Indian Journal of Radio & Space Physics
Vol. 19, October & December 1990, pp. 525-533

Solar eclipses—A powerful tool for the study of nature

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Solar eclipses occur due to periodic coincidences in positions of the moon and the earth with respect to the sun. Characteristics of their orbital paths determine the periodicity, duration and shape, lengths and orientations of tracks of totality. Extreme reduction of background illumination helps observations of faint features surrounding the sun; sudden changes in the illumination level create impulsive conditions at different layers of the atmosphere which expose reaction mechanisms. Unusual disturbance in the circadian rythm affects the living world. The paper briefly reviews the phenomena of solar eclipses and scientific experiments performed during the event.

1 Introduction

The phenomenon of total solar eclipses is due to a strange coincidence in nature; the angular sizes of the sun and moon as viewed from the earth are almost equal. As a result of this coincidence whenever the earth, moon and the sun fall in a straight line in course of the orbital motions of the former two, the shadow cone formed behind the moon, generally, just reaches the earth's surface. Had the moon been slightly smaller in size, or a little too distant, no total solar eclipses would have been visible from the earth's surface, and humanity would have missed the grandest spectacle in the skies. The earth bound scientists would have then missed a very powerful tool for study of nature.

The unique favourable conditions created for studies during total solar eclipses, are in a strange way indebted to the presence of an atmospheric envelope surrounding our planet. On the airless surface of a body like the moon, the conditions for some of the solar eclipse observations can be created by relatively simple experimental set-ups. Such experiments, in fact, have been conducted from orbiting space observatories. But on the surface of the earth, these measurements are possible only during the few seconds of totality. There have been successful attempts to prolong the duration by transfering the platform of observation to a flying observatory aboard an aircraft racing with the shadow of the moon, but the occurrence of eclipse is essential.

Another important class of observations concerns the reactions of our atmosphere to the solar radiations; conditions of abrupt changes in the incoming solar radiation flux are created only during these events, and no artificial arrangements can simulate them. All vital observations in this field can be carried out only by well-planned sets of experiments employing ground-based, aircraft-, balloon- or rocket-borne instruments, during eclipses.

At the outset, it is better to recognize that the term "solar eclipse" is a misnomer. In astronomy two separate classes of events are known, namely (i) Occultations, and (ii) Eclipses. Occultations are those events which occur when a body coming in between the source and the observer cuts off the view of the former. On the other hand, eclipses occur for objects which shine in reflected light and when they enter into the shadow cone cast by another body. Lunar eclipses are real eclipses, whereas the events we call solar eclipses are really occultations of the sun by the moon. For satellites of Jupiter and Saturn, both types of events are regularly noticed; some times the satellites are occulted by the body of the planet, and some times they enter into the shadow cone of the planet, which we call eclipses. Solar eclipses, however, have firmly acquired the nomenclature long before we could understand the difference between the two classes of events.

2 Circumstances of solar eclipses

In trying to understand the events of total solar eclipses, one must recognize some peculiarities of the orbits of the moon and the earth. The earth's orbit projected on the celestial sphere is the great circle, ecliptic; viewed from the earth, this is the apparent path of the sun. Almost all planets follow the same path, with very minor deviations. But satellites of the planets, generally, lie along the equatorial planes of their parent bodies, which show large variations with respect to the ecliptic plane. In the case of the moon, the orbital plane does not coincide with the earth's equator, but lies closer to the ecliptic plane with a mean inclination of 5°08′, The orbit crosses the ecliptic at two points known as nodes. The two nodes being named as "ascending" or "descending", respectively depend upon whether the moon at those points cross to the north or to the south of the ecliptic. Eclipses can occur only when the moon is at either of the nodes.

Owing to a precessional motion of the lunar orbit, the nodes shift along the ecliptic, completing a round in 18.6 years. This ensures that eclipses can occur at any time of the year. The additional requirement for a solar eclipses is that the synodic position of the moon must also coincide with the sun, so that it is always a new moon day when it occurs.

