

# Contribution of the S1 thermal tide to Earth rotation: comparison of geophysical models and geodetic observations

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## Introduction

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Observations of Earth rotation contain contribution of the thermal tide  $S_1$  with a period of 24 hours

- small size – amplitude up to 150  $\mu$ s corresponding to only 5 mm at the Earth's surface, nevertheless already well detectable
- important for modeling global dynamics of the solid Earth and its external fluid layers, the atmosphere and oceans

### Objectives of this presentation

- to give a general description of the  $S_1$  tide and overview of the observation and modeling efforts
- to estimate from the available atmospheric and oceanic excitation data the influence of  $S_1$  on Earth rotation and compare to the determinations from space-geodetic observations

## General description

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$S_1$  thermal (radiational) tide

- Sun-fixed global perturbation, period 24 hours
- origin: diurnal cycle in the solar heating
- manifested by diurnal variation of the atmospheric angular momentum (AAM)
- similar effect in the nontidal ocean angular momentum (OAM) due to the ocean response to the atmospheric forcing
- strong annual and semiannual modulations of  $S_1$  signal giving rise to the side lobes shifted in frequency by  $\pm 1$  cpy ( $P_1, K_1$ ) and by  $\pm 2$  cpy ( $\pi_1, \Psi_1$ )
- gravitational ocean tide signal at the  $S_1$  frequency is several times smaller than the thermal effect (but it is not the case of the side lobes)

For further details concerning the  $S_1$  tide see the paper by Ray and Egbert (2004, *J. Phys. Oceanogr.*, Vol. 34, pp. 1922–1935) and the references therein.

## General description

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$S_1$  signals in AAM and OAM contribute at measurable level to all components of Earth rotation

- nutation
    - contribution to prograde annual term, with amplitude between 100 and 150 microarcseconds ( $\mu\text{as}$ )
  - polar motion
    - prograde harmonic with period of 24 hours and amplitude up to 40  $\mu\text{as}$
  - UT1
    - 24-hours harmonic with amplitude up to 2.5  $\mu\text{s}$  corresponding to 40  $\mu\text{as}$
- ⇒ Only the  $S_1$  contribution to nutation is included in the conventional models as the so-called “Sun-synchronous” empirical correction to the amplitude of the prograde annual nutation in the IAU 2000 precession-nutation model.

# Space-geodetic determinations of S1

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Estimation from the space-geodetic observations of Earth rotation

- contribution to nutation only from VLBI
- contributions to prograde polar motion and UT1 from both VLBI and GPS observations
- difficulties
  - relatively small signal
  - estimation can be corrupted by different Sun-synchronous errors, e.g. those due to the thermal deformation of the VLBI antennas

We consider the following estimates

- **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

## Geophysical excitation data: AAM

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Estimation from high-resolution atmospheric and oceanic excitation data

⇒ needs sampling interval shorter than 12 hours

We used the following time series of the AAM with subdiurnal resolution to estimate parameters of the S1 harmonic and its influence on Earth rotation

- **AAM1**, **AAMIB1** – NCEP-NCAR reanalysis data (Salstein and Rosen, 1997)  
period: 1948–2006; sampling interval: 6 hours
- **AAM2** – ERA-40 reanalysis model (Uppala et al., 2005)  
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

## Geophysical excitation data: OAM

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We used the following OAM models to estimate parameters of the S1 harmonic and its influence on Earth rotation

- **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

We estimated the total excitation of Earth rotation by the dynamically coupled system atmosphere-ocean by considering the following 3 consistent combinations

- **model1** (barotropic) – AAM1B1+OAM2+OTAM
- **model2** (hydrodynamic) – AAM2+OAM1+OTAM
- **model3** (OMCT) – AAM2+OAM3+OTAM

