Impact of the solar eclipse of 15 January 2010 on the surface ozone and nitrogen dioxide concentrations at Kanyakumari, India

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Solar radiation derives the chemistry of the atmosphere. Solar eclipse, being a rare event, provides unique opportunities for studying the changes in the atmosphere due to the sudden reduction in the incoming radiation. The effects of solar eclipse of 15 January 2010 on surface ozone (SOZ) and nitrogen dioxide (NO₂) at the coastal site. Kanyakumari (8°4’8”N, 77°33’6”E), Tamil Nadu, India, has been investigated in the present study. The behaviour of SOZ, NO₂ and variation in meteorological parameters, like temperature, relative humidity (RH) were studied during this annular solar eclipse as well as one day before and after the eclipse. The experimental results showed that solar eclipse phenomenon affects the concentration of SOZ and NO₂ as well as temperature and RH near the ground. Further, few minutes after the total eclipse, SOZ decreased to around 30 ppb, which is 25 ppb less than the normal and the level of nitrogen dioxide increased to 5 ppb. Also, it was noticed that during the course of the eclipse, the RH increased by 3% and temperature decreased by 4°C. The decrease in SOZ concentration was attributed to the reduction in the incoming solar radiation that affects the photochemical reaction. The observed increase in the NO₂ concentration may primarily be due to the low photolysis rate of NO₂.

Keywords: Solar eclipse, Surface ozone concentration, Nitrogen dioxide concentration, Photochemical reaction

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1 Introduction

Solar eclipse, being a rare natural event, provides a unique way for studying the changes in the atmosphere when the incoming solar radiation is sharply turned off and on during the event. The solar eclipse has the advantage over sunset of occurring very rapidly and with the sun hardly moving in the sky. The response of the earth’s environment to this abrupt and short time disturbance in the solar radiation, and in consequence, the thermal balance of the atmosphere has been the subject of many environmental studies. On normal days, at any point on the globe, the changes in the flux are gradual and response characteristics of the atmosphere are difficult to estimate. But during eclipses, sudden changes in radiation flux are produced which gives an opportunity to study the response of the atmosphere to the solar radiation7. It is well known that changes in ozone amounts are closely linked to solar flux and temperature. At the peak of the eclipse, all of the heat exchange parameters are affected and the turbulent processes are diminished8. Hence, it gives an opportunity to investigate how photochemical processes react to the solar radiation changes and enable the evaluation of the understanding of air pollution build up and the response of the gas-phase chemistry of photo-oxidants during drastic perturbation in solar radiation3. The measurements of surface ozone (SOZ) and nitrogen dioxide (NO₂) have been regularly carried out since 2007 at Nagercoil, 17 kms away from Kanyakumari (8°4’N, 77°33’E). The annular solar eclipse on 15 January 2010 at Kanyakumari, where the degree of obscuration was maximum, provided an opportunity to assess the variation in SOZ and NO₂ during this important event. The aim of this paper is to examine the behaviour of SOZ and nitrogen dioxide concentrations as well as other important meteorological parameters, like temperature and RH during this event over Kanyakumari, one of the geographically important coastal sites in India.

2 Description of 15 January 2010 annular solar eclipse

The solar eclipse of 15 January 2010 was an annular eclipse of the Sun with a magnitude of 0.919. A solar eclipse occurs when the Moon passes between the Earth and the Sun, thereby, totally or partially
obscuring the Earth’s view of the Sun. An annular solar eclipse occurs when the Moon’s apparent diameter is smaller than the Sun, causing the sun to look like an annulus (ring), blocking most of the Sun’s light. An annular eclipse will appear as partial eclipse over a region thousands of miles wide. The eclipse of 15 January was seen as annular within a narrow stretch of 300 km width across Central Africa, Maldives, South Kerala, South Tamil Nadu, North Sri Lanka, Burma and China.

The solar eclipse of 15 January 2010 started at 1106 hrs LT and ended at 1515 hrs LT at Kanyakumari. The maximum obscuration was at 1316 hrs LT and the degree of maximum obscuration was 85%. The central line duration of annularity was noticed around 10 minutes and 8 seconds. Figure 1 illustrates the path of the eclipse over south Tamil Nadu, India.

