Laser Ranging Contributions to Earth Rotation Studies

Richard Gross

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109–8099, USA

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Earth Rotation Dynamics

Rotation of Earth changes

- Length of day by few milliseconds
- Wobbles by few hundred milliarcsec
  (10 meters at North Pole)
- Nutation and precession

Rotation changes caused by

- External torques — tidal phenomena
- Internal deformation — earthquakes, glacial isostatic adjustment
- Angular momentum exchange with bounding fluids — atmosphere, oceans, core

Sources of Earth Rotation Variations

Studying Earth’s rotation improves knowledge of

- Rheology and dissipation processes of solid Earth
- Interior figure of Earth
- Core-mantle coupling
Laser Ranging Contributions

• Longest available space-geodetic series of Earth orientation parameters
  • LLR measurements since 1970
  • SLR measurements since 1976
• Needed for studying long-period variations in Earth’s rotation
  • Polar motion
    • Interannual to decadal variations of unknown (?) origin
  • Length-of-day
    • Secular decrease caused by tidal dissipation
    • Interannual variations primarily caused by atmospheric winds
• Provides backbone for combining EOPs from different space-geodetic techniques
  • Geophysical interpretation of observed EOPs usually done using combined series
Lunar Recession

APOLLO station ranging to Moon. Source: Dan Long
Lunar Recession

Moon receding from Earth at rate of $3.79 \pm 0.07$ cm/yr (Williams et al., 2001)
Secular change in the length-of-day during the past 2500 years estimated from lunar and solar eclipse, lunar occultation, optical astrometric, and space-geodetic observations. The difference between the observed secular trend and that caused by tidal friction is due to the effects of glacial isostatic adjustment and other processes such as ice sheet mass change and the accompanying nonsteric change in sea level.
Decadal
Polar
Motion

Potsdam laser ranging station
Observed decadal-scale polar motion variations from the ILS optical astrometric series, the HIPPARCOS optical astrometric series, and the SPACE96 and SPACE2009 combined space-geodetic series. For clarity of display the curves have been offset from each other by an arbitrary amount. Source: Gross (2015)
Interannual Polar Motion Excitation

Climate-induced polar motion. (A) Polar motion excitations caused by four climate-related sources. (B) Total reconstructed (REC) and observed (OBS) excitations. Large positive gradients during 2005–2012 (cyan shadow), followed by negative trends, are apparent for $\chi_2(t)$, and it may be explained by analogous trends associated with TWS. Source: Adhikari and Ivins (2016)
Interannual Length-of-Day

Wettzell laser ranging station
The El Niño / Southern Oscillation

La Niña year
- Walker circulation
- Trade winds blowing westwards
- Warm surface water piling up
- Cold water pressing upwards replacing the warm surface water

El Niño year
- Increased convection
- When trade winds drop, warm surface water may flow upwards
- Warm sea currents replace the cold water and establishes a deep layer of warm water along the coast

(Heffernan, 2014)
SOI: Standardized difference in (Tahiti – Darwin) sea level pressure anomalies

Source: http://www.cpc.ncep.noaa.gov/data/indices/soi
ENSO and LOD

• During an ENSO event
  • Southern Oscillation Index decreases
    • Standardized difference in (Tahiti – Darwin) sea level pressure anomalies decreases
  • Tropical easterlies collapse
    • Atmospheric angular momentum due to winds increases
    • Solid Earth’s angular momentum decreases
    • Length of day increases

• Investigate effect of 2015–2016 ENSO on LOD
  • Compare observations of LOD to models of AAM
    • In interannual frequency band
    • After removing tidal signals from LOD
Interannual Length-of-Day

Excess Length of Day (ms)

Time in years

Interannual Length-of-Day
Summary

• **Lunar laser ranging**
  - Directly measures recession of Moon due to tidal dissipation
    - $3.79 \pm 0.07 \text{ cm/yr}$
  - Associated secular change in length-of-day
    - $+1.8 \text{ ms/cy}$

• **Satellite laser ranging**
  - Longest available series of observed EOPs
    - Is the backbone used when combining EOPs from different techniques
  - Needed when studying long-period changes in Earth’s rotation
    - Interannual to decadal changes in polar motion possibly caused by changes in terrestrial water storage
    - Interannual changes in length-of-day caused by interannual changes in winds

• Observations must continue in order to gain better understanding of long-period changes in Earth’s rotation
https://www.youtube.com/watch?v=RBZmLzv9NKQ