Observing and Modeling Long-Period Tidal Variations in Polar Motion

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Introduction

- Tide raising potential
  - Symmetric about Earth's polar axis
  - Deforms axisymmetric solid Earth
    - Excites length-of-day but not polar motion
  - Deforms asymmetric oceans
    - Excites length-of-day and polar motion
- Examine tidal effects on polar motion
  - Remove atmospheric and oceanic effects from observations
    - Strong fortnightly tidal signal not fully explained by any existing model
  - Revise dynamical ocean tide model of Dickman (1993)
    - Fortnightly tidal signal is further reduced but not eliminated by revised model (Dickman & Gross, 2010)
  - Update empirical ocean tide model of Gross (2009)
    - Determined by fitting tidal terms to observations
    - Has the empirical model converged?

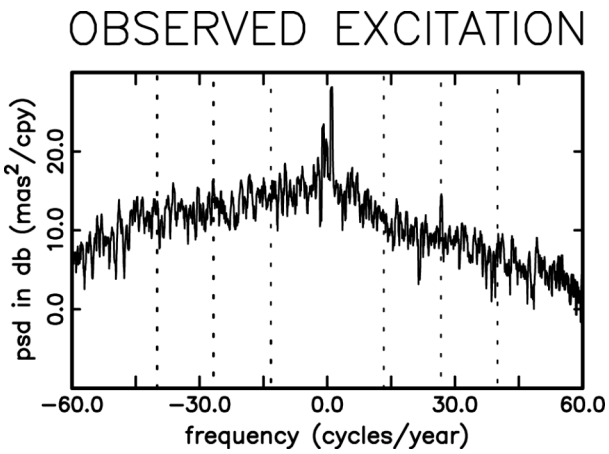
Data Sets

- Observed polar motion excitation
  - COMB2009 combined EOP series
    - Combination of optical astrometric, LLR, SLR, VLBI, & GPS observations
    - Polar motion rate observations not used (contaminated by tidal artifacts)
    - Daily values at midnight spanning January 20, 1962 to May 28, 2010
- Remove atmospheric & non-tidal oceanic effects
  - NCEP/NCAR reanalysis AAM
    - Wind & inverted barometer pressure terms
    - Daily values at midnight spanning January 2, 1948 to July 17, 2010
  - ECCO/JPL OAM model c20010701
    - Simulation of oceans' general circulation not constrained by any data
    - Daily values at midnight spanning January 2, 1980 to March 31 2002
  - ECCO/JPL OAM model kf080
    - Constrained by *in situ* & altimetric data
    - Daily values at midnight spanning January 2, 1993 to June 29, 2010
  - Spliced c20010701 / kf080 model
    - Daily values at midnight spanning January 2, 1980 to June 29, 2010

Tide models

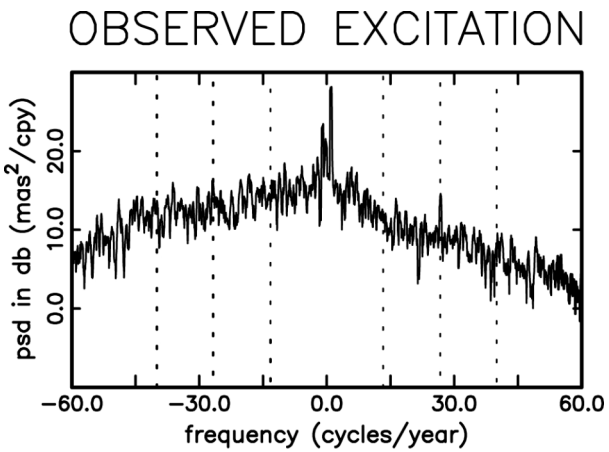
- Dynamical ocean tide models
  - Seiler (1991) as reported by Gross (1993)
    - Hydrodynamic ocean model unconstrained by data (Ssa, Mm, Mf)
  - Dickman (1993) as reported by Gross et al. (1997)
    - Hydrodynamic ocean model unconstrained by data (Sa, Ssa, Mm, Mf, Mtm, …)
  - Weis (2006) as reported by Gross (2009)
    - Hydrodynamic ocean model unconstrained by data (Sa, Ssa, Mm, Mf, Mtm, …)
  - Dickman and Gross (2010)
    - Revised version of Dickman (1993) model
- Empirical ocean tide models
  - Gross et al. (1997)
    - Empirical model determined by fitting observations (Mm, Mf, Mtm)
  - Gross (2009) and its updated version reported here
    - Empirical model determined by fitting observations (Mm, Mf, Mtm)
    - Mf & mf (and, separately, Mtm & mtm) constrained to have the same phase and an amplitude ratio the same as that of the tide raising potential

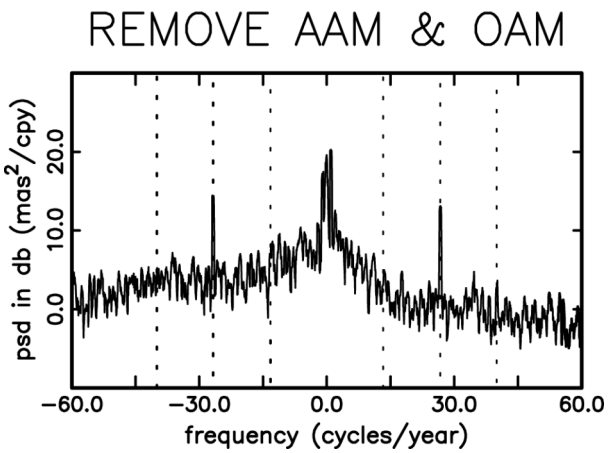
Dynamical Ocean Tide Models



(March 25, 1995 to May 28, 2010)

Dynamical Ocean Tide Models





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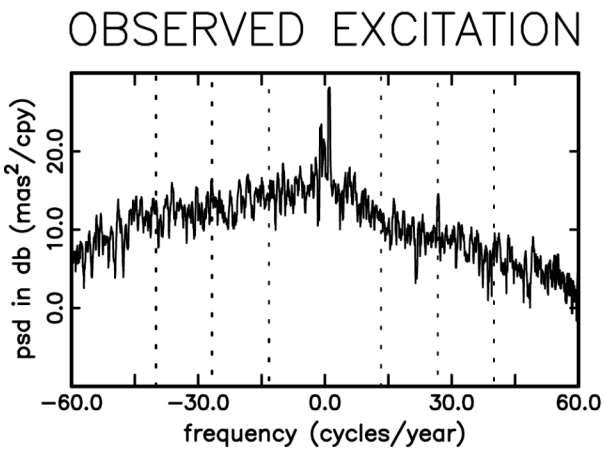

