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Total Solar Eclipse of August 11, 1999

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Abstract. In this article we present the co-ordinates and the circumstances of the total solar eclipse of August 11, 1999, visible from India. We describe the experiments done in the past and suggest the experiments to be conducted during the forthcoming total eclipse, taking the advantages of recent technological developments. Cover data and circumstances of this eclipse indicate that the probability of viewing this eclipse in India is negligible.

1. Introduction

The occurrence of total solar eclipse on October 24, 1995, which was visible in India, had generated a great interest in professional and amateur astronomers, scientists in other fields and public in general. The circumstances of the 1995 eclipse in India were reported at various places (Singh, 1994; 1995). As expected weather conditions were excellent through out the totality path in India and provided a great opportunity to the scientists to conduct a number of experiments (Singh and Cowsik, 1998). The next total solar eclipse whose path of totality will pass through parts of central India will occur on August 11, 1999. It is well known that chances of viewing this eclipse from Indian soil are small due to the monsoon season. Nevertheless it may be advisable to know the circumstances of this eclipse at various places in India quantitatively. In the past, during 1991 eclipse, the places which were expected to be clear turned out to be cloudy and places predicted to have poor visibility had perfect clear weather. In this article we present the experimental trends, the path of totality, circumstances of the eclipse and weather conditions in India. The details of this eclipse in places outside India are given in NASA publication (1997). The importance of eclipse observations is described in Singh (1994, 1995).

2. Experiments

The experiments generally conducted during a total solar eclipse have been discussed in an article by Singh (1994). Here we shall describe additional improvements carried out in the

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recent past. At present most of the observations are carried out by using electronic detectors like CCD camera. A number of observers have used small commercial CCD cameras at video rate to measure the polarization in the solar corona. It is good to use such cameras for this purpose since in this experiment it is more important to have fast time sequence in different polarisation angles than the photometric accuracy. Moreover, the commercial CCD provides the photometric accuracy similar to the photographic film accuracy but has better dynamic range than the photographic film. Some observers have tried to use uncooled commercial CCD camera to study the intensity oscillations in the solar corona. The data was obtained at video rate with 8-bit digitiser. No doubt, it has the advantage of two dimensional imaging of the corona and high temporal resolution required to study intensity oscillations but such a camera does not give the required dynamic range and the photometric accuracy. The exponential fall of intensity with solar radii restricts the area of observations. Also the non-availability of reference DC signal in general commercial CCD cameras limits the use of such cameras to investigate the intensity oscillations. In addition, the high frequency photometry of solar corona, in a limited way, indicates very low amplitude of intensity variations.

Pasachoff et al. (1984, 87, 98) have improved their experimental set up to confirm the coronal intensity oscillations in the range of 1-2 Hz which they observed during earlier eclipses using photomultiplier tubes. Now, they use two dimensional CCD detectors with 12-bit digitiser which can acquire images of corona at 5 Hz. The Indian Institute of Astrophysics, Bangalore group led by R. Cowsik has built a multi-channel photometer to confirm the intensity oscillations in the range of 0.02-0.2 Hz found earlier by Singh et al. (1997). They have employed R647 Hamamatsu photomultiplier tubes which are highly sensitive and have very low dark current and noise. The deadtime is less than 10 ns in the photon counting mode. They conducted the experiment with this photometer during the last total solar eclipse of Feb. 26, 1998 at Don Bosco Mission, Carrasquero, Venezuela. One of the Channels clearly shows the intensity variations. The detailed analysis is yet to be reported. Such experiments need to be repeated during this and future eclipses.

Now, a number of observatories have good Peltier cooled CCD camera systems which can record data in 14-bit format at the rate of 200 KHz. By carefully selecting the limited coronal area of interest and binning the pixels, one can obtain two dimensional information on a limited coronal region say $4' \times 4'$. The binning of pixels may be done in such a way that spatial resolution of about 4 $arcsec^2$ is achieved. Choosing a suitable emission line or continuum filter, it is possible to measure the intensity at the rate of ~ 1 Hz. This provides a good compromise between temporal and spatial resolutions, and between the observed coronal region photometric accuracy and the dynamic range. Another experiment which deserves attention is spectroscopy of solar corona in the wavelength range of 3700 - 4500 Å with medium spectral and spatial resolution to determine the electron temperature in different coronal structures directly. Due to large thermal motion of coronal electrons, most absorption features of the electron scattered photospheric spectra form a nearly continuous spectrum of K-corona. Weak depressions, however, are still present in the K-corona spectrum at ~ 3900 Å including the Ca II lines and at G band at ~ 4300 Å. Ichimoto et al. (1996) did this experiment using peltier cooled CCD camera as the detector during the total solar eclipse of Nov. 3, 1994 at Putre, Chile. Such experiments need to be repeated to determine temperature differences in 'closed' and 'open' field coronal structures. A long data base will help in the realistic modelling of coronal structures and their heating mechanisms.

3. Path of totality

The total solar eclipse of 1999, August 11, is the twenty-first member of the Saros series 145.

