Temporal Evolution of Atmospheric and Oceanic Excitation of Earth Orientation Variations During the Past 50 Years

Richard S. Gross, Ichiro Fukumori, and Dimitris Menemenlis

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

American Geophysical Union
2003 Fall Meeting

December 8–12, 2003
San Francisco, CA
Overview

- **Investigate atmospheric and oceanic excitation of polar motion during 1949–2002**
  - Observed polar motion excitation from COMB2002 combined EOP series
    - Extended back to 1949 using Hipparcos optical astrometric series
  - Atmospheric Angular Momentum (AAM) from NCEP/NCAR reanalysis project
    - Obtained from IERS Special Bureau for the Atmosphere
  - Oceanic Angular Momentum (OAM) from JPL component of ECCO consortium
    - New 50-year simulation spanning 1949–2002
    - 20-year simulation spanning 1980–2001 (Gross et al., 2003a, 2003b)
    - Data assimilative series spanning 1993–2001

- **Intercompare ECCO/JPL OAM series**
  - Evaluate by comparing with observed polar motion excitation series
    - From which atmospheric effects have been removed

- **Study average effect of atmosphere and oceans on polar motion during 1949–2002**
  - Markowitz wobble (decadal variations)
  - Chandler wobble

- **Study temporal evolution of atmospheric and oceanic excitation of polar motion**
  - Compare OAM with observed–AAM residual in non-overlapping 4-year-long segments spanning 1950–2001
Oceanic Angular Momentum (20 Year)

- **ECCO/JPL 20-year simulation**
  - Spans 1980-2002.25 at daily intervals
  - Near global spatial domain
    - 72.5°S to 72.5°N latitude with a variable resolution of 1/3° at equator to 1° at poles and a longitudinal resolution of 1°
    - 46 vertical levels with thickness ranging from 10 m at surface to 400 m at depth
  - Forced with NCEP/NCAR reanalysis surface fluxes
    - Twice daily wind stress
    - Daily heat flux and evaporation-precipitation fields (freshening only)
    - Atmospheric surface pressure not used
  - No data assimilated
  - Series designator: c20010701

- **Pre-processing**
  - Correct for Boussinesq effects
  - Form 10-day averages to be consistent with 50-year OAM series
  - Convert to equivalent LOD and polar motion excitation functions

Gross et al. (2003a, 2003b)
Oceanic Angular Momentum (Constrained)

- ECCO/JPL data assimilative
  - Spans 1993-2001 at daily intervals
  - Near global spatial domain
    - 72.5°S to 72.5°N latitude with a variable resolution of 1/3° at equator to 1° at poles and a longitudinal resolution of 1°
    - 46 vertical levels with thickness ranging from 10 m at surface to 400 m at depth
  - Forced with NCEP/NCAR reanalysis surface fluxes
    - Twice daily wind stress
    - Daily heat flux and evaporation-precipitation fields (freshening only)
    - Atmospheric surface pressure not used
  - Assimilated altimetry and XBT data
  - Series designator: kf047a
- Pre-processing
  - Correct for Boussinesq effects
  - Form 10-day averages to be consistent with 50-year OAM series
  - Convert to equivalent LOD and polar motion excitation functions
Oceanic Angular Momentum (50 Year)

- ECCO/JPL 50-year simulation
  - Spans 1949-2002 at 10-day intervals
  - Near global spatial domain
    - 77.5°S to 79.5°N latitude with a variable resolution of 1/3° at equator to 1° at poles and a longitudinal resolution of 1°
    - 46 vertical levels with thickness ranging from 10 m at surface to 400 m at depth
    - Bottom cells have been lopped to improve representation of bottom topography
  - Forced with NCEP/NCAR reanalysis surface fluxes
    - Twice daily wind stress
    - Daily heat flux and evaporation-precipitation fields (freshening only)
  - Atmospheric surface pressure not used
    - No data assimilated
    - Series designator: 50_year

