CHAPTER IV

4. CONDUCTIVITY VARIATIONS AT THE SURFACE

4.1 INTRODUCTION

Polar conductivities at the surface are known to vary in a rather well defined manner at any given place. The variation pattern at any place is, in fact, often taken as a characteristic of the electrical climatology of the place (Israel, 1971, p 97). Therefore, in the present investigation, for studying the influence of environmental parameters on atmospheric electricity, the first requirement was to form an idea about the normal behaviour of conductivity in this region. As shown in this chapter, conductivity has a more or less similar pattern of variation at all the sites in most of the months when it was monitored (the few exceptions are also discussed and explained below). This is taken to indicate that this region has a uniform electrical climate.

In this chapter, the data from the ground stations are presented and discussed. The salient features of the variation pattern of conductivity in this region are brought out. The influence of the radioactive deposits on the conductivity values at Chavara, and the effect of meteorological variables on them, are demonstrated. Finally, the explanation that is currently accepted for the observed pattern of diurnal variation of polar conductivities is shown to be unsatisfactory, and some suggestions are given for an alternative explanation.
4.2 DIURNAL VARIATION OF POLAR CONDUCTIVITIES

At any station, polar conductivities show a certain regular pattern of variation. As explained in Chapter 1, two types of variation are usually seen - the single oscillation type and the double oscillation type. The variation patterns observed in this study mostly fall into the latter category. This, therefore can be taken to be typical of this region. Figure 4.1 shows the variation pattern of the monthly mean hourly values ($\lambda^+$), that is the average of the values for each hour of the day for a month, of positive and negative polar conductivities, respectively, for the months of May, June, July, August and September, 1991, for Kottarakara. The pattern can be seen to remain constant for all these months. This period covers one month prior to the onset of the south-west monsoon (May), three months (June, July and August) during which heavy monsoon rainfall is present, and one month (September) when the rainfall is generally low. The fact that the variation pattern has remained virtually constant over such varying weather conditions indicates that the pattern is characteristic to this region.

Figure 4.2 shows the diurnal variation of $\lambda^+$ and $\lambda^-$ for five months from June 1991 for Ambalapuzha. The variation pattern is the same as for Kottarakara. Chavara also shows a similar pattern in June, as discussed later. These three stations are widely separated, and are situated in different environments. The fact that all of them show the same type of variation indicates that the pattern is typical of this region. The results from Chavara will be discussed later.
Figure 4.1 Diurnal variation of conductivity at Kottarakara for the months of May, June, July, August and September, 1991.
Figure 4.2 Diurnal variation of conductivity at Ambalapuzha for the months of June, July, August, September and October 1991.
The reason for this kind of diurnal variation is usually explained as given below. This explanation largely follows Kamra (1969, b) and Retalis & Zervos (1976). During night time, the atmosphere is relatively calm with low winds and hardly any convective motion. The radon exhaled from the soil therefore accumulates near the ground and causes an increase in ionization, thus increasing conductivity. Early in the morning, due to human activity and also due to the onset of convection resulting from increase in atmospheric temperature in the morning, aerosols are pushed into the atmosphere. This causes a conversion of small ions into large ions through attachment, thus virtually preventing them from contributing to conductivity, and an increase in the destruction of small ions through recombination with large ions of the opposite polarity. The onset of circulation also removes radon from near the ground to higher altitude regions. These contribute to the observed decrease in conductivity around 0600 to 0800 hrs in the morning.

Once the temperature increases and convection builds up, the aerosols are pumped higher into the atmosphere so that their concentration near the ground decreases. Consequently, a smaller fraction of the small ions only is lost due to attachment to aerosols, and the conductivity increases. Convection becomes maximum in the afternoon, thus giving rise to the maximum in conductivity around 1600 to 1700 hrs. In the evening, with decreasing ground temperatures, the aerosols that had been pushed to higher altitudes begin to settle down and a greater fraction of small ions are lost through attachment. Conductivity therefore again decreases and reaches a minimum around 2000 to 2300 hrs. Finally, after nightfall, the aerosols settle down, and the conductivity gets back to its normal night time high values. The
concentration of small ions is known to be smaller for higher aerosol concentrations (for instance, Mani & Huddar, 1975). RetaUs (1983) found that the large ion concentration has a double oscillation type of diurnal variation. The double oscillation type of behaviour of polar conductivities is thus ascribed to the conversion of small ions into large ions by attachment to aerosols. This hypothesis is more closely examined at the end of this chapter, and some suggestions are made based on the observations during the present investigation and reported measurements from elsewhere.