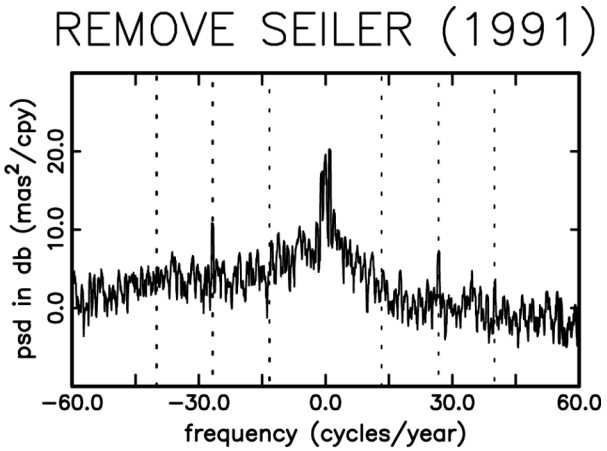

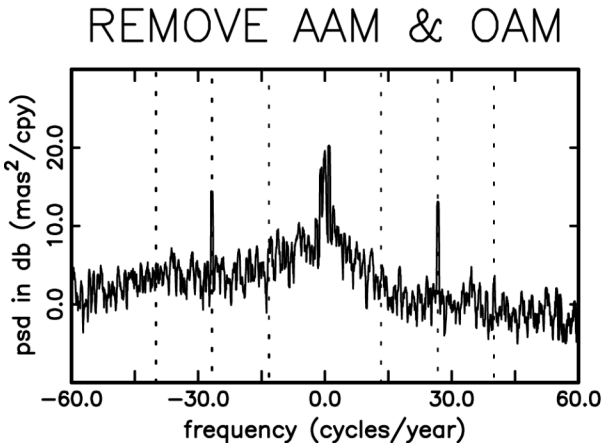

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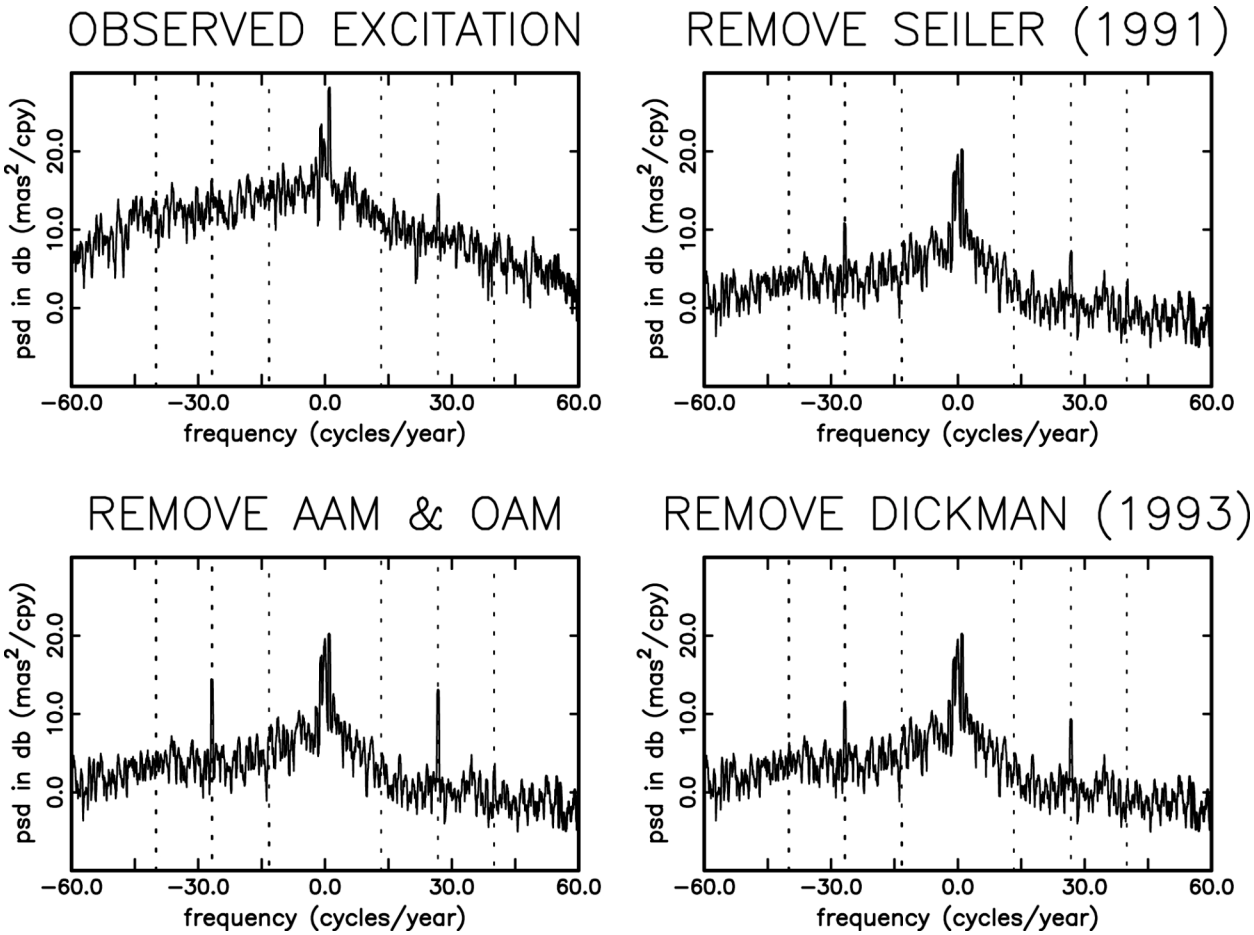

