XXII.—*Observations on a Green Sun and Associated Phenomena.* By Professor
C. MICHIE SMITH. (Plate XLVII.)

(Read July 7, 1884.)

The appearance of a green or blue sun, though not unknown, is of sufficiently rare occurrence to make a full investigation of all the phenomena connected with it highly desirable. I have therefore tried to obtain as accurate and complete information as possible concerning the appearance of a green sun in India during several days in September 1883.

The general features of the phenomena were well seen in Madras, and will probably be best described by my notes taken at the time. On September 9th the sun before setting assumed a peculiar silvery appearance, and its brightness was so much decreased that for about half an hour before sunset it could be observed with the naked eye. This was observed, I believe, though to a less extent, on the two days preceding, but I did not myself see it on these days. On September 10th, from 5.0 to 5.30 P.M., the sun could easily be looked at with the naked eye, yet the limbs were sharply defined. At 5.30 the sun entered a low bank of clouds, and did not fully reappear again, but a narrow strip seen through a rift in the cloud at 5.43 was coloured a bright pea green. Round Madras this colour had been seen in the morning, but in Madras itself clouds concealed the sun till it had risen to a considerable altitude. Of the morning of the 11th I have no record, but in the evening the green colour was very brilliant, and was visible for more than half an hour, being preceded, as on the former night, by the silvery white appearance of the sun's disc. On this evening a large sunspot about one foot long was so conspicuous an object that it attracted the attention of even the most casual observers.

September 12th, at 12.35 A.M., the moon, which was near the horizon, appeared a pale green. Bright stars near the horizon showed the same tint. From 5.15 to 5.30 the clouds to the east were coloured reddish-brown. At 5.55 the sun rose with a yellowish-green colour, but was almost instantly lost in clouds. It reappeared at 6.4, and was then of a bright green colour; this colour rapidly got fainter, but was quite perceptible till 7 o'clock. In the afternoon, the phenomena of the previous nights were repeated, and the horizon being free from clouds, the actual sunset was observed. The entry in my notes is—"6.3, the sunset as a greenish-yellow ball, cumulus, stratus, and nimbus clouds near the horizon, but moon fairly clear. Some blue sky, but hazy." The change from green to greenish-yellow was evidently due to the great increase in the strength of the

low-sun band close to the horizon, which left the strip of yellow between that band and the rain-band by far the most prominent feature in the spectrum.

September 13th.—In the early morning there was a good deal of distant lightning. The sun rose of a bright golden yellow colour; no green was seen. In the afternoon there were slight showers. A most remarkable observation made this morning by Mr Pogson seems very difficult to explain, except by some form of auroral display. I give his notes in full:—

“*September 12, 1883, 17^h 0^m, Madras mean time.*—The sky a most remarkably intense reddish-yellow, so unusually bright that I called up my daughter Isis to witness it. A dark cloud bank from about east to south, and the vivid light above uncommonly auroral in appearance; more so than anything I have seen here before.

“At 17^h 10^m, the red hue considerably diminished, and bright orange yellow the prevailing tint. The light quite bright enough to make notes by.

“At 17^h 20^m, the dark blue-black stratum now from about north to east, and very near the horizon. Sky tolerably clear to about 20° altitude, but of a rich red tint, with bright yellow clouds above, beginning at about 30° and covering the east of the sky.

“At 17^h 30^m, all changed within the last four or five minutes, and writing now difficult without a lamp. A thick dark red stratum over the sunrise point, and everywhere else a very greenish-yellow.

“At 17^h 40^m, the low cloud stratum now sea-green. Light only enough to write by with difficulty.

“At 17^h 50^m, sun rising a bright yellowish-white, and otherwise nothing extraordinary, all unusual tints having disappeared with the sunrise.”

September 14th.—Before sunrise the clouds were blue and grey, with patches of red. Clouds of all sorts,—cirrus, nimbus, stratus, cumulus, and mare's tails. Two bright flashes of lightning about 5.30 A.M. In the evening there was a slight green tinge, and after sunset the sky was golden red till 6.50, while mercury seen through the red haze was twinkling strongly.

September 15th.—The sun rose golden. In the evening the sunset was very fine; in the west the colour was golden to orange yellow, in the east it was greenish; red clouds remained till 7.5; there were very brilliant red “rayons de crépuscule.”

From *September 15th to September 20th* the sunrises and sunsets were very fine, with red and gold for more than half an hour before sunrise and after sunset.

September 21st.—Sunset normal.

September 22nd.—The sun rose as a yellow ball, and showed distinct greenish-yellow afterwards. From ten minutes before till sunset, the sun was greenish-yellow, but the sun was much brighter than on the 10th and 11th.

September 23rd.—The sun rose very green. At 5.37 P.M. the sun appeared

from under clouds very green. Strong absorption in the red end of the spectrum to C, low-sun bands weak. 5.45, clouds greyish-purple. There was only one bank of clouds which was near the horizon; above this was a peculiar greyish haze. At 6.0 the clouds were of a marked purple colour; breaks near the horizon were reddish-brown. During the night there was a great deal of sheet lightning in the south.

September 24th.—The sun rose bright yellow. The spectrum showed complete absorption up to B; the rain-band, α and β were very thick, and the low-sun bands less marked than usual. There was lightning all night, beginning in the south and working round to the south-east. It consisted chiefly of sheet lightning, with occasional zigzag flashes, but no thunder; the stars were fairly clear except near the horizon. Saturn and the moon, when near the horizon, were both very dim.

September 25th.—Sunrise golden green. In the afternoon the shadows cast on white paper were still quite pink, but the sunset was bright yellow.

September 26th.—Much the same as yesterday.

September 27th.—Before sunrise C, β , α , the rain-band and the dry-air band were very strong, but the dry-air band was less than half as dark as the rain-band. The sun rose golden red. The spectrum showed signs of clearing up; glimpses of A could now be obtained. After dark there was very bright lightning in the west—sheet lightning, with a good deal of zigzag, and at least one very fine specimen of a flash such as is obtained by discharging a Leyden jar through a spangled tube, the flash being broken up into a number of detached pieces. During the day there were slight local showers in parts of the town.

