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CHAPTER V

ON THE ASSOCIATION OF SEASONAL RAINFALL VARIATIONS OF INDIA AND KERALA WITH THE SUNSPOT CYCLE

5.1 Introduction

Majority of sun-weather relationship studies belong to the category of the search for the association between sunspot cycle or long term variations in solar activity and terrestrial weather changes (see Chapter 3 of Herman and Goldberg, 1978; Pittock, 1983). Solar electromagnetic radiation, solar wind, energetic particles and coronal mass ejections coming out of the sun and observed near 1 AU has a characteristic dependence on the phase of the sunspot cycle (Gazis, 1996; Storini, 1995). More than 1000 papers has been published in this area since the first half of the 19th century (Herman and Goldberg, 1978). The motivation behind the establishment of the first solar observatory in India at Kodaikanal was to study the association between sunspot activity and monsoon rainfall (Kochar, 1991). There are several reports of the possible influence of sunspot cycle on the annual or monsoon seasonal rainfall over different parts of India (Jaganathan and Bhalme, 1973; Anantha Krishnan and Parthasarathy, 1984; Bhalme and Mooley, 1981; Reddy et.al, 1989; Mohankumar, 1996). Several investigators studied the difference between sunspot cycle-weather
associations during winter and summer for different places in the world (see Chapter 3 of Herman and Goldberg, 1978). However we cannot find studies on the association between rainfall in India during periods other than the monsoon season and sunspot cycle. Further there has been only few attempts to look for reasons behind the existence or absence of sunspot cycle association of rainfall variations in India during different seasons/periods (see 3.3 of Herman and Goldberg, 1978; Pittock, 1983).

In this chapter we will present our investigations on the associations between sunspot cycle and rainfall variations in different parts of India as well as Kerala during the monsoons as well as the non-monsoon seasons separately. Winter rainfall variations in different meteorological subdivisions in India will be studied in particular in relation with the sunspot cycle. Finally we will also attempt to throw some light on the possible cause of the existence / lack of association between sunspot cycle and seasonal rainfall variations for different regions in India.

One application of sunspot weather relation is the following : - If any acceptable association between sunspot cycles and meteorological parameters are obtained for a given place it will help for long range forecasting weather at that place because now we have many techniques of long range predictions of sunspot activity (Obridko et.al, 1994).
5.2 Details of data used

(a) Monthly rainfall data of different meteorological regions and subdivisions including Kerala in India using the uniform and homogenous rain gauges data published by IITM, Pune for the years 1871 - 1994 (Parthasarathy et al., 1995). See Maps given in Fig. 5.1 (a) and (b).

(b) Monthly rainfall data of Trivandrum city (1838-1994) from different sources (Memoirs of IMD, 1899; Mohankumar, 1995).

(c) Sunspot activity data for the period 1830-1994 from solar geophysical data bulletins (Stetson, 1937; Solar Geophysical Data Bulletins).

(d) Dates of onset of monsoon rainfall in Kerala for the period 1891-1997 (Ananthakrishnan and Soman, 1989; Shukla, 1987; Gangadharan, 1998)

(e) Bay of Bengal / Arabian sea depressions related data (Tracks of storms, 1979 and 1996).
Fig. 5.1(a) Map showing different homogeneous meteorological regions of India and corresponding subdivisions (After Parthasarathy et al., 1995)
Fig. 5.1(b) Map showing met subdivisions of India and locations of rain gauge stations for each subdivision (After Parthasarathy et al., 1995)
5.3 Methods Of Data Analysis

(a) Seasonal rainfall data series

From the rainfall data mentioned in 5.2 (a) and 5.2 (b) we have calculated the total rainfall for different met regions/ sub divisions in India including Kerala, Trivandrum City, for the four seasons viz. (i) Winter: January & February (ii) Pre-monsoons: March, April, May (iii) South West Monsoon: June, July, August & (iv) North - East Monsoon: October, November & December.

(b) Dates of sunspot maxima are adopted from the sunspot data for the cycles 13-22 as shown in Table 5.1.

