

SPACE GEODESY

NASA's Role in VLBI

November 20, 2013

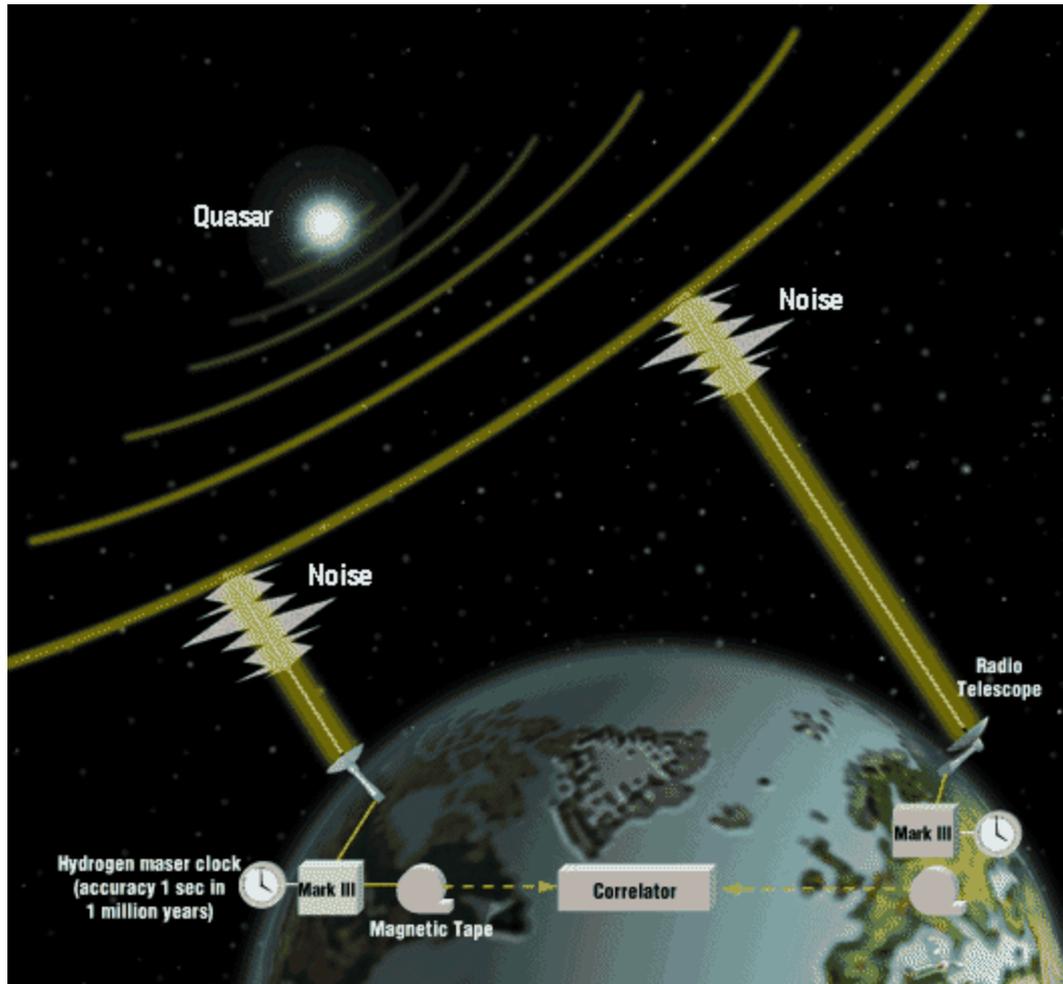
Nigerian Delegation Visit to GSFC

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NVI Inc/NASA, GSFC

PROJECT



What is VLBI?



The VLBI measurement technique consists of measuring the difference in arrival time of a signal from a distance source at two different VLBI antennas. This difference in arrival time is called the 'delay'.

The delay is influenced by anything that effects the propagation of the radio wave or that changes the path.

Delay measurements accurate to $\sim 30 \text{ ps} = 7.5 \text{ mm}$



TRF, CRF, and EOP



The VLBI stations are part of the Terrestrial Reference Frame (TRF).

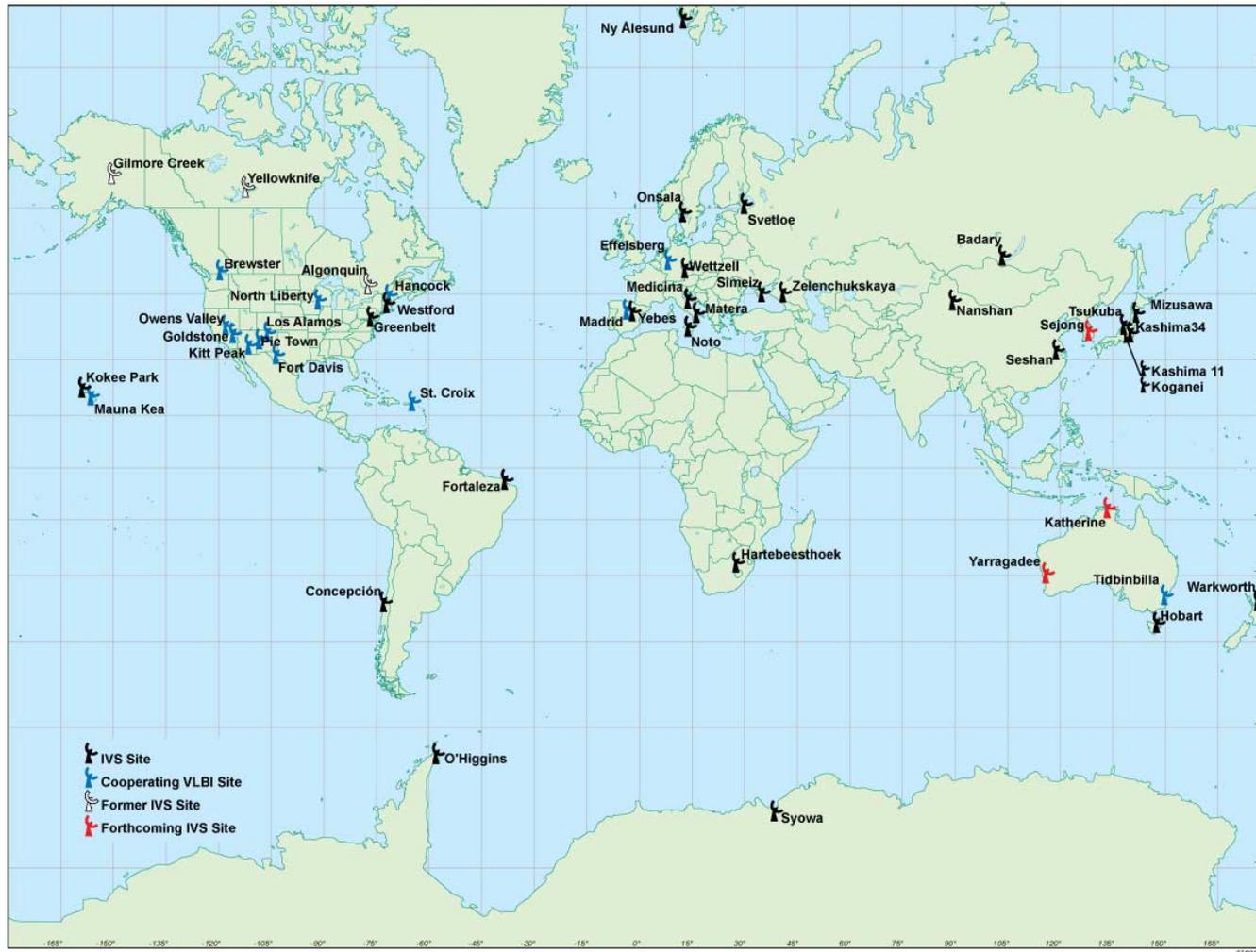
The Quasars are part of the Celestial Reference Frame (CRF).

