Other Space Geodetic Techniques

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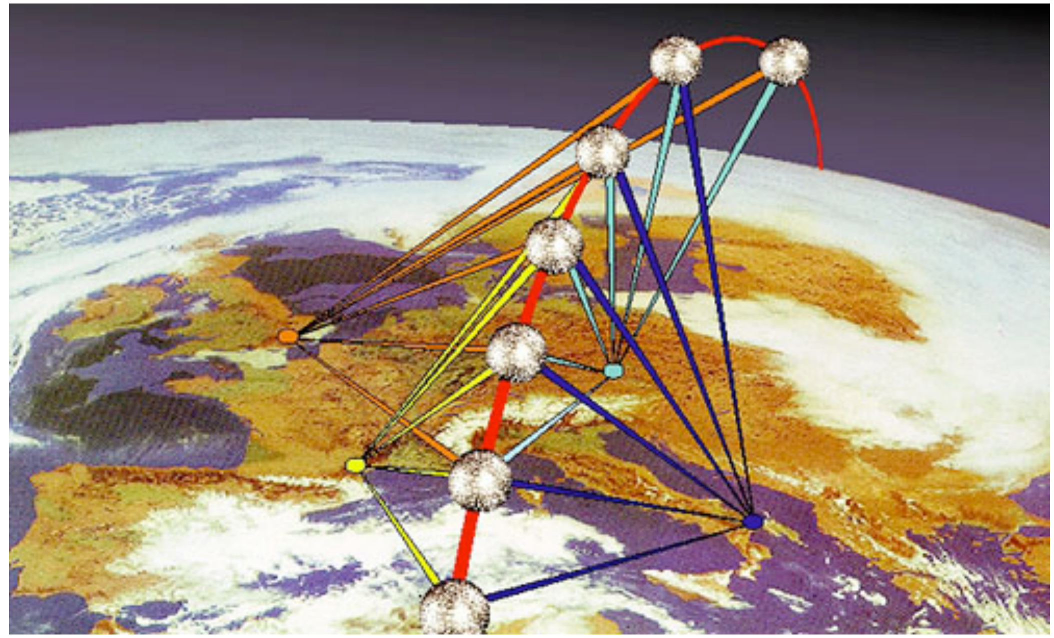
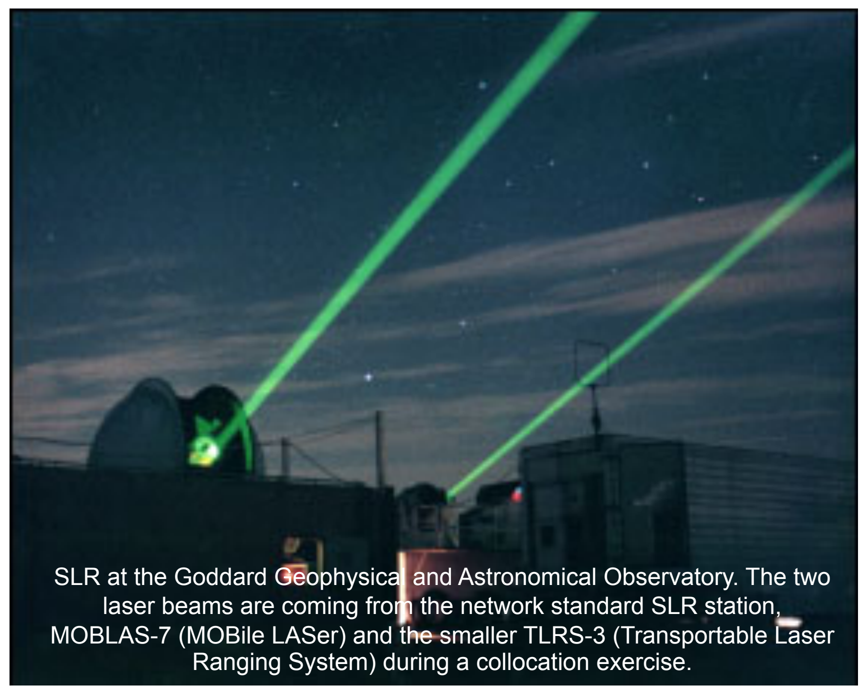
Satellite Laser Ranging = SLR

- Measurement of distance (=range) between a ground station and a satellite
- Ground station transmits a very short laser pulse from a telescope to a satellite
- The laser pulse is retro-reflected by corner cube reflectors on the satellite back to the ground telescope
- Very precise clock at the ground station measures the round trip time $t_{emission} - t_{reception}$
- Time measurement accuracy < 50 picoseconds, or < 1 centimeter in range
- 3 stations, 1 satellite => position of the satellite (if station position known)
- 3 satellites, 1 station => position of the station (if satellite orbit known)

