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Analysis of atmosphere-excited intraseasonal polar motion via the torque approach

Session 4: *Earth rotation – Theory, modelling and observations*

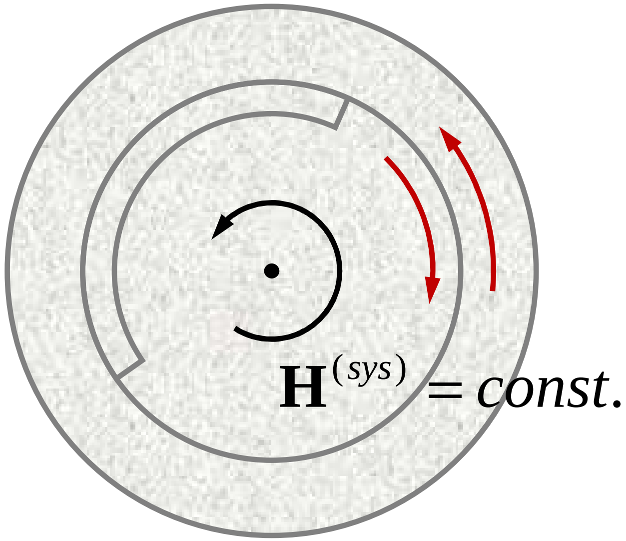
aer Atmospheric and Environmental Research

GGOS Atmosphere

Schindelegger et al. (2013), *Recent estimates of Earth-atmosphere interaction torques and their use in studying polar motion variability*, **J. Geophys. Res.**, Vol. 118, publ. online.

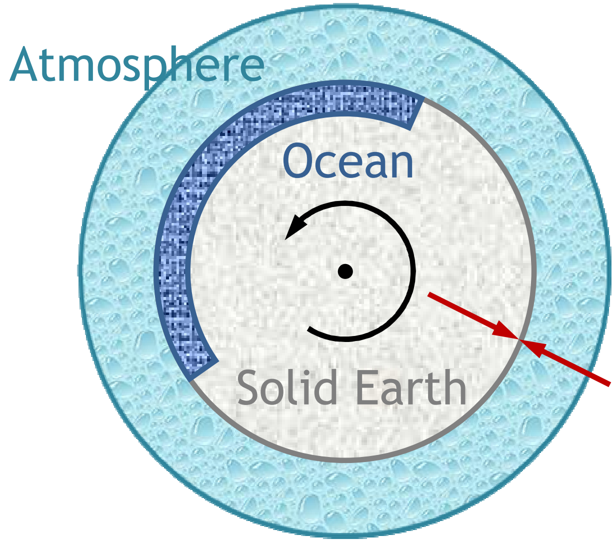
Geophysical excitation: two modeling approaches

Angular momentum conservation in whole Earth system



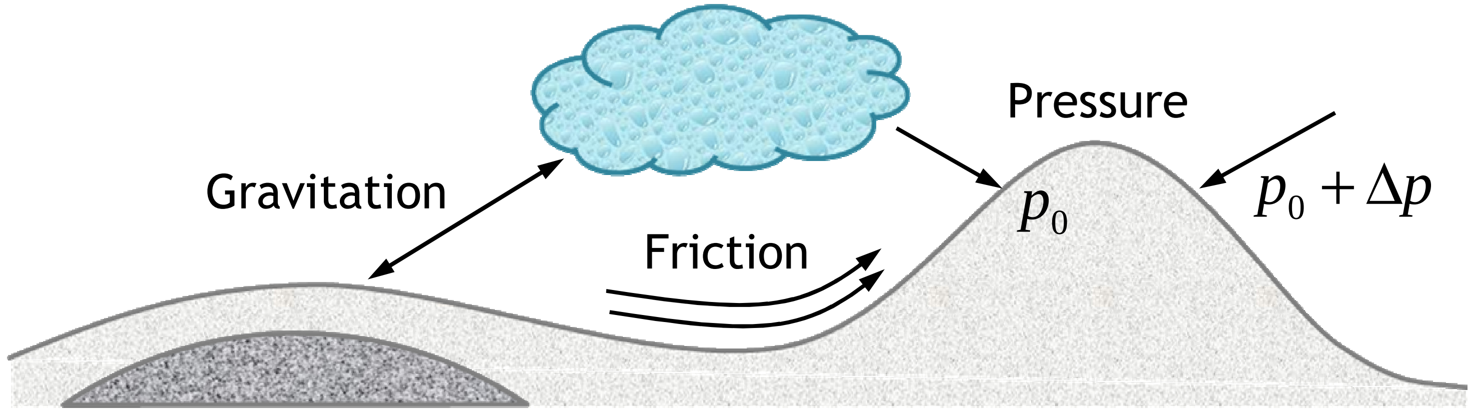
Solid Earth rotation as a mirror-image to change in fluid AM