(c) Superposed epoch analysis

We have carried out a superposed epoch analysis of the seasonal rainfall data for different categories of data mentioned above with the sunspot maximum year as the central or 0th day, considering yearly variations around (± 4 years) the same. The long term mean (X) of each category of data is determined for a given season. The percentage deviation of the superposed epoch mean (μ) for a given relative year (within ±4 years) from the sunspot maximum year from the long term mean is then determined i.e.

\[
\text{Percentage deviation from Mean} = \frac{\mu - \bar{X}}{\bar{X}} \times 100 \%
\]
The percentage deviation from mean of rainfall defined above is calculated for Kerala, All India, five meteorological divisions in India and Trivandrum city separately for the four seasons mentioned in Fig. 5.3(a) around ±4 years from the sunspot maxima years given in Table 5.1 during the period 1871-1994. The plots related to this analysis is given in Fig. 5.2 to Fig. 5.8.

We have also calculated decadal rainfall variations for Kerala (See Fig. 5.9) Trivandrum City (see Fig. 5.9 (b)) and All India (see Fig. 5.10) using relevant rainfall data separately for the four seasons. In Table 5.2 we have given maximum deviations of seasonal rainfall among different years around sunspot maximum for different regions in India, All India and Kerala for the period 1871-1990.

We have also carried out a superposed analysis winter season rainfall of (January - February) of 28 other meteorological sub divisions in India around sunspot maximum years for the above period (1871-1990). The results are shown in Fig. 5.11. In Table 5.3 we have given maximum deviations of rainfall corresponding to different meteorological subdivisions in association with the sunspot cycle.
Fig. 5.2 (a) Superposed epoch analysis of rainfall deviations of Kerala during winter season around Sunspot maxima years for the period 1871-1994.

Fig. 5.2 (a) Superposed epoch analysis of rainfall deviations of Kerala during pre-monsoon around Sunspot maxima years for the period 1871-1994.
Fig. 5.2 (a) Superposed epoch analysis of rainfall deviations of Kerala during summer monsoon season around Sunspot maxima years for the period 1871-1994.

Fig. 5.2 (a) Superposed epoch analysis of rainfall deviations of Kerala during retreating monsoon season around Sunspot maxima years for the period 1871-1994.
Fig. 5.2 (b) Superposed epoch analysis of rainfall deviations of Trivandrum city during winter season around Sun spot maxima years for the period 1871-1994.

Fig. 5.2 (b) Superposed epoch analysis of rainfall deviations of Trivandrum city during Pre-monsoon season around Sunspot maxima years for the period 1871-1994.
Fig. 5.2 (b) Superposed epoch analysis of rainfall deviations of Trivandrum city during summer monsoon season around Sunspot maxima years for the period 1871-1994.
Fig. 5.3(a) Superposed epoch analysis of rainfall deviations of All India during winter season around sunspot maxima for the period 1871-1994.

Fig. 5.3(b) Superposed epoch analysis of rainfall deviations of All India during Pre-monsoon season around sunspot maxima for the period 1871-1994.
Fig. 5.3(c) Superposed epoch analysis of rainfall deviations of All India during summer monsoon season around sunspot maxima for the period 1871-1994.

Fig. 5.3(d) Superposed epoch analysis of rainfall deviations of All India during retreating monsoon season around sunspot maxima for the period 1871-1994.
Fig. 5.4(a) Superposed epoch analysis of rainfall deviations of North-West India during winter season around sunspot maxima for the period 1871-1994.

Fig. 5.4(b) Superposed epoch analysis of rainfall deviations of North-West India during Pre-monsoon seasons around sunspot maxima for the period 1871-1994.
Fig. 5.4(c) Superposed epoch analysis of rainfall deviations of North-West India during summer monsoon season around sunspot maxima for the period 1871-1994.

Fig. 5.4(d) Superposed epoch analysis of rainfall deviations of North-West India during retreating monsoon season around sunspot maxima for the period 1871-1994.
Fig. 5.5(a) Superposed epoch analysis of rainfall deviations of West Central India around during winter season sunspot maxima for the period 1871-1994.

Fig. 5.5(b) Superposed epoch analysis of rainfall deviations of West Central India during pre-monsoon season around sunspot maxima for the period 1871-1994.
Fig. 5.5(c) Superposed epoch analysis of rainfall deviations of West Central India during summer monsoon season around sunspot maxima for the period 1871-1994.

