Assimilation of Earth Orientation Parameters into an CCM

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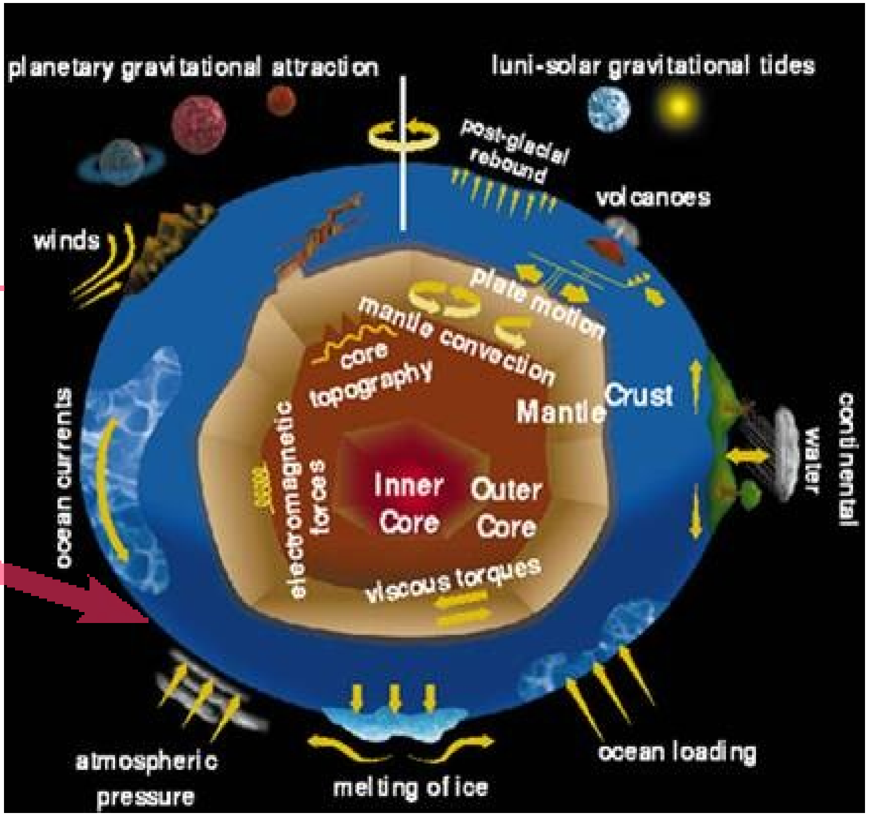
Overview

Wind and mass changes in the atmosphere influence the **angular momentum** of the earth, and thereby its **wobble** and **rotation rate**.



These Earth Rotation Parameters (ERPs) are observed.

Can they inform climate models via data assimilation?

Overview

(1) Background: Earth Rotation Parameters and Atmospheric Angular Momentum
(2) Data and Model
(3) How can ERPs inform our Model?
(4) Towards an ERP data assimilation system
(5) Outlook: Progress and Challenges

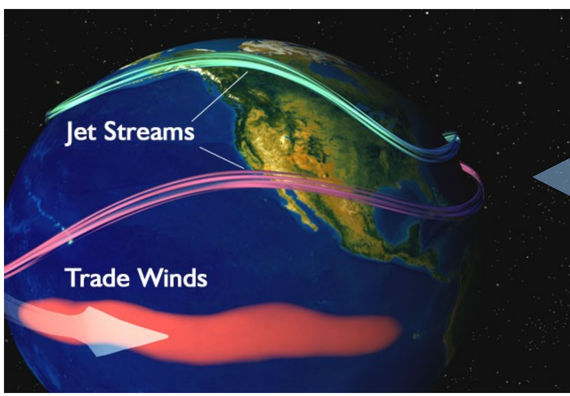
A New Data Assimilation Problem

mass changes

wind changes

Atmospheric Angular Momentum (AAM)

Earth Rotation and Orientation



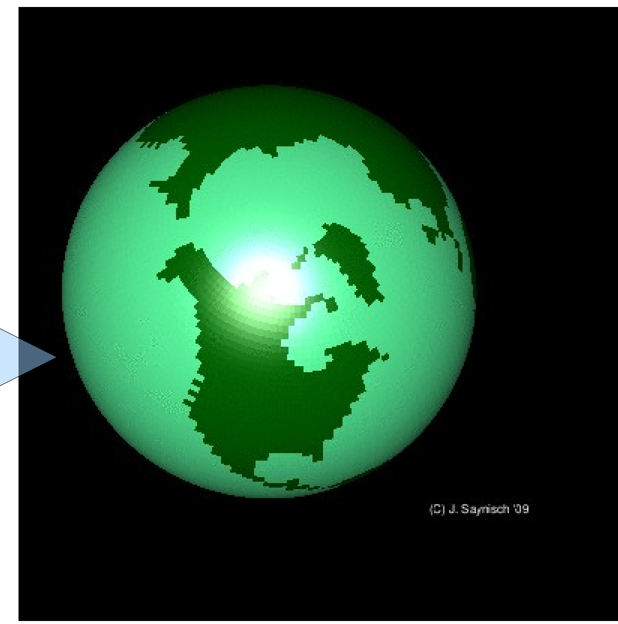
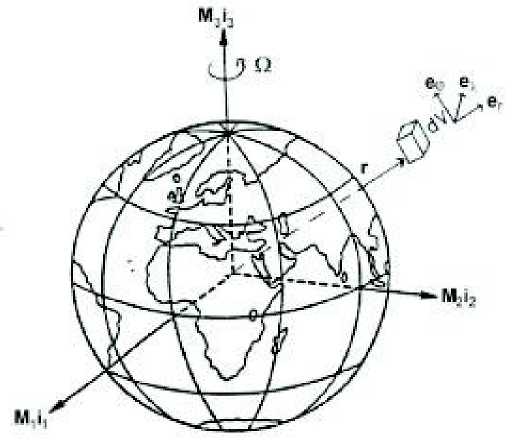


