On the influence of diurnal atmospheric tides on Earth rotation

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Introduction

The diurnal cycle in solar heating give rise to variation in the atmospheric angular momentum (AAM) with main components S1 (period 24 hours) and S2 (12 hours). Similar components can be seen in the nontidal oceanic angular momentum (OAM) due to the ocean response to the atmospheric forcing. These diurnal and subdiurnal variations in the AAM and OAM excite small, below 1 milliarcsecond, but already well detectable variations in all components of Earth rotation including precession-nutation, polar motion and UT1.

Objectives of this presentation

- to give a general description of the perturbations of Earth rotation caused by diurnal thermal tides in the atmosphere and in the oceans
- to give an overview of the observation and modeling efforts
- to report on own estimation using the available high resolution atmospheric and oceanic excitation data and the VLBI observations of Earth rotation

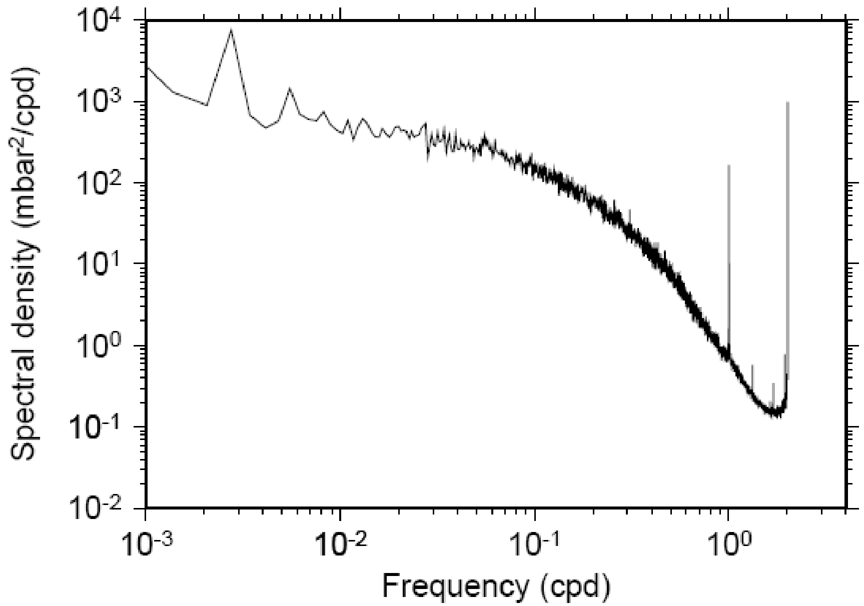
General description

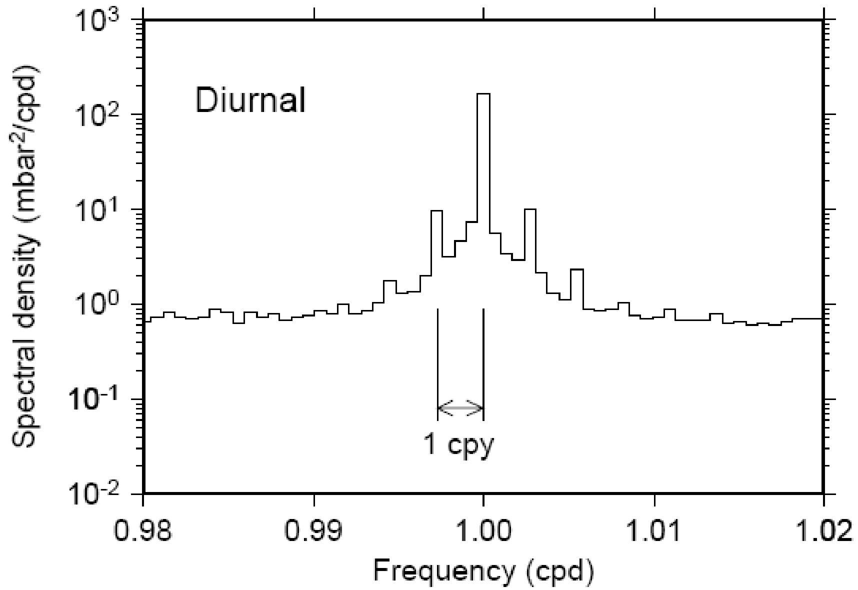
Diurnal atmospheric tides

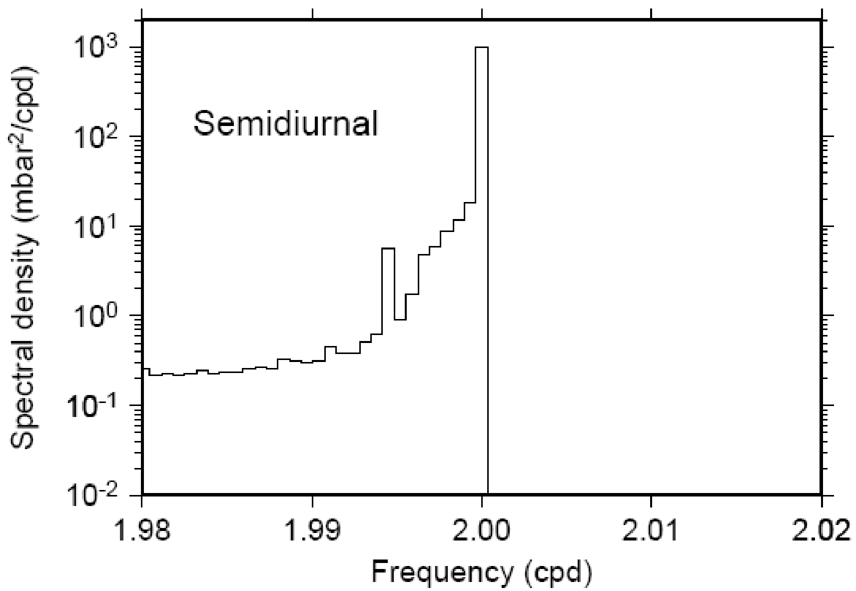
- main origin: differential heating of the Sun
- basic frequency: 1 cycle per (solar) day (cpd)
- departures from the sinusoidal pattern and the differences near the ground (due to ocean-continent distribution, topography, cloudiness, ice coverage, vegetation, etc.) produce additional harmonics with frequencies k cpd, k=2,3
- atmospheric tides are coherent with gravitational tides therefore are usually labeled in the same way: S_1, S_2, S_3
- all diurnal and subdiurnal harmonics (S_1, S_2, S_3) of thermal origin subject to seasonal modulations (annual, semiannual) producing side lobes shifted in frequency by ± 1, ± 2 cycles per year (cpy)

