Science Overview and VLBI2010

Dan MacMillan
NVI, Inc., NASA/GSFC

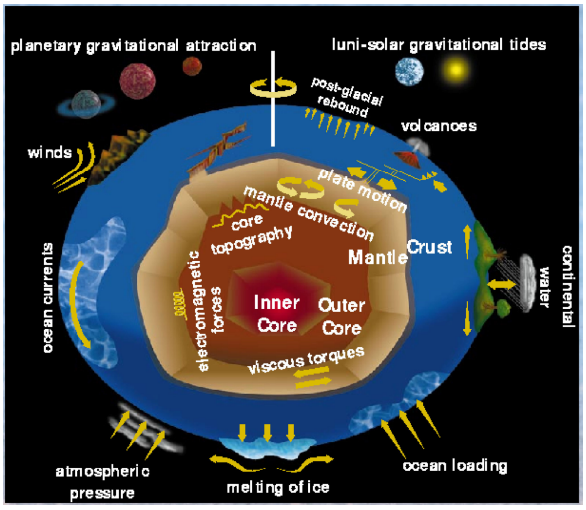
Three Components of Space Geodesy

- Terrestrial Reference Frame (TRF)
- Celestial Reference Frame (CRF)
- Earth Orientation Parameters (EOP)

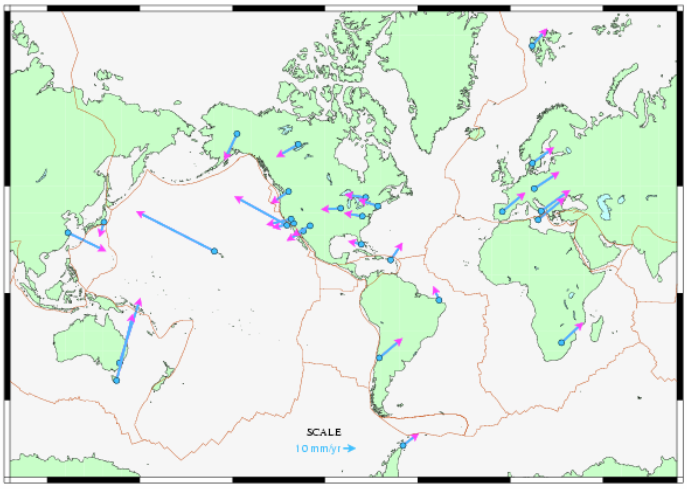
Terrestrial Reference Frame

- Define the positions and velocities of a dense set of reference sites over the entire Earth
- Contributions from VLBI, GPS, SLR, and DORIS
  - VLBI – scale of TRF, nutation, UT1-UTC
  - GPS – polar motion, densification
  - SLR – center of mass, scale of TRF
  - DORIS – global coverage