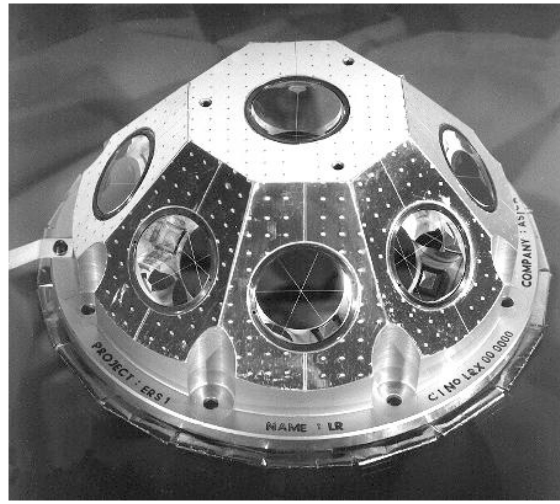


Tracking a satellite with a network of SLR stations



SLR at the Goddard Geophysical and Astronomical Observatory. The two laser beams are coming from the network standard SLR station, MOBLAS-7 (MOBile LASer) and the smaller TLRS-3 (Transportable Laser Ranging System) during a collocation exercise.

Satellite Laser Ranging

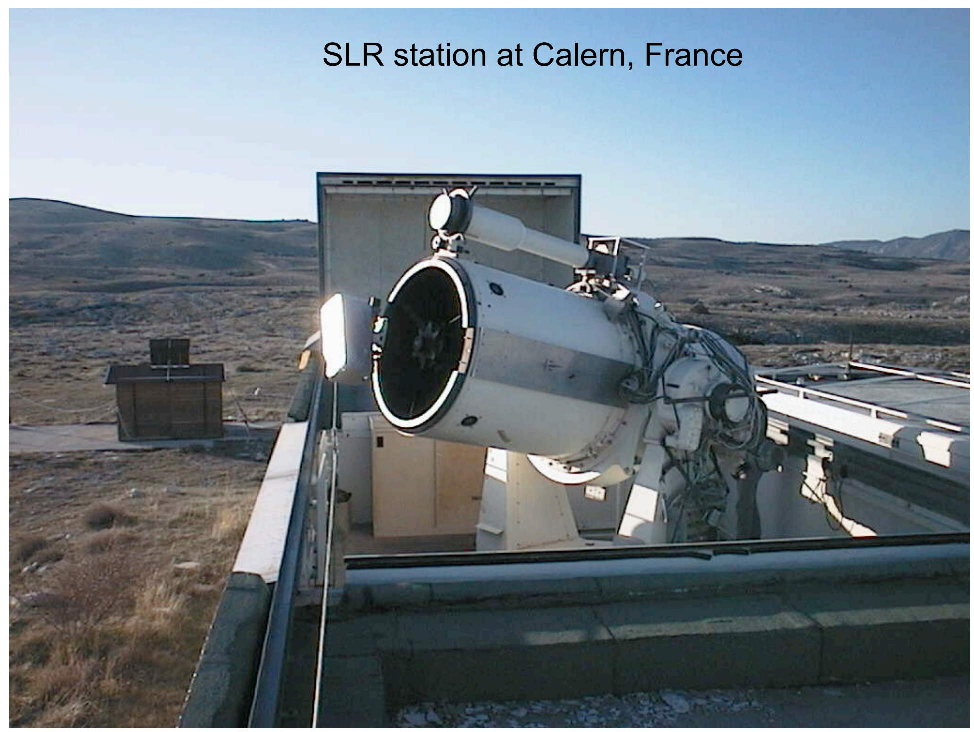


ERS corner cube array

Starlette, a geodetic satellite launched in 1975
48 cm diameter, 47 kg

Geodetic satellites commonly used in SLR:

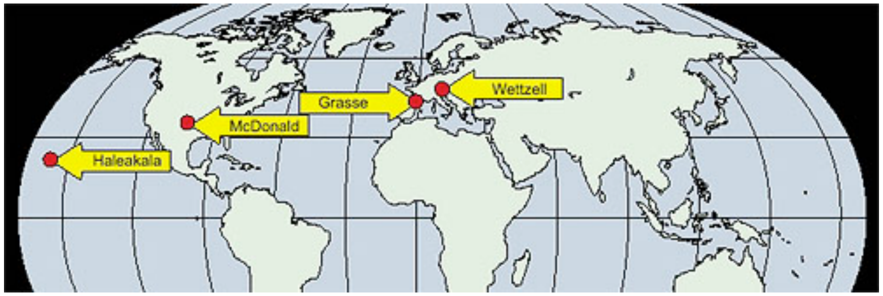
– Starlette (France, 1975)
– Lageos-1 (US, 1976)
– Etalon-1,2 (USSR, 1989)
– Topex/Poseidon (US/France, 1992)
– Lageos-2 (US/Italy, 1992)
– Stella (France, 1993)
– GPS-35,36 (US, 1993/94)
– Glonass-63,67 (Russia, 1994)
– ERS-2 (ESA, 1995)
– GFZ-1 (1996)
– MIDORI/ADEOS (Japan, 1996)
– TiPS (US, 1996)



