PROCEEDINGS OF SCIENCE

Precipitation periodicities in Saudi Arabia and its possible link to solar activity

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The study of solar activity and its possible link to climate variability is of great importance to the scientific community. Several studies have been performed to examine the effect of solar activity on meteorological variables including precipitation. Studying periodic changes in meteorological and atmospheric variables is a common method for studying the relationship between these variables and solar activity.

In this study, power spectral analysis was used to examine the periodicity of precipitation data in Saudi Arabia between 1985 and 2019. In addition, sunspot, radio flux at 10.7 cm, ENSO 3.4 index, and cosmic ray data for the same period as the precipitation data were used to search for common cyclic variations and periodicities consistent with those found in the precipitation data. Several common periodicities are observed in the spectra of the precipitation data and variables considered. Several common periodicities were detected, such as the 1-year, 1.5-1.66 years, 2.08 years, 2.58 years, and 3.08 years periodicities. This evidence suggests that solar activity somehow has a potential impact on rainfall and climate change in Saudi Arabia.

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1. Introduction

Rainfall patterns in Saudi Arabia are highly variable, with some regions receiving more precipitation than others, often in short and intense bursts. This variability is influenced by the country's topography and location, with coastal regions and southwestern mountain ranges receiving more rainfall than interior arid regions. Recent years have seen significant changes in rainfall patterns, including prolonged droughts and more frequent and intense rainfall events, which have been attributed to a range of factors such as climate change, natural climate variability, and human activities [1]. While the potential influence of solar activity and cosmic rays on rainfall patterns has been suggested, the precise nature and strength of their relationships remain uncertain and subject to ongoing research[2-5]. Many studies have investigated the relationship between solar activity and rainfall patterns, which have yielded mixed results regarding the potential correlations between solar activity, cosmic rays, and rainfall patterns in different regions of the world [6-14]. The relationship between solar activity and its impact on rainfall remains a subject of ongoing research, with some studies suggesting a potential correlation while others have found weak or non-significant associations [8-11].

The objective of this study is to explore the relationship between precipitation and solar activity by examining the common periodicities between rainfall patterns in Saudi Arabia and solar activity parameters. By identifying potential associations between rainfall and solar activity parameters, this study aims to contribute to a deeper understanding of the intricate relationships between solar activity and rainfall periodicities.

1. Data and methodology

To carry out this study, rainfall data from 19 weather stations in Saudi Arabia provided by the Ministry of Environmental Protection were used (Figure 1). The selection of these stations was based on their location, topography, and historical record, covering a wide area of the country from east to west and north to south. The southeast Rub al Khali desert was excluded due to the lack of rainfall data in that area.

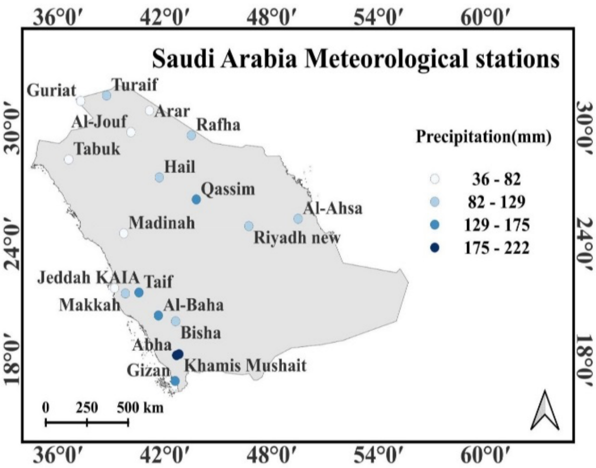

Figure 1. Shows the geographical coordinates of the sites considered in this study. The range of the mean annual precipitations is indicated.

Monthly mean rainfall data from the selected stations were averaged to obtain annual rainfall data. The data underwent quality control procedures, including the nonparametric Kruskal-Wallis test to assess data homogeneity and eliminate random errors found in the original data[15]. Linear interpolation methods were used to fill gaps caused by missing data.