Figure by J. Saynisch

A New Data Assimilation Problem

Atmospheric Angular Momentum (AAM)



Earth Rotation and Orientation

Complex equatorial exciation functions

$$\chi_{\mathrm{eq}}(t) = \frac{1.61}{\Omega\,(C-A)}\left[\Omega\Delta\mathbf{I}(t) + \Delta\mathbf{h}(t)\right]$$

Complex polar motion vectors

$$p_{\mathrm{eq}}(t) + \frac{i}{\sigma_c}\dot{p}_{\mathrm{eq}}(t) \quad = \quad \chi_{\mathrm{eq}}(t)$$

Axial excitation function

$$\chi_3(t) = \frac{-1}{\Omega\,(C)}\left[\Omega\Delta I_{33}(t) + \Delta h_{33}(t)\right]$$

Rotation rate & Length-of-Day (LOD)

$$\Omega\dot{p}_3(t) \quad = \quad \dot{\chi}_3(t)$$

$$\Delta\mathrm{LOD} = \mathrm{LOD}_0\Delta\chi_3$$

Angular Momentum Excitation Functions

$$\chi_1^{\mathrm{P}} = \frac{-1.00R^4}{(C-A)g} \int\int p_s \sin\phi \cos^2\phi \cos\lambda \mathrm{d}\lambda \mathrm{d}\phi$$

$$\chi_1^{\mathrm{W}} = \frac{-1.43R^3}{\Omega(C-A)g} \int\int\int (u \sin\phi \cos\phi \cos\lambda - v \cos\phi \sin\lambda) \mathrm{d}\lambda \mathrm{d}\phi \mathrm{d}p$$

$$\chi_2^{\mathrm{P}} = \frac{-1.00R^4}{(C-A)g} \int\int p_s \sin\phi \cos^2\phi \sin\lambda \mathrm{d}\lambda \mathrm{d}\phi$$

$$\chi_2^{\mathrm{W}} = \frac{-1.43R^3}{\Omega(C-A)g} \int\int\int (u \sin\phi \cos\phi \sin\lambda + v \cos\phi \cos\lambda) \mathrm{d}\lambda \mathrm{d}\phi \mathrm{d}p$$

$$\chi_3^{\mathrm{P}} = \frac{0.70R^4}{Cg} \int\int p_s \cos^3\phi \mathrm{d}\lambda \mathrm{d}\phi$$

$$\chi_3^{\mathrm{W}} = \frac{R^3}{C\Omega g} \int\int\int u \cos^2\phi \mathrm{d}\lambda \mathrm{d}\phi \mathrm{d}p$$

A New Data Assimilation Problem

Atmospheric Angular Momentum (AAM)	⟷	Earth Rotation and Orientation

Now consider the observation increment D:

$$\mathbf{D}_k = \mathbf{y}_k - H\left[\mathcal{M}\left(\mathbf{x}_0, \alpha\right)\right]$$

observation vector — $\mathbf{y}_k$; model — $\mathcal{M}$; initial state — $\mathbf{x}_0$; parameters — α

where

$$H : \mathbf{x}(t) \rightarrow \begin{pmatrix} \chi^m_{\mathrm{eq}} + \chi^w_{\mathrm{eq}} \\ \chi^m_3 + \chi^w_3 \end{pmatrix} \rightarrow \begin{pmatrix} p_{\mathrm{eq}} \\ \Delta\mathrm{LOD} \end{pmatrix} = \mathbf{y}$$

model state — $\mathbf{x}(t)$; observed state — $\mathbf{y}$

Note that this is a global integral.

