e-VLBI for geosciences

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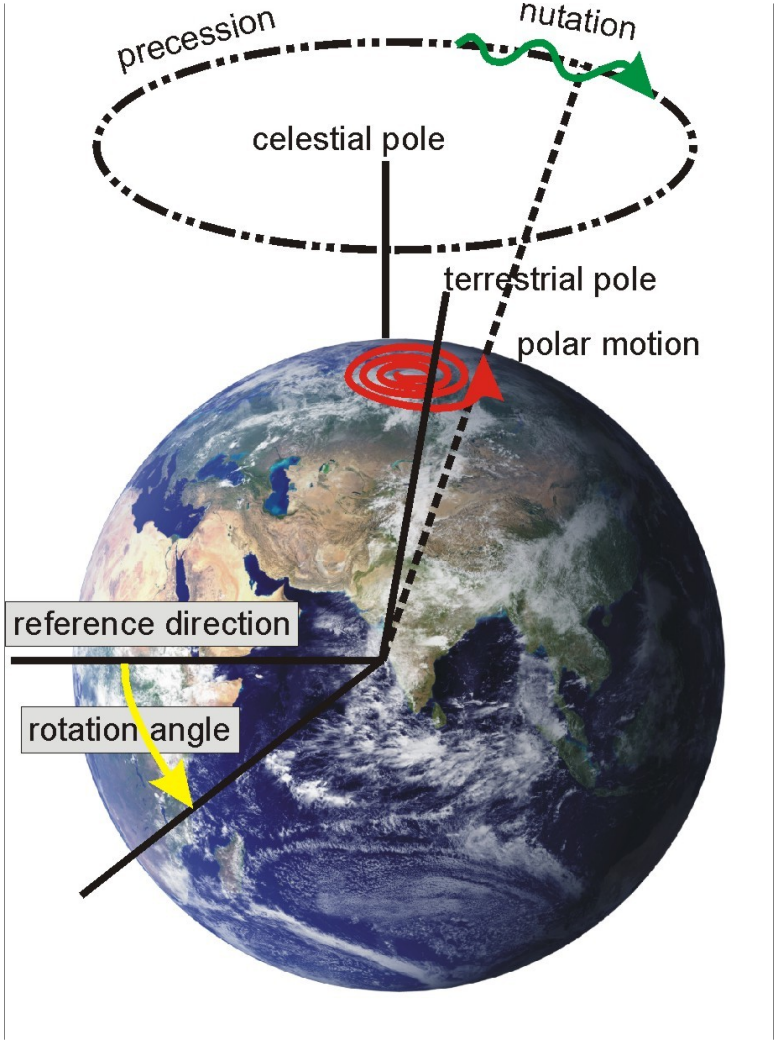
Outline

- Geodetic VLBI
- Current use of e-VLBI
- Geodynamics and earth rotation
- New scientific goals: Episodic events affecting earth rotation
- Summary and outlook

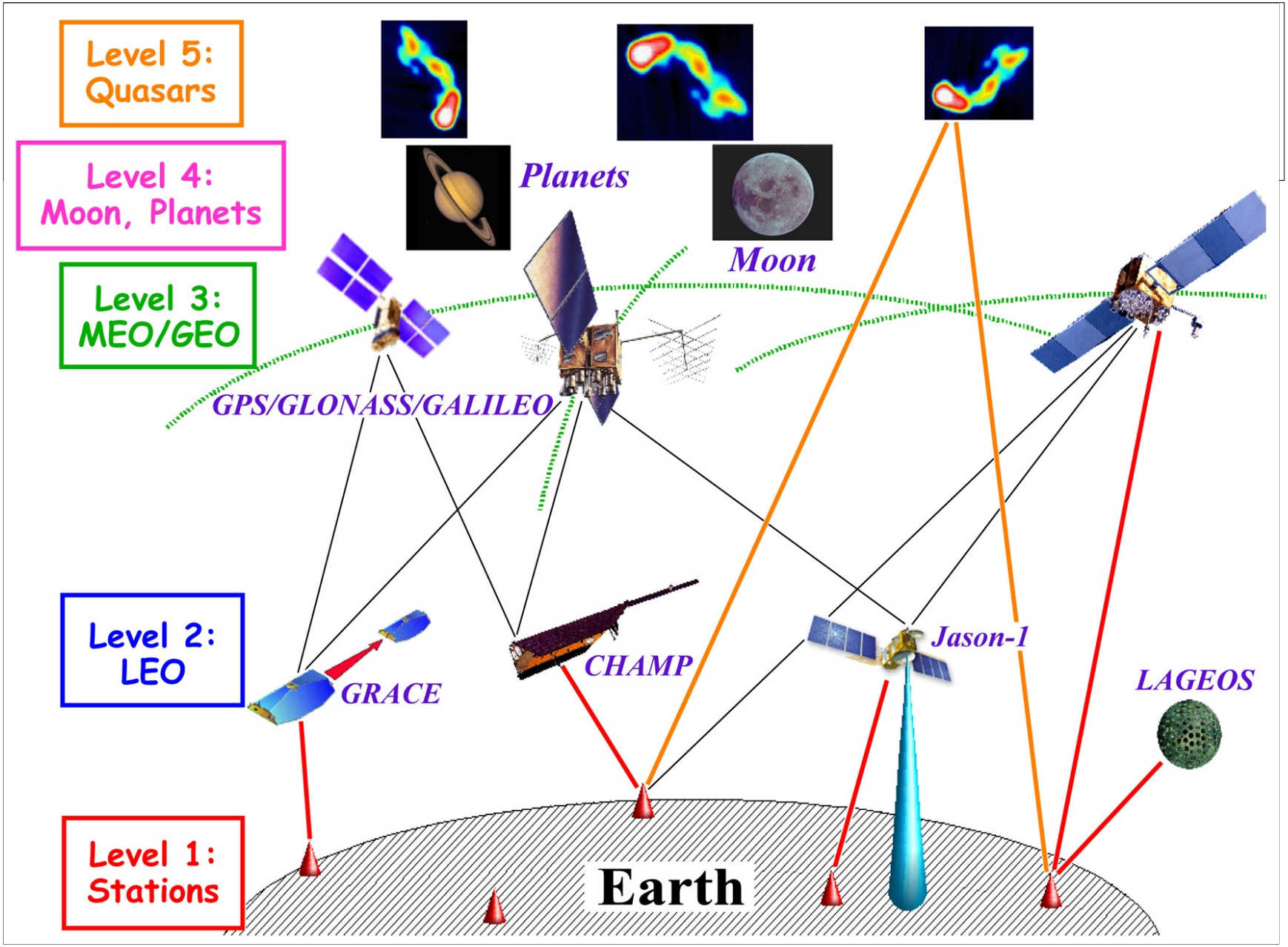
1) – Geodetic VLBI

- Is an important space geodetic technique
- Unique feature: connects directly
  the terrestrial reference frame (TRF) and
  the celestial reference frame (CRF)
- Monitors earth rotation and orientation
- Is an important part of IAG's (International Association of Geodesy) Global Geodetic Observing System (GGOS)

GEO–VLBI's uniqueness

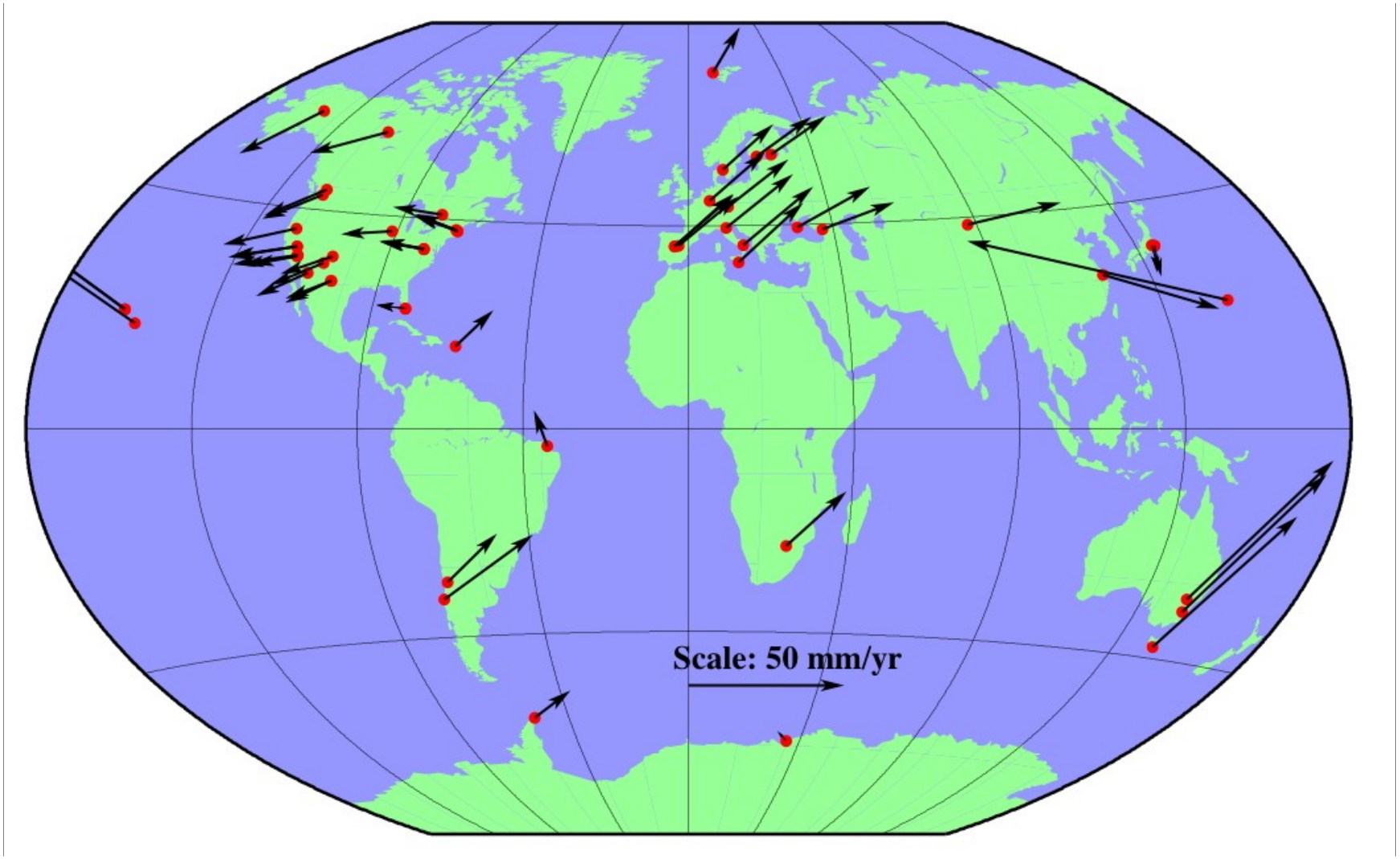


- Is sensitive for both polar motion and nutation
- Is the only technique that gives the unbiased earth rotation angle
- Gives the scale for TRF


