

# Relationship between solar activity, Earth rotation and atmospheric angular momentum

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## INTRODUCTION

Variability in both atmospheric angular momentum (AAM), an index measuring the dynamic state of the general circulation of the atmosphere, and in length-of-day (LOD), a measure of the Earth's rotation rate, both connected through conservation in the global momentum budget, is investigated for a possible connection with Solar Activity (SA).

Analyzing AAM, a useful indicator of the strength of the entire atmospheric circulation, allows an unprecedented opportunity to test and understand solar-atmosphere connections. It contains interannual signals, like the Southern Oscillation Index (SOI), the quasi-biennial oscillation (QBO), as well as decadal signals. The present work explores relations between SA and AAM. This study covers decadal and interannual scales.

A basic aspect of atmospheric dynamics relates to how momentum is maintained locally or transported from one region to another and exchanged with the oceans and solid Earth below. Its conservation properties are closely linked with those of energy conservation. It is therefore a fundamental circulation index used to characterize the dynamic state of the general circulation of the atmosphere and climate (Peixoto and Oort, 1992).

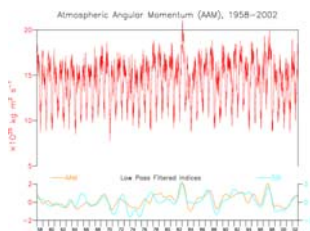
In addition, its knowledge is also important for space geodesy and interplanetary navigation, since AAM is highly correlated with LOD variations, a measure of the Earth's rotation rate (see review by Eubanks, 1993, and figs. below) on sub-decadal time scales. (On decadal scales, much of the LOD variability derives from signals internal to the Earth.) AAM data can be expressed in millisecond (ms) of equivalent length of day (LOD) variability.

## METHODOLOGY

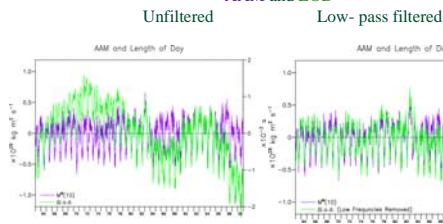
At decadal time scales this study investigates the variability in AAM from the NCAR/NCEP reanalyses, 1948-2002, and it is completed by the analysis of the AAM from runs of the NCAR and UKMO models, each of which simulated the atmospheric variability for 1860-2000. Those results are confirmed by the analysis of longer time series, sea surface temperature (SST) and global surface temperature (GT) over 1700-2000.

At interannual time scales we present results regarding association between the decadal cycle in solar activity and the amplitude and phase of the stratospheric QBO; we also investigate the relationship between the QBO in the solar cycle and the stratosphere. This study uses AAM from the NCAR/NCEP reanalysis over 1948-2002.

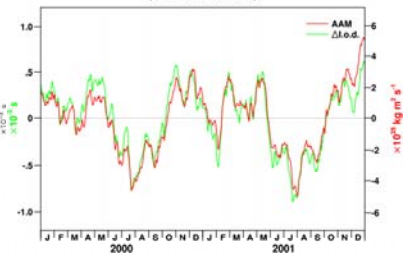
AAM and SOI



AAM and LOD



Atmospheric Angular Momentum and L.o.d. (mean terms removed)



## DATA

### Atmospheric Angular Momentum (AAM)

AAM about the polar axis is calculated by integration of zonal winds from the NCEP Reanalysis. We constructed a set of monthly global AAM from January 1949 to December 2000 from winds on  $2.5^\circ \times 2.5^\circ$  latitude-longitude grid over 17 layers from 1000 to 10 hPa. We computed AAM data sets, from the UKMO and NCAR model run forced by sea surface temperature fields (GISST over 1870 to 1997).

### Length of day (LOD)

LOD data are taken from the compilation of the International Earth Rotation Service (IERS annual report, 2000) based on a combination of astrometric and space-geodetic methods: from 1700 to 1830, at annual resolution; from 1830 to 1949, seasonally; and from 1949 to 2000, monthly.

### Solar Activity (SA)

The Wolf sunspot numbers (the WSN) is an index of solar activity (SA); here it is monthly, 1700 - 2000.