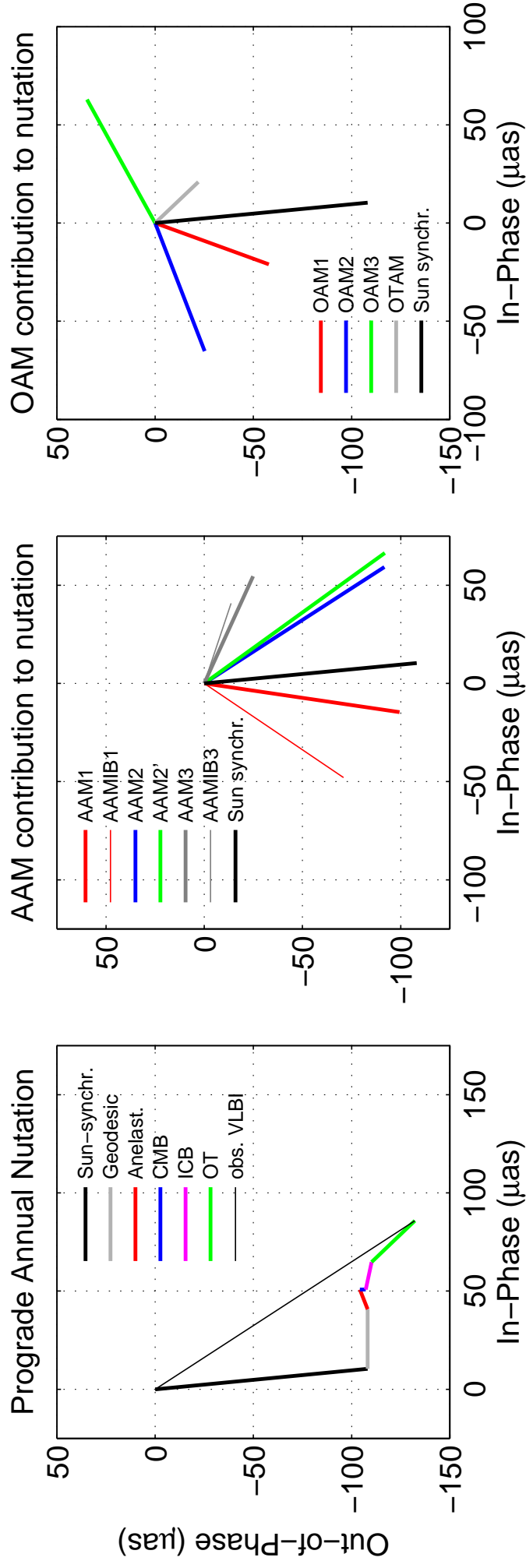
## Geophysical excitation data

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Parameters of the  $S_1$  thermal tide and its contribution to Earth rotation can change from year to year.

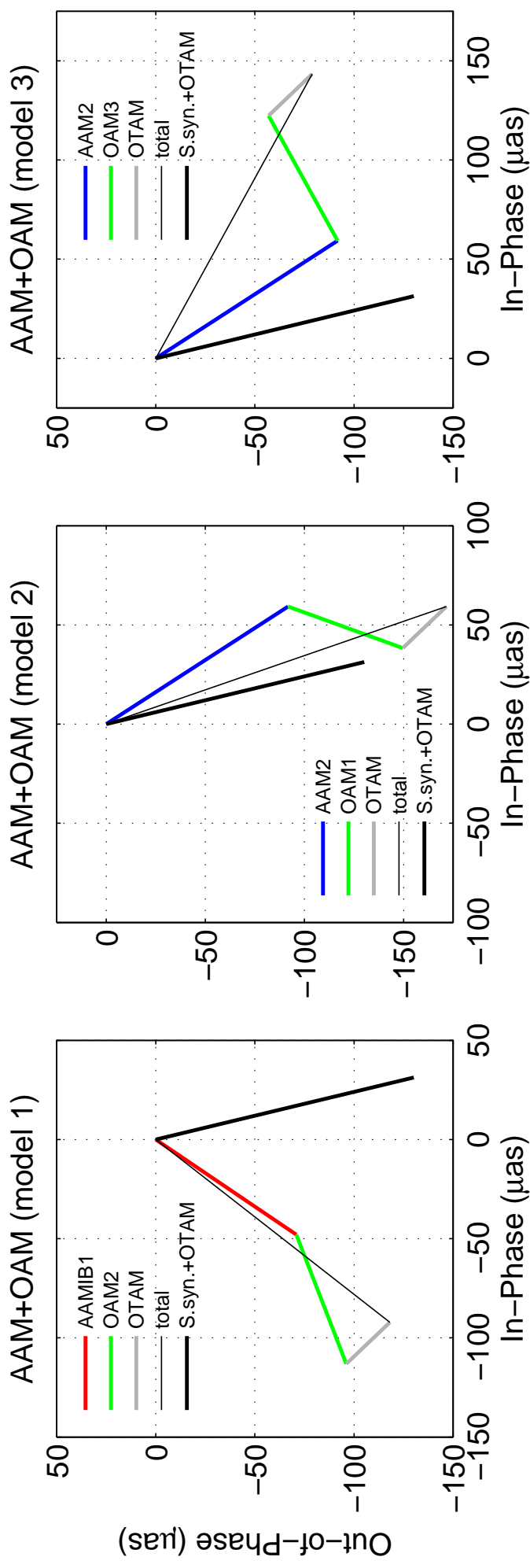
- In order to minimize the influence of this variability on comparisons, we reduced all geophysical series (AAM, OAM) to the common time interval 1993.0–2000.5. The only exception is the operational ECMWF AAM series which is only 3.5 years-long.
- One should bear in mind that the remaining part of the  $S_1$  signal of stochastic character is still important and needs regular monitoring