4.3 EFFECT OF SURFACE RADIOACTIVITY ON CONDUCTIVITIES

Ionization near the earth's surface is mainly due to nuclear radiations from radioactive species in the air and in the soil. The former are released into the air from the soil where they are produced by radioactivity. In a region where the soil contains high concentrations of radioactive substances, therefore, the conductivity of air should be correspondingly higher. In the present study, one of the stations where conductivity was monitored, namely Chavara, has a high concentration of the radioactive mineral monazite. The conductivity at this station is therefore much higher than that at the other stations. The monthly mean values of positive and negative polar conductivities at the three stations are given in Table 4.1. The values for Chavara are much higher than those for the other two stations. In June, for instance, the positive conductivity at Chavara is about 6 times higher than that at Ambalapuzha. In May, it is about 11 times that at Kottarakara. The observed conductivities at Ambalapuzha and Kottarakara are comparable, although the values for Kottarakara are slightly lower. It has to be
Table 4.1. Monthly mean values of conductivity at the three stations.

<table>
<thead>
<tr>
<th>Month</th>
<th>Chavara</th>
<th>Ambalpuzha</th>
<th>Kottarakara</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+ve  -ve</td>
<td>+ve  -ve</td>
<td>+ve  -ve</td>
</tr>
<tr>
<td>Mar</td>
<td>8.59  8.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr</td>
<td>12.06 10.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>10.51 9.28</td>
<td>0.91 0.88</td>
<td></td>
</tr>
<tr>
<td>Jun</td>
<td>7.09  7.23</td>
<td>1.13 1.26</td>
<td>0.88 0.81</td>
</tr>
<tr>
<td>Jul</td>
<td></td>
<td>1.55 1.58</td>
<td>0.93 0.81</td>
</tr>
<tr>
<td>Aug</td>
<td></td>
<td>1.07 1.09</td>
<td>0.87 0.73</td>
</tr>
<tr>
<td>Sep</td>
<td></td>
<td>1.88 1.61</td>
<td>0.88 0.82</td>
</tr>
<tr>
<td>Oct</td>
<td></td>
<td>1.66 1.55</td>
<td></td>
</tr>
</tbody>
</table>

remembered that the measurements at Kottarakara were made at a higher altitude from the ground than at Ambalapuzha, and that the site was located near a town, so that the values would be lower. The ratio of Chavara and Kottarakara values is therefore higher.

In order to test the assumption that the high values at Chavara are due to radioactivity, spot measurements of the $\gamma$-radiation level were taken at Chavara, Kottarakara and Ambalapuzha using a portable scintillometer. At the last two places, the levels were too low for reading clearly. However, it was found that the ratio between the levels at Chavara and the other places was at least 40. This is in broad agreement with the observed conductivities, as discussed below. Conductivity, $\lambda^i$, of air due to ions of one polarity alone is the product of the concentration, $n^i$, and mobility, $\mu^i$, of that polarity of ions and the charge on the ion. Since virtually all the small ions in the
atmosphere are singly charged, the conductivity can be written as $\lambda^+ = n^+ e \mu^+$, where $e$ is the elementary charge. The ion density, in the absence of aerosols, is given by the equation $n^+ = (q / a)^+$, which is the same as equation 1.3. Assuming that the recombination coefficient, $a$, is the same at all the above places, then ion density, and hence conductivity, should be proportional to the square root of ion pair production rate, $q$. The fact that the $\gamma$-radiation level at Chavara was about 40 times that at the other two sites would indicate that the ion pair production rate there also would be correspondingly higher. This is in good agreement with the observed ratio in conductivities. This shows that the measured conductivities are in broad agreement with the radioactivity levels.

