Reference Frames

An introduction to the reference frames that enable positions to be defined on Earth

FRONTIER SI

Rupert Brown
rbrown@frontiersi.com.au

FrontierSI
December 2021

+61 406 966 992

https://frontiersi.com.au/

Door 34, Goods Shed, Village Street, Docklands, VIC, 3008, Australia

A point on Earth ... frames of reference

How is it possible to know the absolute position of a thing when position can only be measured relative to something else and everything is moving?

Stable reference frames are needed so that positions can be defined within the context of those reference frames and everybody has a common understanding as to what they mean.

There are two key reference frames:

- The International Celestial Reference Frame (ICRF),
- The International Terrestrial Reference Frame (ITRF),

The ICRF and ITRF are not static. New versions are produced on a regular basis with the aim of improving positioning performance.

A **geoid** is a model of global mean sea level that is used to measure precise surface elevations.

A **geodetic datum** is a reference frame for precisely measuring locations on Earth.

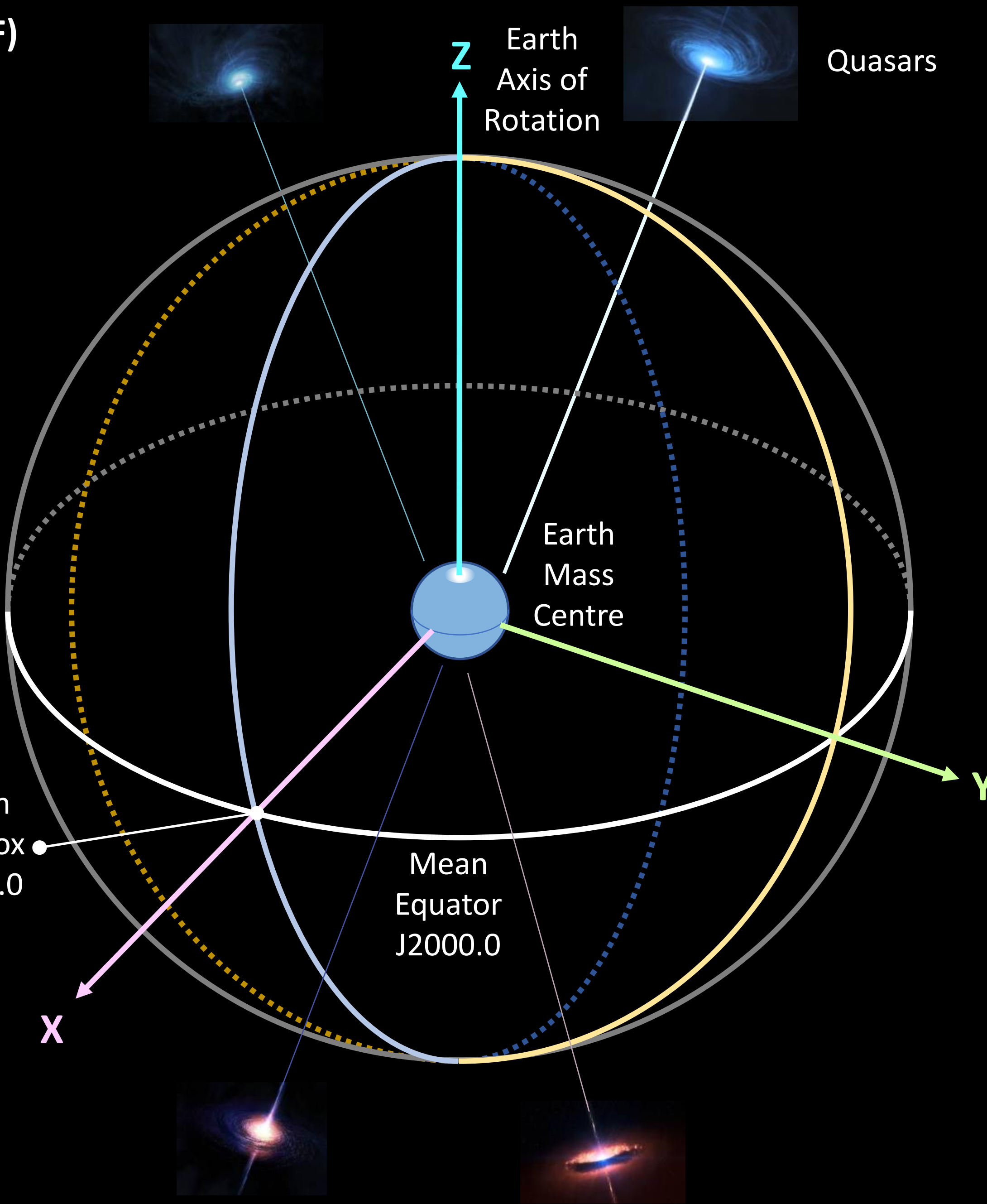
A Position on Earth

Our solar system sits in a spiral arm that rotates around the centre of our galaxy, a galaxy that itself is moving away from the point of the Big Bang. The Earth orbits the Sun and rotates around its own axis. The truth is, in galactic terms, you have never been in the same place twice and never will be. So given all of that how do we work out where we are?

Well fortunately for the vast majority of applications we only need to know where we are with reference to the surface of the Earth. But that too is a little problematic because the surface of the Earth doesn't stay still - it actually slides around a bit. Australia is moving north at the rate of 7 centimetres each year. This whole problem becomes manageable thanks to our use of reference frames.

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.



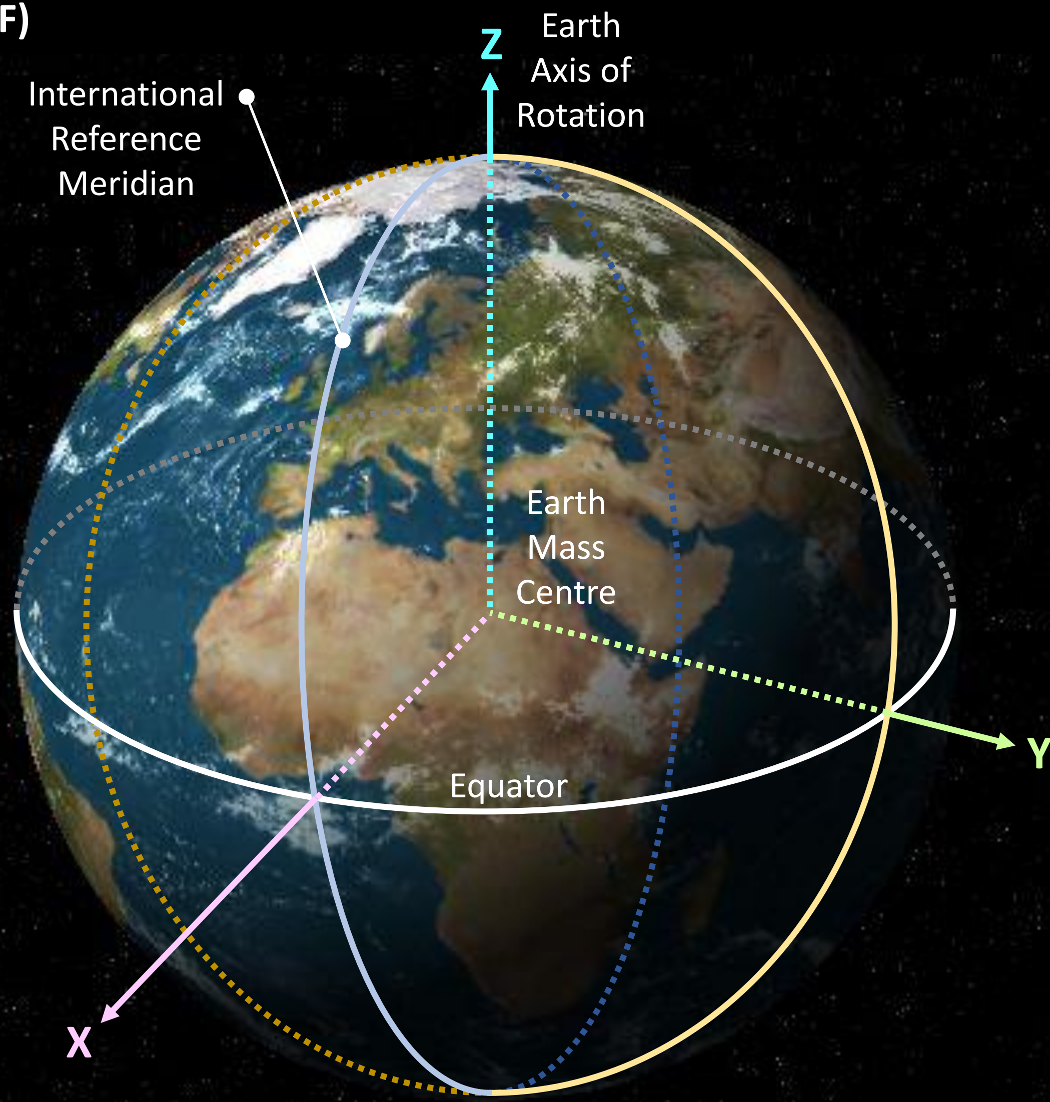
J2000.0 is a standard Julian equinox and epoch - January 1, 2000 at 12:00 TT.