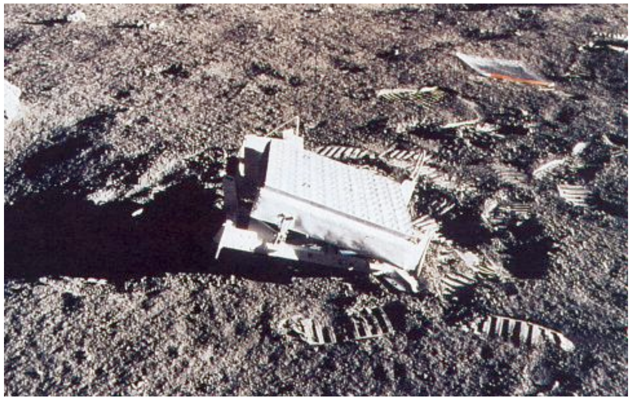
SLR station at Calern, France

Lunar Laser Ranging

= SLR to the moon (first achieved in 1969)

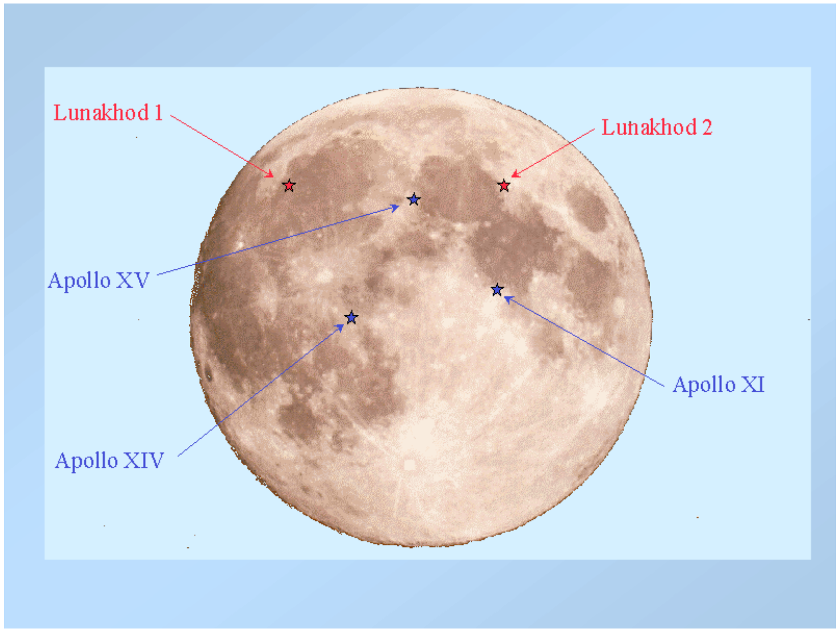


LLR station distribution



Lunar corner cube array (Apollo XIV)

