



UNITED NATIONS GLOBAL GEODETIC CENTRE OF EXCELLENCE

MODERNISING GEOSPATIAL REFERENCE SYSTEM CAPACITY DEVELOPMENT WORKSHOP

Introduction to Geospatial Reference Systems Infrastructure

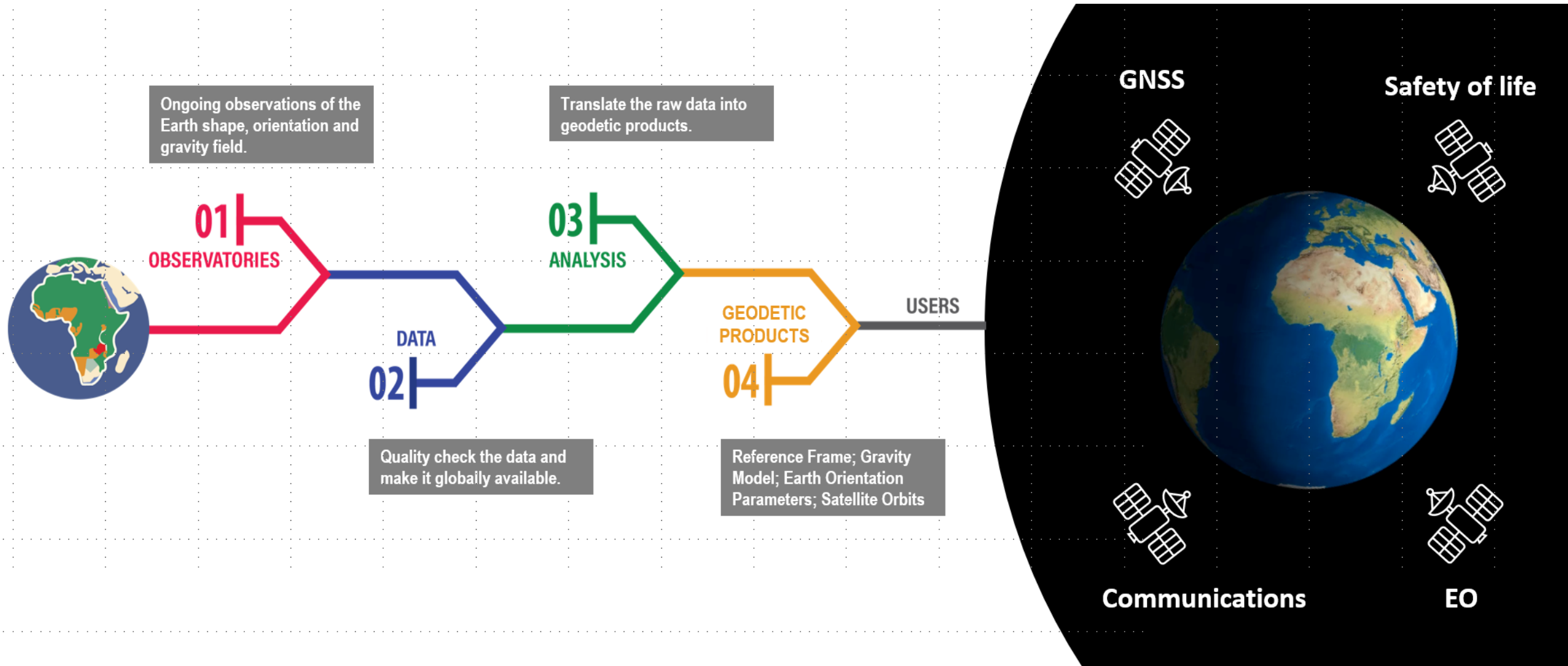
Nicholas Brown
Head of Office, UN-GGCE

HOW

Day 1, Session 2 [1 3 1]

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).

Global Geodesy Supply Chain



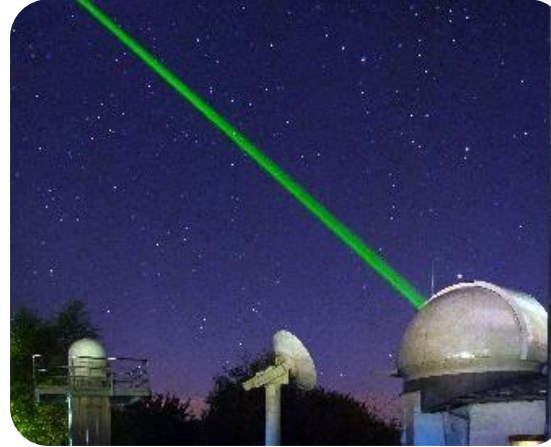
Space geodetic techniques



VLBI

Very Long Baseline Interferometry

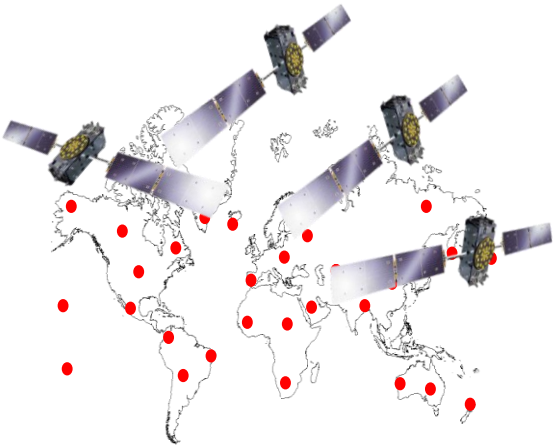
Earth rotation, station coordinates, quasar positions



SLR

Satellite Laser Ranging

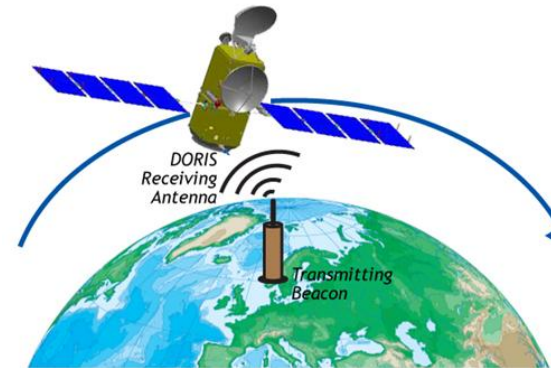
Satellite orbits, station coordinates, Earth rotation, centre of mass of the Earth



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

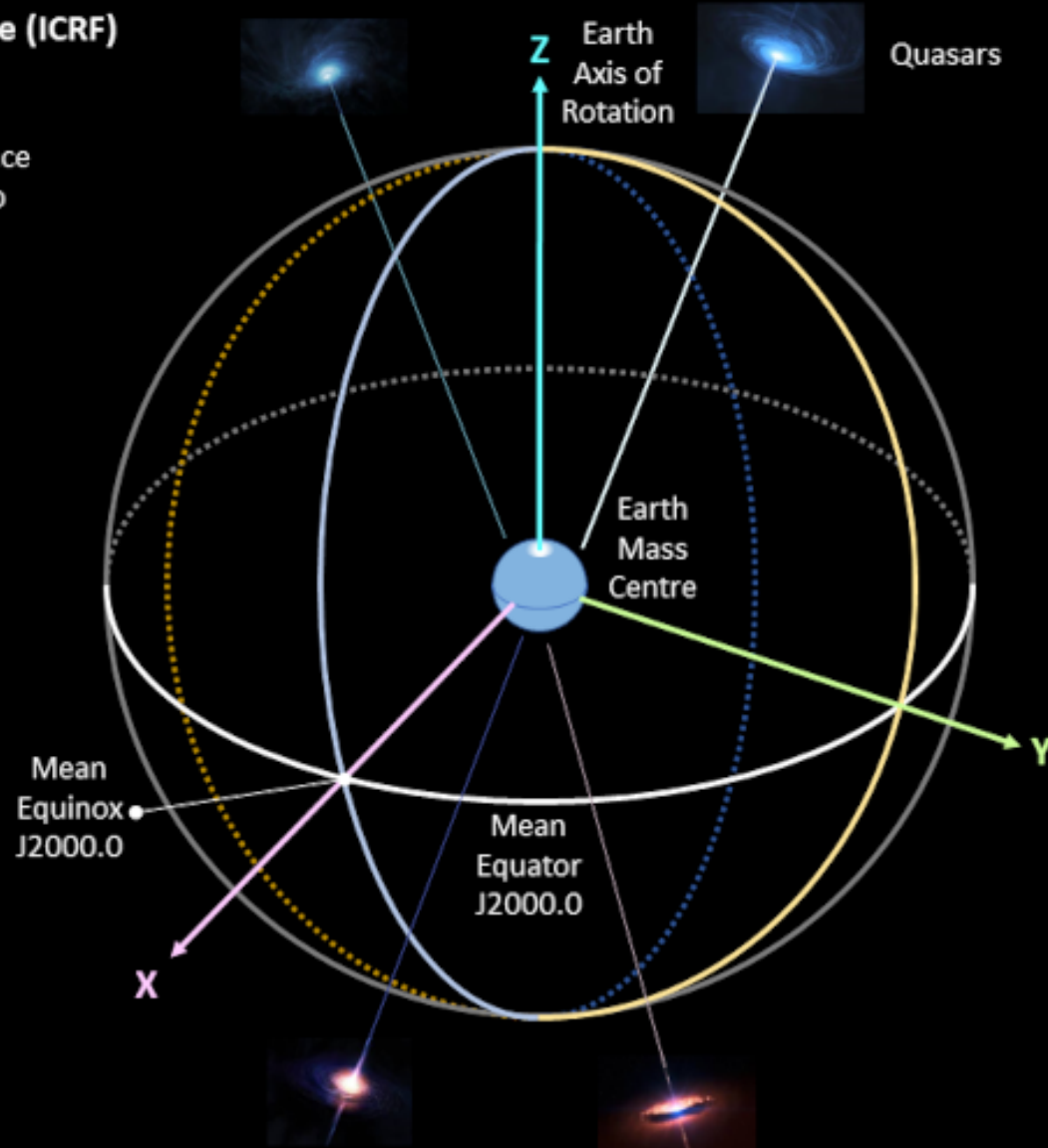
International Celestial Reference Frame (ICRF)

International Celestial Reference Frame (ICRF)

The International Earth Rotation and Reference Systems Service (IERS) was created in 1988 to establish and maintain a Celestial Reference Frame, the ICRF. The ICRF is defined by the position of significant celestial objects. Perhaps the most important of these are the so called radio-loud quasars. These are super massive black holes at the centre of galaxies that radiate huge amounts of energy. A quasar typically emits radiation with a unique signature - a pattern across the radiation spectrum. These quasars, to all intents and purposes, appear as fixed points in the sky and thus as fixed reference points in the ICRF.

