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

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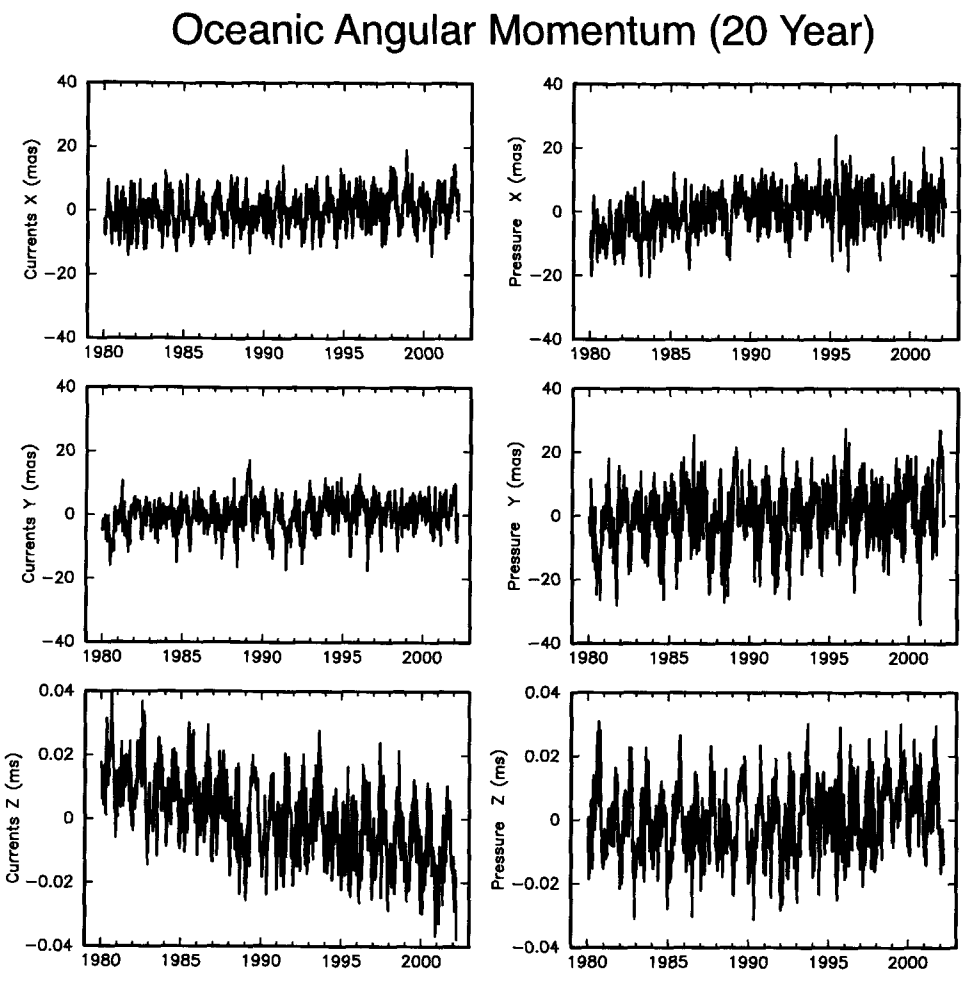
# Overview

- 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)

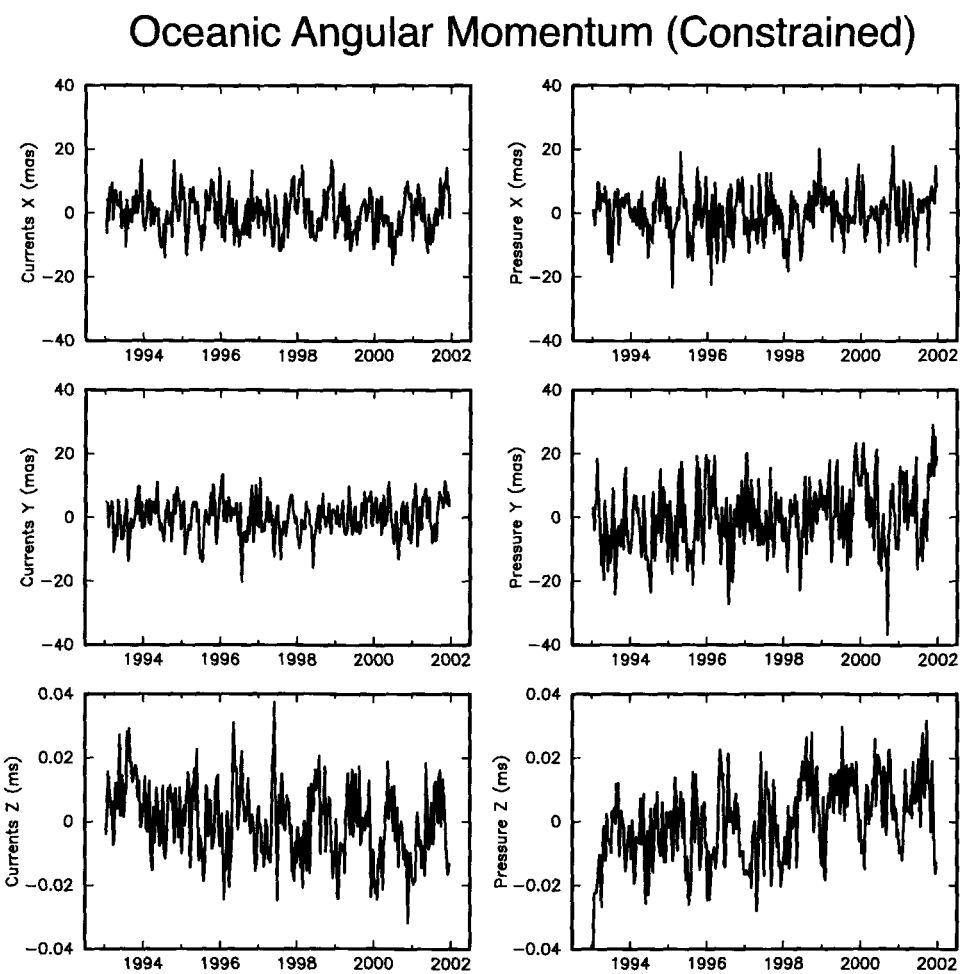
- ECCO/JPL 20-year simulation
  - Spans 1980-2002.25 at daily intervals
  - Near global spatial domain
    - 72.5°S to 72.5°N latitude with a variable resolution of 1/3° at equator to 1° at poles and a longitudinal resolution of 1°
    - 46 vertical levels with thickness ranging from 10 m at surface 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)

