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Short Communication

An evidence for atmospheric exciting seasonal fluctuations of length-of-day change in Madras of India

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Seasonal fluctuations, especially annual fluctuations, are remarkable oscillations in Length-of-Day (LOD) change. Using atmospheric pressure observational series in Madras, India, with the wavelet transform, this study investigates atmospheric excitation of the LOD change on seasonal time scales. The study shows that seasonal fluctuations in LOD changes relate to atmospheric pressure variation. This confirms that the atmosphere largely excites the LOD change on seasonal time scales.

[**Keywords**: Atmospheric pressure, Length-of-Day change, Seasonal fluctuations, Wavelet transform]

Introduction

Theoretical studies and astronomical observations have confirmed that the Earth's rotation exhibits inherent variability. This rotational variability manifests through fluctuations in the Length-of-Day (LOD), polar motion, precession, and nutation. These phenomena originate from gravitational torques exerted by celestial bodies, including the Sun, the Moon, and planets, internal mass redistributions within the Earth system, as well as additional excitation mechanisms. Variations in Earth's rotation may reflect interactions among the solid Earth, atmosphere, and ocean. Variations of the LOD change manifest across diverse temporal scales, ranging from sub-daily intervals to geological epochs. Some studies showed that non-tidal changes in the LOD change on synoptic to interannual timescales exhibit significant correlations with variations in the atmospheric angular momentum[1-4]. Seasonal fluctuations are the most pronounced component of LOD change. Prolonged instrumental records of climatological parameters, even those derived from individual terrestrial locations, yield valuable insights into systemic climate dynamics within the Earth system. Analysis of historical atmospheric pressure measurements obtained at Madras and proximate meteorological stations in southern India provides critical empirical constraints for investigating these phenomena. Allan *et al.*[5] recovered a monthly atmospheric pressure observation series in Madras from January 1796 to March 2003. To investigate the effect of atmospheric excitation on LOD change, the study used the wavelet transform to examine atmospheric pressure in Maras, with emphasis on seasonal time scales.

Materials and Methods

Description of the LOD series

The Earth Orientation Centre of the International Earth Rotation Service (IERS) provides the Earth Orientation Parameters (EOP) time series designated as IERS C04. During the 1960s and 1970s, the LOD data were primarily derived from classical optical astrometric observations. Since the 1980s, modern space geodesy techniques have become the principal source for LOD determinations, offering significantly enhanced precision. This work used the LOD time series from January 1, 1962 to July 20, 2025. To investigate atmospheric excitation effects on LOD variations, zonal tidal contributions from solid Earth deformation were removed following the IERS Conventions 2000 protocols. The resulting detrended series is commonly termed "LODR". The daily LODR series is averaged using a simple mean, yielding a series with a one-month interval, the same as the atmospheric record. The corresponding monthly LODR time series is presented in the lower panel of Figure 1.

Wavelet analysis

As a powerful tool for analysing non-stationary signals, the wavelet transform provides superior localisation in both the time and frequency domains and is adaptive to high- and low-frequency signals. It can obtain both contour features and detail features of the time series. By using wavelet functions to decompose signals, multiple components can be obtained, each corresponding to a different frequency and time range[6-10]. Here, we examine the possible