J2000.0 is a standard Julian equinox and epoch - January 1, 2000 at 12:00 UT.

IERS iers.org
Rupert W Brown September 2021



International Terrestrial Reference Frame (ITRF)

International Terrestrial Reference Frame (ITRF)

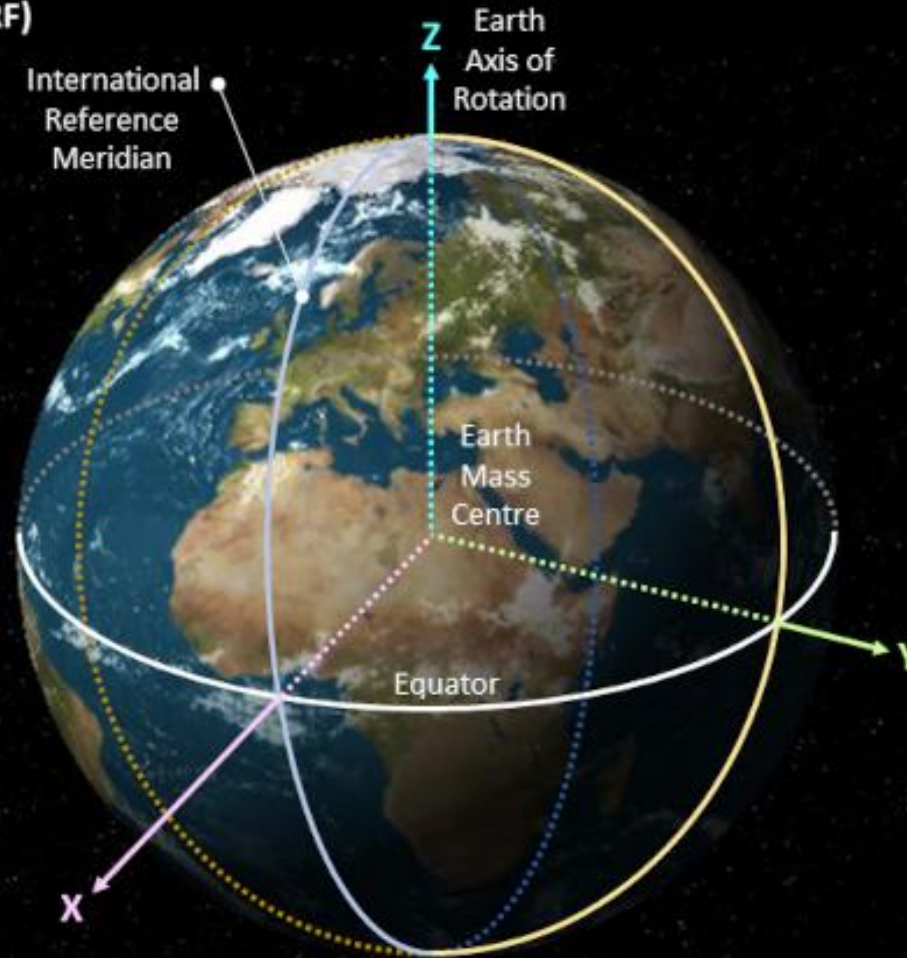
The IERS also maintains the Terrestrial Reference Frame, the ITRF. The ITRF is based on three axes, X, Y and Z with the origin placed at the Earth's centre of mass. The ITRF rotates with and as the Earth rotates across a day. A position in X, Y and Z coordinates can be converted to geographical coordinates (Longitude, Latitude and Height) using a geodetic datum such as WGS84 (world) or GDA2020 (Australia).

Curiously the Earth is not a perfect sphere. It's radius is bigger at the equator than it is at the poles. It also has lumpy gravity. If you ran an altimeter over Earth and plotted out all the points of equal gravity, the picture would look a bit like a potato. This gravity potato is called the geoid.



IERS iers.org
Rupert W Brown December 2021

The relationship between the ICRF and ITRF is defined by Earth Orientation Parameters (EOP).



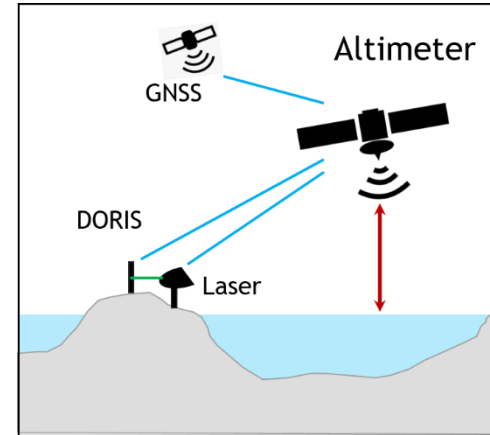
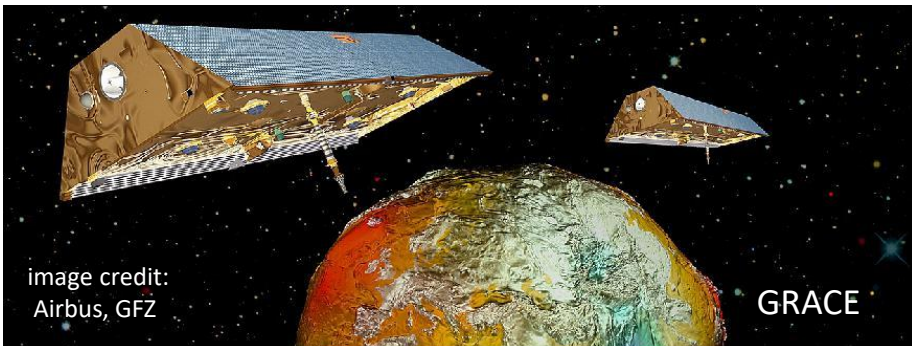
The International Reference Meridian runs approximately 100 m to the west of the original Greenwich Mean Meridian

