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The global S_1 tide and Earth's nutation

Session 4: *Earth's rotation and geodynamics*

aer
Atmospheric and Environmental Research

FWF

Motivation & Background

IAU2000A nutation model, Mathews et al. (MHB):

- MHB noticed a distinct gap of about 100 µas between their theory and VLBI data at the prograde annual frequency
- Residual from **solar S_1 tide**, subtracted prior to adjustment

"Postfit correction term" →  ← Present-day circulation models

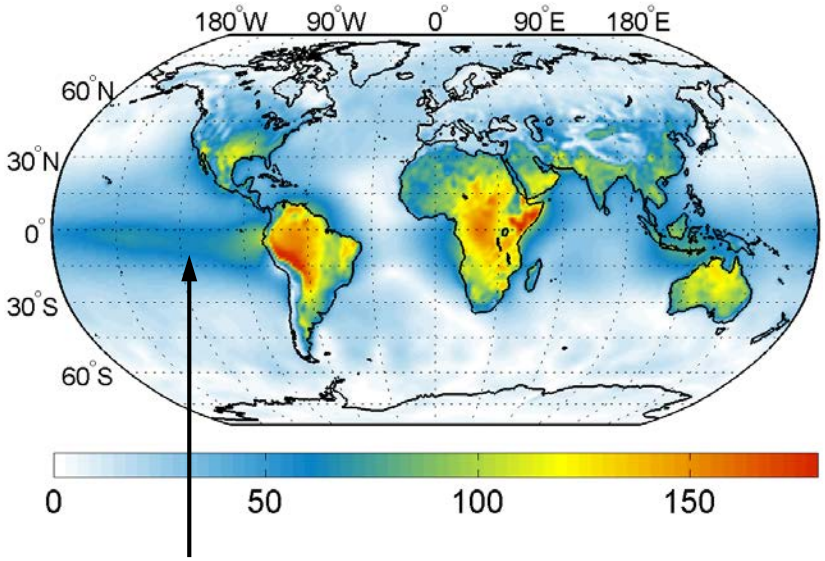
Radiational or thermal tides:

- Caused by the daily cycle of solar heating; stratospheric O_3 and tropospheric H_20 absorb solar radiation
- Excited waves propagate to the ground; diurnal variations in surface parameters dominated by Sun-synchronous or **migrating** oscillations, e.g in …

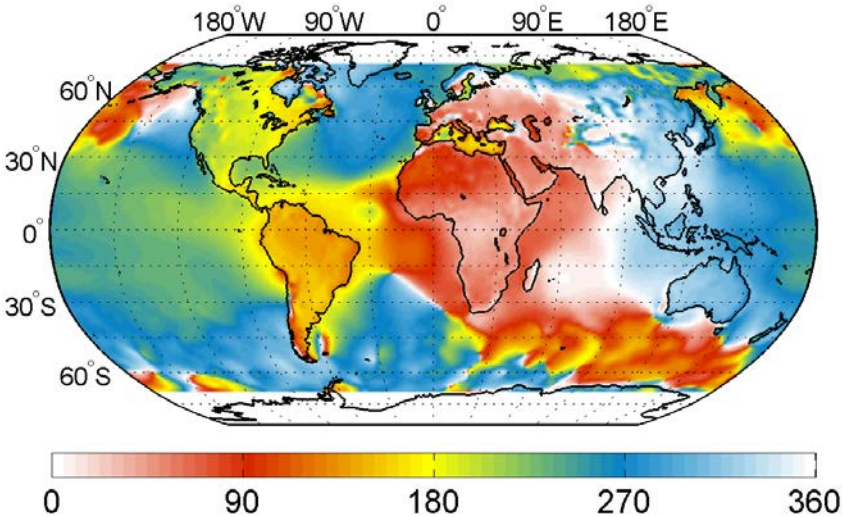
Radiational Tides

… Surface pressure: Global maps of $S_1(p)$

Amplitude (Pa)



Phase lag (deg)



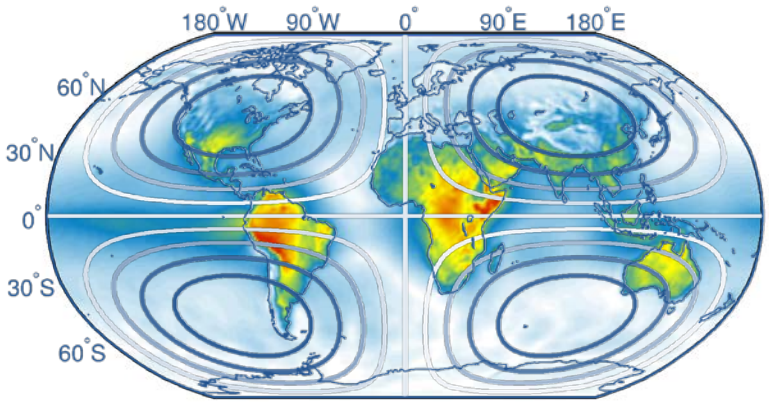
- Signature of **migrating wave**: equatorial belt of ~60 Pa in amplitude / westward increase in phase
- **Non-migrating waves**: strong oscillations over continents, repercussions of the local heat transfer from the ground