The last total solar eclipse of the 20th Century begins in the North Atlantic about 300 km. South of Nova Scotia at 09:30:57 UT. The maximum duration of totality is only 47 seconds as seen from the center of the narrow 49 km wide path of the totality. The umbral shadow continues its path in the ocean upto 10:10 UT until it finally reaches the first landmass of Isles of Scilly of the southwest east of England. At this time the speed of the Shadow decreases from ~ 2 *km/sec* to ~ 1 *km/sec*. The sun is already up at an altitude of ~ 45 degrees above the eastern horizon. The centre line duration is about 2 minutes with path width of about 100 km. Shortly afterwards the umbral shadow reaches England where Plymouth, the largest English city in the path will witness a total phase lasting about 1 min. 39 sec. London misses the total phase but experiences partial phase with a maximum magnitude of 0.968. The shadow leaves England at 10:16 UT and four minutes later it sweeps through French countryside at a speed of about 0.8 *km/sec*. Paris misses the totality zone by 30 kms. Parts of southern Belgium, Luxemberg and Germany will also experience total phase of the eclipse. The city of Metz in Champagne lies very close to the central line and will witness the total eclipse for 2 min 13 sec. at 10:29 UT. Four minutes later, the entire umbral shadow crosses into southern Germany and the beautiful Rhine Valley. Fankfurt experiences a partial eclipse whereas Stuttgart lies near the central line to view the corona for 2 min 17 secs. Although Munich lies 20 kms south of central line, the two million citizens will still witness more than two minutes of totality, provided good fortune brings clear sky on the eclipse day. AT 10:35 UT, the sun's altitude stands at 55 degree, the path width is 109 kms and the shadow ground velocity is 0.74 *km/sec*. Then the umbral shadow crosses through Austria and Hungary. Lake Balaton lies wholly within the path with the totality time being 2 min. 22 secs. Vienna in Austria and Budapest in Hungary miss the total path by 40 kms. The greatest eclipse and maximum totality of 2 min 2.3 secs will occur in Romania with the sun's altitude of 59° and path width of 112 kms. Bucharest, the capital city of Romania lies on the centre line near the instant of greatest eclipse, will enjoy a duration of 2 mins. 22 sec. The shadow before entering the Black sea passes through a small portion of northern Bulgaria.

The next landfall occurs in northern Turkey at 11.21 UT and the central line duration begins a gradual but steady decrease. Turhal falls deep within the shadow for 2 mins. 15 secs. Sivas and Batman, other cities of Turkey lie close to the central line of totality path. The umbral shadow passes through north-west Syria, Iraq before it enters Iran at 11:52 UT. Places like Borujerd, Najafabad near Esfahan lie close to the central line where the totality will be about 1 min 50 secs. Karachi a big city of Pakistan, near the centre line, will experience a totality of 1 min. 13 secs with the sun being at 22° above the western horizon.

Finally, the umbral shadow arrives in India at 12:29 UT before disappearing in space at 12:36:23 UT. As the shadow sweeps across India, its velocity increases rapidly while the centre line duration drops below one minute and the sun's altitude decreases to 7 degree. The path of totality in India shown in Figure 1 indicates that the shadow passes through Rann of Kachchh, Gujarat, Madhya Pradesh, Maharastra and Andhra Pradesh before entering Bay of Bengal near Vishakhapatnam. In Figures 2a - 2c we plot the umbral shadow path on a enlarged scale to help the observers to choose a convenient place to view and/or photograph the solar corona or conduct experiments during the eclipse. Railway lines and important roads are also shown in the figures to plan the journey to the chosen place.