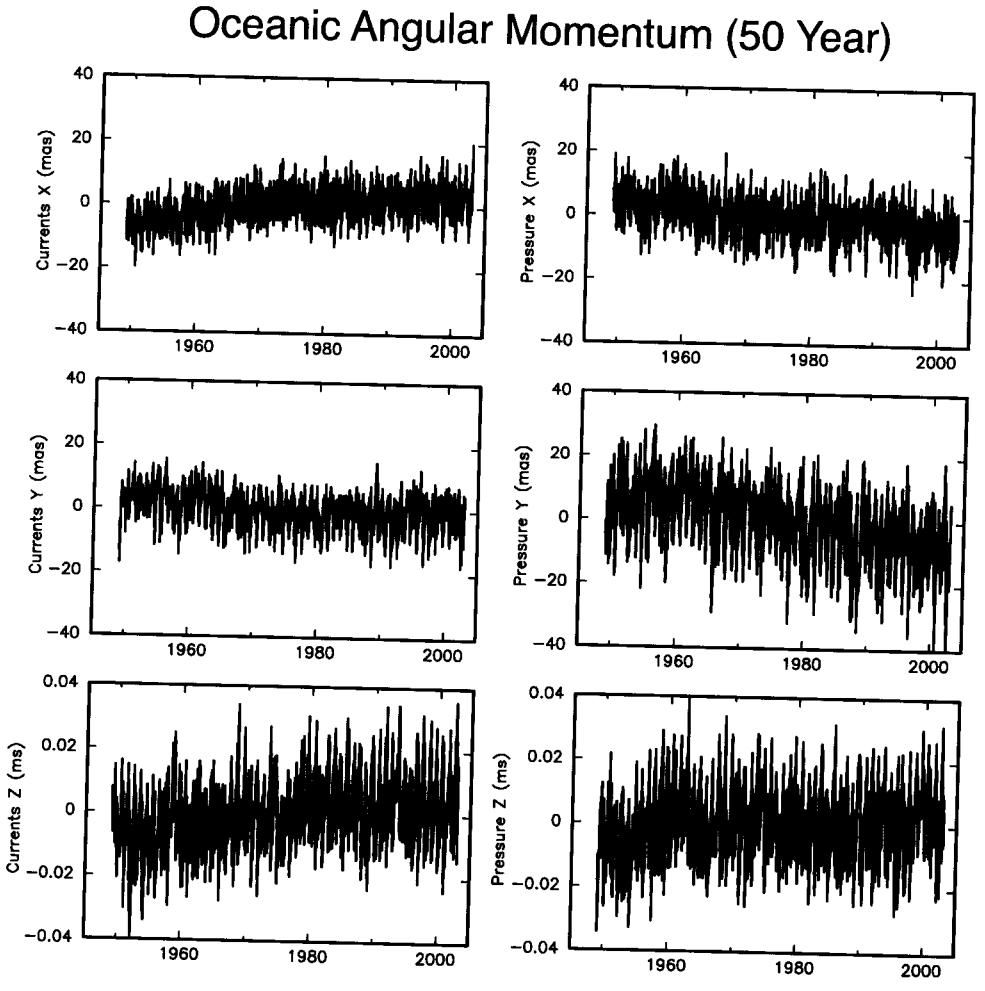
# Oceanic Angular Momentum (Constrained)

- 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)

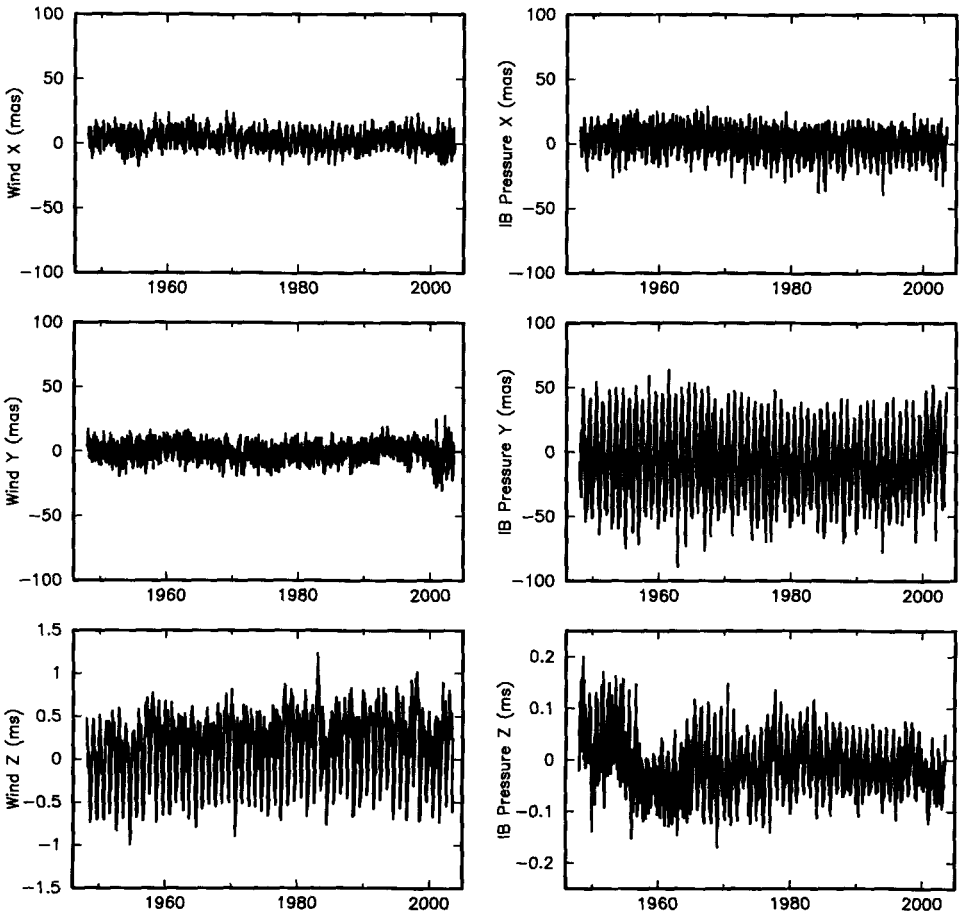
- ECCO/JPL 50-year simulation
  - Spans 1949-2002 at 10-day intervals
  - Near global spatial domain
    - 77.5°S to 79.5°N latitude with a variable resolution of 1/3° at equator to 1° at poles and a longitudinal resolution of 1°
    - 46 vertical levels with thickness ranging from 10 m at surface to 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