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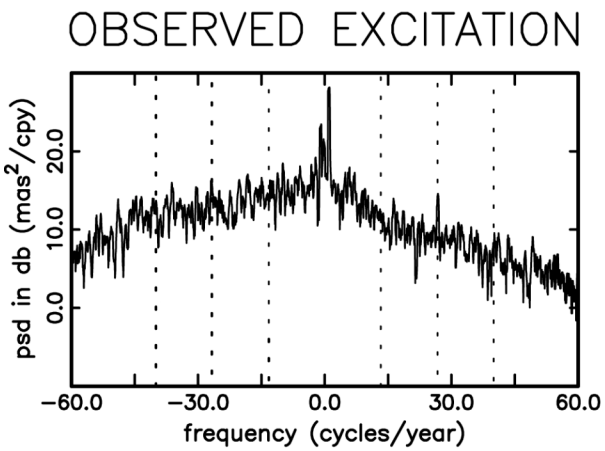
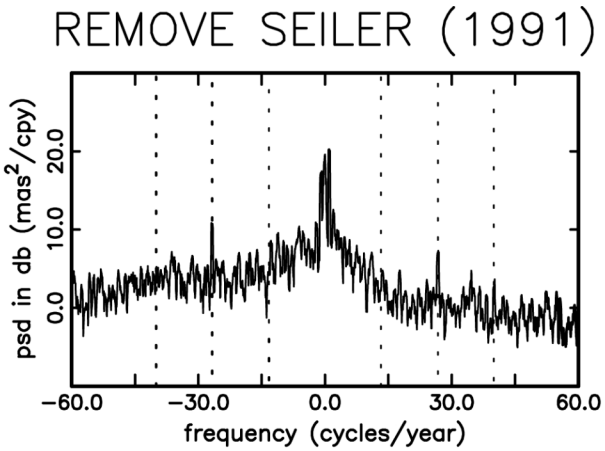
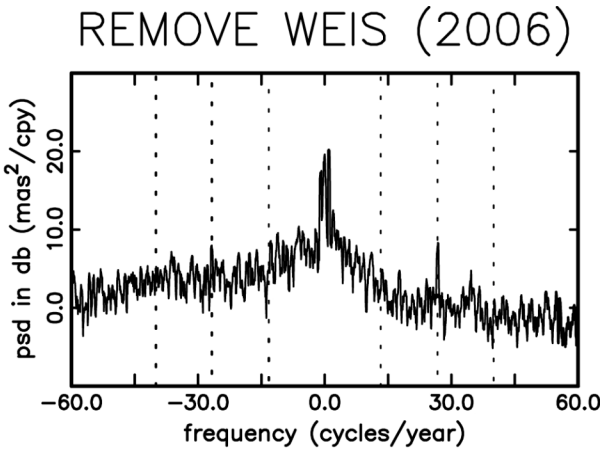
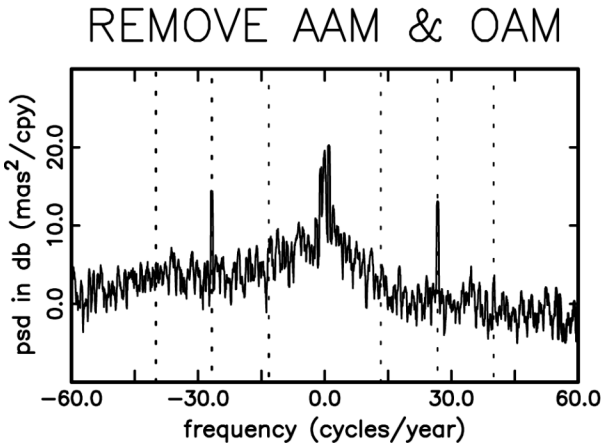
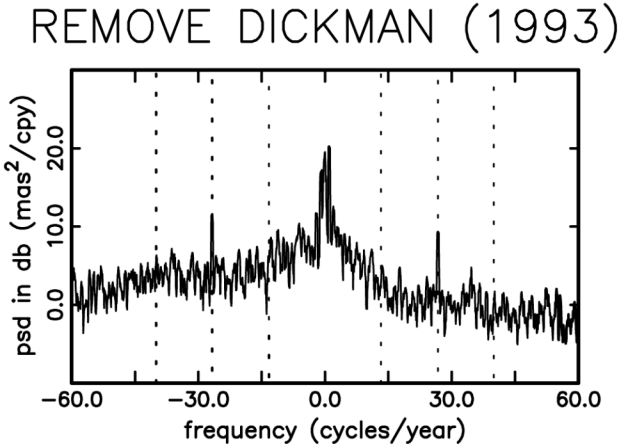
Dynamical Ocean Tide Models











(March 25, 1995 to May 28, 2010)

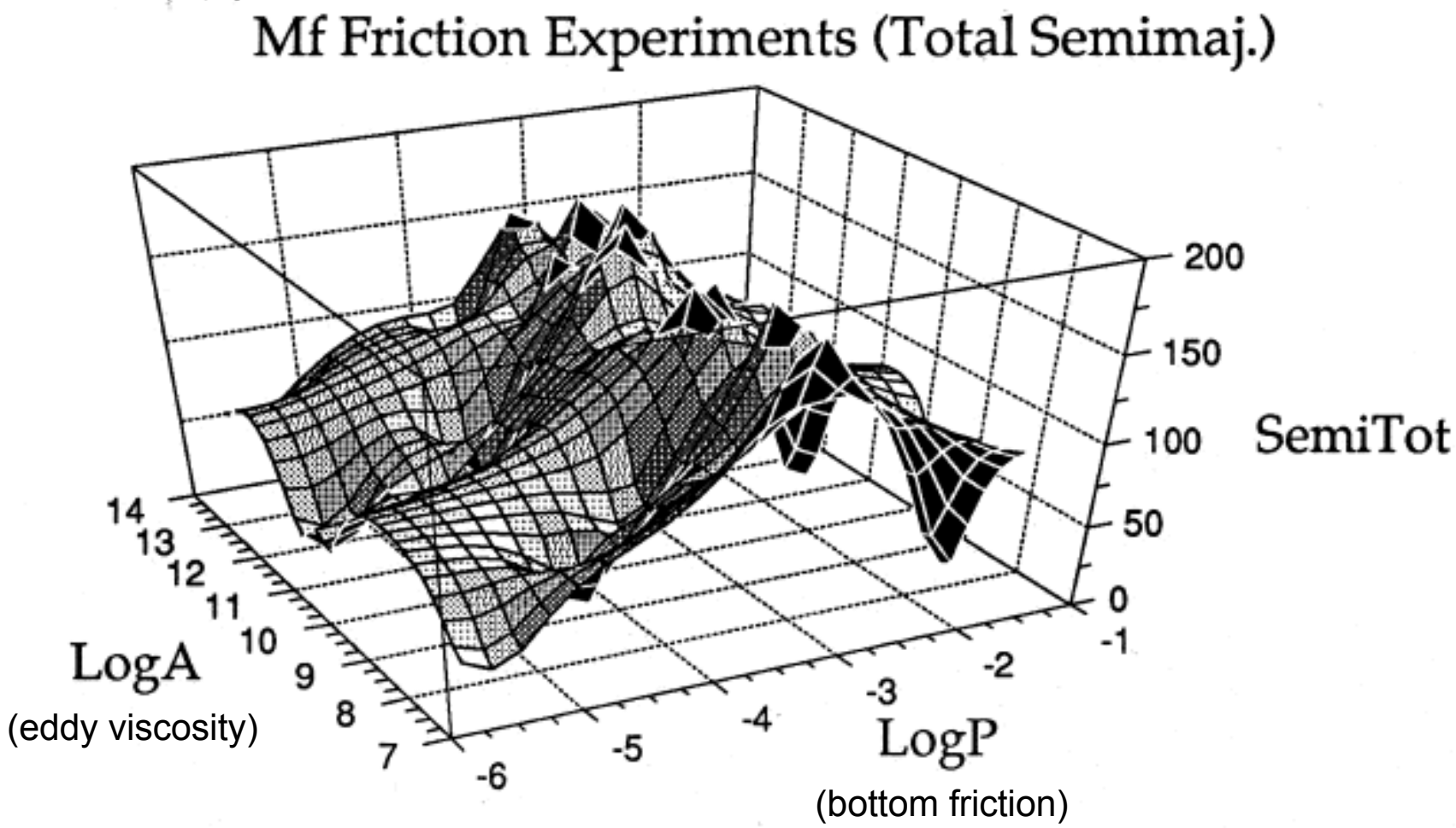
Dickman Tide Model

- **dynamic ocean tide model**
  - **based on Laplace Tidal Equations, with bottom friction & turbulent dissipation** (uniform bottom drag ☹)
  - **includes rigorous self-gravitation and loading**
  - **includes global mass-conservation constraint**
  - **includes variable coastlines & bathymetry**
  - **uses a spherical harmonic approach to solve the Laplace Tidal Eqns + no-flow boundary conditions**