Sunspot numbers, radio flux at 10.7 cm, ENSO 3.4 index, and cosmic ray count (CR) data for the study period were obtained from the National Oceanic Atmospheric Administration, the National Geophysical Data Centre, the National Space Weather Prediction Centre in the USA, and the Sodankyla Geophysical Observatory of the University of Oulu, respectively.

The procedures followed in calculating the power spectra presented in this study are similar to those reported in [e.g., 15-18]. The power spectra were obtained by applying Fast Fourier Transform (FFT) technique with the Welch window method to the time series of monthly measurements from all the considered variables. This method allows us to obtain the strong periodicities across the whole frequency range. For revealing the local quasi-periodicities in the spectra for the frequency range around these strong periodicities we have used the technique of minimum variance as described in [16 and references therein]. The significances of the obtained peaks were calculated using the AutoSignal peak-based critical limit procedures. In this type of tests, one seeks to disprove the null hypothesis where one postulates either a white noise signal (AR(1)=0.0), or a red noise signal (AR(1)>0.0). All the obtained peaks considered in this work are above the 99 % confidence level.

1. Results and Discussions

Figure (2) provides an example that illustrates the inter-annual variability of the mean rainfall in the country and radio flux (f10.7 cm), with the inclusion of a 12-month running mean. The data reveals distinct 11-year cyclic patterns in the f10.7 cm, with peaks during the maximum of solar cycles and a minimum during quiet periods. In contrast, the rainfall variations during the study period exhibited variability from cycle to cycle. These observations underscore the influence of solar activity on the variability of climate patterns, particularly with regards to precipitation.

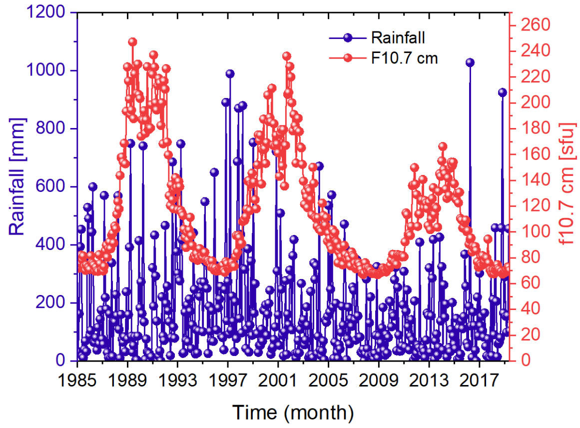

Figure 2. Displays a time series of the monthly mean values of rainfall data over Saudi Arabia and solar radio flux at 10.7 cm (f10.7) from January 1985 to December 2019.

3.1 Stations rainfall periodicities

Figure (3) provides an example of the Lomb periodogram for the rainfall data, representing the average data from all the considered stations, as well as for the Madina station alone, for the period between 1985-2019. The graphs provide a visual representation of the frequency content of the rainfall data, highlighting the presence of significant peaks that correspond to periodicities. These periodicities were identified by analyzing signals that exceed the 99% confidence limit The periodicities obtained for all the stations, classified based on their locations, are summarized in Table (1).