Radiational Tides

S_1 and nutation, important notes:

- Air pressure loads the oceans and induces oceanic angular momentum = „indirect“ atmospheric excitation

- Only the second-order tesseral spherical harmonic of pressure (~10 Pa mode) can couple to Earth rotation variations



- Wind tide effect features a better signal-to-noise ratio, e.g. in terms of S_1 retrograde atmospheric angular momentum (AAM):

motion : **mass** contribution = **7**:**1**

Presence of the ψ_1^1 normal mode, cf. *Brzeziński et al. (2002)*

Atmospheric Model Data

Time line of atmospheric reanalyses (with fixed model configuration):

National Centers for Environmental Prediction Reanalyses I and II

ECMWF 40-year Reanalysis

Japanese Meteorological Agency 25-year Reanalysis

Name	"Generation"	Fixation	Resol. (km)
NCEP RI	1	1995	210
NCEP RII	1	1995	210
ERA-40	2	2001	125
JRA-25	2	2002	120
MERRA	3	2004	60
NCEP CFSR	3	2004	40
ERA-Interim	3	2006	80

Mapped to nutation by *Souchay et al. (1999)*, *Souchay & de Viron (2001)*, fair agreement found

Atmospheric Model Data

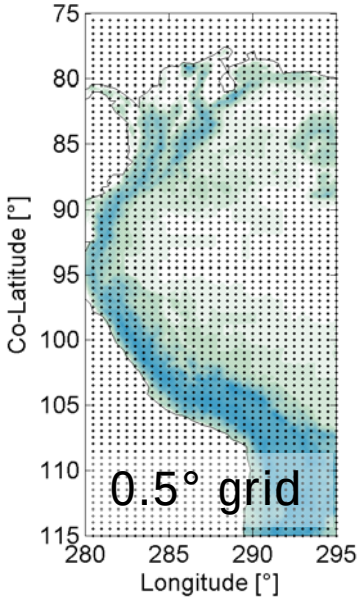
Probing the **3rd generation reanalyses**:

(1) MERRA* of NASA's Global Modeling and Assimilation Office:

*Modern Era-Retrospective Analysis for Research and Applications

(2) NCEP CFSR: Climate Forecast System Reanalysis

(3) ERA-Interim of ECMWF



Key numbers

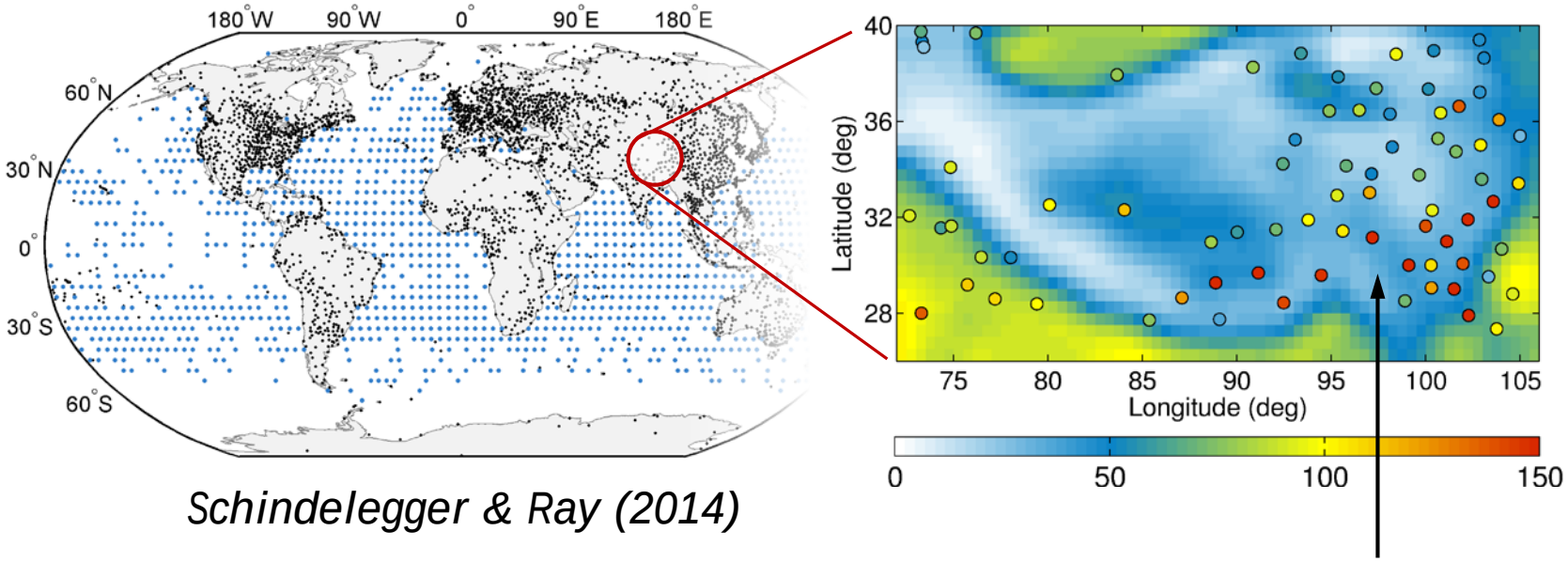
- Temporal resolution: 3^h, analysis & forecast data
- Time span: 1994.0 – 2010.12
- Horizontal spacing: 1.25° – 2.5° (pressure level data), 0.5° (surface pressure, except for MERRA)