External fluid layers exert torques on solid Earth



Exchange of AM at subystems' interfaces

Coupling mechanisms for the case of the atmosphere:



Total interaction torque exerted by solid Earth (s) on atm. (a)

$$\mathbf{L}^{(s)\rightarrow(a)} = -\mathbf{L}^{(a)\rightarrow(s)} = \boxed{\mathbf{L}^{e}} + \underbrace{\boxed{\mathbf{L}^{m}} + \boxed{\mathbf{L}^{f}}}_{\text{Local Torques}}$$

Ellipsoidal torque   Mountain torque   Friction torque

Local Torques

Theoretical Background

Budget equation of atmospheric angular momentum (AAM):

$$\frac{\mathrm{d}\left(\mathbf{H}^{p}+\mathbf{H}^{w}\right)}{\mathrm{d}t}+\boxed{\mathrm{i}\,\Omega\mathbf{H}^{p}}+\boxed{\mathrm{i}\,\Omega\mathbf{H}^{w}}=\boxed{\mathbf{L}^{e}}+\boxed{\mathbf{L}^{m}}+\boxed{\mathbf{L}^{f}}$$

$\mathbf{L}^{(s)\rightarrow(a)}$

riction torque: global integral of surface stresses, ~5% of

llipsoidal torque: combines pressure/gravit. forces due to the $\mathbf{H}^{p}$

flattening of the Earth, proportional to AAM pressure term

$$\boxed{\mathrm{i}\,\Omega\mathbf{H}^{p}=\mathbf{L}^{e}}$$

(θ,λ)

ountain torque: uses pressure gradients in , since friction

torque and AAM tendency (d/dt term) are small:

$$\boxed{\mathrm{i}\,\Omega\mathbf{H}^{w}\approx\mathbf{L}^{m}}$$

$\mathbf{H}^{w}$

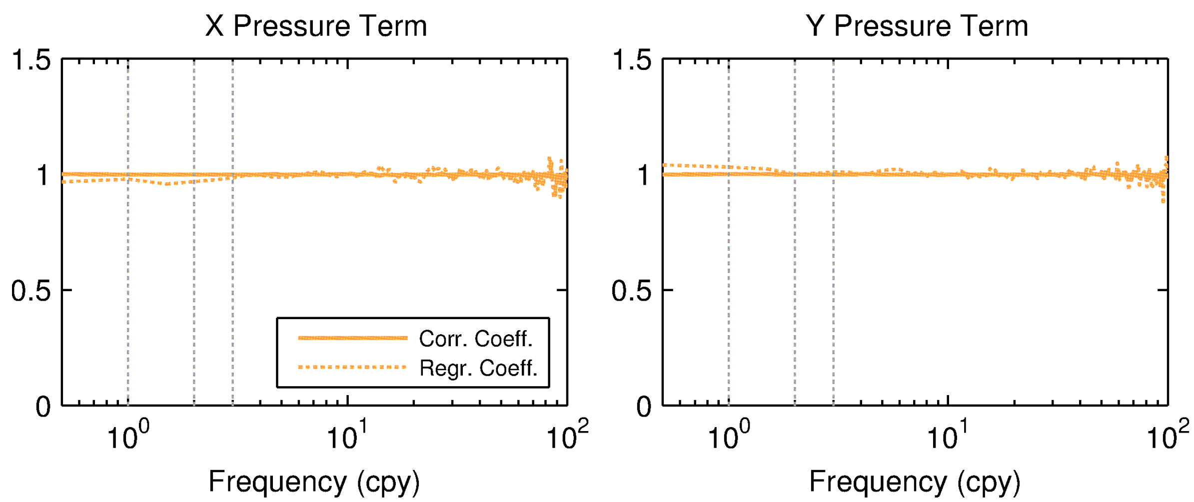
AAM wind term)