The TRF is connected to the CRF by Earth Orientation Parameters (EOP).

I will say a few words about all three.



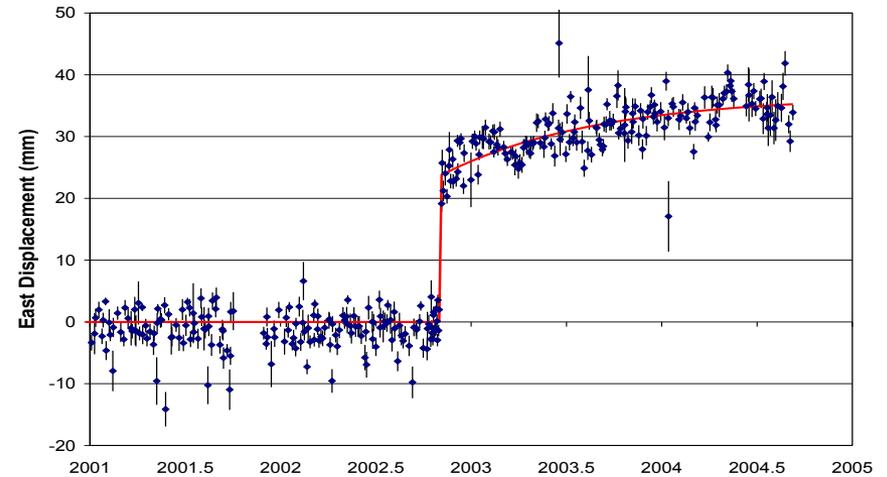
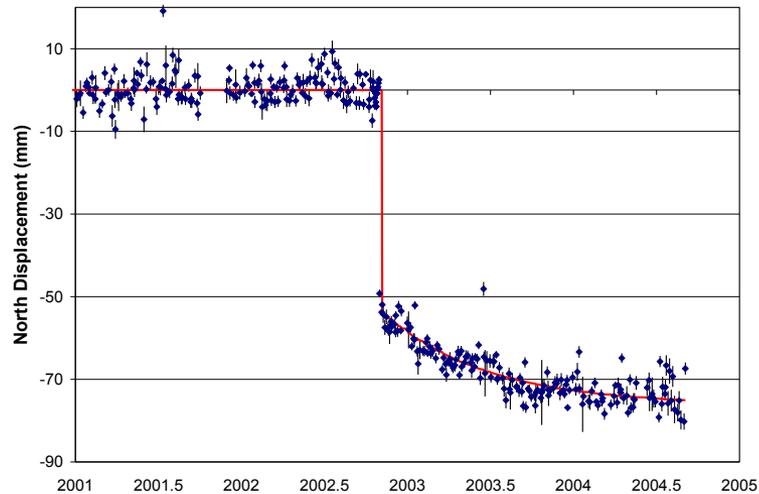
VLBI Stations in 2013