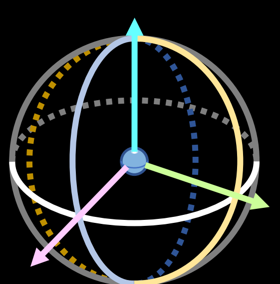
IERS iers.org
Rupert W Brown September 2021

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.



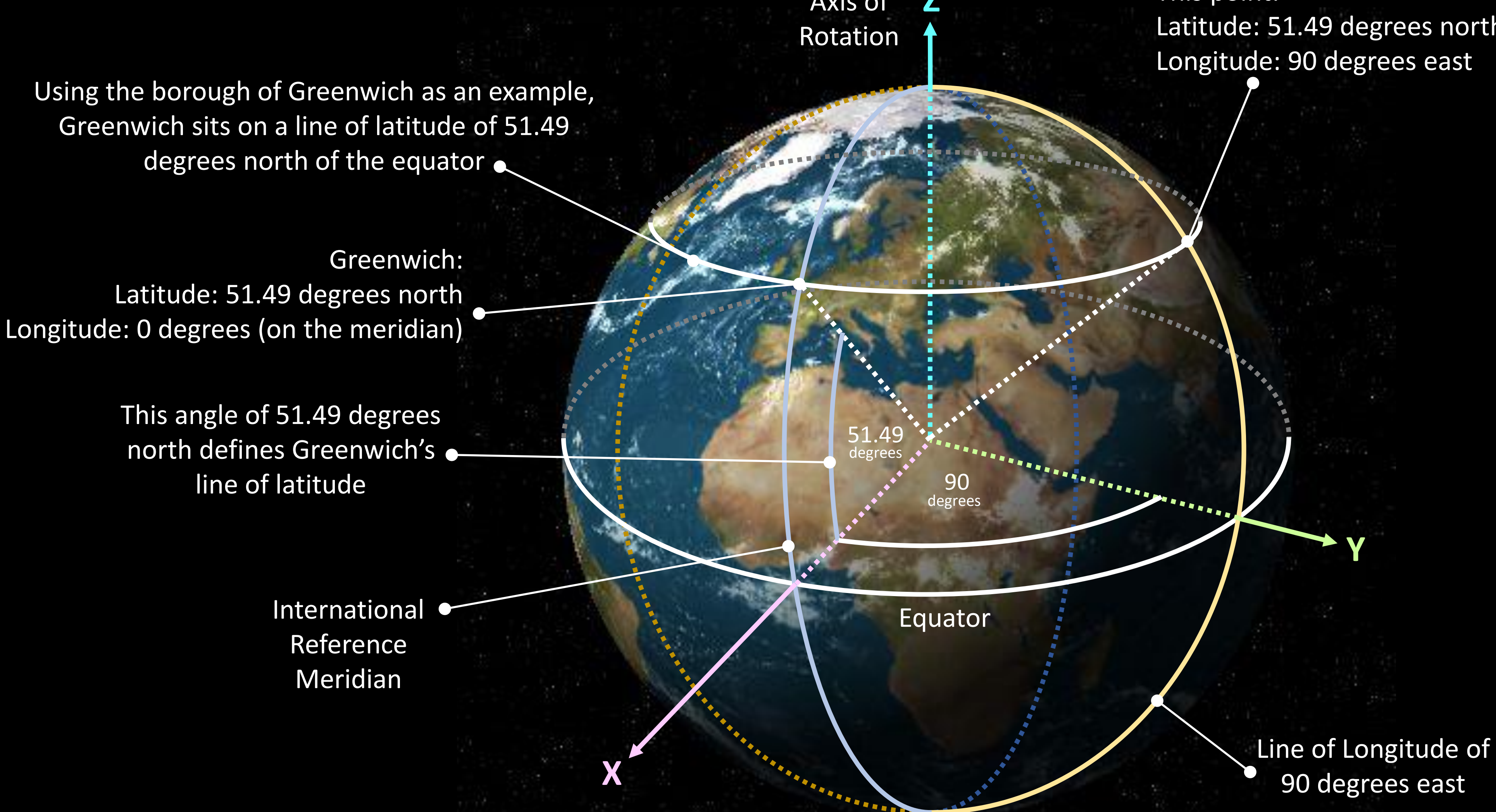


The relationship between the ICRF and ITRF is defined by Earth Observation Parameters (EOP).

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

IERS iers.org
Rupert W Brown December 2021

Latitude, Longitude and Height



Height refers to the distance between a point and the surface of a datum such as the Australian Height Datum. A point defined by coordinates X, Y, Z can be converted to latitude, longitude and height – and vice versa.

