Impact of Chemical Fire Accident on Spectral Solar Irradiance over Urban Environment -A Case Study

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Abstract

Varying levels of atmospheric pollution presently plague many large cities in the world and long-term effect of urban aerosol layer on thermal climate received little attention. Aerosols are important in local and regional climatology through direct and indirect atmospheric processes. The present study deals with the impact of anthropogenic activity associated with chemical factory accident over an urban environment namely Hyderabad, India. Ground based measurements of solar irradiance and aerosol optical depth have been measured by using Multi Filter Rotating Shadow band Radiometer(MFRSR), Multi Wavelength Radiometer(MWR), Quartz Crystal Microbalance(QCM) Impactor and MICROTOPS-II sunphotometer respectively. Spatial variation of Aerosol optical depth (AOD) has been showed distinct increase on the accident day and subsequent days compared to normal days. Aerosol size measurements suggest the dominance of accumulation mode particles at distances ~100km away from accident site. Spectral measurements of solar irradiance exhibited variations based on polluted urban atmospheric conditions. We have made an attempt to quantify the percentage attenuation of solar irradiance due to chemical fire accident. In the highly polluted case, relative attenuations of global solar irradiance has been found to be ~8% and attenuation of direct normal irradiance is ~18% compared to normal days. An enhancement of about ~35% diffuse solar radiation has been observed due to fire accident. The diffuse-to-direct ratio of solar irradiance has been found to depend strongly on the atmospheric conditions. The statistical analysis between columnar aerosol optical depth and direct normal solar irradiance showed negative correlation with 83 W / m^2 reduction in solar irradiance for 0.1increase in aerosol optical depth at 500nm. The results of the study suggested that the effect of chemical fire accident persisted up to 3 days.

Keywords: Aerosol Optical Depth, Global irradiance, Diffuse irradiance, Direct normal irradiance, Attenuation.

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1. Introduction

Atmospheric pollutants and aerosols absorb and scatter solar radiation. The interactions have resultant impacts on atmospheric radiative energy transfer and balance (Charlson et al., 1991; Schwartz and Travis., 1994). Scattering and absorption of solar radiation by aerosol particles and gases results in remarkable attenuation of direct solar beam component and moderate increase in diffuse component. The result is a net decrease in global (direct and diffuse) irradiance that reaches the earth surface. There is a need to know spectral distribution of solar irradiances and the extent to which changes in environmental factors affect energy distribution. In order to improve our understanding of factors that affect spectral radiant energy distribution, a variety of radiative transfer models have been developed. Nevertheless, validation of these models requires accurate and detailed spectral measurements as well as simultaneous observations of environmental factors that affect spectra at various spectral bands. The amount of Solar Ultraviolet (UV) radiation penetrating the earth's surface is critically important to the health of biological systems practically and no solar radiation reaches the ground at wavelengths shorter than 290 nm due to strong attenuation by atmospheric ozone.Erythema, which is defined as a reddening of human skin in response to radiation, extends through both UV-B (wavelengths 280–315 nm) and UV-A (315–400 nm) (Herman et al., 1996). The autocorrelation between total column ozone and the surface UV radiation is a complex function of many variables including solar zenith angle, surface elevation, cloud cover, aerosol loading, surface albedo and vertical profile of ozone. A major fire accident occurred at chemical storage godown at Jeedimetla in Hyderabad on 19th Feb, 2004(Hindu, 2004). The present study aims to analyse changes in aerosol optical depth (AOD), Aerosol mass size distribution, Spectral distribution of solar irradiance and modification of spectral composition of solar radiation by atmospheric loading of pollutants due to chemical fire accident.

2. Instrumentation Setup and Methodology

The study area of Hyderabad is located at 17^0 10$^{'}$ to 17^0 50'N latitude and 78^0 10$^{'}$ to 78^{0}E longitude (Fig. 1). The population of the district according to 1991 census is 31, 45, 939, which is purely urbanized With respect to climate, normal rainfall of the district is 786.8mm. During the experimental period, air temperature varied from 19 to 29^{0}C while relative humidity remained almost constant at 45-55%. Measurements on aerosol spectral optical depth (AOD) have been carried out at NRSA campus located in Balanagar (17.28N/78.26E) and Shadnagar campus (17.02N/78.19E) located ~100kms south west of the accident site. AOD has been estimated at ten narrow wavelength bands centered at 380,400,450,500,600,650,750,850,935 and 1025nm using a Multi Wavelength Radiometer (MWR). MWR makes spectral measurements of ground reaching solar flux as a function of solar zenith angles during clear sky periods for estimating aerosol optical depth (Moorthy et al., 1993). MICROTOPS-II sunphotometer has been used at Shadnagar for measuring aerosol