Causes of Site Motion and Variations in Earth Orientation



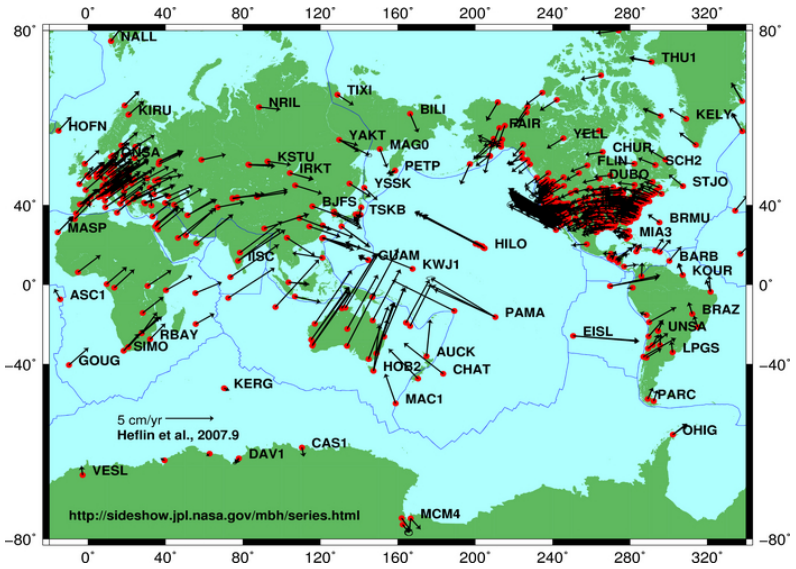
Selected VLBI Velocities



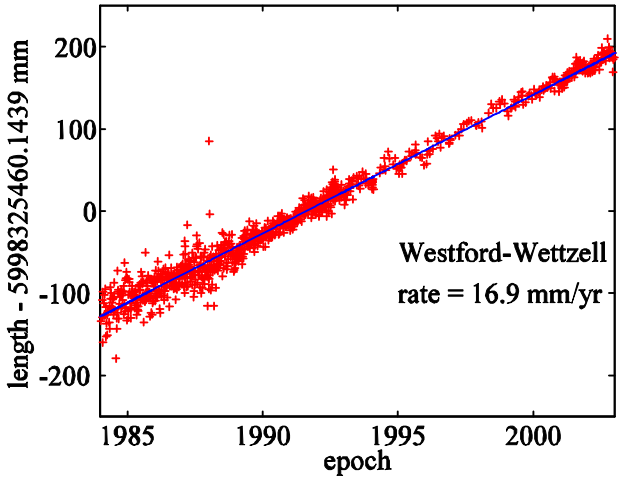
NUVEL1A-NNR reference frame.

A

GPS Velocities



Westford- Wettzell Baseline



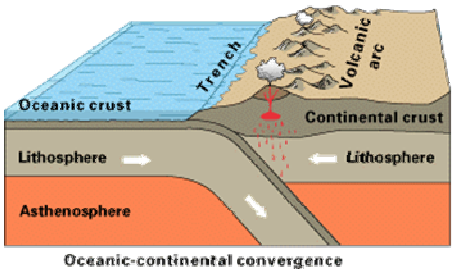
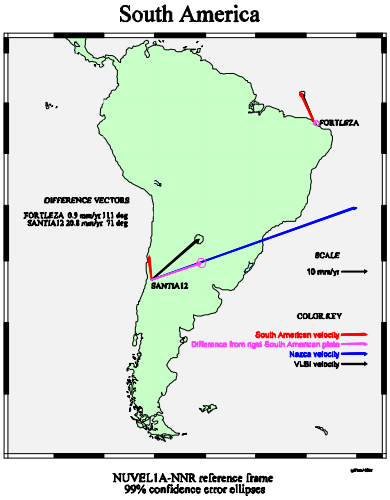


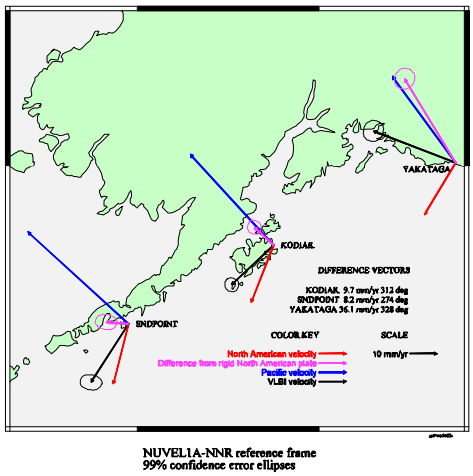
Plate Tectonics

- **Rigid plate motion**
- **Plate boundary region**
- **Earthquakes**

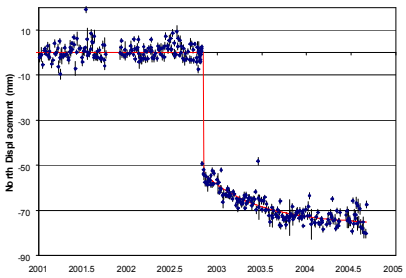
South America Velocities from VLBI

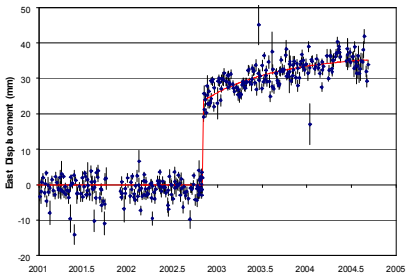


Southern Alaska Velocities from VLBI

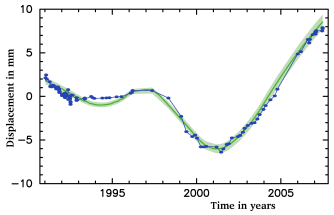


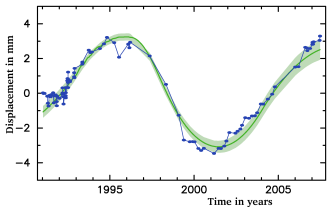
Gilcreek North and East following the 2002 Denali Earthquake



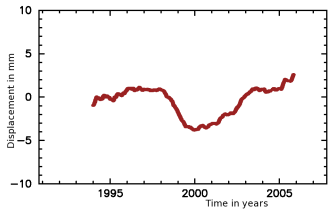


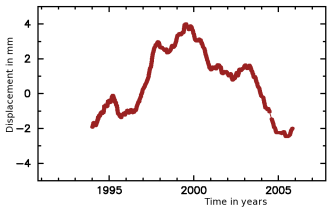
Nonlinear motion of the station PIETOWN (New Mexico)





North and East motion (blue) from measured tilt variation of the antenna compared with the position of the antenna estimated from VLBI analysis (green smoothed curve).

