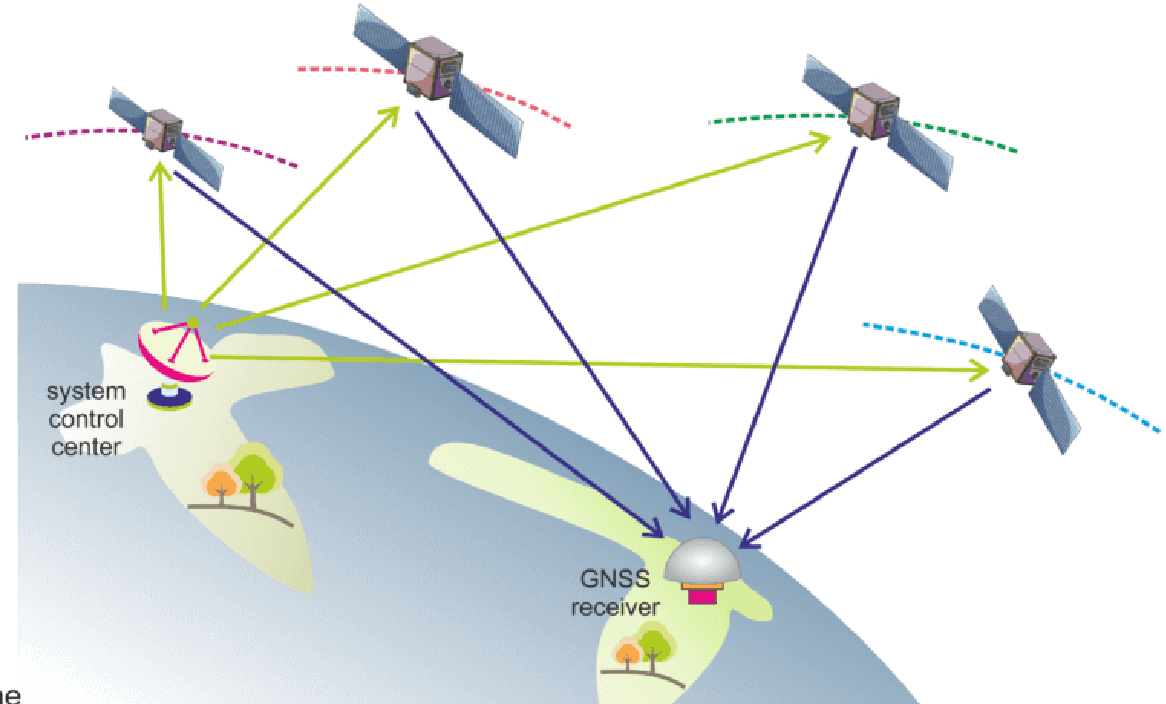
(1) The system operator calculates satellite orbits and clock synchronization using ground stations with known coordinates.

(2) The operator loads the calculated orbits and satellite clock corrections to the satellites.

(3) Orbits and clock corrections are broadcast together with a very stable time stamp from an atomic clock, so that a receiver can continuously determine the time when the signal was broadcast.

(4) The difference between the time of arrival and the time of transmission gives the travel-time of the signal, which, multiplied by the speed of light, provides the distance (or range) satellite - receiver.

(5) With information about the ranges to four satellites and the location of the satellite when the signal was sent, the receiver can compute its own three-dimensional position.



The broadcast information has an accuracy of about one metre and is usually employed for navigation applications. For the precise observation of the Earth, geodesists calculate orbits and clock corrections with a very much higher accuracy (in the centimetre and picosecond ranges). This requires the simultaneous determination of station positions, satellite orbits and Earth orientation parameters in a single consistent calculation. →

image by GGOS

https://ggos.org/item/gnss/ (created by Laura Sanchez)