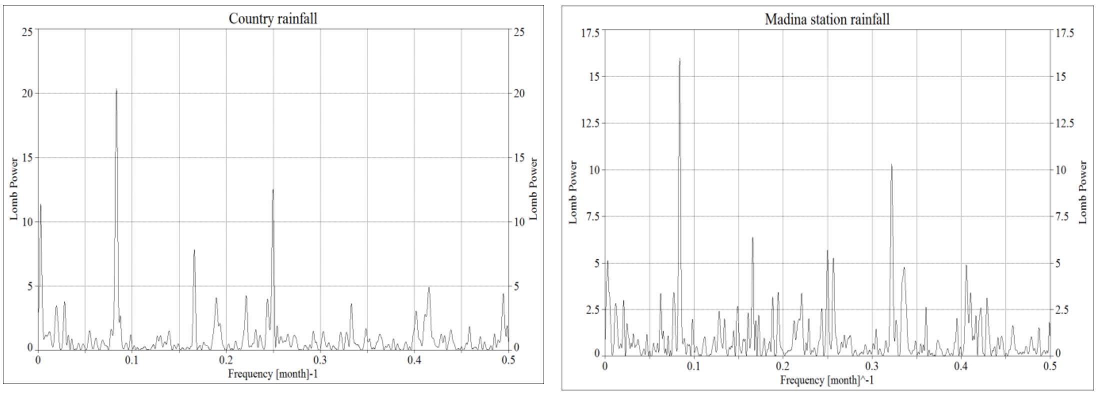

Figure 3. Lomb-Scargle spectra of the monthly mean rainfall time series between 1985-2019. The PSDs were obtained by averaging the mean monthly values from all the considered stations (graph a) and from the Madina site alone (graph b). The Lomb power is in (mag2 /n/var); mag2 is the magnitude-squared of the Lomb spectrum (normalized for spectrum size) at a given frequency, for n dataset size, and for (var) variance of the data series.

Table 1. summarizes the rainfall periodicities for the mean monthly rainfall data from all the considered stations, classified according to their geographical locations in Saudi Arabia. The periodicities were identified for the period between 1985-2019, and the units are expressed in years.

South					North						
Abha	Al-Baha	Bisha	Gizan	Khamis mushait	Al-Jouf	Arar	Guriat	Hail	Rafha	Tabuk	Turaif
0.33	0.25-8	0.25-1	0.33-0.41	0.25-0.33	1-1.16	1	1-1.08	0.58-0.66	1-1.08	0.16-0.25	1-1.08
0.5	10-12	1.33	0.58	0.5	1.83-1.91	1.5	1.5	0.83-1	1.25	1	1.25
1	1.33	1.5-1.66	0.75	0.66	5.25	1.58	2.16	1.16	1.5	1.16	1.5
1.166	1.58	2.66	1.08-1.16	1	7.08	3.08	2.75	1.33	2.58	1.33	2.83
1.41	2	3.08	1.5	1.16			3.08	1.66		1.66	3.08
1.75	4.16	3.91	2.66	1.5				4.08		3.08	4.5
2.41	6.58		4.66	1.91							
2.58				3							
3.83				4.41							
7.75				6.33							
West				Middle			East				
Jeddah	Madinah	Makkah	Taif	Qassim	Riyadh		Al-Ahsa	Country			
1-1.16	0.25-0.33	1-1.08	0.33	0.33	0.33		0.33	0.25-0.66			
1.41-1.5	0.5	1.25-1.58	0.5	0.5-0.66	1		1	0.83			
2.25	1-1.33	2.08	0.83	1-1.08	1.5-1.58		1.5-1.58	1-1.08			
3.66	2.83	3	1	1.25-1.33	2.33		2.33	2.58			
4.5	3.33	4.41		1.5	2.91		2.66	3			
6	4	7.58		3.75			3	4.41			
	6.41			4.58							

The mean rainfall over the entire region showed periodicities ranging from 0.25-0.66 months, 0.83, 1-1.08, 2.58, 3, and 4.4 years. In the southwestern region (Abha, Al Baha, Bisha, Gizan, Khamis Mushait), rainfall periodicities were observed between 0.25-0.33, 0.41-0.5, 0.58-0.66, and 12-14 months (1-1.16 years). Al-Baha, Bisha, and Gizan had periodicities ranging from 0.75-0.91 years, while all southwestern stations, except Abha and Al Baha Bisha, had periodicities between 1.5-1.58 years. Abha showed rainfall periodicity between 1.33-1.41 years, while Bisha, Gizan, and Khamis Mushait had periodicities of 1.5 years. Moreover, Abha had additional periodicities of 1.75, 2.41, 2.58, 3.83, and 7.75 years, while Al-Baha had 2, 4.16, and 6.58 years. Bisha had periodicities of 1.66, 2.66, 3.08, and 3.91 years, while Gizan and Khamis Mushait had 2.66, 4.66, 4.41, and 6.33 years, respectively.