Geodetic techniques



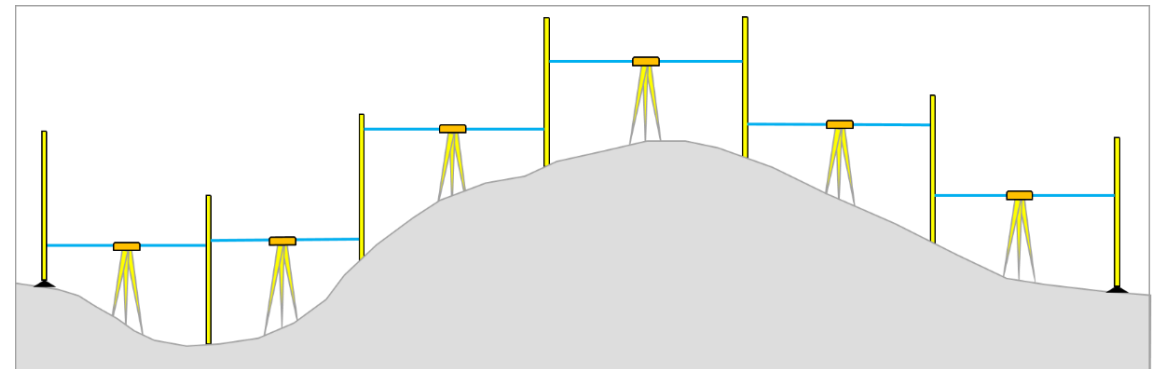
Gravimetry

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



Levelling, Altimetry, Tide Gauges

Vertical reference system
Height component
Sea level



ITRF Observation Techniques



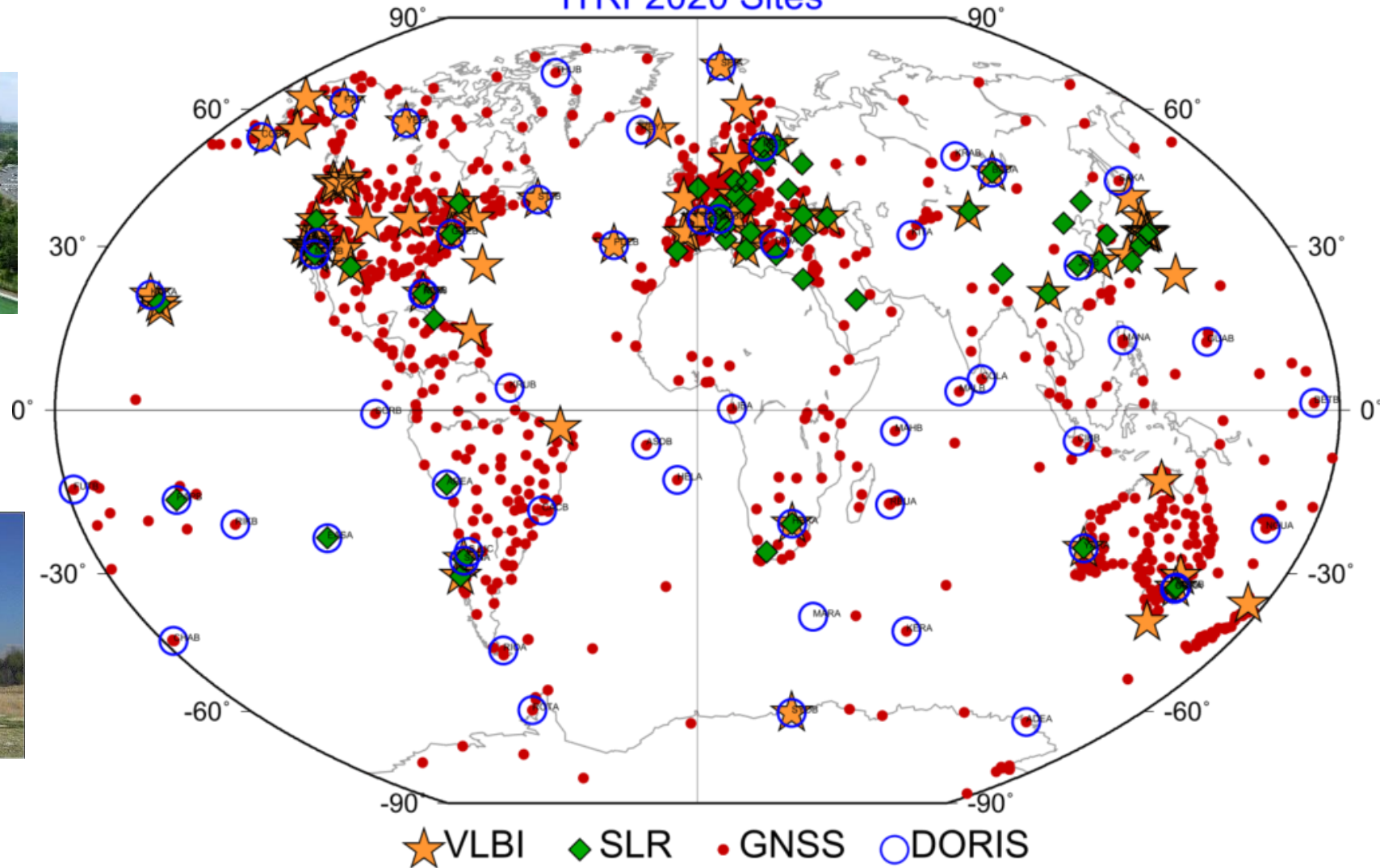
VLBI



SLR



ITRF2020 Sites



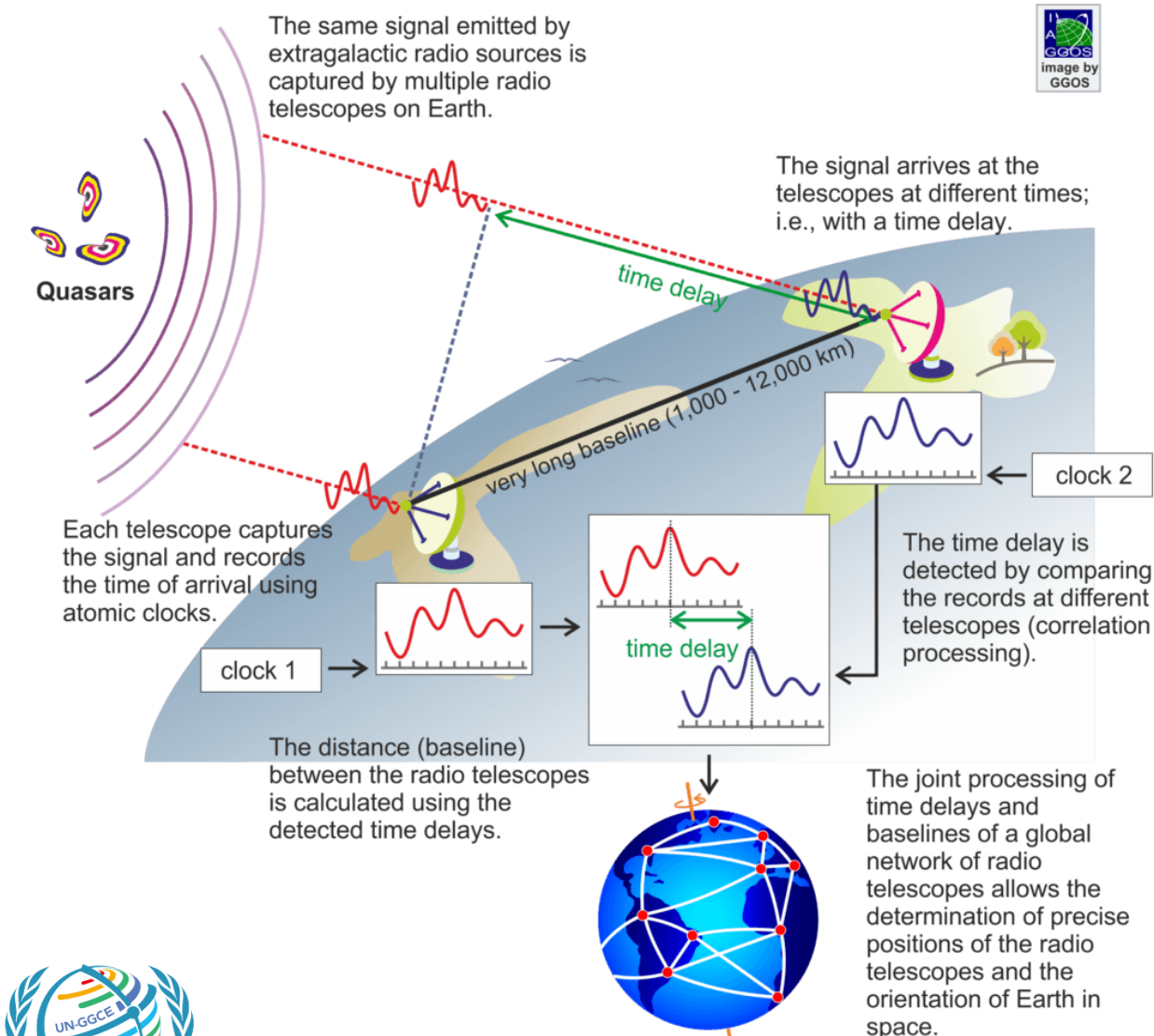
GNSS



DORIS



Very Long Baseline Interferometry (VLBI)



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

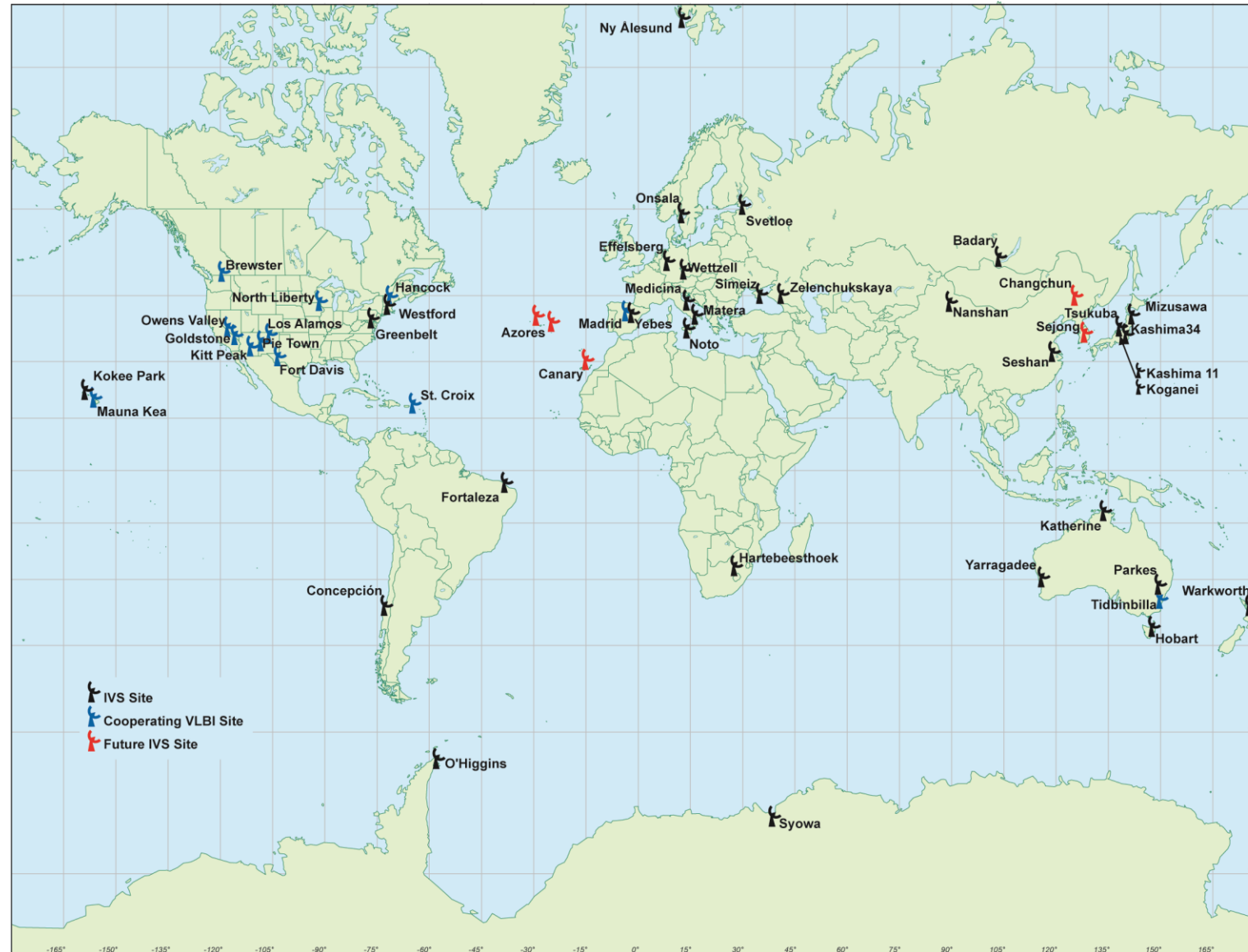
Based on the times recorded at different locations, it is possible to determine the **orientation** of the Earth, **spin-rate** of the Earth and the **distance between the antennas** (which can be 1000s of km apart) with millimeter precision.