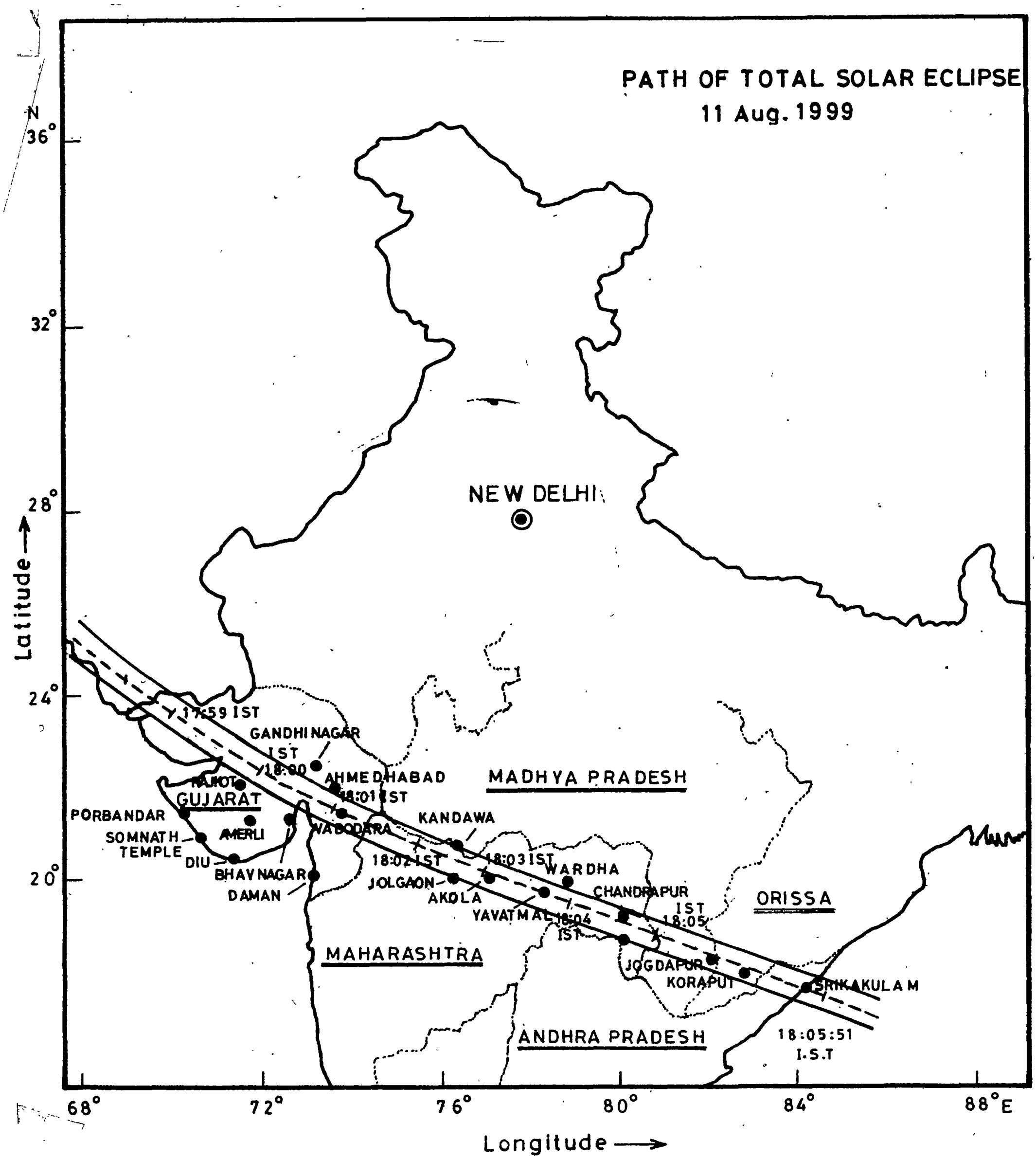


Figure 1. Path of totality through India during the total solar