VLBI helps set the scale of the ITRF

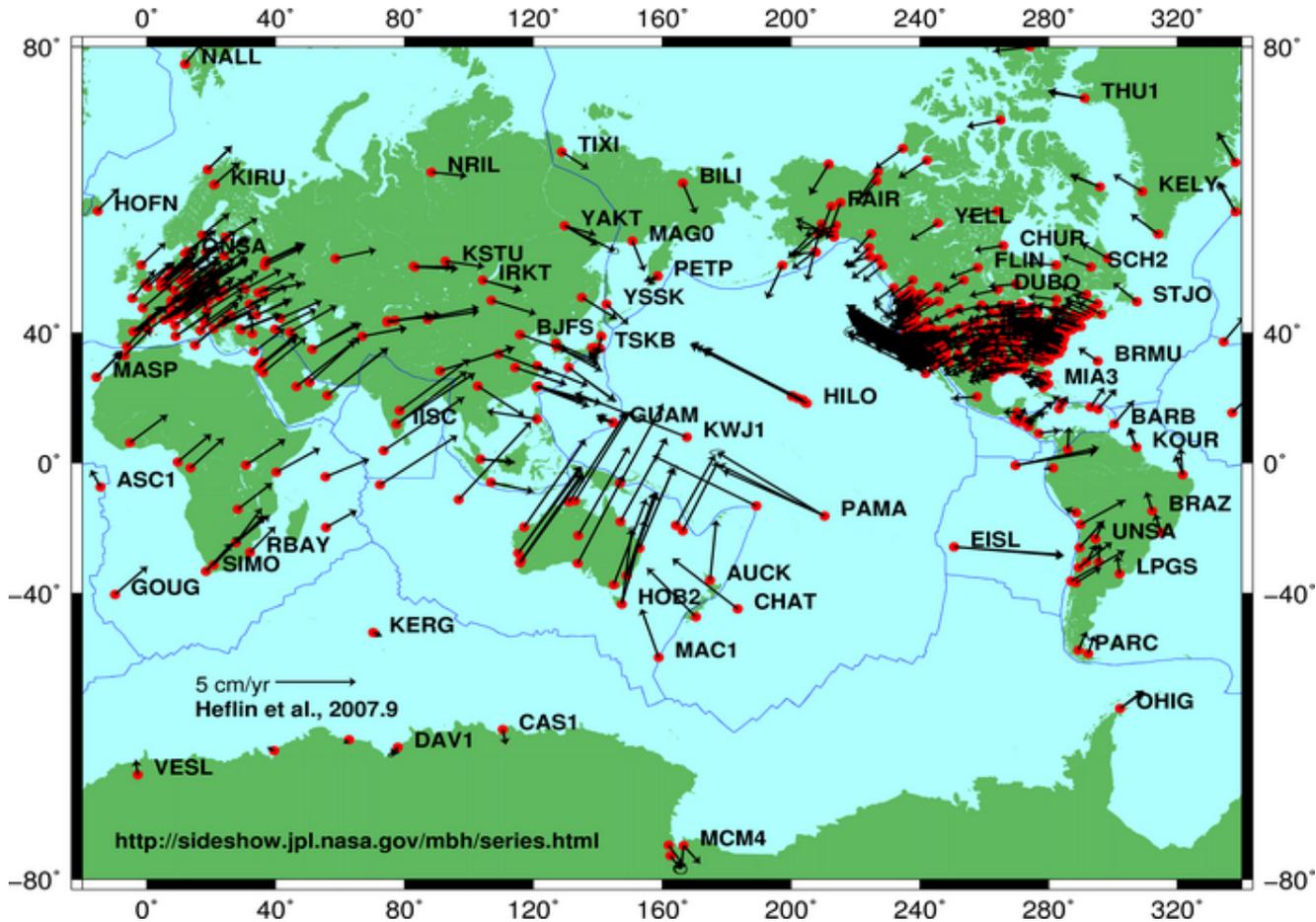
The red sites in Australia are now active.

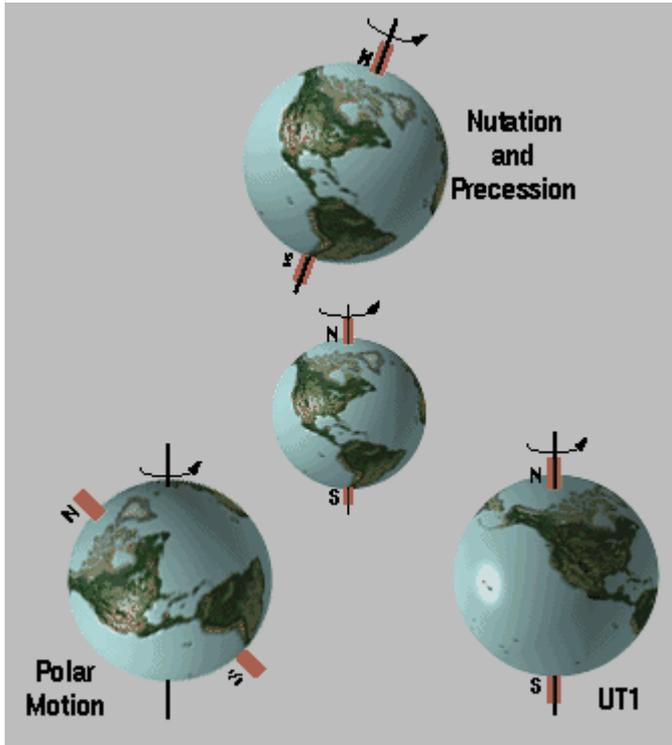
Gilcreek VLBI Antenna following 2002 Denali Earthquake



Terrestrial Reference Frame

Selected GPS Velocities





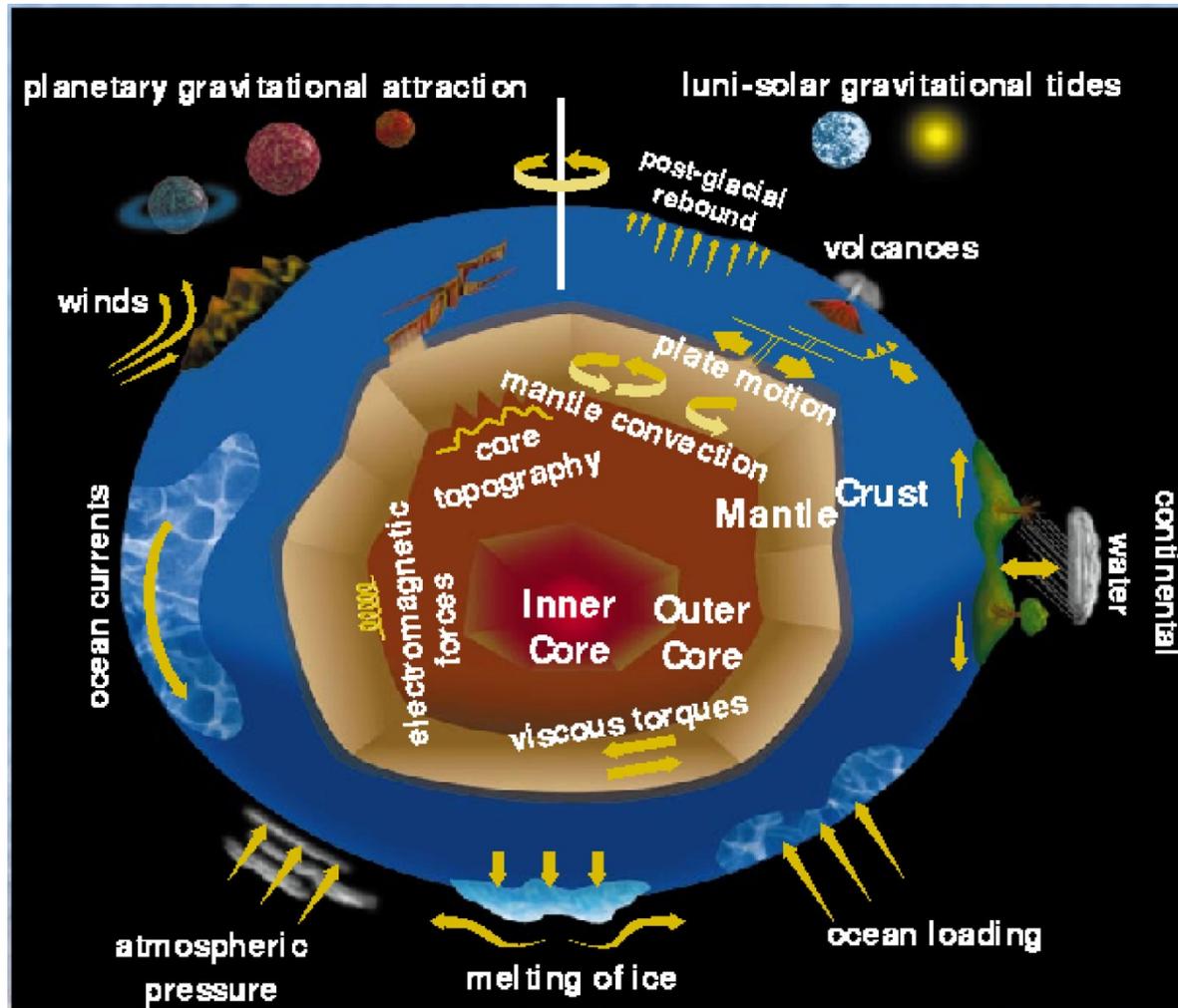
Nutation and Precession measure the orientation of the spin-axis with respect to the celestial reference frame.