For all northern region stations, rainfall periodicity was observed between 1-1.16 years, with most stations showing periodicities longer than a year, except for Tabuk and Hail, which had periodicities of 0.16-0.25 and 0.58-0.66, 0.83-0.91 months, respectively. Hail, Rafha, Tabuk, and Turaif showed periodicities between 1.25-1.33 years, while Arar, Guriat, Rafha, and Turaif had periodicities between 1.5-1.58 years. Hail and Tabuk had a periodicity of 1.66 years. Guriat and Turaif had periodicities of 2.75-2.83 years, while Turaif, Tabuk, Arar, and Hail had a periodicity of 3.08 years. Additionally, unmatched periodicities were noted, such as 1.83, 1.91, 5.25, and 7.8 years for Al-Jouf and 2.16 years for Guriat. Rafha, Hail, and Turaif had periodicities of 2.58, 4.08, and 4.5 years, respectively.

The western region, which includes Jeddah, Madinah, Makkah, and Taif, had periodicities ranging between 1-1.16 years. Jeddah had periodicities longer than a year, ranging from 1-1.16, 1.41-1.5, 2.25, 3.66, 4.5, and 6 years. For Madinah, shorter periodicities were observed, including 0.25-0.33, 0.5 years, 1-1.33, 2.83, 3.33, and 6.4 years. Taif had periodicities of 0.33, 0.5, and 0.83 months, while Makkah had periodicities of

1-1.08, 1.25-1.58 years, in addition to 2.08, 3, 4.41, and 7.58 years.For the middle region, which has monthly rainfall data for two meteorological stations (Qassim and Riyadh), both showed periodicities of 0.33 and periodicities between 1-1.08 and 1.5 years. Qassim had periodicities ranging from 6-8 months and 1.25-1.33 years, in addition to 3.75 and 4.58 years. Meanwhile, for Riyadh, only 1.58, 2.33, and 2.91 years were noted. Finally, Al-Ahsa station had a periodicity of 4 months in addition to 1, 1.5-1.58, 2.33, 2.66, and 3 years.

Common rainfall periodicities observed across multiple stations in Saudi Arabia include 1-1.16 years, which was observed in most stations, including the entire northern region and the western region. Additionally, periodicities of 1.5-1.58 years were observed in southwestern stations except for Abha and Al Baha Bisha, as well as Arar, Guriat, Rafha, and Turaif in the northern region. Other common periodicities included 2.58 years in Rafha and Abha, 3.08 years in Turaif, Tabuk, Arar, and Hail in the northern region, 4.08 years in Hail in the northern region, and 4.5 years in Turaif in the northern region.

3.2 Solar activity, cosmic rays, and ENSO index periodicities

Figure (4) is an example of the Lomb periodogram for the ENSO index and cosmic rays for the period between 1985-2019. Sevel significant peaks can be identified in this example. By following the same procedures of Lomb –Scragle analyese used to obtain the stations' periodicities, several significant periodicites were identified in the spectra of the solar activity, cosmic rays and ENSO index.