eclipse of August 11, 1999.

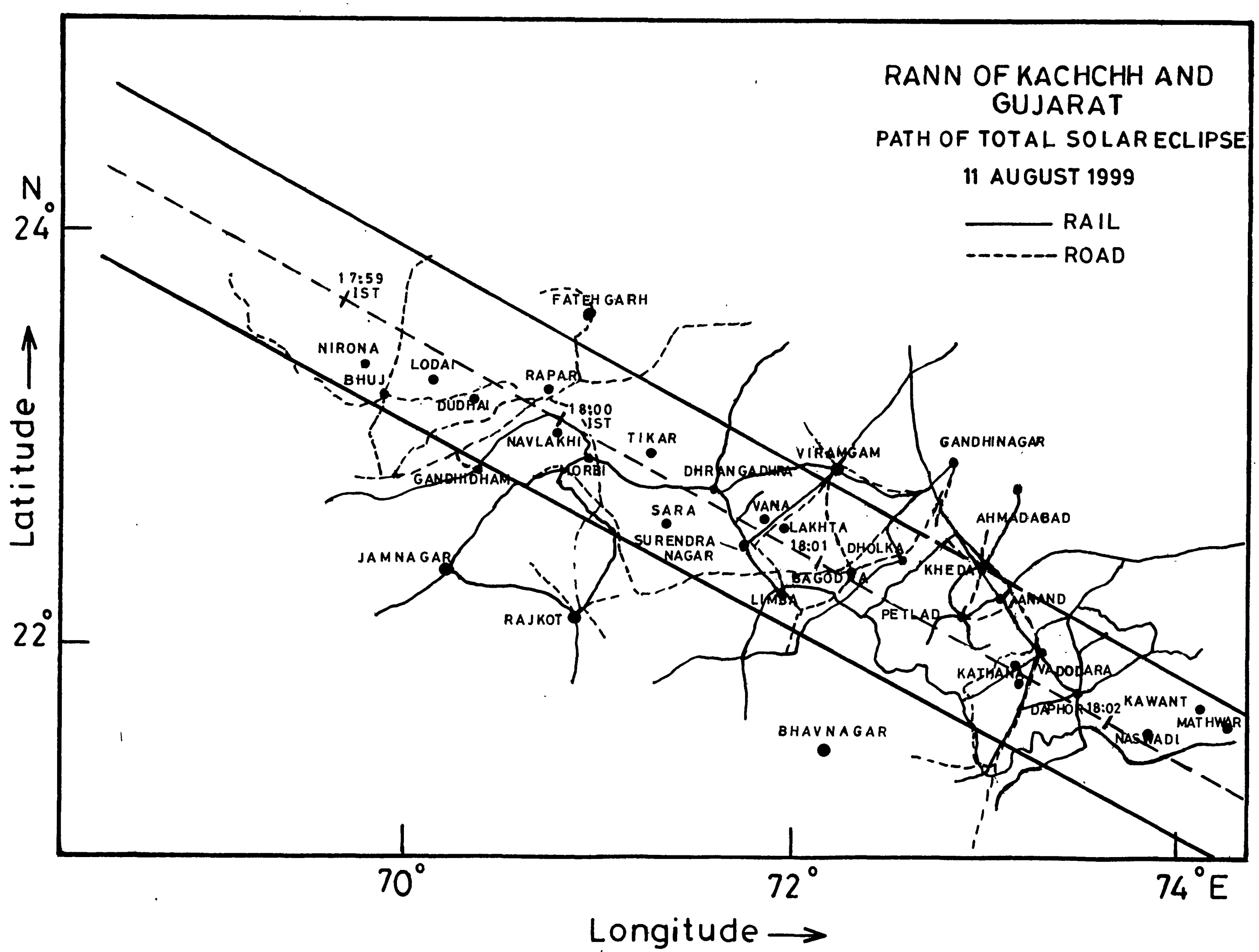
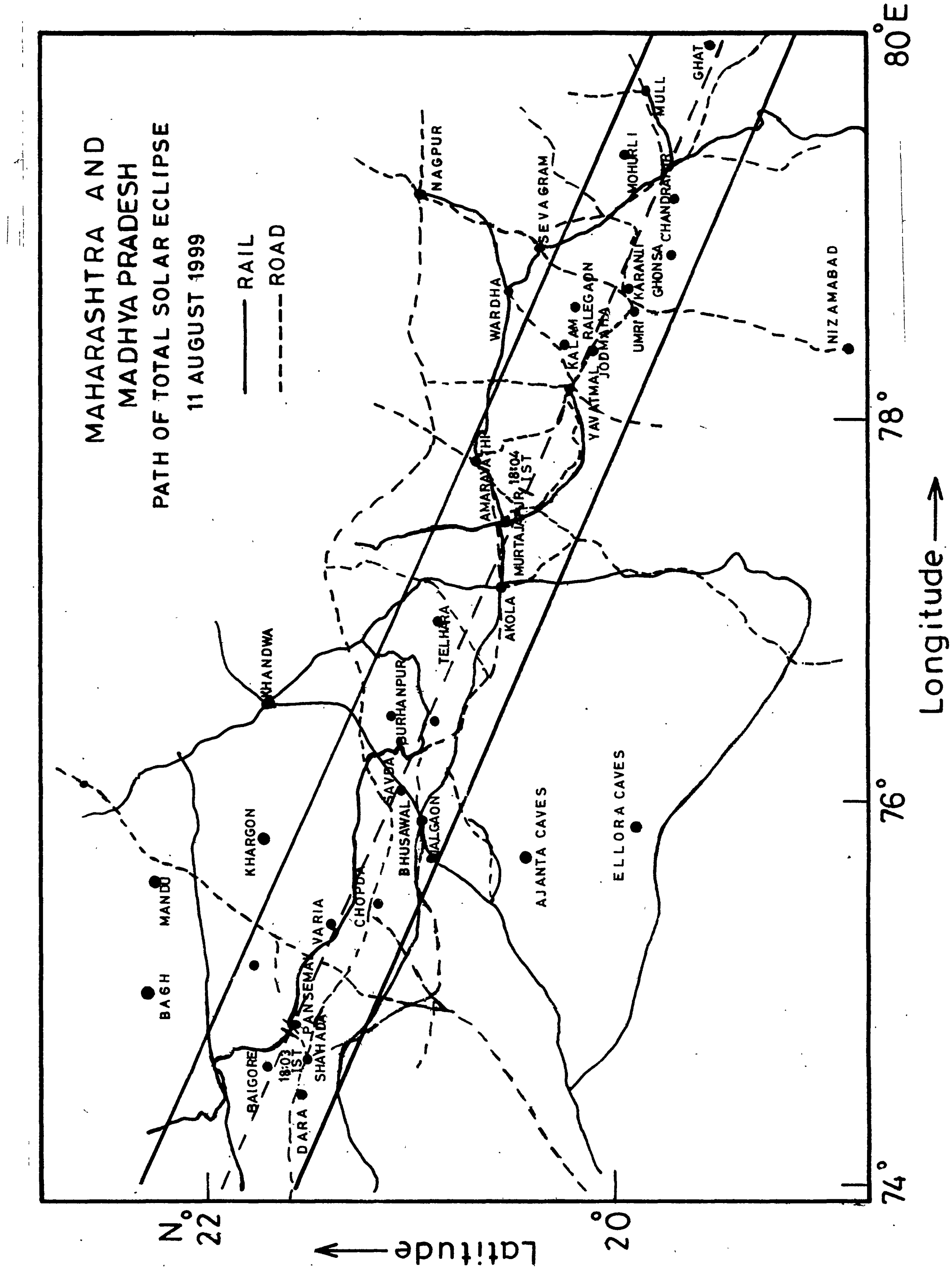