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

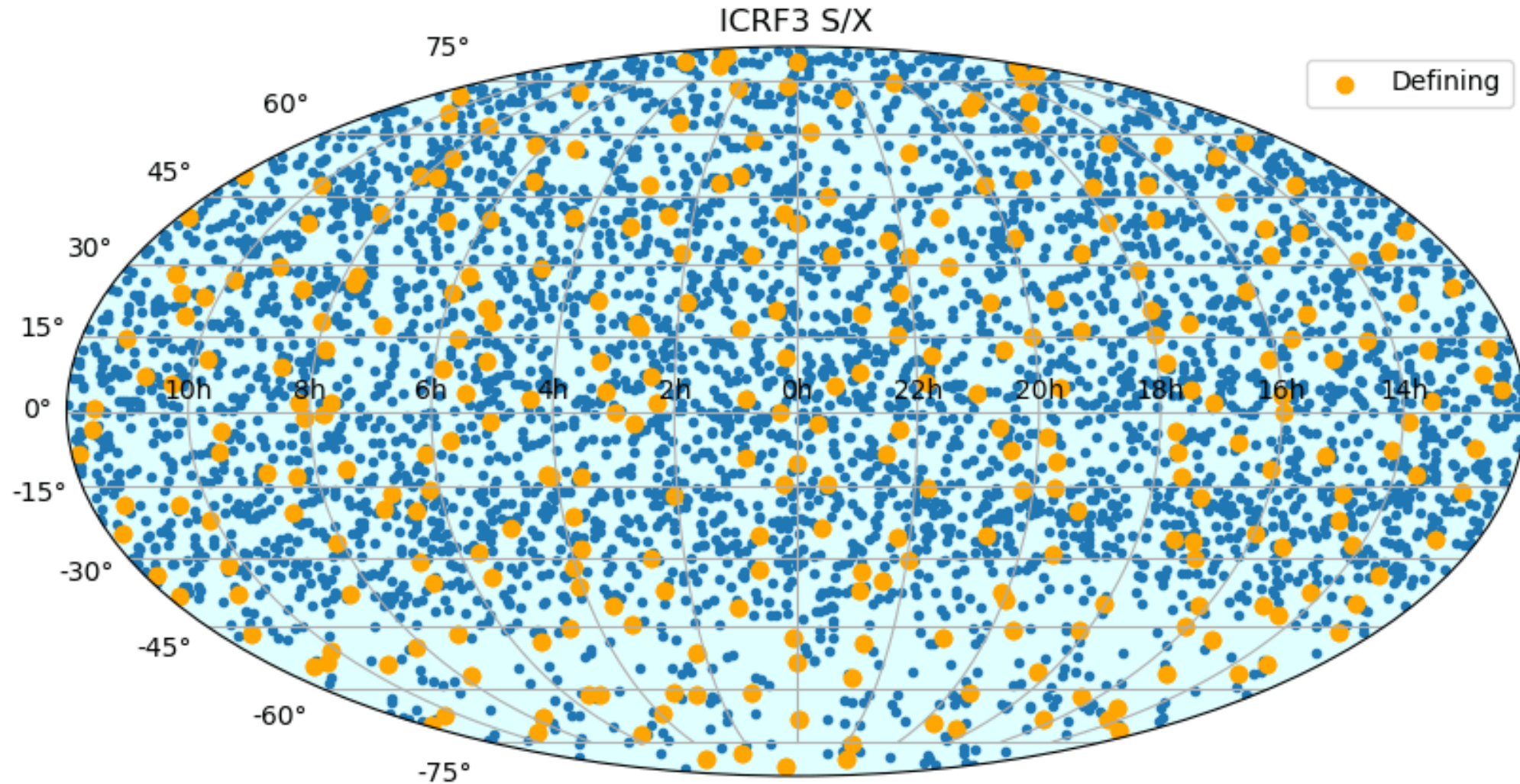


International VLBI Service for Geodesy and Astrometry



(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

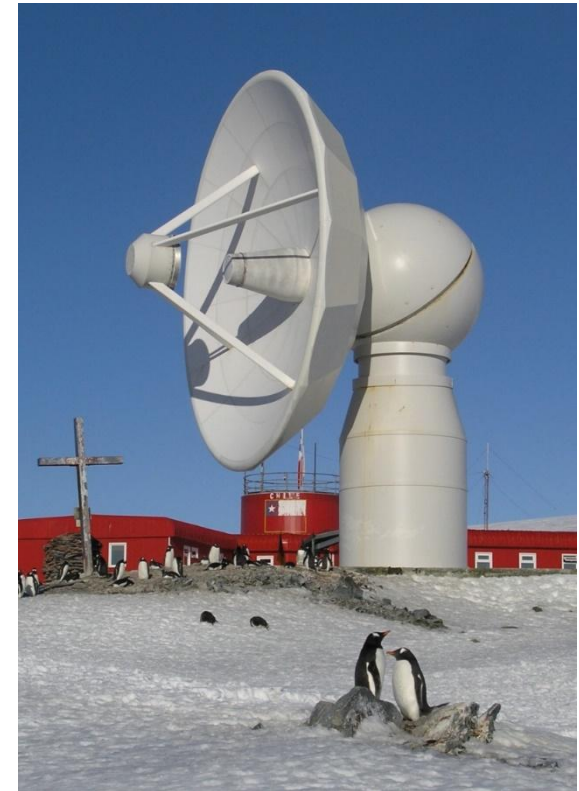
20 m RTW (Wettzell)



13 m TWIN-Teleskope (Wettzell)



6 m Radioteleskop AGGO
(La Plata)