Surface Pressure & AAM

Crosscheck of surface pressure with **empirical S_1 solution:**

- ~7000 in situ estimates
- 1°x 1° multiquadric interpolatio

Tibetan Plateau, W-China



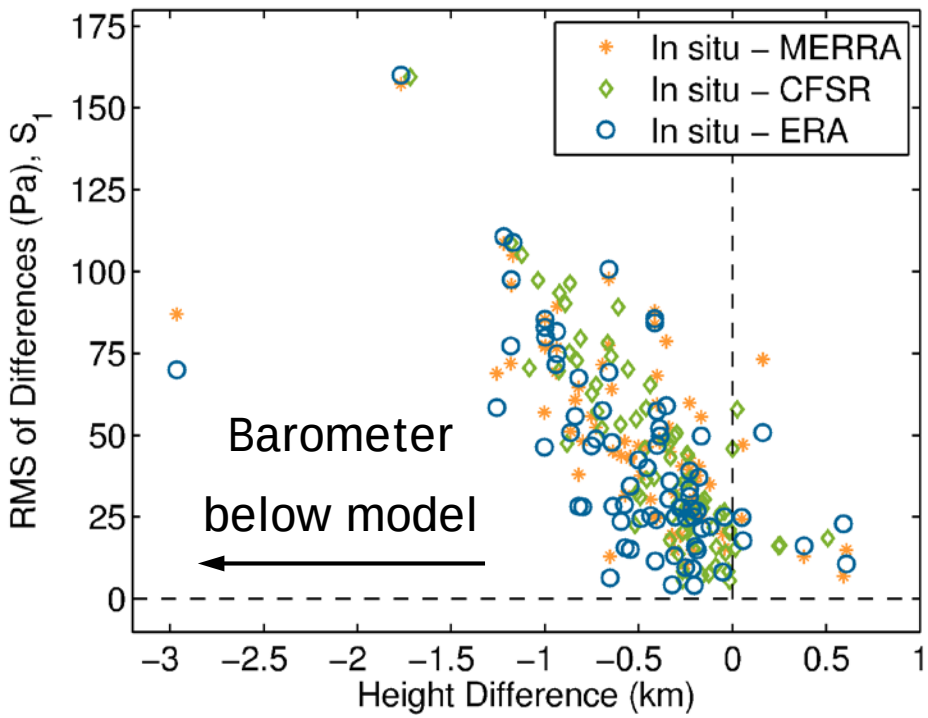
Schindelegger & Ray (2014)

- ERA-Interim amplitude snippet: almost non-existent S_1 tide
- Barometers suggest variations > 100 Pa

Surface Pressure & AAM

Crosscheck of surface pressure with **empirical S_1 solution:**

Tibetan Plateau "anomaly": global numerical models (0.5° or less) too coarse to resolve the topography & associated physics:



- RMS differences in S_1 pressure cycle almost linearly dependent on

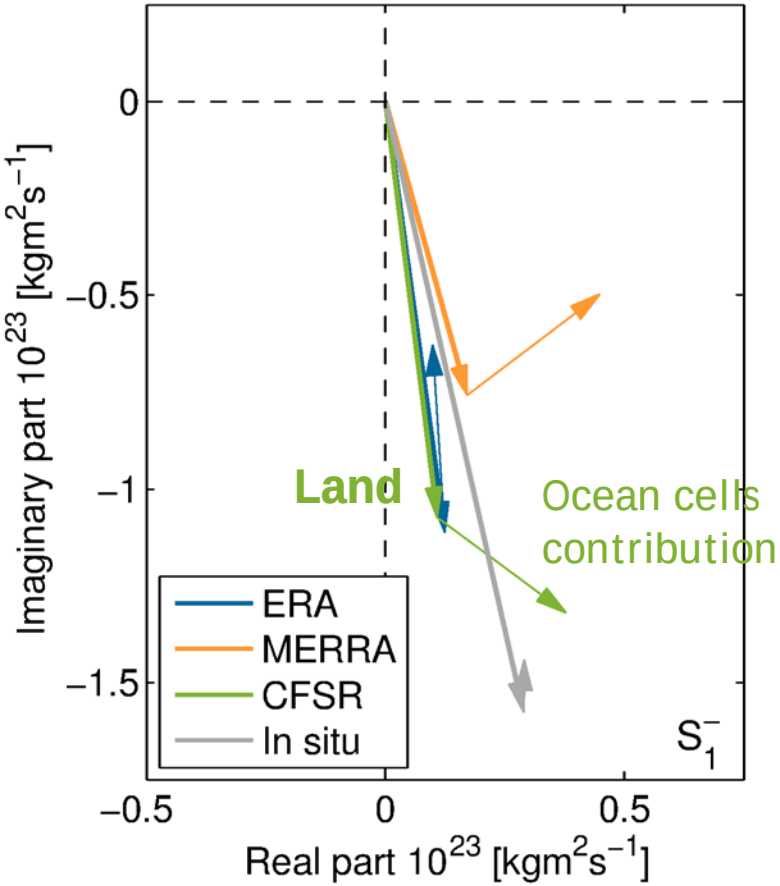
  $$\Delta H = H_{barometer} - H_{model}$$

- Gradient -100 Pa/km
- Strong diurnal oscillations in valleys entailed by mountain-valley breezes

Surface Pressure & AAM

Implications of possible inadequacies in S_1 surface pressure for **nutation estimates?**

- Quick assessment based on S_1^- Fourier coefficients of mass angular momentum
- Oceanic contributions diverge
- Enhanced amplitude of in situ AAM due to W-China S_1 tide

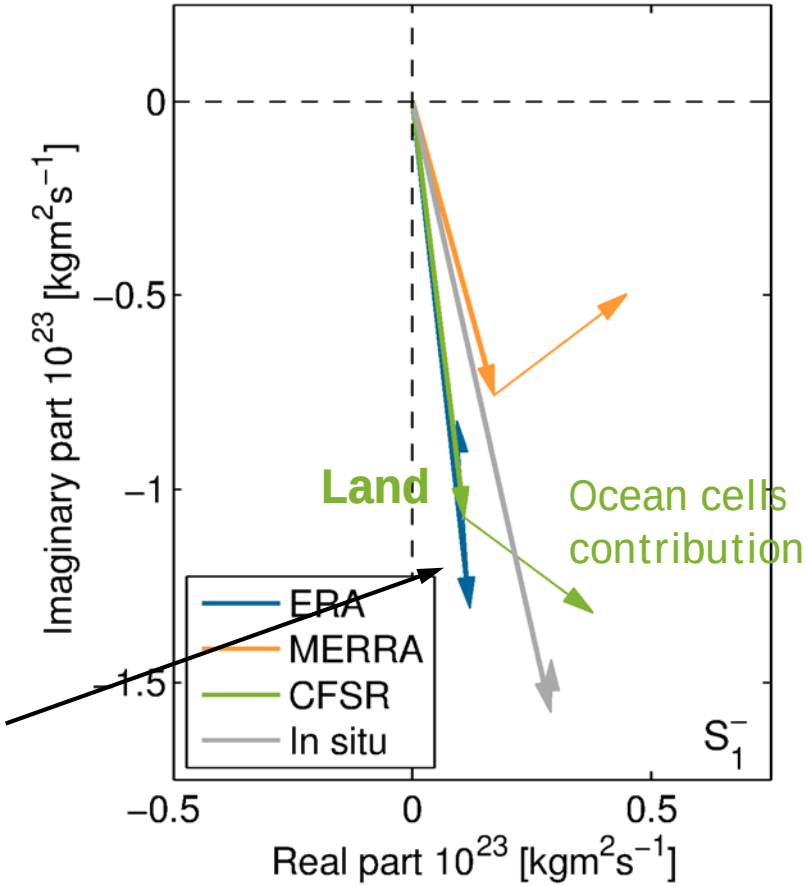


Surface Pressure & AAM

Implications of possible inadequacies in S_1 surface pressure for **nutation estimates?**