September 28th.—Spectrum still showed great absorption. Lightning at night.

September 29th.—Absorption still very strong. After dark there was a display of luminous clouds, specially towards the east. After 11 P.M. there was very heavy rain, with much lightning and some thunder.

September 30th.—Sunrise golden. The spectrum on the sun showed A clearly, and was very thick.

October 2nd.—In the morning from about seven to nine, there was a thunder-storm, in which the thunder was almost continuous for above an hour and a half; but though the storm was almost vertically overhead, hardly any lightning was visible. Apparently the discharges were chiefly from cloud to cloud, and the thick layers of heavy clouds overhead shut out the flashes. The thunder was followed by heavy rain. The official Meteorological Report contains the following reference to this storm—"The weather on the 2nd instant was decidedly remarkable; thunder in the morning; heavy rain at noon, exactly

three inches being recorded by 1 P.M., and continuing less heavily, but steadily till 10 P.M. The total rainfall for the day was 4·88 inches."

To complete the description of the phenomena, I will now quote from the accounts of some reliable observers in other parts of the Presidency. The following is from the diary of the superintendent of the lighthouse at Muttum, in the south of Madras, for September 1883 :—

"6th, 7th, 8th.—After sundown on these days there was a very peculiar saffron glare, which faded as it became dark. On 8th it was very marked.

"9th (*Sunday*).—This day, from about 4 P.M., the sun became perfectly green, and could be looked at without any inconvenience. The saffron glare after sunset seen. The green appearance of the sun continued several days, both in the morning and the evening.

"13th, 6.30 P.M.—A large meteor [? a fire-ball] passed from west to north-east. It burst three times and faded away.

"15th.—There were observed on this day five clusters of spots on the sun; the green tint has been lost, and the sun is of a natural colour.

"22nd.—Sun again appeared of a very green colour, which continued every day up to the 28th."

The next account is from Bellary :—

"*Sunday, 9th September*.—Sun set as usual, but after sunset a lurid glare spread over the sky, the colour being red with mauve in it. [Another correspondent writes that he thought the infantry lines were on fire.]

"*Monday, 10th*.—Sun, both at rising and setting, emerald green.

"*Tuesday, 11th*.—Again the same appearance both at rising and setting.

"12th, 13th, 14th.—Emerald green at sunset. After this week no record."

From Coonoor, on the Nilgiris, more than 6000 feet above sea-level, I have the following notes from Mr J. F. GELL :—

"Sunday week (9th) was remarkable chiefly for a persistent red glow, likened by many to the reflection of some great fire. Our sunsets have been gorgeous for several days, always abounding in the peculiar pea-green tints. Last evening (20th) the eastern sky and the whole landscape showed a most lovely and unusual greenish glow. After sunset a few clouds in the east were tinted lilac. The more distant mountains stood out very distinct against the green—clear but somewhat deep—of the sky. All near trees and other objects at hand had a 'scene-painty' (chromium oxide suggested) green tint. Red predominated in the western sky on the many clouds; but there was an intensely luminous area of hardly yellowish light near where the sun had set, which must have continued an hour. The 'shimmery' appearance of the sun, and the ease with which it could be looked at during Monday to Thursday, were remarked everywhere. There has been a good deal of bright lightning seen at some distance over the plains on many days."

This is particularly interesting on account of its close resemblance to the description so often given of scenes in hill countries just before heavy rain.

Mr MANLEY's observations at Ongole, which is the farthest north point at which satisfactory observations seem to have been made, have already been published in *Nature*, and need not be repeated here.

The Spectrum.

The observations on the spectrum were made partly with a direct vision spectroscope, with a lens in front of the slit (HILGER's rain-band spectroscope), but chiefly with my zodiacal light spectroscope, which has a single large dense glass prism and a collimator three feet long. The great length of the collimator permits the use of a very wide slit, which was found to be a great advantage in this case. The only means of recording the positions of the lines is by reference to a reflected scale; and since all the lenses of the instrument are quartz, the focus of the observing telescope, and consequently of the scale also, has to be changed for different parts of the spectrum. This was found very inconvenient when it was necessary to take a number of readings in different parts of the spectrum in rapid succession. The positions of the bands cannot be considered as strictly accurate, but they cannot be far wrong, as they were fixed by reference to known lines near them, and the scale values for the different parts of the spectrum were obtained by plotting the scale readings for known lines in terms of wave-lengths, and smoothing the curve. The main features of the spectrum taken *on* the sun when green were—

(1) A very strong general absorption in the red end.

(2) A great development of the "rain-band" and of all other lines which are ascribed to the presence of water vapour in the atmosphere, more especially of the group C_1 of α , and of the band at W.L. 504.

The absorption in the red end was of very varying intensity; but when the phenomenon was at its maximum phase it gradually crept up from about B till past C, as the sun sank towards the horizon. On the 12th, when the sun was within a few degrees of the horizon, the absorption was well marked up to W.L. 621—*i.e.*, to beyond α , while at the violet end the visible spectrum ended at W.L. 428, or just beyond G.

The lines A and α were never visible, even *on* the sun, when it was green, and even B could be made out with difficulty from half an hour before sunset onwards; and before it vanished it grew intensely prominent, with enormously thick bands on the less refrangible side. The band C, on the more refrangible side of C, became very broad and black, while the fine line between this and C remained thin and sharp, and C itself thickened out on the less refrangible side. The rain-band was stronger than I have ever before observed it on the plains;

and even with the dispersion produced by a single prism, at least eight lines could be measured in it, while many more were visible.

The low-sun band was not very conspicuous; but this was partly due to contrast with the very strong rain-band. The line W.L. 568 at the more refrangible side of the low-sun band was very well marked, and the band itself seemed to consist of a series of equidistant lines. The apparently much stronger absorption in the red than in the blue end was a very marked feature, which became still more conspicuous when a photograph of the blue end was examined.