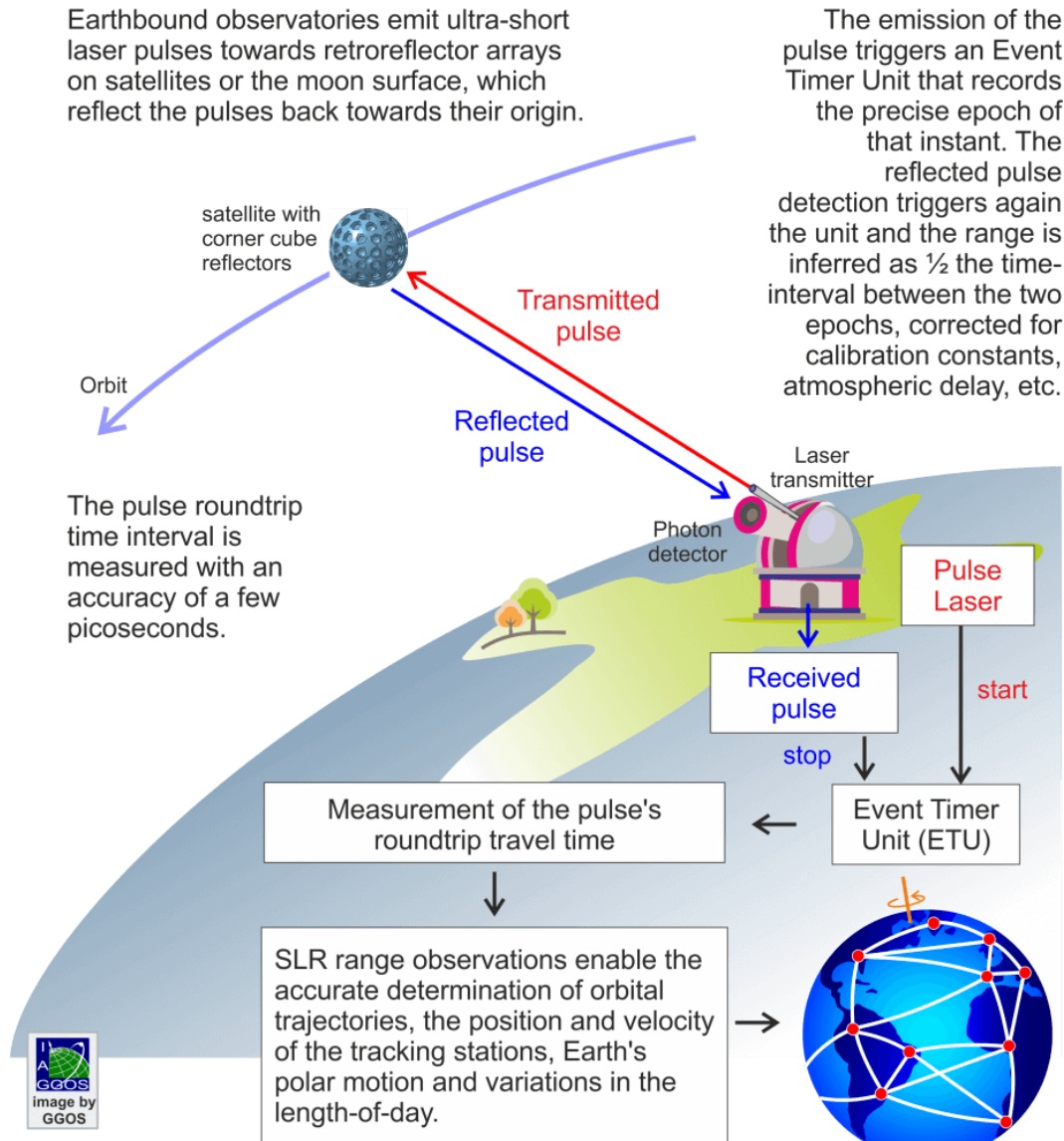
9 m Radioteleskop O'Higgins



Image Credits: BKG

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Satellite Laser Ranging (SLR/LLR)



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

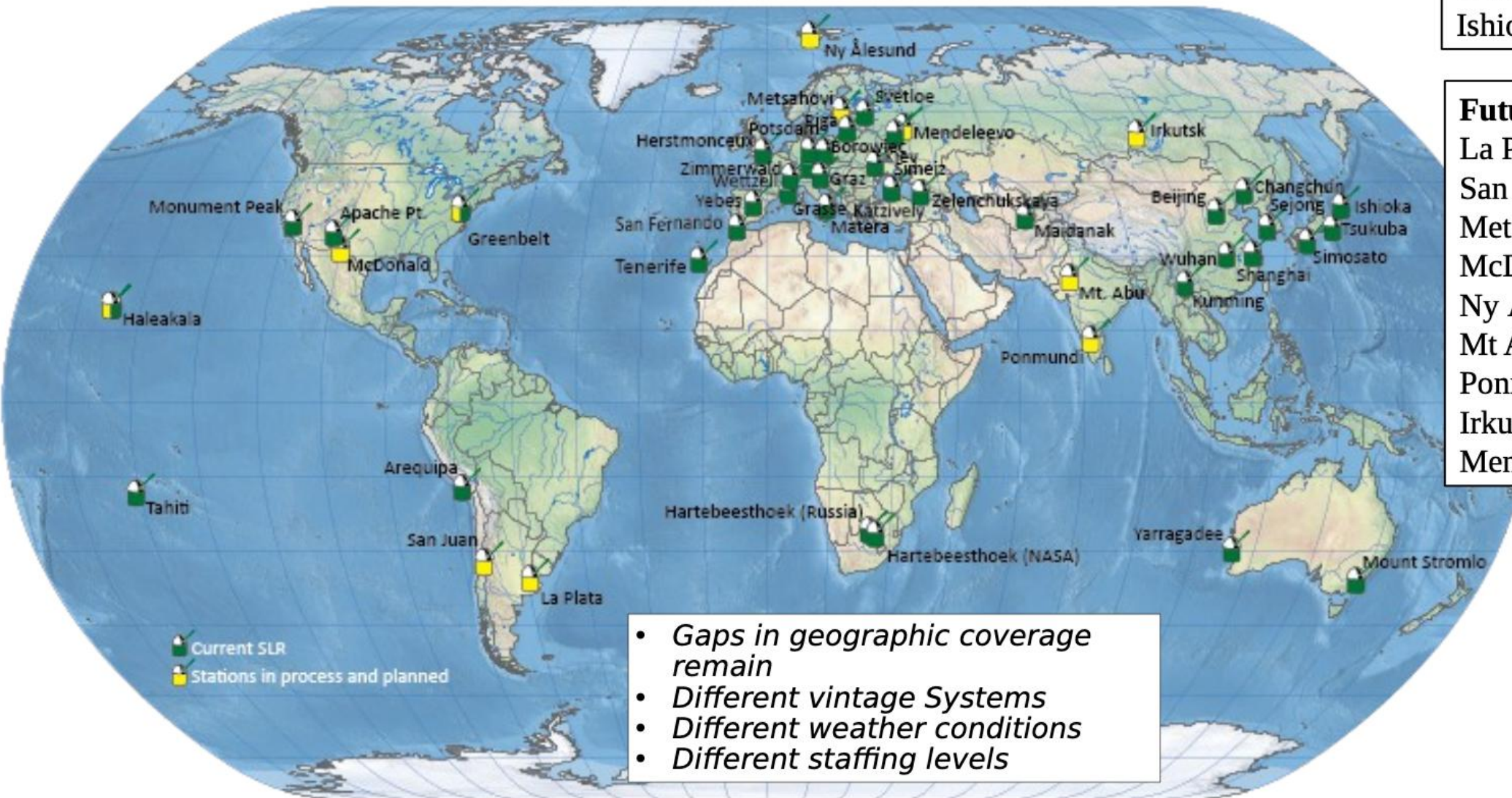
Based on the time delay, geodesists can monitor the orbits of satellites with centimeter accuracy.

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.

International Laser Ranging Service

Current and Planned ILRS Network



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

Ponnundi, India

Irkutsk (Tochka), Russia

Mendeleevo (Tochka), Russia

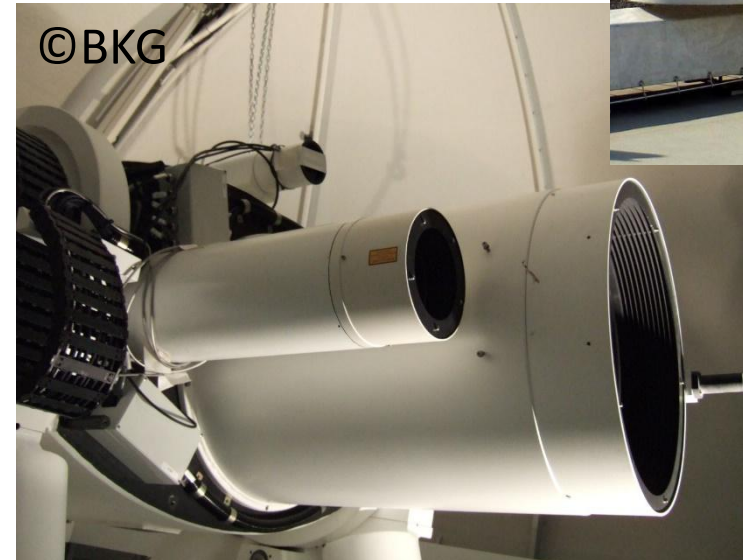
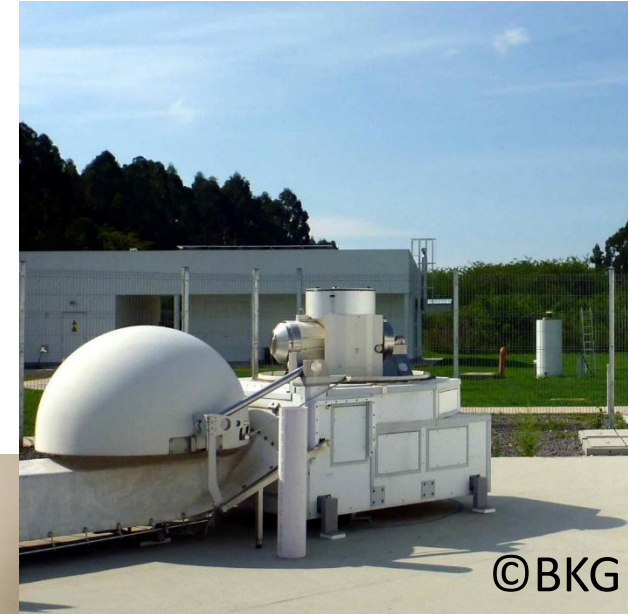
- Gaps in geographic coverage remain
- Different vintage Systems
- Different weather conditions
- Different staffing levels