Figure 2a. The region bounded by solid thick lines represents the path of the umbral shadow at the time of total solar eclipse. Thin solid and dotted lines show the rail lines and metalled roads respectively. The time of the maximum phase of the eclipse is written at the central line in IST at an interval of one minute.



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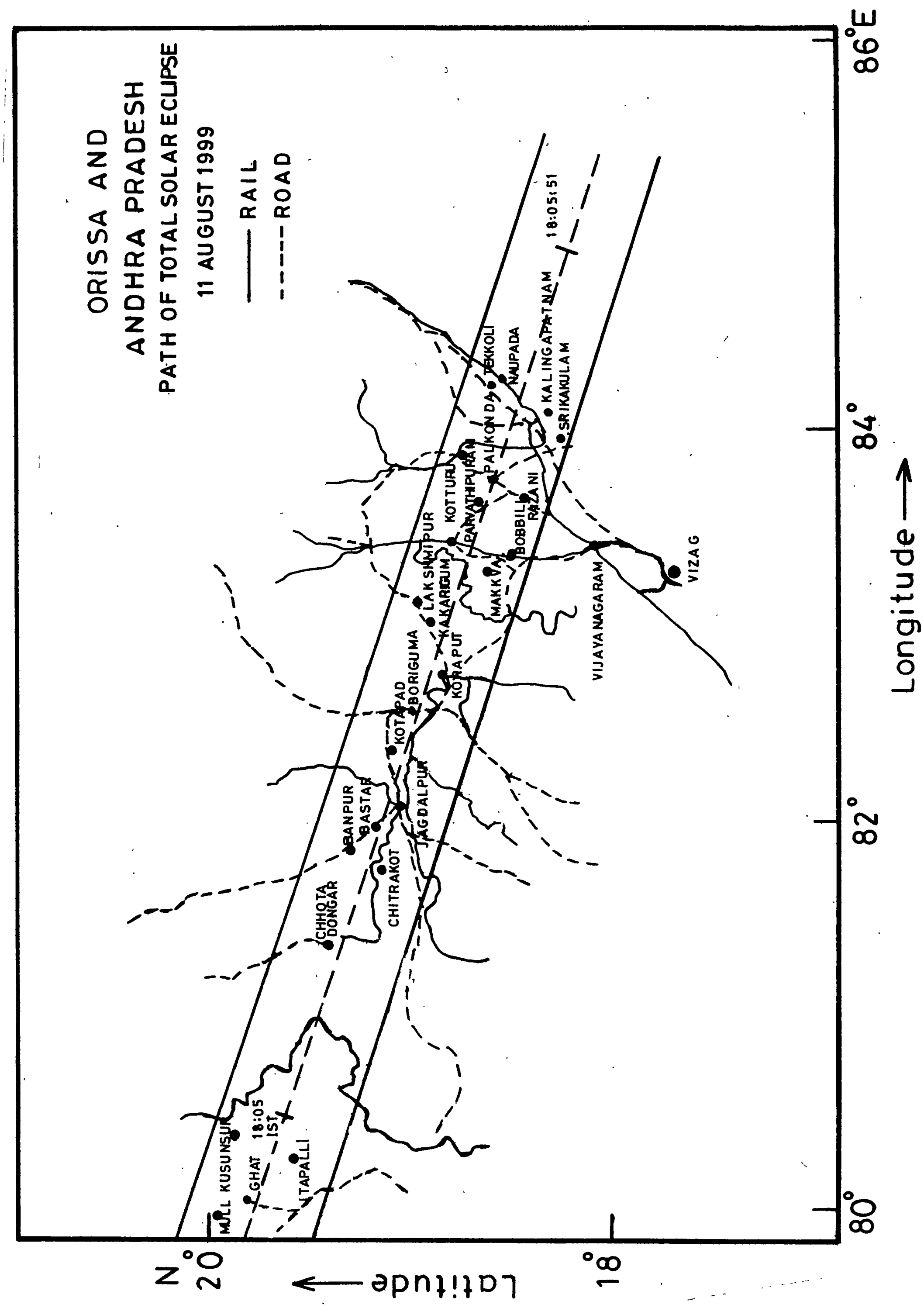

Same as that of Figure 2a

Rann of Kachchh, where the umbral shadow enters India is not a very well developed place. A big town of Bhuj lies just at the southern limit of the totality path. There are many villages in Gujarat which will experience totality (Fig 2a). One may consider places like Surendranagar and Baroda which lie south and north of the centre line respectively and enjoy the totality duration of ~ 1 min. just after 18:00 IST with sun at an altitude of about 16 degree above the western horizon. Then the umbral shadow moving at a rapid speed of ~ 3 km/sec passes through northern Madhya Pradesh for a brief period and then enters Maharashtra. The cities of Akola and Chandrapur lie close to the centerline where as Bhusawal is ~ 20 kms south of the centre line. The speed of the shadow continues to increase at a rapid rate becoming ~ 6 km/sec near Chandrapur and duration of totality and sun's altitude continue to decrease at a steady rate. The umbral shadow passes through small parts of southern Orissa and number of villages of Andhra Pradesh before entering Bay of Bengal. Vishakapatnam, the famous port city of Andhra Pradesh lies about 70 kms south of the southern limit of the eclipse path.

In table 1 we list the coordinates of umbral path, time at the maximum of eclipse in IST and the circumstances at the centre line of this eclipse in India. Details about the partial phase of the eclipse and information about this eclipse at other places in the world may be seen in NASA publication by Espenak and Anderson (1997). In table 2 we give the coordinates and the circumstances of this eclipse at some places close to the centre line of totality path in India. This table includes latitude and longitude of the places of interest, the beginning and the end of the eclipse, the duration of totality and the altitude of the sun at the maximum of the eclipse. A correction needs to be applied to the duration of totality due to Lunar limb which appears irregular when seen as a profile. This correction $\simeq$ 0.1 second is positive for locations south of the central line. This correction $\simeq$ 0 - 3 seconds is negative for locations north of the central line.

4. Weather prospects for this eclipse

The cloud cover and weather are not favourable for viewing this eclipse due to the monsoon season. In order to estimate the chances of observing this eclipse in India, we have analysed 30 years (period 1951-80) of weather data for the month of August obtained by the India Meteorological Department along the path of totality. In Figure 3 we plot the histogram of number of rainy days in August along the path of totality. This figure indicates that the western part of India, the region around Rann of Kachchh and west part of Gujarat may provide a better view of this eclipse. It rains for an average of about 15 days during the August month at other places in the totality path in India. This makes it difficult to set up the experiments in the open eclipse camps. The chances become further poor when we look at the data of low clouds for August month along the path of totality as shown in Figure 4. The number of days, on which an average > 2 Oktas clouds are present range between 17 to 25 at different places in the path of totality in India in the month of August. The Eastern part of India in the path of totality appears marginally better as far as low clouds are concerned, in contrast with the number of rainy days.

Table 1. Coordinates and circumstances of the totality path in India During the Total Solar Eclipse of August 11, 1999.