- **broad-band rotation model**
  - **frequency-dependent Love numbers due to Core**
  - **dynamic oceanic response to rotational fluctuations**

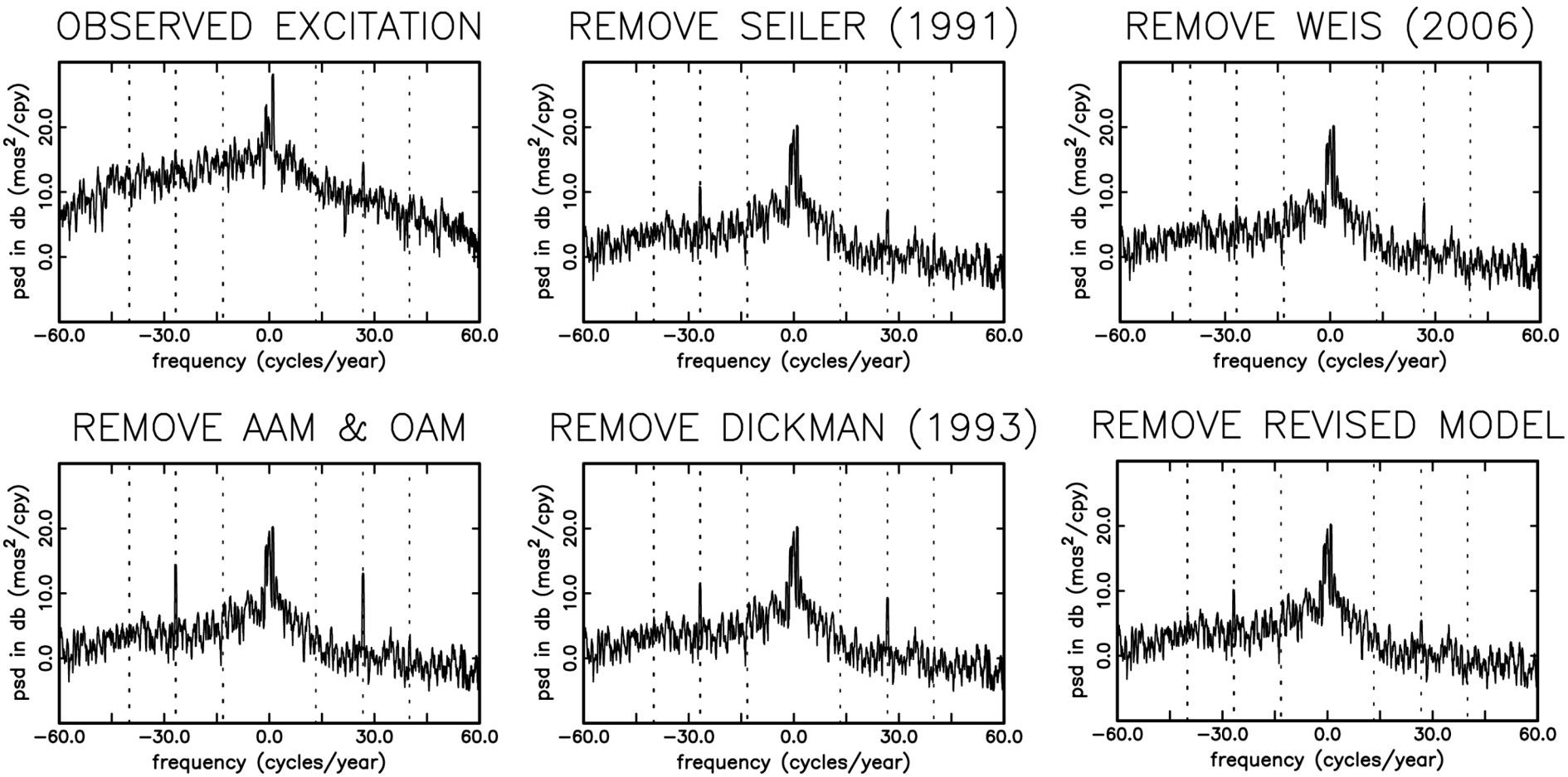
Dickman *Revised* Tide Model

- dynamic ocean tide model
  - frictionally calibrated: bottom drag & turbulence parameters determined such that polar motion effects of Mf are consistent with observations
- broad-band rotation model
  - Love number dispersion at long periods due to mantle anelasticity



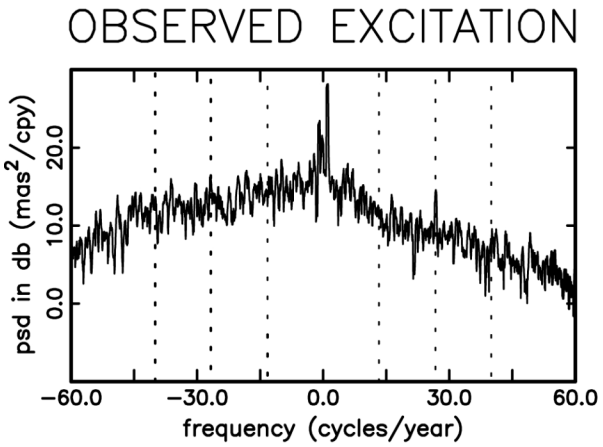
Dickman & Nam (1995)

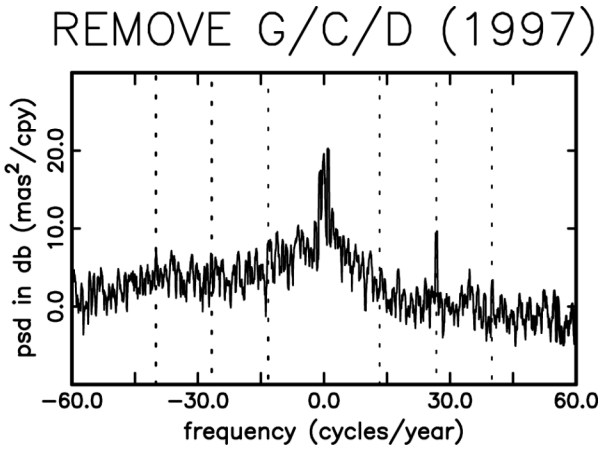
Dynamical Ocean Tide Models

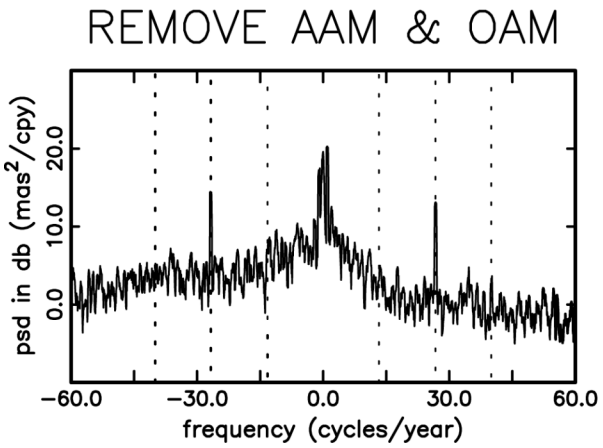


(March 25, 1995 to May 28, 2010)