NCEP/NCAR Reanalysis AAM



# Earth Orientation Variations

- Extend COMB2002 with Hipparcos EOP series
  - COMB2002
    - Kalman filter-based combination of optical astrometric, LLR, SLR, VLBI, and GPS Earth orientation series spanning 1962-2002 at daily intervals (Gross, 2003)
    - 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
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- Pre-processing
  - Remove effect of long-period ocean tides on both LOD (Kantha *et al.*, 1998) and polar motion (Gross, *et al.*, 1997)
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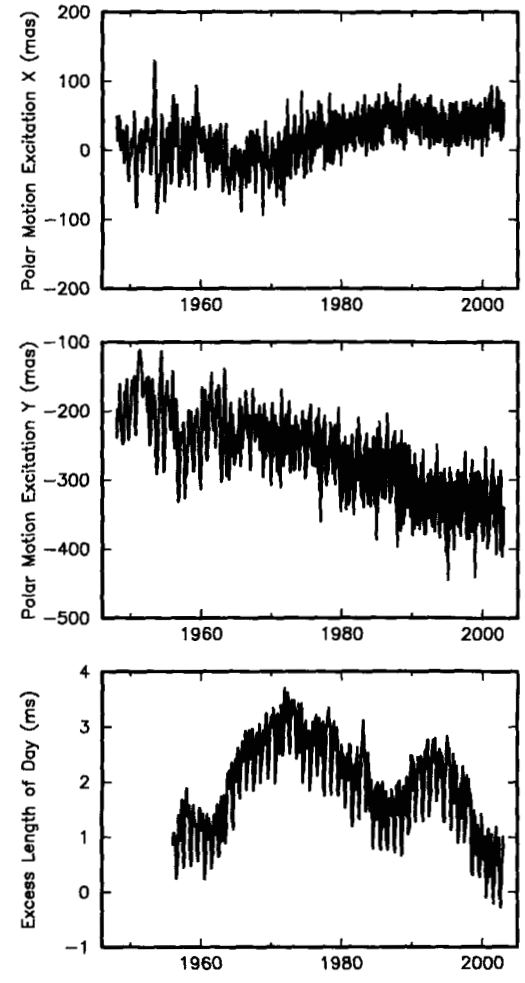
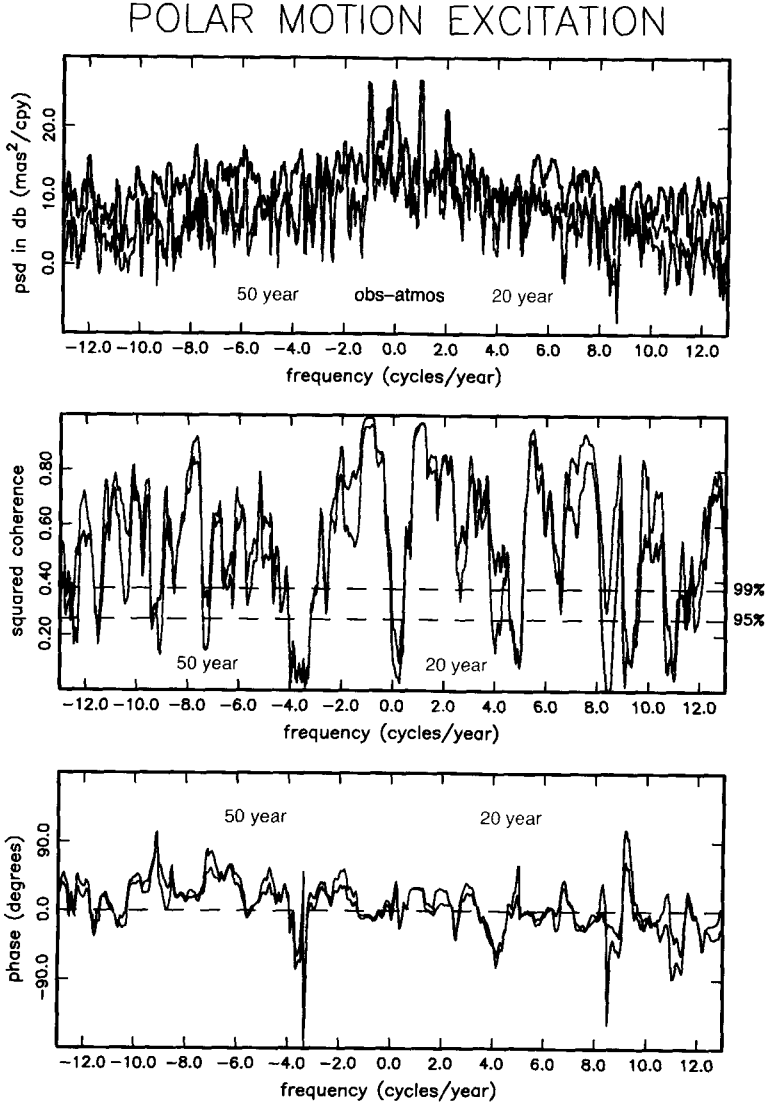
Combined EOP Series



# 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
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    - Sum of NCEP/NCAR reanalysis AAM due to winds and inverted barometer pressure
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    - Data assimilative series in closest agreement with observed residual except at seasonal frequencies
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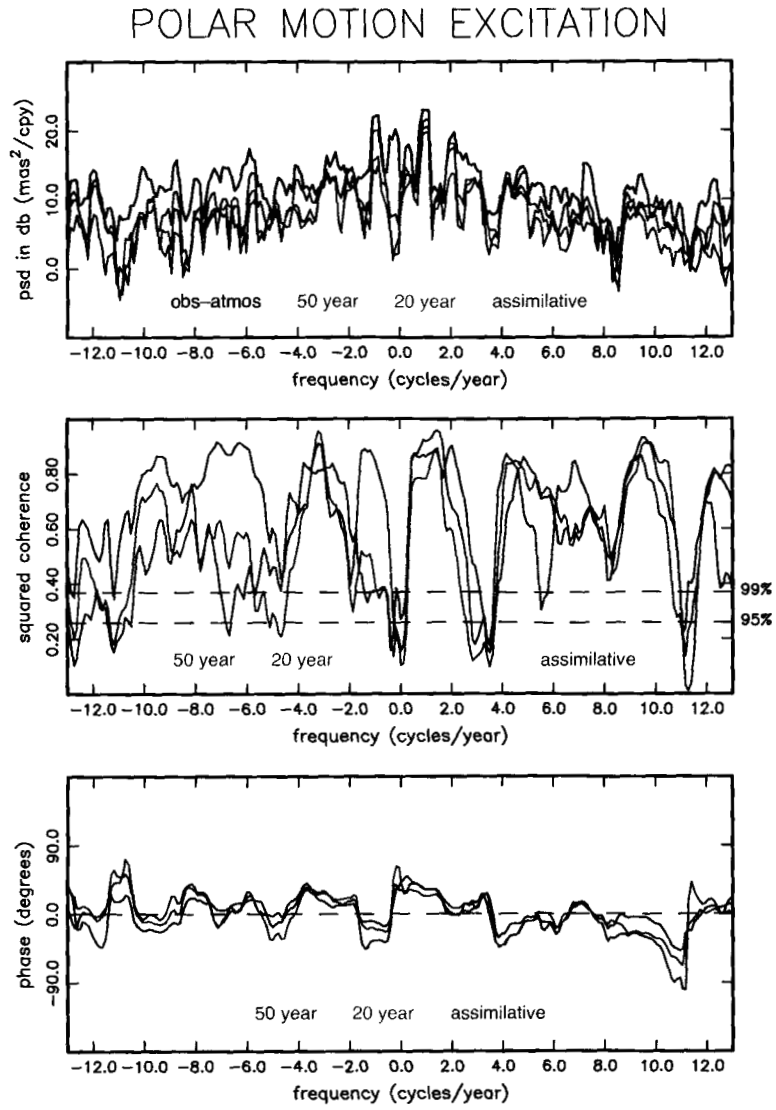
    - At retrograde frequencies, data assimilative series is most coherent with obs. residual (except at –1 cpy)