optical depth at 380, 440,500,675,870 and 1020nm (Leckner., 1978). Near real-time measurements of total, as well as size segregated mass concentration of near surface aerosols have been carryout at Shadnagar site located ~100km towards SW direction of fire accident site using a ten channel Quartz Crystal Microbalance (QCM) Impactor, California Measurements, Inc., USA. QCM measures particle diameters in the range 0.05 to 25μm with an accuracy of about ±20% (Pillai and Moorthy, 2002). UV-meter from Solar Light Co., USA has been used to measure UVery in 280-315nm over the study area. The cosine response of the instrument is ±5% with resolution of 0.01MED/hr. Multi Filter Rotating Shadow Band Radiometer (MFRSR) is a ground-based instrument, that uses independent interference-filter/photodiode detectors and automated rotating shadow band technique to make spectrally resolved measurements at six narrow channels between 0.4μm and 0.96μm and one broadband channel between 0.4μm to 1.0μm of direct-normal, total horizontal and diffuse-horizontal irradiances(Harrison et al., 1994). MFRSR achieves accuracy in direct-normal spectral irradiance comparable to tracking radiometers and is more accurate than conventional instruments for determination of diffuse and total-horizontal spectral irradiances. This is because of angular acceptance function of instrument closely approximates the ideal cosine response and measured direct-normal component can be corrected for remaining angular acceptance error. The three irradiance components are measured using same detector for a given wavelength. UVmeter , MWR and MFRSR have been operated at NRSA Balanagar campus(Fig. 1). Aerosol optical depth provides a measure of atmospheric turbidity. The most frequently used turbidity coefficients obtained by using Angstrom relation (Angstrom, 1961) is

$$\tau_{p\lambda} = \beta\lambda^{-\alpha} \quad (1)$$

Where λ is expressed in μm, $\tau_{p\lambda}$ is the measured AOD, β is the turbidity coefficient at λ μm wavelength, which depends on the concentration of aerosols in the atmosphere and α is related to the size distribution of aerosol particles. Large values of α indicate relatively high ratio of small particles to large particles. α varies from 4 to 0; when the aerosol particles are very small, of the order to air molecules, α should approach 4 and it should approach 0 for very large particles. The equation can be facilitated by the use of linearized form i.e.,

$$\ln \tau p\lambda = \ln\beta - \alpha \ln\lambda \quad (2)$$

Substituting the derived $\tau_{p\lambda}$ values in the equation (2), slope of $\ln\tau_{p\lambda}$ vs $\ln\lambda$ graphs provides coefficient α and its intercept $\ln\beta$ at λμm wavelength.

Back Trajectory Analysis has been performed using the NOAA Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT 4) model (Draxler and Hess, 1998). This analysis provides lat-long distributions of kinetic wind field including horizontal and vertical wind velocities. The (five days

back) trajectories have been computed at 500,1000and 1500m AGL during the experiment period over Balanagar and Shadnagar.

Figure 1. Location map showing study sites.

3. Results and Discussion

A major fire accident occurred at Vardhaman chemicals storage godown on 19th February, 2004situated at Jeedimetla Phase-I (Fig. 2). The burnt chemicals mainly consisted of Isopropyl Alcohol, Benzoic Acid, Toluene, Methanol, Acetone and Methyl Ethyl Ketone. The accident site situated north of NRSA Balanagar campus at an aerial distance of 5kms and the fire occurred at around 11:45AM (The Hindu News Paper dated 20th Feb, 2004). The fire activity continued with barrel containing chemicals blowing up in fire one after the other till 17:00hrs and subsequently the fire was brought under control subsequently. The present study has been taken up to investigate the effects of chemical fire accident on the aerosol optical depth and ground reaching solar irradiance. Meteorological conditions have been fair with clear-sky during the experiment period. Fig. 3 shows variation of day average aerosol optical depth (AOD) 380,400,440,500,600,650,750,850,935 and