Empirical Ocean Tide Models







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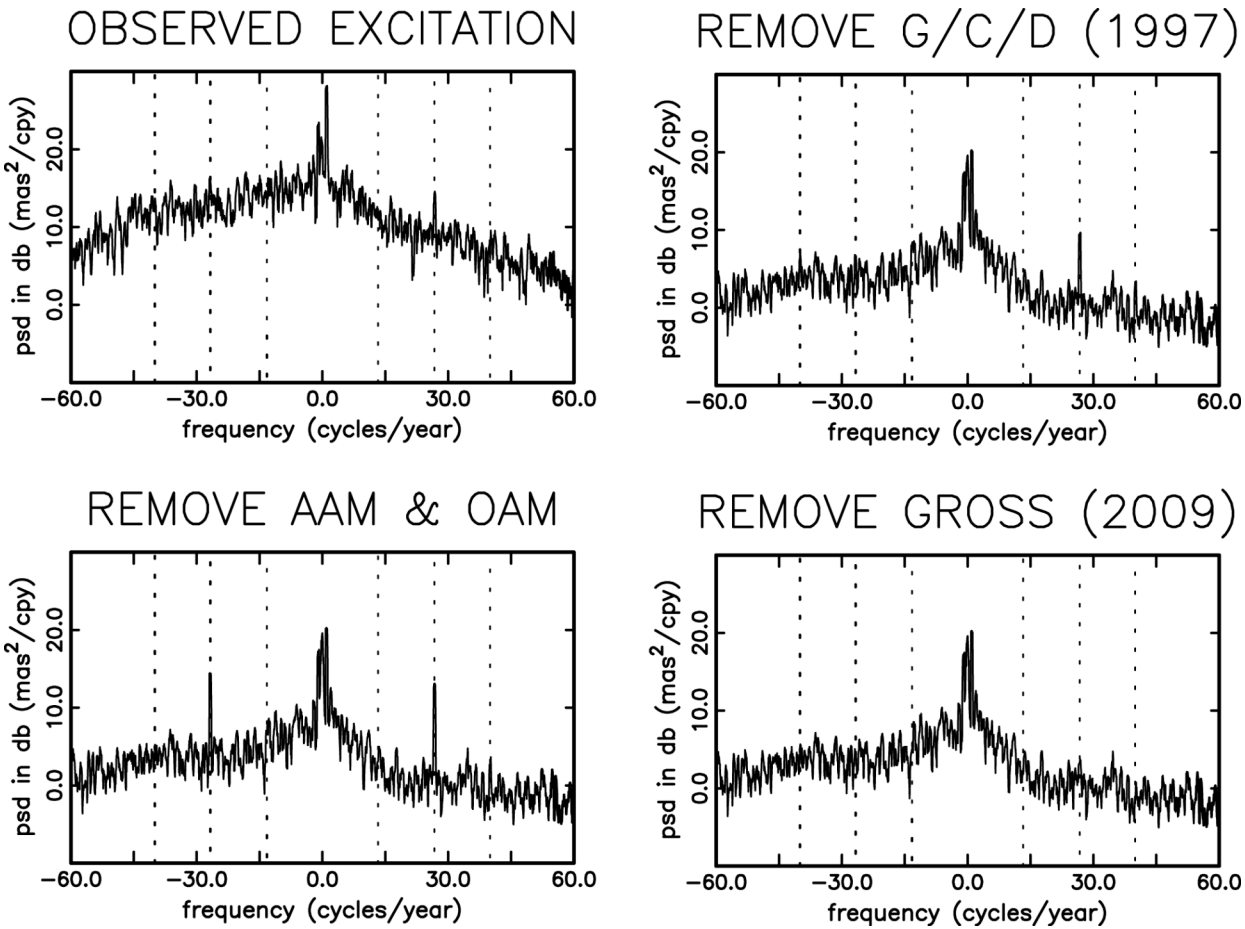
Empirical Ocean Tide Models