For further details concerning the diurnal atmospheric tides see (Chapman and Lindzen, 1970; Volland, 1988; 1997).

General description







Globally integrated spectrum of the ECMWF p_a series (above), based on the four-year span 1996-1999, and detailed view surrounding the diurnal and semidiurnal peaks (right).

From (Ray and Ponte, *Ann. Geophys.*, Vol.21: 1897–1910, 2003).

General description

Diurnal atmospheric tides

- manifested by periodic and quasiperiodic variation of the atmospheric angular momentum (AAM)
- similar effect in the nontidal oceanic angular momentum (OAM) due to the ocean response to the atmospheric forcing
- side lobes produced by seasonal modulations:
  - S_1: annual (P_1, K_1) and semiannual (π_1, Ψ_1)
  - S_2: annual (R_2, T_2) and semiannual (K_2, P_2)
- OAM harmonics forced by the atmospheric thermal tides are superimposed on the harmonics produced by the gravitational ocen tides

$\Rightarrow$ With exception of S_1, in all cases the ocean tide contributions to global AM are significantly larger than the corresponding terms of AAM and OAM

General description

Diurnal and subdiurnal signals in AAM and OAM contribute to all components of Earth rotation.

Diurnal component:

- nutation
  - main contribution to prograde annual term, with amplitude between 100 and 150 microarcseconds (μas)
- polar motion
  - prograde harmonic with period of 24 hours and amplitude up to 40 μas
- UT1
  - 24-hours harmonic with amplitude up to 2.5 μs corresponding to 40 μas

Semidiurnal component:

- 12-hours harmonic with amplitude below 10 μas (estimate from geophysical models)

Estimation from high resolution atmospheric/oceanic models

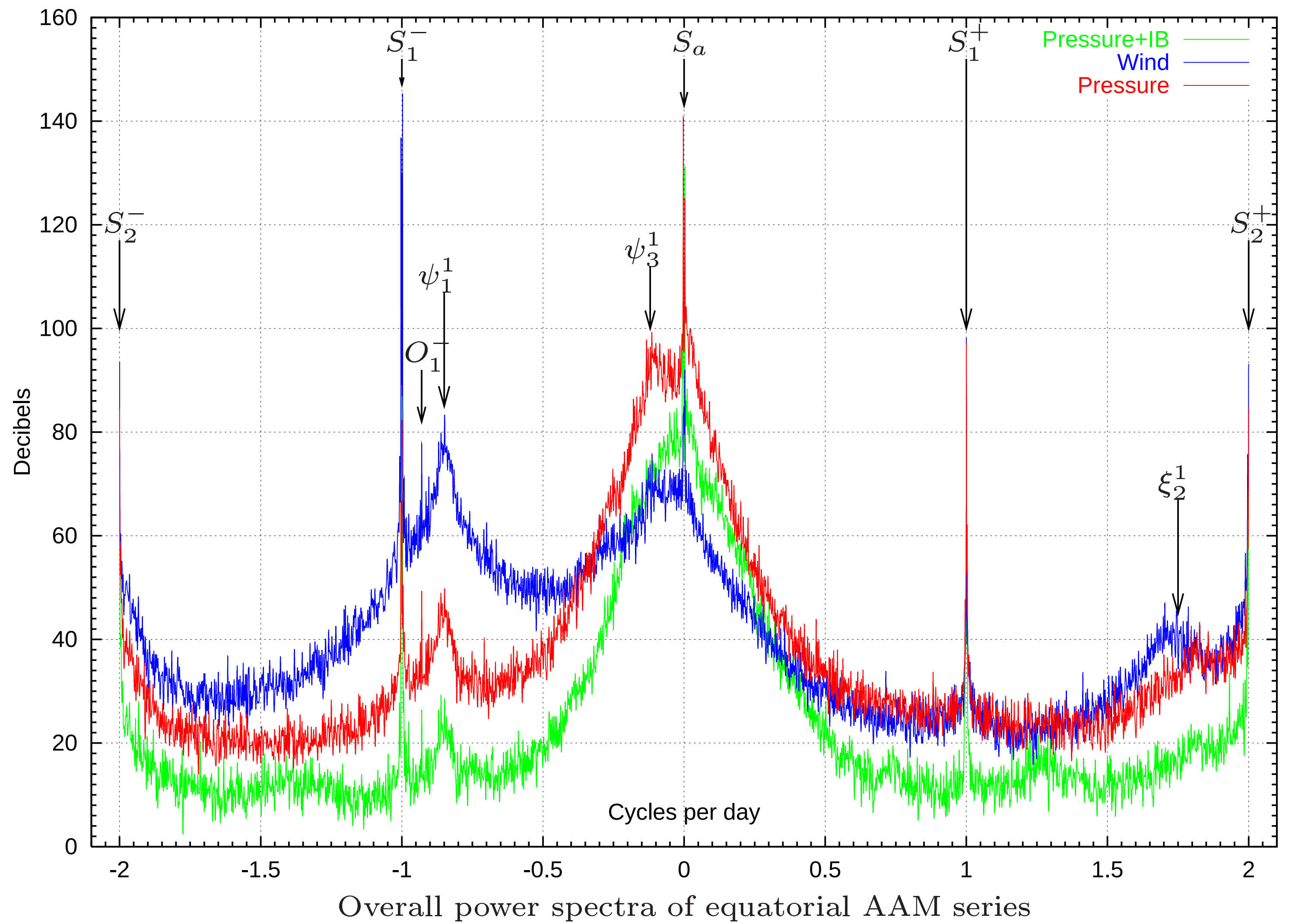
Time series of AAM and OAM with subdiurnal sampling