1025nm during 17-02-04 to 22-02-04 at NRSA, Balanagar study site located at 5km from the accident. 17th Feb, 2004 and 18th Feb, 2004 have been considered as normal days, 19th Feb, 2004 and 20th Feb,2004 have been taken as highly polluted days due to fire accident and 21st Feb, 2004 and 22nd Feb, 2004 have been considered as moderately polluted days. Due to fire accident, day average AOD increased (0.52 to 0.84) considerably during highly polluted days compared to normal days(0.39). Simultaneous measurements on aerosol optical depth (AOD) have also been carried out at Shadnagar located at 100kms south west of the accident site during 18thFeb, 2004(pre-event day), 19th Feb,2004(accident day) and 20th Feb, 2004(post-accident day) using MICROTOPS-II sunphotometers in synchronous with the aerosol optical depth measurements at Balanagar. Fig. 4 shows the variation of AOD at Shadnagar at 380,440,500,675 and 1020nm on pre accident day (18-02-04) on the accident 54day (19-02-04) and post accident day (20-02-04). AOD values over Shadnagar have been observed to be low compared to Balanagar but there is a clear increase in AOD due to chemical fire accident. Back trajectory analysis suggested that the air mass movement is from accident site to observation sites and the observed high values in AOD have been attributed to the accident (Figs. 5&6). Wavelength exponent (0.85) and turbidity coefficient (0.48) have been observed to be high at Balanagar site on the accident day compared to normal days suggesting turbid atmosphere with coarse mode particle loading nearer to the accident site. At Shadnagar, wavelength exponent and turbidity coefficient estimated to be 1.24 and 0.18 respectively suggesting accumulation mode particle loading at distances 100km from source. Fig. 7 shows the variations of accumulation (<0.4μm) and coarse mode (>0.4μm) aerosol mass concentrations during 16th Feb, 2004 using QCM particle analyser measurements over Shadnagar. Accumulation aerosol mass loading has been observed to be high on accident day(~51μg m^{-3}) compared to pre and post accident days(~36μg m^{-3}). In contrast to wavelength exponent values, atmospheric turbidity showed high values at Balanagar site closer to the accident site compared to Shadnagar. The contrasting sensitivities of MFRSR measured global, diffuse and direct normal radiative fluxes with respect to normal, moderately polluted and highly polluted atmospheric conditions have been shown in Figs. 8-10.Reduction in global solar irradiance and direct normal irradiance during highly polluted days have been estimated to be of the order of ~8% and ~18% respectively. The results are in agreement with most observations in different places over the globe (Webb, 1992; Lorente et al., 1994; Jacovides et al., 2000). In the diffuse solar irradiance, an enhancement of about ~35% has been observed during highly polluted days compared to normal days. Results of the study are in agreement with spectral attenuation dependence observed for varying turbidity levels reported in literature (Lorente et al., 1994; Krzyscin et al., 1998; Kylling et al., 1998; Singh et al., 2003; Wenny et al., 1998). Fig. 11 shows diurnal variation of UVery during highly polluted, normal and moderately polluted days. During normal days UVery ranges from 1.1 to 2.6 MED/hr whereas during high pollution days due to chemical burning UVery ranges from 0.57 to 2.5 MED/hr (Fig. 11). The diurnal UVery variation throughout course of the day shows Gaussian type of variation. However it is interesting to note that the diurnal course of UVery curve is bell shaped during normal day where as distortion in shape of

the curve has been observed during high and moderately polluted days. Significant reduction of UVery has been observed during highly polluted days (~20%) compared to normal days (Fig. 11). Similar observations have been reported in studies conducted in urban areas elsewhere (Krzyscin and Puchalski, 1998; Kylling et al., 1998). The ratio of diffuse-to-direct solar irradiances has been considered as useful parameter in isolating the influence of polluted air on spectral characteristics of solar radiation (King, 1979). Variation in diffuse-to-direct ratio during 17th Feb, 2004 to 22nd Feb, 2004 has been shown in Fig. 12. Diffuse to direct ratio has been observed to be high during 19th to 21st February, 2004 corresponding to accident and atmospheric conditions came back to normal limits by 22nd Feb, 2004. The statistical analysis between columnar aerosol optical depth and direct normal solar irradiance showed negative correlation with 83 W/m^2 reduction in solar irradiance for 0.1 increase in aerosol optical depth at 500nm. Results of the study suggest that the atmospheric effects due to chemical fire accident persisted up to three days.