	Latitude (North)			IST time at Maximum eclipse			Circumstances on the centre line		
Longitude (east) (degree)	Northern limit ° ′	Southern limit ° ′	Central line ° ′	Northern limit	Southern limit	Central line	Sun alt. deg	Path width (km)	Central duration sec
65	26 08.75	25 15.58	25 42.01	17:53:50	17:55:09	17:54:30	24	88	79
66	25 40.98	24 48.91	25 14.79	17:54:57	17:56:13	17:55:36	23	86	77
67	25 13.70	24 22.72	24 48.07	17:56:00	17:57:14	17:56:37	22	85	75
68	24 46.92	23 57.02	24 21.83	17:57:00	17:58:11	17:57:36	21	83	73
69	24 20.65	23 3i.83	23 56.10	17:57:56	17:59:04	17:58:30	20	82	71
70	23 54.88	23 07.13	23 30.87	17:58:48	17:59:54	17:59:21	19	80	69
71	23 29.62	22 42.94	23 06.15	17:59:37	18:00:40	18:00:09	17	79	67
72	23 04.88	22 19.26	22 41.94	18:00:23	18:01:23	18:00:53	16	77	65
73	22 40.65	21 56.08	22 18.24	18:01:05	18:02:03	18:01:34	15	76	64
74	22 16.94	21 33.40	21 55.05	18:01:44	18:02:39	18:02:12	14	74	62
75	21 53.74	21 11.22	21 32.36	18:02:19	18:03:12	18:02:46	13	73	60
76	21 31.06	20 49.54	21 10.19	18:02:52	18:03:43	18:03:17	12	71	59
77	21 08.88	20 28.36	20 48.51	18:03:21	18:04:10	18:03:46	11	70	57
78	20 47.22	20 28.36	20 48.51	18:03:47	18:04:34	18:04:11	10	68	55
79	20 26.05	19 47.45	20 06.65	18:04:11	18:04:56	18:04:33	9	67	54
80	20 05.39	19 27.70	19 46.45	18:04:31	18:05:14	18:04:53	7	65	52
81	19 45.25	19 08.40	19 26.74	18:04:49	18:05:30	18:05:10	6	64	51
82	19 25.83	18 49.03	19 07.51	18:05:04	18:05:44	18:05:24	5	63	49
83	19 05.99	18 31.43	18 48.75	18:05:17	18:05:54	18:05:35	4	61	48
84	18 50.16	18 13.57	18 30.45	18:05:25	18:06:02	18:05:44	3	60	47
85	19 09.38	17 56.30	18 12.62	18:05:14	18:06:08	18:05:51	2	58	45
86	18 11.49	17 39.16	17 55.23	18:05:38	18:06:11	10:05:55	1	57	44

Table 2. Coordinates and circumstances of the eclipse at some places in the totality path in India.

Location	Lati. north ° ′	Long. east ° ′	Time in IST at: First contact h m s	Second contact h m s	Third contact h m s	Fourth contact h m s	Totality duration secs	Sun alt degree
Lokhpat	23 49	68 47	16 51 20	17 58 06	17 59 07	18 58 34	61	20
Khavda	23 51	69 43	16 52 04	17 58 20	17 59 19	18 58 23	59	19
Naliya	23 05	70 46	16 54 04	17 59 35	19 00 40	18 59 08	65	18
Dhrangadhra	22 59	71 28	16 54 45	17 59 52	18 00 57	18 59 07	65	17
Surendranagar	22 42	71 41	16 55 20	18 00 19	18 01 21	18 59 25	62	17
Dholka	22 43	72 28	16 55 52	18 00 30	18 01 24	18 59 13	54	16
Petlad	22 28	72 48	16 56 28	18 00 48	18 01 50	18 59 26	52	15
Anand	22 34	72 56	16 56 25	18 00 48	18 01 37	18 59 17	49	15
Baroda	22 18	73 26	16 57 18	18 01 16	18 02 18	18 29 36	62	15
Dabhoi	22 11	73 26	16 57 18	18 01 16	18 02 18	18 29 36	62	15
Choopda	21 15	75 18	16 59 46	18 02 43	18 03 54	19 00 01	51	13
Bhusawal	21 03	75 46	17 00 18	18 03 02	18 03 49	Sunset	47	12
Bushanpur	21 18	76 14	17 00 13	18 02 46	18 03 31	”	45	12
Akola	20 44	77 00	17 01 24	18 03 23	18 04 19	”	56	11
Yavatmal	20 24	78 08	17 02 23	18 03 47	18 04 42	”	55	10
Chandrapur	19 57	79 18	17 03 29	18 04 17	18 05 09	”	52	8
Jagdalpur	19 04	82 02	17 05 35	18 05 03	18 05 52	”	49	5
Koraput	18 49	82 43	17 06 06	18 05 15	18 06 01	”	46	5
Palkonda	18 36	83 45	17 06 38	18 05 18	18 06 05	”	47	4
Narasnnapeta	18 25	84 03	17 06 56	18 05 27	18 06 12	”	45	3