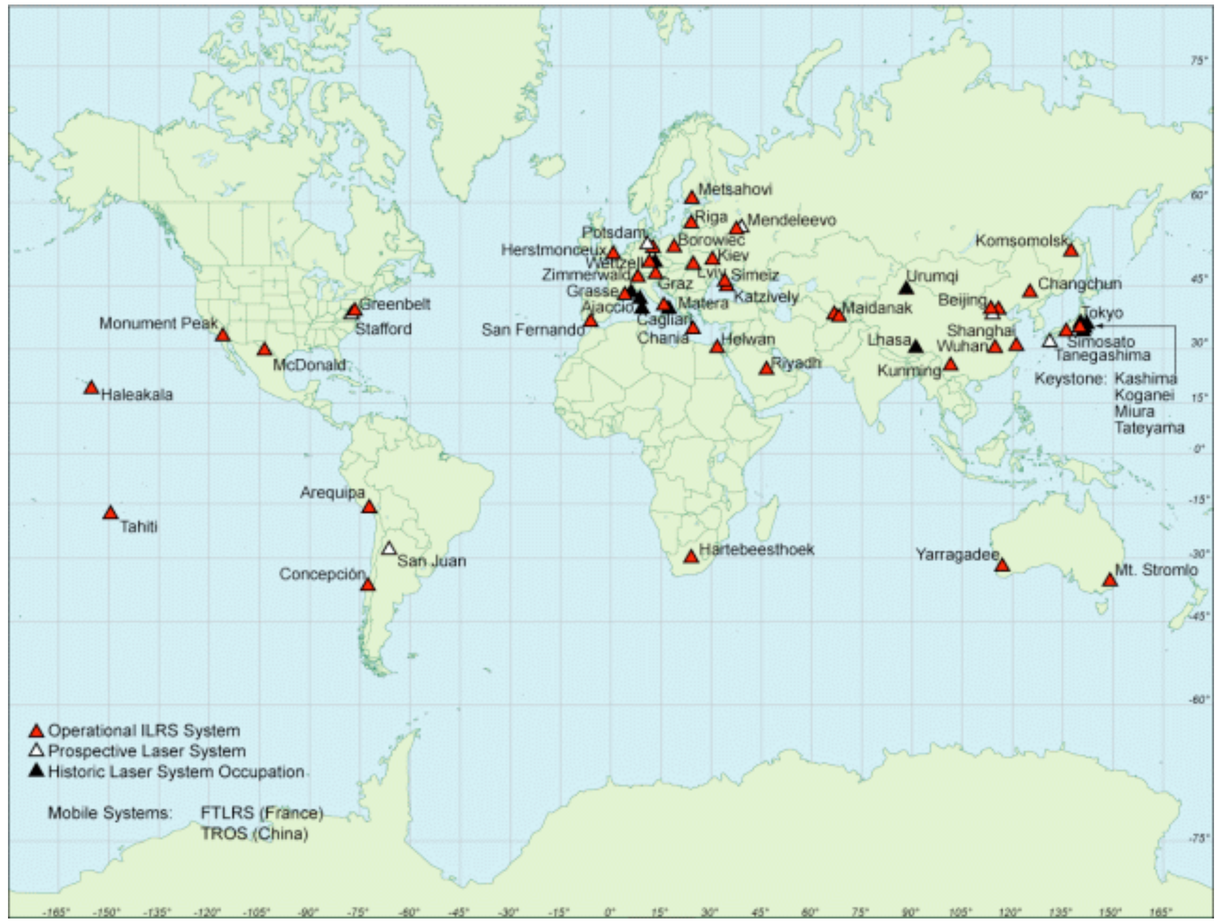
Location of laser reflectors in the Moon



Lunar laser station at Calern, France

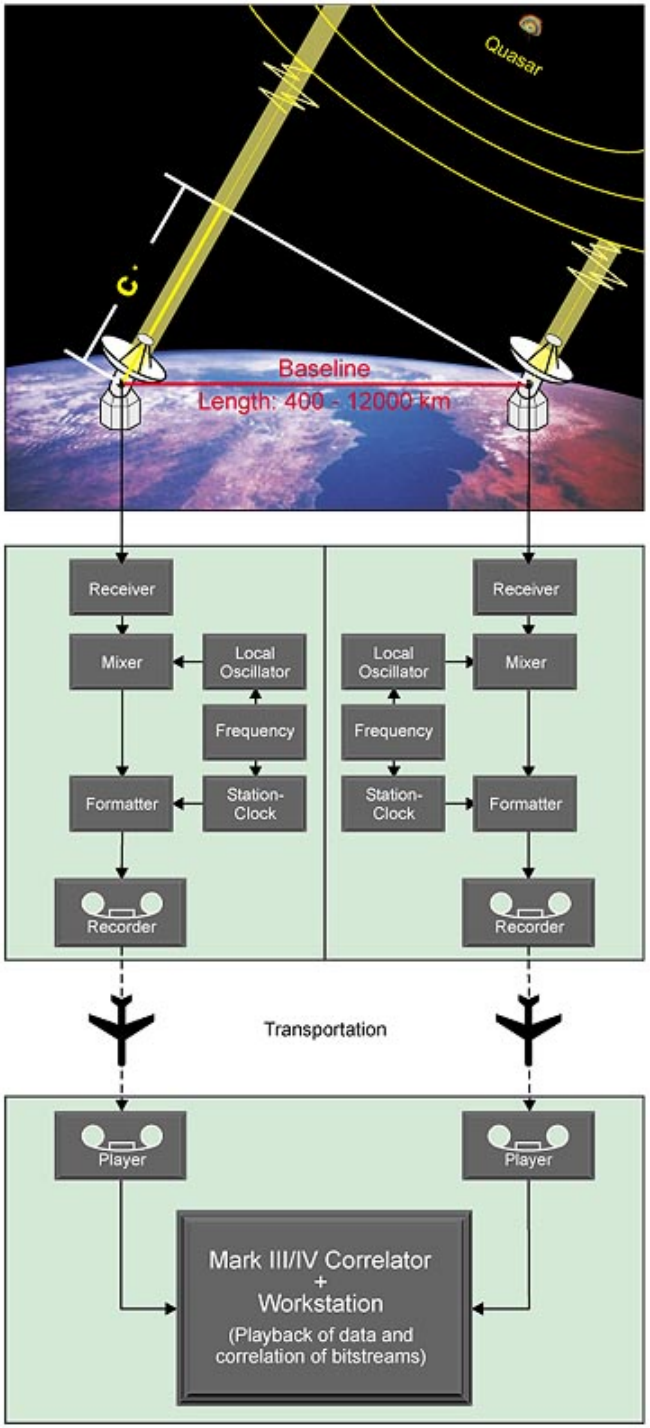
Satellite Laser Ranging

- Pros:
  - Absolute and direct measurement of satellite-receiver distance
- Cons:
  - Expensive
  - Heavy operation
  - Difficult to automate
  - => global coverage poor
- Applications:
  - Orbit determination
    - Earth's gravity field
    - Ocean altimetry
  - Precise positioning of ground stations
    - Geophysics
    - Geodesy