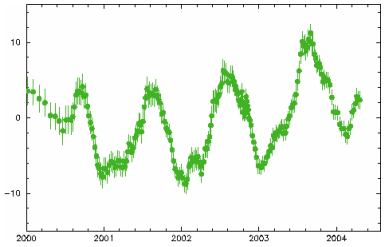




North and East motion estimated from measurements from collocated GPS receiver 50 meters from the VLBI antenna

Why Investigate Mass Loading Effects?

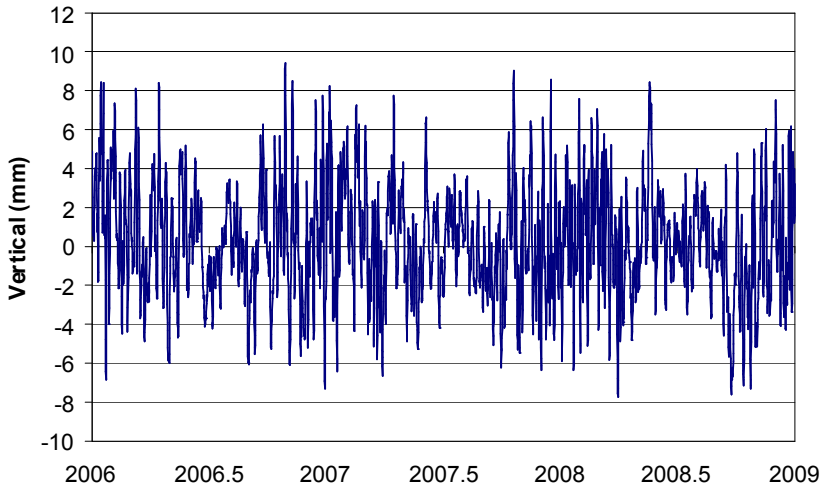
Annual signals are clearly seen in observed VLBI baseline length and site position time series



Baseline length time series (in mm) for Algonquin Park (Ontario) to Wettzell (Germany) smoothed with 2 month boxcar filter.

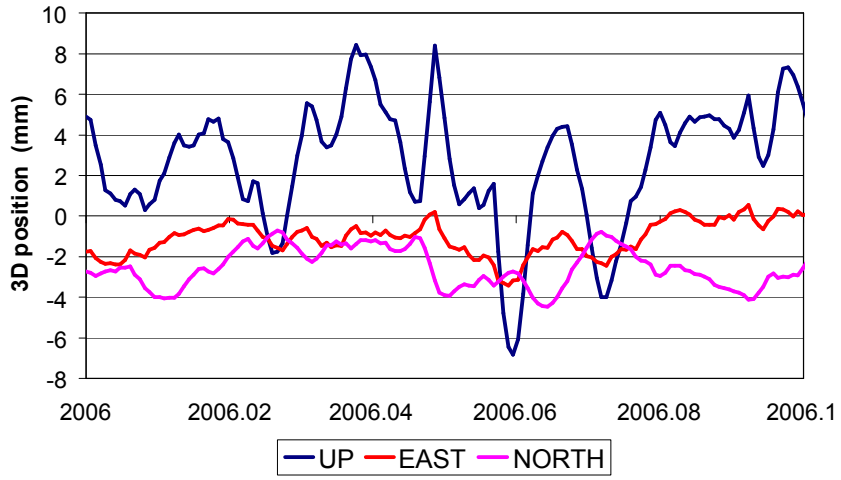
- Mass loading effects can produce site vertical variations of 15-20 mm and annual amplitudes as large as 4 mm at VLBI stations
- For problems like determining the rate of global sea level rise, expected to be ~1-2 mm/year, we need to monitor nontectonic VLBI site position rates at the sub millimeter level