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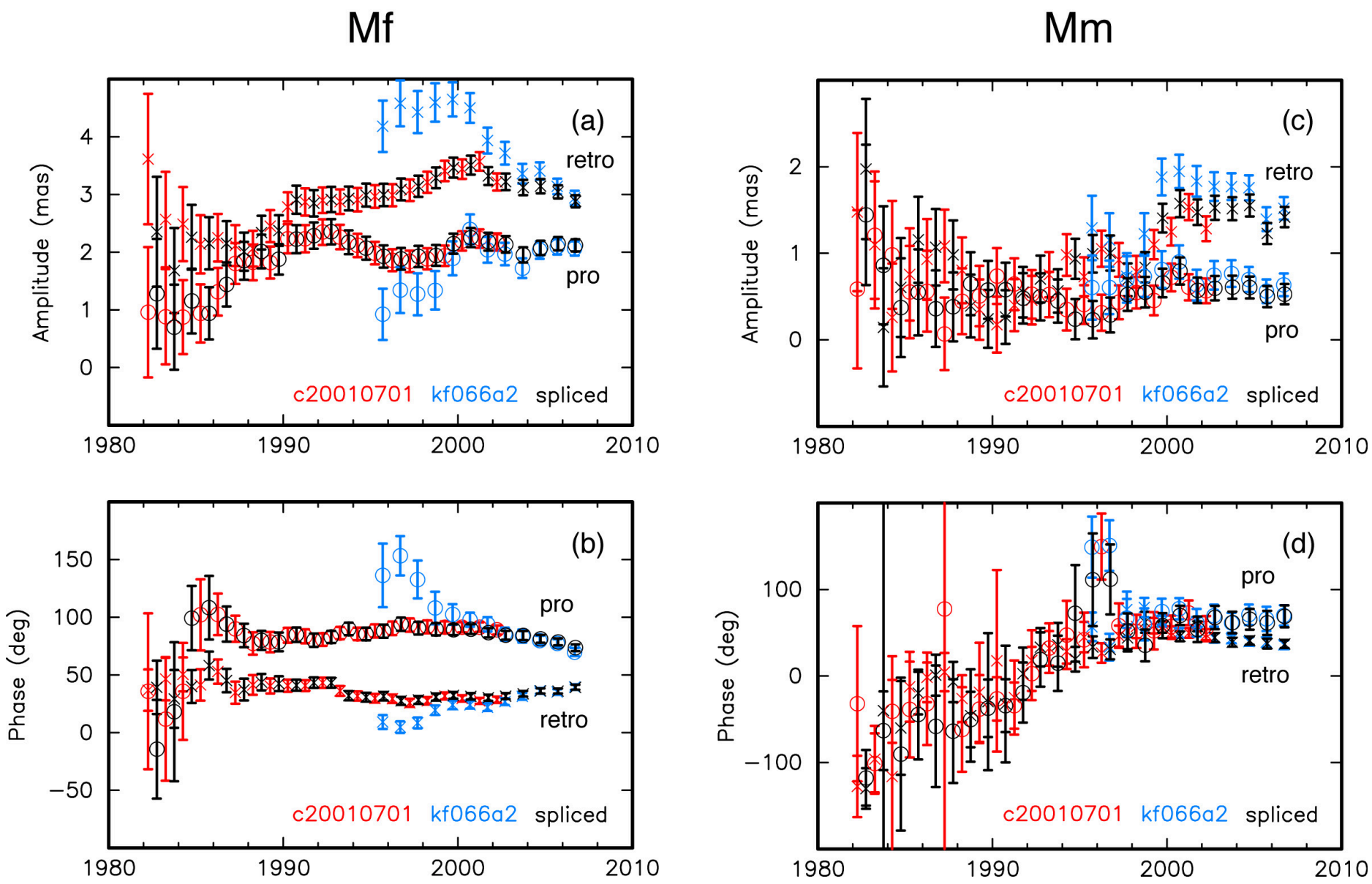
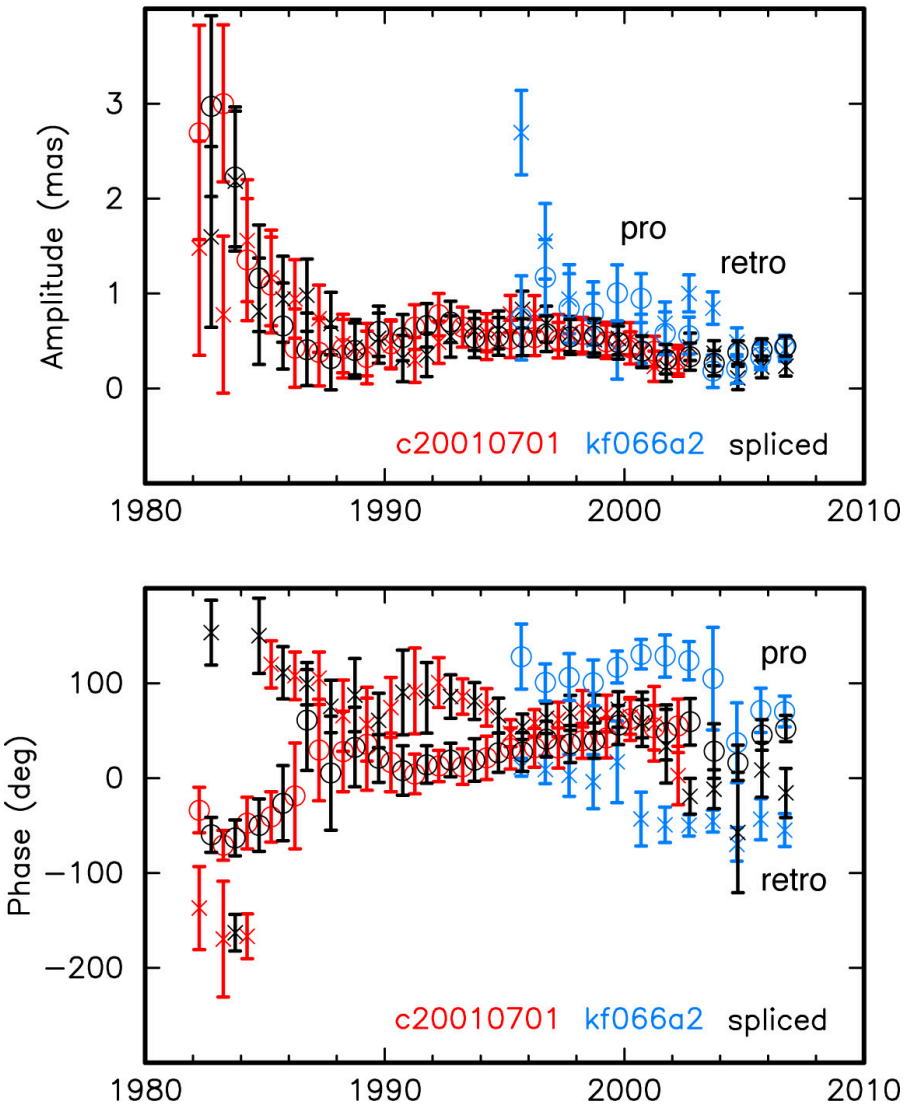

Mf
Mm
(a)
(b)
(c)
(d)
Amplitude (mas)
Phase (deg)
retro
pro
c20010701 kf066a2 spliced
1980
1990
2000
2010

Gross (2009)

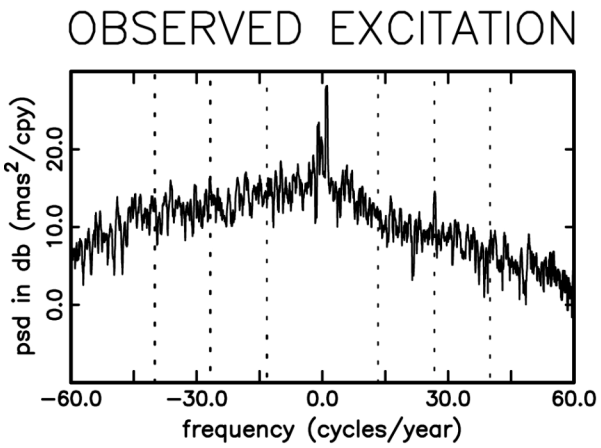
Mtm

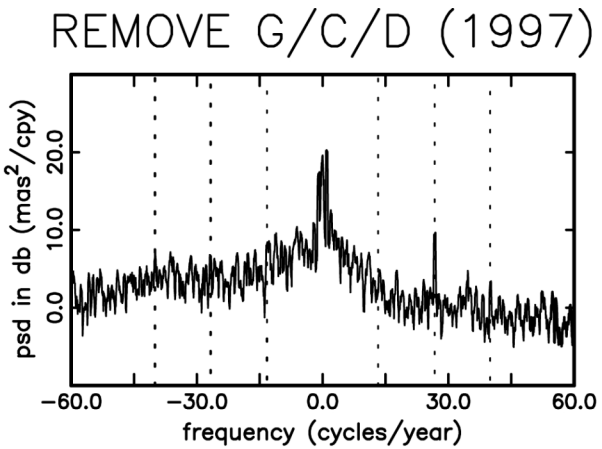

Amplitude (mas)
3
2
1
0
pro
retro
c20010701 kf066a2 spliced
1980
1990
2000
2010
Phase (deg)
100
0
−100
−200
pro
retro
c20010701 kf066a2 spliced
1980
1990
2000
2010