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

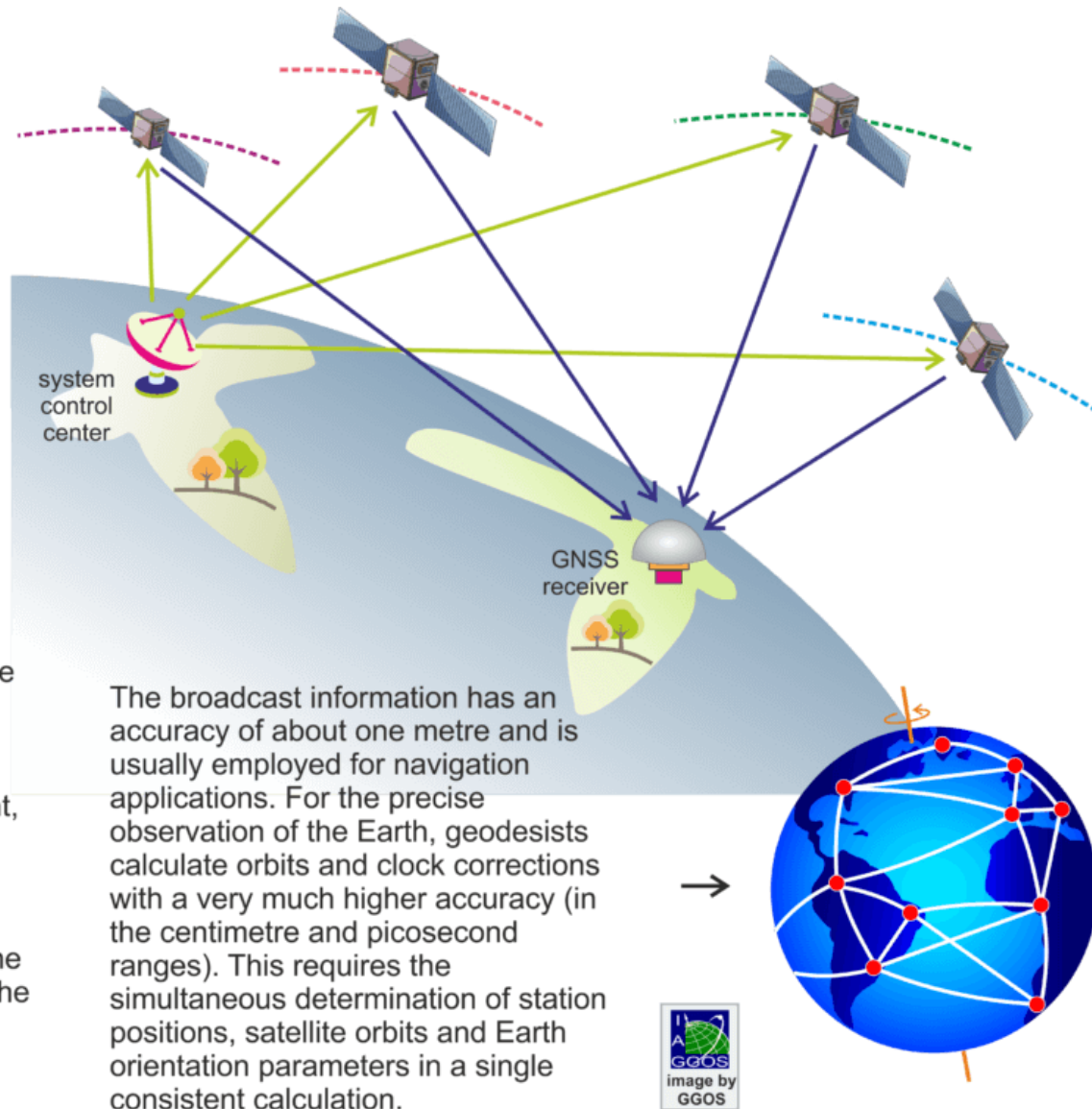
(1) The system operator calculates satellite orbits and clock synchronization using ground stations with known coordinates.

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

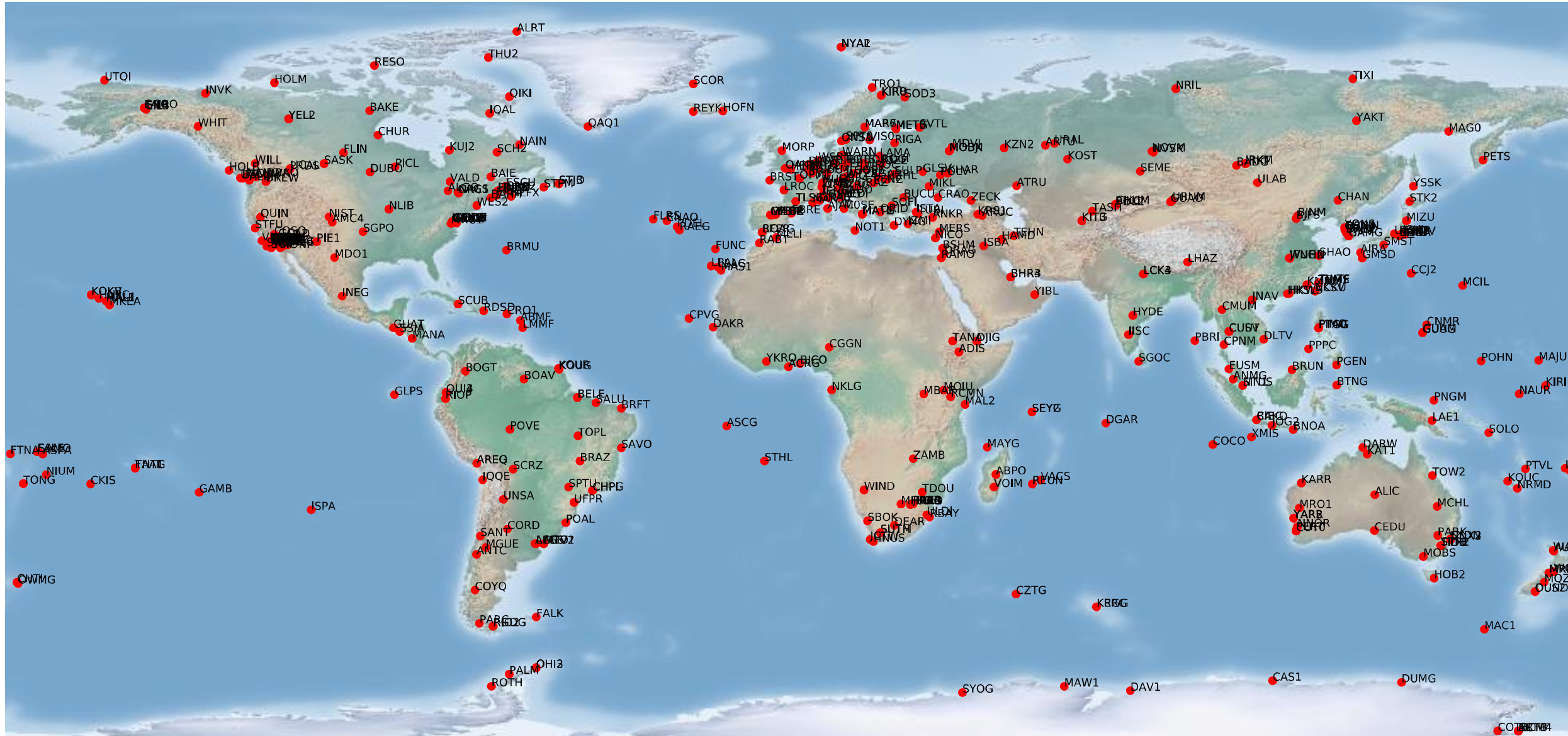
(3) Orbits and clock corrections are broadcast together with a very stable time stamp from an atomic clock, so that a receiver can continuously determine the time when the signal was broadcast.

(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.