# Results: S1 contribution to nutation



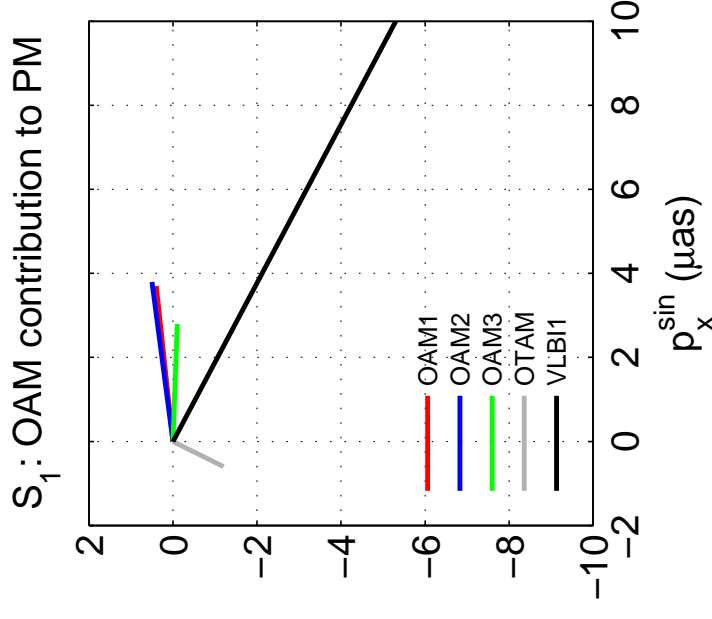
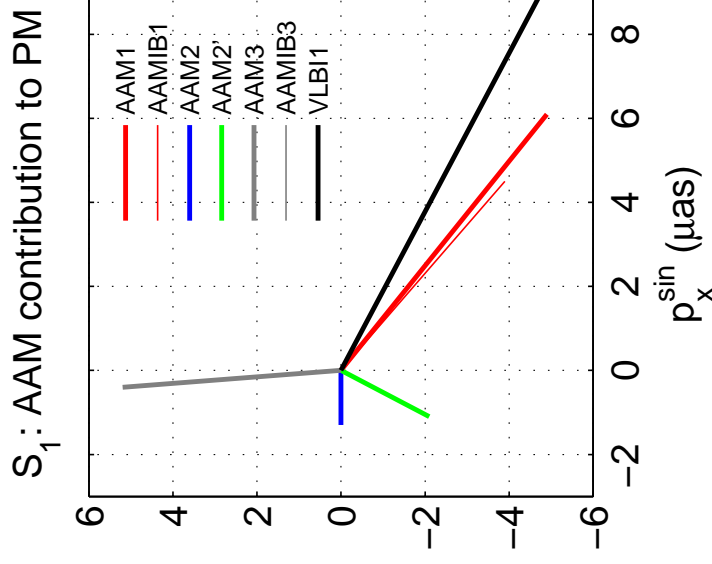
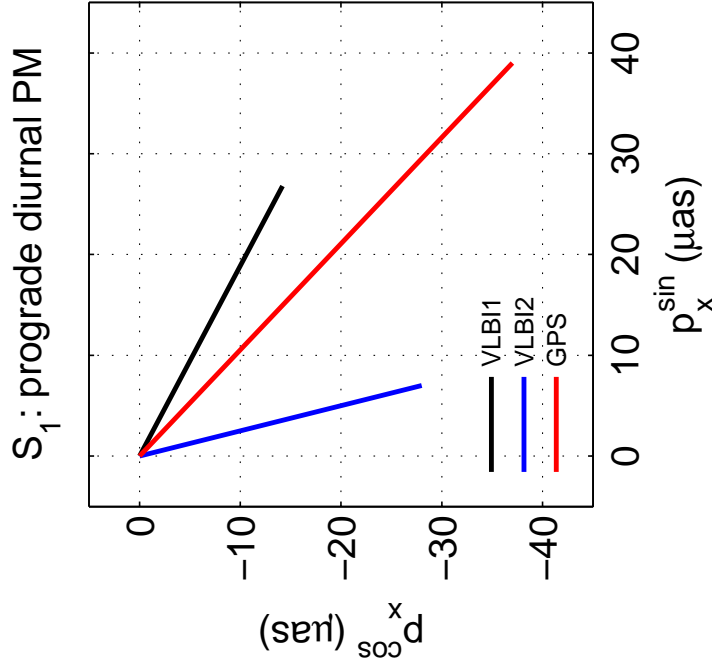
Atmospheric and oceanic contributions to prograde annual nutation: model MHB 2000 (left) vs. modeled geophysical contributions, atmospheric (middle) and oceanic (right)