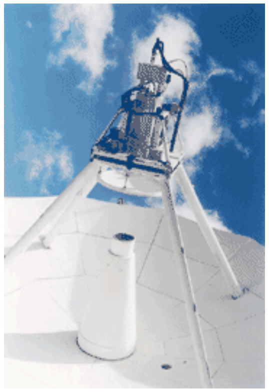
Very Long Baseline Interferometry = VLBI

- Radio-astronomy technique, used to locate and map stars, quasars (=quasi-stellar radio source = very energetic and distant galaxy), etc = "sources"
- Measures the time difference between the arrival at two Earth-based antennas of a radio wavefront emitted by a distant quasar
- Signal = noise, wavelength = 1-20 cm
- If the source positions are known ⇒ ground baseline ⇒ "geodetic" VLBI
- Time measurements precise to a few picoseconds ⇒ relative positions of the antennas to a few millimeters



VLBI

VLBI antenna at Algonquin, Canada



Cryogenic receiver

Hydrogen maser

Mark III correlator

VLBI

- The astronomic sources of geodetic VLBI (e.g. quasars) are located billions of light years away from Earth:
  - They appear point-like, with no motion
  - No need for modeling their motions (cf. satellite orbits) $\Rightarrow$ less errors
- Only technique capable of establishing a direct link between the inertial frame (radio sources) and the terrestrial reference frame
- Only technique capable of measuring all components of the Earth's rotation directly:
  - Variations of the Earth's spin axis in space (precession, nutation)
  - Variations of the Earth's spin axis relative to the Earth's crust (polar motion)
  - Rotational velocity and phase (Universal Time, UT).