Polar motion measures the spin-axis in an Earth-fixed frame with respect to the nominal pole.

UT1 measures the rotation about the spin-axis. The time derivative of UT1 is the change in the length of day, or LOD.

Changes in the orientation of the pole, or the spin axis, are caused by external forces, or by the exchange of angular momentum between the solid Earth, the oceans and the atmosphere.

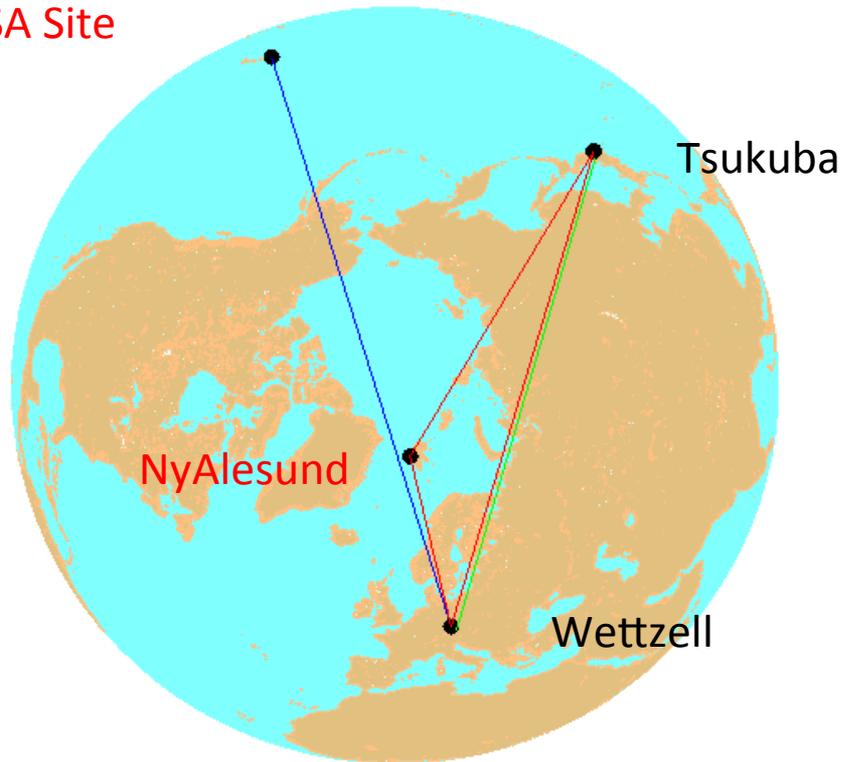
Influences on Earth Rotation



Intensive Networks

Intensive Networks

NASA Site



— IVS-INT1

— IVS-INT2

— IVS-INT3

Because accurate EOP measurements (especially UT1) is crucial to maintaining satellite orbits, UT1 is measured everyday with special VLBI sessions called intensives.

The INT1s occur Monday-Friday.

The INT2s and INT3s on weekends.



Rapid Sessions (R1s and R4s)



The R1s and R4s are 24 hour sessions designed to provide precise rapid measurements of EOP.

R1s run every Monday, and are scheduled by NASA.

R4s every Thursday, and are scheduled by USNO.

Networks vary, but core stations include Kokee, Westford, NyAlesund, Wettzell, Tsukuba.