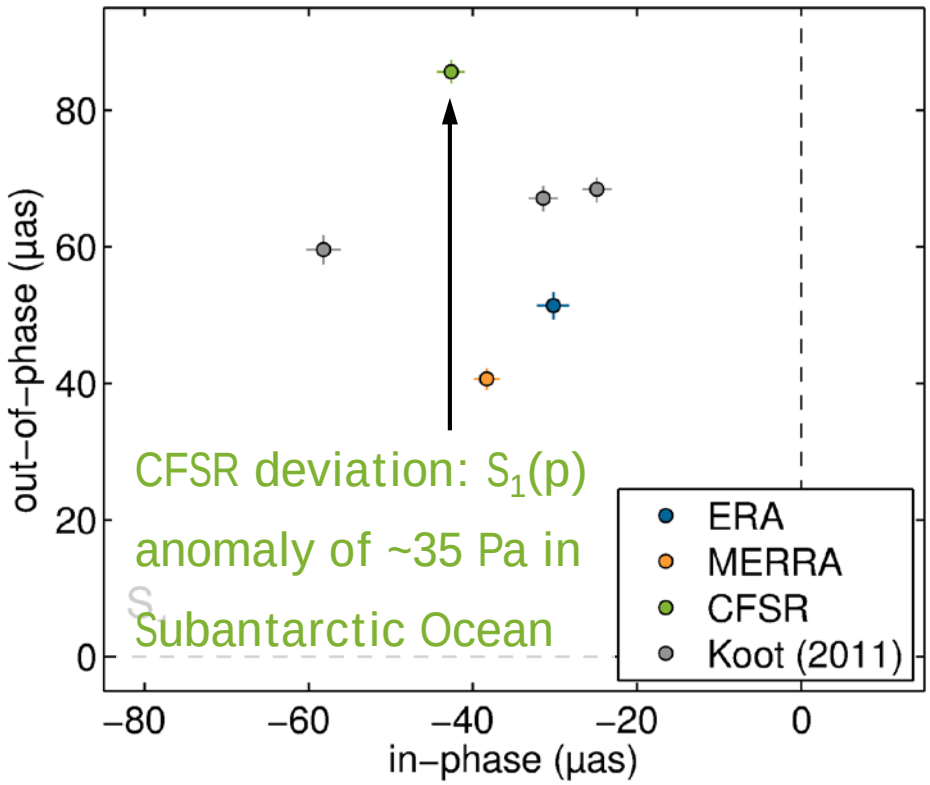
- Quick assessment based on S_1^- Fourier coefficients of mass angular momentum
- Oceanic contributions diverge
- Enhanced amplitude of in situ AAM due to W-China S_1 tide
- ERA-Interim AAM with inserted in situ grid over W-China increases by ~$0.2 \cdot 10^{23}$ kgm^2s^{-1}

  ≙ 13 µas in nutation



Nutation: Atmospheric Excitation

S_1 nutation estimates obtained from standard procedure:

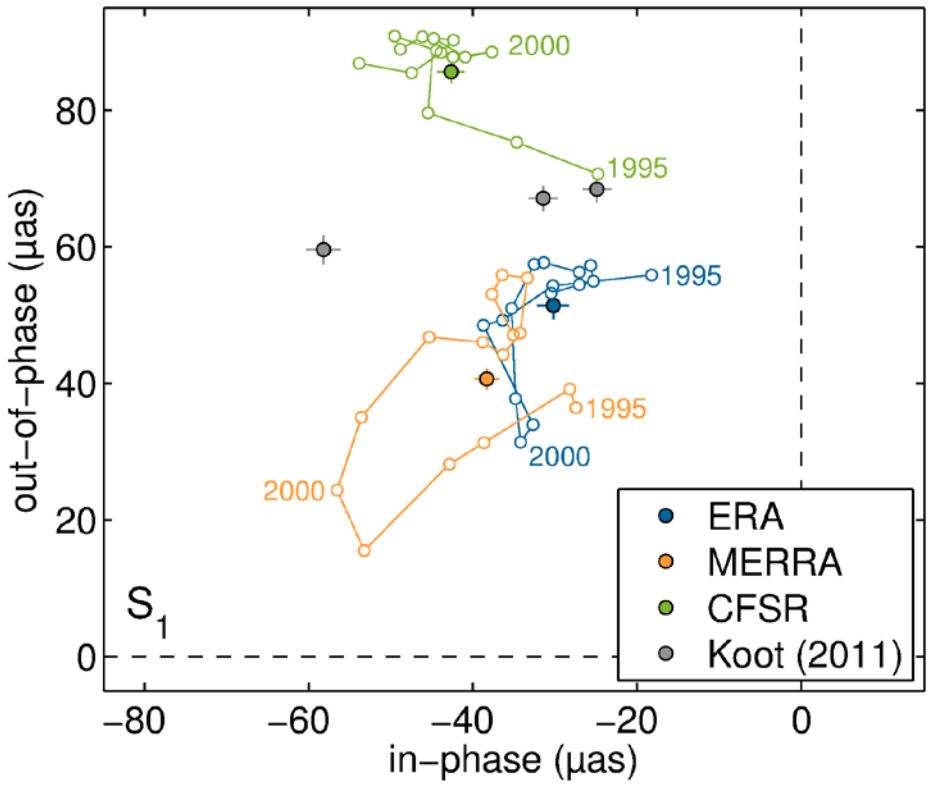


1) Demodulation to celestial AAM functions
2) Low-pass filtering
3) Fit of in- and out-of-phase components w.r.t. fundamental arguments
4) Convolution (Brzezińksi transfer function)

- Good agreement with 1st / 2nd generation reanalyses but amplitude reduction for ERA and MERRA

Nutation: Atmospheric Excitation

S_1 nutation estimates, temporal variability:



- Partition between mass & motion effects in ERA and MERRA about **55:45**
- Estimation repeated with 3-year sliding window

⇓

Interannual variability of up to 40 µas …

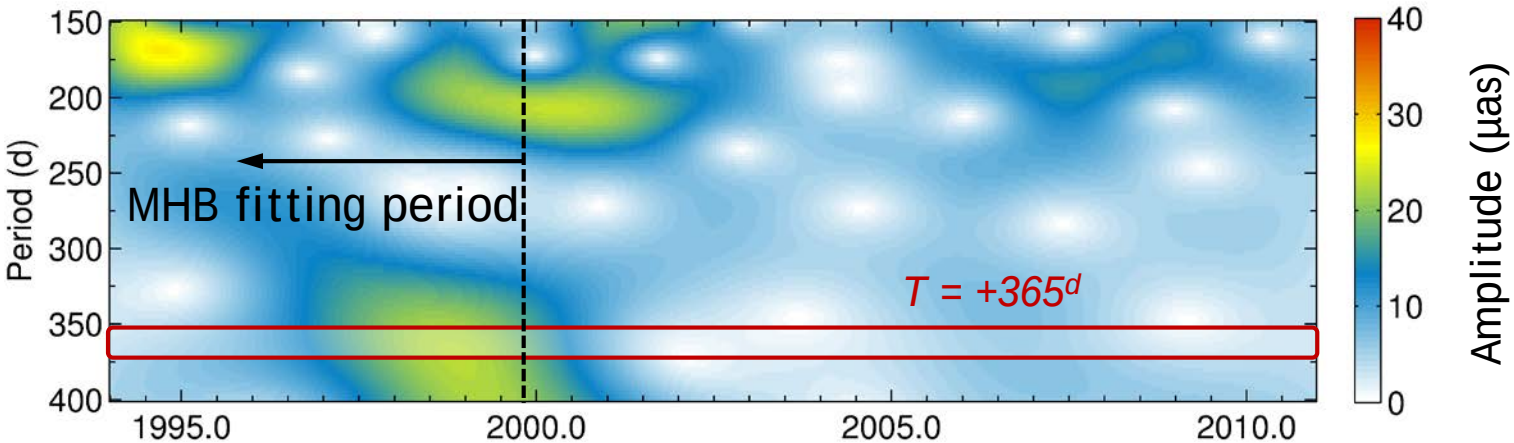
… Is this noise or a real physical signal?

Nutation: Atmospheric Excitation

S_1 nutation estimates, temporal variability – arguments for noise:

- Little coherence among all three reanalyses
- No residual pattern of the same size (40 µas) at the prograde annual frequency in celestial pole offsets:

IERS series, Morlet wavelet analysis

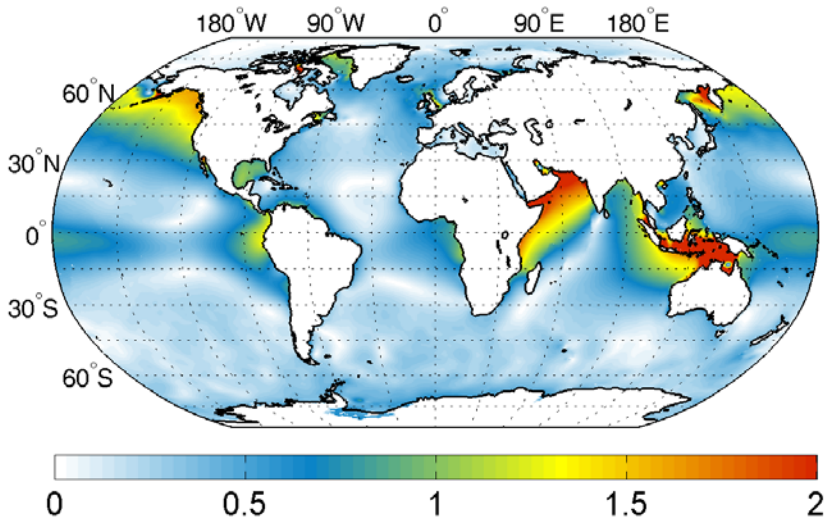


⟹ Atmospheric contribution rather harmonic and well-covered by the MHB empirical correction term (?)