Now, the motion of the moon along its orbit is far from uniform; in modern lunar ephemerides calculations more than 1,500 periodic terms have to be used. Neither is the apparent motion of the sun along the eliptic uniform. The net result is that the interval between two successive crossings of the node by the moon (nodical month) are not equal to those between two successive new moons (synodic month). Thus the coincidences necessary for solar eclipses occur only after a few lunations. As, the diameters of the earth and the moon are also involved in the calculations, the presence of the moon near (and not exactly at) the node is necessary; this ensures that coincidences are not infrequent. It can be shown that every year, atleast, two solar eclipses are expected to be visible from some part of the earth; the number can be as high as five in some years. On an average, in one third of the cases, the line joining the centres of the sun and the moon misses the earth's surface, and the eclipse is seen as partial. In other cases, the eclipse is central, and can be total or annular depending on the distance of the moon from the earth at that moment.

2.1 Durations and tracks of totality

The moon orbits the earth in an eccentric elliptical path; this makes its apparent size and motion both vary over a lunation. The eccentric orbit of the moon has an apsidal motion, as a result of which the line joining the perigee and apogee positions rotates along the orbital plane. This motion called the advance of apsides is relatively fast, and a complete rotation takes 8.85 years. The period between two perigee positions is known as an 'anomalistic month' and is slightly different from the 'nodical' and the 'sidereal' months, all of them being approximately two days shorter than the 'synodic month'. Table 1 shows the different types of month with their periods.

Table 1—Periodicities in lunar motion

Type of month	Days	Duration			
		days.	hr.	min.	s
Synodic	29.530588	29^d	12^h	44^m	$2^s.8$
Sidereal	27.321601	27^d	7^h	43^m	$11^s.5$
Nodical	27.212220	27^d	5^h	5^m	$35^s.8$
Anomalistic	27.554550	27^d	13^h	18^m	$33^s.1$

The eccentricity of the lunar orbit is appreciable, as a result of which the apparent diameter of the lunar disc varies considerably, the variation being of the order of 14%. The duration of totality of solar eclipses heavily depends on this factor. If the moon is at perigee at new moon near a node, the duration of totality will be long.

Like the moon, the earth also has an eccentric orbit, the eccentricity being smaller than that of lunar orbit. As a result, the apparent size of the solar disc also varies during the year. The solar disc is smallest in July and largest in January, the variation being about 3%. Other factors remaining equal, the longest period of totality will be in July with the moon at perigee, the sun on the meridian and the track running close to the equator. The duration of totality under those ideal conditions will be about 7 min 31s. The maximum duration actually observed in the present century was on 30 June 1954 over Southern Asia; with the sun on meridian over the Phillipines the duration was 7^m 8^s.

Total solar eclipses are visible only on the track of totality, which is the locus of the moon's moving shadow cone intersection with the earth's surface. All sorts of lengths and shapes are noticed depending upon the circumstances of the eclipses. Except over areas very close to the poles, all tracks generally move from west to east, the orientation being controlled by moon's motion on the celestial sphere. The orbit being close to the ecliptic, a general pattern of track orientations in different seasons can be estimated. The tracks run near-parallel to the latitude circles in solstice months; around vernal equinox (March), the tracks run from south-west to north-east, and around autumnal equinox (September) the shadow motions are from north-west to south-east. Because of the curvature of the earth's surface, the tracks are rarely straight. The departures are greater when the altitudes of the eclipsed sun is low and the morning portion of the track may have a different shape and orientation compared to the later afternoon portion.

The movements of the shadow are also not uniform. It is faster when the sun is low, and slow with the sun on the meridian. Since the rotational motion of the earth's surface is in the same direction as the motion of the moon, the speed of shadow is the difference between the two. On the equator, at midday the shadow motion is the slowest, and the duration of totality is longer than that at any other part of the eclipse track.

Annular eclipses occur when the shadow cone is shorter than the length required to reach the earth's surface. These usually happen when the moon is at or near the apogee. In critical cases, it often happens when the moon is at or near the apogee. In critical cases, it often happens that the cone just reaches the earth's surface only when the eclipse is near the meridian. In those events the eclipse starts annular at sun rise; the annularity decreases as the shadow reaches towards mid-eclipse area when it becomes total, and then turns annular once again for the afternoon portion of the central track. These eclipses are known as "annular-total eclipses". The eclipse on 24 Mar. 1987 starting from South America and then moving across the Atlantic and Africa was of such a type, the totality being observed only over the Atlantic Ocean at midday; all along the rest of the track it was annular.

2.2. Repetition of eclipses—The Saros

The occurrence of eclipses depends on the locations of the three bodies in space, namely the sun, the moon and the earth, which are changing with different periodicities. The three concerned periods are given in Table 2. It is noticed that once in a period of approximately 6,585 days, i.e. 18 years and 10 or 11 days depending on whether 5 or 4 leap years come in between, almost integral rounds of these periods are covered.