### Sea Surface Temperature (SST) and Global Surface Temperatures (GT)

We also analyze the equatorial SST variability from year 1730 up to 1980, taking advantage of the recent annual reconstructed (marine + land) fields by Mann et al. (2000). We also investigate the Kaplan et al., (1998) monthly fields of sea surface temperature from 1856 to 2000, and construct the Kaplan20 and Mann5 series: Kaplan20 is global average (all oceans) from  $20^\circ\text{S}$  to  $20^\circ\text{N}$  from SST anomaly fields from 1855 to 2000 on  $5^\circ \times 5^\circ$  latitude-longitude grid. The Mann5 time series is from  $5^\circ\text{S}$  to  $5^\circ\text{N}$ , and available annually from 1730 to 1980 on  $5^\circ \times 5^\circ$  latitude-longitude latitude-longitude grid. We will also use the global temperature (marine + land) time series (Mann et al., 2000), 1700 to 2000, named GT.

AAM - Reanalyses

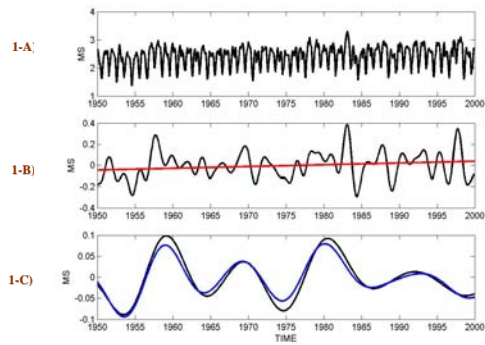


Fig 1A: AAM from NCAR/NCEP reanalyses, 1950 to 2000.

Fig 1B: AAM data is low-pass filtered to remove the seasonal cycle and high frequencies. Trend (red line) may be related to global warming.

Fig 1C: AAM detrended and low-pass filtered include signals >8 years. The blue and black lines are for the troposphere (up to 100 hPa, blue) and whole atmosphere (to 10 hPa, black); the decadal signal is clear.

Power Spectra of AAM

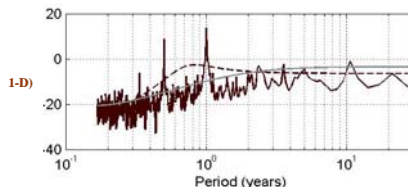


Fig 1D: power spectrum of AAM captures decadal signal—whole atmosphere, to 10 hPa, covered. Decadal cycle in AAM to different heights

Height (hPa)	Amp (%)	Lag (months)
10	0	0
50	93.2	-2.5
100	80.6	-3
200	60.4	-3.5
500	31.6	-4
850	6.3	-4.5

Quasi-biennial (QB) variability

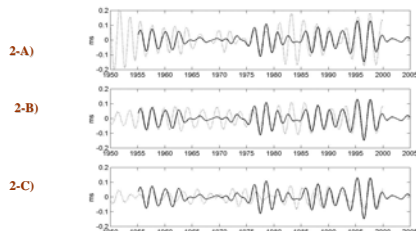


Fig 2A: QB cycle in Solar Activity (bold line) and LOD (dash line).

Fig 2B: ... and with stratospheric AAM (dash line)

Fig 2C: ... and with tropospheric AAM (dash line). [All AAM series lagged by 6 years towards the SA.

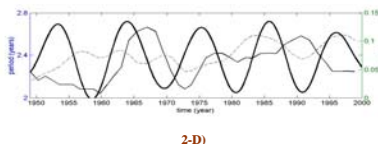
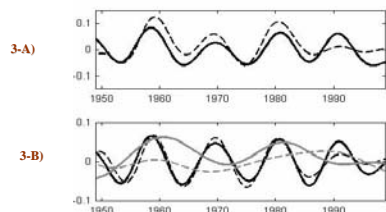


Fig 2D: a comparison of AAM stratospheric QB parameters: period (solid line) and amplitude (grey dashed line) with inverted decadal cycle in SA (bold solid line). SA is dimensionless.