# Results: S1 contribution to nutation



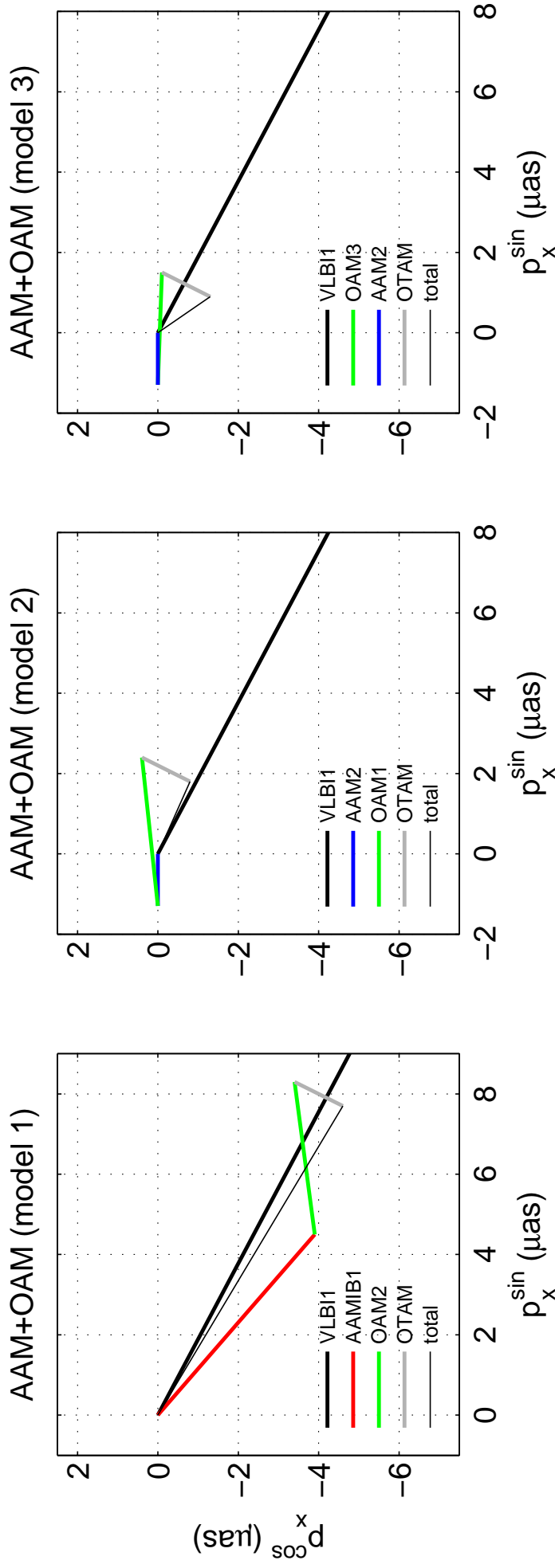
Combined atmospheric and oceanic contribution to prograde annual nutation: comparison of VLB estimate and 3 geophysical models

