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LOD – An Independent Indicator for Climate Variability & Change ?

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Abstract

This study assesses whether trends in the length-of-day (LOD) have occurred in concert with observed changes in atmospheric hemispheric circulation patterns since any change in the wind-driven axial atmospheric angular momentum (AAM(w)) results in variations of the LOD. For this purpose we examine the low-frequency behavior of the LOD excited by large scale atmospheric circulation patterns using ERA40 reanalysis data (1962-2004). Since the El Niño/Southern Oscillation (ENSO) is the most important coupled ocean-atmosphere phenomenon to cause global climate variability on interannual time scales, we correlate observed changes in the strenght of the interannual LOD signal with ENSO sensitive parameters (SST, AAM(w), SOI, MEI, NINO3.4) to explore the relative influence of the ocean and atmosphere on the LOD during ENSO events. Strong correlations between changes of the interannual amplitude of the LOD and ENSO sensitive parameters demonstrate a significant relation between interannual LOD variability and the ENSO phenomenon. However, our analysis also suggests that the influence of ocean and atmosphere on the LOD signal varies highly. Observations suggest that during warm phases of ENSO diabatic heating in the eastern tropical Pacific associated with El Niño amplifies the generation of the Rossby wave train over North America carrying over to observed enhanced patterns of the Pacific North America teleconnetion (PNA). To further explore this relation, we examine the meridional transport of the AAM(w) to the northern hemisphere. As a result the largest momentum transport of AAM(w) can be observed around 30°N associated with strong PNA-like patterns over North America.

Webpage Earth Rotation Portal: *http://www.erdrotation.de (Project P10)*

Data & Methods

Times Series & Fields

- **Length-of-Day (LOD):** IERS EOP C04
- **Atmospheric angular momentum (AAM(w)),** computed using wind data from ERA-40 reanalysis, ECMWF.

$$M_{rel} = \frac{R^3}{g}\int_{1}^{1000}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}}\int_{0}^{2\pi} u\cos^2(\varphi\varphi)\,d\lambda\, d\varphi\, d$$

(Barnes et al., 1983, Proc.Roy.Soc., London, A, 387, 31-73)

ENSO Indices:

- **SOI** -Southern Oscillation Index: surface pressure difference Tahiti - Darwin)
- **NINO3.4** (Sea Surface Temperatures and associated anomalies)
- **MEI** (Multivariate ENSO-Index)

PNA Index:

0.25*[Z(20N,160W)]-Z(45N,165W) +Z(55N,115W)-Z(30N,85W)],
Z = stand. 500hPa geopotential height

(Wallace & Gutzler, 1981, Mon. Wea. Rev., 109, 784-812)

Correlation (Pearson)

Comparison of LOD and AAM with ENSO indices globally integrated over a time period from 1962 to 2001.

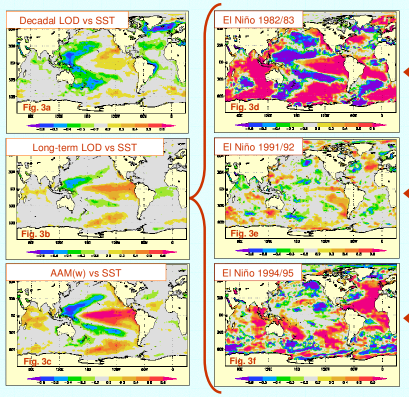
	-SOI	NINO3.4	MEI	AAM
LOD	0.46	0.51	0.58	0.71

(Significance level 99%).

The mean annual cycle has been removed from all time series. Also, long-term variations in LOD time series were filtered out (cut off period: 96 months).

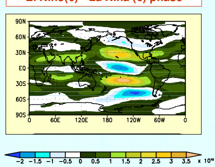
Correlations LOD-SST (1981-2001) & AAM(w)-SST (1981-2004)

- **Decadal LOD variability (Fig. 3a) correlation with SST (Reynolds & Smith, 1994, J.Clim., 7, 929-948) reveals ENSO pattern and decadal variations in the Atlantic.**
- **Correlation with SST and long-term LOD and AAM(w) variability (Fig. 3b&c) reflects clearly ENSO pattern.**
- **'82/83 El Niño: Correlation pattern reveals a high oceanic contribution to long-term LOD variability (Fig. 3d), while correlations for other ENSO events do not clearly reflect this pattern.**



Calculations and plots via Web tool 'Climate, Explorer' http://climexp.knmi.nl)

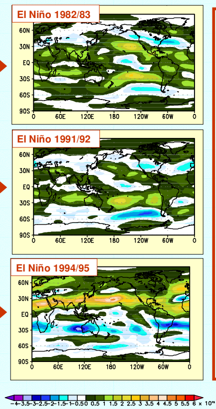
AAM(w) Composites – ENSO events



(NINO3.4 SSTs differing from its mean for at least ± 0.5°C over 5 months.)