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

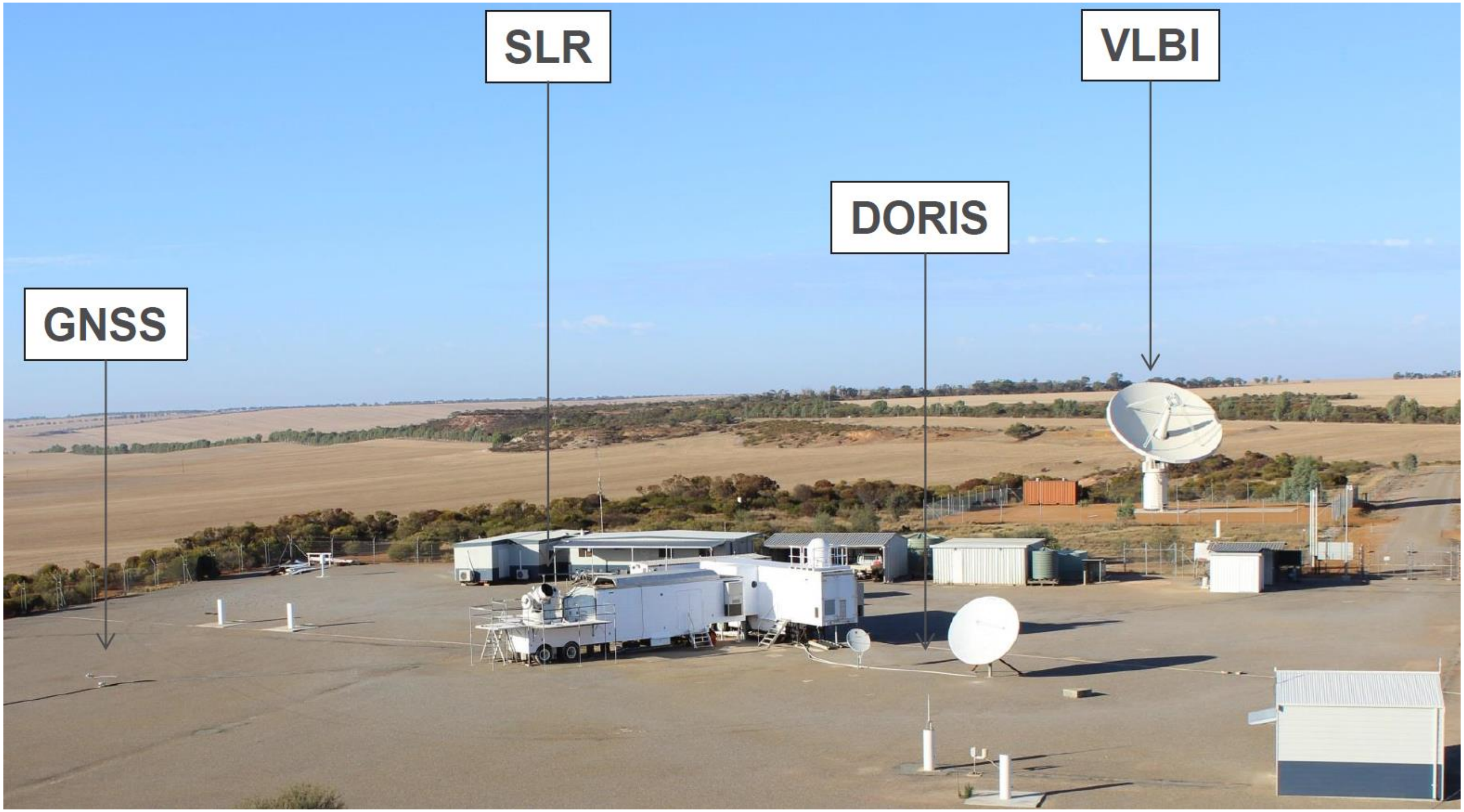
Rupert W Brown December 2021

Reference points for the ITRF

Credit: NASA/Earth Observatory/GSFC

Much like the ICRF's quasars, the ITRF needs reference points to define it. These reference points now number in the hundreds and are spread across the surface of the Earth. The position of each reference point, in the context of the ITRF, has to be determined to a very high degree of accuracy by several independent means.

Means of determining position …



Yarragadee Geodetic Observatory, Western Australia

A slide from “National Positioning Infrastructure” by Dr John Dawson, Geoscience Australia.

See the next slide for an explanation of these terms.

Very-long-baseline interferometry (VLBI) is a technique that uses radio telescopes on Earth to track objects such as those quasars. A number of telescopes, each with its own atomic clock, records the signal coming from one particular quasar. Analysis of this data, essentially using signal correlation and a form of triangulation, is used to determine the location of each telescope to a very high degree of accuracy.

Doppler Orbitography by Radiopositioning Integrated on Satellite (DORIS) is a dual-frequency Doppler system consisting of a receiver flying aboard a satellite and a globally distributed network of ground beacons. Analysis Centers (ACs) of the International DORIS Service (IDS) retrieve DORIS data from ground beacons on a