Level 5:
Quasars
Level 4:
Moon, Planets
Level 3:
MEO/GEO
Level 2:
LEO
Level 1:
Stations
Planets
Moon
GPS/GLONASS/GALILEO
GRACE
CHAMP
Jason-1
LAGEOS
Earth

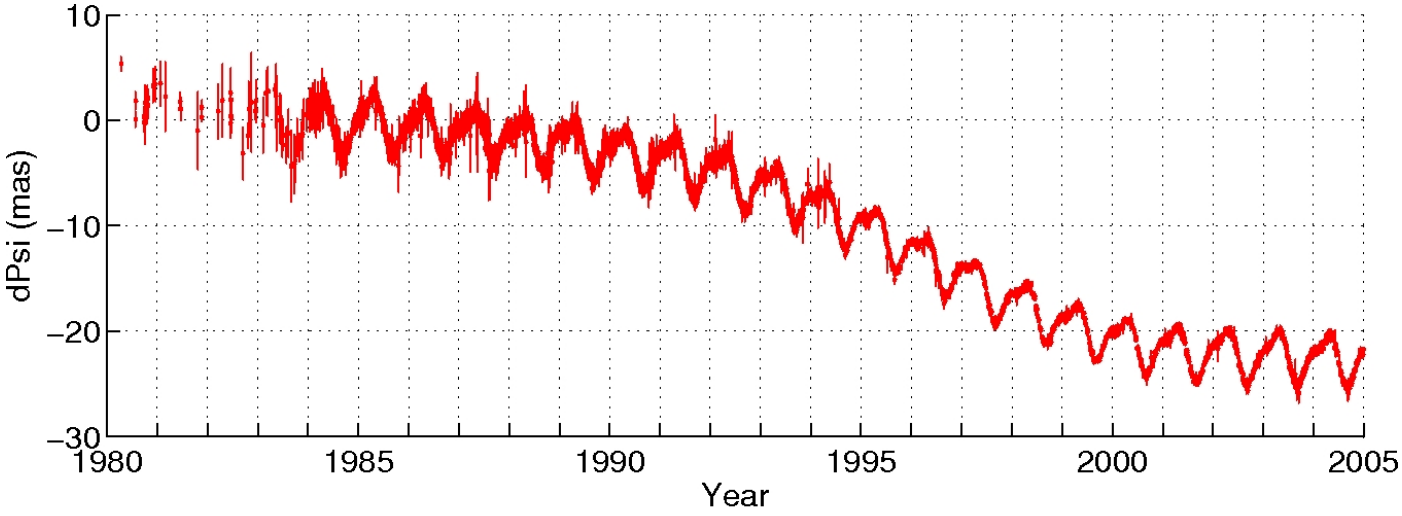
Some highlights from VLBI results

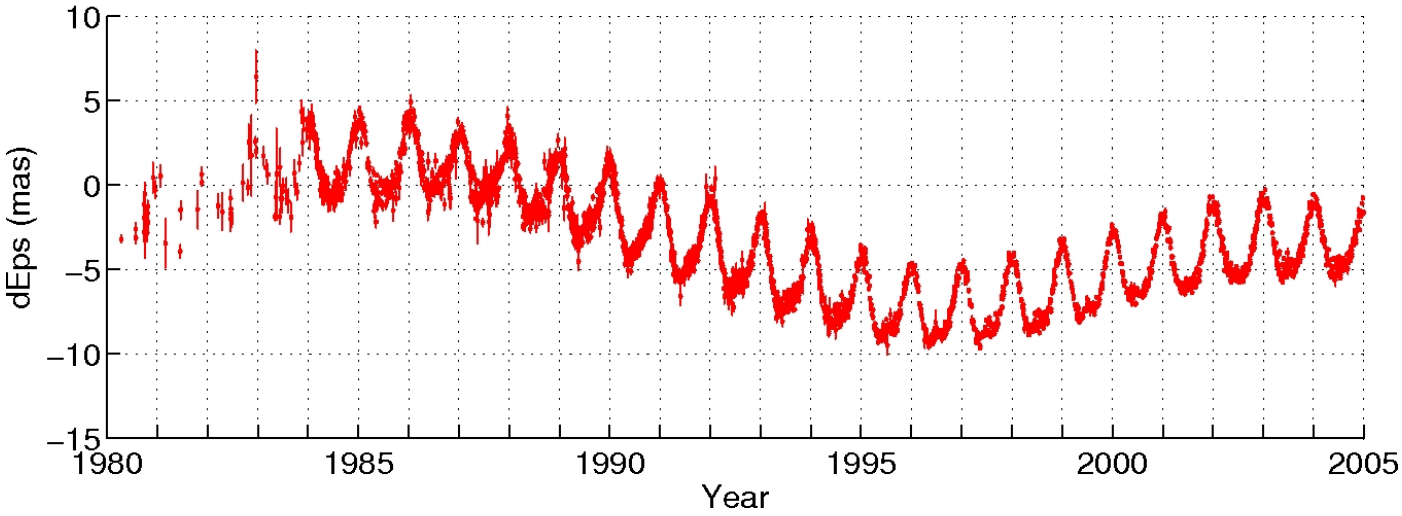
- Reference frames and earth rotation series
- Inter- and intra-plate velocities
- IAU 2000 nutation model is based on VLBI results
- High frequency EOP
- Earth rotation and El-Nino
- Trends in atmospheric water vapour


Scale: 50 mm/yr

Corrections to the IAU1980 nutation model.

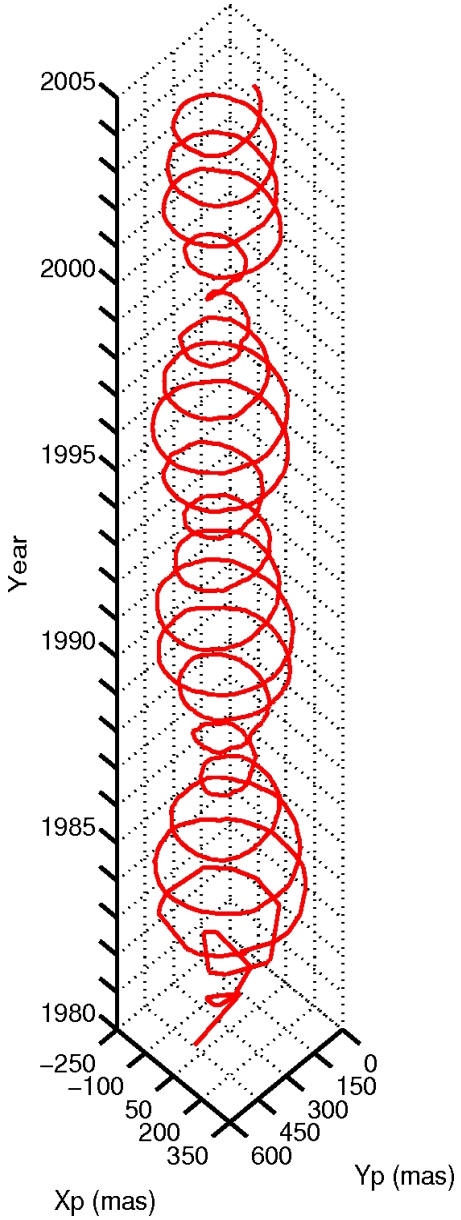
⇒ The new IAU2000 nutation model has been developed based on theory and constraints from geodetic VLBI results.