- Pre-processing
  - Correct for Boussinesq effects
  - Equi-space values by linear interp.
  - Convert to equivalent LOD and polar motion excitation functions
Atmospheric Angular Momentum

- NCEP/NCAR Reanalysis
  - 6-hour values
  - Spans 1948 to present
  - Winds to 10hPa
  - Inverted barometer approximation
  - Obtained from IERS Special Bureau for the Atmosphere

- Pre-processing
  - Average over diurnal cycle
    - Centered average of 5 successive 6-hour values using weights of 1/8, 1/4, 1/4, 1/4, 1/8
  - Form 10-day averages to be consistent with OAM series
    - Centered average of 11 successive daily values using weights of 1/20, 1/10, ..., 1/10, 1/20
  - Convert to equivalent LOD and polar motion excitation functions
Earth Orientation Variations

- Extend COMB2002 with Hipparcos EOP series
  - COMB2002
    - Kalman filter self-consistently estimates polar motion rate and hence polar motion excitation function
  - Hipparcos
    - Optical astrometric series spanning 1900-1991 at 5-day intervals (UT1 since 1956; Vondrák et al., 1998)
    - Enforce consistency with COMB2002 by: (1) correcting bias, rate, & annual component; (2) adjusting uncertainties; and (3) deleting 4σ outliers
    - After adjustment, combine independent portion with COMB2002
  - Extended COMB2002 series
    - Spans 1948-2002 at daily intervals (UT1 and LOD since 1956)

- Pre-processing
  - Remove effect of long-period ocean tides on both LOD (Kantha et al., 1998) and polar motion (Gross, et al., 1997)
  - Form 10-day averages to be consistent with OAM series
    - Centered average of 11 successive daily values using weights of 1/20, 1/10, ..., 1/10, 1/20

Combined EOP Series

[Graphs of polar motion excitation X, Y, and Excess Length of Day (ms)]
OAM Comparison (1980-2001)

- Evaluate OAM simulations
  - ECCO/JPL 50-year and 20-year series
  - During common time span of 1980–2001
- Compare to COMB2002 polar motion excitation observations
  - Remove atmospheric effects from observations
    - Sum of NCEP/NCAR reanalysis AAM due to winds and inverted barometer pressure
  - Compare sum of OAM current and bottom pressure terms to observed residual
    - Power spectra and coherence magnitude and phase
- Results
  - Power spectra
    - 50-year series in closer agreement with observed residual at seasonal frequencies
    - 50-year series has less power than 20-year series at high frequencies
  - Coherence magnitude and phase
    - Both 50-year and 20-year series are similarly coherent with observed residual
OAM Comparison (1993-2001)

- Evaluate OAM series
  - ECCO/JPL simulations and assimilative series
    - During common time span of 1993–2001
- Compare to COMB2002 polar motion excitation observations
  - Remove atmospheric effects from observations
    - Sum of NCEP/NCAR reanalysis AAM due to winds and inverted barometer pressure
  - Compare sum of OAM current and bottom pressure terms to observed residual
    - Power spectra and coherence magnitude and phase

- Results
  - Power spectra
    - Data assimilative series in closest agreement with observed residual except at seasonal frequencies
    - 50-year series in closest agreement with observed residual at seasonal frequencies
  - Coherence magnitude and phase
    - At prograde frequencies, all series are similarly coherent with observed residual
    - At retrograde frequencies, data assimilative series is most coherent with obs. residual (except at −1 cpy)
Atmospheric & Oceanic Excitation (1949-2002)

- Examine influence of atmosphere and oceans on polar motion
  - Compare AAM and OAM to observed polar motion excitation
    - Extended COMB2002 polar motion excitation series
    - NCEP/NCAR reanalysis AAM series
    - ECCO/JPL 50-year OAM series
  - During common time span of 1949–2002

- Pre-processing
  - Remove seasonal cycle by least-squares
    - Mean, trend, annual, semiannual, and terannual