Fig. 5.5(d) Superposed epoch analysis of rainfall deviations of West Central India during retreating monsoon season around sunspot maxima for the period 1871-1994.
Fig. 5.6 (a) Superposed epoch analysis of rainfall deviations of Central North-East India during winter season around sunspot maxima for the period 1871-1994.

Fig. 5.6 (b) Superposed epoch analysis of rainfall deviations of Central North-East India during pre-monsoon season around sunspot maxima for the period 1871-1994.
Fig. 5.6 (c) Superposed epoch analysis of rainfall deviations of Central North-East India during summer monsoon season around sunspot maxima for the period 1871-1994.

Fig. 5.6 (d) Superposed epoch analysis of rainfall deviations of Central North-East India during retreating monsoon season around sunspot maxima for the period 1871-1994.
Fig. 5.7 (a) Superposed epoch analysis of rainfall deviations of North East India during winter season around sunspot maxima years for the period 1871-1994.

Fig. 5.7 (b) Superposed epoch analysis of rainfall deviations of North East India during pre-monsoon season around sunspot maxima years for the period 1871-1994.
Fig. 5.7 (c) Superposed epoch analysis of rainfall deviations of North East India during summer monsoon season around sunspot maxima years for the period 1871-1994.

Fig. 5.7 (d) Superposed epoch analysis of rainfall deviations of North East India during retreating monsoon season around sunspot maxima years for the period 1871-1994.
Fig. 5.8 (a) Superposed epoch analysis of rainfall deviations of South Peninsular India during winter season around sunspot maxima years for the period 1871 - 1994.

Fig. 5.8 (b) Superposed epoch analysis of rainfall deviations of South Peninsular India during pre-monsoon season around sunspot maxima years for the period 1871 - 1994.
Fig. 5.8 (c) Superposed epoch analysis of rainfall deviations of South Peninsular India during summer monsoon around sunspot maxima years for the period 1871 - 1994.

Fig. 5.8 (d) Superposed epoch analysis of rainfall deviations of South Peninsular India during retreating monsoon around sunspot maxima years for the period 1871 - 1994.
Fig. 5.9(a) Decadal average rainfall variations of Kerala for the period 1871-1990 for the winter season.

Fig. 5.9(a) Decadal average rainfall variations of Kerala for the period 1871-1990 for pre-monsoon season.
Fig. 5.9(a) Decadal average rainfall variations of Kerala for the period 1871-1990 for the summer monsoon season.

Fig. 5.9(a) Decadal average rainfall variations of Kerala for the period 1871-1990 for retreating monsoon season.
Fig. 5.9(a) Decadal average of annual rainfall variations of Kerala for the period 1871-1990 for different seasons.

Fig. 5.9(b) Decadal average rainfall variations of All India for the period 1871-1990 for winter monsoon seasons.
Fig. 5.9(b) Decadal average rainfall variations of All India for the period 1871-1990 for pre-monsoon season.

Fig. 5.9(b) Decadal average rainfall variations of All India for the period 1871-1990 for summer monsoon season.
Fig. 5.9(b) Decadal average rainfall variations of All India for the period 1871-1990 for the retreating monsoon season.

Fig. 5.9(b) Decadal average of annual rainfall variations of All India for the period 1871-1990 for different seasons.
Fig. 5.10 (a) Decadal average rainfall variations of Trivandrum City for the period 1841-1990 for winter monsoon season.

Fig. 5.10 (b) Decadal average rainfall variations of Trivandrum City for the period 1841-1990 for pre-monsoon season.
Fig. 5.10 (c) Decadal average rainfall variations of Trivandrum city for the period 1841-1990 for summer monsoon season.

Fig. 5.10 (d) Decadal average rainfall variations of Trivandrum city for the period 1841-1990 for retreating monsoon season.
Fig 5.11. Superposed epoch analysis of winter season rainfall deviations around sunspot maxima years for the period 1871-1994 for different meteorological subdivisions in India.
7 Orissa

![Graph showing % deviation from JF mean rainfall against years from sunspot maximum in Orissa.]

8 Bihar Plateau

![Graph showing % deviation from JF mean rainfall against years from sunspot maximum in Bihar Plateau.]

9 Bihar Plains

![Graph showing % deviation from JF mean rainfall against years from sunspot maximum in Bihar Plains.]