- AAM: $\Delta t = 6$ hours is a standard sampling, great importance of reanalysis series (NCEP/NCAR, ECMWF: ERA-40, JMA: in preparation)
  - can be used for estimation in diurnal band
  - semidiurnal band cannot be resolved, only rough overall estimate possible
- OAM series with subdiurnal sampling are still experimental
  - can be used for estimation in diurnal band
  - semidiurnal signal, even if available, can be incorrect due to insufficient resolution of the atmospheric forcing data

Hydrodynamic models of diurnal and subdiurnal components of OAM (e.g., Ray and Egbert, 2004)

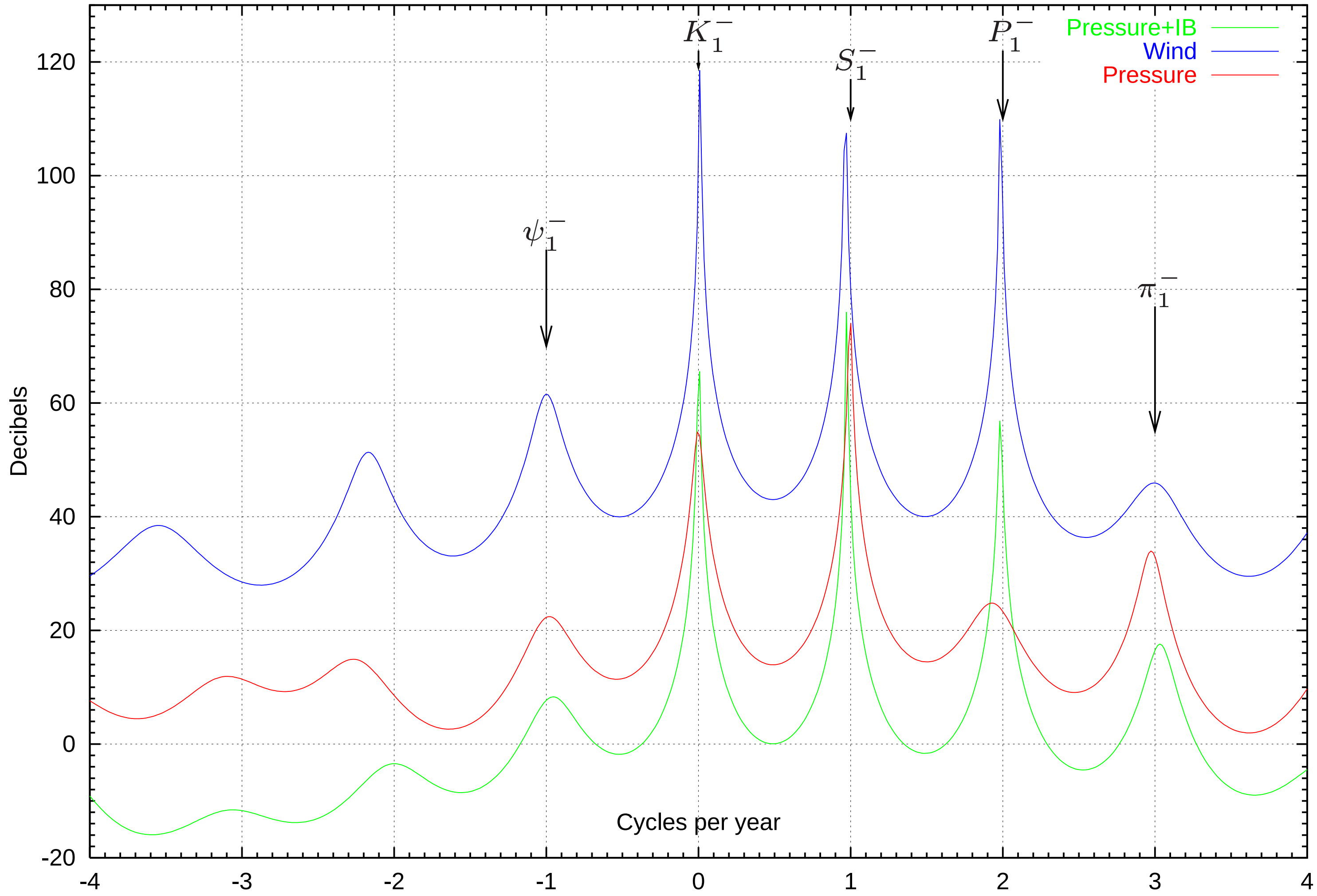
- more realistic results than from the OAM series
- disadvantage: express only harmonic components