Effect of Pressure Loading at Westford

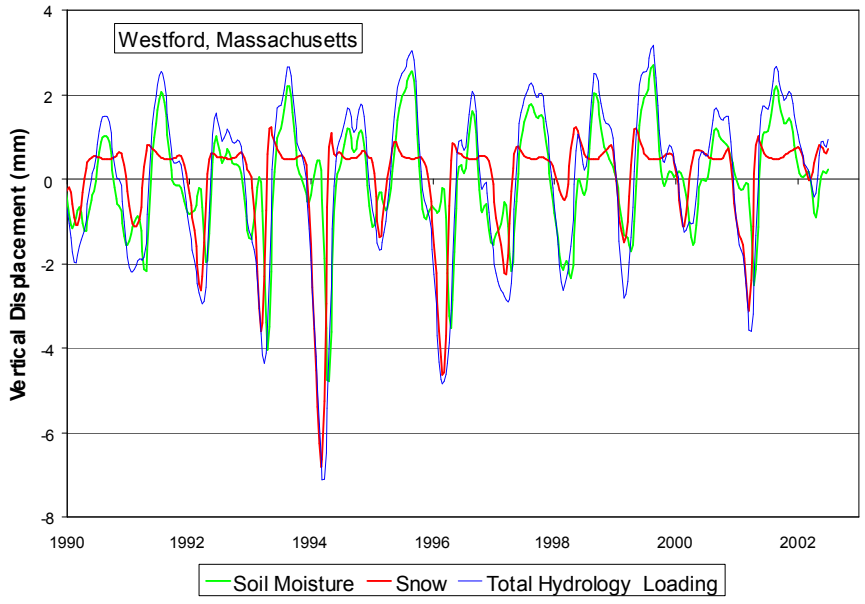


Pressure Loading Sensitivity ~ 0.2 – 0.6 mm/mbar

Effect of Pressure Loading at Westford



April 27-30, 2009 TOW Meeting 15

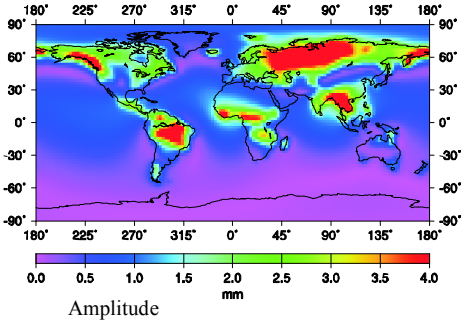


April 27-30, 2009 TOW Meeting 16

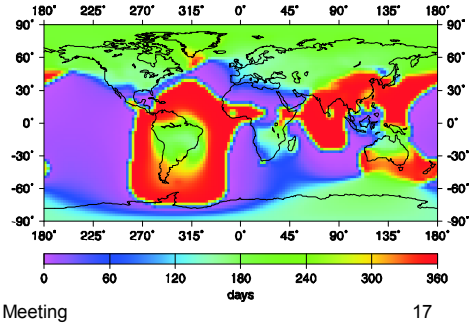
Hydrology Loading

Milly and Shmakin [2002]

- Global model (1° x 1°) of land water and energy balance
- Model storage outputs (soil water, groundwater, and snow) yield monthly continental water storage
- Forced by estimated precipitation, downwelling radiation, and near-surface atmosphere conditions



Amplitude



Phase

Antenna Thermal Expansion

- Model includes delay contributions arising from deformation of the antenna pillar and foundation, axis offset, vertex and subreflector heights.
- Expansion depends on dimensions of antenna, material expansion coefficients, and temperature variation

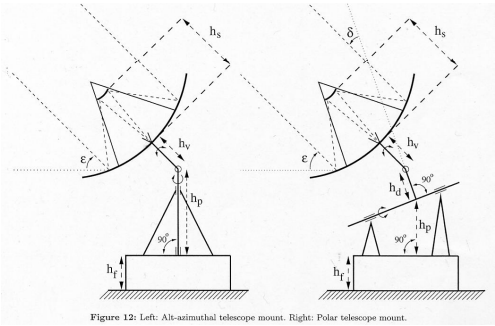
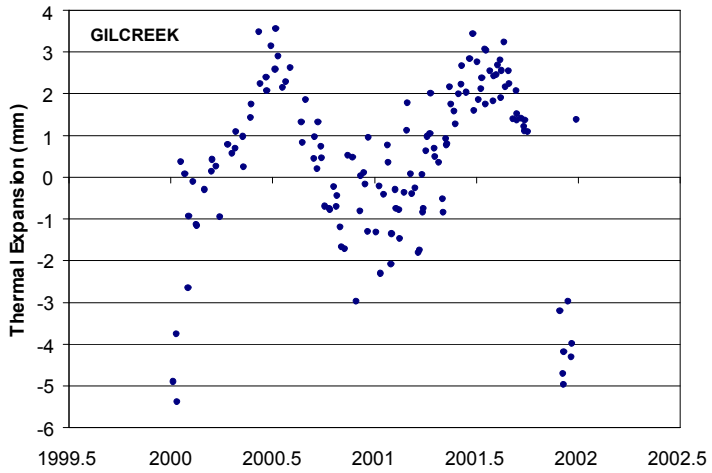