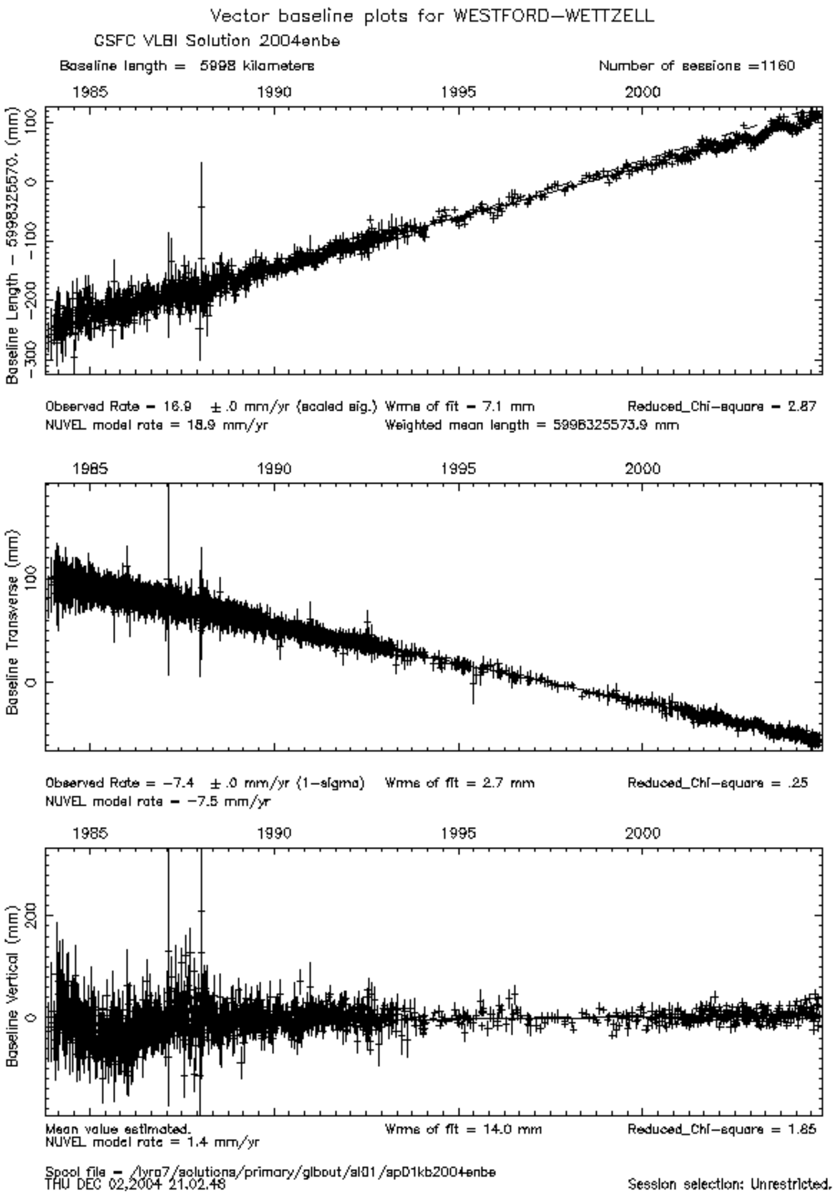
VLBI

VLBI site distribution

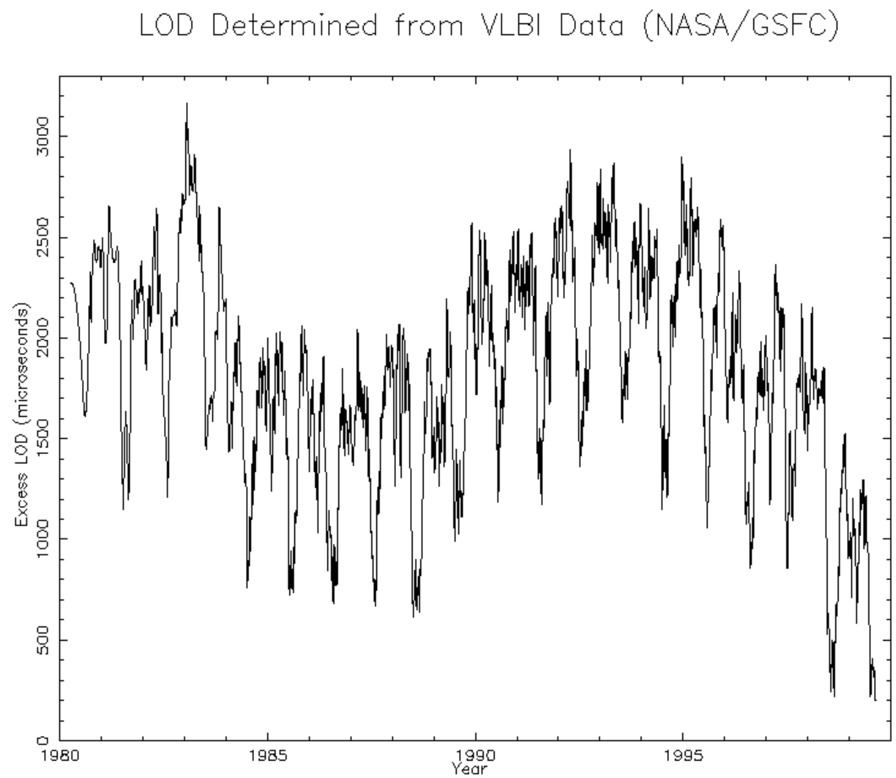
- Pros:
  - The most precise and accurate space geodetic technique
  - Direct link between inertial and terrestrial frames
- Cons:
  - Expensive
  - Heavy operation
  - Difficult to automate

  $\Rightarrow$ global coverage poor
- Applications:
  - Reference frames
  - Geophysics
  - Provides precession, nutation, polar motion, UT1