As a result of this coincidence, eclipses repeat every 6585 days and this was noticed by ancient Greek astronomers who had utilized this knowledge in the prediction of eclipses. The reasons for such repetitions called 'Saros' were explained by Edmund Halley in the eighteenth century.

Because of all the three period almost coinciding, the eclipses not only repeat, but their nature, durations and tracks become very similar. Only because of the residual fractional part of the day in the lowest common multiple, eclipses occur about one third of a day later, as a result of which the longitudes of the eclipse tracks are shifted by about 120° westward after each 'Saros' interval. This is illustrted in Fig. 1, where tracks of three recent eclipses of the same 'Saros' are shown.

Table 2—Coincidences in solar and lunar position

No. of complete months in a Saros	Type of month	Days
223	Synodic	6585.7806
247	Nodical	6585.3211
239	Anomalistic	6585.3572

A new Saros number start with an eclipse with tracks near one of the poles, then gradually drifts across and finally exits near the other pole. The interval between two eclipses of the same Saros is the usual 18 years and 10/11 days, and the series may last for several centuries.

It is necessary to bear in mind that the coincidences noticed are likely to change, if a long enough interval is chosen; for, the orbital characteristics of the earth and the moon show very small, yet definite changes with time. But over the last few millennia the repetition of Saros has been considered to be exact within narrow limits, and is likely to remain so for the next several thousands of years.

3 Experiments during total solar eclipses

Experiments conducted during total solar eclipses broadly concern three different disciplines: (i) Astronomy (ii) Geophysics and (iii) Physiology. As mentioned in the introductory section special conditions are created which favour some critical observations and measurements.

3.1 Astronomical measurements

The main object of observation during total solar eclipses is the sun. The two permanent outer layers of the sun, the chromosphere and the corona, surrounding the bright photosphere are not visible outside totality. This is due to scattering in our atmospheric envelope and the fact that these layers

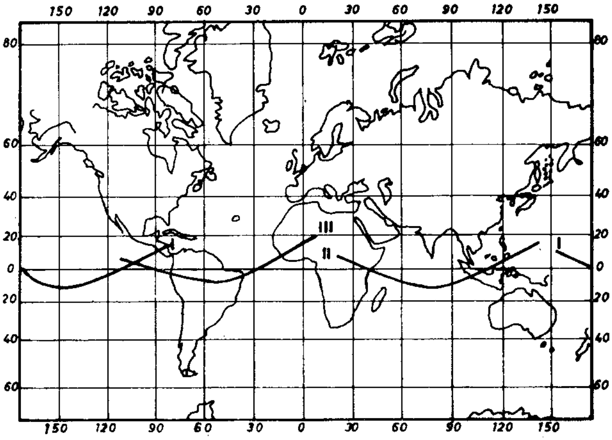

Fig. 1—Eclipses of Saros No. 130 (I, 3-4 Jan. 1908; II, 14 Jan. 1926; III, 25 Jan. 1944)

are several orders of magnitude fainter than the bright photosphere. Atmospheric scattering creates a strong halo around the solar disc which totally drowns the light from the two outer layers. During totality, the bright disc of the sun becomes completely covered, and the scattered halo vanishes, and the faint features surrounding the sun become visible and accessible for scientific measurements. The brightness levels surrounding the solar disc under various conditions are shown in Fig. 2.

The importance of these two outer layers, both in their effects on the surrounding space and in understanding the physical processes in the sun is enormous. Before the advent of the present space age, virtually all the information came from observations during totality. Even now, some of the critical measurements depend on the success of total solar eclipse observations.

3.1.1 *Chromosphere*—By employing advanced techniques in solar instrumentation, it is now-a-days possible to study, to a limited extent, the above two outer layers outside totality. For the studies of the chromosphere, the common instrument is the spectroheliograph, where narrow lines of emission or absorption are isolated and utilized to map this thin layer overlying the photosphere. The main information one gets is the distribution of brightness with its characteristic plages and supergranular cells, as well as some of the bright extended features (the prominences) over the active areas. The advantage for use of this technique is the possibility of studying temporal variations (growth evolution, life time etc.) of the visible features, but what it misses are the details. Even by using the largest spectroheliograph one gets a resolution of about 1,000 km on the sun, whereas theoretical speculations suggest finer vital features smaller than 100 km, which, if studied, will take our understanding of solar physics a big step ahead. Along with many other possibilities total eclipses provide this opportunity.