An interesting feature is seen in the behaviour of the monthly mean values, and of the percentage variation of conductivity values over the mean, at Chavara. The monthly mean positive polar conductivity, $\lambda_{\text{pp}}^+$, i.e. the average of the daily mean values over a month, is the highest for April, followed by May, March and June in that order. The variation in $\lambda_{\text{pp}}^-$ is also similar. The percentage variance of the hourly means, that is the variance expressed as a percentage of the mean, of $\lambda_+^+$ and $\lambda_-^-$ also follow a similar pattern. This could be a reflection of the seasonal variation of the exhalation rate of radon, as mentioned earlier, coupled with the effect of meteorological parameters. The mean maximum temperatures for these months recorded at India Meteorological Department's observatory at a similar coastal station (Alleppey) about 60 km north of Chavara are the highest in April, followed by March, May and June. The monthly mean temperatures, the monthly mean polar conductivities and the percentage variances of the monthly mean hourly
values are presented in Table 4.2. Except for the monsoon month of June, the other three months show a linear relationship between the mean maximum temperature and the percentage variance of polar conductivities. The percentage variances are plotted against temperature in Figure 4.3. Another point that may be noted from the table and the figure is that the variability in negative polar conductivity is higher than that of positive. The rate of change with temperature also

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean max Temp.</th>
<th>Conductivity</th>
<th>% Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>+ve</td>
<td>-ve</td>
</tr>
<tr>
<td>March</td>
<td>33.71</td>
<td>8.59</td>
<td>8.56</td>
</tr>
<tr>
<td>April</td>
<td>33.83</td>
<td>12.06</td>
<td>10.09</td>
</tr>
<tr>
<td>May</td>
<td>33.38</td>
<td>10.51</td>
<td>9.28</td>
</tr>
<tr>
<td>June</td>
<td>29.62</td>
<td>7.09</td>
<td>7.23</td>
</tr>
</tbody>
</table>

Table 4.2 Monthly mean maximum temperatures (in °C) at Alleppey; monthly mean conductivity (in $10^{11}$ Sm⁻¹) and percentage variances of monthly mean hourly values of polar conductivities at Chavara.

Figure 4.3 Percentage variances of the monthly mean hourly values of polar conductivities at Chavara plotted against monthly mean temperatures for Alleppey.
appears to be higher for negative values. This is probably due to the influence of aerosols. Since negative ions have a larger attachment coefficient to aerosols, changes in aerosol concentration can affect them more than positive ions.

In spite of the limited extent of data, the observed relationship could be real. This behaviour is possibly due to the dependence of radon exhalation rate on soil temperature, and that of atmospheric transport of the gas on turbulence, which again depends on temperature. Higher soil temperatures induce higher exhalation of radon from the soil so that night time values of conductivity would be higher. On the other hand, higher air temperatures during day time increase the transport of the gas from the vicinity of the surface, so that day time values of conductivity would be lower. Another factor that could contribute to this is the change in aerosol concentration. The variation over a day would therefore be larger for a warmer day. But this relationship is not seen when each day's data are taken. This is possibly because of the influence of other random factors like wind, rain, etc., which would average out when a monthly mean is taken. Also, this dependence may be seen only at a highly radioactive site like Chavara. Similar relationship is not seen for the Ambalapuzha data. There, the variance is found to be more or less the same for the months of July, September and October, but is somewhat lower for June and August.
4.4 DIURNAL VARIATION OF CONDUCTIVITY AT A RADIOACTIVE SITE

It was shown in Section 4.2 that the diurnal variation pattern of polar conductivities in the region where this study was carried out is of the double oscillation type. The results from Chavara were not presented there because they showed a behaviour that was different from that of the other stations. In this section, the diurnal variation patterns seen at Chavara during the four months from March to June are presented and an explanation is suggested for the observed departure from 'normal' behaviour.

The diurnal variation pattern of conductivity is generally understood to remain more or less the same in all seasons. Retalis and Zervos (1976) for example, present the diurnal variation patterns for Athens, Greece, for all the months, averaged for a period of 4 years. The difference between seasons is seen to be minimal. The pattern of variation seen at Pune (Dhanorkar, 1992) also remains constant throughout the year, with low values during day time and high values at night, although the amplitude of variation is much larger during the winter months. This is the case at Kottarakara and Ambalapuzha, at least for the five months for which data have been presented. Israel (1971) states that 'since the nature of the trend at the individual stations displays a low variability throughout the year, the diurnal variation of the conductivity at one station apparently constitutes a certain characteristic for the local "atmospheric electric climate".' (vol. 1, p 97). Chavara is one station for which this is not true. The most striking feature of the behaviour of polar conductivities at Chavara is
the significant difference in the pattern of diurnal variation between the pre-monsoon months and a monsoon month.