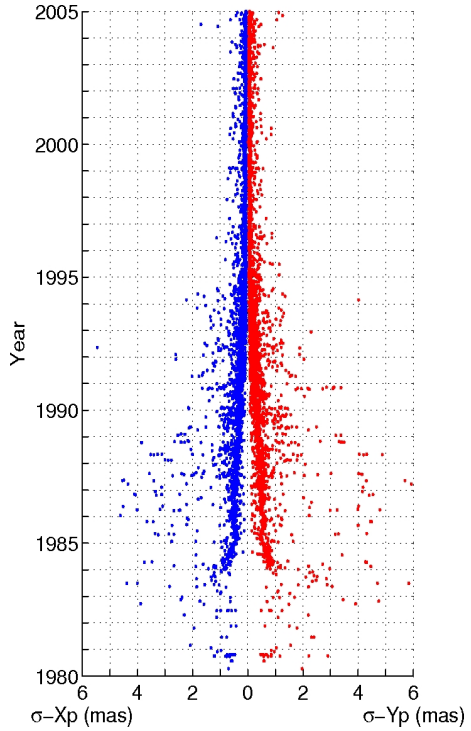




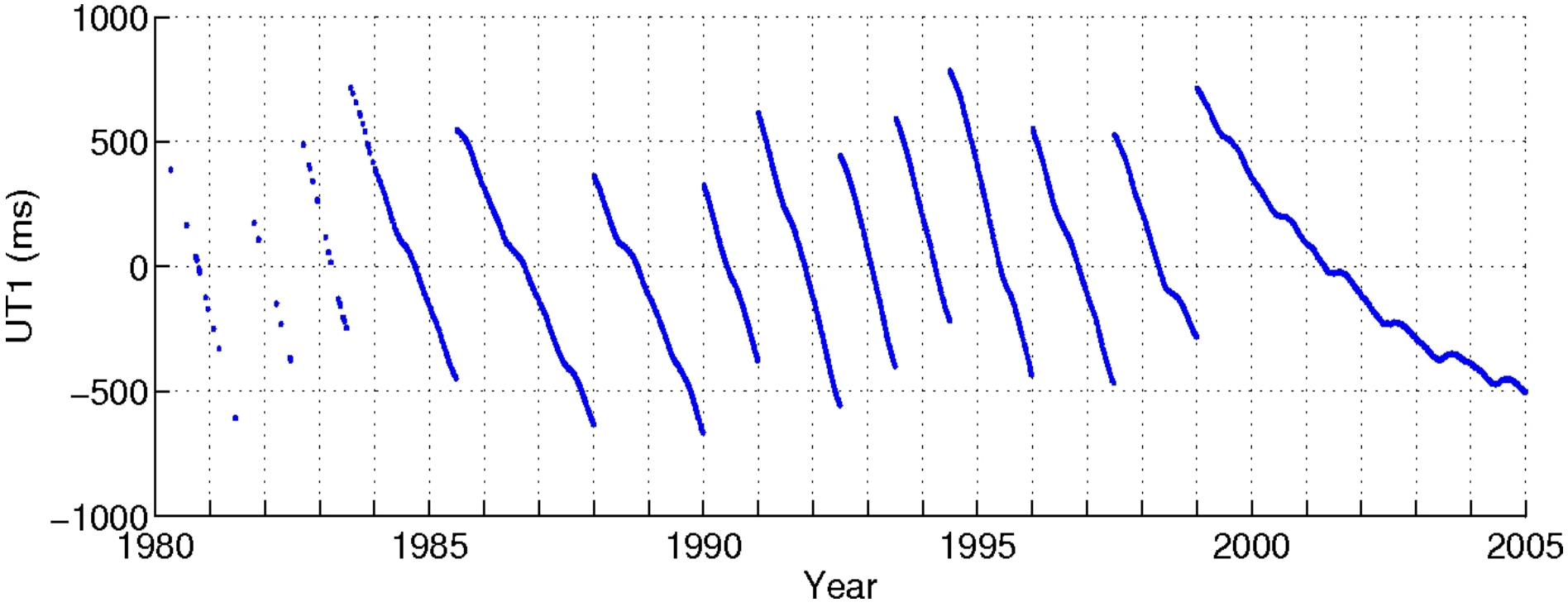
Polar motion results,
daily mean values.

==> Mainly superposition
of annual
component
and Chandler
component





Earth rotation in terms of UT1-UTC,
Daily mean values



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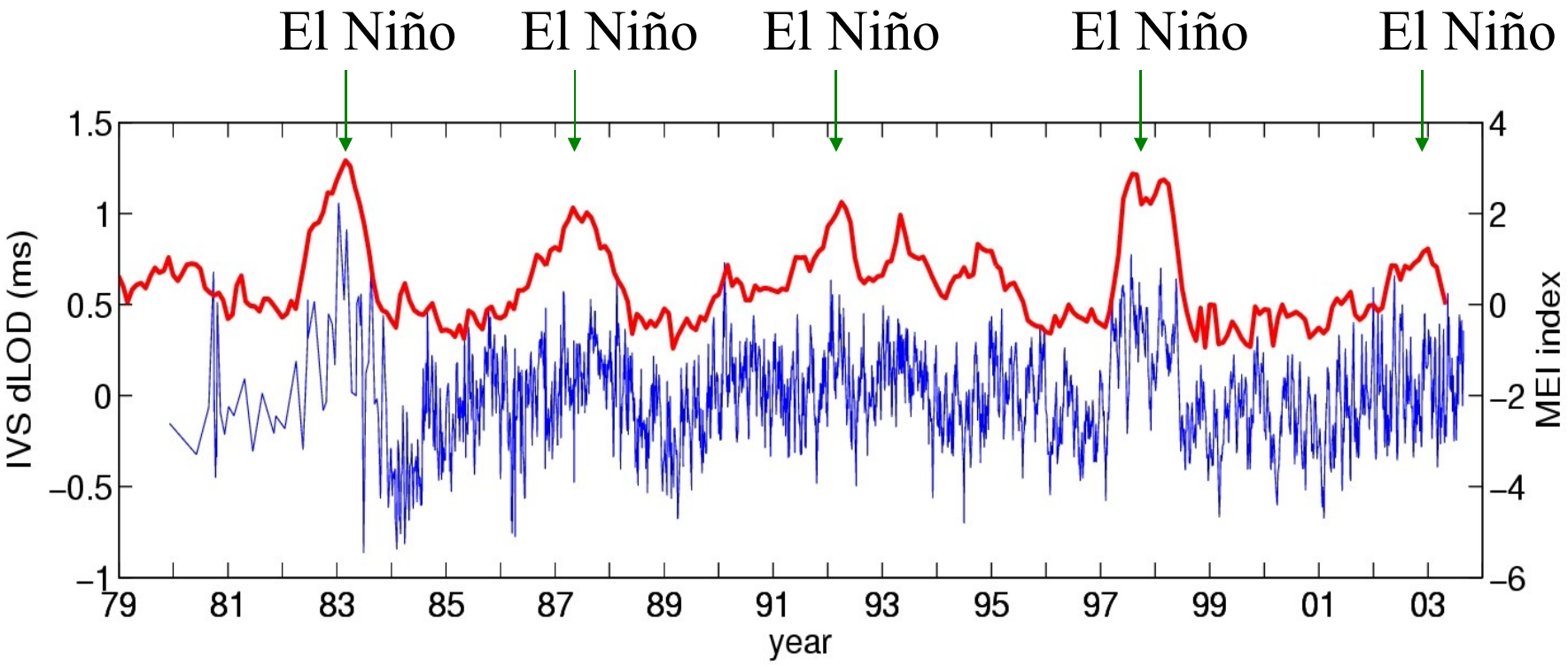
Earth rotation in terms of length-of-day (lod) changes



VLBI derived earth rotation (blue) and meteorological index (MEI, red).

⇒El-Niño/Southern Oscillation (ENSO) are effects detectable.

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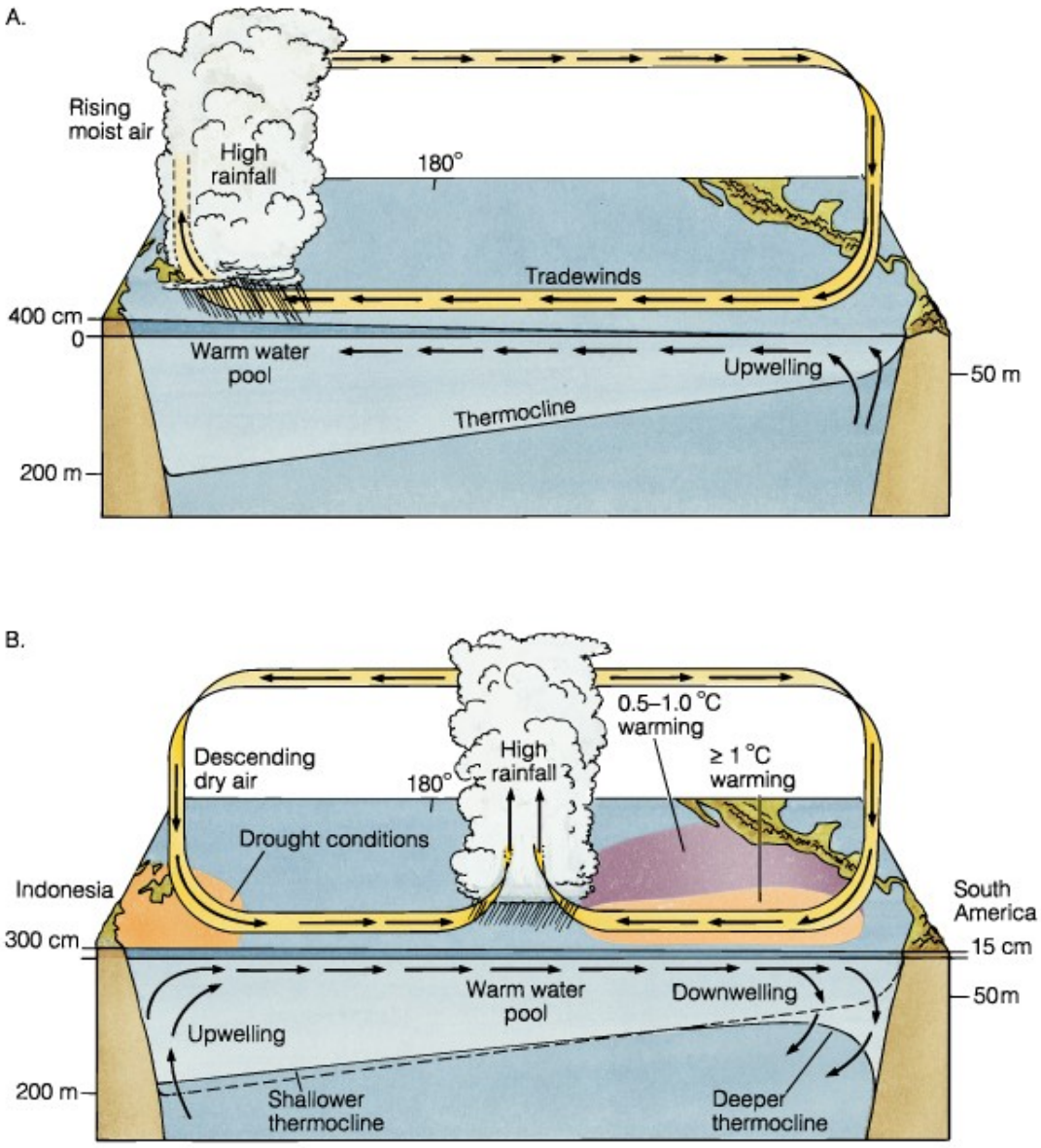
Mass redistribution in the Pacific Ocean, El Niño/Souther Oscillation (ENSO)