Fig 5.11. Continued...
10 East Uttar Pradesh

11 West Uttar Pradesh Plains

13 Haryana

Fig 5.11. Continued...
14 Punjab

17 West Rajasthan

18 East Rajasthan

Fig 5.11. Continued...
19 West Madya Pradesh

Years from Sunspot Maximum

20 East Madya Pradesh

Years from Sunspot Maximum

21 Gujarat

Years from Sunspot Maximum

Fig 5.11. Continued...
22 Saurastra and Kutch

Years from Sunspot Maximum

24 Madya Maharastra

Years from Sunspot Maximum

25 Marathwada

Years from Sunspot Maximum

Fig 5.11. Continued...
26 Vidarbha

Years from Sunspot Maximum

27 Coastal Andra Pradesh

Years from Sunspot Maximum

28 Telengana

Years from Sunspot Maximum

Fig 5.11. Continued...
29 Rayalaseema

Years from Sunspot Maximum

31 Coastal Karnataka

Years from Sunspot Maximum

32 North Interior Karnataka

Years from Sunspot Maximum

Fig 5.11. Continued...
33 South Interior Karnataka

Years from Sunspot Maximum

4. South Assam

Years from Sunspot Maximum

23. Konkan and Goa

Years from Sunspot Maximum

Fig 5.11. Continued...
30. Tamil Nadu
Table 5.1 Years of Sunspot maximum for the cycles 8 - 22

<table>
<thead>
<tr>
<th>Sunspot Cycle No.</th>
<th>Years of Sunspot maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1837</td>
</tr>
<tr>
<td>9</td>
<td>1848</td>
</tr>
<tr>
<td>10</td>
<td>1860</td>
</tr>
<tr>
<td>11</td>
<td>1870</td>
</tr>
<tr>
<td>12</td>
<td>1883</td>
</tr>
<tr>
<td>13</td>
<td>1893</td>
</tr>
<tr>
<td>14</td>
<td>1905</td>
</tr>
<tr>
<td>15</td>
<td>1917</td>
</tr>
<tr>
<td>16</td>
<td>1928</td>
</tr>
<tr>
<td>17</td>
<td>1937</td>
</tr>
<tr>
<td>18</td>
<td>1947</td>
</tr>
<tr>
<td>19</td>
<td>1957</td>
</tr>
<tr>
<td>20</td>
<td>1968</td>
</tr>
<tr>
<td>21</td>
<td>1979</td>
</tr>
<tr>
<td>22</td>
<td>1989</td>
</tr>
</tbody>
</table>

Table 5.2 Maximum Deviations of rainfall around sunspot maximum years for different regions in India and Kerala for the period 1871 - 1990

<table>
<thead>
<tr>
<th>Location</th>
<th>JF. Mean RF (mm)</th>
<th>SS effect (%)</th>
<th>MAM Mean RF (mm)</th>
<th>SS effect (%)</th>
<th>JJAS Mean RF (mm)</th>
<th>SS effect (%)</th>
<th>OND Mean RF (mm)</th>
<th>SS effect (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerala</td>
<td>27.68</td>
<td>0.37.25</td>
<td>390</td>
<td>Nil</td>
<td>1938.3</td>
<td>-3,-13.8</td>
<td>475.24</td>
<td>-2,-22.8</td>
</tr>
<tr>
<td>All India</td>
<td>23.77</td>
<td>0.36.2</td>
<td>93.9</td>
<td>Nil</td>
<td>852.4</td>
<td>+1,11</td>
<td>120.3</td>
<td>-1,-17.2</td>
</tr>
<tr>
<td>NWI</td>
<td>14.5</td>
<td>0.42.6</td>
<td>19.9</td>
<td>Nil</td>
<td>490</td>
<td>-1,-12.2</td>
<td>20.65</td>
<td>0,64.6</td>
</tr>
<tr>
<td>WCI</td>
<td>19.06</td>
<td>0.46.1</td>
<td>43.4</td>
<td>0.30.6</td>
<td>933.2</td>
<td>Nil</td>
<td>84.7</td>
<td>-1,34.8</td>
</tr>
<tr>
<td>CNEI</td>
<td>34.97</td>
<td>0.52.76</td>
<td>72.1</td>
<td>Nil</td>
<td>1002.4</td>
<td>Nil</td>
<td>92.3</td>
<td>-1,18.9</td>
</tr>
<tr>
<td>NEI</td>
<td>44.06</td>
<td>Nil</td>
<td>427.9</td>
<td>Nil</td>
<td>1419.12</td>
<td>Nil</td>
<td>177.6</td>
<td>-1,26</td>
</tr>
<tr>
<td>SPI</td>
<td>20.59</td>
<td>-2,-37.3</td>
<td>135.8</td>
<td>Nil</td>
<td>659.4</td>
<td>Nil</td>
<td>342.2</td>
<td>Nil</td>
</tr>
</tbody>
</table>