Estimation from high resolution atmospheric/oceanic models



Spectral analysis of the NCEP/NCAR reanalysis series over 1979–1997. From (Brzeziński and Petrov, 1999).

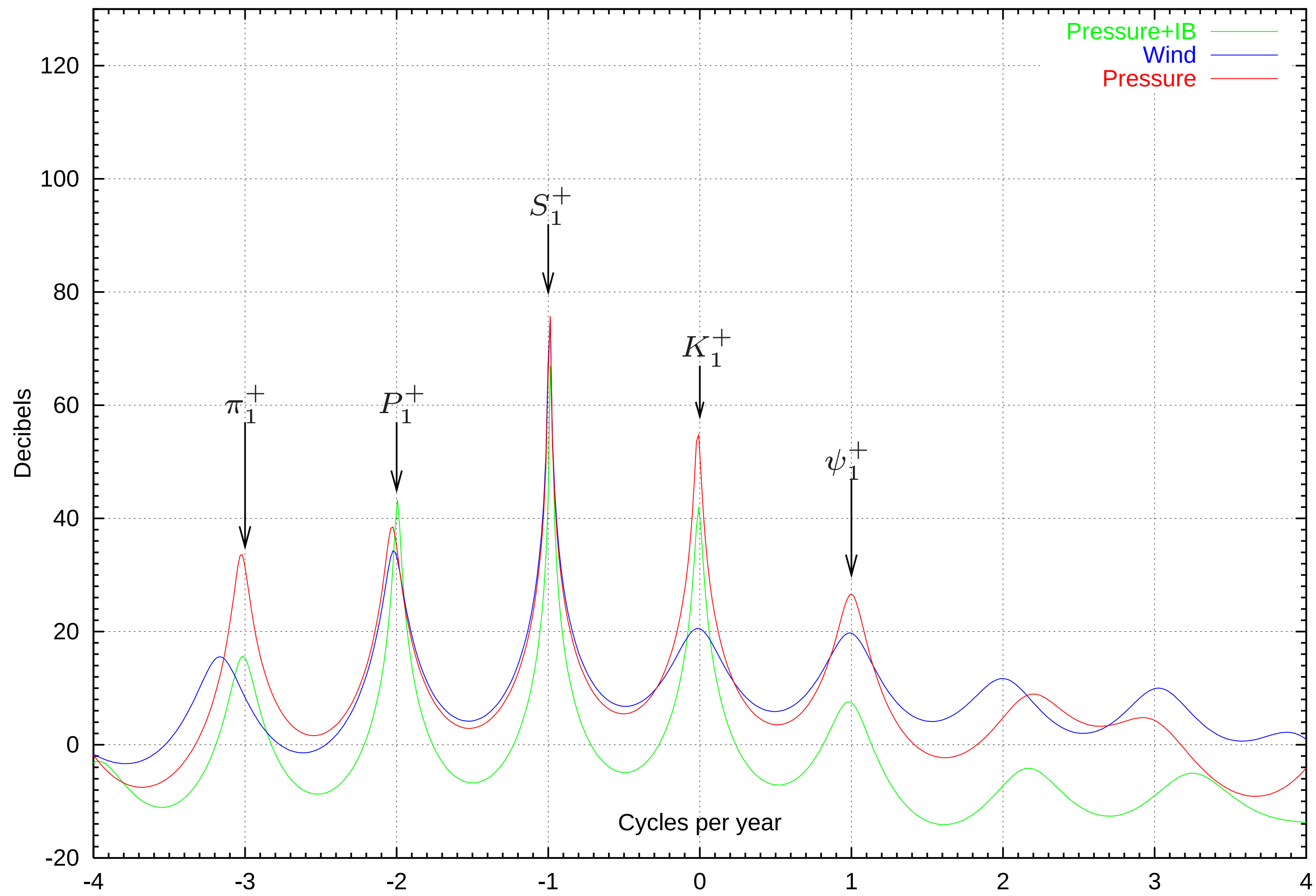
Estimation from high resolution atmospheric/oceanic models



Power spectra of equatorial AAM series in diurnal retrograde band

Spectral analysis of the NCEP/NCAR reanalysis series over 1979–1997. From (Brzeziński and Petrov, 1999).