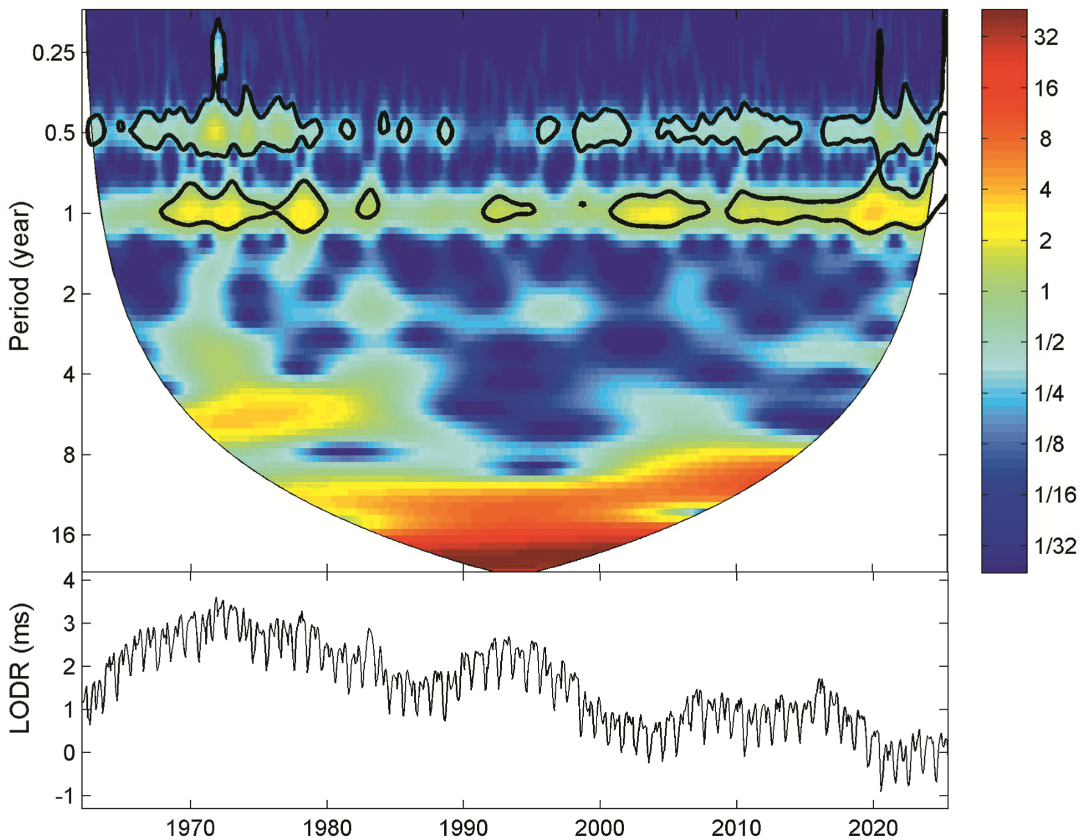

Fig. 1 — The LODR series (lower) and its continuous wavelet power spectrum (upper), January 1962 to July 2025. The thick black contour designates the 5 % significance level against red noise, and the Cone of Influence (COI), where edge effects might distort the picture is shown in a lighter shade

connection between the LODR change and atmospheric pressure in Madras (hereinafter, shortened as APM), especially exploring seasonal fluctuations in the two time series.

The Continuous Wavelet Transform (CWT) of the LODR time series is presented in the upper panel of Figure 1. Prior to wavelet transformation, the time series was normalised to have zero mean and unit standard deviation. The black closed curve shows the 5 % significance region. Prominent oscillatory characteristics manifest as significant peaks at seasonal timescales, exceeding the 5% significance threshold. The seasonal fluctuations, including annual and semiannual components, exhibit temporal variation. The periodic signal is remarkable from about 1970 to 1980 and from about 2000 to 2025.

The APM time series and its CWT are shown on the lower panel and the upper panel of Figure 2, respectively. The series has also been normalised before the wavelet transform is performed. It’s well known that seasonal fluctuations occur in some geophysical processes of the Earth's system. Atmospheric pressure variation is no exception. From Figure 2, the obvious oscillation in the APM time series is an annual change, exceeding the 5 % statistical significance level against red noise throughout the period from 1796 to 2003. The signal has always been very strong during the whole time span.

The CWT presents challenges in identifying potential connections between the LODR and APM time series. In this work, we make use of the cross wavelet transform (XWT) to analyse the possible connection. Figure 3 shows the XWT of the two time series. With the XWT, common features have been observed that are not present in the individual wavelet transform. In the figure, remarkable association signals exist in the LODR and the APM series at annual time scales over almost the entire period, with significance above the 5 % level. These results suggest a robust connection between LODR and APM as indicated by the cross-wavelet power spectra.

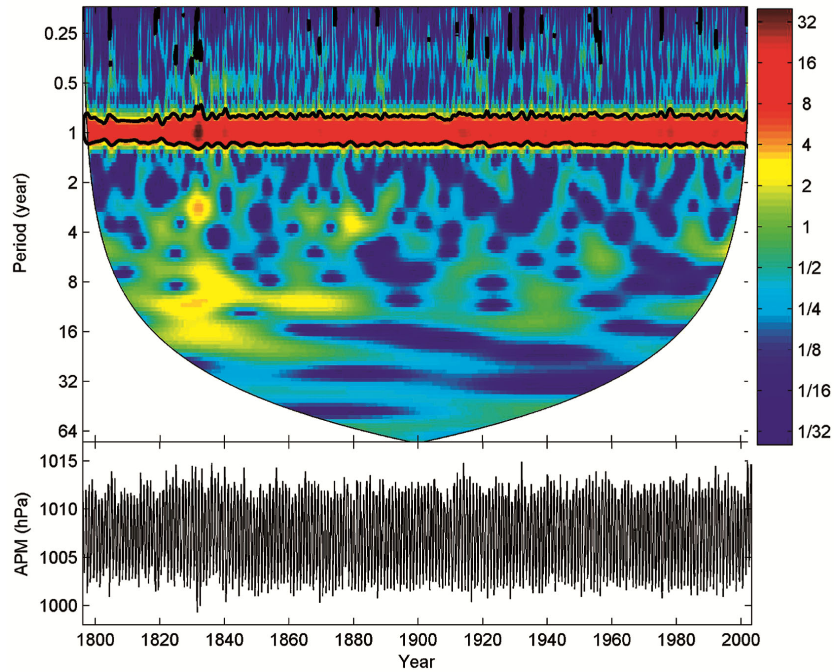

Fig. 2 — The APM (lower) series and its continuous wavelet power spectrum (upper) from January 1796 to March 2003. Explanation of the figure is similar to Figure 1