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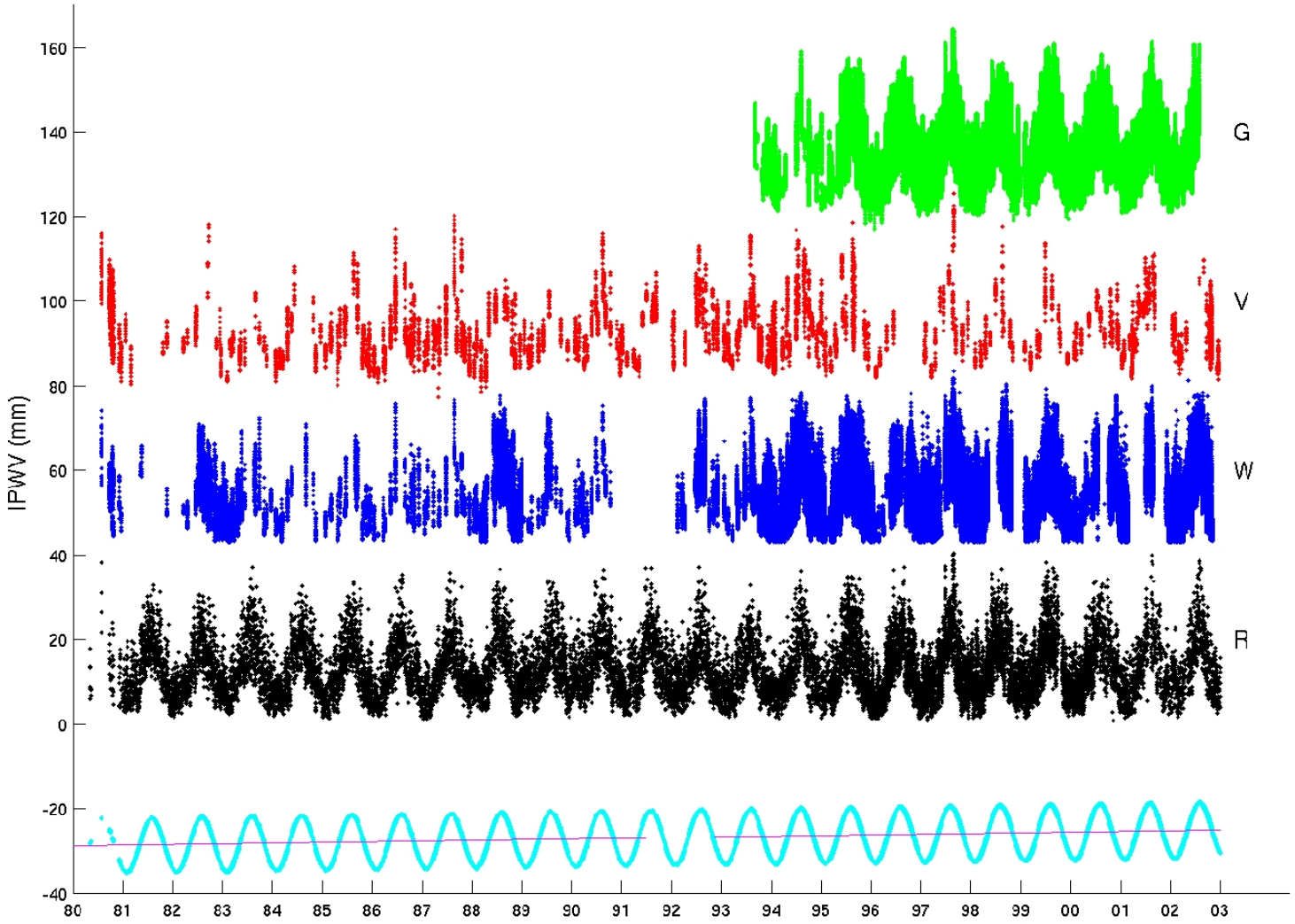
Zenith wet delays over ca 20 years from VLBI and independent collacated techniques at Onsala:



VLBI group delay precision

$$\sigma_\tau = \frac{1}{2 \times p \times SNR_{corr} \times \Delta f_{rms}}$$

$$\Delta f_{rms} = \sqrt{\left(\frac{1}{n}\sum_{1}^{n} f_i^2\right) - \left(\frac{1}{n}\sum_{1}^{n} f_i\right)^2}$$

$$SNR_{corr} = h_{corr} \sqrt{\frac{h_x \times A_x \times h_y \times A_y \times 2 \times B \times t_{\text{int}}}{T_{sys-x} \times T_{sys-y}}} \times \frac{F_{source}}{k}$$

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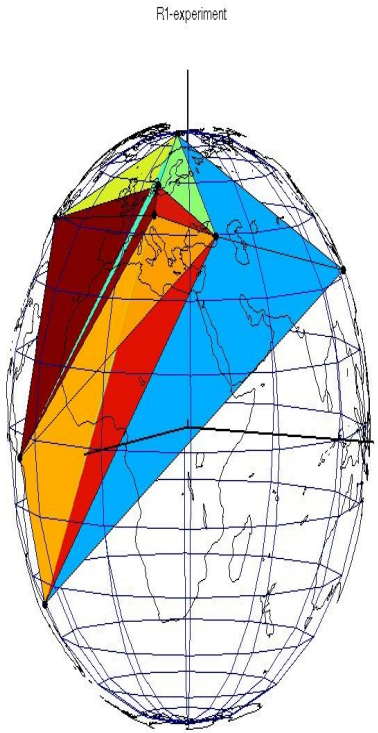
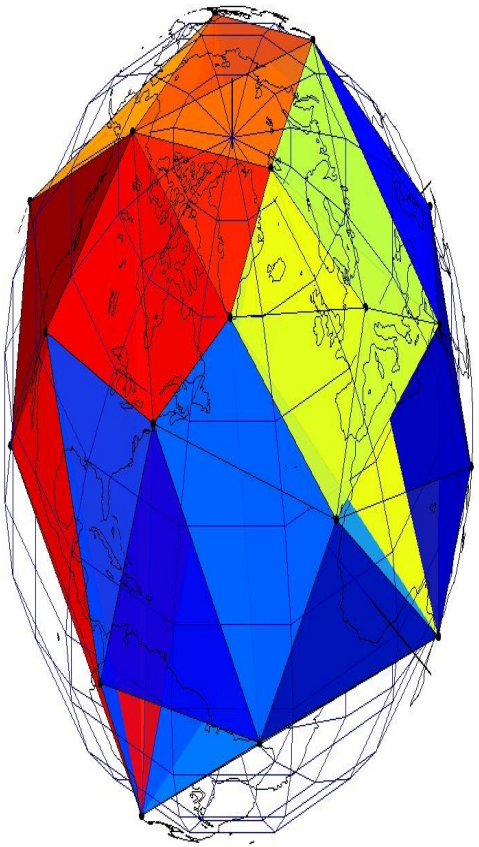
VLBI2010

- IVS initiative for a renewal of GEO-VLBI
- Ambitious goals:
  - 1 mm position accuracy on global scales
  - Continuous observations of station positions and earth orientation parameters
  - Turnaround time for results < 24 hour
- Plan:
  - Broad-band observations (at least 2-14 GHz)

Global VLBI networks





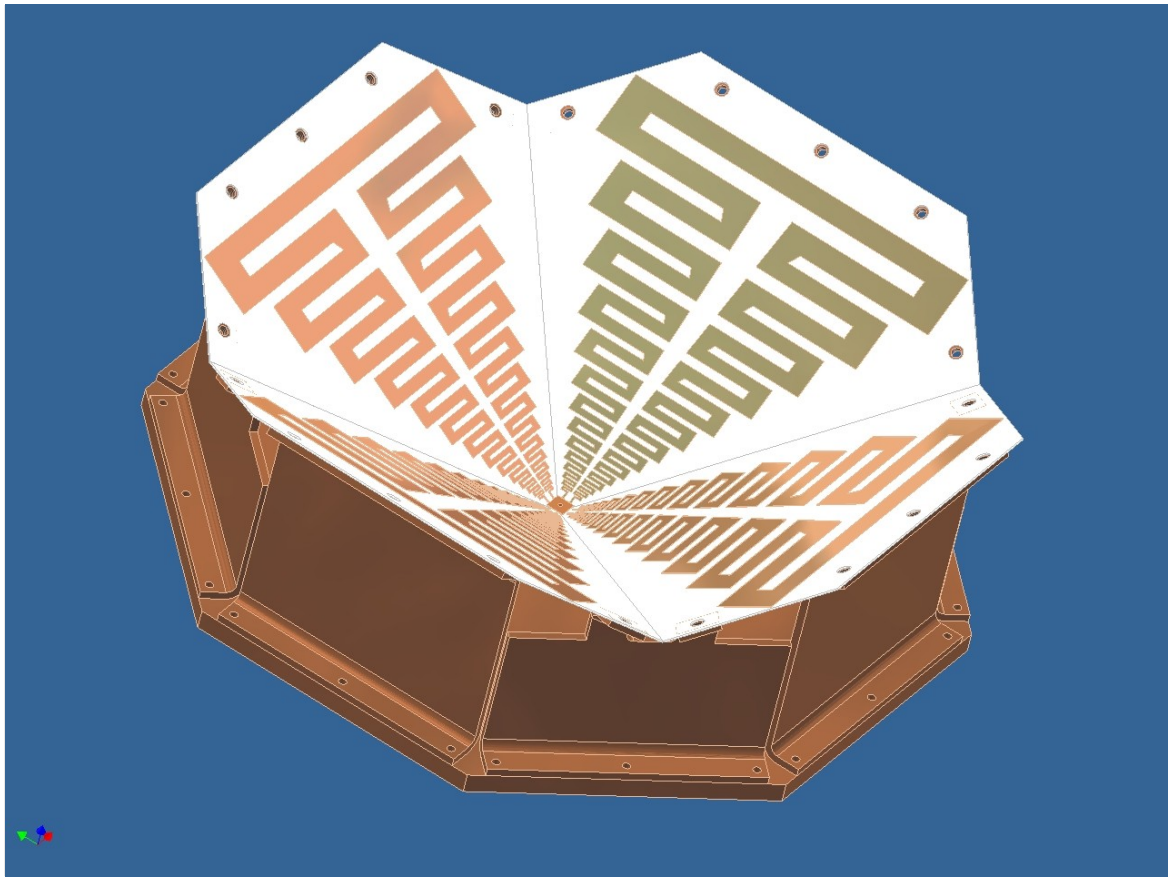
Today: IVS R1

Future: VLBI2010

VLBI2010 development

- Wettzell (Germany): Twin-Telescope funded
- Ny-Ålesund (Spitsbergen, Norway): proposal submitted for a Twin-Telescoep and optical fibre connection to Spitsbergen
- New telescopes in Australia and New Zeeland
- Plans for telescopes in North America (Washington & Alaska)
- Spain: Yebes and RAEGE project