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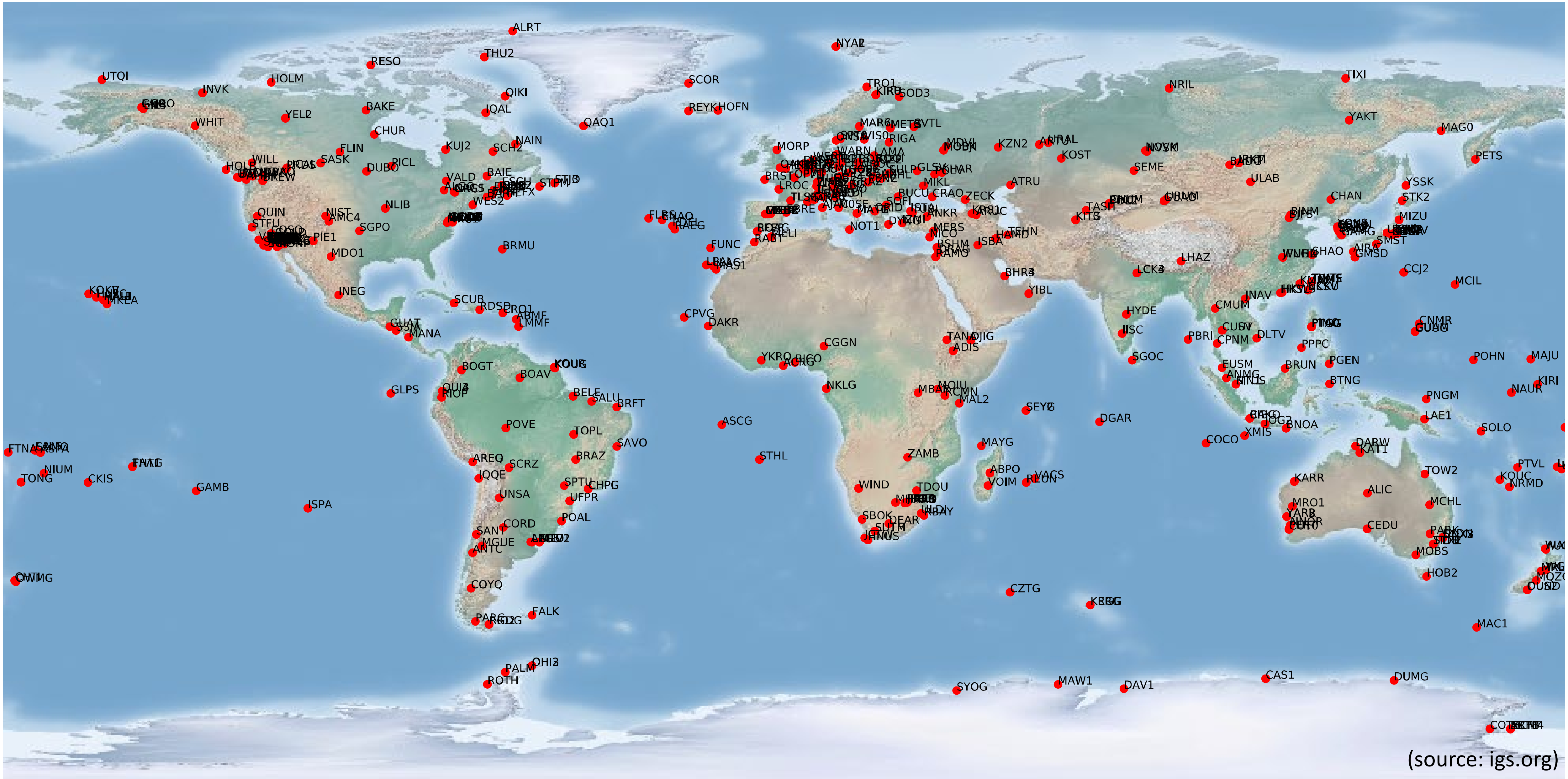
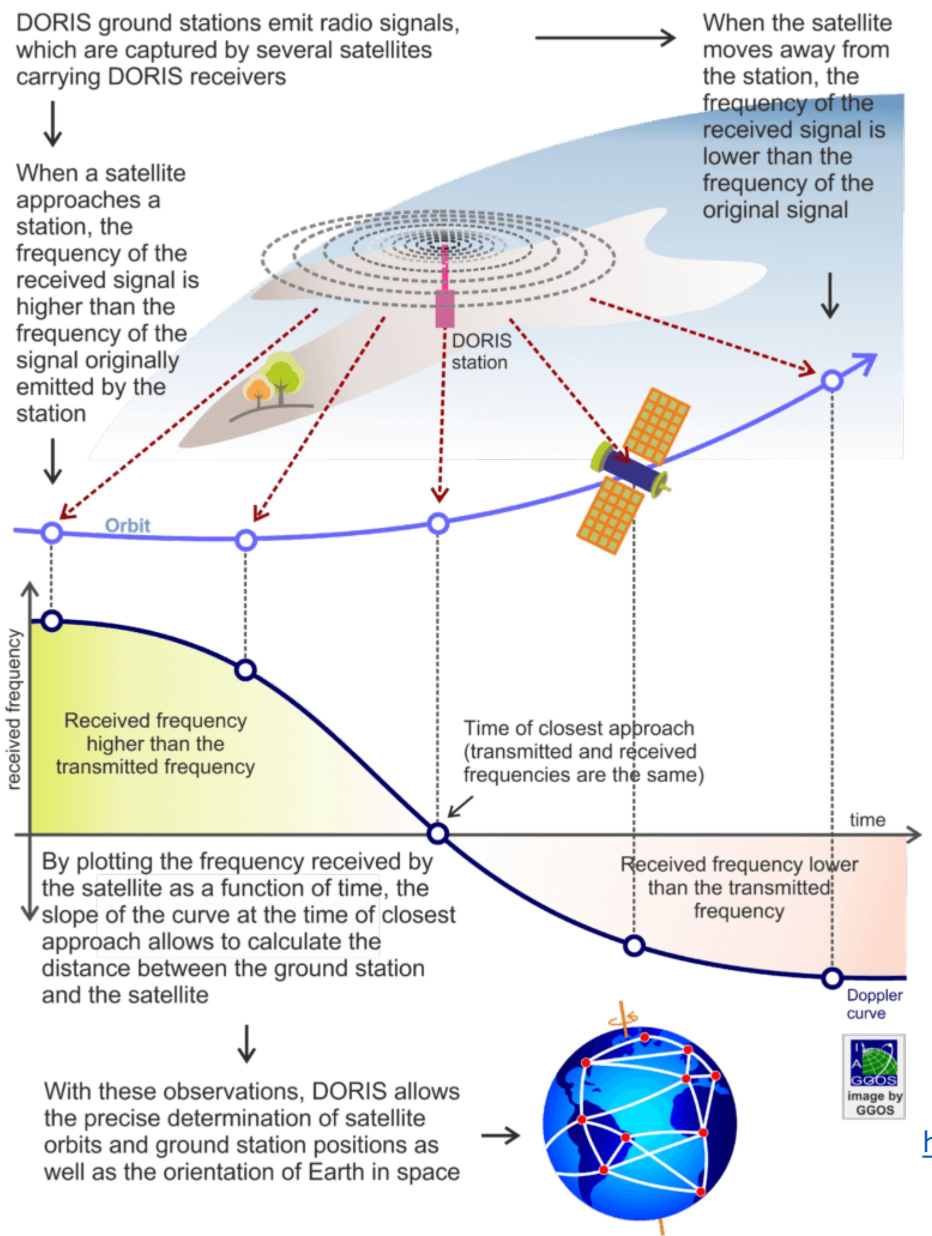
International GNSS Service