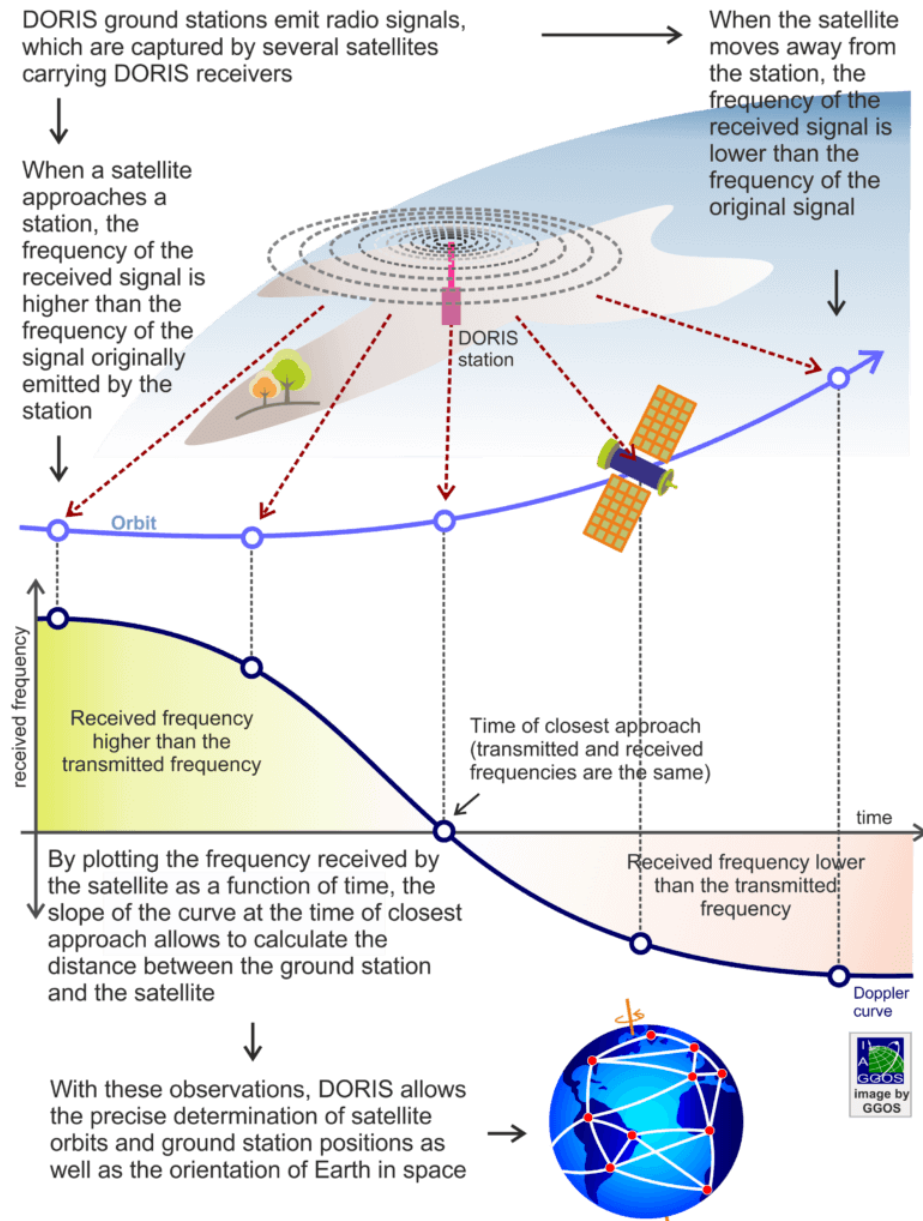


International GNSS Service



(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

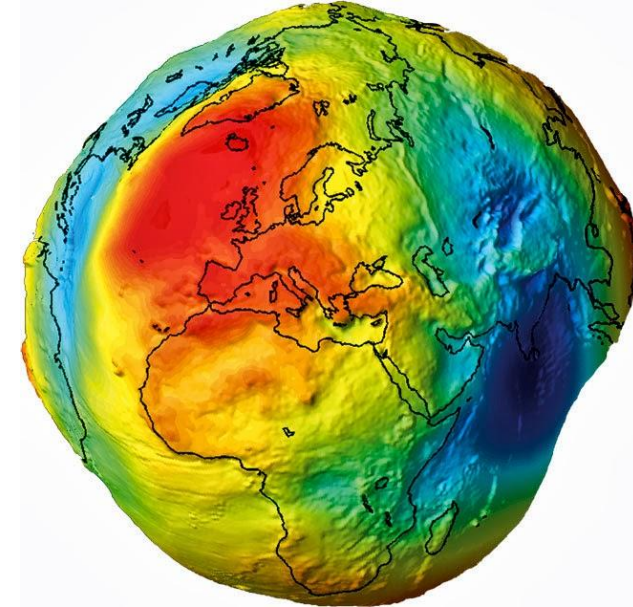
Free Fall Gravimeter

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

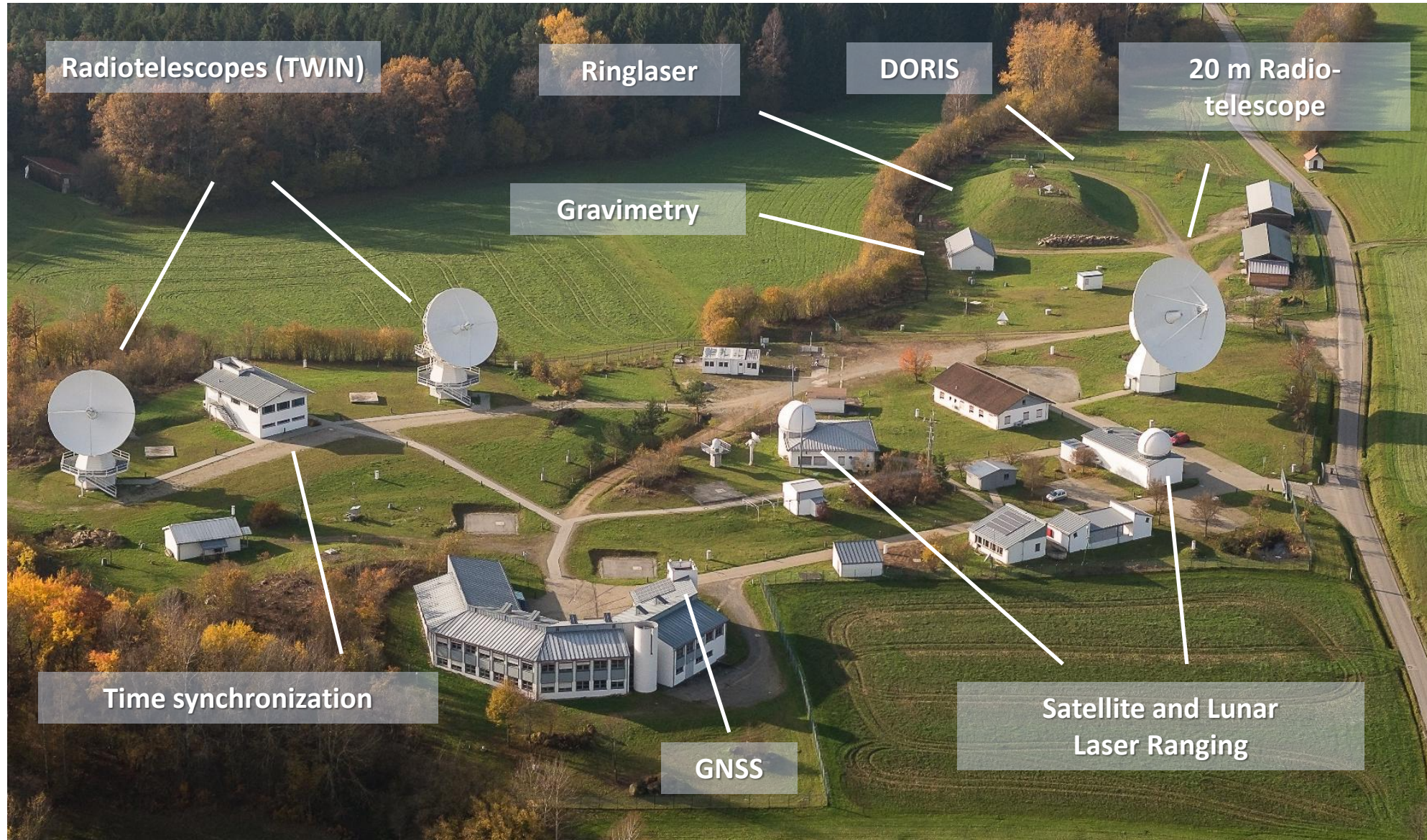


Geoid, the physical shape of the Earth

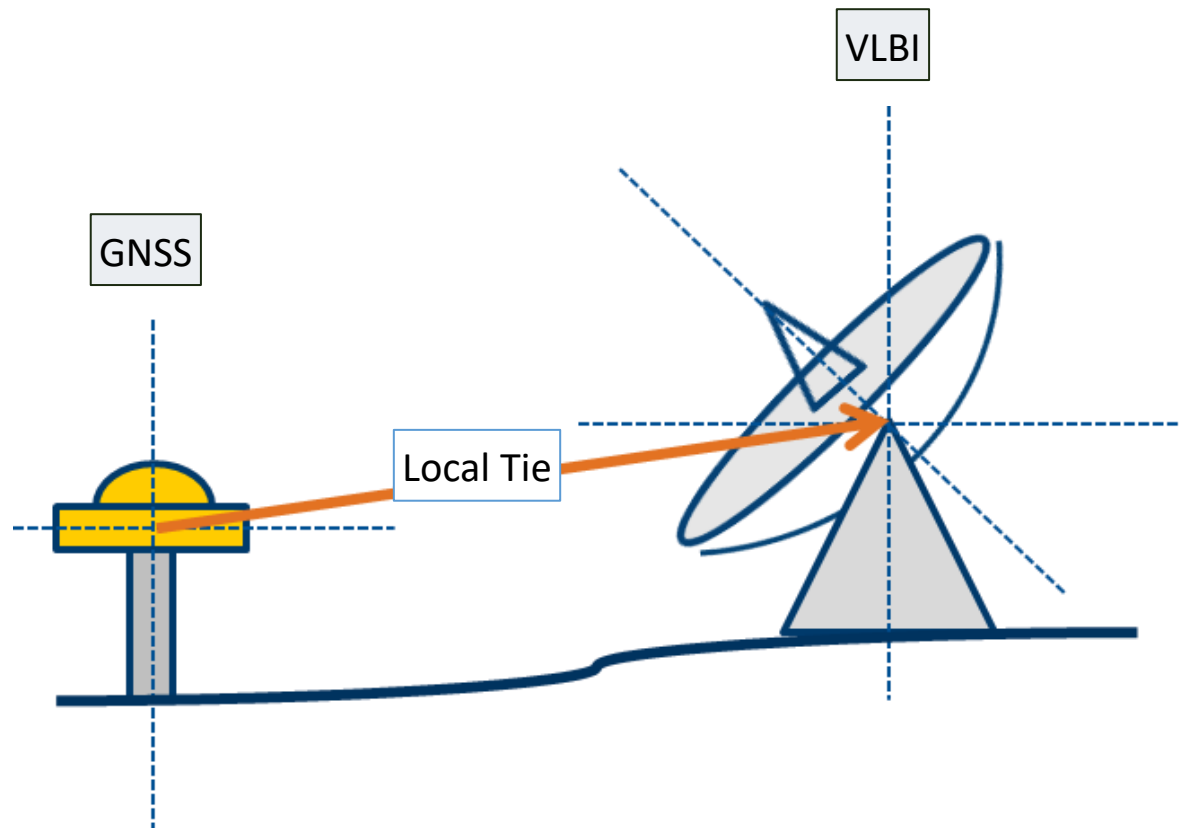


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Geodetic Observatory Wettzell, Germany