ERA-Interim (ECMWF reanalysis) vs. **MERRA*** from NASA's Global Modeling and Assimilation Office:

- Consistent calculation of interaction torques and AAM terms
- Δt = 1 day, 2007-2010

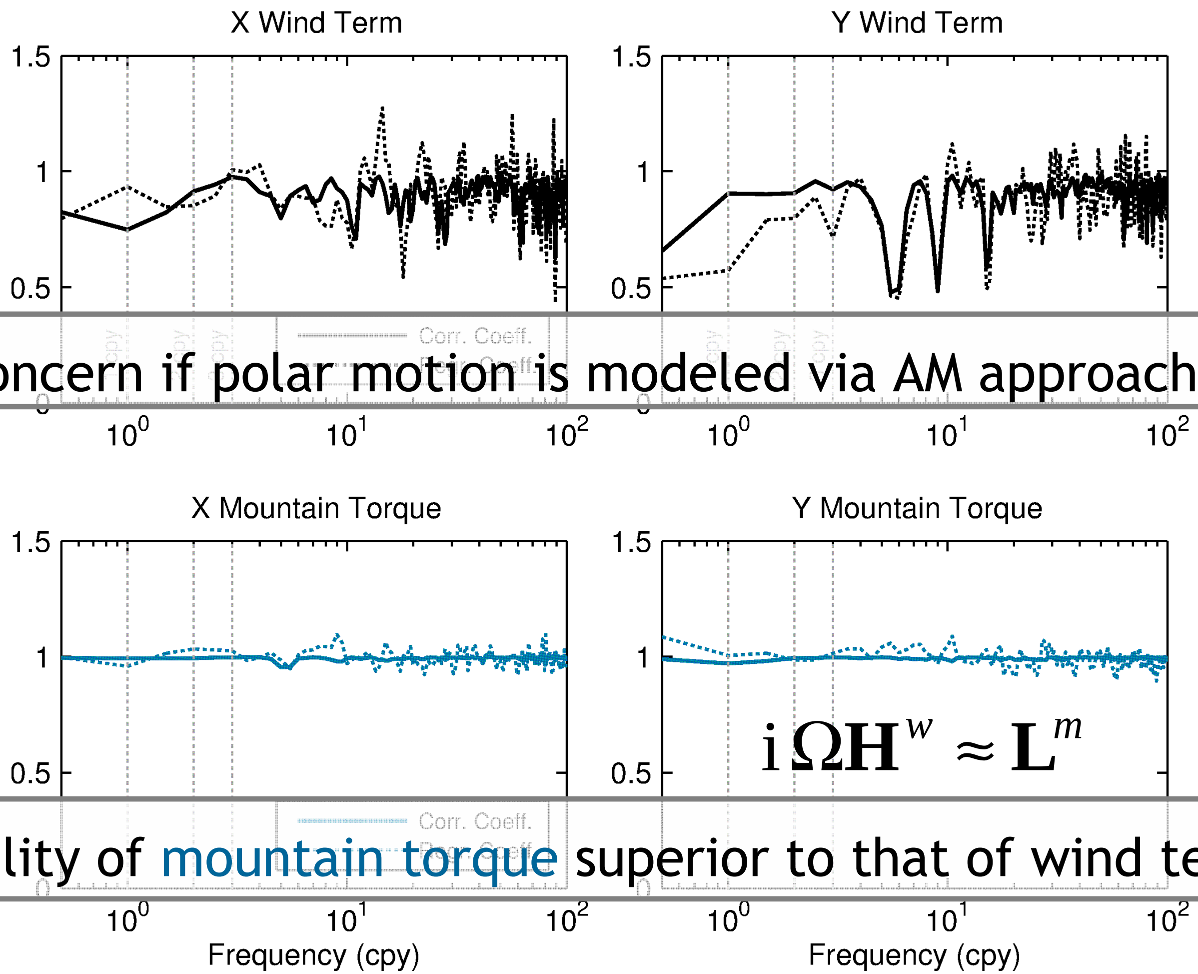
*Modern Era-Retrospective Analysis for Research and Applications