Figure 12: Left: Alt-azimuthal telescope mount. Right: Polar telescope mount.



antenna height ~ 15 m, annual temperature swing ~ 40 K,

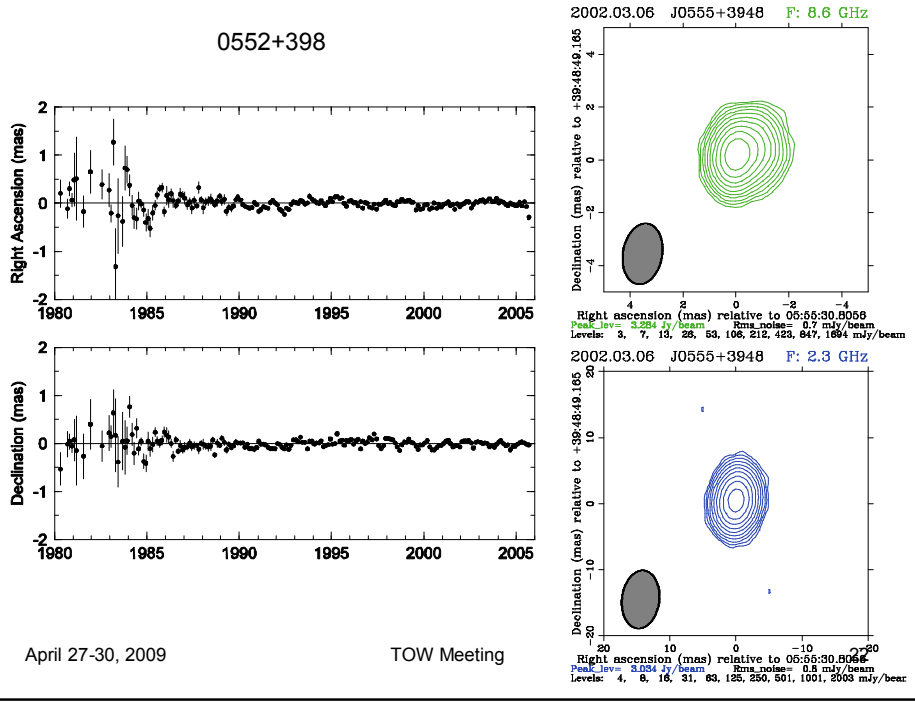
expansion coefficient ~ 1.2x10-5 => peak-to-peak variation ~ 7 mm

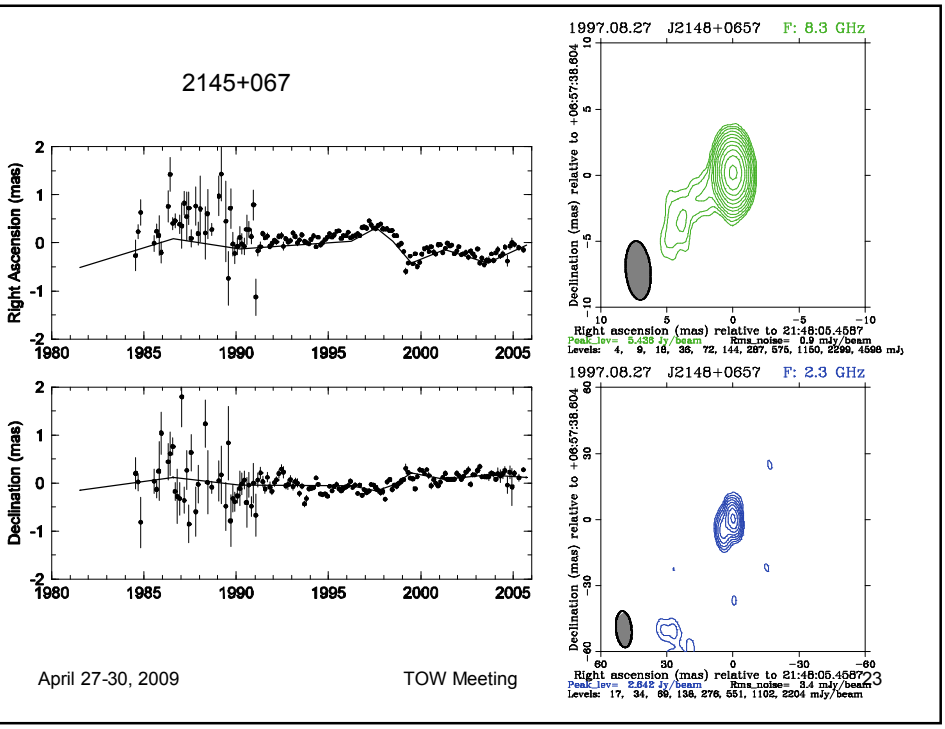
Celestial Reference Frame (CRF)