A photograph was taken on the evening of the 23rd September, when the sun was very green, and the visible spectrum extended between W.L. 645 and W.L. 410. Half of the slit was exposed for twenty seconds, and the other half for thirty-three seconds. Both gave good photographs, extending from about F to a distance beyond H, twice as great as the distance between F and H. This is very nearly the same length as I obtain under similar circumstances in ordinary weather, though not nearly so long as I obtained last summer at an altitude of 6000 feet. The lines were sharp and well defined, and contained no bands that were specially prominent, though some seemed darker than usual. I have, unfortunately, no means at present of making an accurate determination of these lines. The atmospheric band C was very strongly marked, and was decidedly more conspicuous than C itself. It was thick and dark even at an altitude of 60° or 70° in the middle of the day, and formed then, next to the general absorption, the most characteristic feature of the spectrum. The contrast of the thin line between C and C' with these lines was most interesting.

Since the passing away of the abnormal conditions, I have made careful observations of the sunset spectrum with the same apparatus, and I find that ordinarily A and α are clearly visible, as well as B, though at times they are strongly marked, and a good deal of shading is observable between them. C' is much thinner, and the rain-band is less prominent than the low-sun band, which, however, does not now have the appearance of a number of fine lines. The nearest approach to the green sun spectrum was observed recently during a severe thunderstorm, which was accompanied by a fall of about $1\frac{1}{2}$ inch of rain.

A very similar though less intense spectrum can be observed almost any evening by taking advantage of the passage of a small thin cloud over the sun's disc. If a lens is used in front of the slit of the spectroscope, the absorption due to the cloud will be seen as a band in the middle of the bright spectrum from the unclouded part of the sun; and, owing to the strong contrast, the details of the absorption will be well seen, just as in the case of a spectrum of a sunset.

Meteorological.

My attention was first called to the peculiar state of the atmosphere on September 3rd, when making observations on atmospheric electricity. Observations made at 10 A.M. on August 31st showed a normal but rather low electrification; no observations were made on the 1st or 2nd September, the electrometer being out of order. On the 3rd, after the instrument had been carefully dried, observations were begun at 1.10 P.M., when the air potential was found to be negative, the electrometer readings varying from -28 to -17 divisions. By 2.45 it had become positive, amounting, however, to only $+6$, which was also the reading at 4.45. During the succeeding days numerous readings were taken, and these show a remarkable state of electrification (see Appendix A). The general results of the observations may be summed up thus:—In the early morning the potential of the air was positive; it continued positive, but gradually decreased in strength till some time between 9 and 10 A.M., when it fell to zero, and then became negative. The strength of the negative charge varied greatly and with remarkable rapidity, and the maximum readings were obtained either just before or during strong gusts of wind. The negative charge continued till the sea breeze set in in the afternoon, when it became positive, and continued so all night, and in all cases, I believe, the change of sign coincided with a change in the direction of the wind. Very high readings were at times obtained; in one case the reading was -459 divisions of the scale (=about 1900 Daniell cells or 2100 volts) at about 5 feet above the ground, in bright sunshine with a clear sky, but with a gusty wind, which raised clouds of dust. At other times there would be scarcely a trace of electricity perceptible. In all cases in which the potential was negative it decreased with height, but when it was positive it increased with height. Another point worth noticing is that, when negative, the potential might vary very much, but with two exceptions (and these are a little doubtful) it did not change sign, as one finds so often in a thunderstorm. This state of affairs continued from September 3rd to September 6th. On the 7th the potential was positive all day, the day being cool and cloudy throughout. On the 8th it was negative for a short time; on the 9th it was again positive all day; on the 10th, 11th, and 12th, it was as from the 3rd to the 6th; from the 13th to the 19th it was normal, though on the last of these days it fell to zero at 11 A.M. From the 20th to the 27th it was again abnormal,—positive till about 9.30 A.M., then negative and then positive again,—except on the 23rd, when the lowest reading obtained was zero. After the 27th the readings were all positive.

It will be observed that all the negative readings were obtained when the

wind was westerly, and after the day had so far advanced that the ground had begun to grow hot. This westerly wind is a hot land-wind, and on a previous occasion I obtained negative readings during its prevalence (*Proc. Roy. Soc. Edin.*, vol. ix. p. 615), but then there were local showers a few hours afterwards. Thinking at the time that this was probably a similar case, I wrote a note to the local papers on the 6th, asking particulars of the weather within a radius of 100 miles of Madras, especially with reference to rain, thunder, and lightning, and wind direction between the 1st and 6th of the month. In reply to this I got information from various stations which was of considerable interest, but apparently no rain fell within 100 miles of Madras up to the 6th, but on that day there were a few showers in and around Madras (0·03 inches at Madras Observatory). On the same day there was a storm at Tindivanam, about 75 miles south of Madras, which is thus described by a correspondent :—"At about 3 P.M. on the 6th a severe storm passed over this place, direction west by a little south to east by a little north. Wind preceded rain by a quarter of an hour, and blew steadily (not in gusts) for an hour; velocity not known, but must have been very great. . . . Rain fell in torrents from 3.15 to 3.45, and from this time till 6 P.M. it continued to drizzle. There was only one clap of thunder, which lasted some two or three minutes, and seemed to roll on eastward; it took place about 3.30. This seemed to break the violence of the storm. . . ."

Of this storm, which seems to have been very violent and local, I received another account from a gentleman who passed through it in the train, and who stated that the storm was such as he had seldom, if ever, experienced before. From Canajore in Mysore I received the following :—" . . . Here, 6 miles from the Western Ghauts, altitude 3100 feet, the weather during the first week of this month was abnormally wet. The average rainfall for September is about 12 inches, but between the 1st and the 9th I gauged 18·04 inches, the aggregate on the 6th, 7th, and 8th being 10·85 inches. No thunder." From the Koondahs, near Coonoor on the Nilgiris, another correspondent reports that he was awakened about 4 A.M. on the 9th by a terrific gale, which lasted for only about half an hour, and passed off as suddenly as it began. The reports show an abnormal state of the atmosphere, which tended to give rise to local disturbances. This abnormal condition is also shown in a report from Kodaikanal, on the Pulney Hills, kindly sent me by Mr LEVINGE, who has kept a rainfall register since 1873. He writes—"There was the same peculiar colour of the sun at rising and setting here which was noticed in other places, and on the same dates as recorded in the newspapers. The atmosphere here all the time was very hazy. The only other remarkable events were that we had frosts in the beginning of September, which I never observed before at that time of the year. The rainfall for September was also the lowest I have any record of; it was as follows :—1st to 13th, none; 14th, 0·40; 15th, 1·35;

19th, 0·40;—total, 2·15 inches. [Average for September, 6·65 inches on thirteen days.] During the month we had no thunder or lightning. Early in the month the wind was from the north, which was unusual." An examination of the daily weather reports for the month shows that in the earlier part the "general weather" to the north was threatening or overcast, in the central parts of the Presidency it was fine with passing clouds, and in the south sultry. From about the 7th onwards for some days there are frequent reports of "dust haze," "sultry," and "dark gloomy weather" in the reports; while, on the other hand, at two stations the report is, "atmosphere unusually clear."