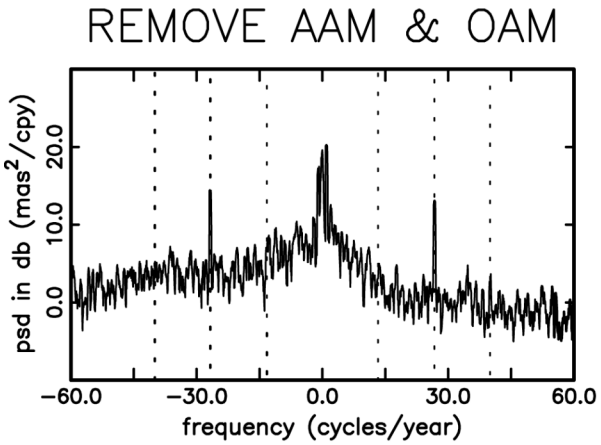
Determine Updated Empirical Tide Model

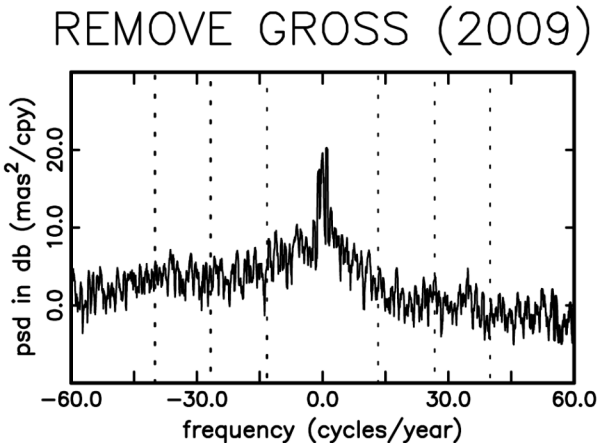
- Fit periodic terms to polar motion excitation observations
  - COMB2009 combined EOP series
    - January 2, 1980 to May 28, 2010
  - Remove atmospheric and non-tidal oceanic effects
    - NCEP/NCAR reanalysis AAM
    - Spliced ECCO/JPL c20010701 simulation and kf080 data constrained OAM
  - Weighted least-squares fit
    - Bias, rate, termensual (Mtm, mtm), fortnightly (Mf, mf), monthly (Mm), semiannual (Ssa), annual (Sa)
- Constrain fit
  - Oceans, and hence Earth's rotation, should have same relative response to tide raising potential at Mf and mf tidal frequencies
    - Mf and mf differ in frequency by only 1/18.6 cpy
  - This implies that at Mf and mf, polar motion excitation should have the same phase and an amplitude ratio that is the same as that of the tide raising potential
    - Same for Mtm and mtm since they also differ in frequency by only 1/18.6 cpy
  - Constrain Mf and mf periodic terms to have the same phase and an amplitude ratio the same as that of the tide raising potential during weighted least-squares fit
    - Do same for Mtm and mtm