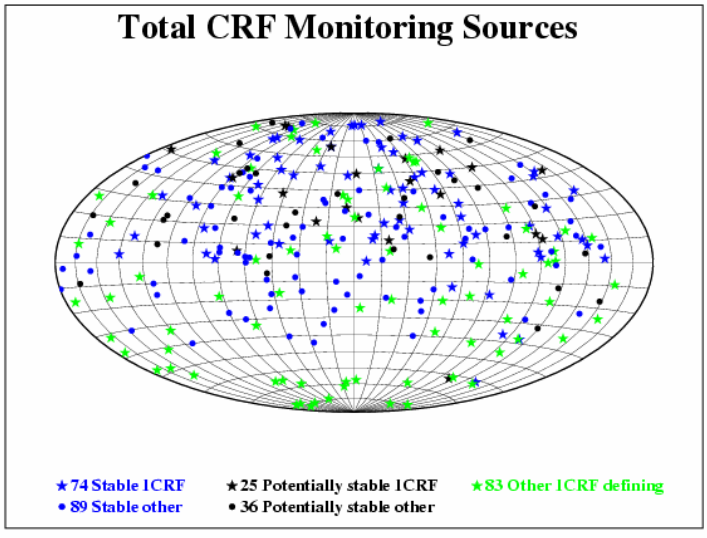
- Extragalactic radio sources serve as the definition of all positions on the sky.
  - positions measured by VLBI
- Most sessions use about 100 sources, but CRF needs about 600 (or more) sources
  - Have been monitoring positions and strengths
  - CRF sources being added to R1s and RDVs
- CRF provides inertial frame for absolute orientation of Earth in the Universe
  - allows measurement of properties of mantle and core
  - necessary for maintaining satellite orbits

ICRF2

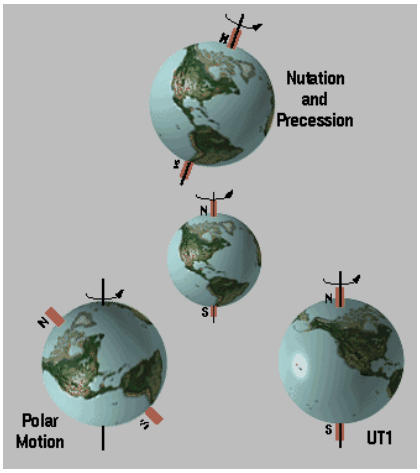
- ICRF2 is the Second Realization of International Celestial Reference Frame -- the first ICRF was adopted in 1997
- Will be presented at the International Astronomical Union General Assembly in August
- ICRF2 working group has analyzed many test solutions from different analysis centers
  - Identified unstable sources
  - Determined good distribution of ~300 defining sources over the sky
  - Investigated different analysis strategies and solution parametrizations
  - Currently in process of generating final solution




2145+067
Right Ascension (mas)
Declination (mas)
1980
1985
1990
1995
2000
2005
1997.08.27 J2148+0657 F: 8.3 GHz
Declination (mas) relative to +06:57:38.604
Right ascension (mas) relative to 21:48:05.4587
Peak_Jsv= 5.435 Jy/beam Rms_noise= 0.9 mJy/beam
Levels: 4, 9, 18, 36, 72, 144, 287, 575, 1150, 2299, 4598 mJy
1997.08.27 J2148+0657 F: 2.3 GHz
Declination (mas) relative to +06:57:38.604
Right ascension (mas) relative to 21:48:05.456723
Peak_Jsv= 2.842 Jy/beam Rms_noise= 3.4 mJy/beam
Levels: 17, 34, 69, 138, 276, 551, 1102, 2204 mJy/beam
April 27-30, 2009
TOW Meeting


Total CRF Monitoring Sources
★74 Stable ICRF
• 89 Stable other
★25 Potentially stable ICRF
• 36 Potentially stable other
★83 Other ICRF defining