VLBI

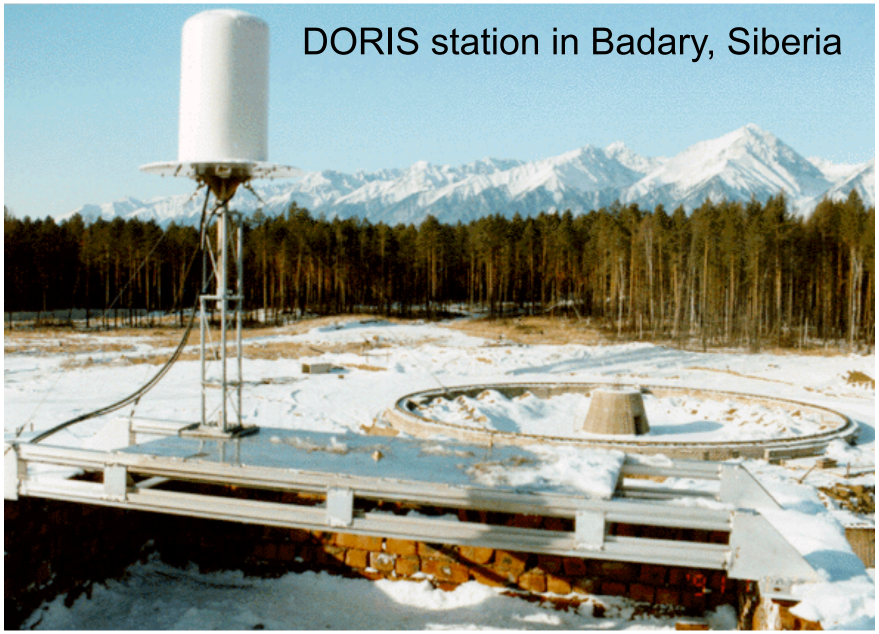


Vector baseline plots for WESTFORD–WETTZELL
GSFC VLBI Solution 2004enbe
Baseline length = 5998 kilometers
Number of sessions =1160
Baseline Length – 5998325570. (mm)
Observed Rate = 16.9 ± .0 mm/yr (scaled sig.) Wrms of fit = 7.1 mm Reduced_Chi-square = 2.87
NUVEL model rate = 18.9 mm/yr Weighted mean length = 5998325573.9 mm
Baseline Transverse (mm)
Observed Rate = –7.4 ± .0 mm/yr (1–sigma) Wrms of fit = 2.7 mm Reduced_Chi-square = .25
NUVEL model rate = –7.5 mm/yr
Baseline Vertical (mm)
Mean value estimated. Wrms of fit = 14.0 mm Reduced_Chi-square = 1.65
NUVEL model rate = 1.4 mm/yr
Spool file = /lyra7/solutions/primary/glbout/al01/apD1kb2004enbe
THU DEC 02,2004 21.02.48
Session selection: Unrestricted.



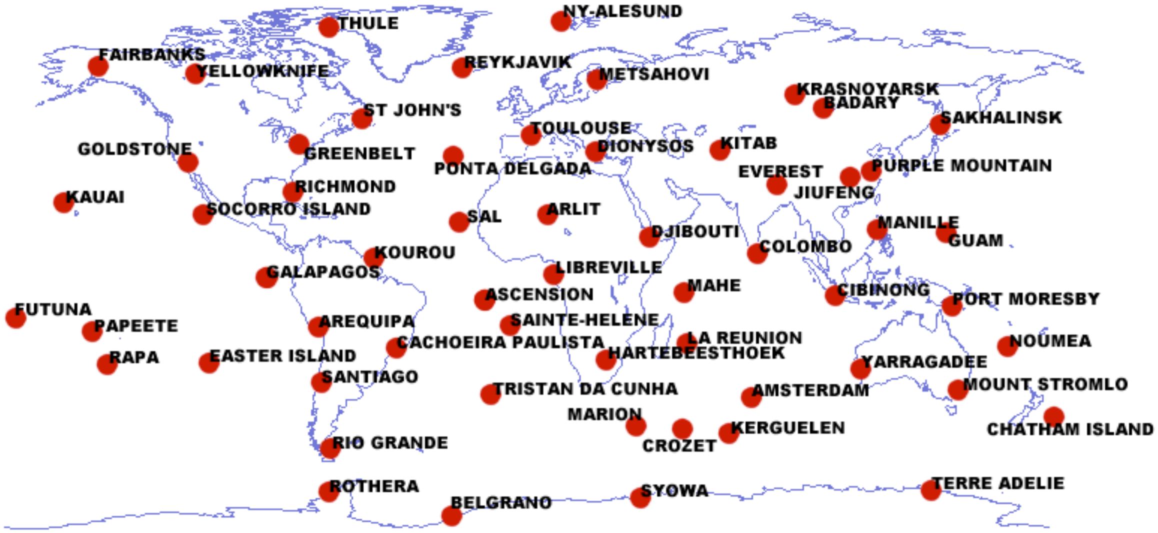
LOD Determined from VLBI Data (NASA/GSFC)
Excess LOD (microseconds)
Year

Doppler Orbitography



DORIS (France), PRARE (Germany):

- Doppler orbitography,
- Receiver in the satellite, emitter on the ground
- Satellite records data and downloads it to a data center (centralized system)
- DORIS on Spot 2, 3, 4, on ERS1 and 2, on Topex-Poseidon, on EnVISAT, on Jason
- Excellent geographic coverage