The rainfall for September over the whole Presidency was much less than usual. The average for fifteen stations for which reliable data are available is 3·24 inches, instead of 6·90, the average for preceding years. The monsoon rainfall, on the other hand, was much above the average for the same fifteen stations. The rain at some stations continued into January, but taking only the months of October, November, and December, the average rainfall was 21·75 inches, while the average due for the same time is 17·36. This includes Bellary, at which the fall was 11·90 inches *below* the average.

The barometric variations during the month also seem worth a careful study. Except for Madras, I have only the 10 A.M. readings, but these may generally be taken as yielding a fairly accurate, though rather less smooth, barometric curve than that which would be obtained from the mean of the corrected three daily observations. The accompanying diagram shows the curves for Colombo, Madras, Belgaum, Allahabad, and Calcutta (Alipore). The first point that strikes one on examining the curves is their strong general resemblance, showing the same causes at work in producing change of pressure over the whole area of India. We have first a minimum, which was on the 6th at Colombo, Madras, and Allahabad, and on the 7th at Belgaum and Calcutta. The delay at these two last places was exceptional, for out of ninety-three stations sending in reports only thirteen show a falling barometer on the 7th, and these are connected with small local areas of depression. The rise to a maximum is rather irregular, but it is reached for most stations on the 18th, and the report for the 19th shows a fall at every station except Sholapur and Moulmein. The fall continued till the 21st, when a rise took place at the great majority of stations. A third minimum falls on the 27th. Observations made with the black bulb solar radiation thermometer *in vacuo* and the grass minimum thermometer will be referred to further on.

In any attempt to discover the cause of the phenomena observed it is of importance to determine exactly the dates at which they were first seen at different places. This, however, is a very difficult thing to do, inasmuch as most of those who have reported on the subject have been untrained in exact

observations, and in many cases have made more definite statements than their observations warranted. Thus, for example, I watched the sunset on the 9th, and certainly there was no trace of green in the silvery colour of the sun's disc; yet several people in Madras told me that they had seen the sun set green on that night; but this was after they had seen the green sunsets on the following nights. I believe this is only an illustration of what happened in many cases, the peculiar sunset on the evening of the 9th was observed casually, then when people began to talk about the green sunsets of the 10th and 11th, the casual observer recollected that he had seen something peculiar, and his imagination gave the silvery whiteness a green tinge. This has made me careful to sift as far as possible the various statements which I have received, and, though I cannot claim that the dates which I have accepted are in all cases absolutely accurate, I think that they come very near the truth.

The general result of my investigation into the dates of occurrence of the phenomenon is, that in Ceylon, in the south part of the Madras Presidency, and at Ongole, in the north, the sun first appeared green on the evening of the 9th, and that over the rest of the Presidency, where seen at all, it was first seen on the morning of the 10th. At Belgaum it is reported to have appeared on the 8th, and if this is accurate it is the earliest date on which it was seen anywhere in India, and would at once negative the idea of a gradual propagation either from south to north or from east to west. I have no good reason to doubt the accuracy of my Belgaum correspondent, but as no notes seem to have been taken at the time, it is possible that he is not strictly correct. Beyond India I have two reports from ships at sea—one from the captain of the "Cleomene," who reports that there was a green sun and moon on the 9th, 10th, and 11th, when his position was from lat. 8° N. to lat. 16° N., and from long. $83^{\circ} 30'$ E. to long. $88^{\circ} 40'$ E. In the same letter he reports that his ship was struck with lightning on the 1st. The other report is from the chief officer of the s.s. "Pelican," who has given me the following extract from his log:—"September 10th—The sun rose this morning looking quite green; never saw the like before. Last evening the sky had a greenish haze, making the moon look sickly pale green, and a few peculiar black clouds like wisps or mare's tails. Light breeze from S. to S.W. with high S.E. swell. Position at noon, lat. $10^{\circ} 4'$ N., long. $64^{\circ} 12'$ E. It was preceded by squally weather, with strong S.W. wind and *very damp* weather;—heavy dews at night." Thus at two places—Madras and the position of the "Pelican"—more than 1000 miles apart, the phenomenon appeared simultaneously, while to the south and east it appeared on the previous day. At Ongole, lat. $15^{\circ} 30'$ N., long. $80^{\circ} 8'$ E., Mr MANDEY saw the green sun on the 10th, and was informed that it had been seen on the 9th by one whose evidence he thinks entirely satisfactory. I have no information to show that the green sun was seen at