(source: igs.org)

Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)



- Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) is a French satellite system used to help determine and monitor satellite orbits and for positioning.
- The principle of DORIS is similar to GNSS but in reverse.
- Active ground-based radio beacons send out a signal which is detected by receiving satellites.
- A frequency shift of the signal occurs, which is caused by the movement of the satellite (Doppler effect).
- Broadcast on 2 frequencies (400 and 2036 MHz) allows determination of signal propagation delays through atmosphere

- Orbit determination of Earth observation satellites
- Coordination determination of beacon on the Earth's surface
- Co-location with other space methods and contribution to GGRF

https://ggos.org/item/doris (created by Laura Sanchez)

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International DORIS Service

(source: ids-doris.org)

Gravimetry

Credit: Micro G Lacoste

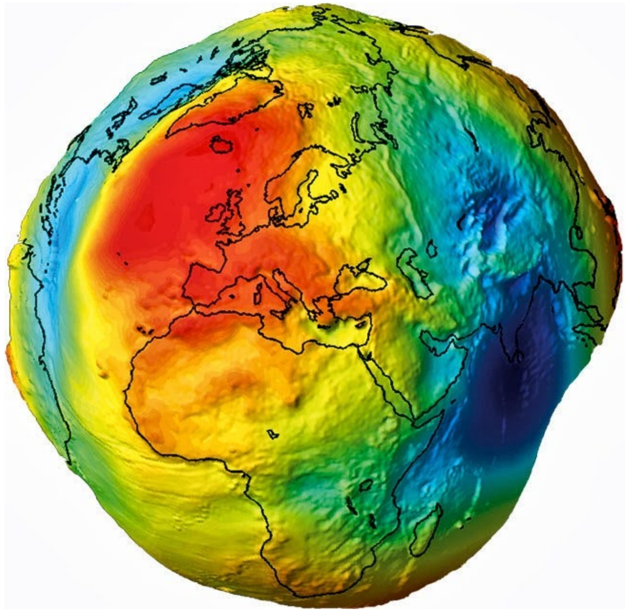
Free Fall Gravimeter

Principle

- Gravimetry instruments observe the gravitational acceleration
- Two different kind of gravimeters:
    - Absolute, e.g. free fall gravimeter
    - Relative, e.g. spring or superconducting gravimeter,
- Types of measurements:
    - Terrestrial
    - Airborne
    - Satellite