3 Photochemistry of surface ozone

The composition of atmospheric trace gases and the structure of the atmosphere are controlled by the photochemical reactions due to solar radiation at 180 – 220 nm in the stratosphere and above 400 nm in the troposphere. Ozone levels are generally increasing with increasing temperature and decreasing with increasing RH (ref. 4). The variability of solar radiation affects the temperature and hence SOZ concentration. SOZ is produced from photochemical oxidation of CH₄, VOCs and CO in the presence of NOₓ. During daylight hours, NO₂ is converted photolytically to NO leading to the formation of ozone.

\[ \text{NO}_2 + h\nu (\lambda \leq 430 \text{ nm}) \rightarrow \text{NO} + \text{O} \quad \ldots \quad (1) \]

\[ \text{O} + \text{O}_2 + \text{M} \rightarrow \text{O}_3 + \text{M} \quad \ldots \quad (2) \]

Reaction (2) produces more ozone when NO₂ levels increase. Here ‘M’ represents a molecule (e.g. N₂ or O₂) that absorbs energy from the reaction as heat and thereby stabilizes the O₃ formed. NO reacts relatively rapidly with ozone and forming NO₂ under atmospheric conditions. The reaction (3) consumes less ozone when NO levels decrease.

\[ \text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 \quad \ldots \quad (3) \]

counts less ozone when NO levels decrease.

Reactions (1-3) constitute a cycle with no net chemistry which gives a steady state concentration of ozone. However, the presence of CO and VOCs can disturb this relationship by producing peroxy radicals (HO₂⁺ and RO₂⁺).

\[ \text{CO} + \text{OH}^* \rightarrow \text{CO}_2 + \text{H}^* \quad \ldots \quad (4) \]

\[ \text{H}^* + \text{O}_2 + \text{M} \rightarrow \text{HO}_2^* + \text{M} \quad \ldots \quad (5) \]

\[ \text{CH}_4 + \text{OH}^* (+\text{O}_2) \rightarrow \text{CH}_3\text{O}_2^* + \text{H}_2\text{O} \quad \ldots \quad (6) \]

\[ \text{RCH}_3 + \text{OH}^* (+\text{O}_2) \rightarrow \text{RCHO} + \text{HO}_2^* \quad \ldots \quad (7) \]

The NO, reacting with HO₂⁺ and RO₂⁺ instead of ozone, results in an increased ozone concentration.

\[ \text{NO} + \text{HO}_2^* \rightarrow \text{NO}_2 + \text{OH}^* \quad \ldots \quad (8) \]

\[ \text{NO} + \text{RO}_2^* \rightarrow \text{NO}_2 + \text{RO}^* \quad \ldots \quad (9) \]

4 Measuring instruments

The concentrations of SOZ and NO₂ were measured with the instrument S200 obtained from Aeroqual, New Zealand which employs active sampling technique for the measurement. SOZ was measured by using an ultra low concentration ozone sensor model OZU and NO₂ was measured by the sensor model NO₂0-0.2, respectively. The ozone sensor was calibrated against a certified UV photometer and the NO₂ sensor was calibrated against a certified chemi-luminescence NO₂ analyzer. The RH at Kanyakumari during the eclipse was obtained from the website (http://www.intellicast.com). A
5 Discussions and Results

Figure (2) presents the SOZ, NO$_2$ and temperature measurements during the day of the eclipse. To delineate the effects of solar eclipse on SOZ and NO$_2$ concentrations, the SOZ and NO$_2$ data before and after the day of the eclipse were averaged and used as normal values. SOZ and NO$_2$ concentrations on the eclipse day relative to the normal values are presented in Figs (3 and 4), respectively.

During the particular day of the eclipse, there was an overall increase in SOZ concentration when compared to the mean values of the pre and post eclipse days and this increase may be due to the increased vehicular emission levels. The increase of SOZ from 0530 hrs LT to the onset of the eclipse was 28 ppb and from the onset to just before the maximum phase of the eclipse (1250 hrs LT) was 15 ppb, respectively. At the time of the total eclipse (1316 hrs LT), the SOZ concentration was 55 ppb. There was a decrease in the SOZ value around 1330 hrs LT (i.e. 15 minutes after the total eclipse). The decrease of SOZ from 1250 hrs LT to 1330 hrs LT was 35 ppb. This reduction in ozone value may be due to the sudden fall in the sunlight intensity that decreased the efficiency of the photochemical reaction mechanism. The solar radiation as well as SOZ concentration started to increase after the total eclipse. The increase of SOZ after the maximum phase (1330 hrs LT) till the end of the eclipse (1515 hrs LT) was 11 ppb, which is clearly indicated in Fig. 3. The increase in SOZ may be due to the sharp increase in the solar flux during the recovery phase of the eclipse. Around 1930 hrs LT (i.e. four hours after the end of the solar eclipse), the variation of SOZ was found to be similar to the variation of pre and post eclipse days. On the pre and post eclipse days with clear sky condition, the maximum hourly SOZ concentration were most prevalent around 1400 hrs LT and is attributed to local ozone formation processes. But an interesting observation during the day of the eclipse was that the SOZ concentration showed a maximum value of 65 ppb around 1250 hrs LT (30 minutes before the formation of ring of fire). It may be due to the increase in solar flux and temperature in the beginning of the total eclipse. This happens because in the beginning of the eclipse, only