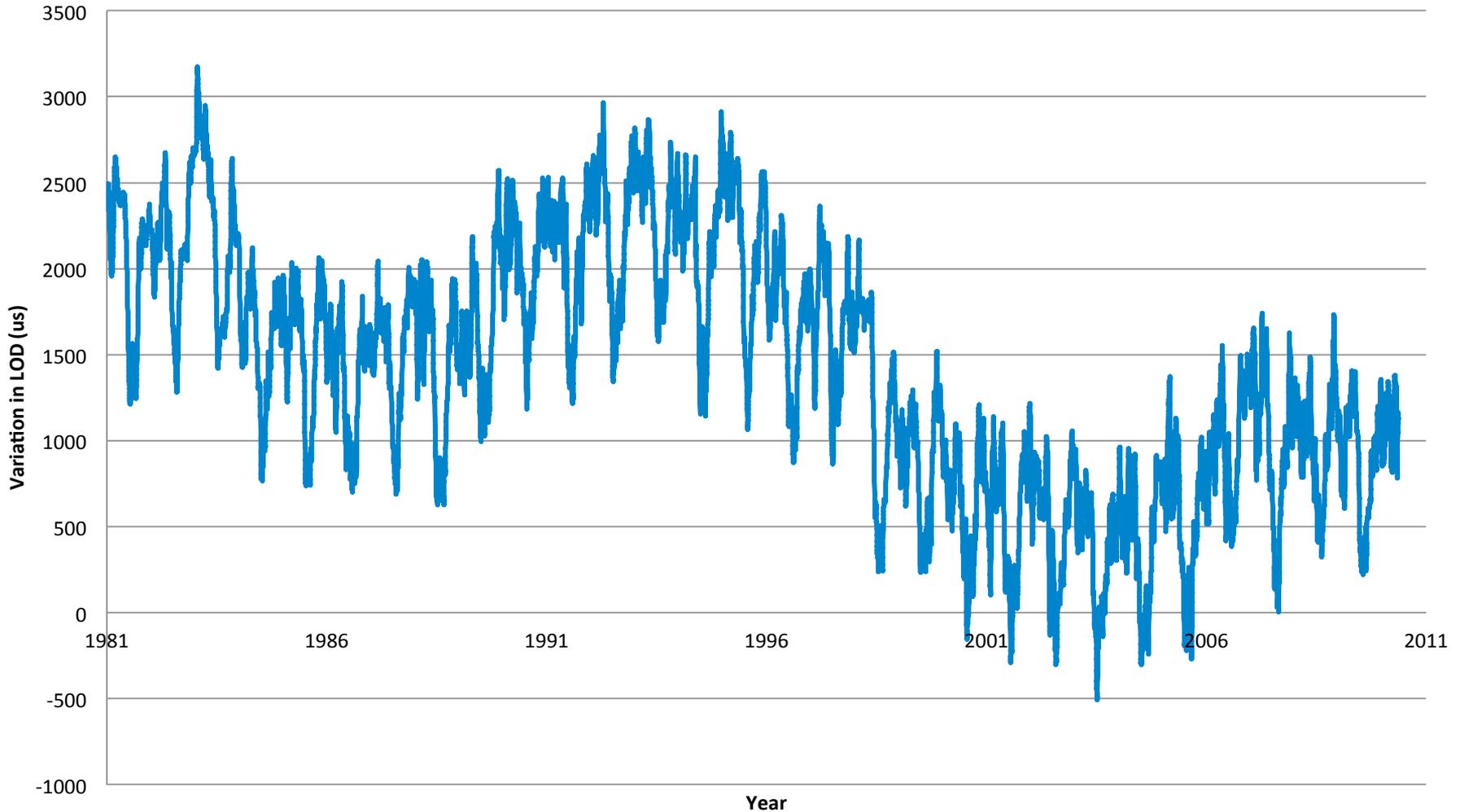
This session is R1612.



Variation in Earth Rotation



VLBI Measured Length of Day (LOD)