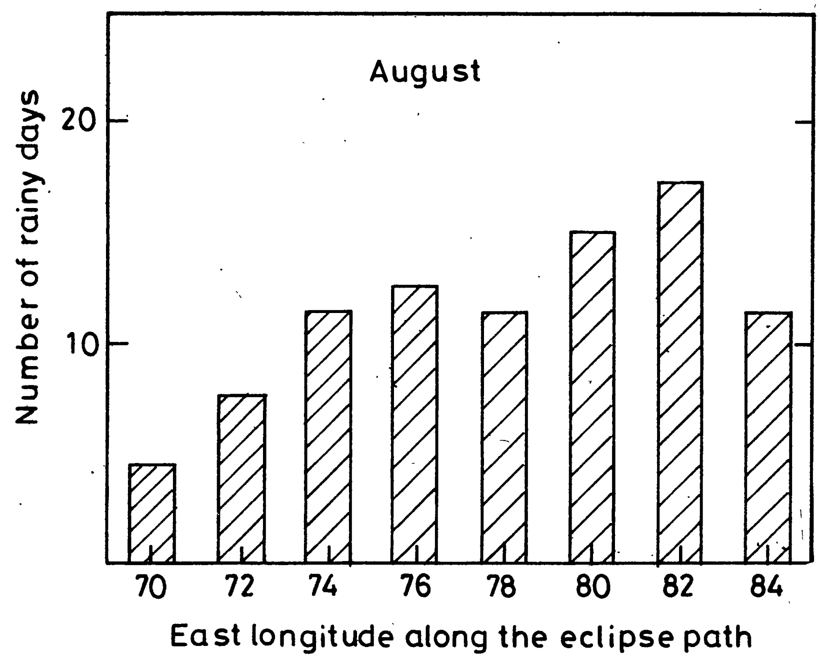

Figure 3. Mean number of rainy days in August month as a function of longitude along the totality path as derived from the weather data for the period 1951-80.

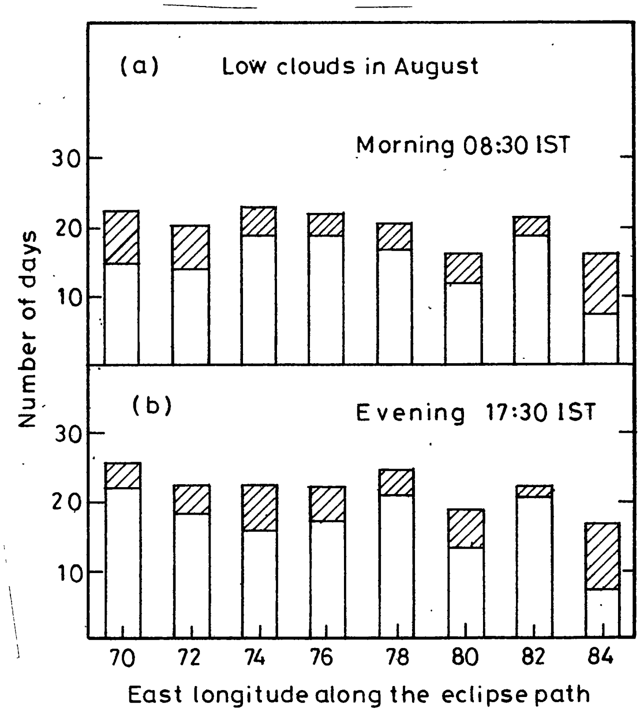

Figure 4. In panel (a) the lower unshaded part of the histogram shows the mean number of days with clouds > 3 Oktas considering low clouds only at 08:30 IST in August month as a function of longitude along the eclipse path in India based on the weather data for the years 1951-80. The shaded portions indicate the number of days with low clouds between 1-2 Oktas. The panel (b) shows the same in the evening at 17:30 IST.

The probability of viewing this eclipse in India becomes very poor when we consider the data on all clouds including high clouds as indicated by Figure 5. The number of days with all clouds > 2 oktas vary between 25-31 days at various places in the umbral shadow in India. No trend appears to exist in the cloudiness, from west to east, morning to evening, in the totality path in India.