The pattern is more or less similar for the first three months for which data are presented in Figure 4.4. The values are high during night time. There is a rather sharp drop early in the morning reaching a minimum around 0700 hrs IST. The behaviour after that is slightly different for each month. In March the conductivities recover as rapidly as they fall, and reach a sharp peak around 0900 hrs. They remain low almost throughout the rest of the day, and recover only by nightfall. In April, the 9 O'clock peak is not as sharply defined as in March, and the profile almost resembles the trough of a sinusoidal variation. The daytime trough is less marked in the profile for May, and the variation in conductivity is rather small for this month, except for the sharp early morning drop.

The situation is quite different in June. For this month, the curve is similar to the diurnal variation pattern for the other two stations, and also those reported by Retalis & Zervos (1976). Conductivity is large during night time. It starts decreasing around 0400 to 0500 hrs and falls rapidly to a minimum around 0700 hrs IST. A slow increase follows, leading to a broad maximum around 1400 to 1700 hrs. A secondary minimum around 2000 to 2100 hrs is also seen. The daytime variation is almost the mirror image of what is seen in the other months.

A qualitative explanation for the observed behaviour may be as follows: The dominant winds at the site, a coastal one, will be the land
Figure 4.4 Monthly mean diurnal variation of polar conductivities at Chavara for the months of March, April, May and June, 1991.
and sea breezes during the months from March to May. The sea breeze would bring in fresh air from over the sea, and carry away part of the radon released from the soil near the instrument. This would explain the low values observed during day time in these months. The sharp drop in the morning is often attributed to the destruction of small ions through attachment to aerosols and recombination with large ions of opposite polarity. The rapid increase in conductivity after the minimum around 0700 hrs must be due to the relative calm between the subsidence of the land breeze and the onset of the sea breeze, when radon exhaled from the soil remains in the same locality.

At night, the sea breeze subsides about two hours after sunset, and the land breeze begins to pick up. Land breeze is generally a weaker phenomenon compared to sea breeze. Since the monazite deposit extends somewhat into the land region, the land breeze, unlike the sea breeze, would bring along with it the radon released from the soil. During night time generally the vertical circulation is also inhibited. All these factors contribute to an increase in the concentration of radon, and therefore in conductivity, near the surface.

In June, with the onset of the southwest monsoon, the local wind systems are overridden by the large scale winds of the monsoon. These winds blow almost continuously from the sea, so that variations over a day are relatively small. The diurnal profile in June therefore agrees with that observed at other sites in this region.
4.5 EFFECT OF RAINFALL ON CONDUCTIVITY

Conductivity can be influenced by several environmental and meteorological factors. One of them is rainfall. Most of the rainfall obtained in this state is from the two monsoons. During this period, rain is widespread and continuous. The clouds seen most often are stratus and stratocumulus. Most parts of the state also obtain a small amount of rainfall during one or two months before the onset of the south-west monsoon. These are isolated intermittent spells of rain due mostly to thunderstorms, and are often obtained in the evenings. The general weather conditions will therefore be different in this period from that during the monsoons. The effect on atmospheric electrical conductivity also could hence be expected to be different.

4.5.1 Effect of pre-monsoon rainfall

Polar conductivities were measured in the institute campus during the period from April to June 1993. Rainfall also was measured simultaneously using a self-recording rain gauge (SRRG). Comparison of these two sets of data shows an interesting relationship. The results for the pre-monsoon months are presented here.