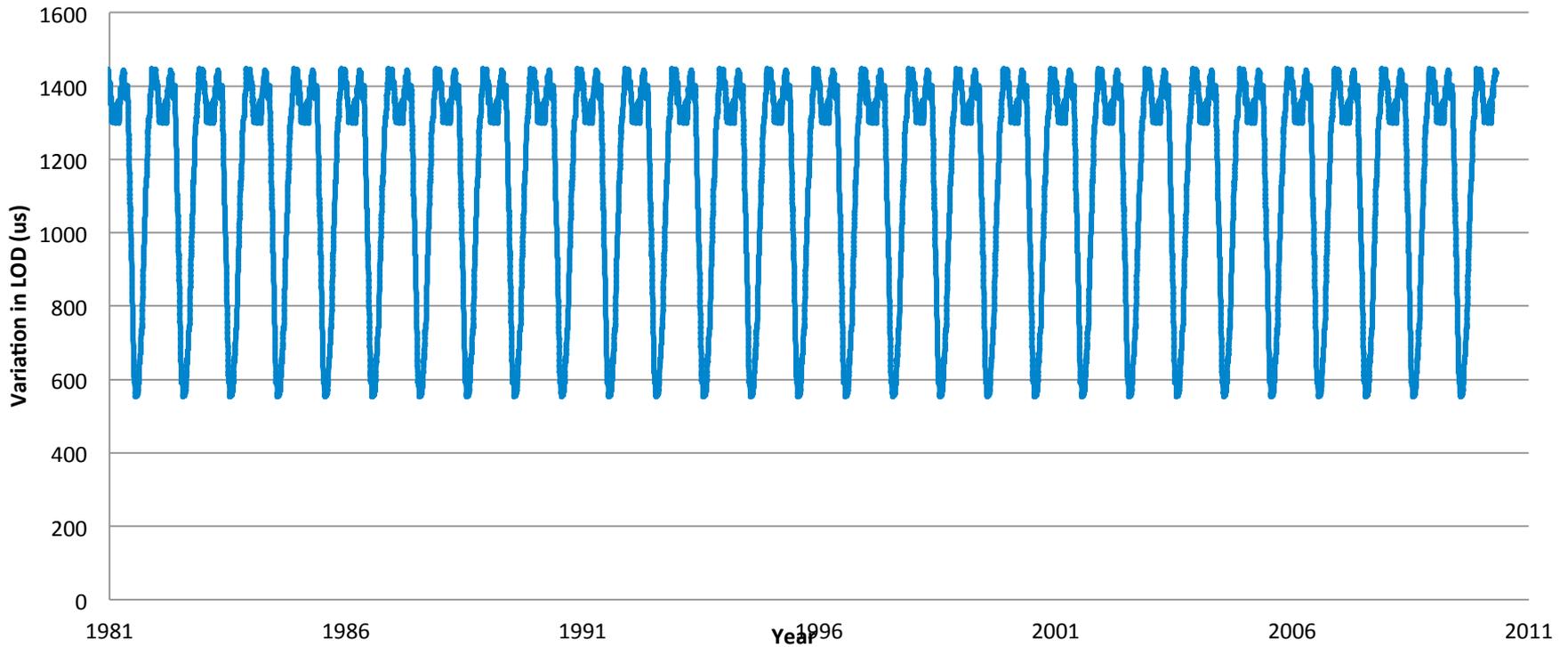




Variation in Earth Rotation



Seasonal Terms in LOD



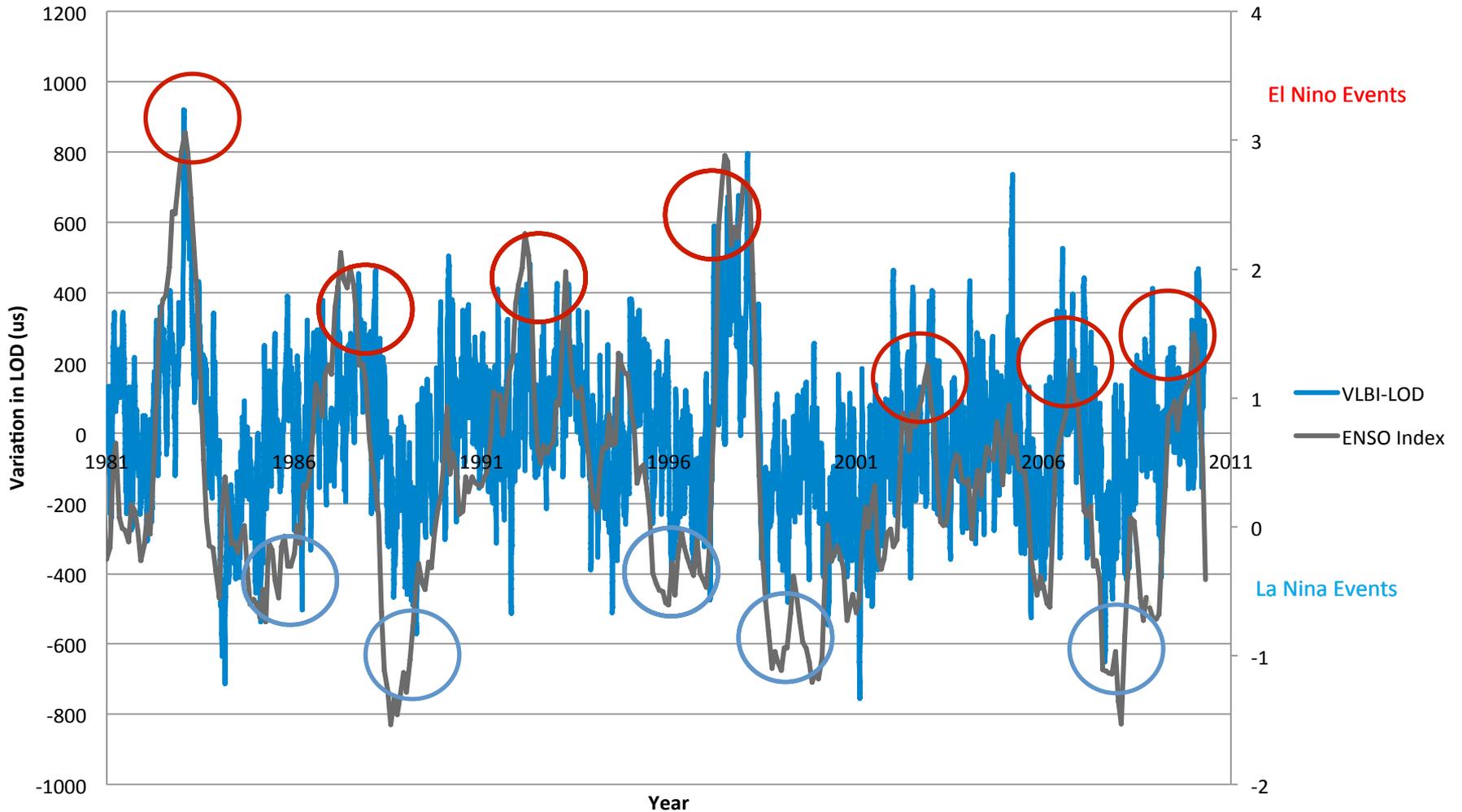
Days are longer by (800 microsecond) in Northern Hemisphere Winter