# Results: S<sub>1</sub> contribution to prograde diurnal polar motion



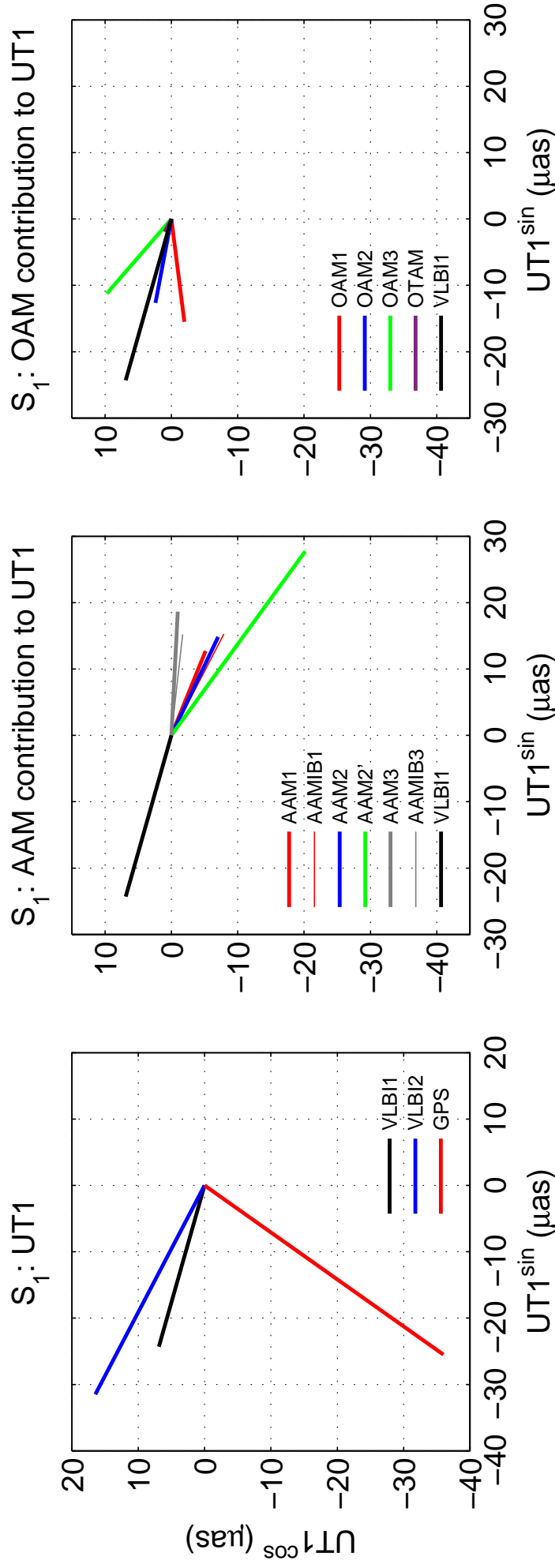
Atmospheric and oceanic contributions to prograde diurnal polar motion, S<sub>1</sub> term: space-geodetic observations (left) vs. modeled geophysical contributions, atmospheric (middle) and oceanic (right)