Nutation: Oceanic Excitation

Substantial contribution of **radiational S_1 oceanic tide**:

FES2012 tidal heights (1 cm = 100 Pa)



- FES: Finite Element Solution
- CLIO: Coupled Large-Scale Ice-Ocean Model
- OMCT: Ocean Model for Circulation and Tides (1.875°)

Collection of estimates – from heights & currents, or already published papers:

phase (μas):	*in*	*out-of*
FES2012	-11.7	51.9
Ray & Egbert (2004)	11.6	62.3
de Viron et al. (2004): CLIO	8	57
Brzeziński et al. (2012): OMCT	-29.4	30.3

Atmospheric + Oceanic Excitation

Superposition of atmospheric & oceanic effects:

- Not fully consistent w.r.t. surface pressure forcing fields
- In terms of RMS differences at sea surface, MERRA fits well to ECMWF input data of both *Ray & Egbert (2004)* and FES2012

phase (µas):	*in*	*out-of*
ERA	-30.2	51.4
MERRA	-38.3	40.6
(CFSR	-42.7	85.6)

phase (µas):	*in*	*out-of*
MERRA + FES	-50.0	92.5
MERRA + Ray	-26.7	102.9
VLBI observ.	**-10.4**	**108.2**

Similar conclusion in *de Viron et al. (2004)*: CLIO + NCEP, but apparent anomaly (40 µas) in atmospheric out-of-phase estimate

S_1 and Earth's nutation

Summary and conclusion:

- Atmospheric pressure term probably the "bottleneck" in explaining the observed prograde annual nutation, even if examined by aid of 3rd generation reanalyses
- Total (mass + motion) excitation varies with time in a rather spurious manner $\Longrightarrow$
- Critical role of averaging period
- Uncertainty in atmospheric contribution therefore likely to be in the range of 20 μas ≈ accuracy of VLBI estimates

The End

Thank you for your attention!

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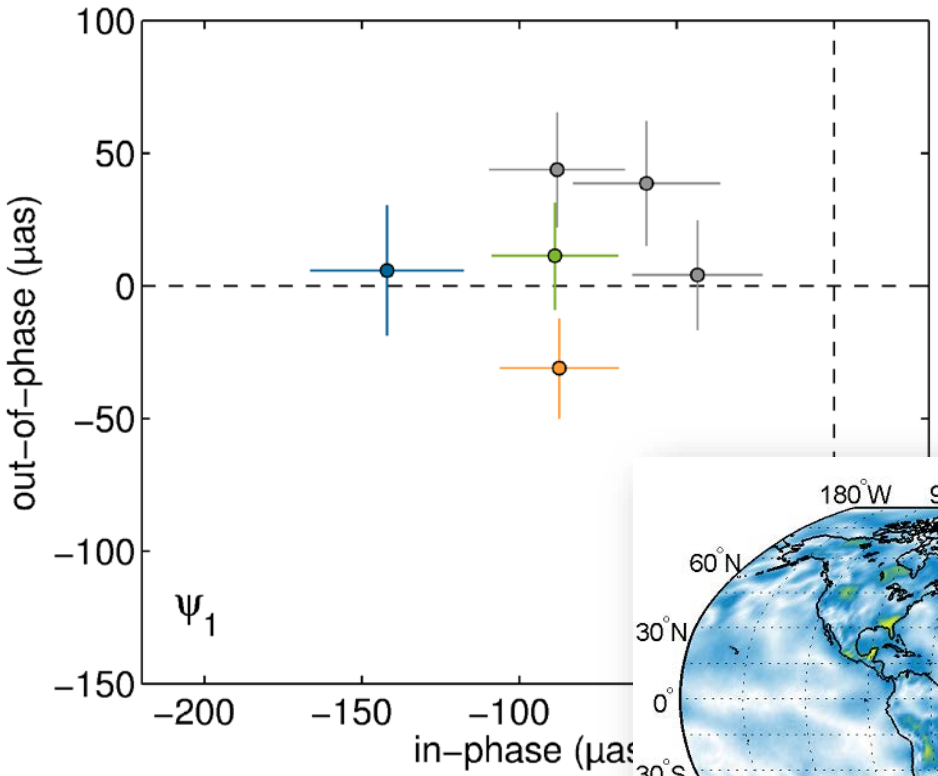
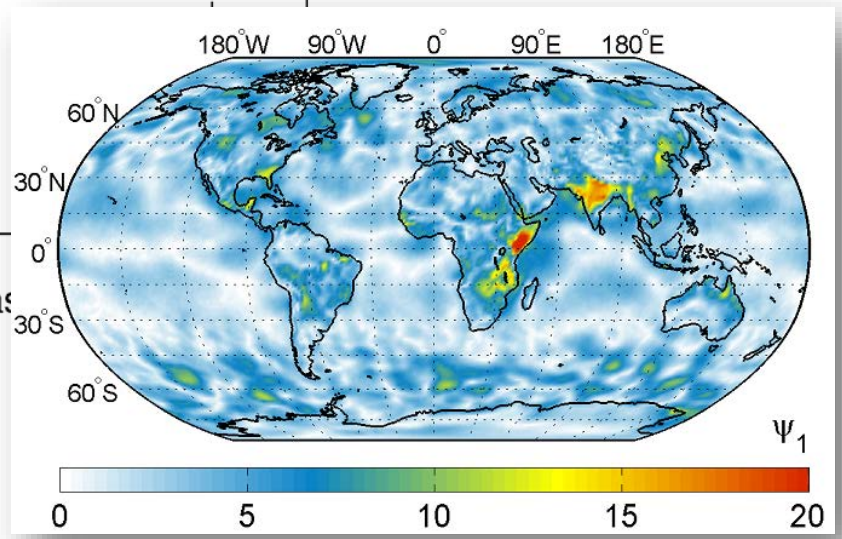
FWF Der Wissenschaftsfonds.