any stations farther north except Vizagapatam, Rajamundry, and Simla, and unfortunately I cannot obtain the dates at which it was seen at these places. At Bombay it cannot have been at all conspicuous, for though noticed by some persons it was not seen at the Observatory, and so I cannot obtain any accurate details as to the date of first appearance, &c. Beyond India we have several dates which seem to be fixed with considerable certainty. In Honolulu, on September 5th, the sun's disc before setting was seen to be green (*Nature*, vol. xxix. p. 549). On September 4th, at 5 P.M., the master of the "Jennie Walker" "noticed the strange appearance of the sun, which was greenish." The ship's position then was long. $155^{\circ} 28'$ W., lat. $8^{\circ} 20'$ N. A passenger travelling from San Francisco to Sydney, three days out from Honolulu, writes:—"On Wednesday, September 5th, we witnessed a most curious phenomenon. The sun set perfectly blue, and next morning it rose a flaming ball of blue" (*Nature*, vol. xxix. p. 181). From Barinas, in Venezuela, we have a report that "on September 2nd, from daylight until noon, and from 3 P.M. to sundown, the sun appeared like a globe of burnished silver; between noon and 3 o'clock it was of a bluish-green colour" (*Nature*, vol. xxix. p. 77). At Trinidad, on September 2nd, the sun was observed as a blue globe at 5 o'clock (*Nature*, vol. xxviii. p. 577). It was seen at Panama on the 2nd and 3rd, and at Cape Coast Castle, apparently, on the 1st. All these dates refer to the first appearance, but we have a series referring to the second. Of these the earliest that I can find is in an extract from the log of the P. and O. s.s. "Nizam," with which Captain HARVEY has favoured me:—"September 20th, in lat. $12^{\circ} 50'$ N., long. $48^{\circ} 26'$ E., and the sun at the time being about 15° high, a greenish haze was noticed gathering over it and the sky generally in the west. As the sun decreased in altitude the green became more distinct, until a bank of green cloud, of various shades, formed on each side of the sun, and as the sun disappeared below the horizon so the cloud closed over the point of its setting. This peculiar sky lasted nearly an hour after sunset, and made a greenish twilight most wonderful to look at. The light air blowing at the time was from the eastward, and the weather fine and clear." On the 21st the same phenomena were observed, but not so clearly, owing to the ship's proximity to Socotra, "the wind at this time was S.S.W. and the air moist." The entry for the following day is also of interest. "September 22nd, in lat. $12^{\circ} 00'$ N., long. $58^{\circ} 00'$ E., the S.W. monsoon blowing fresh in this position and the sky cloudy, but there was unmistakably a greenish tinge in the west at sunset. From this date until September 25th the weather was overcast and cloudy, so that no observations were made; but in lat. $8^{\circ} 50'$ N., long. 71° E., the sun was again observed to set with a green tinge over it. The weather at this time was fine and clear, with a light northerly wind." At almost all stations in South India the greenness reappeared on the 22nd. Finally, we have the letter from

HICKS PASHA, dated Duem, September 24th—"To-day, when it [the sun] rose it was of a pale green colour." There is no proof, of course, that this is the date of its first appearance in the Soudan, but if the green was nearly as brilliant there as it was here, it could not have escaped observation.

Before discussing the causes of the phenomena that have been described, it will be well to point out that we must distinctly separate the green sun and the sunsets that appeared along with it from the remarkable sunsets which occurred nearly all over the world some time later, and which were visible here till at least the end of April. My reasons for making this separation are—1. The general appearance was quite different in the two cases. The sunsets accompanying the green sun were peculiarly lurid, and were, so far as I could judge, simply an exaggerated form of what we usually have some time before the bursting of the monsoon, and round the horizon we had then a most decided fog, in which stars were lost some time before setting. The main features of the subsequent sunsets, on the other hand, were the delicacy of the colours, and the beautiful rosy afterglow reflected apparently from very light cirrus clouds high up. The horizon at this time was remarkably clear, as is shown by the circumstance that Mr POGSON was able to make accurate measurements of the faint comet "Ross" within less than 5° of the horizon. 2. The spectrum was totally different in the two cases, for in the latter case the red end was very free from general absorption A, a , and B standing out clear and sharp, while the rain-band was slight, or altogether wanting, and the low-sun bands were strong—a complete contrast to what I have described as being visible in the former case. I may add, that any increase in the strength of the rain-band has been accompanied by a decrease in the brilliance of the afterglow.

To account for the green sun, three hypotheses have been put forward—

1. That it was due to vapours or dust from the volcanic eruption at Krakatao. First suggested by Mr POGSON.

2. That the cause was the presence of an abnormal amount of aqueous vapour. An explanation which I offered at the time of the occurrence.

3. That it was caused by a cloud of meteoric dust.

Mr LOCKYER has taken up the first of these theories, and starting with the assumption that the sunset effects were due to the same cause as the green sun, has attempted to trace the general propagation of the dust round the earth. His first line passes through Mauritius, the Sechelles, Cape Coast Castle, Brazil, Trinidad, Panama, and Honolulu. His second is a line passing from south to north through India. Taking the dates of the appearance of the phenomena which can be relied on, we find that they would require approximately the following velocities of propagation—

Krakatao to Mauritius,	161 miles per hour.
„ Cape Coast Castle,	71 „
„ Trinidad,	74 „
„ Near Honolulu, lat. $8^{\circ} 21' N.$, long. $155^{\circ} 28' E.$, 85	„

These are the velocities if we assume that the column of dust was sent up by the great explosion which took place between 8 A.M. and 9 A.M. on the 27th; and even the plutonists seem to hesitate to affirm that the violence of the previous explosions was sufficient to send the dust up to the required height, though the first great shower of dust must have been ejected some time previous to that hour. When we consider that, from the nature of the case, the deduced velocities can only be very rough approximations, being in each case the minimum value, it must be admitted that the more distant ones agree fairly well with each other. Here, however, we are met by two difficulties, viz., is there any reason to believe in the existence of an upper current moving with anything like the requisite velocity? and, if it moved so fast along the one track, how was it so long of reaching Southern India? Regarding the first of these difficulties, it seems absolutely certain that no such uniformly strong currents exist, at least at any altitude to which the dust could possibly have been projected. Mr LOCKYER attempts to overcome the second difficulty by assuming an upper current from east to west, nearly along the equator. It crossed to the north however to reach Cape Coast Castle and Trinidad—and an under current from south to north. If, however, Mr MANLEY's observations are accurate, as there seems every reason to believe they are, it appeared at Ongole as soon as in Colombo, and at least twelve hours sooner than in Madras; and, if the Belgaum observations are accurate, it appeared there a day before it was seen in Colombo. Taking, however, only those observations about which there can be no doubt we get the following velocities, taking the shortest lines between Krakatao and the various stations:—

To Colombo,	2000 miles, 6·7 miles per hour.
„ Madras,	2240 „ 7·3 „
„ Bellary,	2450 „ 7·9 „
Lat. $10^{\circ} 4' N.$, long. $64^{\circ} 12'$, 3100	„ 9·8 „

velocities increasing with the distance from the source.