*RF: Rain Fall.*
Table 5.3: Maximum Deviations of rainfall around sunspot maximum years for different Meteorological subdivisions in India during January - February for the period 1871 - 1990

<table>
<thead>
<tr>
<th>No.</th>
<th>Met Sub division</th>
<th>Mean rainfall(mm)</th>
<th>Solar cycle effect (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>North Assam</td>
<td>55.4</td>
<td>-1, +19.5</td>
</tr>
<tr>
<td>4</td>
<td>South Assam</td>
<td>45.13</td>
<td>Nil</td>
</tr>
<tr>
<td>5</td>
<td>Sub Himalayan West Bengal</td>
<td>26.73</td>
<td>0, +38.87</td>
</tr>
<tr>
<td>6</td>
<td>Gangetic West Bengal</td>
<td>38.29</td>
<td>0, +48.73</td>
</tr>
<tr>
<td>7</td>
<td>Orissa</td>
<td>31.6</td>
<td>0, +41.9</td>
</tr>
<tr>
<td>8</td>
<td>Bihar Plateau</td>
<td>45.09</td>
<td>0, +42.83</td>
</tr>
<tr>
<td>9</td>
<td>Bihar Plains</td>
<td>31.7</td>
<td>0, +58.9</td>
</tr>
<tr>
<td>10</td>
<td>East Uttarpradesh</td>
<td>33.05</td>
<td>0, +61.91</td>
</tr>
<tr>
<td>11</td>
<td>West Uttarpradesh</td>
<td>38.88</td>
<td>0, +66.85</td>
</tr>
<tr>
<td>13</td>
<td>Haryana</td>
<td>37.5</td>
<td>0, +41.87</td>
</tr>
<tr>
<td>14</td>
<td>Panjab</td>
<td>57.87</td>
<td>0, +30.49</td>
</tr>
<tr>
<td>17</td>
<td>West Rajasthan</td>
<td>9.93</td>
<td>0, +68.18</td>
</tr>
<tr>
<td>18</td>
<td>East Rajasthan</td>
<td>12.8</td>
<td>0, +51.95</td>
</tr>
<tr>
<td>19</td>
<td>West Madhyapradesh</td>
<td>20.33</td>
<td>0, +40.83</td>
</tr>
<tr>
<td>20</td>
<td>East Madhyapradesh</td>
<td>35.39</td>
<td>0, +31.87</td>
</tr>
<tr>
<td>21</td>
<td>Gujarat</td>
<td>3.9</td>
<td>Nil</td>
</tr>
<tr>
<td>22</td>
<td>Sourashtra &amp; Kuch</td>
<td>4.47</td>
<td>+2, +35.57</td>
</tr>
<tr>
<td>23</td>
<td>Konkan &amp; Goa</td>
<td>4.3</td>
<td>Nil</td>
</tr>
<tr>
<td>24</td>
<td>Madhya Maharashtra</td>
<td>5.73</td>
<td>+1, +138</td>
</tr>
<tr>
<td>25</td>
<td>Marathwada</td>
<td>9.4</td>
<td>0, +120</td>
</tr>
<tr>
<td>26</td>
<td>Vidarbha</td>
<td>24.12</td>
<td>0, +95.98</td>
</tr>
<tr>
<td>27</td>
<td>Coastal Andhpradesh</td>
<td>17.88</td>
<td>+1, +45.92</td>
</tr>
<tr>
<td>28</td>
<td>Telengana</td>
<td>13.45</td>
<td>-1, +92.19</td>
</tr>
<tr>
<td>29</td>
<td>Rayalaseema</td>
<td>9.9</td>
<td>0, +62.63</td>
</tr>
<tr>
<td>30</td>
<td>Tamil Nadu</td>
<td>37.7</td>
<td>+2, 25.89</td>
</tr>
<tr>
<td>31</td>
<td>Coastal Karnataka</td>
<td>3.45</td>
<td>+1, +160</td>
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<td>32</td>
<td>North Interior Karnataka</td>
<td>6.03</td>
<td>0, +82</td>
</tr>
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<td>33</td>
<td>South Interior Karnataka</td>
<td>8.19</td>
<td>0, +100</td>
</tr>
<tr>
<td>34</td>
<td>Kerala</td>
<td>27.68</td>
<td>+1, +39.28 ; 0, +37.25</td>
</tr>
</tbody>
</table>
5.4 Discussion