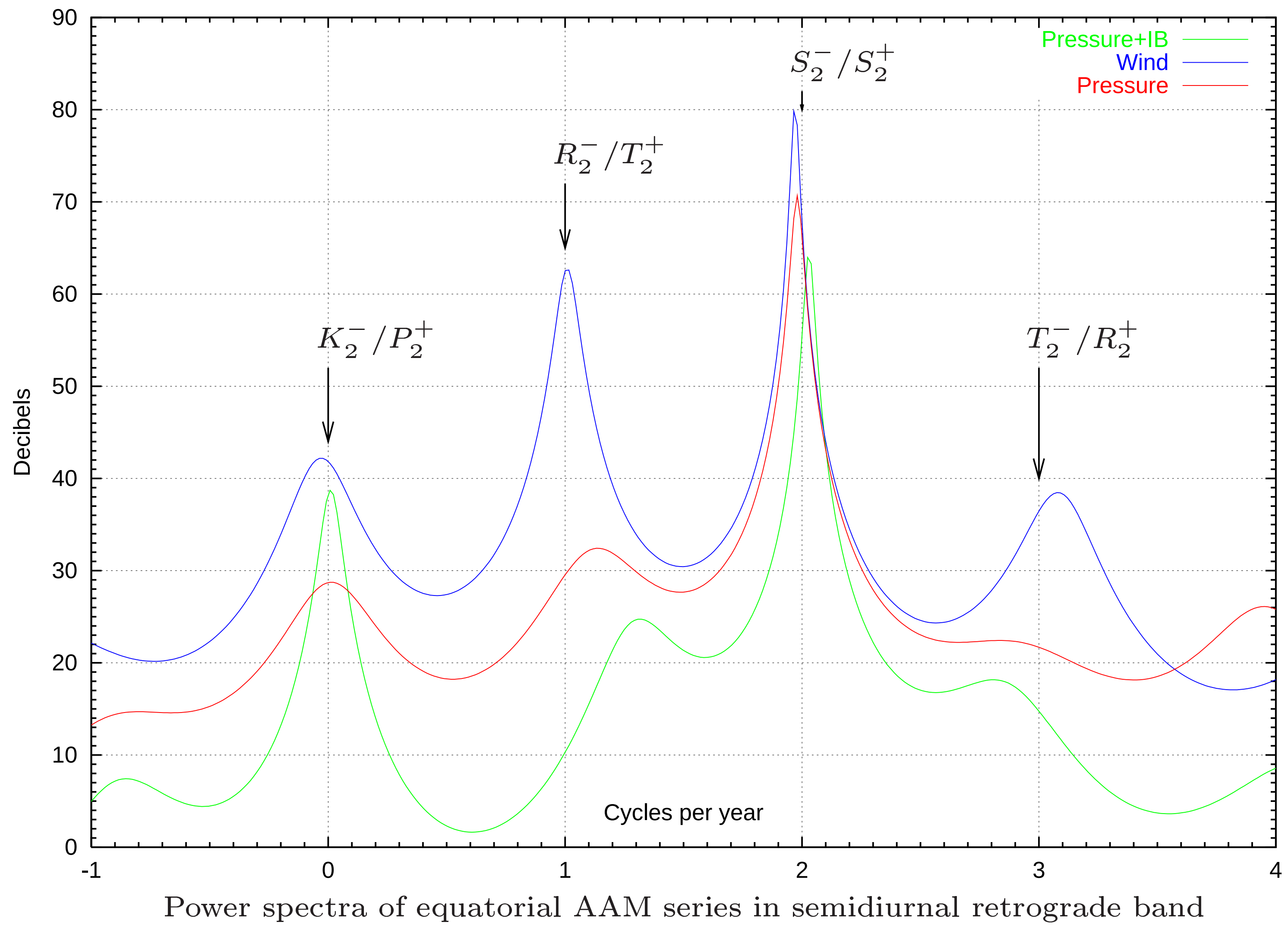
Estimation from high resolution atmospheric/oceanic models



Power spectra of equatorial AAM series in diurnal prograde band

Spectral analysis of the NCEP/NCAR reanalysis series over 1979–1997. From (Brzeziński and Petrov, 1999).

Estimation from high resolution atmospheric/oceanic models



Spectral analysis of the NCEP/NCAR reanalysis series over 1979–1997. From (Brzeziński and Petrov, 1999).