- Results
  - Broadband
    - Adding OAM to AAM generally improves agreement with observed polar motion excitation
  - Markowitz wobble (decadal variations)
    - AAM exhibits enhanced low-frequency power
    - But not as great nor coherent with that observed
  - Chandler wobble
    - Adding OAM to AAM improves agreement with observed Chandler excitation
Temporal Evolution of Excitation

- Compare OAM to observations
  - Remove atmospheric effects from observed polar motion excitation
  - NCEP/NCAR reanalysis AAM series
  - Compute correlation and variance explained within 4-year segments
  - Remove trend from each segment
  - With and without seasonal component

- Results
  - Little agreement prior to 1980
  - 50-year and 20-year OAM series agree equally well with obs. residual
  - Data assimilative series agrees best
  - Particularly for nonseasonal excitation

- Why does agreement improve?
  - Space geodetic measurements are more accurate than optical astrometric
  - Satellite era of global weather observing system started 1979
  - TOVS temperature soundings became available then

Kistler et al. (2001)
Summary

- New 50-year OAM series
  - Comparable to previously available 20-year series
    - During their common time interval of 1980–2001
  - Extends available OAM series back to 1949
    - Will soon be available through IERS Special Bureau for the Oceans web site at <http://euler.jpl.nasa.gov/sbo>

- Decadal polar motion variations (Markowitz wobble)
  - AAM has enhanced low-frequency power
    - But it is not as great nor is it coherent with observed polar motion excitation
  - Adding OAM increases power but not coherence

- Chandler wobble
  - AAM alone does not have enough power and is not coherent with observed excitation
  - Adding OAM increases power to that observed, coherence becomes significant, and phase becomes closer to zero

- Temporal evolution of atmospheric and oceanic excitation
  - Agreement of OAM with observed–AAM residual dramatically improves after 1980
    - Space geodetic measurements, which are substantially more accurate than optical astrometric, started in 1976
    - Atmospheric fields, including AAM, improved with start of TOVS temperature soundings in 1979
Acknowledgments

The work presented here was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.
Temporal Evolution of Atmospheric and Oceanic Excitation of Earth Orientation Variations During the Past 50 Years

Richard S. Gross, Ichiro Fukumori, and Dimitris Menemenlis

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

American Geophysical Union
2003 Fall Meeting

December 8–12, 2003
San Francisco, CA
Overview

- Investigate atmospheric and oceanic excitation of polar motion during 1949–2002
  - Observed polar motion excitation from COMB2002 combined EOP series
    - Extended back to 1949 using Hipparcos optical astrometric series
  - Atmospheric Angular Momentum (AAM) from NCEP/NCAR reanalysis project
    - Obtained from IERS Special Bureau for the Atmosphere
  - Oceanic Angular Momentum (OAM) from JPL component of ECCO consortium
    - New 50-year simulation spanning 1949–2002
    - 20-year simulation spanning 1980–2001 (Gross et al., 2003a, 2003b)
    - Data assimilative series spanning 1993–2001

- Intercompare ECCO/JPL OAM series
  - Evaluate by comparing with observed polar motion excitation series
    - From which atmospheric effects have been removed

- Study average effect of atmosphere and oceans on polar motion during 1949–2002
  - Markowitz wobble (decadal variations)
  - Chandler wobble

- Study temporal evolution of atmospheric and oceanic excitation of polar motion
  - Compare OAM with observed–AAM residual in non-overlapping 4-year-long segments spanning 1950–2001
Oceanic Angular Momentum (20 Year)

- ECCO/JPL 20-year simulation
  - Spans 1980-2002.25 at daily intervals
  - Near global spatial domain
    - 72.5°S to 72.5°N latitude with a variable resolution of 1/3° at equator to 1° at poles and a longitudinal resolution of 1°
    - 46 vertical levels with thickness ranging from 10 m at surface to 400 m at depth
  - Forced with NCEP/NCAR reanalysis surface fluxes
    - Twice daily wind stress
    - Daily heat flux and evaporation-precipitation fields (freshening only)
    - Atmospheric surface pressure not used
  - No data assimilated
  - Series designator: c20010701