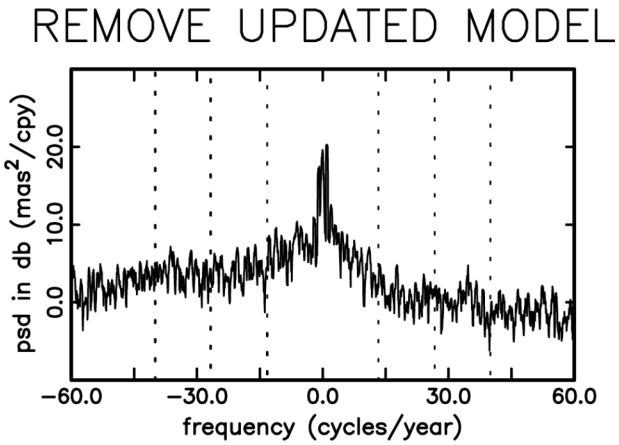
Empirical Ocean Tide Models





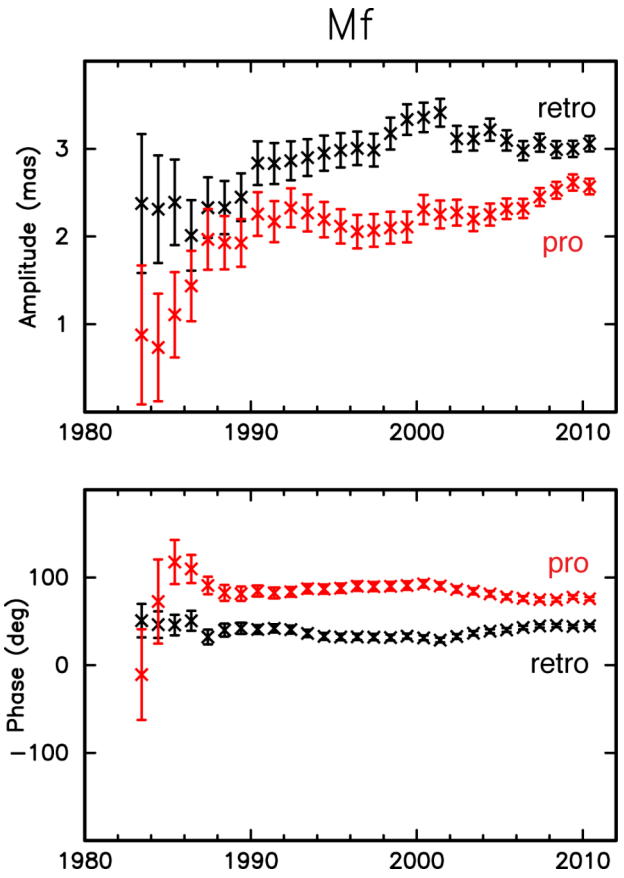




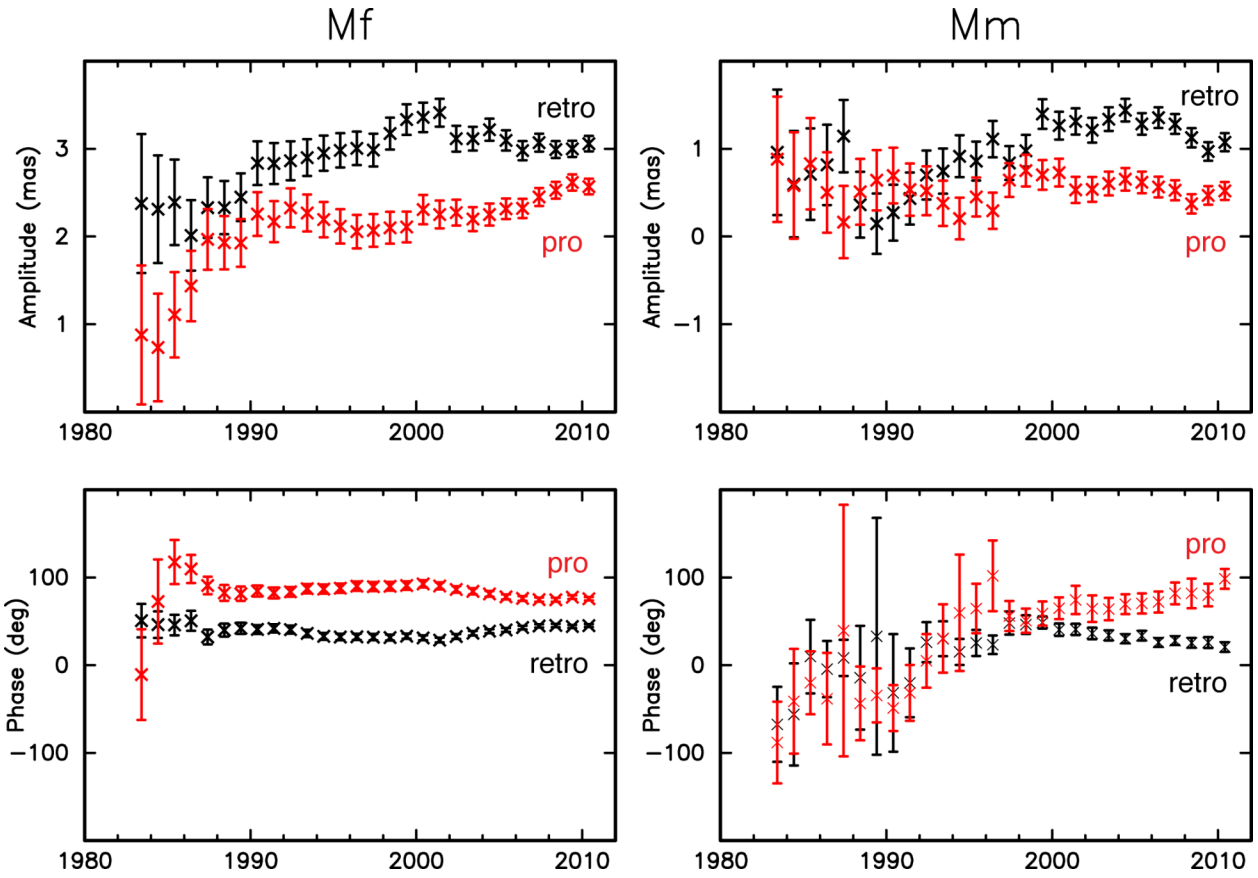


(March 25, 1995 to May 28, 2010)

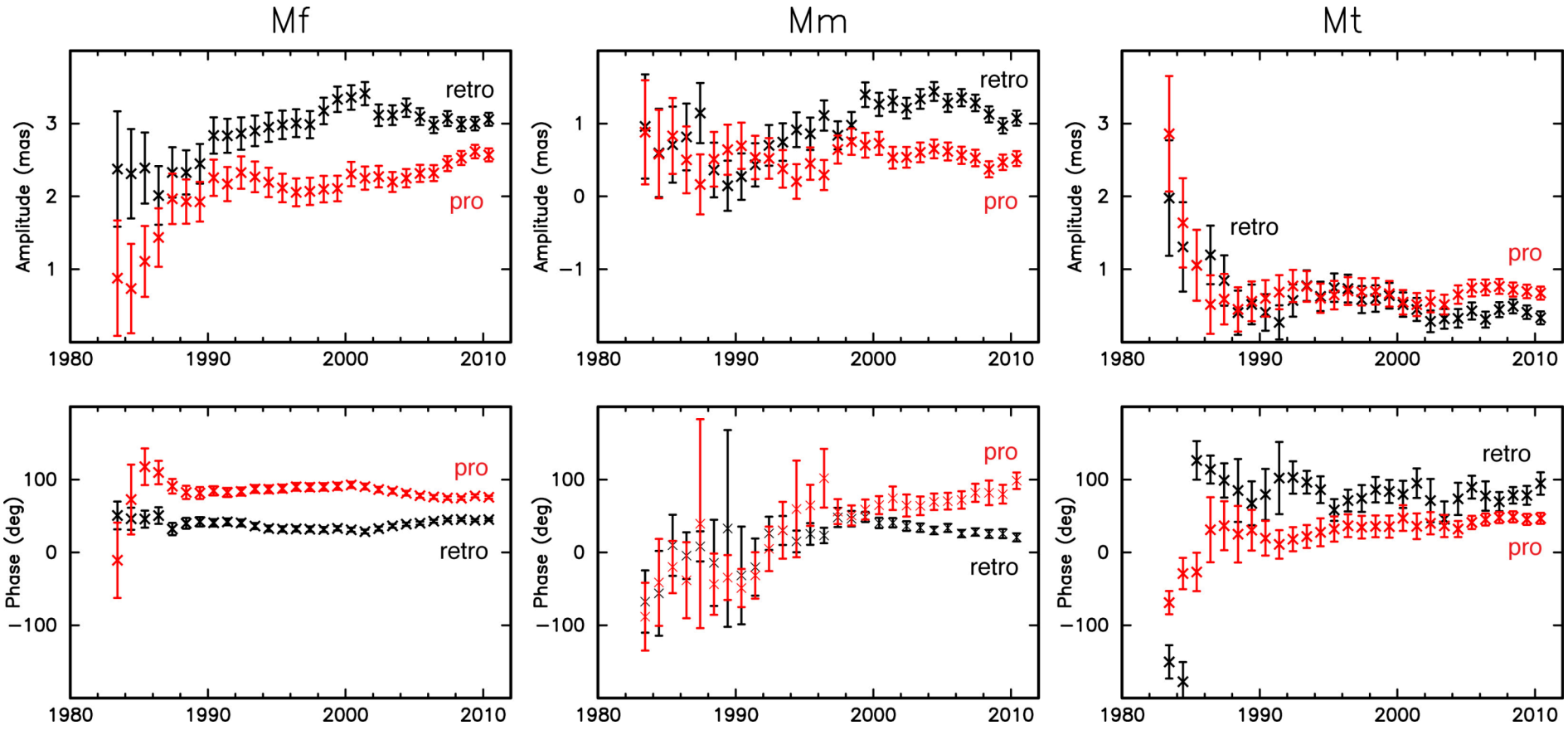
Updated Empirical Model



Updated Empirical Model



Updated Empirical Model



Summary

- Updated empirical tide model
  - Completely accounts for observed fortnightly tidal power
    - Model determined from observations spanning January 2, 1980 to May 28, 2010
    - Assessment done on observations spanning March 25, 1995 to May 28, 2010
  - By design, Mf & mf (and Mtm & mtm) have same phase and same relative amplitudes as tidal potential
  - But has it converged?
- Revised Dickman dynamical tide model
  - Further reduces but does not eliminate fortnightly tidal signal
- More accurate dynamical model still desirable
  - But most tide models do not include currents
    - Needed for their contribution to ocean tidal angular momentum