Other Space
Geodetic Techniques

E. Calais
Purdue University - EAS Department
Civil 3273 – ecalais@purdue.edu
Satellite Laser Ranging

- Measurement of distance (=range) between a ground station and a satellite = Satellite Laser Ranging (SLR)
- 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 $t_{\text{emission}} - t_{\text{reception}}$
- 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)
Satellite Laser Ranging

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)
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, 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) ⇒ less errors
- Only technique capable of establishing a direct link between the quasi-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

Pros:
- The most precise and accurate space geodetic technique
- Direct link between inertial and terrestrial frames

Cons:
- Expensive
- Heavy operation
- Difficult to automate
  ⇒ global coverage poor

Applications:
- Reference frames
- Geophysics
- Provides precession, nutation, polar motion, UT1
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
GLONASS

- “Russian GPS”
- First satellite launched in 1982
- As of March 2005 = 12 satellites operational
- Several manufacturers sell GPS/GLONASS receivers
- [www.glonass-center.ru](http://www.glonass-center.ru)

<table>
<thead>
<tr>
<th></th>
<th>GPS</th>
<th>GLONASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbital planes</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Orbit inclination</td>
<td>55</td>
<td>64.8</td>
</tr>
<tr>
<td>Orbit height</td>
<td>20200 km</td>
<td>19100 km</td>
</tr>
</tbody>
</table>
| Carrier frequency    | \(L_1: 1575.42 \text{ MHz}\)  \
|                      | \(L_2: 1227.60 \text{ MHz}\)       | \(L_1: 1602 + k \times 0.5625 \text{ MHz}\)  \
|                      |                  | \(L_2: 1246 + k \times 0.4375 \text{ MHz}\)  \
|                      |                  | \(k=1,...,24\)   |
| 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

“European GPS”, + China, + Israel
Commercially-oriented system, (GPS was originally military)
~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
VLBI-GPS comparison

<table>
<thead>
<tr>
<th></th>
<th>GPS mm/yr</th>
<th>VLBI mm/yr</th>
<th>Time span of the GPS data in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATERA</td>
<td>$-0.6 \pm 0.8$</td>
<td>$-0.5 \pm 0.5$</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>$24.1 \pm 0.4$</td>
<td>$24.0 \pm 0.1$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$17.4 \pm 0.2$</td>
<td>$16.9 \pm 0.1$</td>
<td></td>
</tr>
<tr>
<td>MEDICINA</td>
<td>$0.4 \pm 1.6$</td>
<td>$-4.5 \pm 0.6$</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>$24.5 \pm 0.9$</td>
<td>$23.2 \pm 0.1$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$14.9 \pm 0.5$</td>
<td>$15.2 \pm 0.1$</td>
<td></td>
</tr>
<tr>
<td>NOTO</td>
<td>$-4.2 \pm 1.0$</td>
<td>$-2.3 \pm 0.5$</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>$21.8 \pm 0.6$</td>
<td>$22.5 \pm 0.1$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$16.6 \pm 0.3$</td>
<td>$17.1 \pm 0.1$</td>
<td></td>
</tr>
</tbody>
</table>
GPS-DORIS-SLR comparison