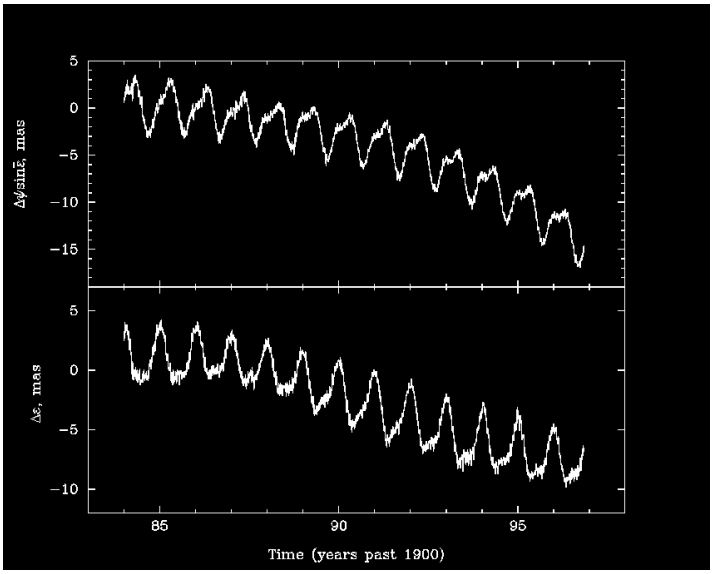
Earth Orientation Parameters (EOP)



Nutation/precession: periodic and long-term motion of the spin axis relative to CRF

Polar motion: motion of the geographic pole relative to the spin axis

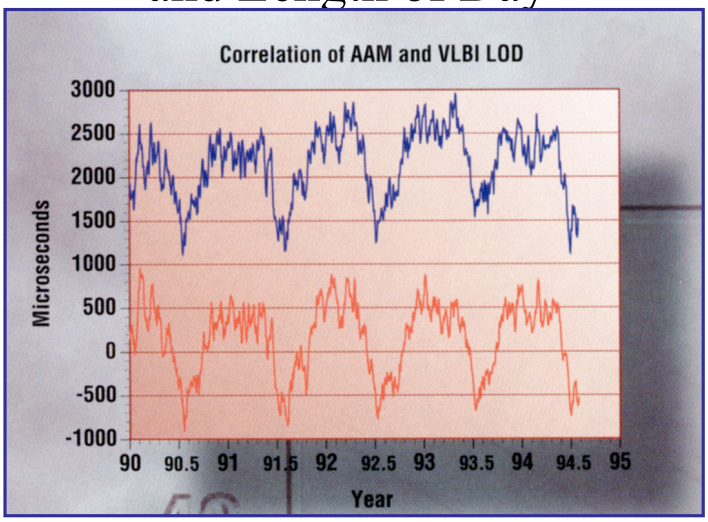
UT1: describes the non uniform daily rotation of the Earth

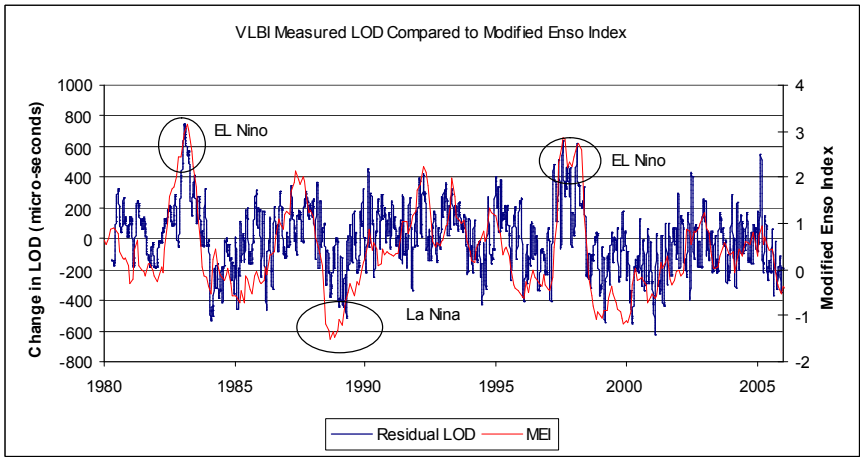


Nutation:

Celestial Pole moves in space

Atmospheric Angular Momentum and Length of Day





VLBI measures changes in the Length of Day at the level of a few microseconds. El Nino's result in angular momentum going from the Earth into the oceans and the atmospheres. The Earth's rotation slows down (days are longer), and this effect is measured by VLBI.

VLBI2010 Specification

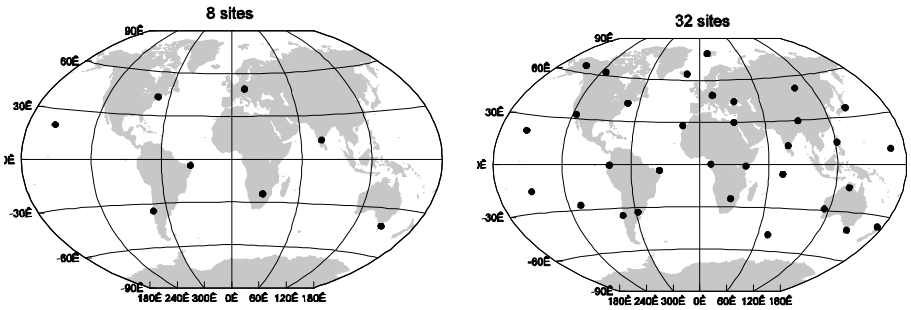
• Global network of small (at least 12 m diameter) fast-slewing antennas.