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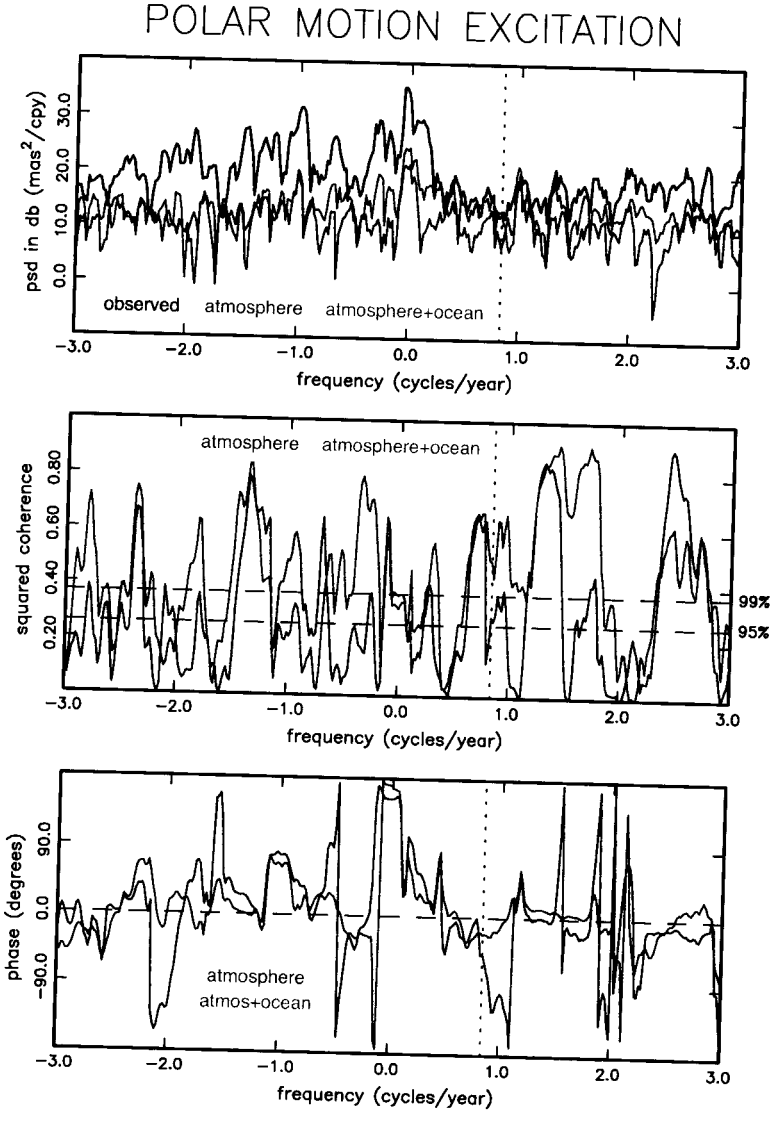
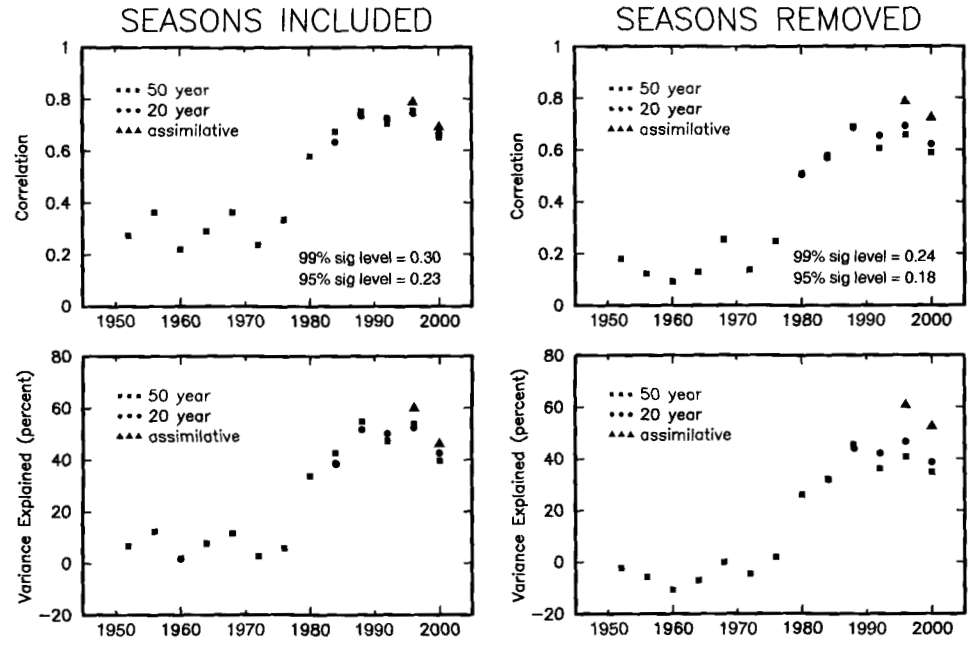
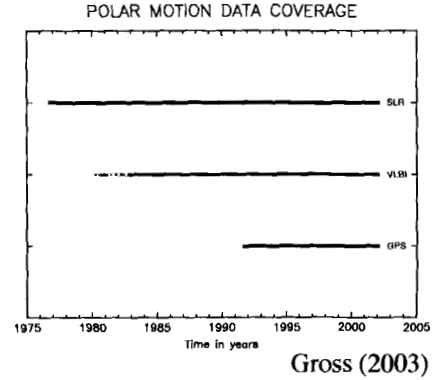
  - Broadband
    - Adding OAM to AAM generally improves agreement with observed polar motion excitation
  - Markowitz wobble (decadal variations)
    - AAM exhibits enhanced low-frequency power
    - But not as great nor coherent with that observed
  - Chandler wobble
    - Adding OAM to AAM improves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

Fig. 1. Zonal mean number of all types of observations per 2.5° latitude box per month from 1946 to 1998. A 12-month running mean has been applied.