- Pre-processing
  - Correct for Boussinesq effects
  - Form 10-day averages to be consistent with 50-year OAM series
  - Convert to equivalent LOD and polar motion excitation functions

Gross et al. (2003a, 2003b)
Oceanic Angular Momentum (Constrained)

- **ECCO/JPL data assimilative**
  - Spans 1993-2001 at daily intervals
  - Near global spatial domain
  - 72.5°S to 72.5°N latitude with a variable resolution of 1/3° at equator to 1° at poles and a longitudinal resolution of 1°
  - 46 vertical levels with thickness ranging from 10 m at surface to 400 m at depth
  - Forced with NCEP/NCAR reanalysis surface fluxes
    - Twice daily wind stress
    - Daily heat flux and evaporation-precipitation fields (freshening only)
    - Atmospheric surface pressure not used
  - Assimilated altimetry and XBT data
  - Series designator: kf047a

- **Pre-processing**
  - Correct for Boussinesq effects
  - Form 10-day averages to be consistent with 50-year OAM series
  - Convert to equivalent LOD and polar motion excitation functions
Oceanic Angular Momentum (50 Year)

- **ECCO/JPL 50-year simulation**
  - Spans 1949-2002 at 10-day intervals
  - Near global spatial domain
    - 77.5°S to 79.5°N latitude with a variable resolution of 1/3° at equator to 1° at poles and a longitudinal resolution of 1°
    - 46 vertical levels with thickness ranging from 10 m at surface to 400 m at depth
    - Bottom cells have been lopped to improve representation of bottom topography
  - Forced with NCEP/NCAR reanalysis surface fluxes
    - Twice daily wind stress
    - Daily heat flux and evaporation-precipitation fields (freshening only)
    - Atmospheric surface pressure not used
    - No data assimilated
    - Series designator: 50_year

- **Pre-processing**
  - Correct for Boussinesq effects
  - Equi-space values by linear interp.
  - Convert to equivalent LOD and polar motion excitation functions
Atmospheric Angular Momentum

- **NCEP/NCAR Reanalysis**
  - 6-hour values
  - Spans 1948 to present
  - Winds to 10hPa
  - Inverted barometer approximation
  - Obtained from IERS Special Bureau for the Atmosphere

- **Pre-processing**
  - Average over diurnal cycle
    - Centered average of 5 successive 6-hour values using weights of $1/8, 1/4, 1/4, 1/4, 1/8$
  - Form 10-day averages to be consistent with OAM series
    - Centered average of 11 successive daily values using weights of $1/20, 1/10, \cdots, 1/10, 1/20$
  - Convert to equivalent LOD and polar motion excitation functions

**NCEP/NCAR Reanalysis AAM**

![Graphs showing wind and pressure variations over time, with data spanning from 1960 to 2000.](image)
Earth Orientation Variations

- Extend COMB2002 with Hipparcos EOP series

  - COMB2002
    - Kalman filter self-consistently estimates polar motion rate and hence polar motion excitation function

  - Hipparcos
    - Optical astrometric series spanning 1900-1991 at 5-day intervals (UT1 since 1956; Vondrak et al., 1998)
    - Enforce consistency with COMB2002 by: (1) correcting bias, rate, & annual component; (2) adjusting uncertainties; and (3) deleting 4σ outliers
    - After adjustment, combine independent portion with COMB2002

  - Extended COMB2002 series
    - Spans 1948-2002 at daily intervals (UT1 and LOD since 1956)

- Pre-processing

  - Remove effect of long-period ocean tides on both LOD (Kantha et al., 1998) and polar motion (Gross, et al., 1997)
  - Form 10-day averages to be consistent with OAM series
    - Centered average of 11 successive daily values using weights of 1/20, 1/10, …, 1/10, 1/20
OAM Comparison (1980-2001)