Prototype for a VLBI2010 feed



2 linear polarizations, 2-14 GHz

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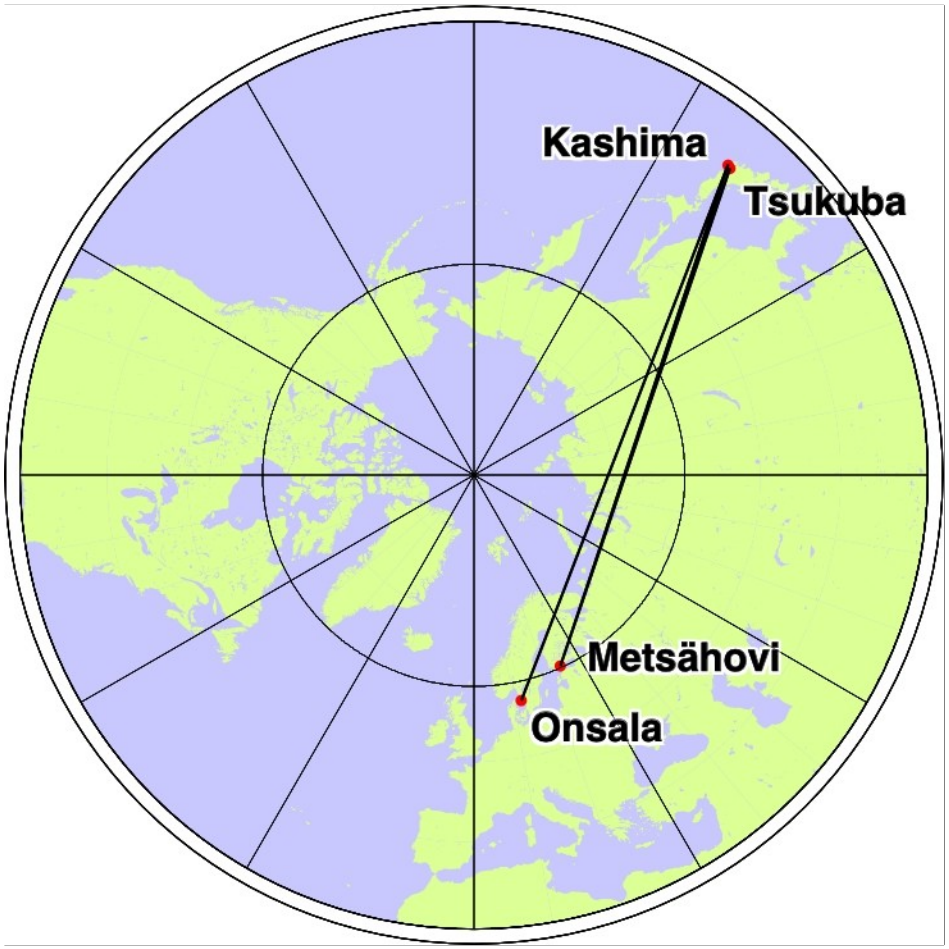
2) Current use of e-VLBI

- Offline e-transfer to Bonn correlator (e.g. Onsala, Wettzell, Medicina, Ny-Ålesund, Tsukuba) for 24h sessions (R1, EURO, T2)
- Offline e-transfer to Bonn correlator for1h-INT3-sessions (Ny-Ålesund, Tsukuba, Wettzell)
- Real-time e-VLBI with real-time data conversion, correlation and analysis in the Fennoscandian-Japanese project for ultra-

Fennoscandian-Japanese ultra-rapid dUT1 observations



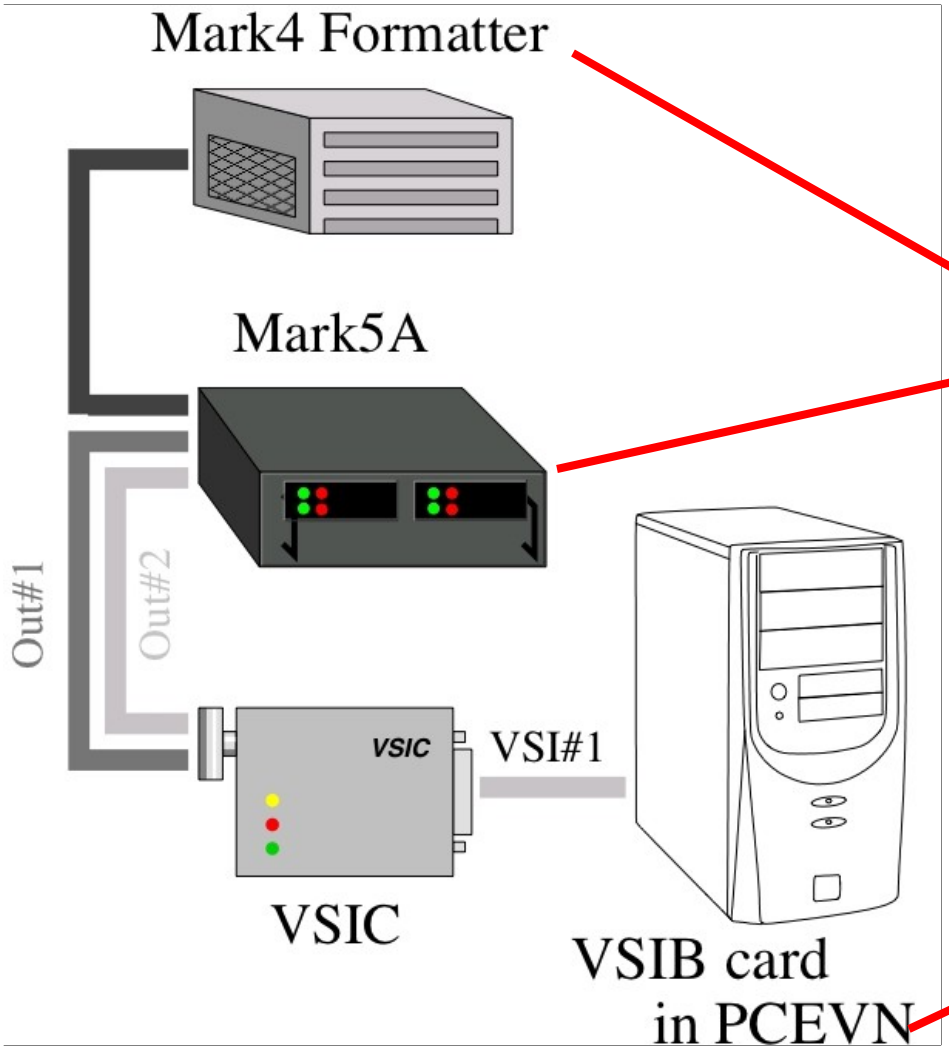
· Started 2007
· On 2 almost parallel baselines
· Offline and real-time data transfer at data rates beteween 64 and 512 Mbps
· Real-time correlation and analysis
· Record: dUT1-results within 4 minutes after end of 1h session

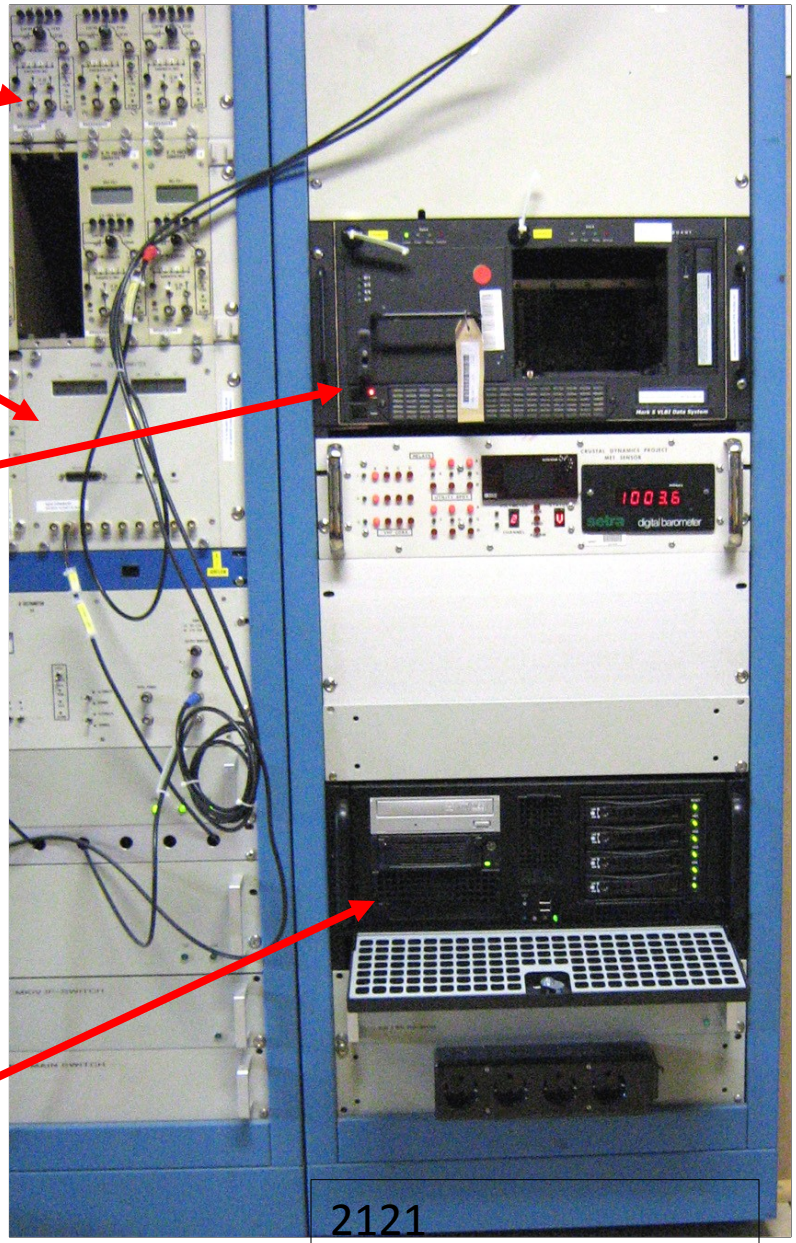
· next step: real-time e-VLBI of a whole 24 h session (Onsala-Tsukuba baseline)
· higher bandwidth with Mark5B or Mark5C