Estimation from observations of Earth rotation

Concerns mostly the purely harmonic ocean tide influence

- VLBI solutions: (Sovers et al., 1993; Herring & Dong, 1994; Gipson, 1996)
- SLR solution: (Watkins & Eanes, 1994) with later updates by R. Eanes
- GPS solution: (Rothacher et al., 2001)

⇒ The thermal contributions to S_2 and the side lobes of S_1 and S_2 can hardly be separated from much larger ocean tide contributions

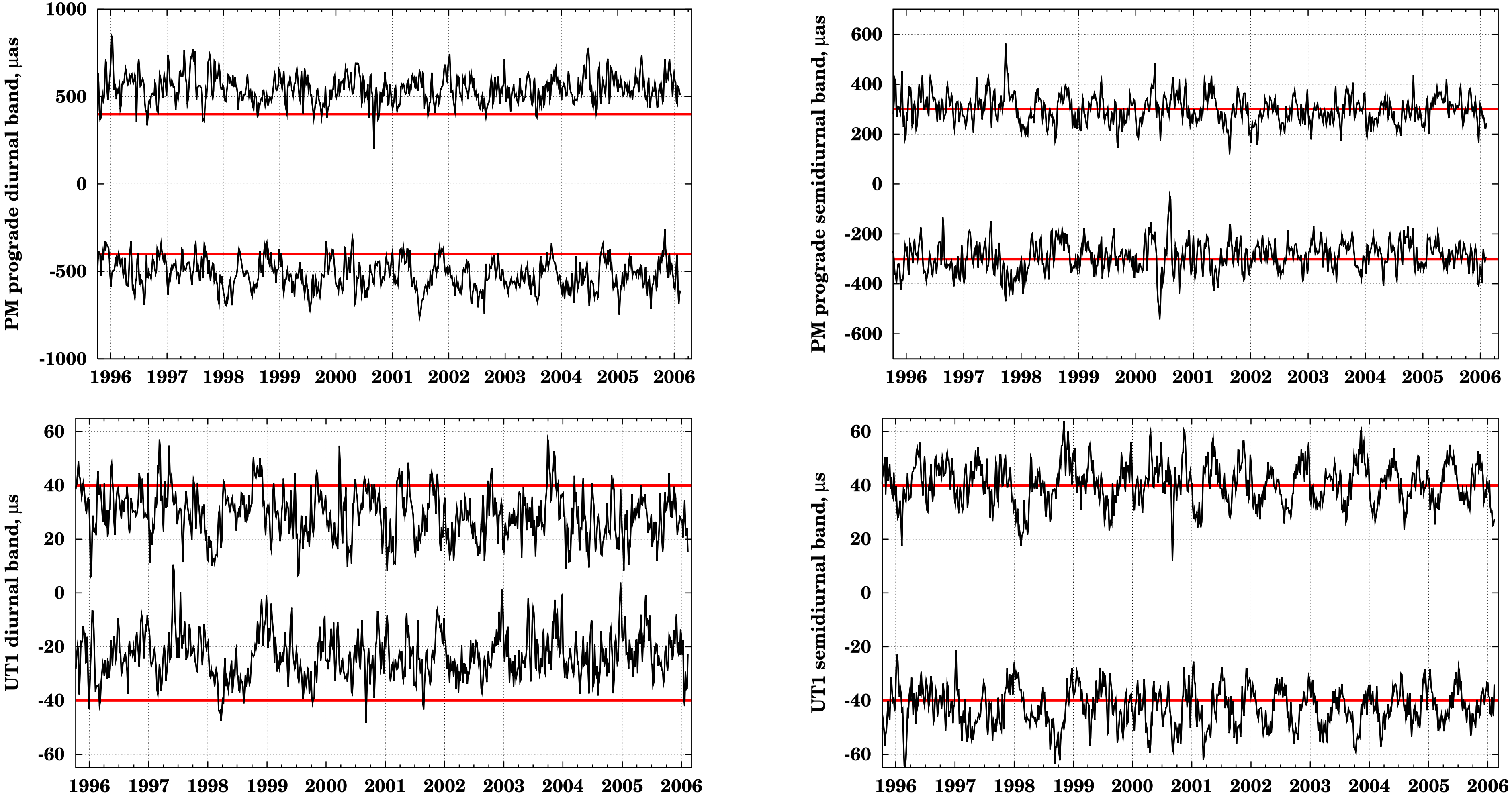
⇒ Estimation of the S_1 component is possible but difficult

- relatively small signal
- can be corrupted by different Sun-synchronous errors, e.g. those due to the thermal deformation of the VLBI antennas

Continuous observation campaigns, like CONT94, CONT02, CONT05

- cannot resolve the diurnal and semidiurnal bands, but are (at least potentially) important for terdiurnal variations

Estimation from observations of Earth rotation



Diurnal and semidiurnal signals in prograde polar motion (top) and in UT1 (bottom) demodulated from VLBI data (Bolotin and Brzeziński, 2006)

S1: observations vs. geophysical models – data sets

- VLBI1 – (Bolotin and Brzeziński, 2006), input data span 1984–2005
- VLBI2 – (Gipson, 1996), input data span 1979–1994
- GPS – (Rothacher et al., 2001), data span 1995–1998.1

- AAM1, AAMIB1 – NCEP-NCAR reanalysis data (Salstein and Rosen, 1997)
  period: 1948–2006; sampling interval: 6 hours
- AAM2 – ERA-40 reanalysis model (www.ecmwf.int/research/era)
  period: 1948–2004; sampling interval: 6 hours
- AAM2′ – ECMWF operational data available from the IERS SBA
  period: 1993.0–1996.5; sampling interval: 6 hours with gaps
- AAM3, AAMIB3 – JMA operational data available from the IERS SBA
  period: 1993.3–2000.5; sampling interval: 6 hours with gaps