Purpose

- Determination of physical shape of the Earth defined by gravitation equipotential surface
- Determination of the Centre of Mass of the Earth
- Monitoring of geophysical dynamics



Geoid, the physical shape of the Earth

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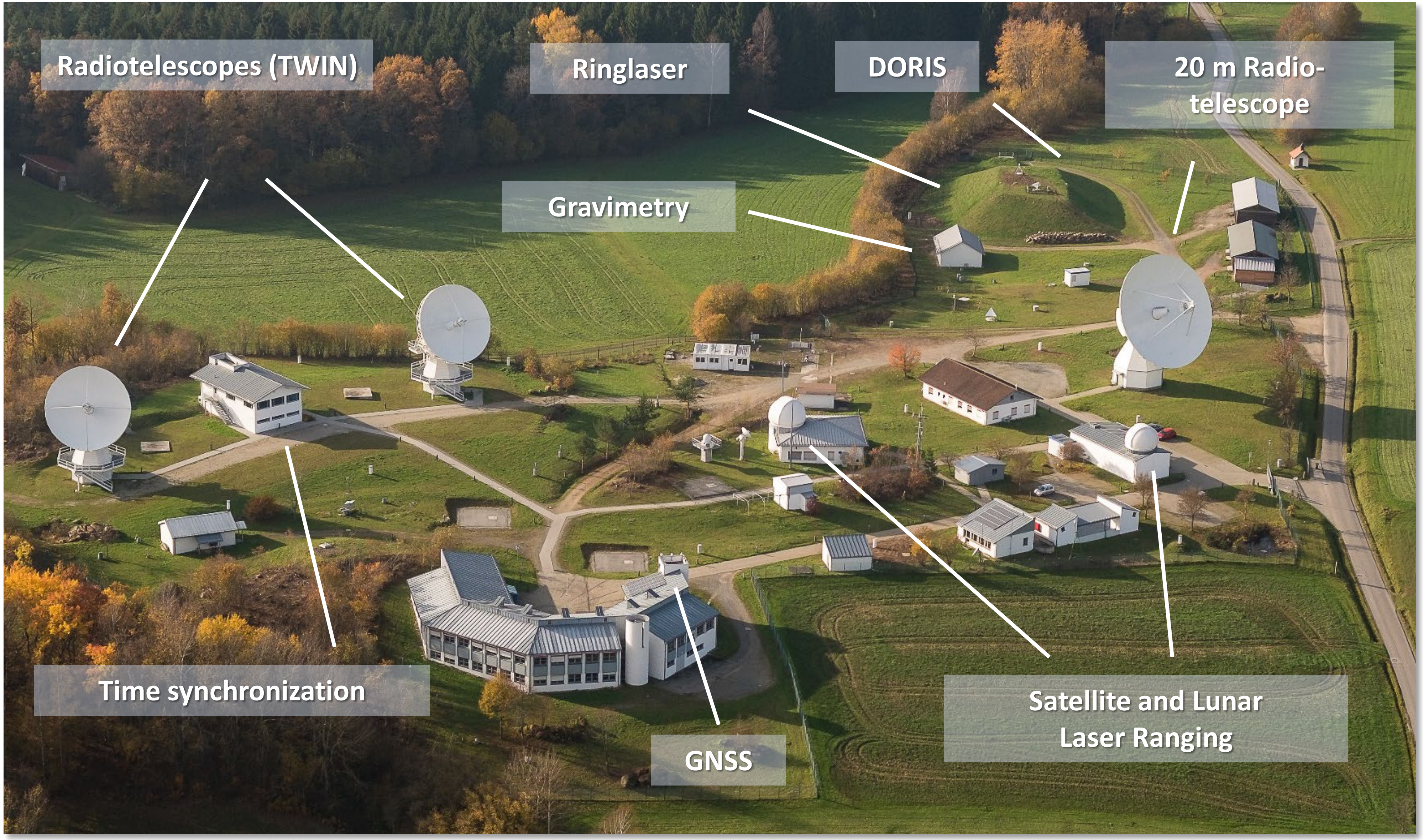
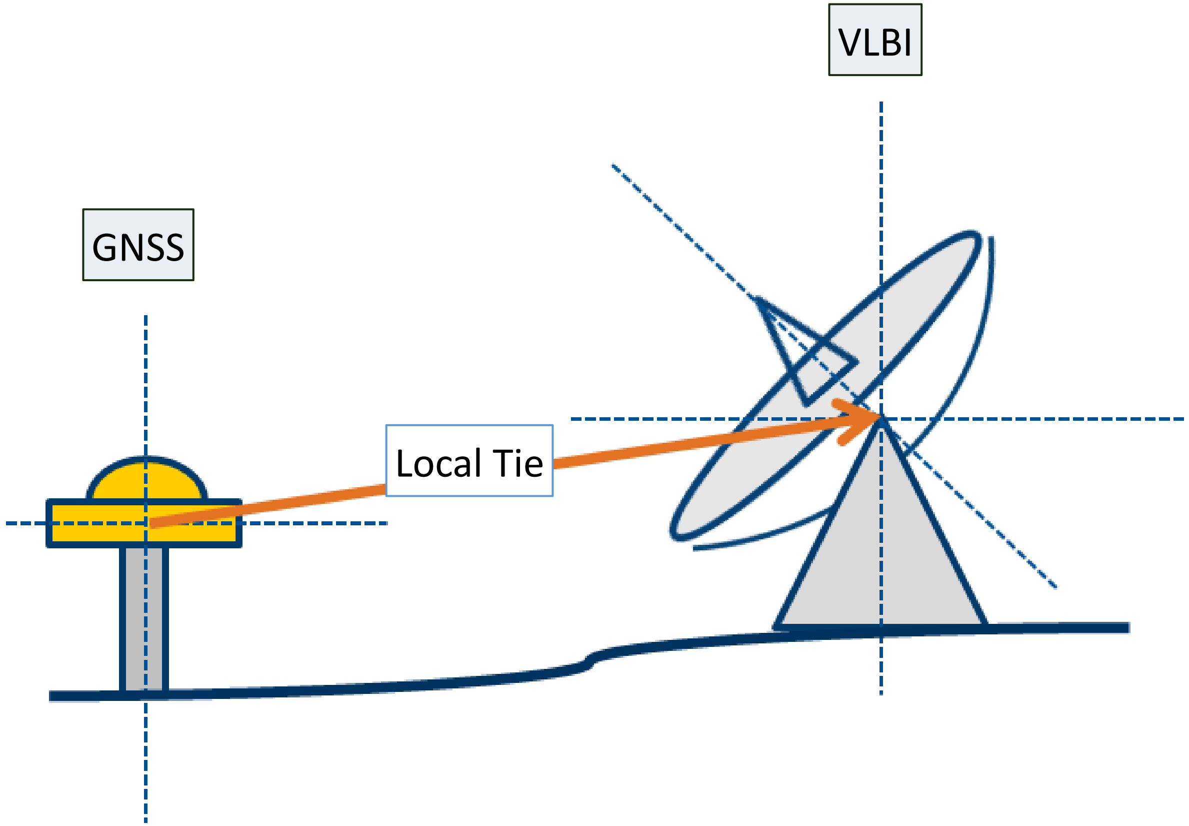
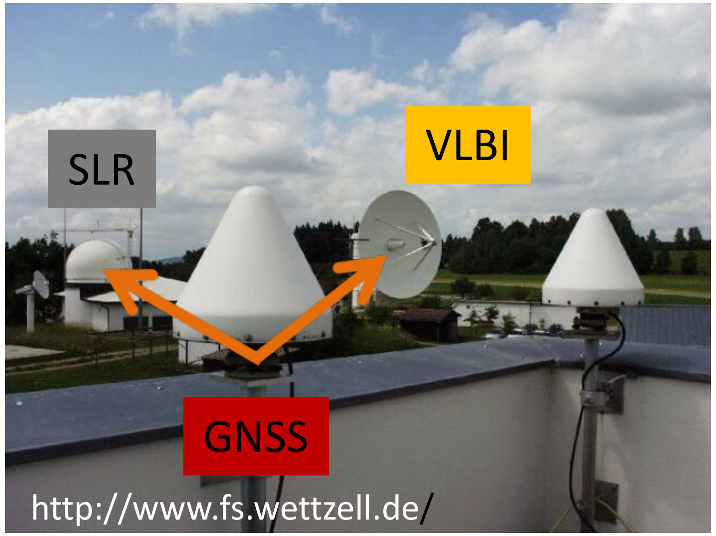
Geodetic Observatory Wettzell, Germany