2020

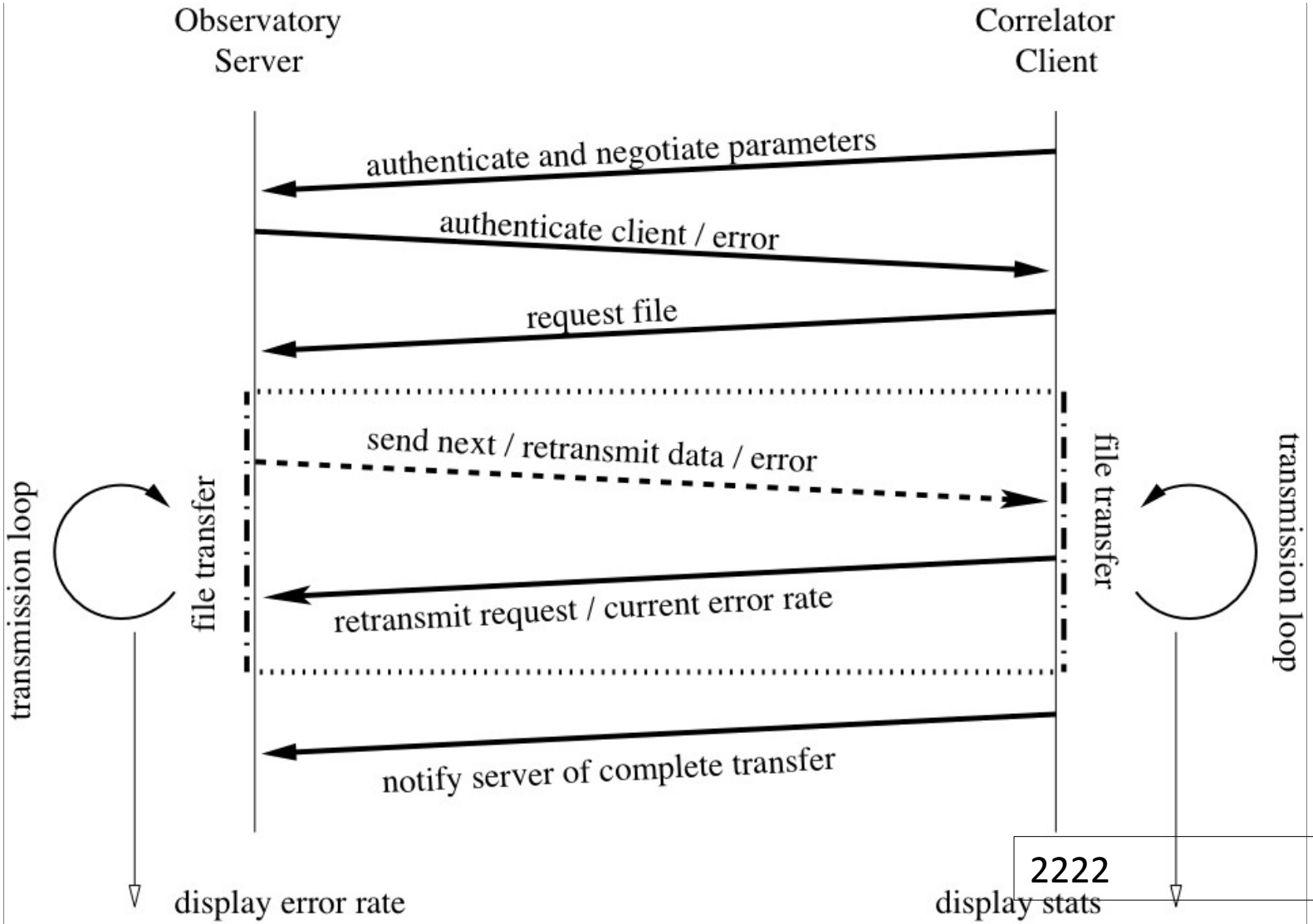
VLBI racks @ Onsala

Videoconvertors





Tsunami transfer protocol



3) Geodynamics and earth rotation

- Governing principle: conservation of angular momentum
- External gravitational torques
- Relativ angular momentum changes (crust, ocean, atmosphere, earth's interior)
- Changes of the inertial tensor (mass redistribution)

Conservation of angular momentum

$$\frac{dH}{dt} + \Omega' \times H = G$$

Angular momentum

$$H = I \times \Omega$$

Tensor of inertia

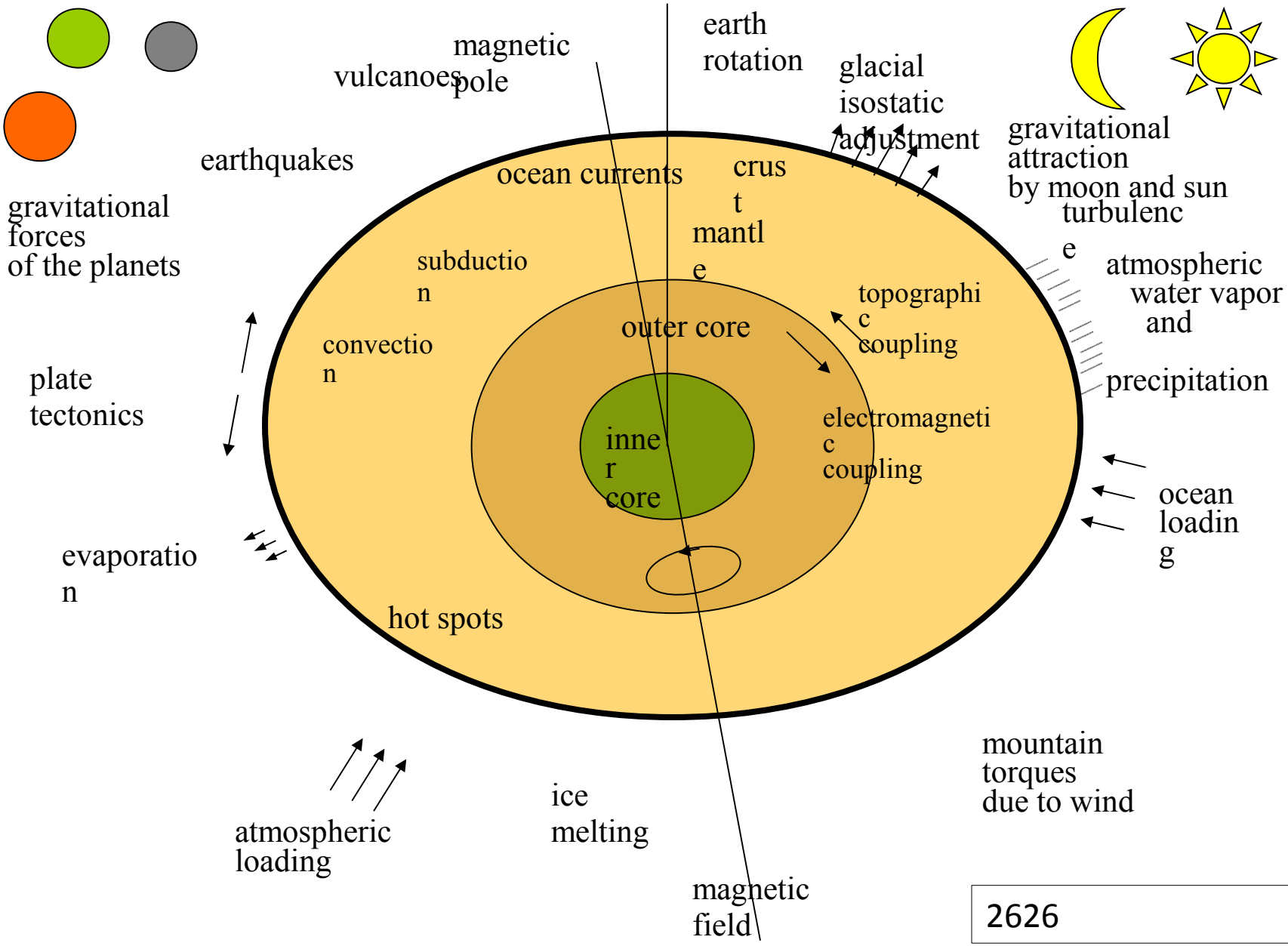
$$I = \begin{bmatrix} A & 0 & 0 \\ 0 & B & 0 \\ 0 & 0 & C \end{bmatrix}$$