Taking these along with the Japan observations, which require a velocity of over 40 miles per hour, it seems very difficult to believe that dust would have travelled in these different directions with such very different velocities. Finally, we have the negative evidence, which in this case seems to have some weight, that the first rain which fell after the appearance of the green sun contained no volcanic dust. I collected several gallons of the rain which fell on the night of the 29th, and had the sediment which it contained carefully

examined under the microscope by Dr T. K. ROGERS, a skilled chemist, but no trace of volcanic matter could be detected in it. I do not suppose that the asserted discovery of volcanic ejecta in rain and snow in Europe will be allowed to have much weight in the decision of the question, since, even if the volcanic nature of the materials found is proved, it still remains an open question where they came from.

With regard to the water vapour theory, there is at least some definite evidence upon which to found an argument. The spectroscopic evidence detailed above shows that all the prominent lines in the spectrum which are due to the presence of aqueous vapour were stronger than usual, and that there was, in addition, a strong general absorption in the red. This general absorption might doubtless be produced by the presence of dust of a suitable fineness suspended in the air, but that it may also be produced by water vapour, or at least by clouds, is amply proved by observations which I have since made on several occasions. In a recent thunderstorm, to which I have referred above, and which was predicted spectroscopically forty hours before it developed, I found almost exactly the same spectrum as in the case of the green sun, but the absorption in this case was produced by the passage of the sunlight through a comparatively thin stratum of dense cloud, instead of through a fairly transparent atmosphere. We know, too, that the absorption produced by aqueous vapour in certain conditions is capable of producing the observed appearance. On this point we have the observations made by Mr. LOCKYER, confirmed by other observers, of the sun being seen green through the steam escaping from the funnel of a steamboat, and his further observation of a green sun seen through a mist on the Simplon. We have also an observation made by Professor PIAZZI SMYTH (*Edinburgh Astronomical Observations*, vol. xiv. Appendix, p. 29), represented in a plate of which the following description is given:—"Two eye views of varieties of daylight, whereof the first represents a remarkable case of the sun looking *blue* rather than yellow, red, or the colours usually given to it by extra thickness of atmosphere; and the second shows a peculiarly green sunset sky—both of them proving to be forerunners of the sirocco's stifling wind and its concluding warm rain." The spectrum of the cloud light on this occasion shows a strong similarity to the spectrum observed here, only the absorption in the red end is less, and in the blue end rather more strongly marked. For my own part, I do not believe that a more or less green sunset is so rare an occurrence as has been supposed, and since my attention has been called to it, I have seen it several times and very markedly on the 13th and 14th of May, when it was perhaps the earliest symptom of the coming monsoon.

The abundance of water vapour present is also shown by the very heavy monsoon which followed the appearance under discussion, when in Madras

itself the rainfall was 19·17 inches, and in Masulipatam 15·71 inches above the average. We see then that aqueous vapour was present in large quantities, and that the presence of aqueous vapour is sufficient to account for the phenomena, so that it seems unscientific to call in the aid of any other agents, such as dust or sulphurous vapours, unless their actual presence can be proved, which, I submit, has not yet been done. Assuming then that the cause was aqueous vapour, the farther question arises, Why the phenomena should not be more frequently observed? This question cannot perhaps be fully answered at present, but some light can, I think, be thrown upon it by the following considerations:—In most cases, where we have an excessive amount of vapour present in the atmosphere, part at least is condensed into clouds, and these even when light, form a screen near the horizon which shuts out the sun at the time when the greenness would be observed. In the present case, on the other hand, the vapour was almost entirely uncondensed, only a very light haze being observed, and a few clouds low down on the horizon. The vapour was also at a greater height than usual, and was probably diffused through a great depth of the air; while in India, at least, the meteorological conditions near the surface of the ground prevented the formation of low clouds.

An interesting question arises as to whether electrical action may not have had something to do with this distribution of moisture. The observations already described, both those made with the electrometer and those made on lightning, show that the air was very highly charged with electricity. I am not prepared to lay much stress on the electrometer observations, however, until I have had an opportunity of investigating more fully the ordinary state of the atmosphere during the prevalence of west and south-west winds. The circumstance that the potential of the air was negative only when the wind was westerly, and even then only when the surface of the ground was hot, seems to indicate that the chief cause of the peculiar electrical state lay in the lower parts of the atmosphere. At the same time, it seems well to record these electrical observations along with the other meteorological ones. Even neglecting the electrometer observations, we have still various indications of an abnormal electrical state, for all the clouds that were formed about this time were evidently highly electrified, and the abundant displays of sheet lightning—which I ventured to say were not due to the reflection from distant storms—accompanied by occasional flashes of forked lightning, were indications of the great storm which burst on October 2nd, when the vapour had at length condensed into clouds. In this connection, it ought to be noticed that the storm of October 2nd was one in which the discharges took place almost entirely between cloud and cloud. I do not know that there is sufficient experimental data to show whether or not highly electrified vapour would be less ready to condense into clouds than non-electrified vapour, but it seems probable that

this would be the case. The experiments made by Dr OLIVER LODGE (*Nature*, vol. xxix. p. 612) seem quite insufficient to found any theory upon, inasmuch as they deal simply with the effect produced on a mass of very fine particles of water in an enclosed space by a highly electrified point.

The presence of abundance of vapour seems to be explained, naturally enough, by the setting in of the moist monsoon currents in the upper parts of the atmosphere; or at least by the conflict between the north-east and south-west monsoons, which was apparently begun by that time.* It is by no means impossible that the Krakatao eruption may have had some influence on the direction of these currents, for we have proof of the immense displacement of the air caused by the eruption in the barometric waves which were traced three times round the earth. Further, the ascent of a heated column of air and vapour over the volcano would tend to produce an area of low pressure round it, and thus to set up a cyclonic influx of air from other places, and it is quite possible that this influx is indicated in the oscillations of the barometer shown in the accompanying diagram, the sudden cessation of the cause of inflow after the eruptions ceased, causing a series of decreasing waves—direct and reflected. The eruption may also have had something to do with the electrical state of the air, for we know from observations made on the spot, that much electricity was generated by the eruption, and Professor PALMIERI'S observations show that the material ejected from Vesuvius is negatively electrified. A hypothesis connecting the phenomena with the eruption at Krakatao in this way would not be liable to the same difficulties regarding the velocity of propagation as one which involves the actual transport of dust, for the delay at one place relatively to another might be caused by the absence of a sufficient quantity of vapour. The theory which I have suggested would also account naturally for the second appearance of the green sun, the interval being due to one of the familiar lulls in the contest between the two monsoons. On the dust theory, it seems very difficult to account for this second appearance.