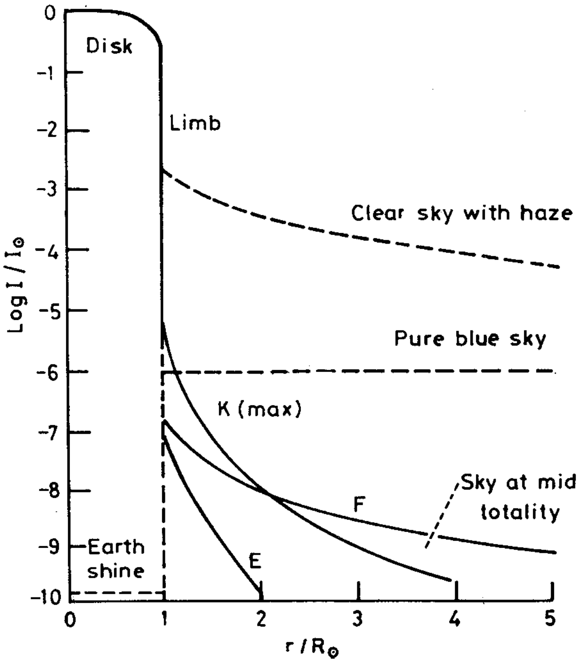

Fig. 2—Brightness levels surrounding the solar disc under various conditions

During eclipses, experiments are arranged to record spectra of the solar limb, as the occulting moon's edge cuts off radiations from different heights in the chromosphere. Projected on the solar disc the speed of the occulting edge of the moon is around 20 $\mathrm{kms^{-1}}$, thereby providing the much needed high resolution in determining the emission profiles of several lines simultaneously[1]. The sub-arc second structures known as 'spicules' have been best recorded during the few seconds near the second and third contacts, i.e. the beginning and end of totality. Even the true line profiles of chromospheric spectra are best obtained during this time, when chances of contamination from scattered light from the photosphere are at a minimum.

Several new ideas of chromospheric measurements have been attempted during recent eclipses. One such experiment has been the precise determination of the height of the temperature minimum region in the photosphere-chromosphere interface[2]. The idea is to monitor a set of temperature sensitive spectral lines as the advancing moon's edge covers or uncovers different heights in this region. Such information cannot be obtained without the use of this type of events.

3.1.2 *Corona*—Among the solar experiments during eclipses, an overwhelming majority is concerned with the outermost region, the corona. This extensive feature which is visible in its full glory during totality, is practically inaccessible at other times. Special instruments like 'Lyot Coronagraph' have, of course, been constructed, by means of which, the brightest portions of the inner corona are available for measurements; these instruments require locations on very high mountain tops to reduce the atmospheric scattering to very low levels, but even there, outer regions of corona are missed. From space laboratories, corona can be made visible by blocking the photosphere with occulting discs, but practical limitations aboard spacecrafts prevent measurements with high spatial and spectral resolutions. For precise measurements of corona in the visible bands, use of total solar eclipses is still inescapable.

The main problem underlying coronal observations during eclipses is the small interval of time over which the observations are limited, giving fragmentary information. The shape and distribution of brightness over the corona vary from eclipse to eclipse, and it is only possible to derive some idea of the general physical conditions in the coronal regions. Experiments during solar eclipses have, therefore, concentrated more on the verifications of ideas that have arisen from coronal models.

To give an example, it is known that high temperatures exist in the coronal region; the information is derived from the strengths of various emission lines from highly stripped Fe and other ions. Now the high temperatures also broaden the line profiles. Another agency which can create this broadening is the presence of microturbulence, i.e. turbulence whose scale lengths are much smaller than the resolution limits of measurements. Attempts have been made to separate out the two effects. Over the past few eclipses, experiments have been conducted[3,4] aiming at studying the coronal line profiles with high spectral resolutions. Analyses of the results have provided estimates of the microturbulence in corona and an independent measure of the temperatures.

Temperatures in the corona vary with the height above the solar photosphere. This has been found from coronal spectra taken during earlier eclipses; but do they have any azimuthal variations? It was discovered serendipitously by the Indian team at Miahuation, Mexico, during the total eclipse of 7 Mar. 1970, when along the spectrograph slit over the lower corona, pockets of low temperature zones were found[5]. In subsequent eclipses narrow band filter pictures have confirmed the findings[6].