Pressure term (=ellipsoidal torque): correlation and regression coeff.



ERA-Interim vs. MERRA

Wind term and mountain torque: correlation and regression coeff.



Concern if polar motion is modeled via AM approach…

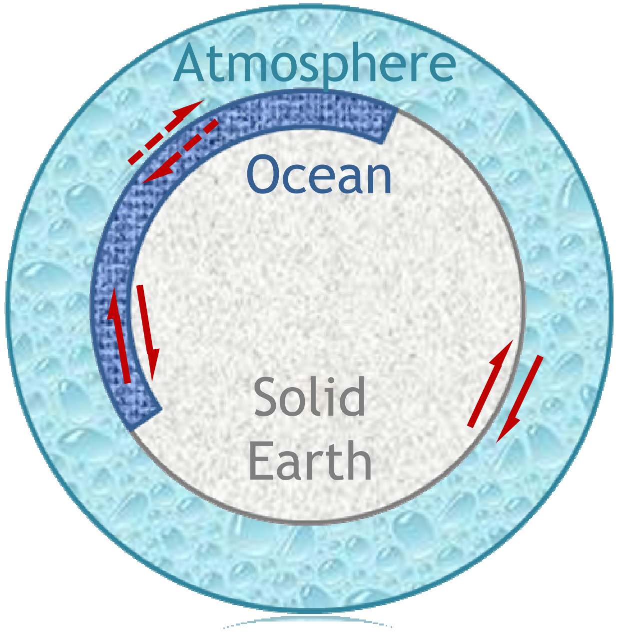
$$\mathrm{i}\,\Omega\mathbf{H}^{w} \approx \mathbf{L}^{m}$$

Reliability of mountain torque superior to that of wind term (?)

Atmospheric torques and oceanic excitation:

(1) IB-corrected ellipsoidal torque, mountain and friction torques in „torque excitation scheme“ (Wahr, 1982):

$$\hat{m} + \frac{\mathrm{i}}{\sigma_{cw}}\dot{\hat{m}} \leftrightarrow \frac{\mathrm{i}}{(C-A)\Omega^2}\left[1.61\mathbf{L} - 0.49\mathbf{L}^e\right]$$



– IB-corrected oceanic angular momentum (OAM) function can be added

– rather approximate scheme

(2) Atmospheric + oceanic torques in a coupled atmosphere-ocean model

Atmospheric torques and oceanic excitation:

(3) Angular momentum approach formula with torque terms converted to AAM values:

$$\hat{p} + \frac{\mathrm{i}}{\sigma_{cw}}\dot{\hat{p}} \leftrightarrow \frac{\mathrm{i}}{(C-A)\Omega}\left[1.100\boxed{\mathbf{H}^{p}} + 1.608\boxed{\mathbf{H}^{w}}\right]$$