AAM and EOPs: Some Examples

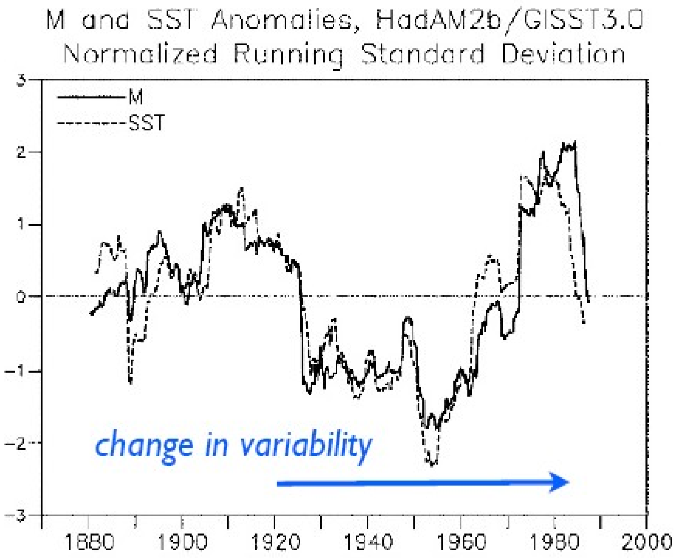
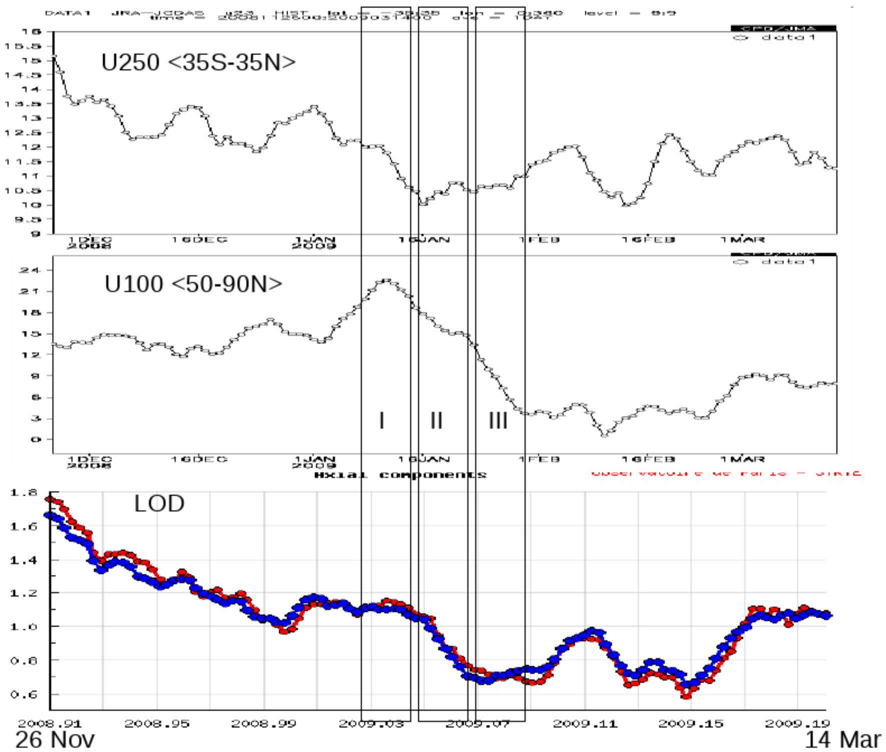


Fig. 5 Normalized running standard deviations in 21-year moving windows of atmospheric angular momentum from the HadAM2b/GISST 3.0 model run and sea surface temperature anomalies in the Niño-3 region from GISST 3.0

Rosen & Salstein, 2001: std. of AAM anomalies and SST anomalies in the Nino-3 region



LOD decreasing during MSW of 2009 (figure from K. Kodhera)

2: Model and Observations

Model

ECHAM5/MESSy → EMAC

T42 spectral resolution

90 hybrid vertical levels (up to .01 hPa)

Shown here: CCMVal Ref1B Run (1960-2000)

See also:

Joeckel et al. (2006)

Morgenstern et al. (to appear)

Observations

International Earth Rotation Service (IERS) EOP-C04 series

Combination of:

- Lunar Laser Ranging (LLR)
- Very Large Baseline Interferometry (VLBI)
- Satellite Laser Ranging (SLR)
- GPS
- Doppler satellite positioning (DORIS)

Available at:

http://hpiers.obspm.fr

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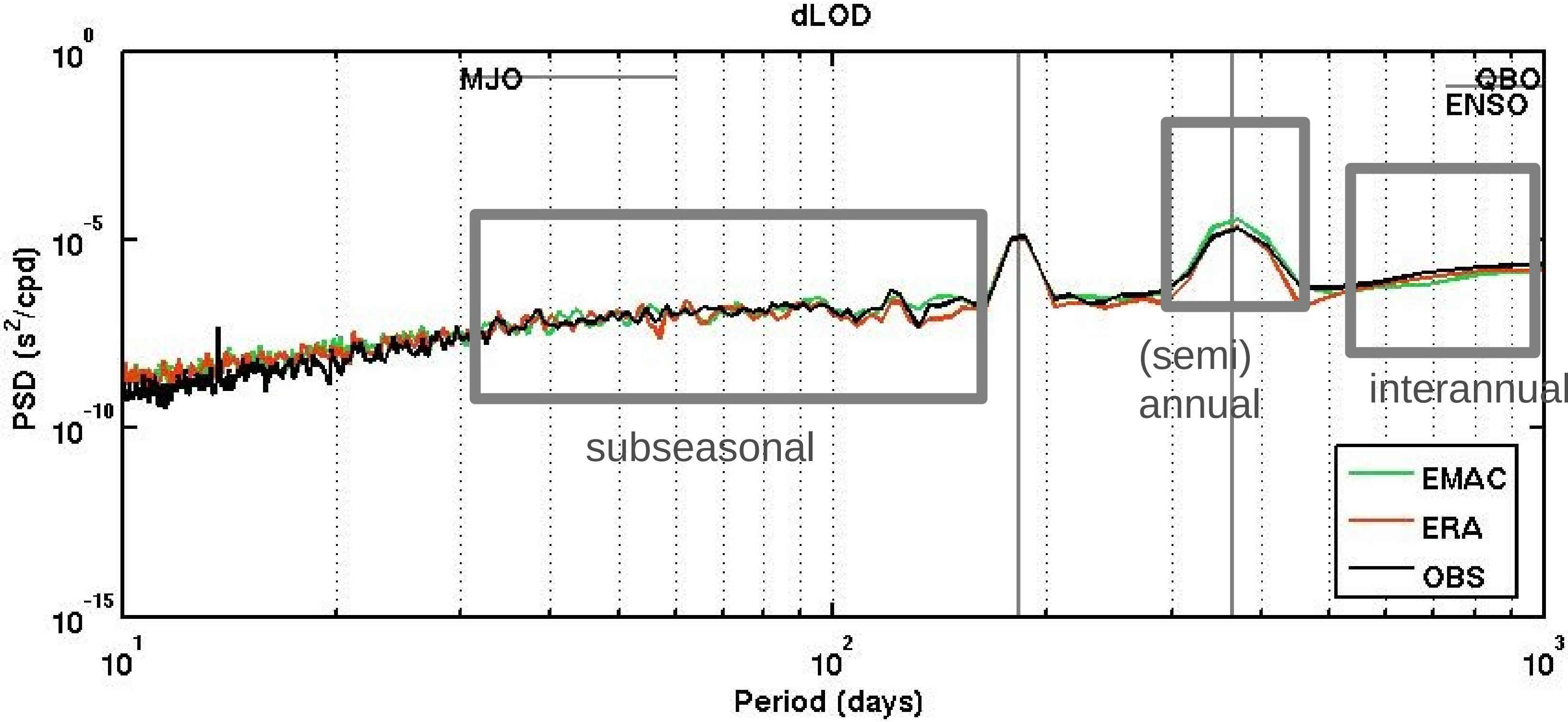
2: Model and Observations