In recent times, availability of image intensifying devices and high quantum efficiency detectors have made some experiments possible. There are more yet undiscovered faint lines in the coronal spectra which could not be recorded within the limited time span of totality by earlier devices; now they appear to be well within the reach of eclipse observers.

Several other questions of astrophysical interest about the corona are sought to be answered during eclipses. The polarization of coronal light has been measured and compared to earlier eclipse observations and simultaneous disc observations from uneclipsed sites to understand the mechanism and nature of the scattering medium and influences of the solar magnetic fields[7]. The fine rayed appearances of corona and the loops and holes are sought to be extracted from eclipse photographs by elegant photographic techniques and correlated to the underlying photospheric magnetic field structure.

Although no direct advantage of greatly diminished background light is applicable to radio observations, solar eclipses have helped certain high resolution measurements. The sources of radio emission observed from the sun lie totally in the corona, and even the biggest apparent disc of the moon cannot totally occult it. All eclipses of the radio-sun are, therefore, partial. But as the advancing lunar limb covers or uncovers small bright regions, the total flux received displays changes, from which the locations and strengths of those emitting regions can be determined. In the earlier days of radio-astronomy such information could not be obtained otherwise; but nowadays very long base lines are utilized in radio-interferometry rendering the eclipse methods obsolete.

Similar experiments aiming at estimating the strengths and locations of high energy radiation sources on the sun were conducted by measuring the changes of ionization densities in the upper atmosphere during eclipse. Directly imaging ultraviolet and X-ray sources from space telescopes have made this method redundant. Ionospheric changes, however, continued to be carefully monitored during eclipses, but for different purposes as mentioned in later sections.

3.1.3. *Photospheric measurements*—Eclipses make some of the measurements of the bright disc of the sun possible which are beyond reach at other times. Two such measurements are described as examples; there are others which have been attempted, and many new ideas keep coming up.

The bright limb of the solar disc shows a gradual darkening towards the edge; the effect is due to the vertical temperature gradient in the top photosphere. Its precise measurement is vitiated under normal conditions by the scattered light. Close to the totality when rest of the disc is covered, the measurement of limb darkening gradient can be done very precisely. Such measurements are also done in annular eclipses[8].

In our efforts to understand the physical processes in the sun, one question about its variability constantly arises. The question concerns not only its luminous output, but also its size. In normal times the uncertainty in determining the solar diameter is about a thousand kimometres. During eclipses it is possible to estimate the same with much higher accuracies. The method consists of precisely determining contact times from a few places along the track of the totality. A scientific group from the U.S.

Naval Observatory has been painstakingly collecting the data in all present day eclipses[9]. They have even traced back old eclipse records of the last two centuries, when observations from locations at the edges of totality have either seen total eclipses or just missed it. Such records intrinsically give accuracies of about a kilometre or less. They have been able to estimate that probably the sun has shrunk in size by a few hundred kilometres over the last two centuries.

3.1.4. *Search for faint bodies in the solar system*—Some of the bodies in the solar system, which shine by reflected sunlight, become very bright when close to the sun. But their detection at this phase is vitiated by the scattered halo of sunlight. A total eclipse creates a condition when under a very low scattered background these objects become detectable. Atleast one comet was discovered this way during an eclipse[10], and some newly discovered bodies observed over the past hundred years[11]. At one time, an intramercurial planet was believed to exist, which could explain the excess perihelion movement of mercury's orbit. The object, which was given a name Vulcan, reported as found during one total eclipse[12], but later observations failed to confirm the discovery.

During the total solar eclipse of 16 Feb. 1980 in India, a team of scientists searched around the eclipsed sun for a possible dust ring[13]. They employed a near infrared detector scanning the area where indications of the ring was supposed to exist; the results were inconclusive.