Integration of space techniques



Geodetic Observatory Wettzell



Co-location sites and local ties play a fundamental role for the integration of different space geodetic observation techniques

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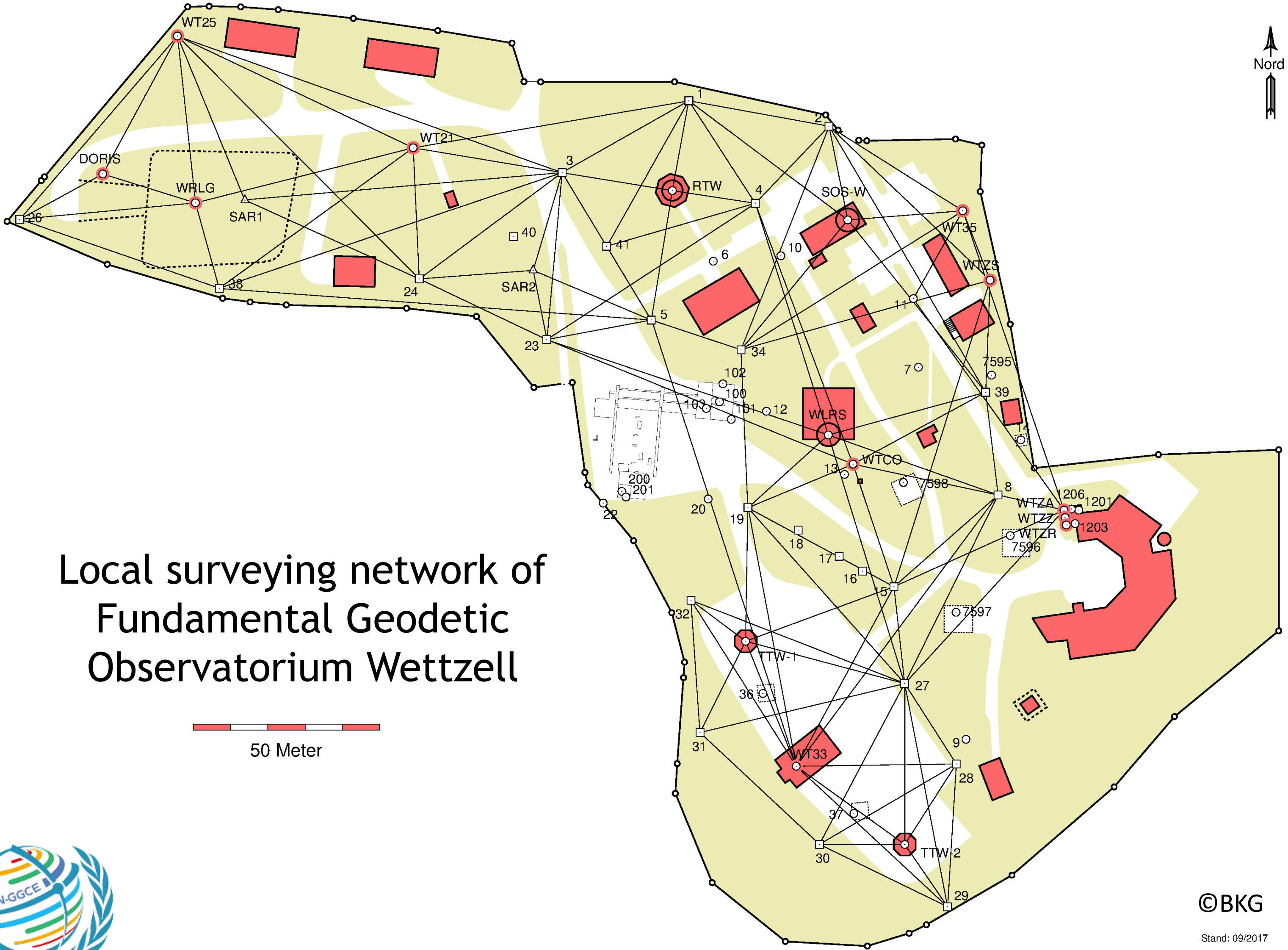
Local tie survey network



- Precise link between the individual observing components
- Provides tie vectors between the space techniques
- Allows data combination from the geodetic techniques
- Proof of local stability of the reference points