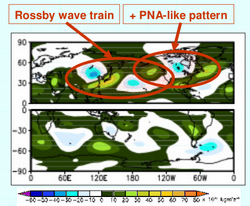
- **Central equatorial Pacific: negative anomalies representing enhanced trade winds during La Niña.**
- **Subtropical Pacific: positive anomalies are associated with an intensification of the subtropical jet during El Niño events.**

Composites of selected El Niño anomalies and climate average



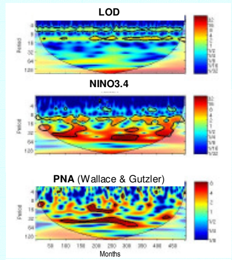
- **The El Niño '82/83 event reveals a spatial distribution similar to the all-El Niño anomaly in Fig. 3d, indicating that both, atmosphere and ocean effect significantly the LOD variability.**
- **The El Niño '91/92 corresponds well to atmospheric patterns. Considering the missing El Niño signal in Fig. 3e, processes associated with atmospheric anomalies might dominate this event.**
- **For the El Niño '94/95 correlations between SST and LOD (Fig. 3f) as well as this composite for El Niño anomalies show arbitrary signals. Processes affecting the LOD variability need to be further investigated.**

Meridional AAM(w) Transport Composite for El Niño

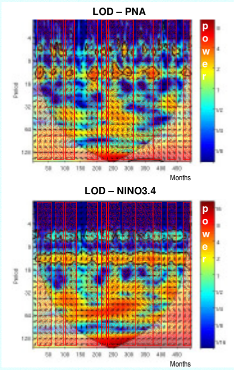


- **Positive numbers describe meridional AAM(w) transport to the northern hemisphere during all-El Niño (1962-2001) while for the southern hemisphere opposite signs are shown.**
- **During El Niño strong meridional AAM(w) transport is observed to the northern hemisphere enhancing the Rossby wave train. Rossby waves can be associated with patterns similar to a positive Pacific North America Oscillation (PNA) correlated with precipitation departures over North America (not shown here).**

Cross Frequency Analysis (Wavelets)



Continous wavelet power spectra for LOD (top), NINO3.4 (center) and PNA (bottom) times series. Black contour: 5% sign. level against red noise. Lighter shades: edge effects.



El Niños; ´63-´66, ´68-´70,´72-´73, ´76-´78, ´79/´80, ´82/´83, ´86-´88, ´90-´93, ´94/´95, ´97/´98, ´02/´03.

Cross frequency analysis:

- **Annual band LOD – PNA: high common power for each of the observed El Niño events.**
- **Annual band LOD - NINO3.4: high common power regardless of any ENSO event.**

Phase relation: In-phase => arrows pointing right; anti-phase => arrows pointing left; arrows pointing straight down => PNA and NINO3.4 leading LOD.

Red bars mark observed El Niño events between 1962 to 2002.

(Matlab software by Grinsted et al., 2004: Nonlin.Proc.Geophy., 11, 561-566).

Findings & Outlook

Results of this study demonstrated so far an highly variable influence of ocean and atmosphere related to ENSO events on LOD and AAM(w) variability reflected in:

- **High correlation coefficients (r>0.6) between LOD and SST for the ENSO event 1982/83 indicating oceanic influence on the LOD variability.**
- **Atmospheric effects on LOD indicated on anomaly composite for ENSO event 1991/92.**
- **Maximum momentrum transport of AAM(w) during El Niño events generates strong PNA-like cells over the North America region.**
- **Prominent frequencies of high common power for LOD and PNA variability on an annual scale during 1962 to 1997 and for LOD and NINO3.4 from 1962 to 2002 corresponding to correlation results between long-term LOD-SST.**
- **Prominent frequencies of high common power for LOD and PNA and LOD and NINO3.4 for 4-6 year oscillations (1982 to 1989).**
- **Annual band displays common power in LOD and NINO3.4 variability for complete time period (95% sign. level) regardless of any observed ENSO event. LOD-PNA variability shows common power for each observed El Niño event within the annual band (95% sign. level).**
- **Our results suggest that observed variations in the amplitude of the LOD signal can be used as an indication for changes in the low- and high frequency spectrum of hemispheric circulation systems led off by warm ENSO events. The analysed statistical relation between LOD as an independent parameter and ENSO sensitive variables (i.e. SST) emphasizes the use of LOD as a potential climate indicator**
- **Ongoing investigations focus on underlying processes and mechanisms (e.g. momentum transport) to reveal causes of this inter-ENSO variability.**