regular basis and after producing the weekly SINEX files using the current ITRF, compute station position time series solutions for the DORIS beacons supporting the IDS network. DORIS satellites include TOPEX/Poseidon, Jason-1 and -2, Envisat, Cryosat-2, HY-2A, and SPOT-2, -3, -4, and -5.

Satellite Laser Ranging (SLR) measures the time intervals required for pulses emitted by a laser transmitter to travel to a satellite and return to the transmitting site. The "range", or distance between the satellite and the observing site is approximately equal to one half of the two-way travel time multiplied by the speed of light. Laser ranging data consists of the distance or range (round-trip, station to satellite and back) and time, together with data correction information such as atmospheric effects, which are to be applied to the data. SLR satellites include LAGEOS-1 and 2, Etalon-1 and -2.

Global Navigation Satellite System (GNSS). A GNSS is a constellation of satellites, usually 24, that orbit the Earth at an altitude of 20,000km in three distinct orbits. The satellites are maintained and controlled by a network of ground stations. Each satellite transmits a unique timing and ranging signal along with its orbital position. GNSS receivers can detect the transmissions, and if there are enough visible satellites, calculate a precise position. GNSS constellations in operation are GPS Navstar (USA), GLONASS (Russia), Galileo (Europe) and Beidou (China).


FrontierSI – we know where