The daily mean positive polar conductivity for the months of April and May is plotted against day number in Figure 4.5. This shows large fluctuations. The daily rainfall is also plotted in the same figure. It can be seen that conductivity starts decreasing after a rain. A large decrease is seen especially after a heavy rainfall of 29.4 mm, which fell within 15 minutes on 25.4.93. Conductivity tries to recover during days
Figure 4.5 Daily mean positive polar conductivity at Trivandrum for April and May, 1993, and the daily rainfall.

of dry weather. The reduction in conductivity associated with rainfall may be due to the suppression of radon exhalation. Increased humidity could be a contributing factor. But in a hot month like April, the high humidity caused by the thundershower may not persist for long.

4.5.2 Effect of monsoon rainfall

The period over which conductivity data are available at the radioactive site (Chavara) and the inland site (Kottarakara) covers one month prior to the onset of the monsoon and one month after the onset. The behaviour of conductivity has been found to be different during these two periods. The change is striking at Chavara, where the positive polar conductivity showed a significant reduction after the onset of the monsoon. The average values of positive polar conductivity
for the months of May and June are 10.51, and 7.09, in units of $10^{14} \text{ S m}^{-2}$ (see Table 4.1). The variation in the daily means of positive polar conductivity during these two months is shown in the graph in Figure 4.6. The sharp reduction after June 1st is clearly seen. The decrease in conductivity is more or less uniform for the entire length of the day. The data obtained from Trivandrum also show similar reduction with the onset of the monsoon. The daily mean values for May and June for Trivandrum are presented in Figure 4.7. The rainfall during this period, measured alongside with an SRRG, is also shown in the figure.

The reduction is probably due to two reasons: one, the suppression of exhalation of thoron ($^{220}\text{Rn}$) gas from the soil by the rain water,
and two, the prevalence of strong monsoon winds that blow almost throughout the day from the sea, as mentioned earlier. It is known that rain fall can cause large reductions in exhalation rate (Junge, 1963). Another possible factor could be the higher humidity leading to a larger fraction of ions becoming heavier through attachment. However, the data from Kottarakara does not show any significant reduction, the average values for the months of May and June 1991 being 0.91 and 0.88 (x10^{-14} \text{ S m}^{-1}). This could mean that the increase in humidity may not have contributed significantly to the reduction in conductivity. For the station at Ambalapuzha, data for the month of May are not available since the station was established only in June.

Another effect of the onset of monsoon is a change in the ratio of polar conductivities. The ratio of the monthly mean of the positive
polar conductivity to that of the negative polar conductivity was greater than unity for the pre-monsoon month of May at Chavara. In June, after the onset of monsoon it became less than unity. The ratio of the monthly mean hourly values of the polar conductivities shows a consistent decrease from May to June, but the ratio is not less than unity for every hour of the day. Figure 4.8 shows the monthly mean diurnal variation in the ratio of polar conductivities for the months of May and June for Chavara. The ratio for June for this station is seen to be always below unity. The reason for the observed increase in the ratio of polar conductivities could be the so-called Lenard effect, the ejection of negative charges when rain drops hit the ground and break up. A second possible reason is the reversal of the sign of the space

Figure 4.8 Monthly mean diurnal variation in the ratio of polar conductivities at Chavara for May and June, 1991.
charge near the ground during periods when electrically charged clouds are present overhead. Large negative potential gradients have been observed under monsoon clouds (Kamra & Sathe, 1983).

4.6 DIFFERENCE BETWEEN COASTAL AND INLAND SITES

The behaviour of polar conductivities may be expected to be different at a coastal site from that at an inland site. Several factors may contribute to this difference. The weather conditions at the coast is different from inland. Apart from the moderating influence of the sea on temperature, the higher humidity and the effect of sea and land breezes are also important. Another factor that is important is the space charge generated by surf (Muir, 1977). The breaking sea waves are known to release positive space charge into the atmosphere. In the present study, however, striking differences have not been observed between the behaviour of polar conductivities at Ambalapuzha and Kottarakara.

The polar conductivities at Ambalapuzha are slightly higher than those obtained at Kottarakara. One of the reasons for this difference is possibly the fact that the measurements at Kottarakara were made at a higher altitude from the ground. However, the influence of marine air is also one possible reason since conductivities are known to be slightly higher over the sea compared to the average values over land. An interesting observation is that the amplitude of the monthly mean diurnal variation of polar conductivities is the maximum at Ambalapuzha. This appears to be a genuine effect of the proximity to the sea. In marine air, the amplitude is small (Israel, 1971, p 97). But at a coastal
station like Ambalapuzha, where the influence of marine and continental air may be felt alternately, this could lead to a larger amplitude of variation, compared to an inland site where the effect of marine air is not felt. The diurnal variation patterns at these two sites do not show any other difference. The effect of surf-generated space charge also is not seen at either Ambalapuzha or Chavara. This could be because the sea is rather shallow with a small slope at both these places, as along much of the Kerala coast.