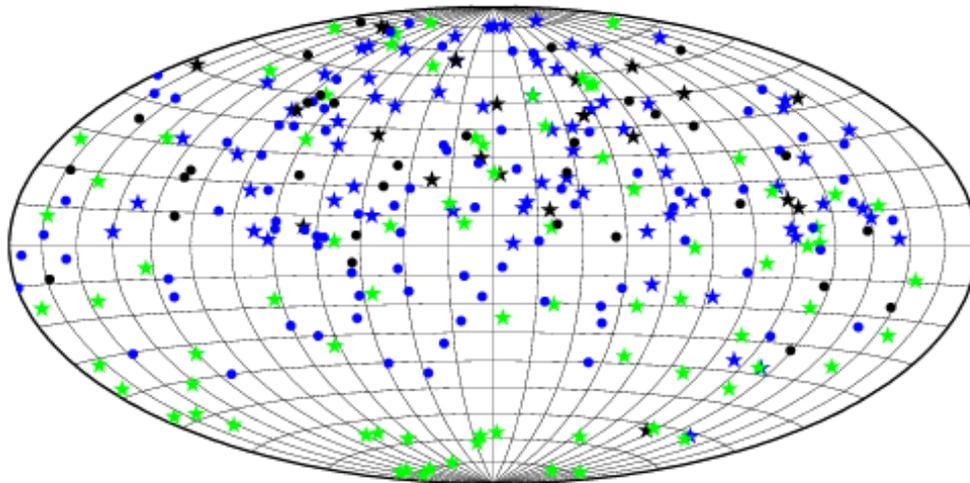
Variation in Earth Rotation



VLBI Detects El Nino



Total CRF Monitoring Sources

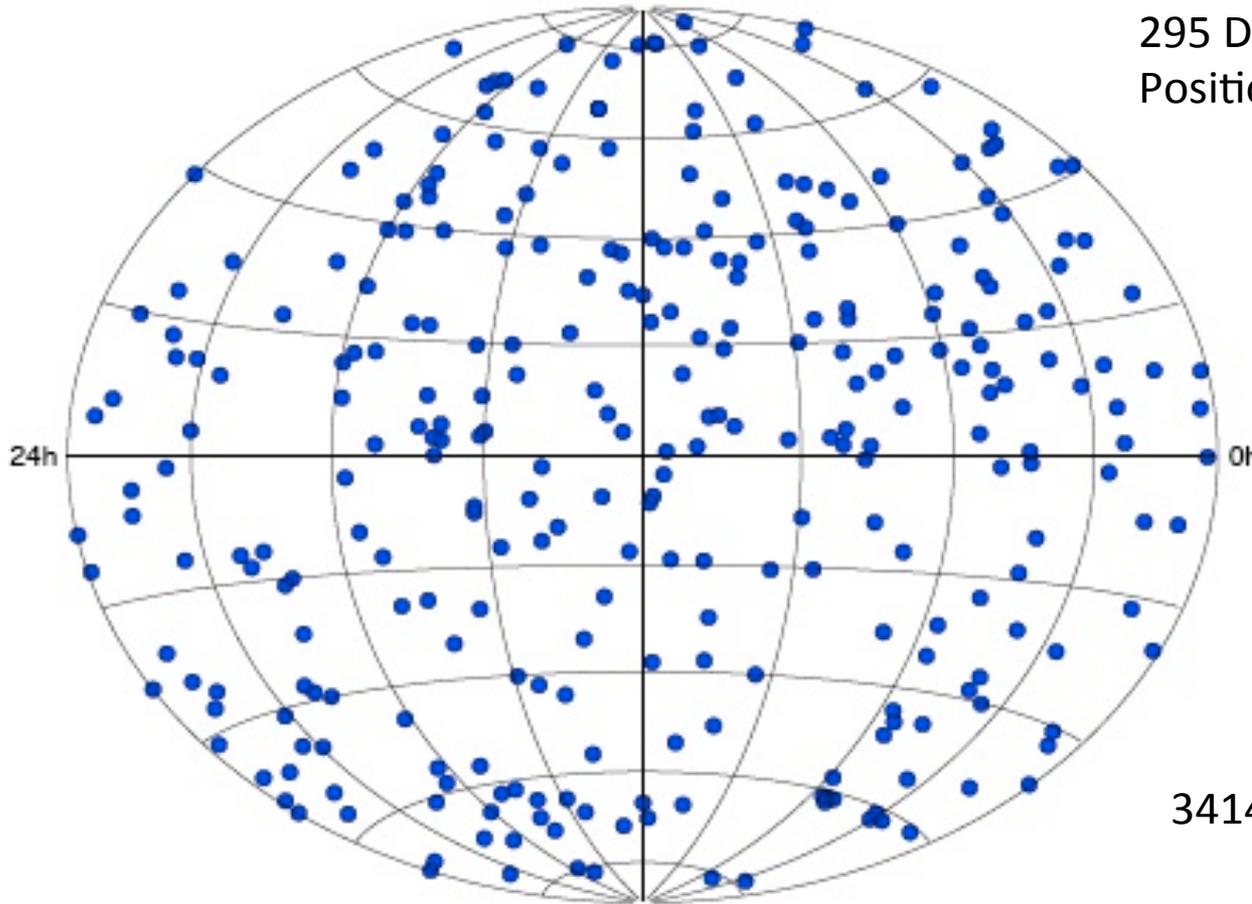


★ 74 Stable ICRF
● 89 Stable other

★ 25 Potentially stable ICRF
● 36 Potentially stable other

★ 83 Other ICRF defining

ICRF2 Defining Sources

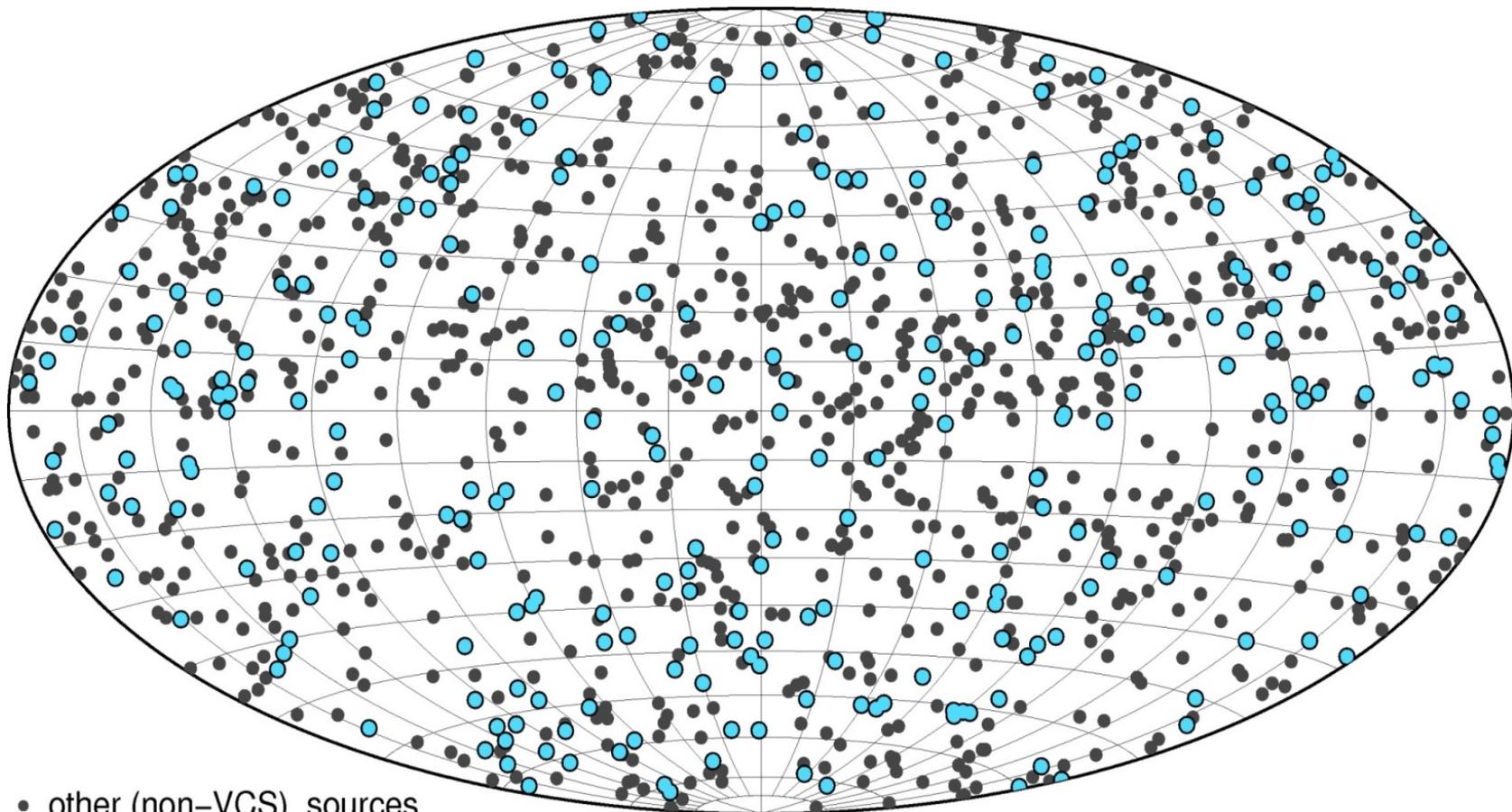


295 Defining Sources
Position good $\sim 40\mu\text{s}$

3414 Total Sources

ICRF2 was adopted at the 2009 IAU General Assembly
It is the Fundamental Astrometric Reference Frame