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.

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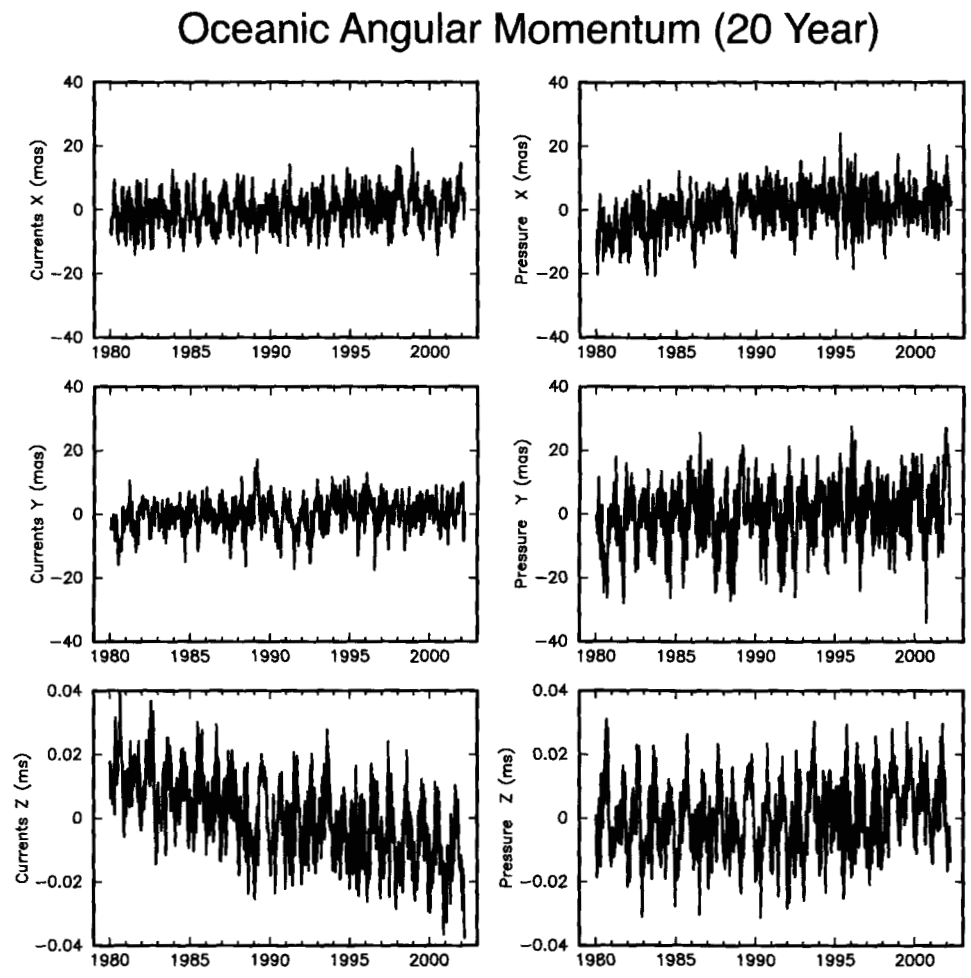


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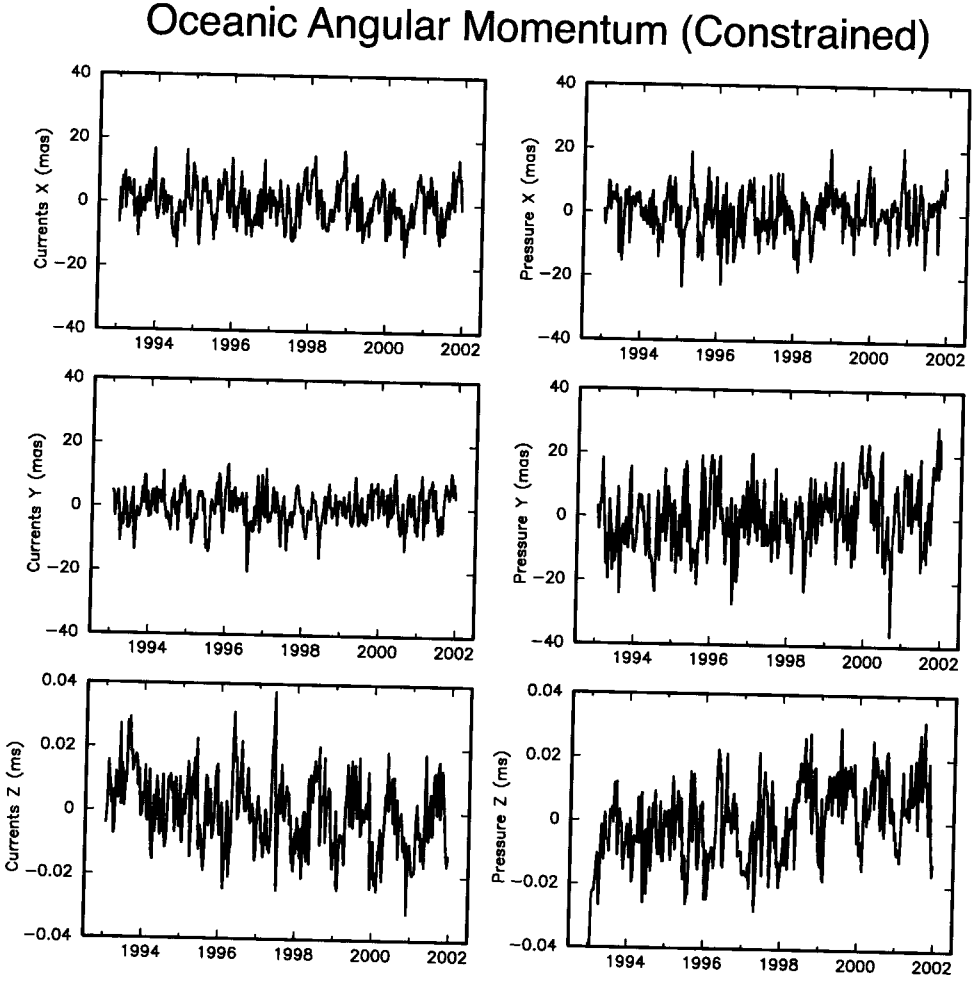