We will now examine the results of different superposed epoch analysis of seasonal rainfall data separately for different locations in India around sunspot maxima years.

Winter Season (January - February)

Winter season is the season of lowest rainfall for most regions/subdivisions in India. The best solar cycle response is seen for Central North East India (CNEI) which shows a distinct rainfall enhancement during the sunspot maximum year on an average. Similar enhancement is also seen for North West India (NWI) and West Central India (WCI). Solar cycle response is not seen for rainfall of North East India (NEI). South Peninsular India (SPI) rainfall shows a distinct decrease two year prior to sunspot maximum. All India rainfall exhibits maximum solar cycle response during this season (enhancement at sunspot maximum year). Kerala also shows a similar result. Trivandrum city rainfall shows a small enhancement around sunspot maximum.

In Fig. 5.11 we have shown the winter rainfall deviation from the mean of different meteorological subdivisions in India around sunspot maximum years for the period 1871-1994. The mean rainfall and the solar cycle effect for different subdivisions are given in Table 5.3. Out of 29 subdivisions for which rainfall data is available (Parthasarathy et al, 1995) 26 divisions show a sunspot cycle
association. Gujarat and South Assam are the subdivisions which are exceptions. Most of the subdivision rainfall show an enhancement close to the year of sunspot maximum.

During the winter season similar to other parts of India, there is a significant increase (40% from the mean) in the rainfall over Kerala during the sunspot maxima. The physical cause for winter rainfall variations in different parts of India are different. For eg. in Northern India, effect of western disturbances can cause winter rainfall variations. In places near geographic equator like Kerala, Southern hemisphere synoptic systems can affect the rainfall. One can see a global control of winter rainfall between 8°N to 35°N within India in association with the sunspot cycle.

**Pre monsoon season (March - May)**

WCI is the only region which shows a sunspot cycle response. For this region a distinct enhancement in rainfall is observed around sunspot maximum. The other four regions is observed to show irregular rainfall variations around sunspot maximum. The above result is also true for Kerala, All India and Trivandrum city rainfall.

**South West Monsoon season (June - September)**

NWI is the only region which shows sunspot cycle association during this season (enhancement of rainfall during the year before sunspot maximum).
It is again the region of least rainfall. All India rainfall shows an enhancement one year after sunspot maximum. Other meteorological regions doesn't show any solar cycle response.

Kerala rainfall shows a notable decrease on an average three years prior to the sunspot maximum year (this period may fall either close to sunspot minimum or early ascending phase). This result is of some practical application in the long range forecast of summer monsoon in Kerala. There are several methods which can be used for forecasting the year of sunspot maximum 3-4 years in advance. Once we know the year of sunspot maximum we can suggest the possibility for a deficiency in summer monsoon rainfall in Kerala well in advance. However more detailed analysis is required to establish this result. This result is also true for Trivandrum city rainfall.

Retreating Monsoon season (October - December)

For this season also the NWI rainfall shows the best association with sunspot cycle (enhancement by 65% during sunspot maximum). Sunspot cycle effects also seen on the rainfall variations of WCI (enhancement, one year prior to sunspot maximum) and CNEI (enhancement, three years prior to sunspot maximum), other regions does not show any solar cycle response. Kerala rainfall shows an enhancement on an average two years prior to sunspot maximum. All India rainfall shows an enhancement one
year prior to sunspot maximum similar to WCI. Trivandrum city rainfall also shows a notable sunspot cycle associations with a distinct enhancement during the year after the sunspot maxima.