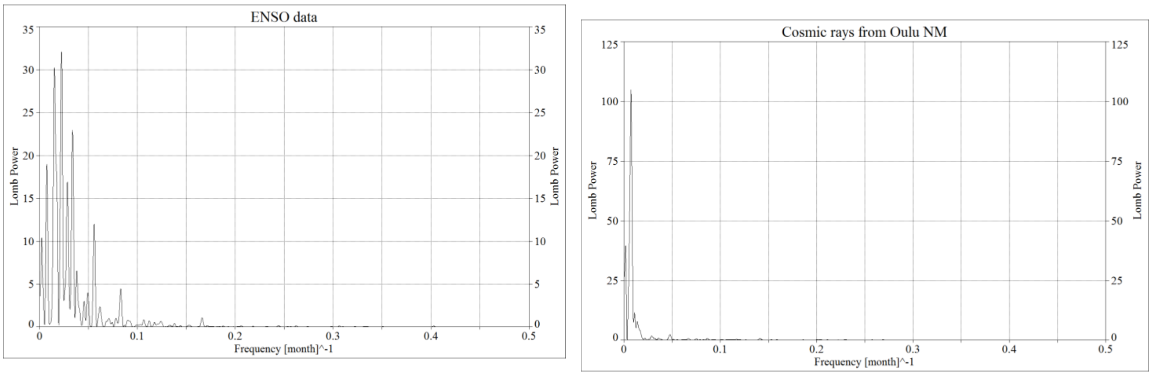

Figure 4. Lomb-Scargle spectra of the monthly mean (a) ENSO index and (b) Cosmic rays time series between 1985-2019.

For the sunspot numbers, periodicities of 5.92, 4.25, 3.25, 2.83, 2.58, 2.08, 1.92, and 1.75 years were observed, in addition to periodicities ranging from 1.5-1.42 to 0.5-0.25 years. Cosmic rays displayed periodicities of 6.08, 5, 4.42, 3.75, 3.25, 2.92, 2.5, and 2.08 years, along with periodicities ranging from 1.92-1.83 to 0.42-0.25 years. Radio flux F10.7 exhibited periodicities of 5.92, 4.92, 4.17, 3.75, 3.25, 2.83, 2.58, 2.08, 1.83, and 1.67 years, as well as periodicities ranging from 1.25-0.75 to 0.58-0.25 years. ENSO had periodicities of 5.5, 4.58, 3.67, 3.17, 2.92, 2.5, 2.17, 2, 1.83, and 1.5-1.25 years, with a periodicity of 1.08 years also detected. All four parameters showed similar or slightly shifted periodicities by 1-2 months. The periodicities for all parameters, including ENSO, ranged from 11.42 to 1.08-1.25 years. In addition, periodicities ranging from 1-0.75 years were found for all parameters except for Nino3.4, which also exhibited periodicities ranging between 0.5-0.66 years and 0.25-0.416 years [e.g., 15-16 and 19-20].

3.3 Discussions

By comparing the periodicities in rainfall data from different stations with those of the sunspot number, cosmic ray, F10.7 cm radio flux, and ENSO data, the study revealed the presence of common periodicities, including the 1-year, 1.5-1.66 years, 2.08 years, 2.58 years, and 3.08 years periodicities. While the one-year periodicity is expected to be of terrestrial origin and is associated with seasonal and climatic variations, the presence of other periodicities consistent with those previously found in the solar activity variables and cosmic rays data [15-20].

Numerous studies have been conducted to investigate the influence of solar activity and associated disturbances on precipitation across different regions worldwide, using various techniques and time spans [6-12 and [21].

1. Conclusion

This study employed power spectral analysis to examine periodic precipitation data in Saudi Arabia from 1985 to 2019. The analysis encompassed sunspot, radio flux at 10.7 cm, ENSO 3.4 index, and cosmic ray data to detect any common cyclic variations and periodicities with the precipitation data. The results disclosed several common periodicities, suggesting a plausible relationship between solar activity and rainfall patterns in Saudi Arabia. However, it is noteworthy that the relationship between solar activity and precipitation patterns is intricate and may differ across various regions. While the observed periodicities provide evidence of a potential link between solar activity and rainfall patterns, the exact mechanisms underlying this relationship are not yet fully understood. Furthermore, factors such as topography, land use, and atmospheric circulation patterns can also affect precipitation patterns, further complicating the relationship between solar activity and precipitation. Consequently, future research should aim to investigate the various factors that contribute to the variability in precipitation patterns and how they interact with solar activity to better comprehend the impact of solar activity on rainfall and climate change in Saudi Arabia.

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