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Time and Frequency

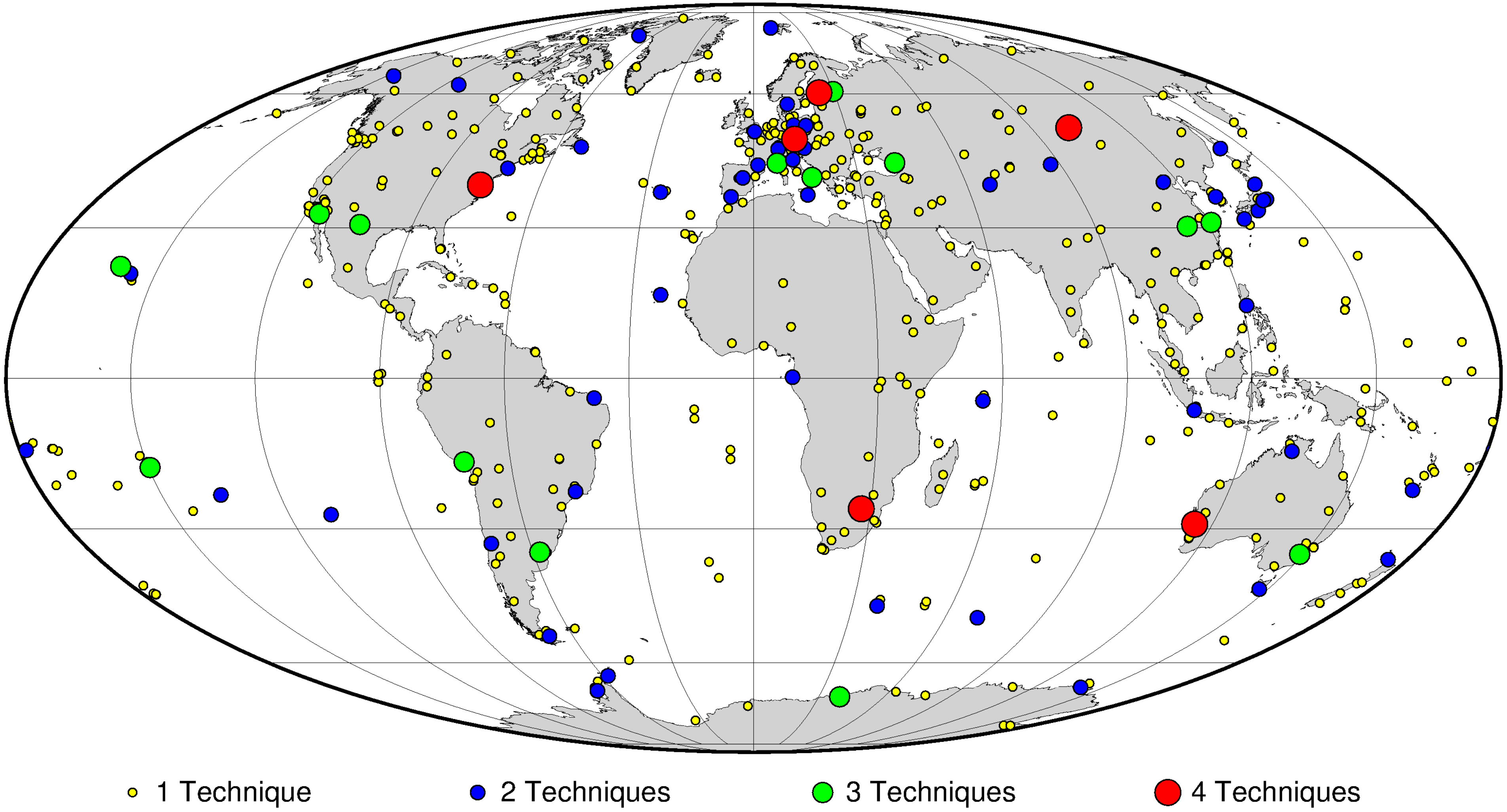
Cesium clocks

Hydrogen maser
max. Stability
$<10^{-15}$ sec.