OAM function

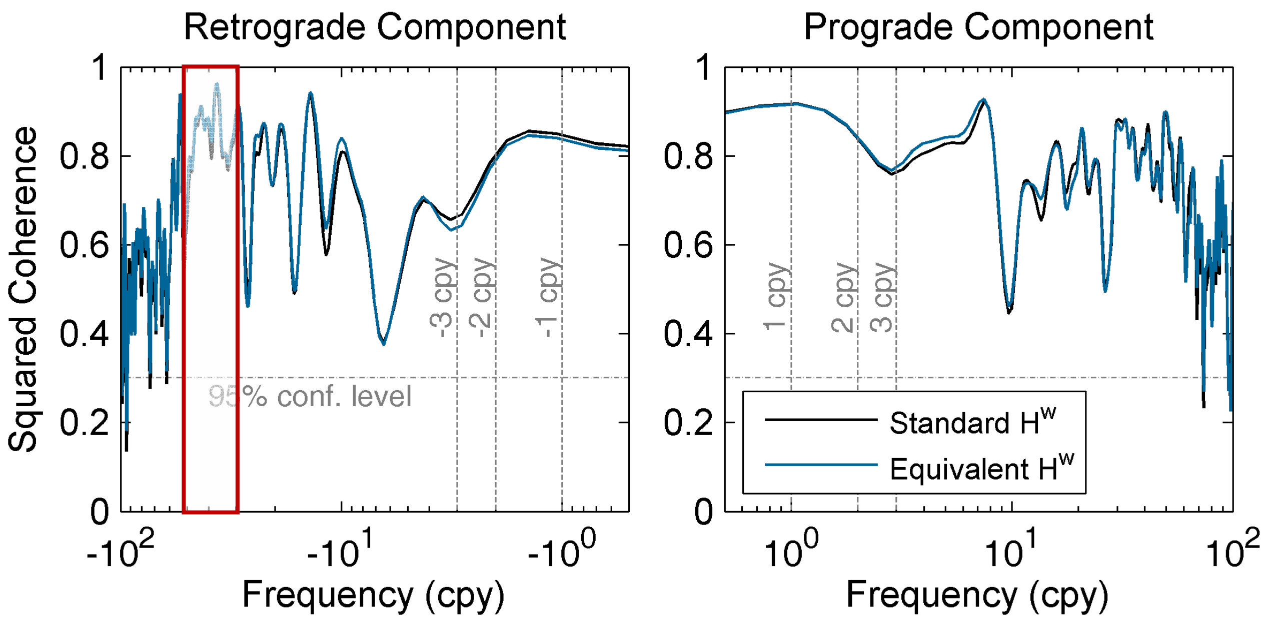
llipsoidal torque (IB)

orque-based wind term:

– Exact solution: integration of the AAM budget equation, e.g. in frequency domain

– Gives equivalent wind term

Test against geodetic excitation: (OAM function included)



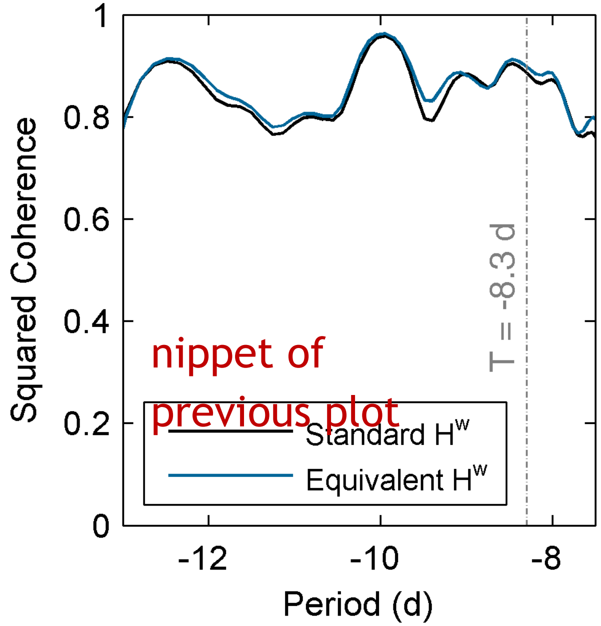
oherence spectra for both equivalent and **standard** wind terms