# Results: S1 contribution to prograde diurnal polar motion



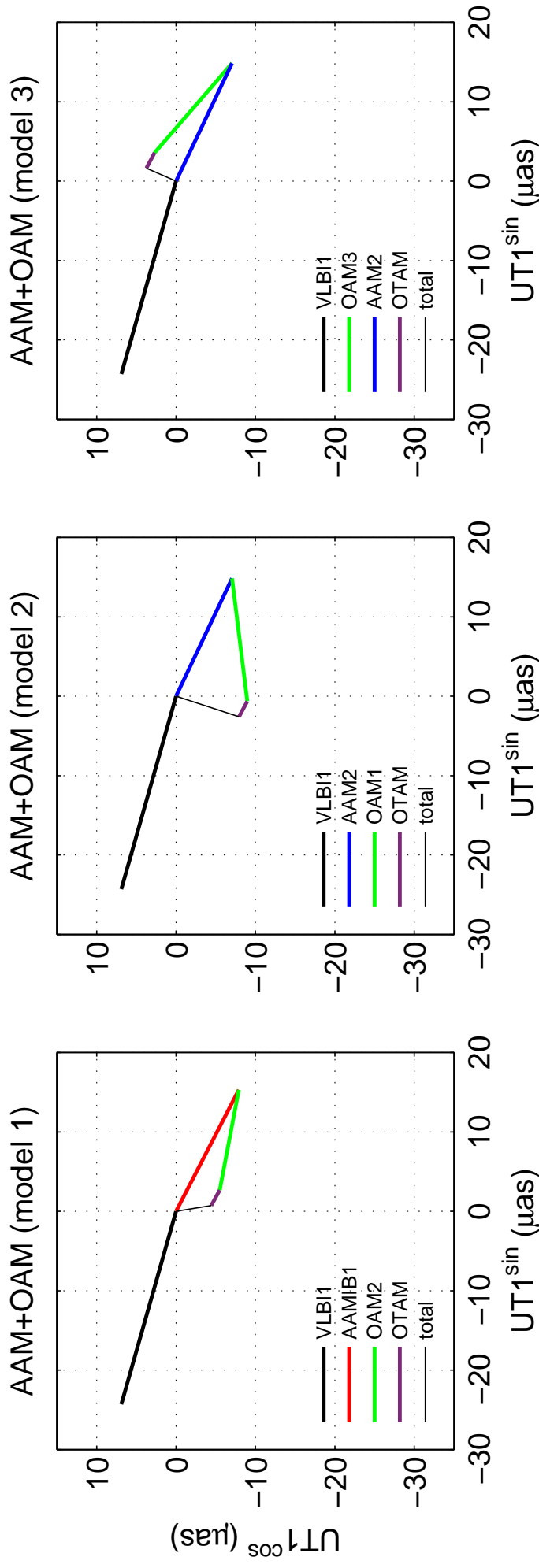
Combined atmospheric and oceanic contribution to prograde diurnal polar motion, S1 term: comparison of VLB1 estimate and 3 geophysical models

# Results: S<sub>1</sub> contribution to UT1



Atmospheric and oceanic contributions to diurnal variation of UT1, S<sub>1</sub> term: space-geodetic observations (left) vs. modeled geophysical contributions, atmospheric (middle) and oceanic (right)

# Results: S1 contribution to UT1



Combined atmospheric and oceanic contribution to diurnal variation of UT1, S1 term: comparison of VLBI estimate and 3 geophysical models

## Summary and conclusions

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S1 contribution to nutation

- there is a rough agreement between the estimated contributions of AAM but surprisingly, the OMCT and barotropic OAM yield almost opposite results
- the best agreement with observations is found for the hydrodynamic OAM combined with ERA-40 AAM

S1 contribution to prograde polar motion

- the OAM results are coherent while there are large differences between the estimated contributions of AAM
- the best agreement with observations is found for the barotropic OAM combined with the NCEP-NCAR reanalysis AAM

S1 contribution to UT1

- good agreement between the estimated contributions of AAM and OAM
- the contributions of AAM and OAM tend to cancel each other and the total effect does not agree with the observation