4.7 DIURNAL VARIATION OF CONDUCTIVITY –

TOWARDS AN ALTERNATIVE EXPLANATION

4.7.1 Need for an alternative explanation

As described earlier, the diurnal variation of conductivity shows a double oscillation pattern in this region, except at Chavara in the pre-monsoon months. The generally accepted explanation for this behaviour also was given in an earlier section. However, one of the intriguing features of the pattern is the sharp decrease seen in the morning, which is usually attributed to the destruction of small ions through attachment to aerosols and recombination with large ions of opposite polarity. As per the hypothesis, the variation seen in conductivity over the period of a day is mainly due to the variation in aerosol concentration. In the morning, the concentration of aerosols increases as the atmospheric temperature increases, and consequently conductivity decreases. Kamra (1969 a), for instance, found that there was rather good agreement between the time at which atmospheric temperature started increasing and the time at which the vertical
electric field started increasing. The variation during daytime is also attributed to the variation in aerosol concentration near the ground due to changes in the strength of the convective motion of air. Retalis (1983) found a double oscillation type of variation in the large ion concentration at Athens. This is in agreement with the observed conductivity variation. The explanation therefore appears to be well supported by observations.

A closer inspection, however, would reveal some limitations of this hypothesis. One drawback of this hypothesis is that some stations show a single oscillation type of diurnal variation. For instance, of the data from five stations shown by Israel (1971, p 98), two, namely, Watheroo and Davos, show single oscillation type of behaviour. If the above hypothesis is to be accepted, then one would expect all stations to show the double oscillation type of variation. Another difficulty is that the morning decrease often starts very early, around 0400 hrs. This is too early in the morning for either human activity or sunrise to affect conductivity. Also, in the present study, it is seen that the morning decrease is seen in all the months in all the stations. Even at Chavara, during the pre-monsoon months when the pattern is on the whole different from the normal pattern for this region, the early morning decrease is consistently seen. Moreover, in June, when continuous and heavy rainfall is present, the explanation for the decrease seen in the morning does not appear to be satisfactory. The phenomenon therefore appears to be independent of the season, weather, etc.

The diurnal variation patterns at Athens for the different months obtained by Retalis & Zervos (1976) are shown in Figure 4.9. Here
Figure 4.9 Diurnal variation of positive and negative polar conductivities at Athens for each month and for the year (from Retalis & Zervos, 1976).
the morning decrease is seen to be a regular phenomenon. They mention that the morning minimum and the afternoon maximum present a time shift according to the time of the year - the morning minimum occurring earlier in summer, and the afternoon maximum and the evening minimum occurring later in summer. However, they later mention that the morning minimum usually occurs between 0700 and 0900 hrs. The spread in time appears to be small for a station like Athens, where the time of sunrise varies by about four hours over a year. Considering all these factors, it appears that an alternative hypothesis is needed to completely explain the diurnal variation of conductivity.

4.7.2 Harmonic analysis of conductivity

In order to obtain a better understanding of the variation pattern of conductivity, the mean hourly values were subjected to harmonic analysis. In the case of Chavara, the first three months (ie. March, April and May) and June show different types of diurnal variation. Only June has a pattern that is similar to that of the other stations. The second harmonic of the mean hourly values for this month are shown in Figure 4.10. In the case of the other stations, the second harmonics shown are for the average data for all the months. In spite of the relatively small extent of the data, all the curves show a similar behaviour, the morning crest falling around 0400 hr. The phase of the second harmonics may be affected by random influences on conductivity. This influence will be limited if data for a longer period is studied.