Different Timescales of Interest



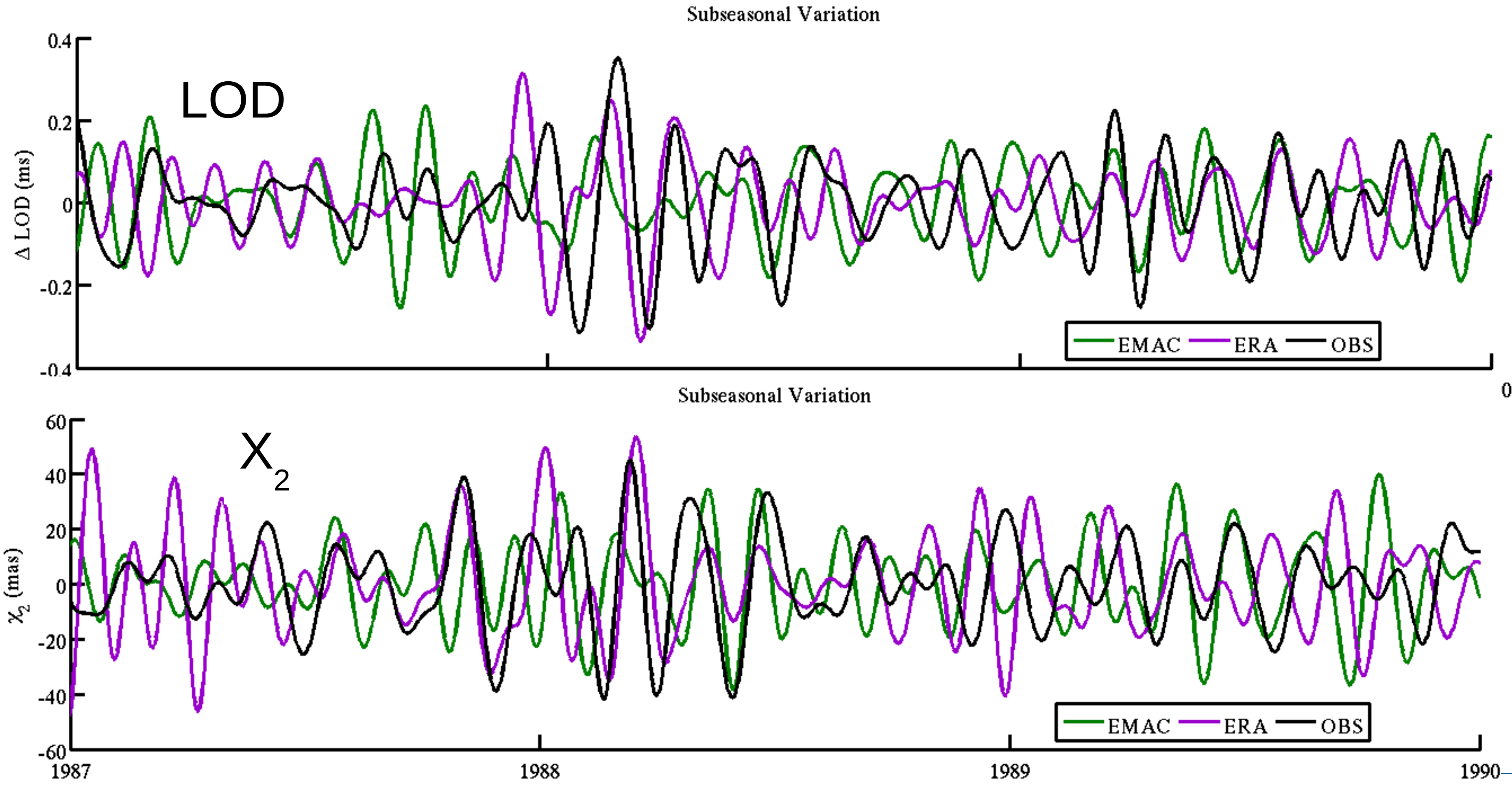
Model

Reanalysis

Observations

3: How Can ERPs Inform the Model?

Subseasonal Timescales (1-6 months)



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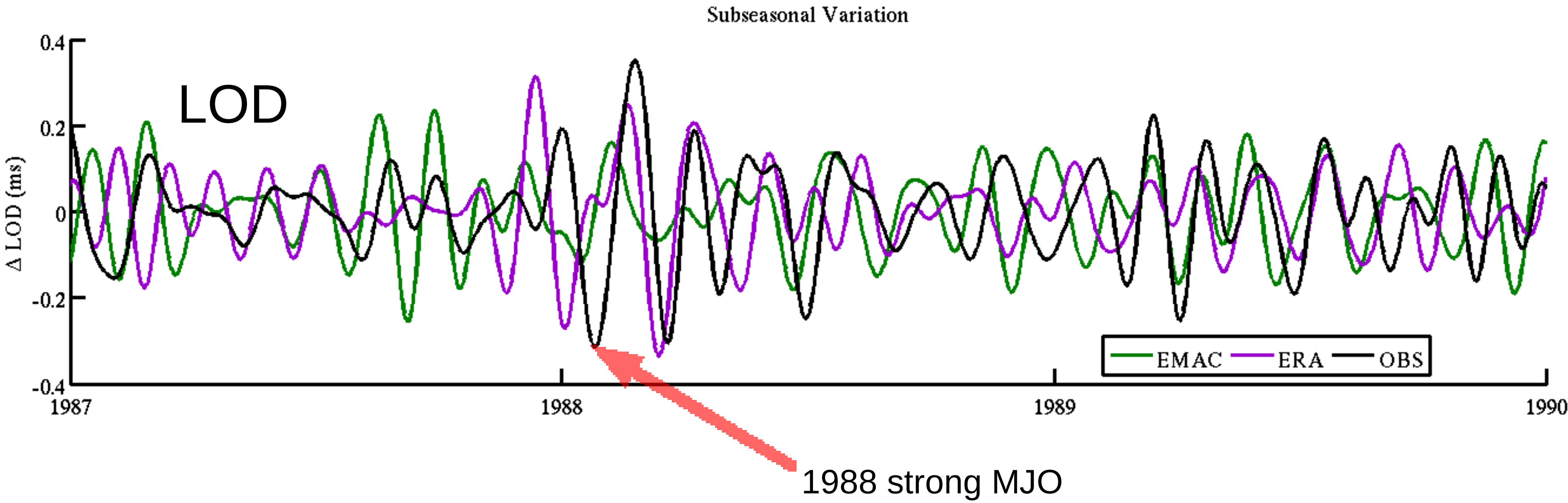
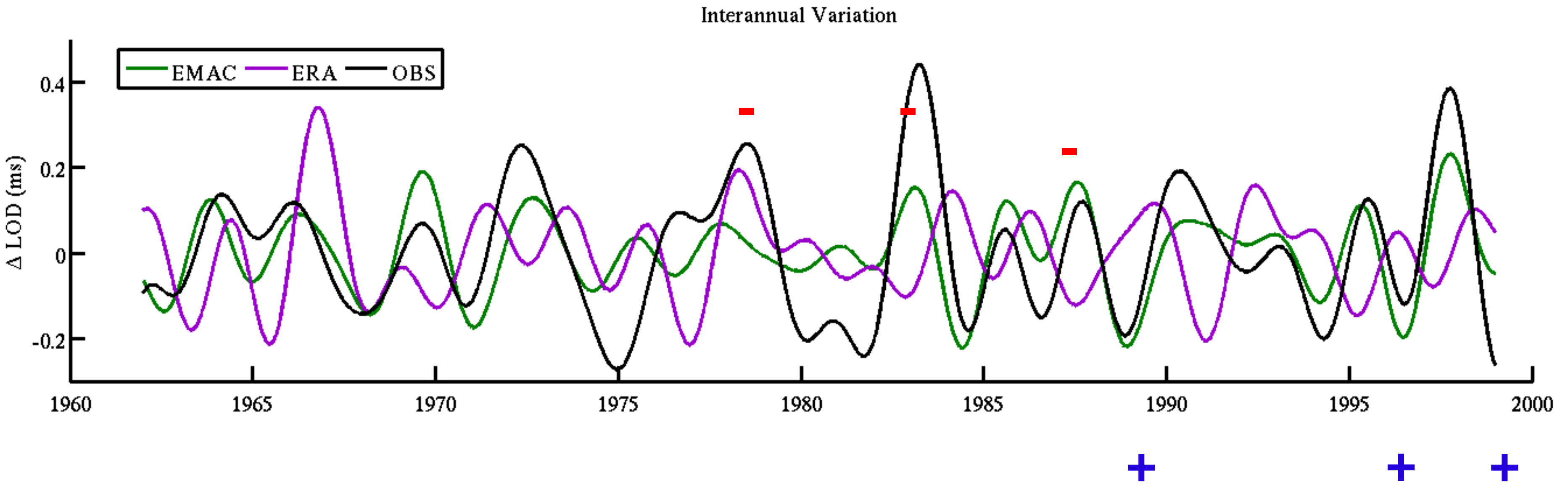
Subseasonal Timescales (1-6 months)