At one time I was inclined to think that the theory which made the phenomena depend on cosmic dust was an extremely probable one, and that the dust formed nuclei, about which the vapour condensed in the manner shown by Mr AITKEN. Various observations, however, seem to negative this. It seems hardly possible that vapour was condensed in any quantity, else the absorption of solar heat would have been considerable. Observations made with the black bulb thermometer *in vacuum* are not very satisfactory, yet when carefully made with the same instrument under similar circumstances, they have some value. The Madras observations show that the readings were above the average for the month, and that on the 23rd, one of the days of

* See Mr LEVINGE'S remarks, *ante*, p. 396, and the extract from the log of the "Nizam," p. 399.

maximum greenness, $160^{\circ}7$ was reached. The mean for the month was $147^{\circ}3$, against an average of $136^{\circ}5$. The presence of either dust or condensed moisture in quantities sufficient to have produced the observed effect would, it seems certain, have intercepted the solar heat to a great extent, but vapour, on the other hand, probably would not. Admittedly the question of the absorption of radiant heat by aqueous vapour is still a moot one, but the recent experiments made by Professor M'GREGOR, by Professor TAIT's new method, show conclusively that the absorption cannot be nearly so great as many people have supposed; and we find such an experienced meteorologist as Mr BLANFORD stating, as the most probable conclusion from meteorological observations, that "both air and vapour, as compared with other gaseous bodies, are moderately good absorbers of heat, and in nearly equal degree."* The minimum temperatures, which are perhaps a safer guide to the transparency of the air, yield results similar to those of the black bulb thermometer; and observations of double stars showed that the atmosphere was clearer and steadier than usual. We must therefore, I think, give up any theory involving the presence of sufficient dust to render the sun green. Whether or not the following sunset glows were due to the presence of dust I cannot discuss here, but I would point out that an amount of dust sufficient to produce these effects would probably not materially affect the transparency of the atmosphere.

* *Indian Meteorologist's Vade Mecum*, part ii. p. 24.

[APPENDIX.

APPENDIX A.

Date.	Hour.	Wind.	Electrometer.		Remarks.
			Positive.	Neg.	
Sept. 3	1.10 P.	Lt. S x W.	...	28	
"	2.45	Do.	6	17	
Sept. 4	10.5 A.	Fr. S.W.	...	136	} On roof.
"	{ 10.10 to 10.17 }	Do.	...	44	
"			...	299	} Ground—wind in gusts with much dust flying ; bright sun.
"			...	460	
"			...	425	
"	...	...	...	182	When wind light, R. B. 2.
"	Noon	Do.	...	67	Very fine and bright.
"	1.10 P.	Lt. S.W.	...	11	Ground.
"	3.0	Lt. E'ly.	35	...	Do.
"	6.30	...	5	...	Do.
Sept. 5	5.50 A.	Lt. W'ly.	5	...	Roof—clear.
"	9.0	Fr. S.W.	...	2	Ground—bright.
"	...	...	...	Trace.	Roof.
"	10.0	Do.	...	72	Do.
"	...	...	...	86	} Ground—dust flying.
"			...	122	
"			...	325	} Wind gusty.
"	11.5	Do.	...	368	
"	...	...	...	40	Calm.
"	1.5 P.	Lt. S.W.	...	20	
"	2.5	Do.	...	35	Cloudy.
"	2.10	...	...	1	Roof—wind going round to S.E.
"	3.15	Very light.	12	...	Ground.
"	5.0	Fr. S x E.	10	...	Cloudy.
"	6.20	Do.	29	...	12 feet above ground—thin clouds.
"	10.10	Light.	2	...	Do.—starry, with light clouds.
Sept. 6	6.0 A.	Light W.	5	...	} Do.—cloudy.
"	8.0	...	11	...	
"	9.0	...	7	...	} Ground—cloudy.
"	9.45 A.	Lt. W. x S.	...	74	
"	{ 10.5 to 10.10 }	Do.	...	188	} Do.—just before slight dust-cloud.
"			...	432	
"	...	...	...	18	} Steady.
"	1.10 P.	Do.	...	24	
"	{ 2.5 to 2.10 }	Do.	6	67	} From window about 40 feet high—dust-storm, and a few drops of rain, followed by heavy rain.
"			...	45	
"			...	125	
"			...	106	
"	2.20	Lt. W'ly.	...	560	Roof—rain ceased. This was followed by one clap of thunder. R. B. 8.
"	4.20	S.W.	10	...	Roof—followed almost immediately by a shower.
"	6.15	Fr. S.	31	...	Steady—dry.