Liouville equations:

$$\chi^*(t) = p^*(t) + \frac{i}{s_{CW}} \frac{dp^*(t)}{dt}$$

$$= \frac{1.61}{W(C - A)} \left\{ D h^*(t) + \frac{W[D I_{13}(t) + i D I_{23}(t)]}{1.44} \right\}$$

$$\Delta\Lambda(t) = \frac{L_0}{C_m W} [D h_3(t) + 0.756 \times W \times D I_{33}(t)]$$


gravitational forces of the planets
earthquakes
vulcanoes
magnetic pole
earth rotation
glacial isostatic adjustment
gravitational attraction by moon and sun
turbulence
atmospheric water vapor and precipitation
ocean loading
ocean currents
crust
mantle
subduction
convection
outer core
topographic coupling
electromagnetic coupling
inner core
plate tectonics
evaporation
hot spots
atmospheric loading
ice melting
magnetic field
mountain torques due to wind

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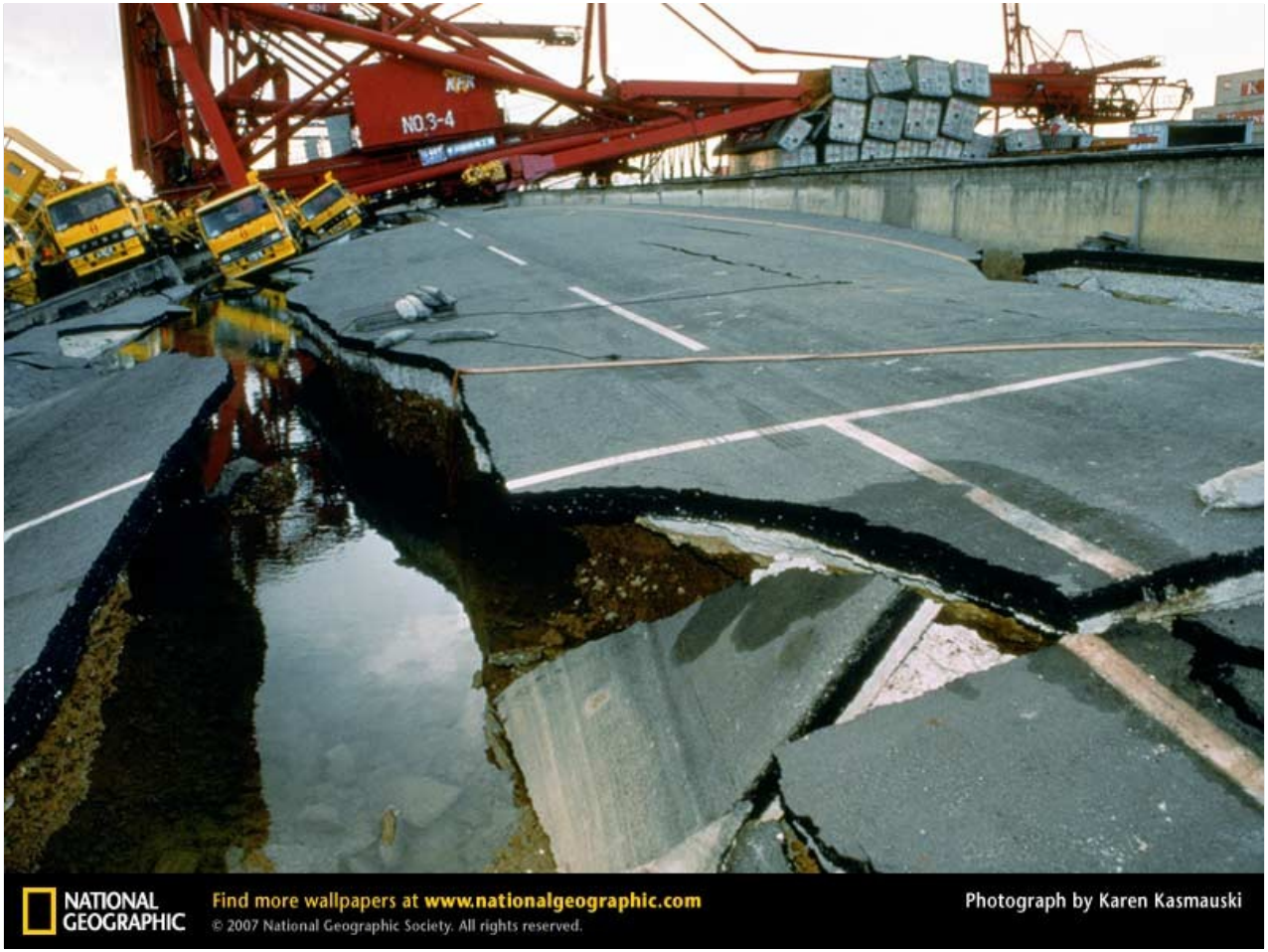
4) New scientific goals: Episodic events affecting earth rotation

- Mass redistribution due to:
  - Strong earth quakes
  - Tropical storms
  - Volcanic eruptions
- Corresponding changes in earth rotation and orientation should be detectable
- Free oscillations of the earth (?)

Earthquakes



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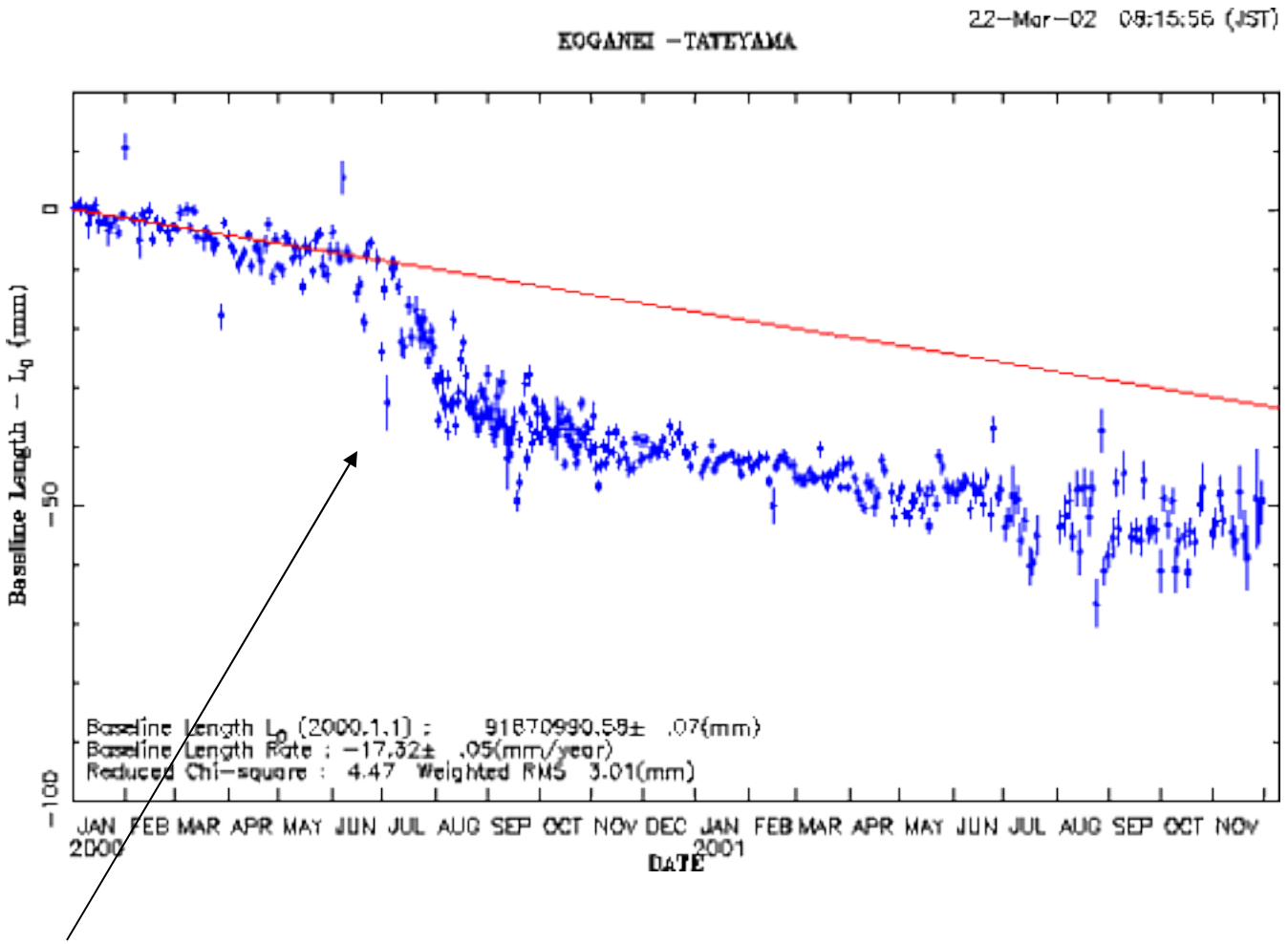
Example of baseline measurements in the Key-Stone-Peoject-network:

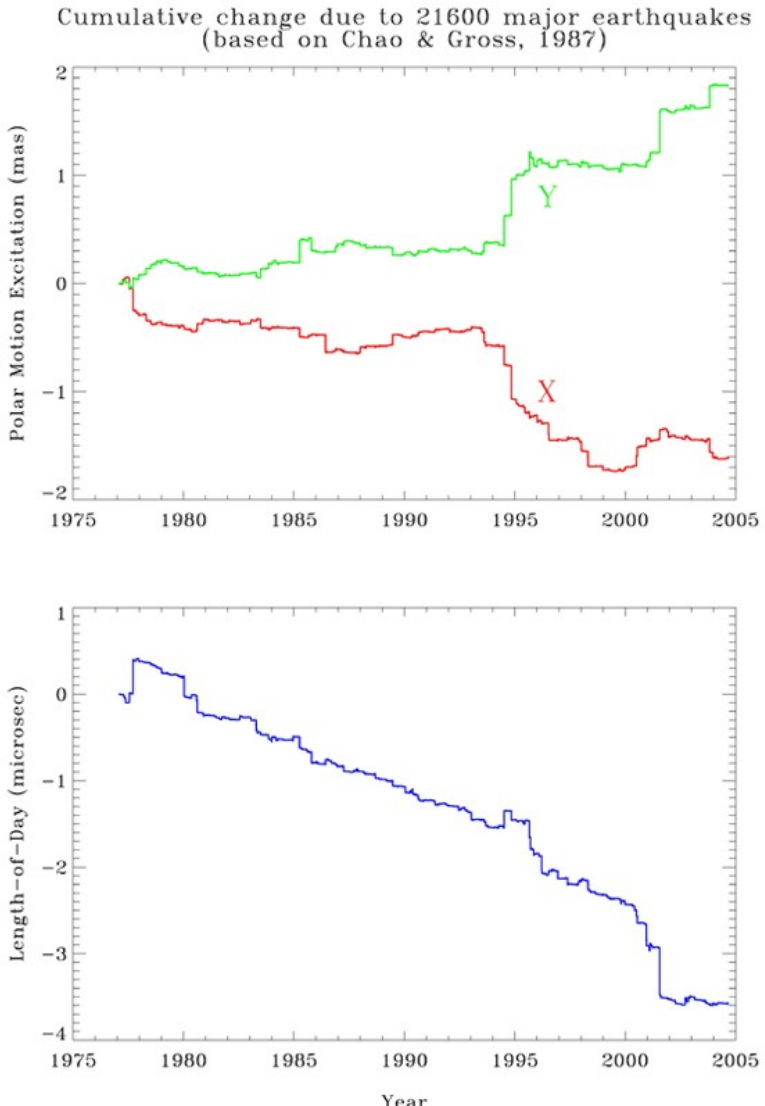


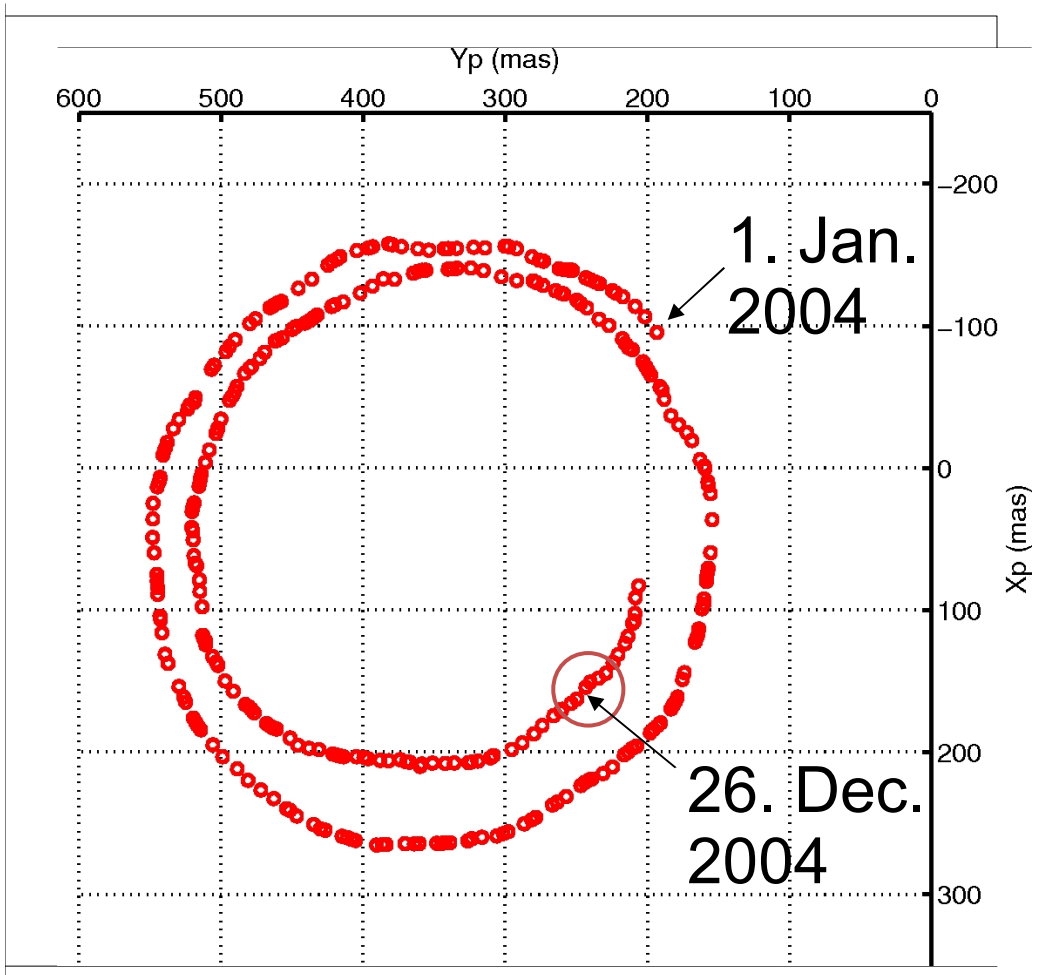
”real-time” observation of crustal motion due to volvcanic activity

Mass redistribution and polar motion

- Earthquakes redistribute mass and change the earth's inertial tensor
- Depends on seismic moment, location and strike, dip and slip angle…
- Equatorial earth quakes have smaller influence on polar motion than high latitude ones
- Alaska (1964), M 9.2: => 15 cm
- Sumatra (2004), M 9.0: => 3 cm

Predictions and observations ?





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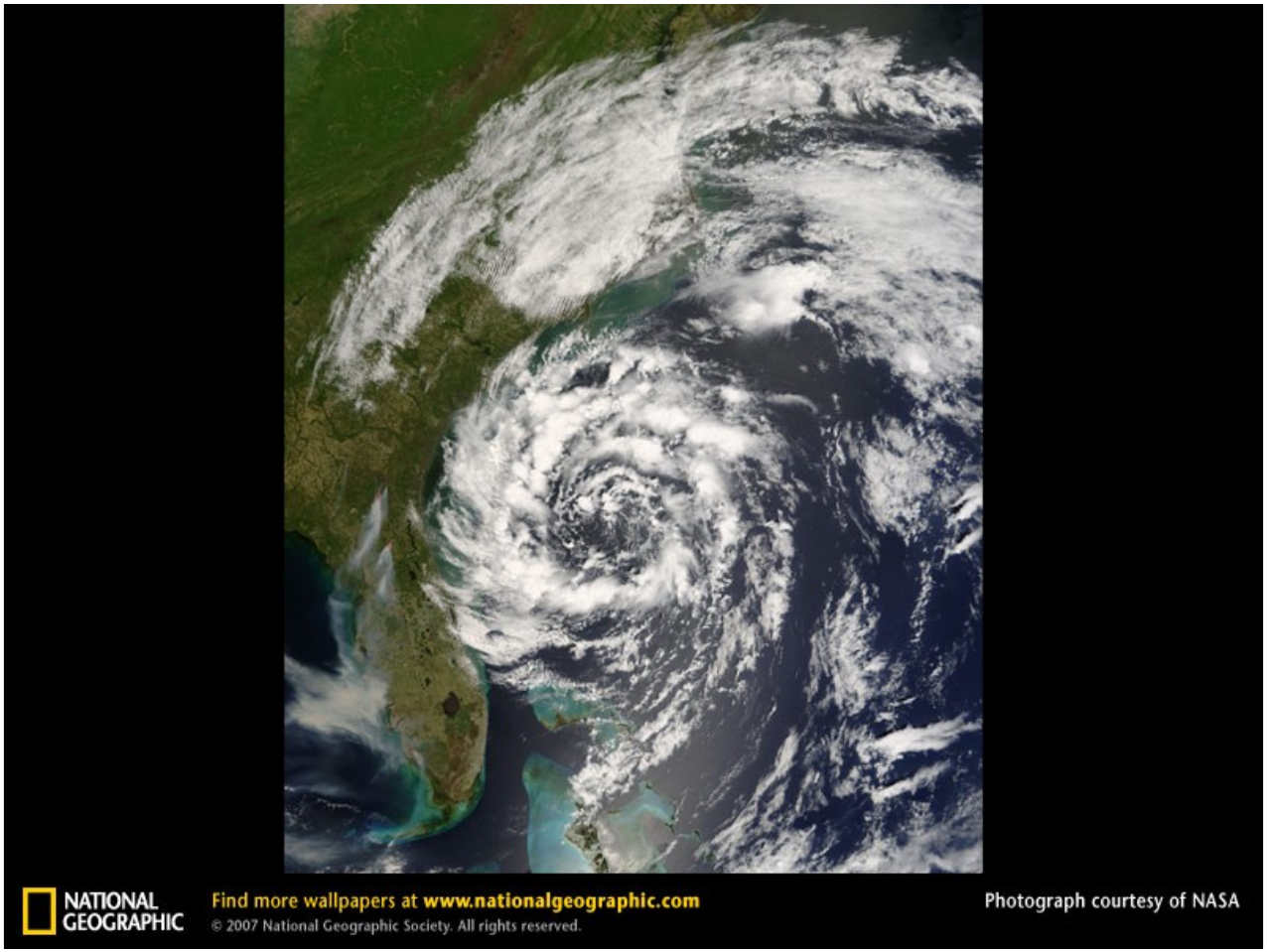
Tropical storms



Redistribution of atmospheric and oceanic masses (flooding).

Volcanic eruptions

Pinatubo (1991), mass of plume ca. 10^13 kg.

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5) Summary and outlook

- e-VLBI will be necessary for VLBI2010
  - Low latency requirement
  - High bandwidth requirement
  - Distributed correlation
- Real-time e-VLBI offers the opportunity to study episodic events that affect earth rotation and orientation

’Vision’

- Global network with ’twin telescopes’
- Routine operations 24/7
- Special ’triggered’ sessions for episodic events, e.g. large earth quakes, with special setup (high bandwidth, real-time distributed correlation)