Timeseries of ΔLOD from **observations**, and as implied by axial AAM in **EMAC** and **ERA-Interim** **(all filtered** to permit only subseasonal (30-60 d) oscillations. Note enhanced subseasonal fluctuations in ΔLOD observed in early 1988, attributed by *Dickey et al. (1991)* to a strong MJO. ERA-Interim has these fluctuations, but the EMAC run does not.

3: How Can ERPs Inform the Model?

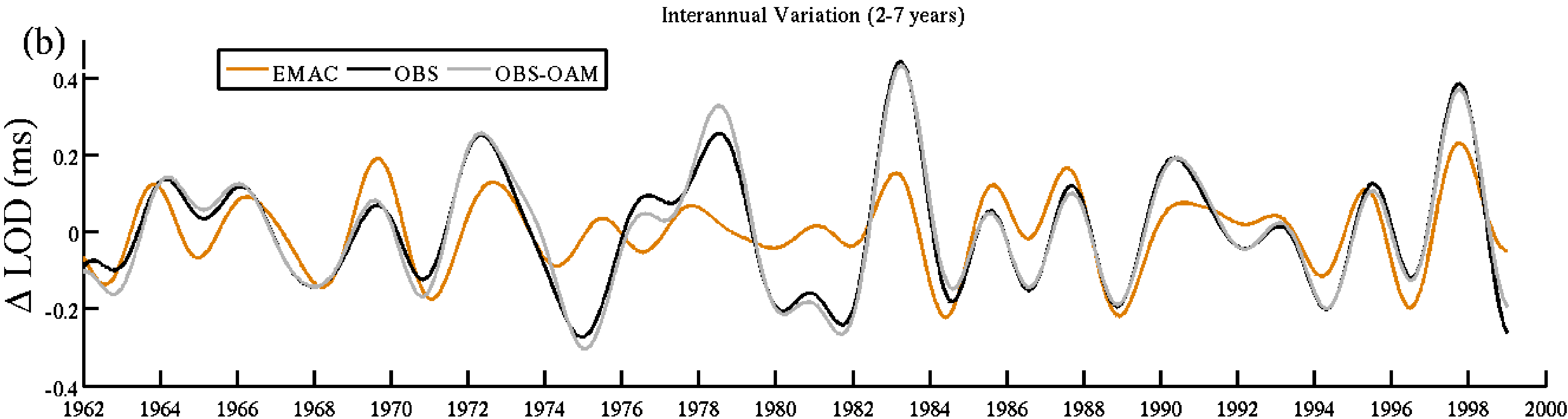
Interannual Timescales (2-7 years)



Timeseries of ΔLOD from **observations**, and as implied by axial AAM in **EMAC** and **ERA40/ERAInterim**, (high-pass filtered to isoltate interannual variations). Note, e.g. the minima in ΔLOD during La Nina and maxima during El Nino. On this timescale, ERA is almost completely out of phase with **EMAC** and the observations.

3: How Can ERPs Inform the Model?

Role of Other Components, e.g. Ocean AM

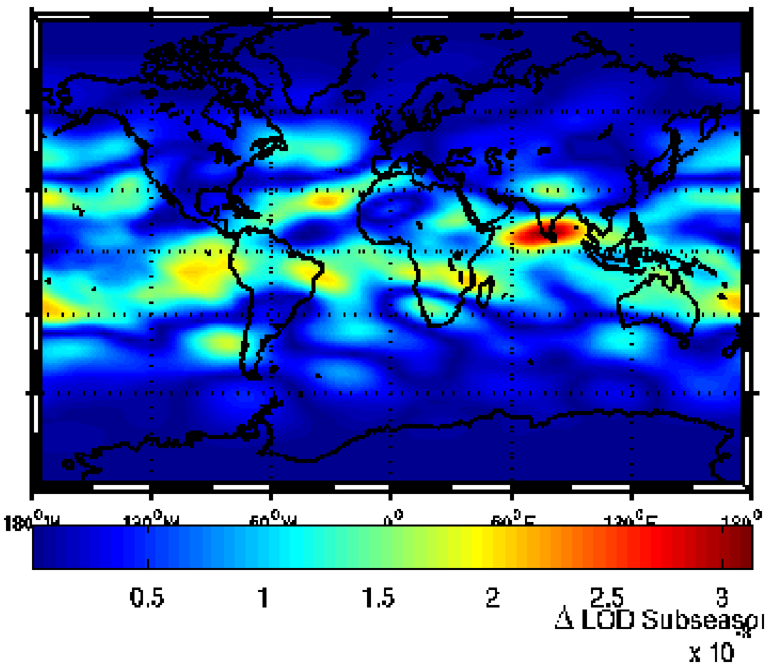


Consideration of other sources of angular momentum is also necessary. Here approximate ocean AM (OAM, Dobslaw et al., 2010) is taken out of the observations. Other sources include core-mantle ineration (CAM), hydropshere (HAM)