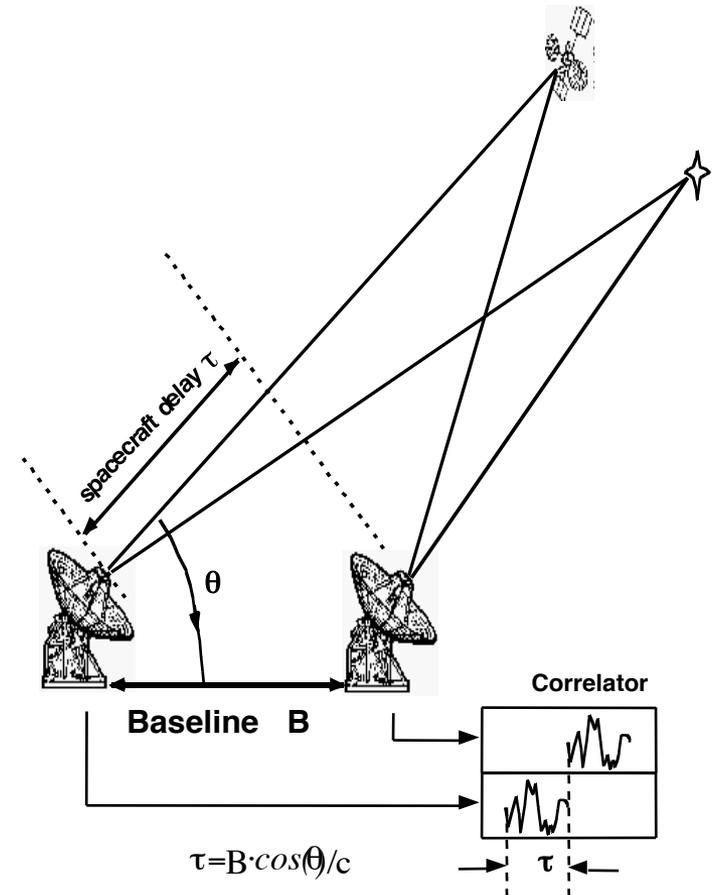
ICRF2 non-VCS sources



- other (non-VCS) sources
- defining sources

VLBI is used in spacecraft navigation to determine the angular position of spacecraft.

This complements other techniques (radar, laser) which measure the range to the spacecraft.





NASA's Role in VLBI: History



- ◆ NASA has been a key player in supporting *all* aspects of geodetic VLBI beginning in 1974. This includes
 - Data acquisition hardware
 - Data acquisition software
 - Correlator development
 - Post correlation software
 - Building and maintaining VLBI stations
 - Developing data analysis software
 - Developing scheduling software
 - Improvement of VLBI technique.



NASA's Role in the IVS



◆ The Goddard VLBI group

- IVS Coordinating Center (Dirk Behrend)
- Analysis Center (Chopo Ma)
- Operation Center (Cynthia Thomas)
- Technology Development Center (Ed Himwich)
- Home of the Network Coordinator (Ed Himwich)
- Home of the Analysis Coordinator (John Gipson)

◆ Haystack VLBI Group

- Analysis Center (Arthur Niell)
- Technology Development Center (Alan Whitney)
- Haystack Correlator (Alan Whitney)



NASA's Role in the IVS



- ◆ NASA supported VLBI antennas
 - Westford Antenna
 - Kokee
 - GGAO12M and GGAO5M
- ◆ NASA partner stations
 - Hobart (Australia)
 - NyAlesund (Norway)
 - Fortaleza (Brazil)



GSFC: IVS Coordinating Center



- ◆ Provides overall coordination of the IVS components:
 - Stations
 - Correlators
 - Analysis Centers
- ◆ Generates and Maintains Master schedule
 - Around 200 24 hour sessions/year
 - Around 400 intensive sessions/year
 - Ensures adequate media at all stations
- ◆ Publishes
 - IVS Annual Report (every year)
 - IVS General Meeting Proceedings (every two years)
 - IVS News letter (3 times a year)



GSFC: IVS Analysis Center



- ◆ Develops and maintains calc/solve
 - Premier VLBI analysis software in use around the world.
- ◆ Develops and maintains sked
 - Used to schedule VLBI sessions
- ◆ Develops and maintains Field System
 - Used to control antenna, front-end and recording system.
- ◆ Analyzes all VLBI sessions
 - Makes the data available for scientists at other institutions.
- ◆ Produces VLBI data products
 - Earth orientation parameters
 - Station position time series
 - Source positions
- ◆ Auxiliary products used in VLBI analysis
 - Pressure loading series
 - Met data derived from numerical weather models
 - Tropospheric delay.



GSFC: Network Coordinator



- ◆ Reviews all sessions to catch problems early.
- ◆ Helps stations troubleshoot problems.
- ◆ Helps organize semi-annual 'Technical Operations Workshop' held at Haystack Laboratory.
- ◆ Helps bring new-stations on line.



NASAs Role in VGOS=VLBI2010



- ◆ VLBI Geodetic Observing System
- ◆ Supported development of data-acquisition system
 - Broadband feed
 - Digital components
 - Purchase of 12M antenna
- ◆ Supported development of software
 - Data acquisition software
 - Scheduling software
 - Data analysis software
- ◆ First successful demonstration of concept with Westford-GGAO baseline.
 - Still much work to be done.



Summary



- ◆ NASA played a key role in the development of VLBI.
- ◆ NASA provides strong ongoing support to the VLBI community.
 - Haystack Correlator
 - Coordinating Center
 - Data Center
 - Analysis Center.
 - ...
- ◆ NASA provides strong leadership to the VLBI community
 - IVS Coordinating Center Director
 - IVS Network Coordinator
 - IVS Analysis Coordinator
- ◆ NASA has supported and continues to support development of the next generation VLBI system.