Decadal cycle

In AAM Reanalyses (1949-2000)



Comparison of SA (bold line) and LOD (dashed line):

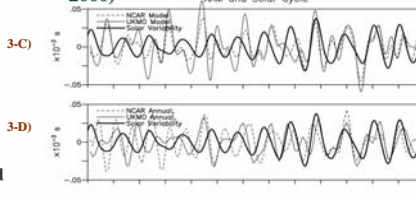
Fig 3A: low-pass filtered, >8 years.

Fig 3B: pass filtered (8-to-16 years) indicates a nearly perfect match. Also >16 years (grey and grey dashed lines, for SA and LOD, resp.).

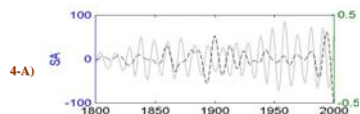
Fig 3-C: AAM in NCAR (dashed) and UKMO (solid) model simulations with SA (bold solid), band pass filtered 8-13 years.

Fig 3-D: Amplitude of annual cycle of above simulations.

In AAM from two model runs (1870-2000)



In LOD



Here SA variability in grey line; all band-passed decadal, compared with:

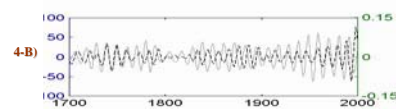
Fig 4-A: LOD

Fig 4-B: Global Surface Temperatures.

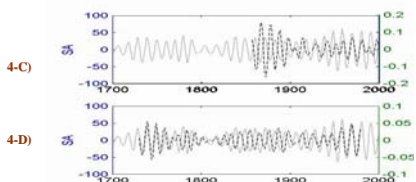
Fig 4-C: SST Kaplan20 time series

Fig 4-D: Mann5 time series.

In Global Surface Temperature



In Sea Surface Temperature



1. Terrestrial and SA quantities on decadal time scales

Decadal cycles in global AAM (from reanalyses) and SA have no significant phase shift with each other (last 50 years).

UKMO and NCAR simulations: at the turn of the 20th century out of phase with the Schwabe cycle, and thus in phase with each other.

SST series, Kaplan20 (1856-2000) and Mann5 (1730-1980) lag solar activity since 1930 but out of phase prior to about 1900; however, partial agreement was present during the mid 18th century. Global surface (land + marine) temperature reconstruction by Mann et al., (2000) back to 1700 has agreement with the above.

Other measurements (SST, GT, AAM, LOD) confirms the out-of-phase lag of the climatic decadal variability at the turn of the 19th to the 20th century, as well as the partial agreement over the last 50 years, which therefore may be coincidental.

CONCLUSIONS

2. Origin of the Decadal Cycle in the Atmosphere

The decadal cycle in AAM from the reanalysis can originate in surface processes, as the troposphere leads the stratosphere. This oscillation in the global atmosphere (troposphere and stratosphere) may thus be generated by upward propagation of surface atmospheric modes, from the surface through the troposphere and then through the stratosphere.

AAM represents the dynamic state of the global atmosphere, but does not show full association with the Schwabe cycle. Such decadal stratospheric vacillations associated with the solar cycle may not have been evident in all past times.

However, AAM and LOD are not strongly connected on decadal scales, as in higher frequency scales; angular momentum at these scales involve signals internal to Earth.

3. Quasi-biennial oscillations (QBO)

Decadal cycle in solar activity and amplitude/phase of stratospheric QBO

We examined the QBO in AAM over the stratosphere, mostly in the stratosphere (the s-QBO). A fuller analysis shows a lag between those decadal oscillations, though it varies slightly from about 3 years in 1965 to 5 years in 1995.

QBO in solar activity and QBO of stratospheric QBO

The QBO in the stratospheric AAM presents a phase variability lagged by 6 years (73 months) regarding the QB cycle present in solar activity. Consequently, we might consider that the atmosphere is affected by solar activity at this scale. This large lag needs further investigation.

Main reference, including collection of citations: Abarca del Rio et al., 2003; Solar activity and Earth rotation variability, *J. Geodynamics.*, 36, 423-443.