3.1.5. *Tests for general theory of relativity*—Perhaps the most famous of the eclipse experiments in the present century was the test for bending of light close to the solar limb as predicted in the general theory of relativity (GTR), first conducted during the total eclipse of 29 May 1919 in Brazil. The theory predicted that while passing close to the solar limb, light rays from distant stars will be bent inwards, as a result of which the stars' apparent positions should be shifted away from the sun. The experiment consists of taking deep exposures of the eclipsed sun, so that some of the background stars are photographed through the corona. The positions of those stars are measured and compared with standard measurements of the same field obtained through regular astrometric methods. The amount of shift was predicted as 1.75 arc sec. Although it is definitely above normal errors expected in such measurements, actual results showed large scatter around the predicted value[14]. The experiment was repeated several times in many eclipses later, and the reality of the shifts has been established. Still further refinments have been introduced. Experiments have been performed by keeping the telescope system undisturbed and taking photographs of the same field six months later by the same system when the region is available under the identical elevation so that even small errors due to differential atmospheric refraction etc, can be eliminated. The main aim is to reduce the scatter of the observed data. Although this aspect of the GTR has been verified from other laboratory measurements, the eclipse method still holds out a fascination for the scientists.

Another experiment aimed towards the verification of GTR was the measurements of small shifts in spectral lines from the solar limb[15]. The expected deviations known as Einstein shifts are very small and total eclipses are favoured because of low contamination by scattered sunlight spectra. The results obtained so far have been inconclusive, because sun's surface gravity is not high enough to give unambiguous indications. Scientists are considering looking for these effects in other supermassive objects in the universe, a large number of which have been discovered in recent years.

3.2 Geophysical measurements

The physical conditions of the outer layers of our planet is strongly influenced by the sun. The temperature and ionization structure, chemical composition, dynamics etc. of our atmospheric envelope are controlled mainly by the solar radiation flux. On normal days at any point of the globe the changes of flux are gradual, and the response characteristics of atmospheric layers are the resultant of many factors which are difficult to estimate separately. During eclipses, sudden changes of radiation flux are produced whose effects on the behaviour of different layers disclose some characteristics of the responses of the atmosphere to solar radiation.

3.2.1 *Troposphere*—Eclipse experiments concentrate on three layers of the atmosphere: (i) Troposphere (ii) Stratosphere and (iii) Ionosphere. The boundary layer, overlying the surface of the earth, has its temperature and turbulence structure influenced by the energy input through insolation. With the progress of the partial phase of the eclipse, the solar flux diminishes rapidly, which results in drop in air and soil temperatures and changes in the surface wind pattern. Electrical characteristics of the boundary layer also change. All these give important clues to the interaction mechanism between the incoming solar radiation and the lower atmosphere. Aims of these experiments are to faithfully record the variation, magnitude and pattern of these parameters.

An atmospheric optical phenomenon, the characteristic of total eclipses, has attracted considerable attention of scientists. This is the phenomenon of 'shadow bands' which manifests itself in the final moments before totality. This is believed to be equivalent to the twinkling phenomena observed in case of stars. In the final moments, before totality, the dwindling solar crescent takes the form of series of bright point sources, and the illumination pattern on the ground becomes the unsteady interference fringes caused by turbulent inhomogeneities in the lower atmosphere. Although spectacular, the phenomena do not represent any unusual happenings. In dark night, all the bright stars create these bands, but they are too faint to view with naked eye.

Part of the ozone in our atmosphere is found in the lower layers which has been seen to get changed during eclipses. The production mechanism is not fully understood. It is believed that part of the ozone found in the upper troposphere comes through diffusion from the stratosphere. Eclipse, perhaps, disturbs the transport mechanism resulting in temporary decreases[16]. These studies form an important part of the geophysics experiments during eclipses.

The moon's shadow cone rushes through the atmosphere at supersonic velocities. Across the edge of the shadow, physical conditions change and the fast moving edge is likely to create a shock front, which could generate shock waves. In a few recent eclipses, attempts to detect and study these waves have been made[17]. Based on these results, refinements in measuring techniques are being planned for future eclipses.

3.2.2 *Responses in the stratosphere*—Rapid decrease of the ultraviolet flux from the sun was earlier thought to produce temporary reduction in ozone concentration, but considering the slow response time of the stratospheric layers, it is highly unlikely that such an effect will be observed. But large temperature changes have been observed at the heights during eclipses[18], suggesting other minor constituents which play vital roles in atmospheric heating. One of the major experiments during eclipses is the precise monitoring of the temperatures at all heights, which are expected to give vital clues to radiative transfer mechanism in upper atmosphere, and the role atmospheric chemistry plays in the process.

Appreciable changes in the cooling rates at these layers open up the possibility of generating gravity waves at the edges of the eclipse shadow cone. Although indications of such waves have been detected both at lower and upper layers, no convincing proof of their existence in the middle atmosphere is yet known. As the role of the middle atmosphere in the overall climatic control is believed to be vital, all possible means of understanding the behaviour of this region are employed; total solar eclipses happen to provide one such means.