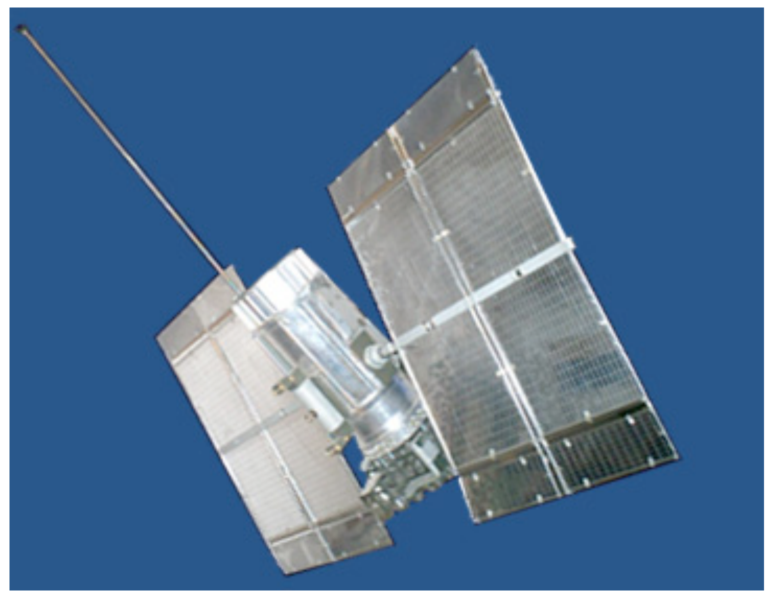


DORIS network

GLONASS

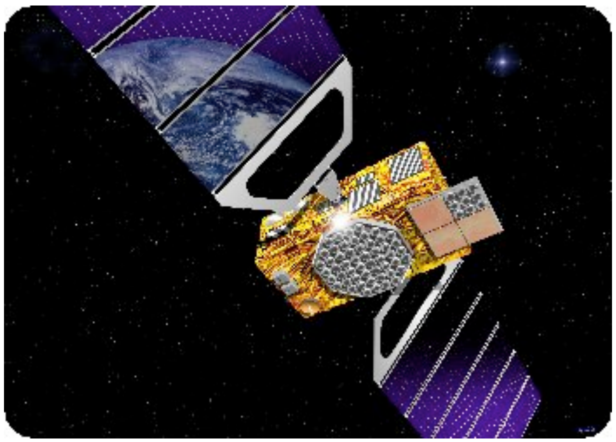
- “Russian GPS”
- First satellite launched in 1982
- As of December 2009 = 16 satellites operational
- Several manufacturers sell GPS/GLONASS receivers
- http://www.glonass-ianc.rsa.ru/

	GPS	GLONASS
Orbital planes	6	6
Orbit inclination	55	64.8
Orbit height	20200 km	19100 km
Carrier frequency	L_1: 1575.42 MHz L_2: 1227.60 MHz	L_1: 1602 + k 0.5625 MHz L_2: 1246 + k 0.4375 MHz k=1,...,24
Codes	CA-Code for L_1 P-Code for L_1 and L_2	CA-Code for L_1 P-Code for L_1 and L_2
System time	GPS-Time	UTC(SU)
Repeat time	Sidereal day	8 days



A GLONASS satellite

GALILEO



Signal			Central Frequency MHz	Chip rate Mchip/s	Ranging Code Encryption	Data rate symbol/s (bit/s)	Data encyption	Reference Service
Id	Name							
1	E5a-I	data	1176.45	10	None	50 (25)	None	OS/SoL
2	E5a-Q	pilot	1176.45	10	None	No data	~	OS/SoL
3	E5b-I	data	1207.14	10	None	250 (125)	some	OS/SoL/CS
4	E5b-Q	pilot	1207.14	10	None	No data	~	OS/SoL/CS
5	E6-A	data	1278.75	5	Government	tbd	Yes	PRS
6	E6-B	data	1278.75	5	Commercial	1000 (500)	Yes	CS
7	E6-C	pilot	1278.75	5	Commercial	No data	~	CS
8	E2-L1-E1-A	data	1575.42	M	Government	tbd	Yes	PRS
9	E2-L1-E1-B	data	1575.42	2	None	250 (125)	Some	OS/SoL/CS
10	E2-L1-E1-C	pilot	1575.42	2	None	No data	~	OS/SoL/CS
11	L6 downlink	data	1544.10	~	~	~	~	SAR

- “European GPS”, + China, + Israel
- Commercially-oriented system, (GPS was originally military)
- Original plan: ~30 launches 2006-2008, operational 2008: 27 operational + 3 spares
- 3 circular orbits at 23,616 km, inclination 56 degrees
- L-band, dual-frequency
- Key difference with GPS: integrity monitoring
- Commercial services
- http://europa.eu.int/comm/dgs/energy_transport/galileo/index_en.htm
- GNSS

	Open Service (OS)	Commercial Service (CS)		Public Regulated Service (PRS)		Safety of Life Service (SoL)
Coverage	Global	Global	Local	Global	Local	Global
Accuracy - horizontal (h) - vertical (v)	h = 4m v = 8m (dual frequency) h = 15 m v = 35 m (mono frequency)	<1m (dual frequency)	< 10cm (locally augmented signals)	h = 6,5m v = 12m	1m (locally augmented signals)	4-6m (dual frequency)
Availability	99.8%	99.8%		99-99.9%		99.8%
Integrity	No	Value-added service		Yes		Yes