Figure 2. Fire billows from Vardhaman chemicals storage godown, which was gutted following accident (Deccan Chronicle, 20th Feb, 2004).

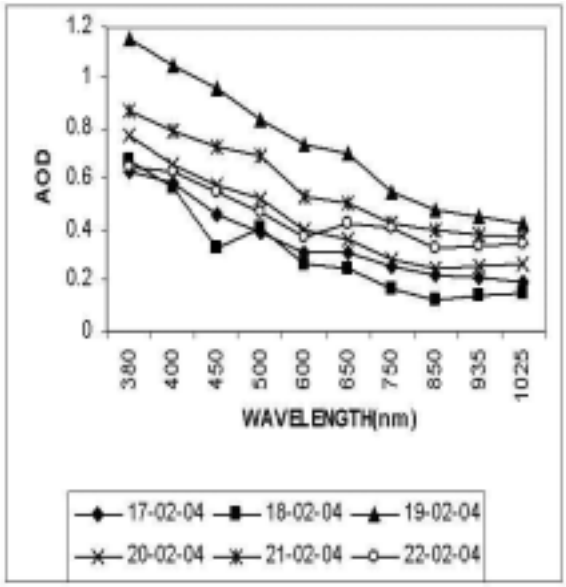

Figure 3. Variation of aerosol optical depth at Balanagar.

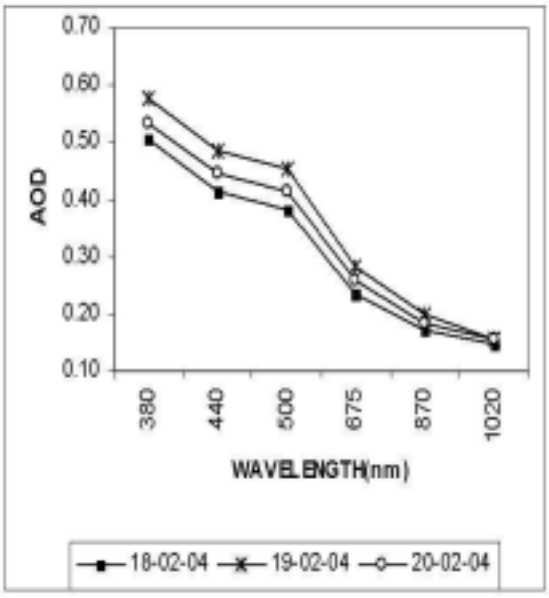

Figure 4. Variation of aerosol optical depth at Shadnagar.

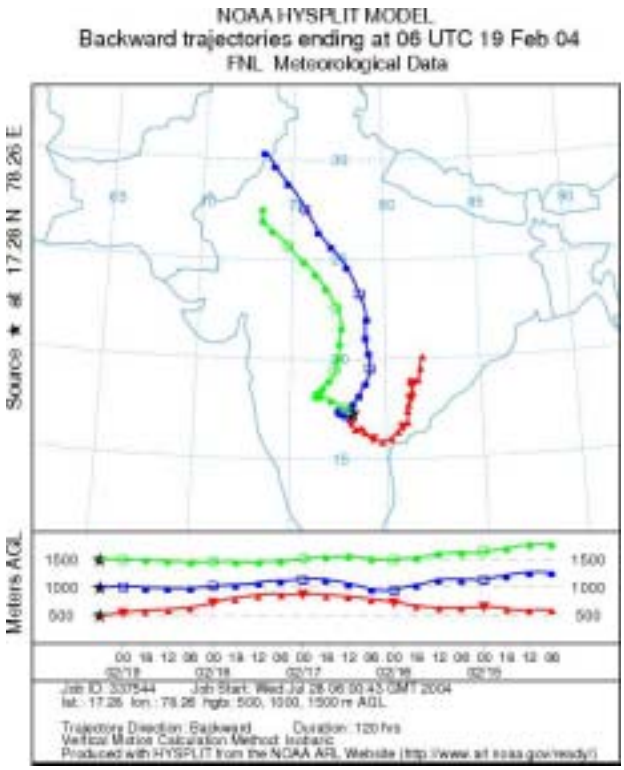

Figure 5. Back trajectory analysis of air mass characteristics over Balanagar.