3.2.3 *Ionospheric effects*—Of all the layers of the ionosphere, the lowest D-layer appears to directly show the effects of solar radiation flux changes. The layer normally disappears after sunset. Besides the quantity of radiation, other factors determining the ionization density are the atmospheric chemistry and physical properties. Observations during eclipses consist of studies of height profiles of temperature, O_2 density and nitric oxide concentrations[19]. Changes are expected to clarify the exact processes in the formation of the D-layer. Precise quantitative measurements are still needed to put the idea on a firm base.

Around these heights, anomalous changes in the ozone concentration have been noticed in some eclipses. The concentration of ozone increases with the reduction of solar radiation flux. The possible explanation of the effect is that not only the production, but also the destruction is controlled by the ultraviolet radiation from the sun; the delicate balance between the two processes are disturbed during the eclipse. Similar anomalies are noticed in the absorption of radio waves propagating through these layers, and efforts are made during eclipses to carry out controlled observations which may shed some more light on these processes.

Because of the slow response of the upper layers to the changes in radiation flux densities, no large effects are noticed due to eclipses at these heights. But signatures of gravity waves in these layers have been detected during past eclipses, indicating other factors and reactions which we have failed to take into account in our understanding of these layers based on normal day observations. Persistent effects noticed during eclipses point out those gaps in our understanding of the physical processes in the upper atmosphere.

Ground-based or rocket-borne geomagnetic observations also show peculiarities in changes during total solar eclipses. The explanations, however, are not simple, as contributions of many layers and many agencies may be involved. Present efforts are to carefully and precisely measure those changes and preserve the records. We are all aware of cases in the history of science, when such measurements have provided vital clues to our understanding of nature.

3.3 Physiological measuements

Several experiments on living organisms continue to be conducted during total solar eclipses. The subject organisms range from unicellular protozoic animals or plants to human beings. The main question sought to be answered is whether the circadian rhythm observed in living beings are largely or even solely controlled by day light.

Experiments in the past covered the studies of movements of zooplanktons, shoals of fishes, birds, insects, molluscs, even domestic cattle[20-23]. Certain physiological functions, e.g. oxygen uptake in animals have also been studied to look for some abnormalities during eclipses[24]. Detailed studies of physiological changes on human volunteers are also conducted[25].

Some of the experiments aim at disproving or confirming some of the superstitious beliefs rooted in the minds of common men. One such belief is that viewing eclipse by pregnant females results in deformed foetuses. No recorded cases of human volunteers are available, but controlled experiments on sheep have shown no such effects[23]. The superstition, however, lingers on and more experiments in future eclipses may be reasonably expected.

On human mind, the effects of total solar eclipses are varied and strong. The unusual darkness and stillness all around, the display of shadow bands and the magic spectrum of solar corona in the sky, all create a sense of wonder and awe. Reactions in primitive minds had been a feeling of abject terror, which still survives at the depths of the present day enlightened human brains. The custom of fasting, penances and ritual baths after the event are all remnants of the original fear. Some of the carefully measured physiological responses of human bodies cannot be free from each psychological stresses.

4 Importance of eclipses in scientific research

In recent times, the utility of eclipse events in scientific experiments has been questioned. The main point raised therein is that, in the view of availability of space observatories, the monopoly of eclipse events in studying the solar corona no longer exists, and the huge expenditure on eclipse expeditions becomes infractuous. The question, however, is based on incomplete information. It is true that artifical occultation of the solar disc is possible from space observatories, when some details of solar corona can be studied; but the quality of these studies cannot match that of ground-based instruments. Spectral and spatial resolutions obtained in eclipse experiments are still beyond reach of space observatories. In fact, most of the space experiments concern measurements at those parts of the electromagnetic spectra which are inaccessible from ground, e.g EUV, XUV, X-rays and gamma rays, leaving the task of collecting information of visual corona during total eclipses from ground, and sometimes cost of eclipse expeditions are orders of magnitude lower than that encountered even in the simplest of space experiments.