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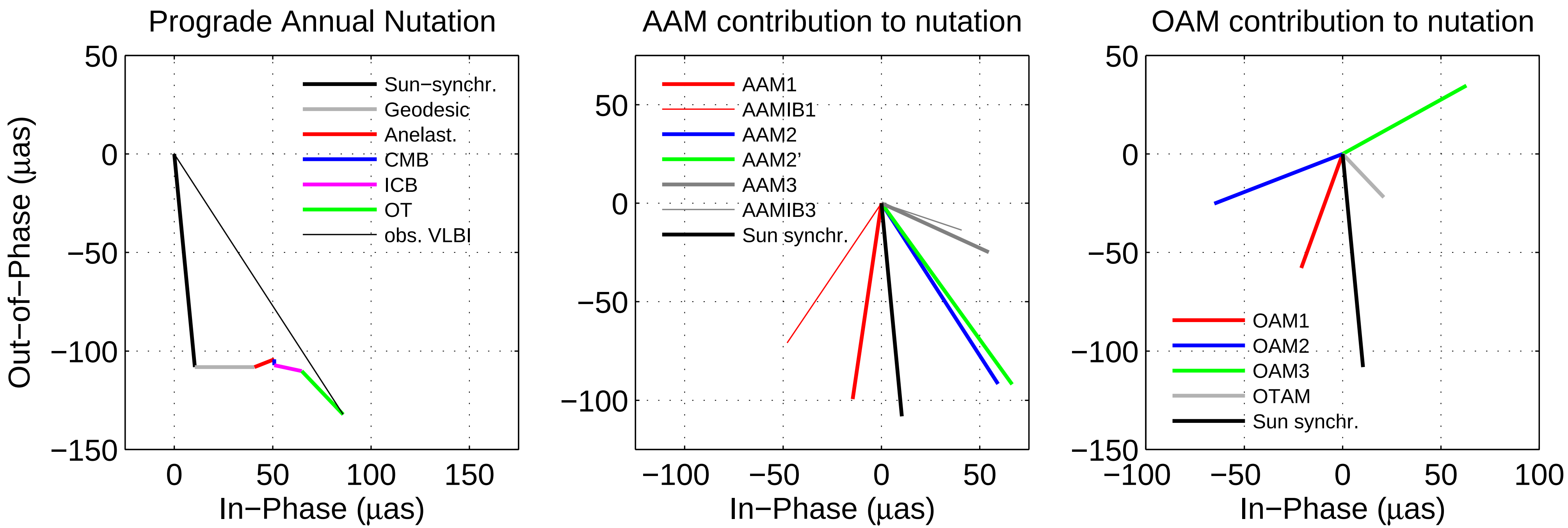
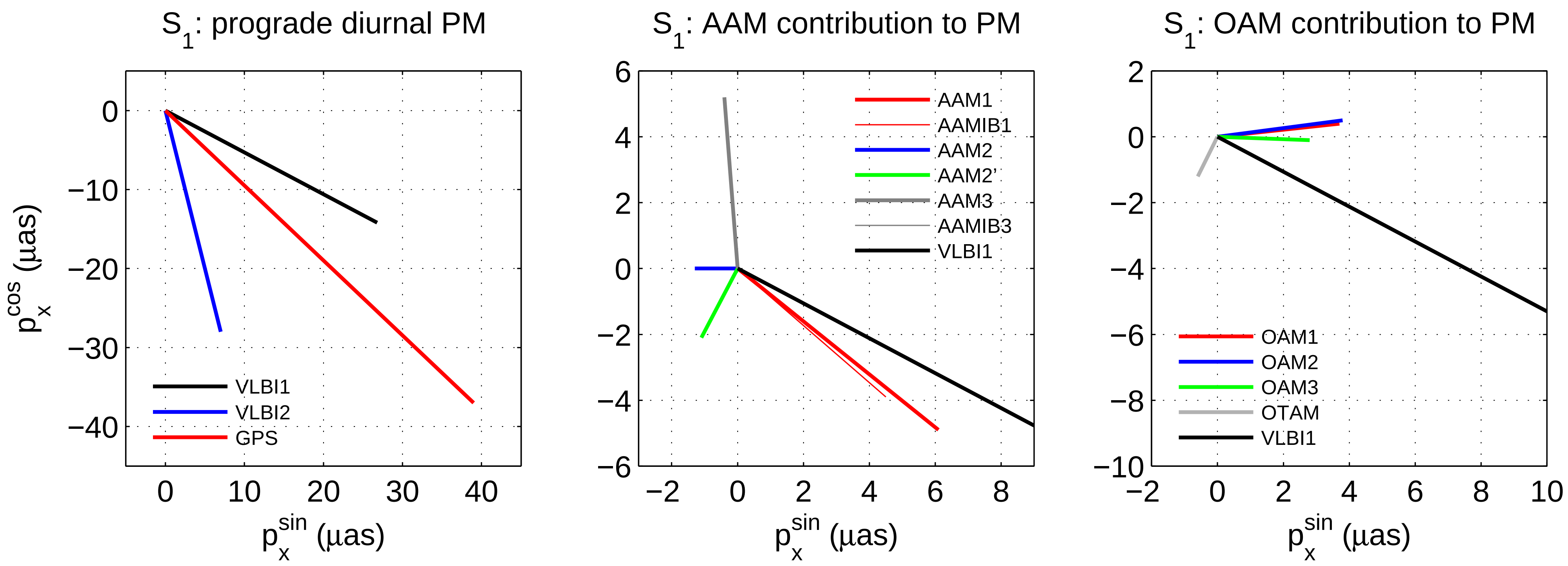
- OAM1 – hydrodynamic model of the S1 component (Ray and Egbert, 2004)
- OAM2 – barotropic model (Ponte and Ali, 2002) forced by wind and atmospheric pressure fields from the NCEP-NCAR reanalysis model
  period: 1993.0–2000.5; sampling interval: 1 hour
- OAM3 – ocean model for circulation and tides (OMCT) (Thomas et al., 2001) forced by wind and pressure fields from the model ERA-40
  period: 1963–2001; sampling interval: 30 minutes