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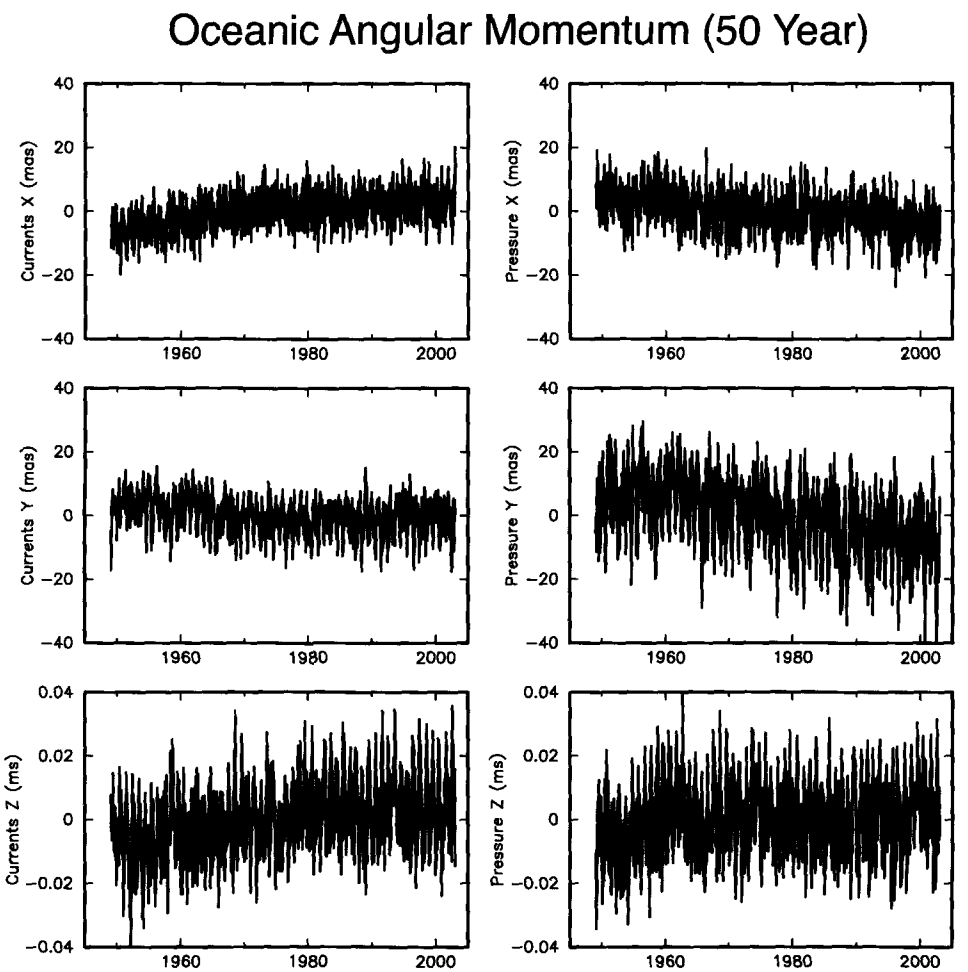

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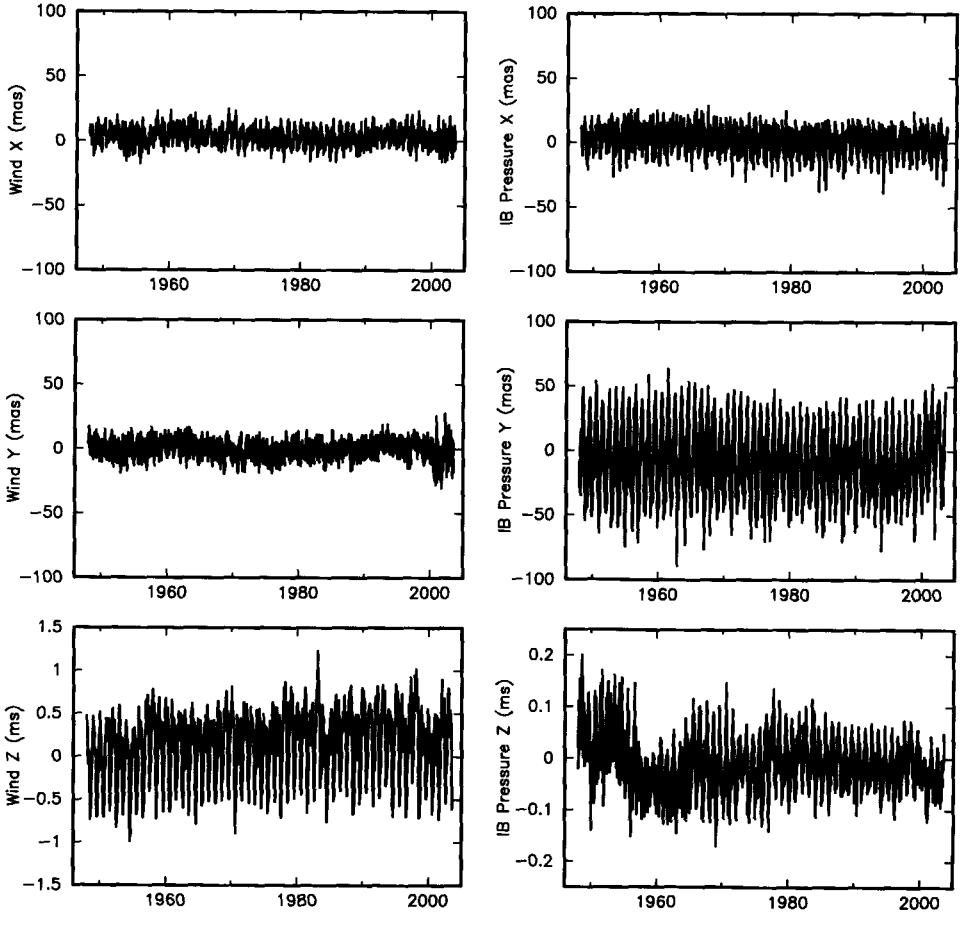
NCEP/NCAR Reanalysis AAM