Fig. 2—SOZ, NO$_2$ and temperature measurements during the annular eclipse of 15 January 2010 at Kanyakumari: (a) beginning of the solar eclipse; (b) maximum phase of solar eclipse; and (c) end of the solar eclipse

Fig. 3—Variations of SOZ concentrations during the solar eclipse on 15 January 2010 (curve A). Curve B presents the average SOZ concentrations observed on 14 January 2010 and 16 January 2010 with standard deviation

Fig. 4—Variations of NO$_2$ concentration during the solar eclipse on 15 January 2010 (curve A). Curve B presents the average NO$_2$ concentrations observed on 14 January 2010 and 16 January 2010 with standard deviation
the outer part of the solar disc is covered. The outer part has a lower temperature so the mean temperature of the sun at this moment is dominated by the temperature of the central part of the solar disc. This leads to an increase in the solar flux before the start of the eclipse. 

From Fig. 4, it is evident that NO\textsubscript{2} concentration decreased to 2 ppb before the maximum phase of the eclipse and few minutes after the total eclipse, it increased to 5 ppb indicating the low photolysis rate of NO\textsubscript{2}. This low photolysis rate may be due to cooling of the atmosphere and damping of the convective processes\textsuperscript{6}. The sudden reduction of SOZ concentration during the eclipse was accompanied by an increase in NO\textsubscript{2} concentration. This fast response of SOZ to solar eclipse was due to the fact that the primary pollutant NO destroys ozone through the titration reaction (3) without ozone being resumed through the NO\textsubscript{2} photolysis. The changes in OH* and HO\textsubscript{2}* concentrations induce changes in the rates of ozone loss pathways via reactions (10) and (11):

\[
\text{HO}_2 + O_3 \rightarrow OH + 2 O_2 \quad \ldots \quad (10)
\]

\[
\text{OH} + O_3 \rightarrow \text{HO}_2 + O_2 \quad \ldots \quad (11)
\]

The photolysis of other species which are secondary sources of radicals such as HCHO, CH\textsubscript{3}CHO via radical formation can also affect the SOZ concentration\textsuperscript{8}.

The air temperature near the ground decreased from 32°C to 28°C during the eclipse and thereafter it began to increase. From the available data, it was noticed that RH was 55% at 1240 hrs LT and 58% at 1340 hrs LT (i.e. a 3% increase in RH).

6 Conclusions

On 15 January 2010, an annular solar eclipse occurred over Kanyakumari, the southern most tip of India. This eclipse offered a unique opportunity to study the responses of SOZ and NO\textsubscript{2} concentration to eclipse. In addition to SOZ and NO\textsubscript{2} concentrations, one of the important meteorological parameters, temperature was also monitored. The RH data was obtained from the website (http://www.intellicast.com). The results showed that SOZ, NO\textsubscript{2}, temperature and RH are affected by the solar eclipse. Unlike other similar SOZ studies on eclipse days, a maximum concentration of SOZ (~65 ppb) was observed at Kanyakumari just before the total eclipse. With a time lag of ~15 minutes after the total eclipse, the SOZ measurement displayed a reduction of around 25 ppb. This is in agreement with the studies and observations by Tzanis et al.\textsuperscript{3} on SOZ measurements during 29 March 2006 eclipse at Thessalonika, Greece which displayed a reduction of around 10-15 ppb. This decrease in SOZ concentration was attributed to the reduction in the incoming solar radiation that affects the photochemical reaction. The observed increase in the NO\textsubscript{2} concentration may primarily be due to the low photolysis rate of NO\textsubscript{2}. The temperature near the ground dropped around 4°C and the RH increased to 3% during this eclipse event. This sudden change in temperature and RH led to the unusual diurnal variation in SOZ and NO\textsubscript{2}. This leads to the conclusion that photochemical parameters are strongly responsible for significant destruction of SOZ in the daytime during the eclipse. The results presented in this study are based on the current status of available literature which deals mainly with photochemical loss of ozone by photochemistry in the coastal and marine environment. All the possibilities which appear to be responsible for destruction of SOZ in the daytime during eclipse have been explored and came to the conceptual conclusion that prolonged depletion of sun light and subsequent resulting of photochemistry played essential role in the destruction of SOZ. The present work was an attempt to assess the variations in SOZ concentrations on a local scale during solar eclipse. However, the monitoring network may be expanded to study the variability in SOZ concentrations over a regional scale. Remote sensing techniques need to be used to model ozone concentrations over wider areas to understand the variability of SOZ after the natural event like eclipse.

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