- Evaluate OAM simulations
  - ECCO/JPL 50-year and 20-year series
    - During common time span of 1980–2001
- Compare to COMB2002 polar motion excitation observations
  - Remove atmospheric effects from observations
    - Sum of NCEP/NCAR reanalysis AAM due to winds and invetted barometer pressure
  - Compare sum of OAM current and bottom pressure terms to observed residual
    - Power spectra and coherence magnitude and phase
- Results
  - Power spectra
    - 50-year series in closer agreement with observed residual at seasonal frequencies
    - 50-year series has less power than 20-year series at high frequencies
  - Coherence magnitude and phase
    - Both 50-year and 20-year series are similarly coherent with observed residual
OAM Comparison (1993-2001)

- Evaluate OAM series
  - ECCO/JPL simulations and assimilative series
    - During common time span of 1993–2001
- Compare to COMB2002 polar motion excitation observations
  - Remove atmospheric effects from observations
    - Sum of NCEP/NCAR reanalysis AAM due to winds and inverted barometer pressure
  - Compare sum of OAM current and bottom pressure terms to observed residual
    - Power spectra and coherence magnitude and phase
- Results
  - Power spectra
    - Data assimilative series in closest agreement with observed residual except at seasonal frequencies
    - 50-year series in closest agreement with observed residual at seasonal frequencies
  - Coherence magnitude and phase
    - At prograde frequencies, all series are similarly coherent with observed residual
    - At retrograde frequencies, data assimilative series is most coherent with obs. residual (except at −1 cpy)
Atmospheric & Oceanic Excitation (1949-2002)

- Examine influence of atmosphere and oceans on polar motion
  - Compare AAM and OAM to observed polar motion excitation
  - Extended COMB2002 polar motion excitation series
  - NCEP/NCAR reanalysis AAM series
  - ECCO/JPL 50-year OAM series
  - During common time span of 1949–2002

- Pre-processing
  - Remove seasonal cycle by least-squares
    - Mean, trend, annual, semiannual, and terannual

- Results
  - Broadband
    - Adding OAM to AAM generally improves agreement with observed polar motion excitation
  - Markowitz wobble (decadal variations)
    - AAM exhibits enhanced low-frequency power
    - But not as great nor coherent with that observed
  - Chandler wobble
    - Adding OAM to AAM improves agreement with observed Chandler excitation
Temporal Evolution of Excitation

- Compare OAM to observations
  - Remove atmospheric effects from observed polar motion excitation
  - NCEP/NCAR reanalysis AAM series
  - Compute correlation and variance explained within 4-year segments
  - Remove trend from each segment
  - With and without seasonal component

- Results
  - Little agreement prior to 1980
  - 50-year and 20-year OAM series agree equally well with obs. residual
  - Data assimilative series agrees best
    - Particularly for nonseasonal excitation

- Why does agreement improve?
  - Space geodetic measurements are more accurate than optical astrometric
  - Satellite era of global weather observing system started 1979
    - TOVS temperature soundings became available then

Gross (2003)

Kistler et al. (2001)
Summary

- **New 50-year OAM series**
  - Comparable to previously available 20-year series
    - During their common time interval of 1980–2001
  - Extends available OAM series back to 1949
    - Will soon be available through IERS Special Bureau for the Oceans web site at <http://euler.jpl.nasa.gov/sbo>

- **Decadal polar motion variations (Markowitz wobble)**
  - AAM has enhanced low-frequency power
    - But it is not as great nor is it coherent with observed polar motion excitation
  - Adding OAM increases power but not coherence

- **Chandler wobble**
  - AAM alone does not have enough power and is not coherent with observed excitation
  - Adding OAM increases power to that observed, coherence becomes significant, and phase becomes closer to zero

- **Temporal evolution of atmospheric and oceanic excitation**
  - Agreement of OAM with observed–AAM residual dramatically improves after 1980
    - Space geodetic measurements, which are substantially more accurate than optical astrometric, started in 1976
    - Atmospheric fields, including AAM, improved with start of TOVS temperature soundings in 1979
Acknowledgments

The work presented here was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.