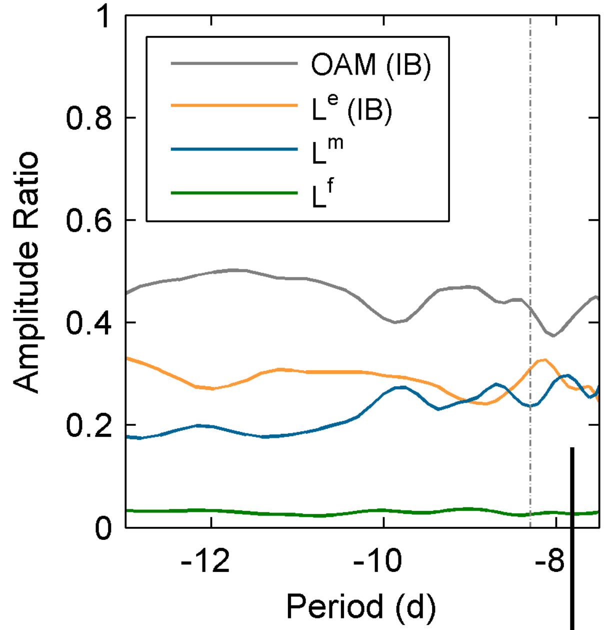
10-day normal mode

ERA-Interim (intraseasonal)	Correlation		RMS of differences (mas)	
	x	y	x	y
Standard wind term	0.59	0.50	14.4	20.2
Equivalent wind term	0.63	0.52	13.8	19.9

Torques & Polar motion variability

10-day normal mode: T=(-13,-7.5)^d (Feldstein, 2008)





ontributions of torque terms and OAM to total excitation function

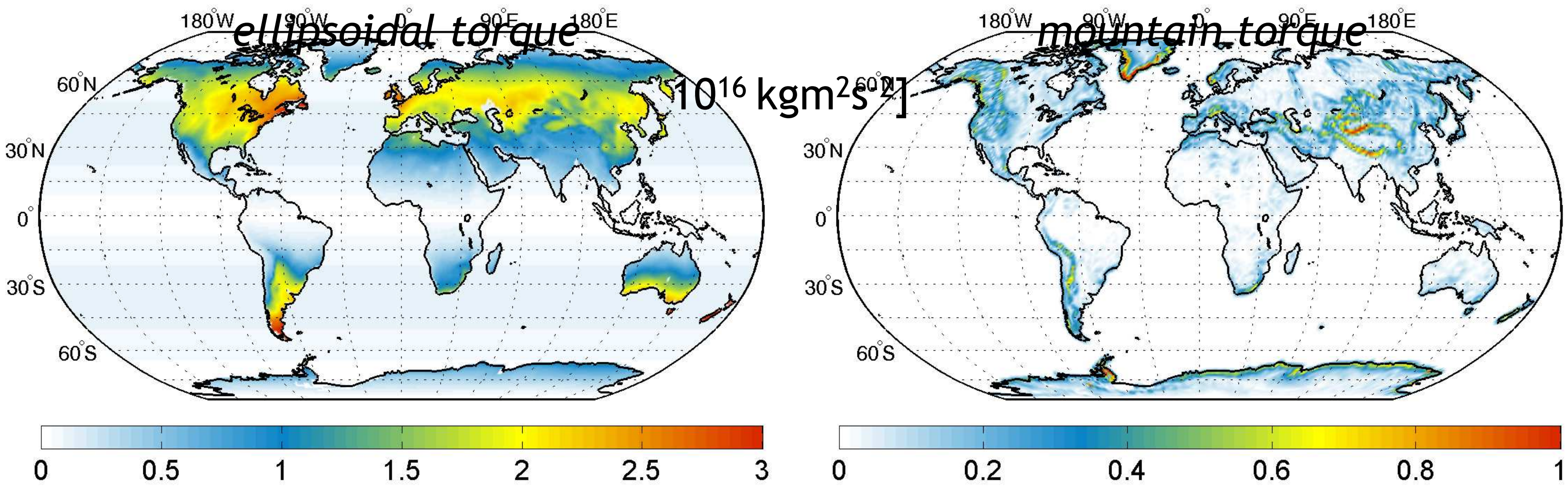
$$\sum_{i=1}^{4}(ratio)_i = 1$$

$\boxed{\mathbf{L}^e}, \boxed{\mathbf{L}^m}, \boxed{\mathbf{L}^f}$ and OAM entered in torque excitation function ϕ of Wahr (1982) and expressed as amplitude ratio w.r.t. their sum

$$\left|\phi^e\right| + \left|\phi^m\right| + \left|\phi^f\right| + \left|\phi^{OAM}\right|$$