DFG Deutsche Forschungsgemeinschaft

ψ_1 retrograde annual nutation: mean estimates 1994.0 – 2010.12

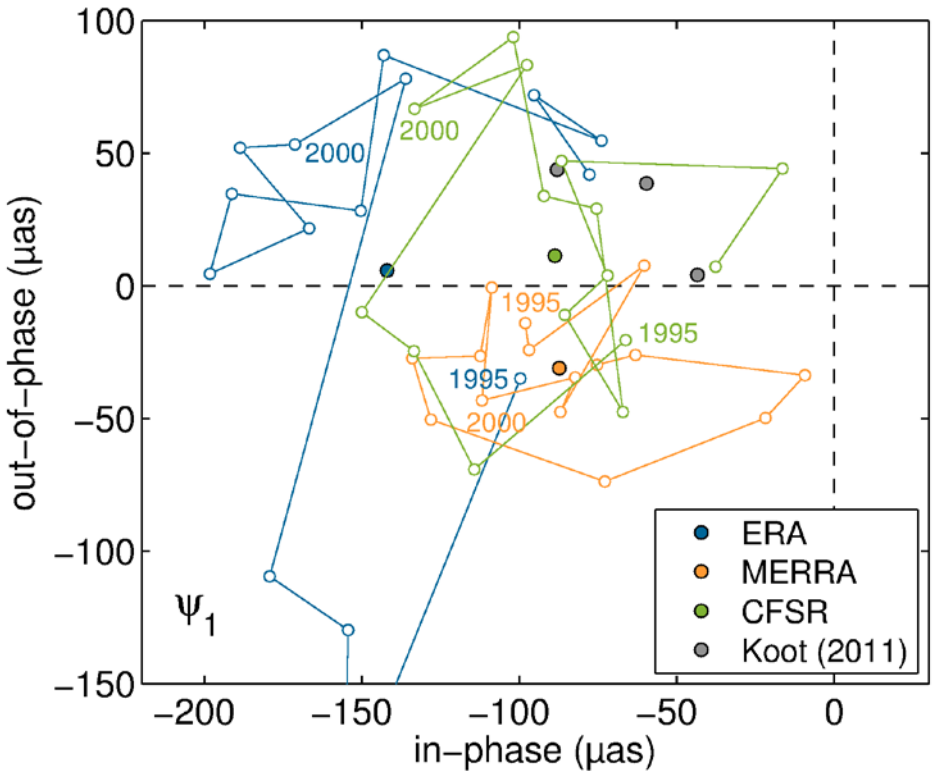


- Inter-model disparities of about 100 μas (!)
- Large formal errors indicative of "noise-like" character of the ψ_1 tide:



Amplitude (Pa) in surface pressure

ψ_1 **retrograde annual nutation**: temporal variability



- Estimation repeated with 3-year sliding window
- Large-magnitude fluctuations, probably non-physical
- Partition between mass & motion effects about **95:5**