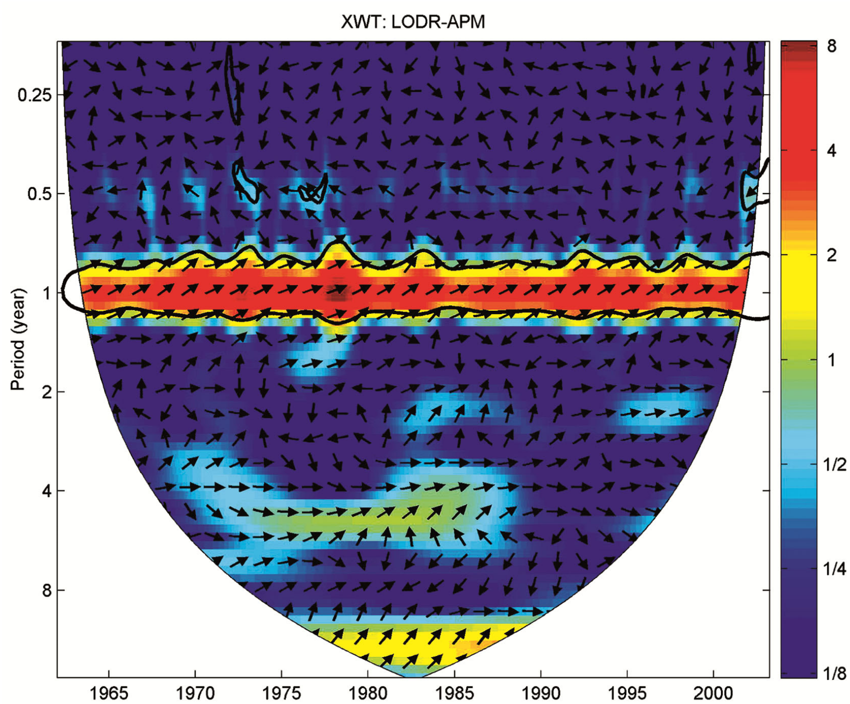

Fig. 3 — Cross wavelet transform of the LODR and APM series from January 1962 to March 2003. The 5 % significance level against red noise is shown as a thick contour. The relative phase relationship is shown as arrows

Furthermore, the phase difference between the LODR and the APM is calculated. The complex phase distribution, visualised using directional arrows in Figure 3, reveals that rightward-pointing arrows indicate positive correlations between the two time series, while leftward-pointing arrows denote inverse correlations. Vertical arrows represent leading/lagging relationships between the temporal sequences. As shown in Figure 3, excitation signals originating from the APM exceed the 5 % significance threshold, particularly at annual timescales. The LODR activity consistently lags behind the APM throughout the entire observation period.

Results and Discussion

Seasonal fluctuations, especially annual fluctuations, are remarkable oscillations in the LOD change and atmospheric pressure observations in Madras, India. The cross-wavelet transform analysis reveals a robust correlation between these two parameters, with wavelet techniques further demonstrating that atmospheric pressure drives the annual fluctuations in LOD changes. During the whole period, the LODR activity lags behind the APM, especially on annual time scales.

The principle of angular momentum conservation necessitates differential variations across distinct layers of the coupled Earth system. When atmospheric subsidence occurs, atmospheric angular momentum decreases, and the solid Earth's angular momentum increases, so the Earth's rotation rate slows. Finally, the LOD change becomes longer. It is likely that atmospheric pressure is a factor in advancing the LOD change. Meanwhile, a semiannual change link between the LOD and atmospheric pressure observations is also noted, with a significance level below 5 %. However, it is an anti-relationship, unlike an annual change. The detailed physical mechanisms underlying these phenomena will be presented in a forthcoming extension of this study.

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Conflict of Interest

The authors of this paper declare no competing or conflicts of interest.

Author Contributions

LM: Manuscript writing, performed wavelet transform and drew the corresponding figures. WK: Performed wavelet transform and verified analysis results. YH: Contributed to the conceptualisation of the study, data collection and interpretation of results.

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