- Geodetic observations depend on precise frequency and time keeping
- Instruments have to be connected to precise frequency and time keeping
- Atomic clocks at geodetic observations
    - Accuracy up to picosecond (ps) level
    - Time synchronisation between different geodetic techniques
    - Contribution to UTC
    - Contribution to timekeeping comparison
- GNSS systems
    - work with own timekeeping
    - Time transmission and synchronisation across different observation sites in the world
    - UTC time transfer and synchronisation

Collocation of the techniques

ITRF: International Terrestrial Reference Frame

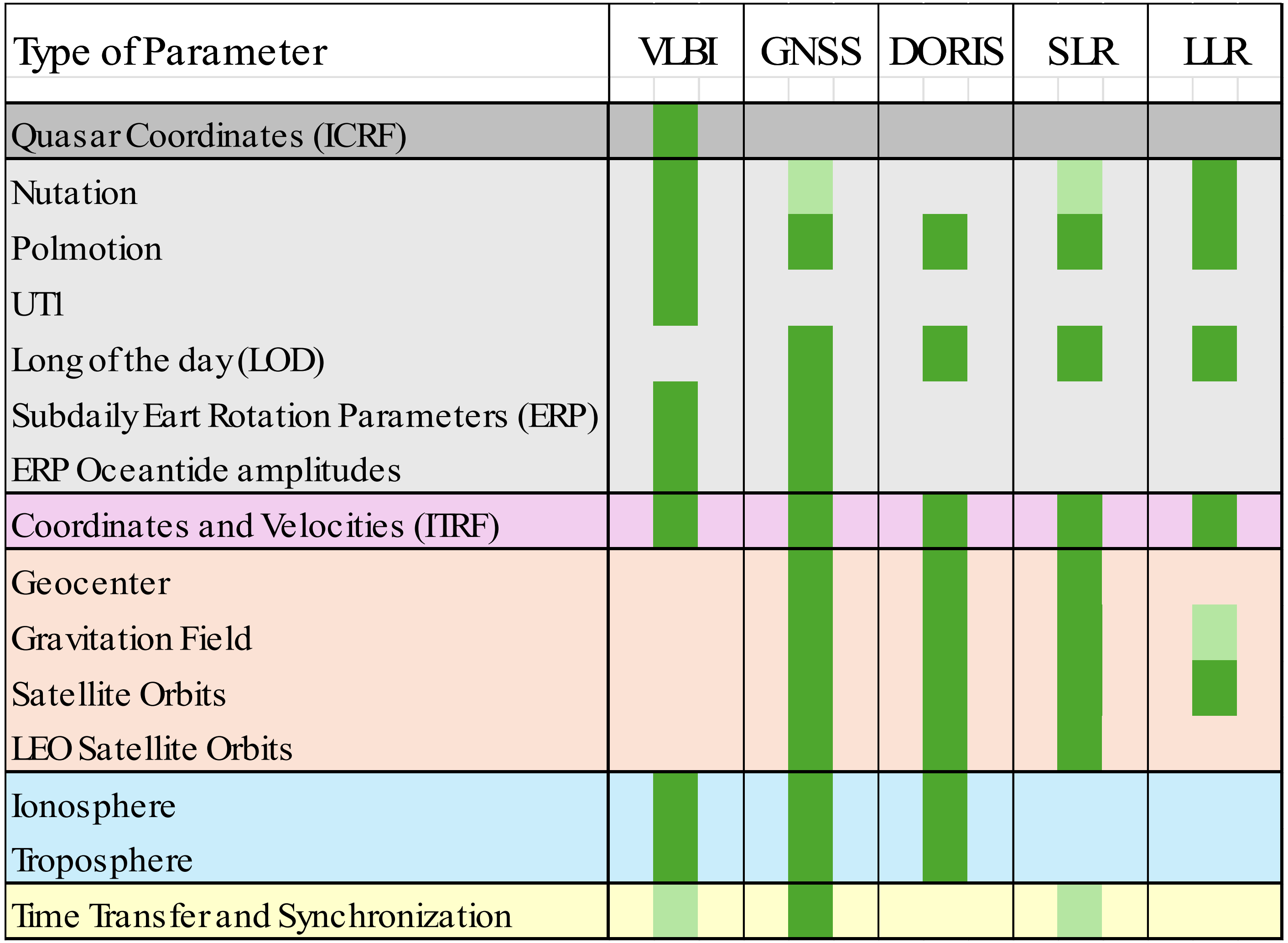


- Only one continent has at least three sites where VLBI and SLR are collocated.
- The global geodesy supply chain is not robust.

Contributions from space techniques

- Different techniques allows independent measurements.

- Each technique is unique and have different contributions to geodetic products.



Resources

- Further reading on ITRF and ICRF - https://geoscienceaustralia.github.io/ginan/theory.html
- Geodetic techniques and Services of the International Association of Geodesy - https://ggos.org/services/