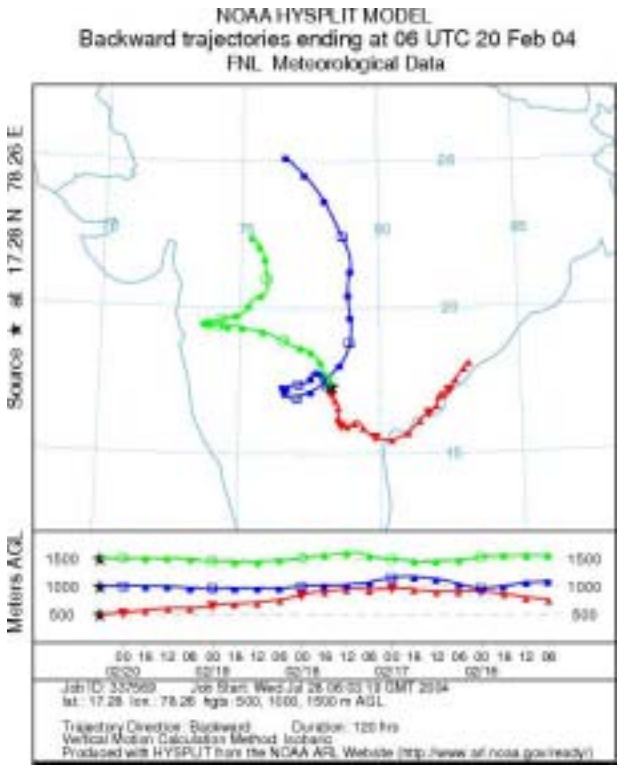

Figure 6. Back trajectory analysis of air mass characteristics over Shadnagar.

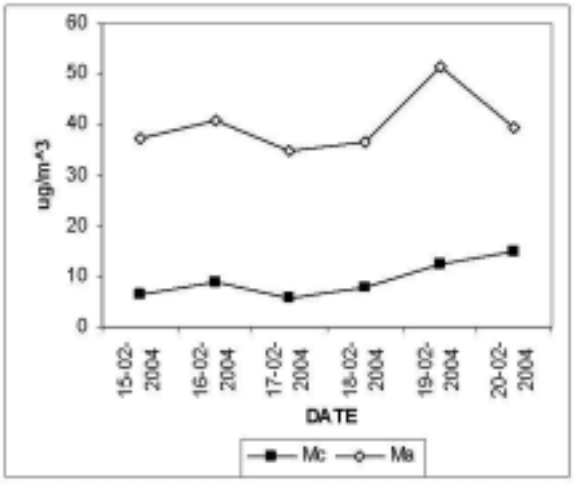

Figure 7. Variation of accumulation and coarse mode particle loading over Shadnagar.

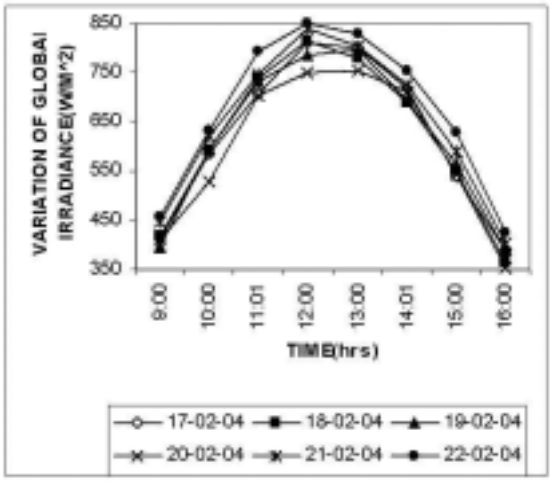

Figure 8. Variation of global irradiance during 17th to 22nd Feb, 2004.