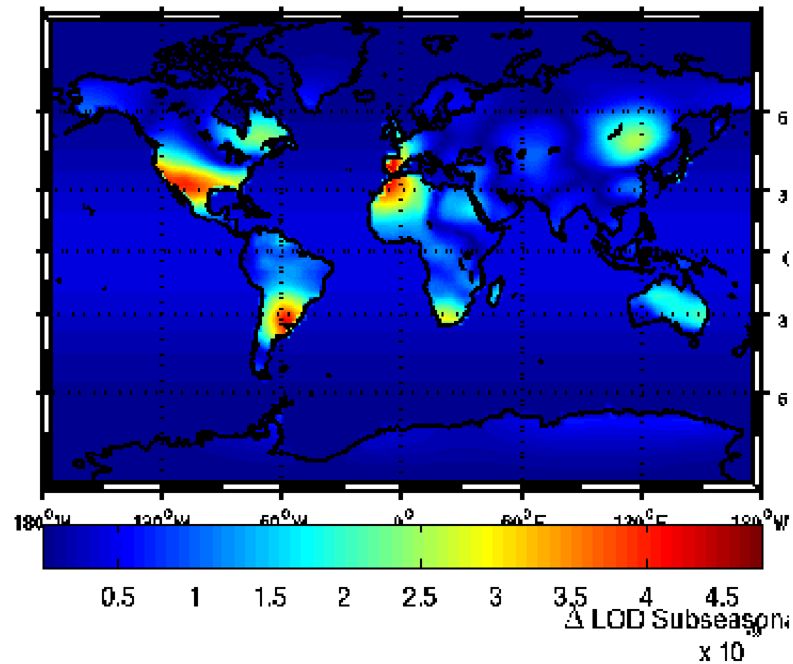
3: How Can ERPs Inform the Model?

Spatial Covariances

Wind Term



Mass Term

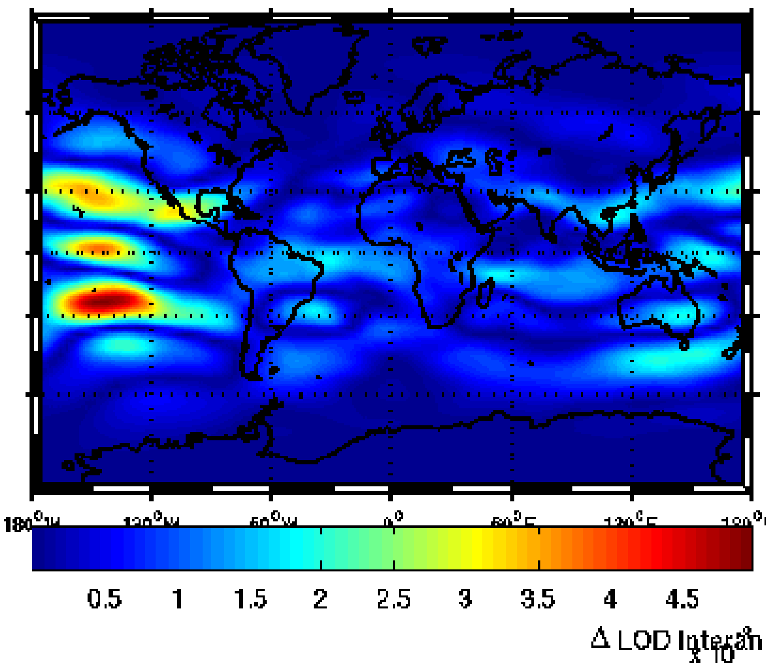


Covariance / correlation between regional axial AAM and global term (filtered to subseasonal variations)

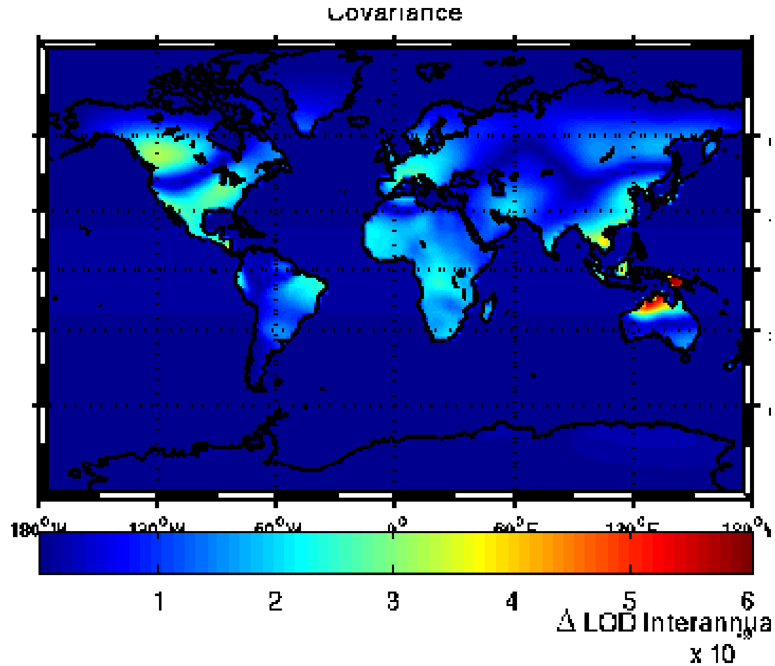
3: How Can ERPs Inform the Model?