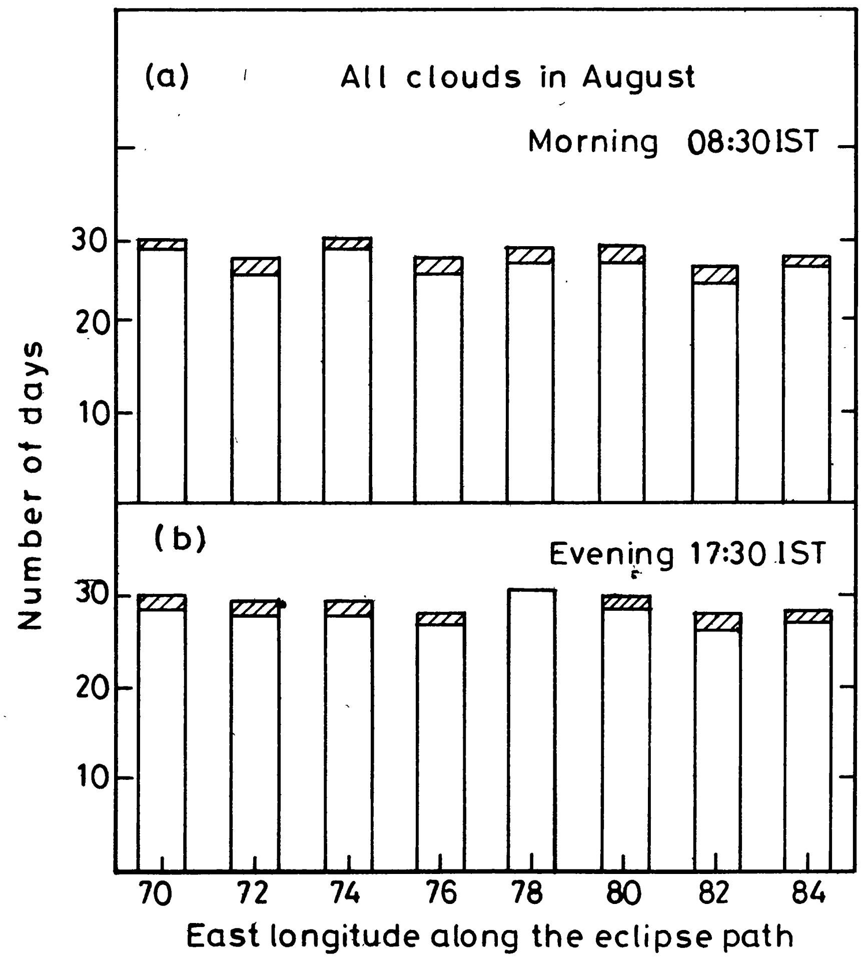

Figure 5. In panel (a) the lower unshaded part of the histograms have been plotted considering all kinds of clouds > 3 Oktas considering low clouds only at 08:30 IST in August month as a function of longitude along the eclipse path in India based on the weather data for the years 1951-80. The shaded portions indicate the number of days with low clouds between 1-2 Oktas. The panel (b) shows the same in the evening at 17:30 IST.

There is a small variation in the temperature along the path of totality in India during the August month. The mean monthly maximum temperature at different locations in the totality path lie between 29-33° C and minimum at night between 23-26° C. The relative humidity in the whole of totality path in India varies only by small amount. The monthly mean humidity for this month ranges between 80-90 percent in the morning and 70-80 percent in the evening. The monthly mean water vapour pressure range between 26 to 31 mb with no trend along the totality path in India.

These are the average weather conditions in the totality path in India. The poor weather conditions coupled with low altitude of the sun at the time of totality makes the probability of viewing this eclipse negligible but not zero. The chances of viewing this eclipse through high clouds may be about 30 percent in the Rann of Kachchh and west Gujarat.

A close look at the weather conditions at individual places gives better prospects, Surendranagar in Gujarat remains free from low clouds for about 15 days in the morning and 12 days in the evening with an average of 6.4 rainy days. This may be the best location in India to view the total phase of this eclipse for 62 secs. at 18.00 IST with the sun at about 17 degree above the western horizon. But, professional astronomers need much better sky conditions, sky almost free from clouds for many days and much less rain because they need to do photometry and record very low signal from the corona; align and test their equipment before the eclipse in an open camp. Therefore, Indian solar astronomers, wishing to conduct some serious experiments with good results may look for an observing site out of India. Figure 6, showing the cloud cover along the whole of totality path from the beginning to the end of this eclipse, indicates that Iran may offer the best conditions to conduct a successful experiment. Turkey may be the second best choice. An international symposium is being arranged in Turkey at the time of this eclipse by Kandilli Observatory Eclipse Committee.

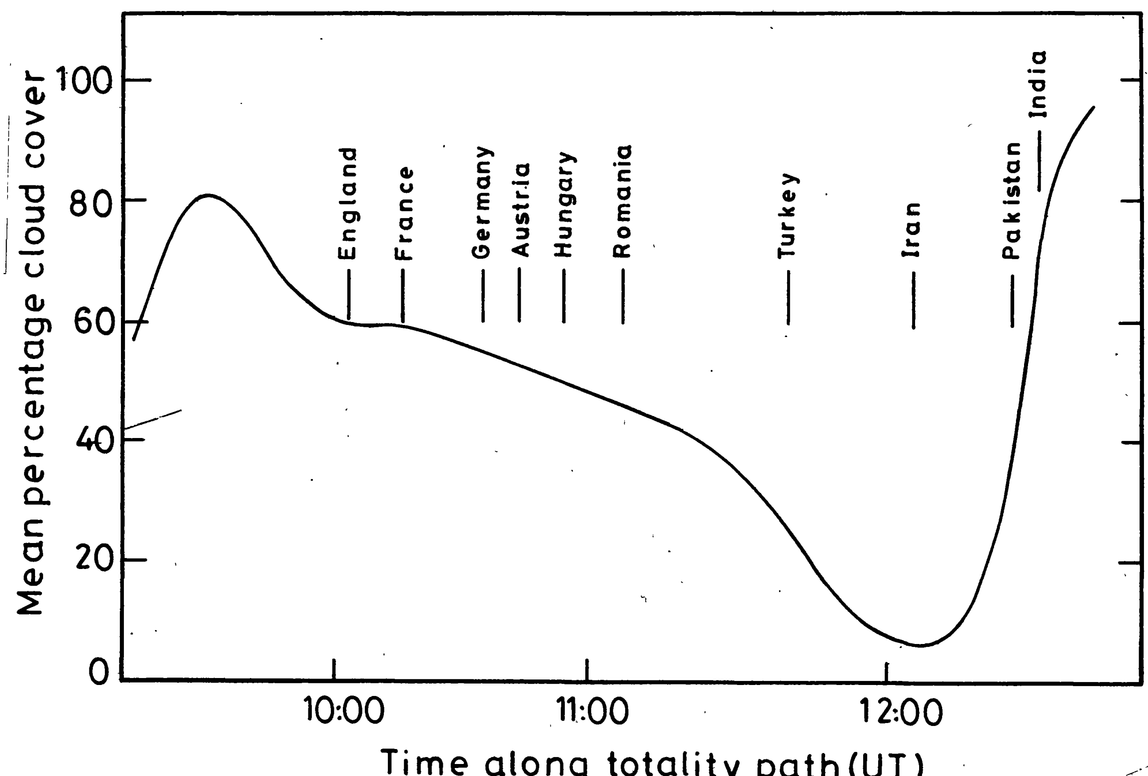

Figure 6. Mean percentage of cloud cover along the whole path of totality as a function of time of maximum phase in UT (adopted from NASA publicaton no. 1398).

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