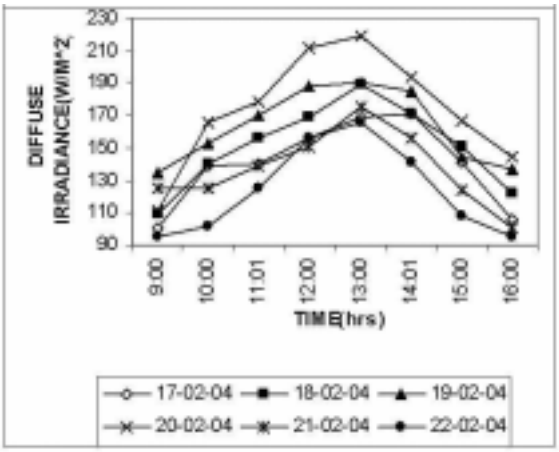

Figure 9. Variation of diffuse irradiance during 17th to 22nd Feb, 2004.

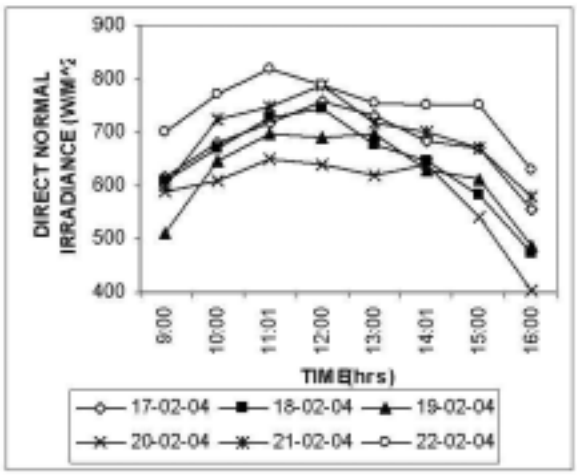

Figure 10. Variation of direct normal irradiance during 17th to 22nd Feb, 2004.

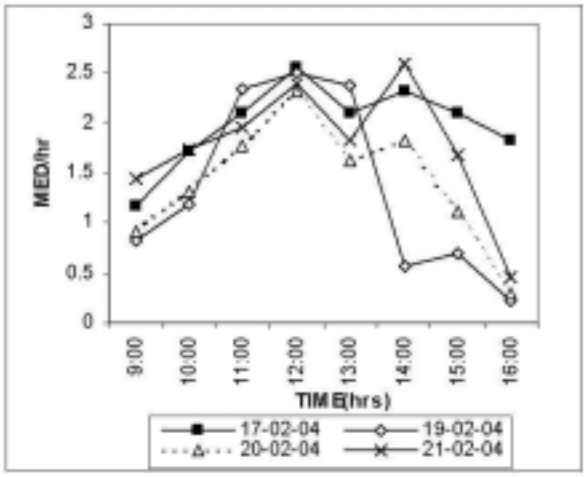

Figure 11. Variation of UV_{ery} irradiance during 17th to 21st Feb, 2004.

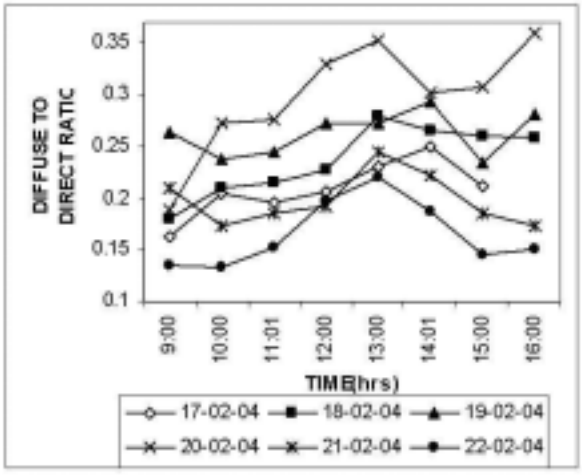

Figure 12. Variation of diffuse to direct irradiance ratio during 17th to 22nd Feb, 2004.

4. Conclusions

Analysis of aerosol optical depth and solar irradiance suggested that

(1) Chemical fire accident caused increase in aerosol optical depth and the effect of has been observed up to 100kms.

(2) Aerosol particle size distribution suggest high accumulation mode particle loading even at distances of ~100km from the accident site.

(3) Considerable increase in diffuse irradiance has been observed due to fire accident compared to normal days.

(4) The diffuse-to-direct ratios of solar irradiance has been found to depend strongly on the polluted atmospheric conditions and the ratio suggested that the effects persisted up to three days after the fire accident.

(5) Significant reduction in UV_{ery} irradiance has been observed due to the chemical fire accident.

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