Decadal rainfall variations of All India and Kerala

From a comparison of Fig. 5.9 and Fig. 5.10 we can find a increasing trend in the decadal mean rainfall of All India 1900-1970. It is interesting to find a similar increasing trend in the decadal mean rainfall of Kerala for the period 1900 - 1960 during the Pre-monsoon season. This result is of some relevance in the forecast of summer monsoon rainfall of India. However this increasing trend is not observed in the decadal rainfall variations of Trivandrum city for the same period.

A correlated increasing trend in sunspot activity and northern hemisphere temperature (related to global warming is found for the period 1900 - 1960 which is evident from Fig. 5.15(a) (Fris Christenson and Lassen, 1994). There are several studies on the correlated variations of northern hemisphere temperature and summer monsoon rainfall of India over a century or more (eg. Verma, 1983). From Fig. 5.9b(iii) it can be seen that from 1900-1960 on an average the decadal average rainfall of India during the summer monsoon has increased by 15%. But during the same period the decadal rainfall of Kerala for the pre-monsoon season [Fig. 5.9a (ii)] has shown an increase of 70%. In Fig. 5.15 (b) we have reproduced a figure published by lockwood et.al (1999). In this figure changes in
yearly magnetic flux of solar corona for 1868 - 1996 is shown. From this figure we can find that solar magnetic flux has increased by an amount of 70% during the period 1900 - 1960 which is exactly similar to that of pre-monsoon rainfall variations. Geomagnetic activity (Bucha, 1989) also shows a correlated increase with global mean air temperature during the above period as shown in Fig. 5.15c.

**Sunspot cycle association of monsoon onset**

The day of onset of summer monsoon in Kerala fluctuates between May 11 and June 18 with the best probability on June 1st. We have collected the monsoon onset dates in Kerala for the period 1891-1997. We have calculated the deviation in days for each year for the above period from June 1st. This deviation is subjected to modified superposed epoch analysis around sunspot maximum years. The results are shown in Fig. 5.12. We observed that on an average maximum deviation from June 1st is more probable to occur 2 years prior to sunspot maximum i.e., a delay by 4-5 days from June 1st. This result can also be used for longterm forecast of monsoon onset in Kerala if we make use of solar sunspot maxima forecasts.

**Sunspot cycle and depressions in Indian seas.**

We have also carried out a superposed epoch analysis of the frequency of occurrence of Bay of Bengal / Arabian Sea depressions around sunspot maximum years for the period 1877-1990 seperately for the following seasons.
(a) January - February (b) March - May (c) June - September (d) October - December

The results of the analysis are shown in Fig. 5.13. During the summer monsoon season, we can observe an increase in the occurrence of depressions one year prior to the sunspot maximum. This result may find some association with the enhancement of rainfall in North West India during the same solar cycle phase. Occurrence of depressions does not show any notable solar cycle association for other seasons.

**Trivandrum city pentad rainfall and sunspot cycle.**

We have already mentioned in 3.7 the year to year variations of the pentads of maximum rainfall in the Trivandrum city during the South West and retreating monsoon seasons. We have also carried out superposed epoch analysis of the pentad dates where maximum rainfall occurs around sunspot maximum years seperately for the two monsoon seasons. The results are shown in Fig. 5.14. This study does not reveal any notable sunspot cycle association for the summer monsoon season. However a notable increase in the pentad number of maximum rainfall is seen during the retreating monsoons period.
General Comments

It is interesting to note that the North-West India is the only meteorological region in India (out of 5) which shows a meaningful association with sunspot cycle for 3 out of four seasons under consideration (for the period 1871-1994). Here it is worth mentioning that this region is having the lowest annual rainfall compared to other meteorological regions in India. It also shows lowest rainfall during the 3 seasons and second lowest for the winter. Another result of significance is that during winter season we can find notable enhancement in rainfall throughout India including Kerala. Thus it is found that (i) a least rainfall region of a given season (eg. North-West India) shows the best sunspot cycle association (ii) a season with lowest total rainfall for most places in India shows the best sunspot cycle association. The above results suggests that whenever internal causes of rainfall is weak (weakening seasonal forcing such as monsoon winds, synoptic features etc) external forces such as solar activity changes can play some role in a given place. Thus one can understand the presence or lack of correlations found for different places in India earlier in the light of the above new hypothesis. This idea may be applied to other parts of the world where sun-weather relations are studied in the solar cycles time scales.