APPENDIX A.—*continued.*

Date.	Hour.	Wind.	Electrometer.		Remarks.
			Positive.	Neg.	
Sept. 7	6.0 A.	Mod. W.	25	...	Steady—cloudy and cool.
"	9.0	{ Very light W. x S. }	35	...	Do. do.
"	10.0	Lt. do.	16	...	Do. do.
"	11.30	Do.	15	...	Do. do.
"	1.35	...	Trace.	...	
"	2.45	S.W.	15	...	
Sept. 8	6 A.	Lt. W.	14	...	Roof—steady.
"	9.0	Do.	11	...	
"	10.0	Fresh.	...	6	
"	11.0	...	...	Trace.	{ Some clouds, but sun pretty bright. R. B. 5 to 6.
"	2.0 P.	...	5	...	
"	4.20	...	146	...	Cloudy, apparent thunder cloud overhead.
"	6.15	S. fresh.	38	...	Rain at 7 P.M.
Sept. 9	6.35 A.	Lt. W.	32	...	Cool and cloudy.
"	8.10	Fresh.	16	...	Steady.
"	9.0	Do.	14	...	R. B. 3 to 4.
"	10.0	Do.	16	...	Thin clouds.
For the rest of the day maximum 16, minimum 13.					
Sept. 10	5.40 A.	Lt. W.	16	...	Cloudy.
"	9.0	Do.	8	...	
"	10.0	Very light.	...	21	Very little dust.
"	11.30	Light.	...	46 to 10	{ Do.
"	2.10 P.	Calm.	Trace.	...	Cloudy.
"	5.10	Do.	...	31	Do.
"	{ 5.43 6.0 }	{ Do. Do. }	{ 20 41 }	...	{ Thin clouds—very close and still.
Sept. 11	6.10 A.	Light W.	27	...	Steady.
"	9.0	...	8	...	Roof.
"	9.10	...	2	...	Ground.
"	9.30	...	No	trace.	
"	{ 10.15 to 10.22 }	{ }	{ }	{ 5 to 23 }	{ Cloudy, but hot.
"	2.15 P.	...	13	...	
"	10.20	...	9	...	{ Light clouds.
Sept. 12	12.35 A.	Lt. W.S.W.	10	...	Light haze.
"	5.30	Lt. W.	18	...	
"	6.30	...	23	...	R. B. 4 to 5.
"	{ 10.15 to 10.45 }	{ }	{ }	{ 143 to 28 }	{ Ground—thin haze, and plenty of dust.
"	...	...	...	4	Roof.
"	3.50 P.	Lt. S.E.	42	...	
"	5.30	Lt. E.	56	...	
Sept. 13	...	...	...	...	{ Positive all day. Max. 66 at 2.30 P. ; min. 8 at 1.5 P.
" 14	...	...	...	...	Do. Max. 60 at 5.45 A.M. ; min. 11 at 9.40 A.
" 17	...	...	...	...	{ Do. Max. 60 at 6 P.M. ; min. 47 at 1.10 P. No observations in forenoon.
" 18	...	...	...	...	{ Do. Max. 74 at 11.50 A.M. ; min. 37 at 9 A.M. Cloudy.

APPENDIX A.—*continued.*

Date.	Hour.	Wind.	Electrometer.		Remarks.
			Positive.	Neg.	
Sept. 19	...	...	...	...	{ Positive all day. Max. 78 at 3 10 P.M.; min. trace at 11 A.M. Bright.
Sept. 20	6 A.	Light W.	63	...	Light clouds. R. B. 5. Cloudy. Clear. Do.
"	9.0	...	18	...	
"	9.55	...	...	34	
"	11.55	Very Lt. E.	44	...	
Sept. 21	6 A.	Lt. W'ly.	29	...	Do.
"	9 A.	...	...	Trace.	
"	{ 10.10 to 10.15 }	Very Lt. W.	9 to	19	
"	11.0	...	No	trace.	
"	11.50	Light E.	{ 19 to 34 42		Hazy.
"	4.30 P.	...			
Sept. 22	8 A.	Light W.	No	trace.	
"	9.0	...	...	Trace.	
"	10.0	...	...	4	Cloudy.
"	11.0	...	No	trace.	
"	...	...	6	...	
"	...	...	4	...	
Sept. 23	...	...	...	...	{ Positive all day. Max. 11 at 3.30 P., min. 0 at 10.20 A.
Sept. 24	5.45	Light W.	35	...	Fine—slight mist.
"	9.0	...	15	...	Hazy.
"	9.50	...	...	25	Ground—bright.
"	...	...	...	8	Roof.
"	11.30	Light E.	25	...	Lightning all night to S. and S.E.
Sept. 25	7.15	Light W.	18	...	Cloudy and hazy.
"	9	Very Lt.	8	...	Hazy.
"	9.55	Light W.	...	{ 33 to 8 }	{ Cloudy.
"	11.45	Light E.	{ 27 to 50 }	...	Sun very hot.
"	4.40	...	22	...	
Sept. 26	{ ...	...	...	...	{ Slightly negative between 9 and 10, but positive at all other times. Thereafter no negative readings were got except in storms; but the readings have been low, except in stormy weather.
" 27					

APPENDIX B.

Station.	Rainfall for October, November, and December.		Difference from Average.	
	Actual.	Average.	Above.	Below.
Vizagapatam,	19·40	20·13	...	0·73
Masulipatam,	28·12	12·41	15·71	...
Bellary,	5·47	17·37	...	11·90
Madras,	48·21	29·04	19·17	...
Salem,	19·48	10·17	9·31	...
Wellington,	25·11	18·98	6·13	...
Coimbatore,	15·73	9·92	5·81	...
Trichinopoly,	14·25	16·07	...	1·82
Negapatam,	32·48	31·27	1·21	...
Madura,	22·57	16·01	6·56	...
Cochin,	22·44	17·94	4·50	...
Mangalore,	8·47	10·50	...	2·03
Mercara,	17·21	10·58	6·63	...
Bangalore,	17·43	8·58	8·85	...
Colombo,	29·82	31·43	...	1·61
Average,	21·75	17·36	4·39	...

APPENDIX C.

Abstract of the Mean Meteorological Condition of Madras in September 1883, compared with the Average of past Years.

Mean Value of	1883.	Difference from	Average.
Reduced atmospheric pressure,	29·791	0·017 above.	29·774
Temperature of air,	84·7	1·6 do.	83·1
Do. of evaporation,	76·6	0·6 do.	76·0
Percentage of humidity,	68	5 below.	73
Greatest solar heat in vacuo,	147·3	10·8 above.	136·5
Maximum in shade,	95·9	3·8 do.	92·1
Minimum in shade,	77·9	0·6 do.	77·3
Do. on grass,	76·1	1·7 do.	74·4
Rainfall in inches on six days,	0·56	4·24 below.	4·80
Do. since January 1st on fifty-two days,	12·54	7·19 do.	19·73
General direction of wind,	S. by W.	2 points South.	S.W. by S.
Daily velocity in miles,	190	30 above.	160
Percentage of clear sky,	40	4 do.	36

N. R. POGSON, *Government Astronomer.*

SPECTRUM OF THE GREEN SUN.

H² H¹ h G F b E D α C' C B a A