• Choose antennas that are both mechanically reliable and cost effective enough to be reproduced economically

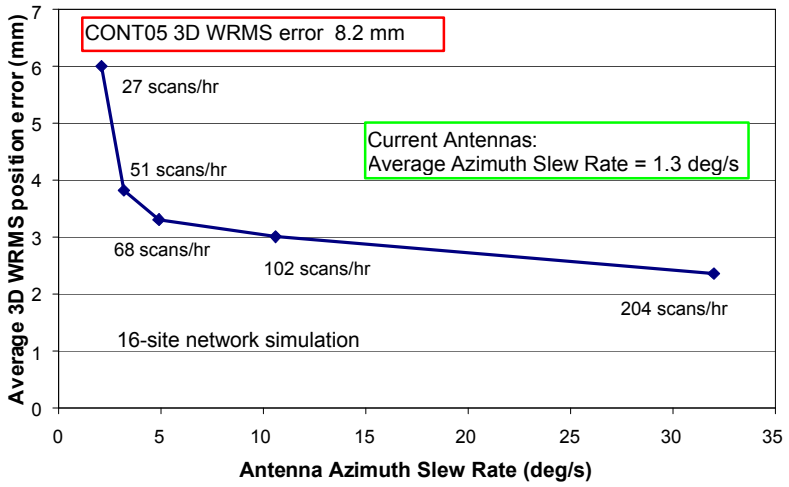
• Expand the global network of VLBI stations to provide superior global coverage compared to the current network of antennas that is dominated by Northern Hemisphere sites.

• A critical part of the development of specifications for VLBI2010 is the investigation of the geodetic performance of networks of VLBI2010 antennas.

• IVS VLBI2010 Committee used a Monte Carlo procedure for simulating the performance of different antenna networks and observing scenarios.



VLBI2010 8-site and 32-site simulation networks



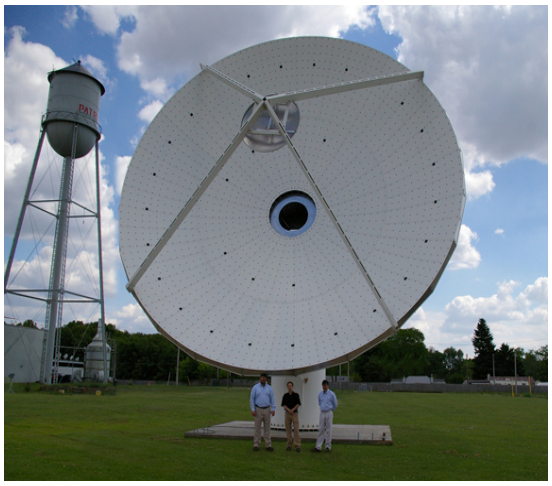
- Simulation of performance of VLBI2010 antenna with different slewing rates
- Driven by input simulated troposphere, clock, and measurement noise

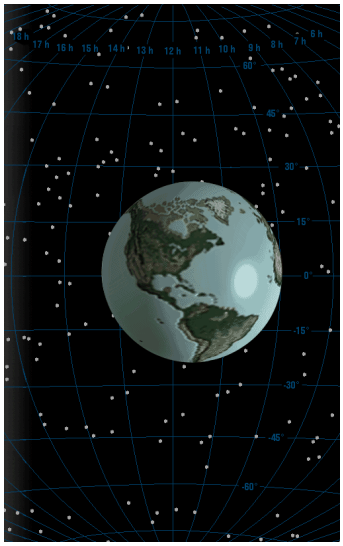
Improvements in Precision with VLBI2010 Based on Simulations

	CONT05	VLBI2010
3D RMS Site Position	8 mm	2-3 mm
TRF Scale	0.36 ppb	0.07-0.15 ppb
EOP	40 uas	8-15 uas

Ranges for scale and EOP for network sizes from 8 to 32 sites

Patriot 12 m Antenna





"Looking at everything possible with a sharply improved capability is a good prescription for making important contributions. Who would have guessed even a decade ago that the most reliable estimate yet of the shape of the core-mantle boundary would have come from VLBI observations of quasars from the surface of the Earth?"
-- Prof. Irwin Shapiro, Acceptance speech for the William Bowie Medal of the American Geophysical Union (1993).