Space observatories can offer an alternative means of getting solar information, but these are totally inadequate for answering queries in geophysics whose answers are sought during eclipses. Conceptually it is possible to create occultations by man-made discs flying in orbit around the earth, which would create shadow zones simulating total eclipses; but the size of that disc has to be much bigger. For an orbit keeping a height of about 400 km, the disc needs to be of about 4 km in diameter for the umbral cone to just reach the earth's surface (for creating a shadow zone of about 10 km, it must be 14 km in diameter). For geostationary orbits, the disc should be of 400 km diameter; these feats are still far beyond the capabilities of present day space technology.

To sum up; total solar eclipses still provide the most convenient means for studying the outer layers of the sun and the response of our atmosphere to the energy flux radiated by it. Until further advancements are achieved by man in mastering the nearby space, it will continue to be the most powerful tool for the scientists aiming at unlocking the secrets of the sun and our near space environment.

References

1 Dunn R B, Evans J W, Jefferies J T, Orrall F Q, White O R & Zirker J B, *Astrophys J* (*USA*), 150 (1967) 1167.

2 Bappu M K V, *High resolution spectrophotometry of the extreming limbs of the sun* in *Total solar eclipse, February* 16, 1980, *general information, P.* 16.

3 Livingston W & Harvey J (Editors), *Proc Int Sci Acad* (*USA*), 48 Suppl 3 (1982) 18.

4 Singh J, Bappu M K V & Saxena A K, *J Astrophys & Astron* (*India*), 3 (1982) 249.

5 Bappu M K V, Bhattacharyya J C & Sivaraman K R, *Sol Phys* (*Netherlands*), 26 (1972) 366.

6 Sivaraman K R, *Experiment in* 1983 *total solar eclipse, Indonesia,* unpublished.

7 Sivaraman K R, Jayachandran M, Scaria K K, Babu G S D, Bagare S P & Jayarajan A P, *J Astrophys & Astron* (*India*) 5 (198) 1 9.

8 Saito K & Hata S, *Publication of Astronomical Society of Japan,* 12, 1960, 143.

9 Fiala A D, Dunham D W, Dunham J B, Sofia S, *Bull Am Astron Soc* (*USA*), 17 (1985) 62 .

10 Trepied C, *Compte Rendus* (*France*), 95 (1882) 898.

11 Swift Lewis, *Popular Astronomy* (*USA*), 3 (1895) 159.

12 Airy G B, *Nature (GB)*, 18 (1932) 495.

13 Rao R, Alex T K, Iyengar V S, Phadke M S, Prasad P D, Kasturirangan K, Marar T M K, Mathur B S & Sharma D P, *Observation of total solar eclipse of 16th February* 1980 *(preliminary results)* INSA, India, 1981, p 26.

14 Dyson F W, Eddington A S & Davidson D (Editors), *Mem R Astron Soc (GB)*, 52 (1923) 291.

15 Royds T, *Mon Not R Astron Soc (GB)*, 97 (1937) 692.

16 Chatterjee *et al.*, *Proc Indian Natl Sci Acad*, 48, Suppl 3 (1982) 125.

17 Raghava Rao, Desai J N, Martelli G & Pamela Rothwell, *Observations of total solar eclipse of 16th February* 1980 *(preliminary results)*, INSA, India, 1981, p. 97.

18 Subbaraya B H, *Observations of the total solar eclipse of 16th February* 1980 *(preliminry results)*, INSA, India, 1981, p. 101.

19 Subbaraya B H, *Proc Indian Natl Sci Acad*, 48A Suppl 3 (1982) 494.

20 Bhattacharyya S S, *Observations of total solar eclipse of 16th February* 1980 *(preliminary results)*, INSA, India, 1981, p. 120.

21 Datta Munshi J S, Ghosh T K & Biswas N, *Observations of total solar eclipse of 16th February* 1980 *(preliminary results)*, INSA, India, 1981, p. 122.

22 Anasuya D R & Gopinath K, *Observations of total solar eclipse of the 16th February* 1980 *(preliminary result)*, INSA, India, 1981, p. 115.

23 Uppal P K, Kamal Kishore, Balwar L M, Prasad V S S, Banerjee R & Ravindra Kumar, *Observations of total solar eclipse of the 16th February* 1980 *(preliminary result)*, INSA, India, 1981, p. 131.

24 Radhakrishna Murthy P, *Observations of total solar eclipse of the 16th February* 1980 *(preliminary results)*, INSA, India, 1981, p. 124.

25 Shanmukhappa N J & Narayana Shetty C S, *Observations of total solar eclipse of the 16th February* 1980 *(preliminary results)*, INSA, India, 1981, p. 126.