Torques & Polar motion variability

10-day normal mode: regions of angular momentum exchange with solid Earth detected by virtue of *gridded*…



- Bandpass filter (7.5;13)^d at each grid point
- Mean amplitude extracted
- IB assumption and strong mid-latitude dependency visible

Torques & Polar Motion Variability

Summary and conclusion:

- ❖ For the current atmospheric reanalyses, the margin between torque and angular momentum approaches in the equatorial component has become small
- ❖ Agreement of mountain torque estimates from different models superior to that of the wind term
- ❖ Torque-based wind term improves the agreement with observed polar motion excitation
- ❖ Potential of the torque approach to highlight regions of angular momentum exchange has been demonstrated for the 10-day normal mode

The End

Thank you for your attention!

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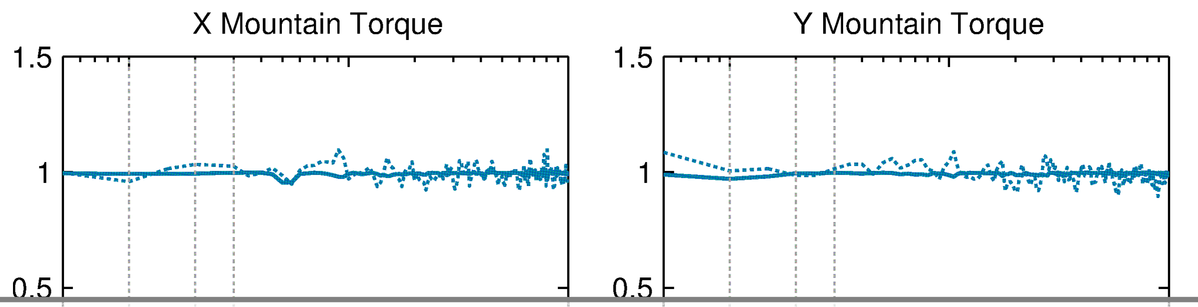
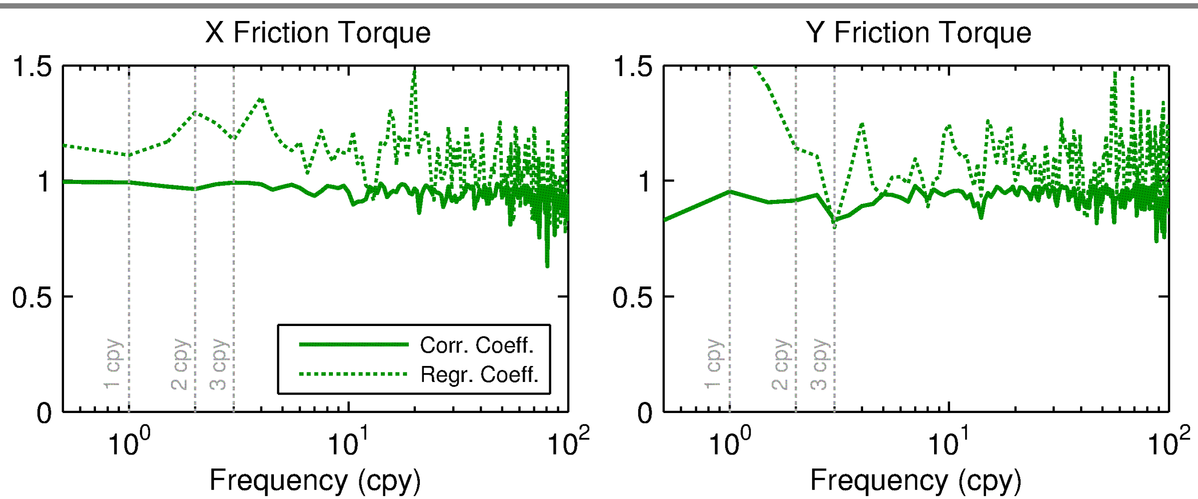
ERA-Interim vs. MERRA