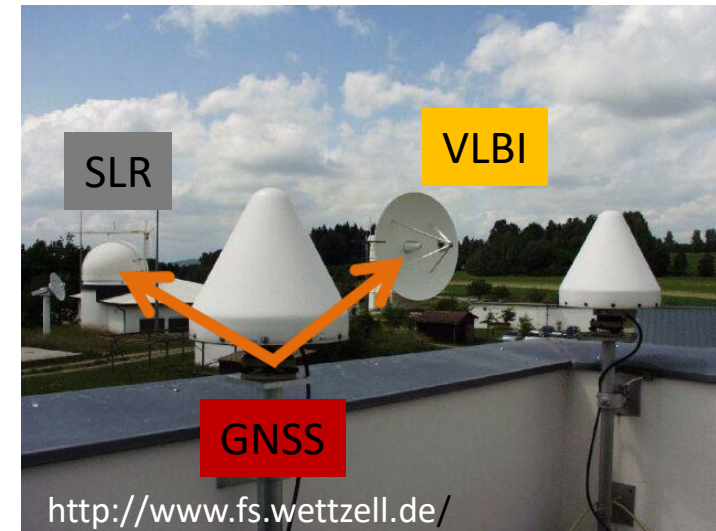


Integration of space techniques



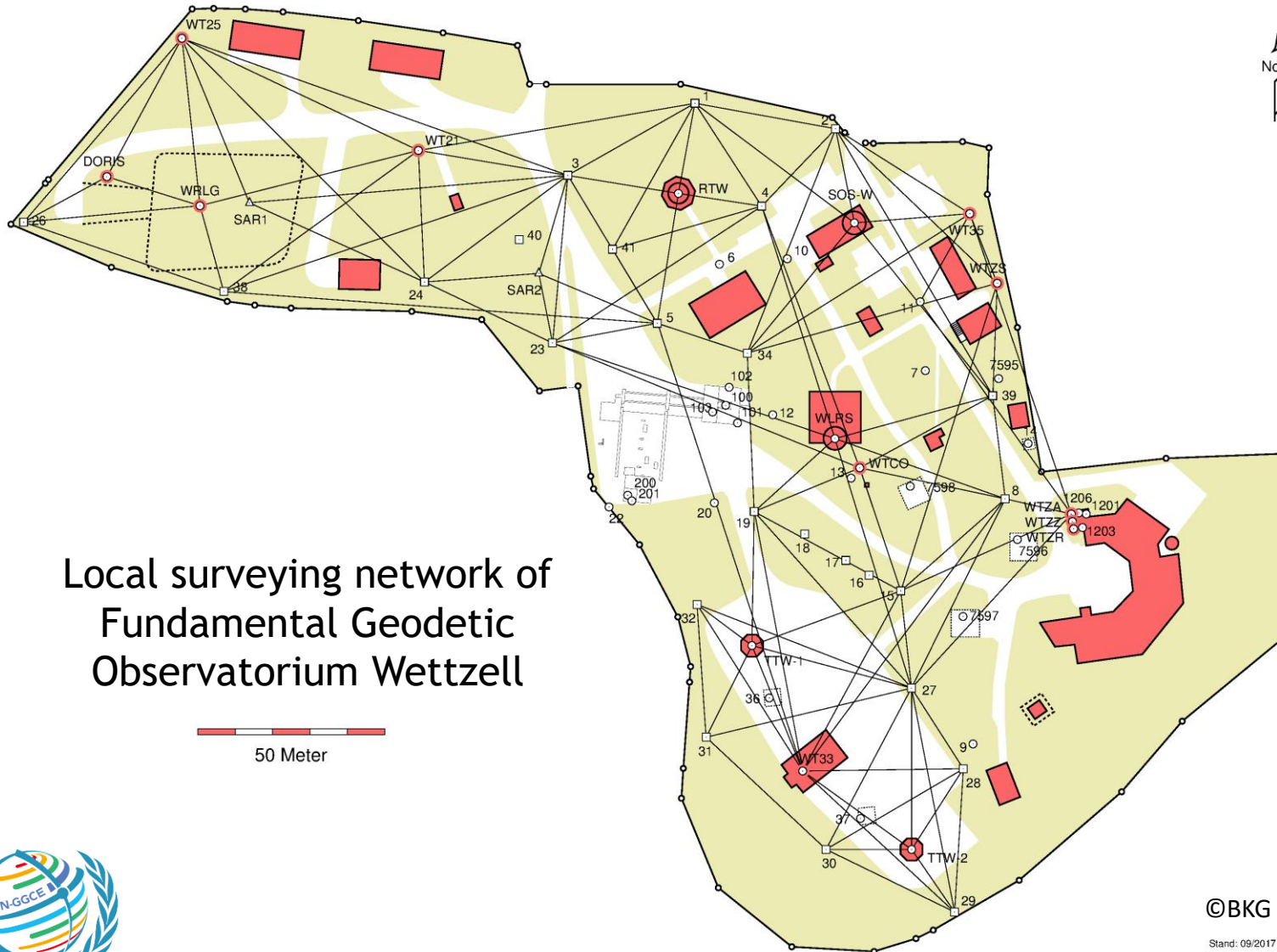
Co-location sites and local ties play a fundamental role for the integration of different space geodetic observation techniques

Geodetic Observatory Wettzell



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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

Time and Frequency



Cesium clocks

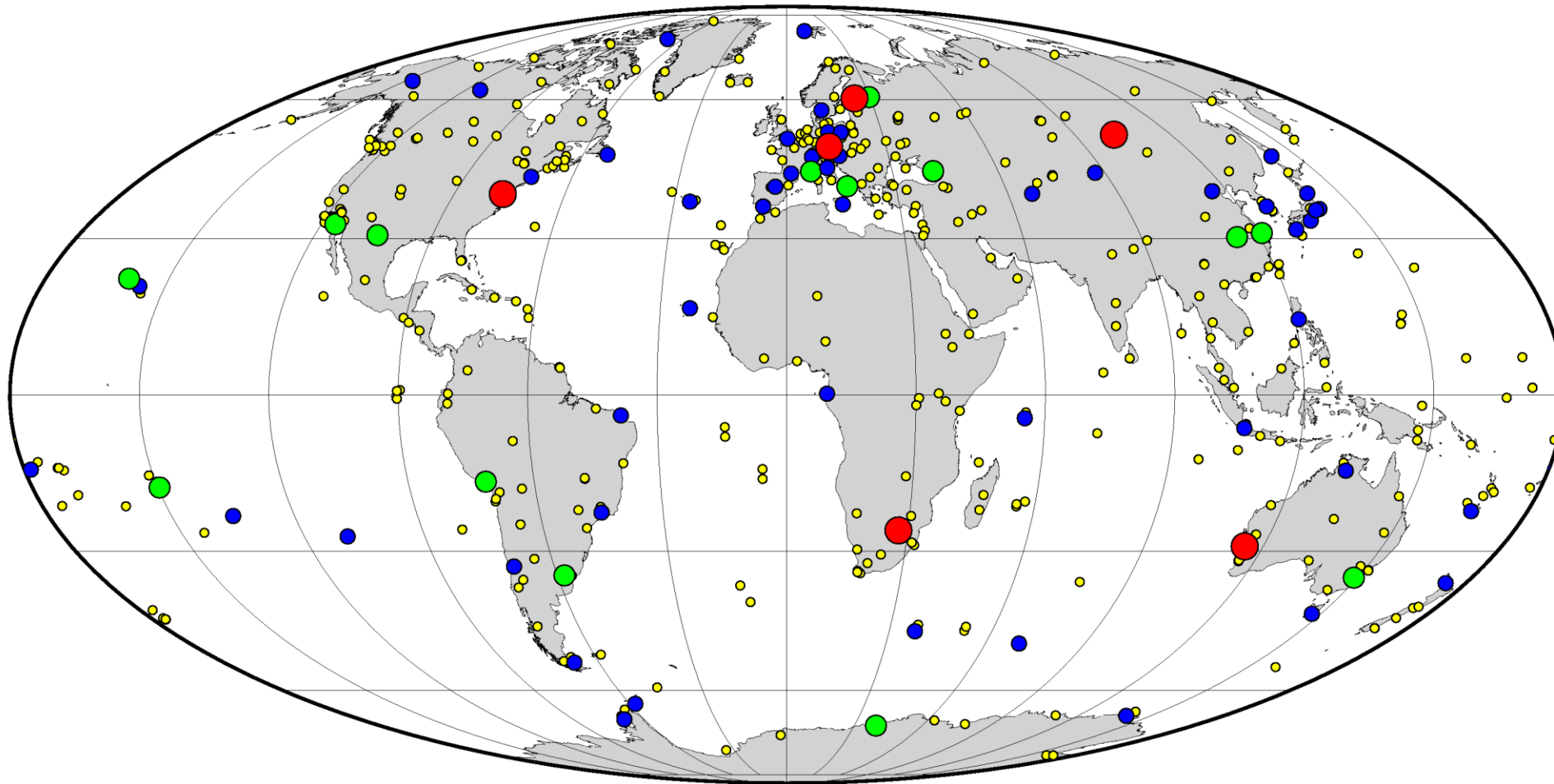
Hydrogen maser
max. Stability
 $<10^{-15}$ sec.



- 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



● 1 Technique

● 2 Techniques

● 3 Techniques

● 4 Techniques

- 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.

Type of Parameter	VLBI			GNSS			DORIS			SLR			LLR		
Quasar Coordinates (ICRF)															
Nutation															
Polmotion															
UT1															
Long of the day (LOD)															
Subdaily Eart Rotation Parameters (ERP)															
ERP Oceantide amplitudes															
Coordinates and Velocities (ITRF)															
Geocenter															
Gravitation Field															
Satellite Orbits															
LEO Satellite Orbits															
Ionosphere															
Troposphere															
Time Transfer and Synchronization															

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/>