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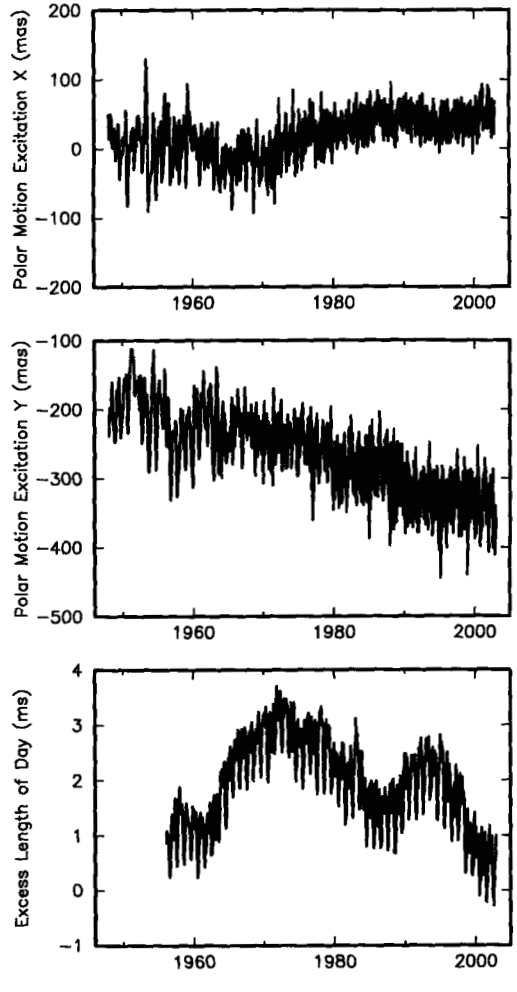

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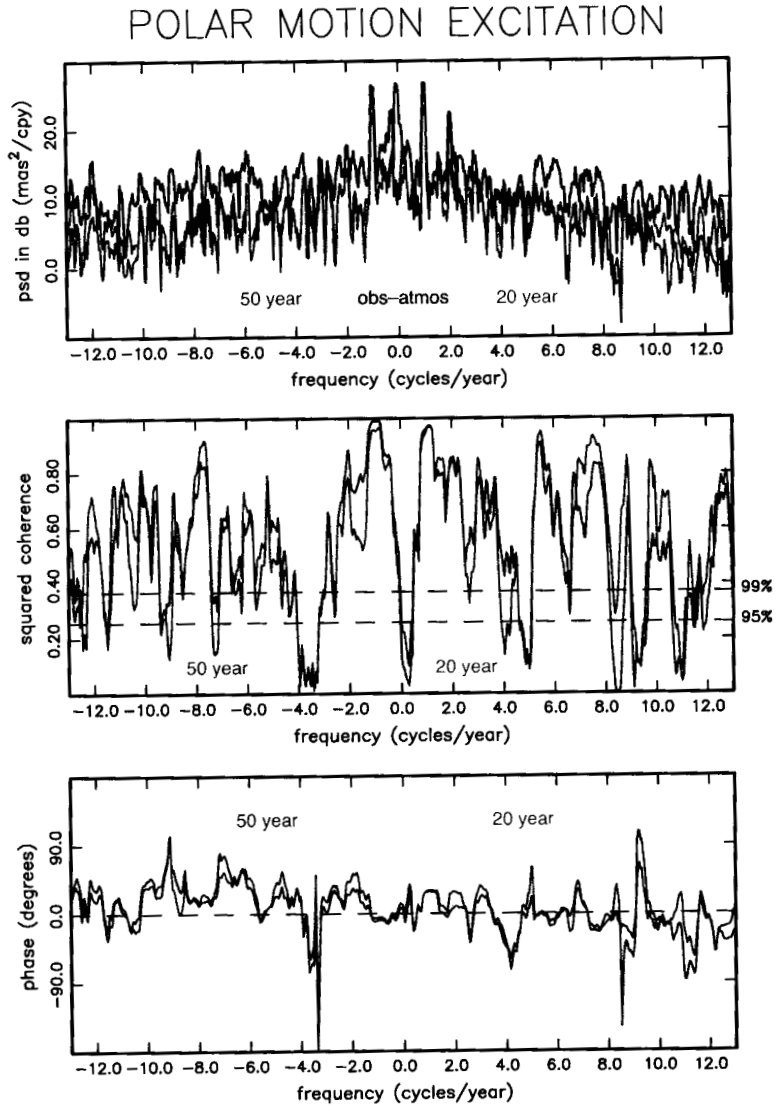

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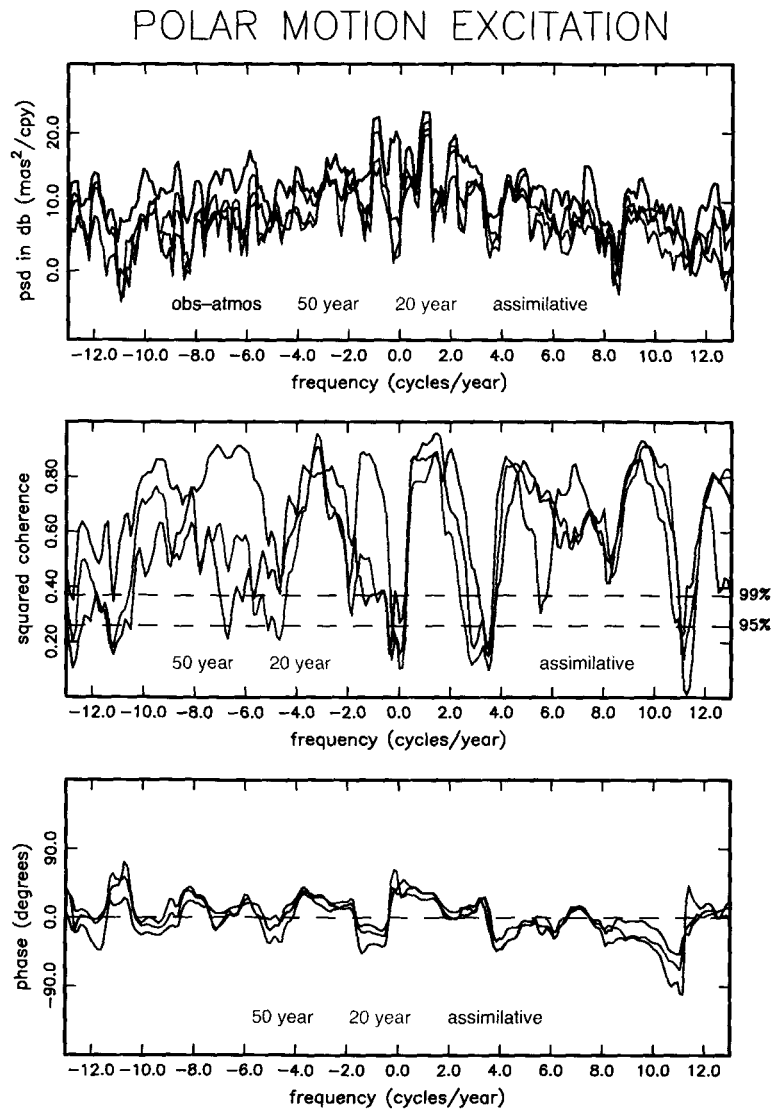