Mountain torque and friction torque: corr. and regr. coefficients



f. earlier studies

Mountain torque contributes to the total torque at about the same level as wind term to total AAM



RA-Interim with stronger friction amplitudes

AAM Budget Equation

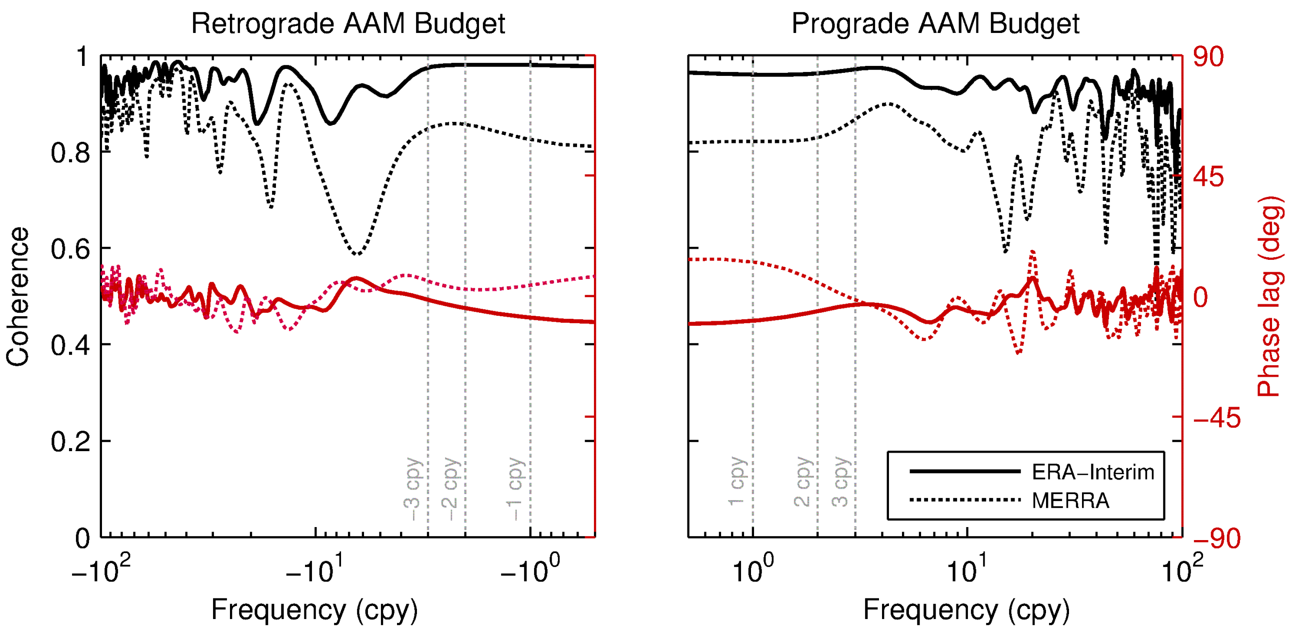
Torques need to **balance** the changes in AAM:

pressure wind

$$\frac{\mathrm{d}\left(\mathbf{H}^p + \mathbf{H}^w\right)}{\mathrm{d}t} + \mathrm{i}\,\Omega\mathbf{H}^w = \mathbf{L}^m + \mathbf{L}^f$$

esidual AAM budget

(ellipsoidal t removed):



uality of reanalysis:

RA-Interim

ERRA

Reliability of MERRA wind term?