Spatial Covariances

Wind Term



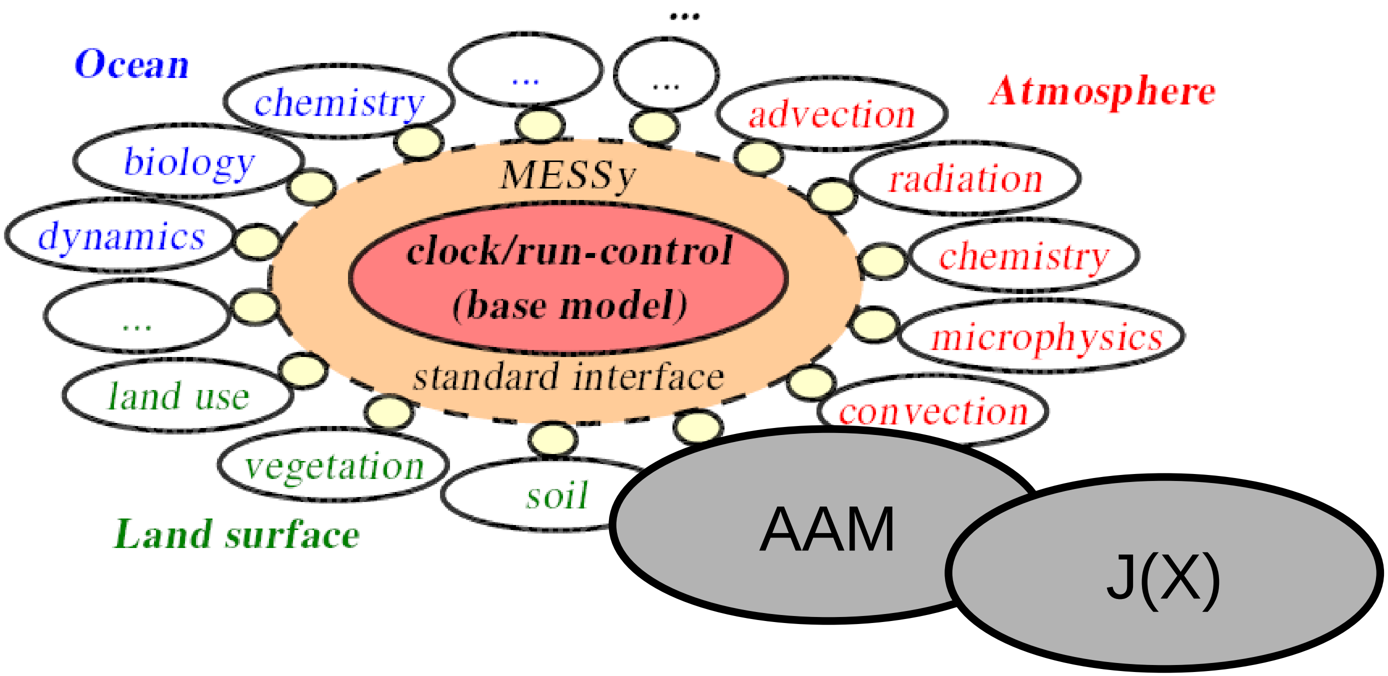
Mass Term



Interannual Timescales (1-6 months)

4. Towards an ERP Data Assimilation System

The Modular Earth Submodel System (MESSy) – Joeckel et al., 2005.



Submodel AAM: periodically compute observation increment.	**Submodel J**: compute costfunction

Eventually evolve into Variational or Sequential DAS.

5. Summary & Outlook

Summary

- AAM is a global measure of atmospheric variability.
- Model-obs misfit on various timescales related to respective phenomena.
- LOD most directly influenced by atmosphere.
- There exist local correlations, making DA possible.
- Development of MESSy submodel AAM (ongoing)

Challenges

- Assimilation of a global integral to improve state variables.
- Selection of data assimilation algorithm – which is best for the above?
- Implementation of algorithm in parallel computing environment
- Separating out other sources of AM (ocean, core-mantle interaction), especially in polar motion.

References

Joeckel et al., 2006: The atmospheric chemistry general circulation model ECHAM5/MESSy: Consistent simulation of ozone from the surface to the mesosphere. *ACP* 6: 5067-5104.

Morgenstern et al., 2010: Review of the formulation of present-generation stratospheric chemistry climate models and associated external forcings. *JGR*, In press.

Dickey et al., 1991: Extratropical aspects of the 40-50 day oscillation in length-of-day and atmospheric angular momentum. *JGR* 96: 22643-22658.

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