S1: observations vs. geophysical models – nutation



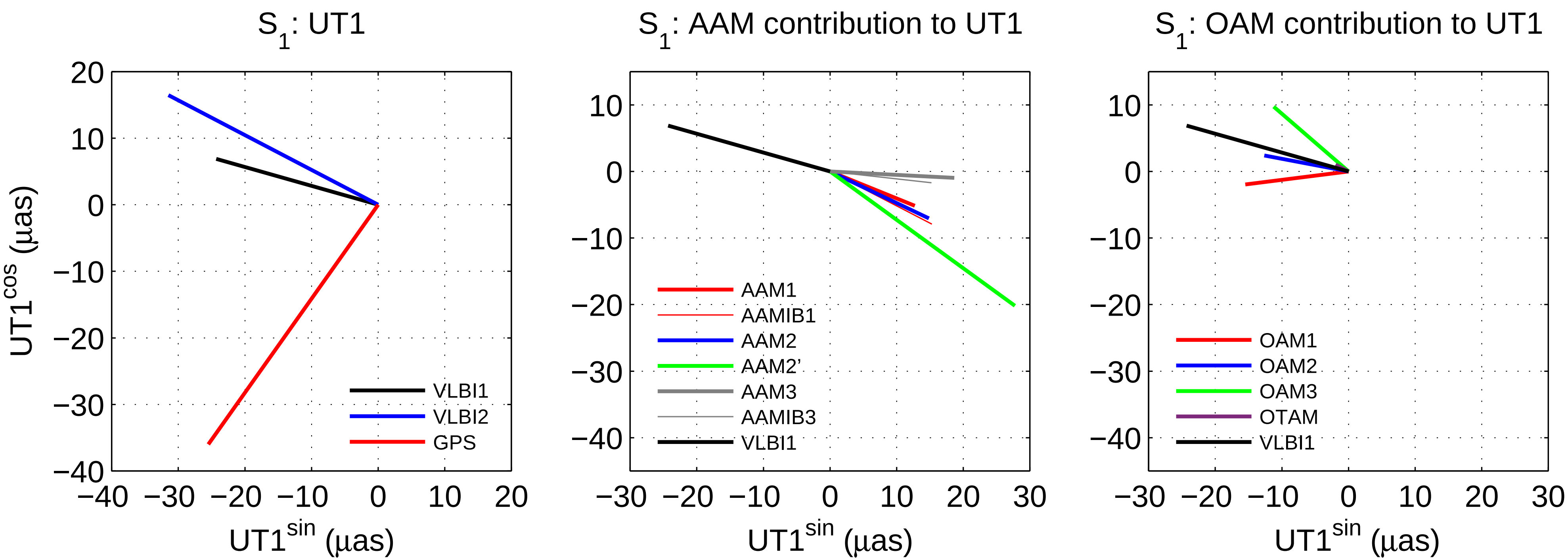
Atmospheric and oceanic contributions to prograde annual nutation: model MHB 2000 (left) vs. modeled geophysical contributions, atmospheric (middle) and oceanic (right)

S1: observations vs. geophysical models – polar motion



Atmospheric and oceanic contributions to prograde diurnal polar motion, S1 term: space-geodetic observations (left) vs. modeled geophysical contributions, atmospheric (middle) and oceanic (right)

S1: observations vs. geophysical models – UT1



Atmospheric and oceanic contributions to diurnal variation of UT1, S1 term: space-geodetic observations (left) vs. modeled geophysical contributions, atmospheric (middle) and oceanic (right)

Summary and conclusions

- The diurnal cycle in solar heating give rise to variations in AAM and OAM with main components S1, S2 of periods 24 and 12 hours, and their side lobes due to seasonal modulations.
- These variations of AAM and OAM excite small perturbations in all three components of Earth rotation, including precession-nutation, polar motion and UT1.
- So far, only the S1 contributions to Earth rotation could be detected in both geophysical models and space-geodetic observations.
- However, comparison shows significant differences between estimates from different models and different observation techniques, as well as between the models and observation.
- Investigations should be continued using improved geophysical models and space-geodetic data derived by improved reduction procedures.