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  - Compare AAM and OAM to observed polar motion excitation
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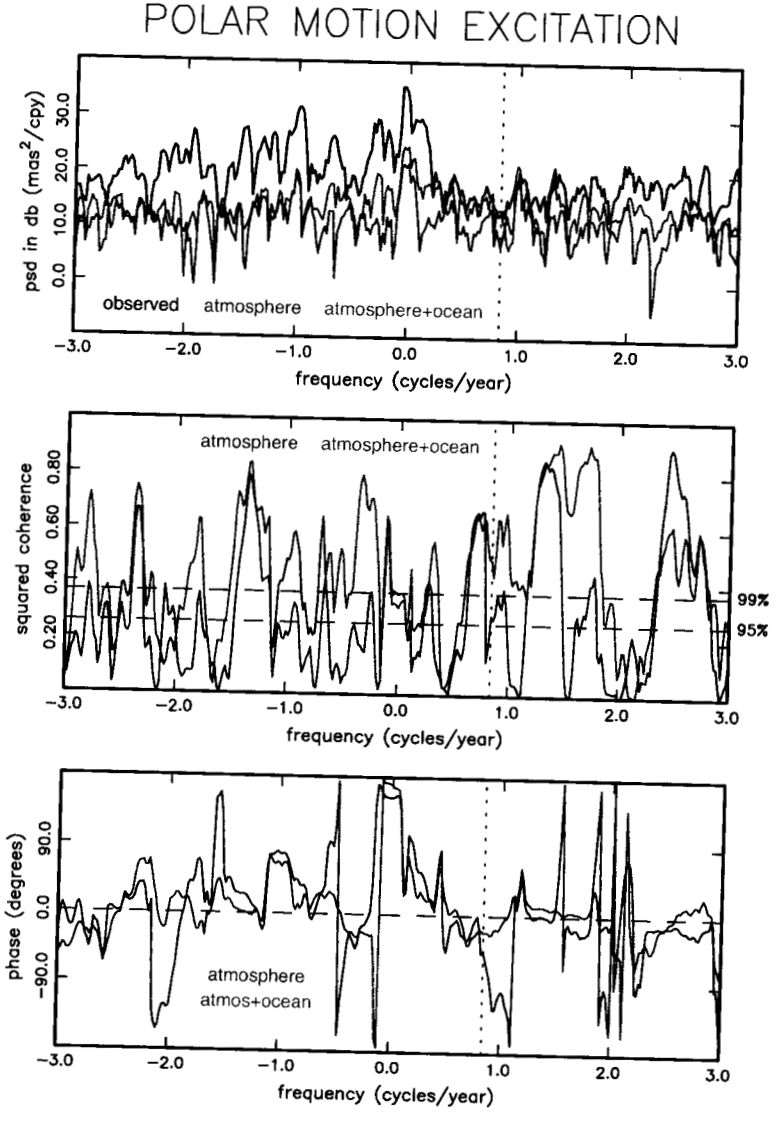

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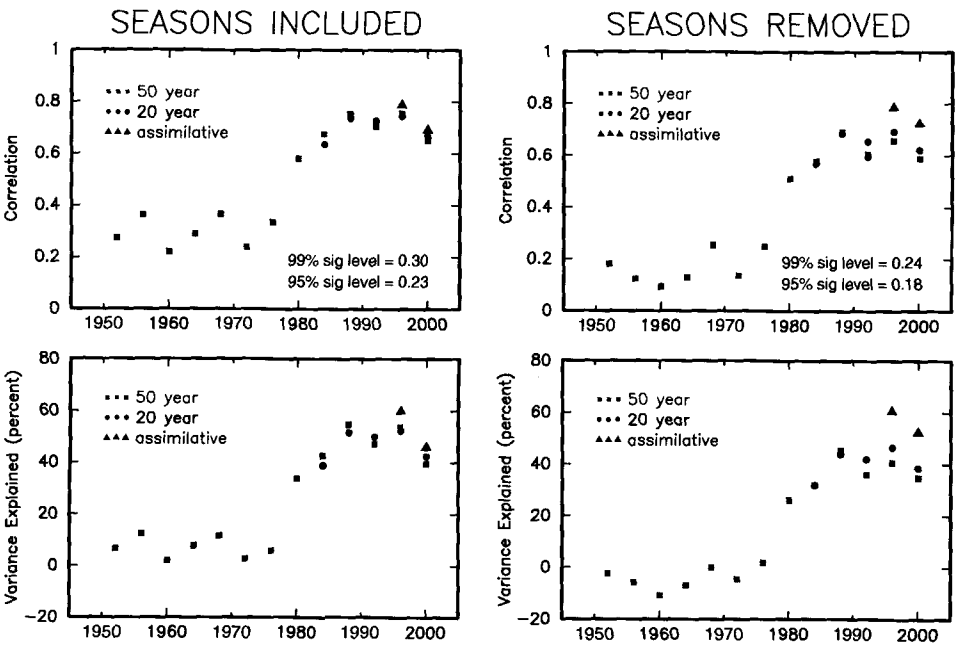


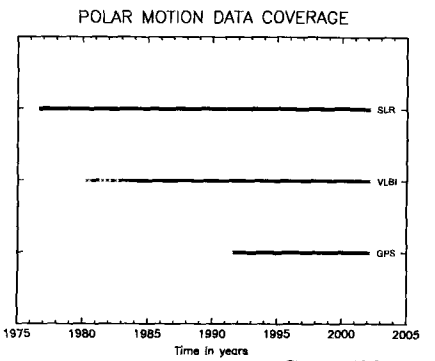


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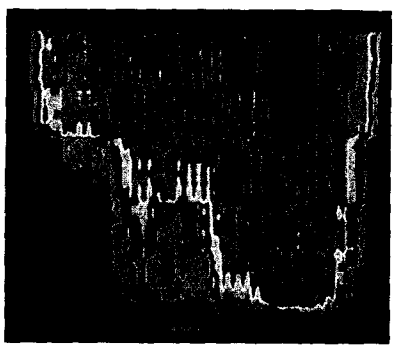

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    - During their common time interval of 1980–2001
  - Extends available OAM series back to 1949
    - Will soon be available through IERS Special Bureau for the Oceans web site at <http://euler.jpl.nasa.gov/sbo>
- Decadal polar motion variations (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

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