We can observe a sunspot cycle association of rainfall variations in Kerala
during the summer monsoon, retreating monsoon and the winter seasons. Trivandrum city rainfall also show a similar result. However the rainfall variations around sunspot maxima for Trivandrum and Kerala are not in phase except for the summer monsoon season. We cannot find a relation between solar cycle variations of summer monsoon onset dates and summer monsoon rainfall variations in Kerala. The no. of occurrences of depressions in the South India seas, seasonal rainfall of Kerala and the phase of the sunspot cycle does not seem to have a combined relationship during the summer monsoon season eventhough individually the two weather phenomena are associated with sunspot cycle. During the retreating monsoon seasons both Kerala (2 years prior to sunspot maxima) and Trivandrum city rainfall (1 year after the sunspot maxima) showed distinct enhancement during the sunspot cycle.
Fig. 5.12  Superposed epoch analysis of the deviations on the onset of South West monsoon rainfall in Kerala from June 1st around sunspot maxima years for the period 1891 - 1997.

Fig. 5.13 (a)  Occurrence of Bay of Bengal/Arabian sea depressions during January - February for the period 1877-1990 around sunspot maximum.
Fig. 5.13 (b) Occurrence of Bay of Bengal/Arabian sea depressions during March-May for the period 1877-1990 around sunspot maximum.

Fig. 5.13 (c) Occurrence of Bay of Bengal/Arabian sea depressions during June-September for the period 1877-1990 around sunspot maximum.
Fig. 5.13 (d) Occurrence of Bay of Bengal/Arabian sea depressions during October - December for the period 1877-1990 around sunspot maximum.

Fig. 5.14 (a) Average pentad of maximum rainfall of Trivandrum city around sunspot maximum years for South West monsoon season.
Fig. 5.14 (b) Average pentad of maximum rainfall of Trivandrum city around sunspot maximum years for Retreating monsoon season.
N. Hemisph. land T and sunspot number

Fig. 5.15 (a) Smoothed yearly average Northern hemisphere air temperature deviations and variations of running means of sunspot number for the period 1860 - 1990 (After Friis Christenson and Lassen, 1994)
Fig. 5.15 (b) Variations of yearly mean values of solar magnetic flux in the corona (solid lines unshaded) and sunspot number variations (shaded) for the period 1868 - 1996. (After Lockwood et al., 1999)
Fig. 5.15 (c) Smoothed geomagnetic activity index $aa$ (five year means) and global air temperature variations for the period 1880 - 1985 (After Bucha, 1989)
5.5 Results

i) Compared to other three seasons winter season (January-February) rainfall of All India, Kerala and majority of the meteorological sub-divisions in India shows a better association with the sunspot cycle, exhibiting a distinct enhancement during sunspot maximum. This result is in contrast to the prevailing belief that solar cycle effects on weather parameters during winter is negligible.

ii) Among the five meteorological regions in India, North - West India shows the best association with sunspot cycle. It appears that least rainfall regions in India is more vulnerable to solar activity forcings.

iii) Summer monsoon rainfall in Kerala shows an association with sunspot cycle with a probability of deficient rainfall three years prior to the year of sunspot maximum. During the retreating monsoon seasons we can find a distinct enhancement in the rainfall of Kerala 2 years prior to the year of sunspot maxima

iv) One can find an association between depression formation in Indian seas and sunspot activity only during the summer monsoon season where relatively larger number of depressions form during the sunspot maximum epoch.

v) The onset of monsoon in South Kerala seem to show a tendency to be delayed by 4-5 days from the June 1\textsuperscript{st} is two years prior to the sunspot maxima.
vi) Trivandrum city rainfall shows an association with sunspot cycle similar to that of All Kerala rainfall during the summer monsoon season. During the retreating monsoon season there is a probability of rainfall in Trivandrum which shows a distinct enhancement during the sunspot maximum epoch.

vii) We have observed an increasing tendency in the pre-monsoon rainfall in Kerala during the period 1900-1960 where similar increase in sunspot activity and coronal magnetic flux is observed.