Retalis & Zervos (1976) have presented the results of harmonic analysis of conductivity data for the period 1968-72, averaged for each
Figure 4.10 Second harmonics of the mean hourly values for the three stations.
The second harmonics of the data for all months are shown in Figure 4.11. Their behaviour is similar to that obtained in the present investigation. They show a maximum around 0400 hrs and a minimum around 1000 hrs. As mentioned earlier, the sunrise time at Athens varies widely over the year. If the observed diurnal variation pattern is mainly determined by sunrise and human activity, one would have expected some significant change from month to month. The phase angles of the second harmonic of positive conductivity given by them shows a variation from a high of 343° in February to a low of 315° in June for all weather, and from 313° in June to 342° in December for fine weather. This represents a variation of about ±1 hour, which is the time resolution of their data, over the year.

Figure 4.11 The second harmonics of the monthly mean diurnal variation of positive polar conductivity at Athens for every month of the year (computed using figures given in Retalis & Zervos, 1976).
4.7.3 Towards an alternative explanation

From the discussion given above, the limitations of the present explanation are clear. While the role of aerosols and the effect of sunrise cannot be totally ruled out, it appears to be necessary to look for additional mechanisms that may be influencing the behaviour of conductivity over a day. In this context, one factor that emerges as important is the relatively small variation in the time at which the morning maximum and minimum occur. As seen in the present study, the conductivity starts decreasing around 0400 hrs irrespective of the season, weather, location, etc. The explanation, therefore, has to be sought in some phenomenon that shows a constant behaviour in all seasons, and is independent of the weather conditions.

One such phenomenon is the semi-diurnal variation in atmospheric pressure that is seen predominantly in the tropics. This is a well known, but poorly understood phenomenon, which is independent of the seasons, weather conditions, and other effects. In the tropics, atmospheric pressure goes through a well defined semi-diurnal oscillation that has a minimum at 0400 hrs and a maximum at 1000 hrs. A mean profile is shown in Figure 4.12 (Nieuwolt, 1977). The amplitude of this variation is highest in the tropics, around 3 to 4 mb, and decreases towards higher latitudes. The reason for this behaviour has not been successfully explained. But we see that the conductivity variation is almost the inverse of that of pressure. In particular, the conductivity maximum around 0400 hr almost coincides with the pressure minimum. Figure 4.13 shows the second harmonic of a typical day's pressure variation at Trivandrum along with the second harmonic for Kottarakara.
Figure 4.12 Diurnal behaviour of atmospheric pressure in the tropics (from Nieuwolt, 1977).

Figure 4.13 Second harmonic of a typical day's pressure variation at Trivandrum and that of the mean value for Kottarakara for all the months.
Atmospheric pressure can influence conductivity through its effect on ion mobility. The mobility, \( \mu \), at STP and that at pressure \( p \) and temperature \( T \) are related by the expression \( \mu = \mu_0 \cdot (p_0/p) \cdot (T/T_0) \). A decrease in pressure would, therefore, result in an increase in conductivity. This, however, cannot explain the observed diurnal behaviour of conductivity, since the variation in pressure at the surface is very small, as mentioned earlier. The causal link, therefore, has to be found in some other process. One such possibility is the influence of atmospheric pressure on radon exhalation. An increase in atmospheric pressure would tend to reduce radon exhalation from the soil, and consequently reduce the ionization and conductivity. To what extent this may be effective in producing the observed variation depends on the extent of the influence of pressure on radon exhalation. The strong influence of isolated rainfall on conductivity, presented earlier, shows that reduction in radon exhalation can significantly affect conductivity.

It thus appears that the present explanation for the daily variation of conductivity may not be complete. Factors other than the variation in the concentration of aerosols may have to be taken into consideration. Aerosols do influence small ion concentration and therefore their effect on conductivity cannot be ignored. However, some aspects of the behaviour of conductivity over a day, especially the reduction that starts early in the morning, is not satisfactorily explained by the influence of aerosols alone. What is attempted here is only to present a new relationship that has been observed. Conductivity is most certainly controlled by a combination of factors, and a simplistic explanation based on one of them alone may miss some of the
important aspects. The difference in the phase of the second harmonic for the months of March, April and May at Chavara, for instance, must be due to the dominating influence of another factor, the wind, for instance. A complete understanding can emerge only after the question is closely examined in a comprehensive study.