5th International Conference on Fog, Fog Collection and Dew
Münster, Germany, 25–30 July 2010
FOGDEW2010-48
© Author(s) 2010

Visibility Degradation during Foggy Period due to Anthropogenic Urban Aerosol at Delhi, India

Suresh Tiwari (1), Swagata Payra (2,3) and Deewan Singh Bisht (1)

(1)Indian Institute of Tropical Meteorology-Pune, Delhi Branch, New Delhi-110060, INDIA
(2) Remote Sensing Department, Birla Institute of Technology, Extension Centre, Jaipur, India
(3)Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110016, India
(smbtiwari@tropmet.res.in / Fax: +91-11-28742020)

Abstract

Fog frequencies dominate in urban area than rural area. Increased air pollution in urban area may lead to the atmospheric reactions, resulting into the formation of secondary pollutants similar to cloud condensation processes. Northern regions of India experience severe fog conditions during the winter period (November-January) each year. In this study, simultaneous measurements of particulate mass concentration (0.23µm to 20µm), meteorological parameters and atmospheric visibility in Delhi city, India during 2007-2008 have been studied in order to understand their role in fog formation. The effects of aerosols on fog formation are discussed through an analysis of trends in fog frequency and comparison with meteorological parameters, and visibility as an indicator of aerosol load. The existing dataset of fog frequency, meteorological parameters and visibility is used to find linear regression model, that explained the variation in visibility due to depression in temperature and aerosols load.

1. Introduction

Fog is defined as visual obscurity of less than 1000 m near the surface layer due to suspended water droplets and aerosols. A very high level of ambient aerosol loadings has been recognized to intensify the fog formation in the urban areas (Mircea et al., 2002; Bergot and Guedalia, 1994; Stoelinga and Warner, 1999; Bott et al., 1990) due to the various considerable facts (Toon, 2000) and presence of ammonium, nitrate and sulphate (Frank et al., 1998).

Fog is more likely to form in an environment with large concentrations of aerosols characterized by a low activation super saturation. Organic compounds change the surface tension of pure water and can cause cloud condensation nuclei activation at lower relative humidity than that which is possible in the atmosphere of unpolluted regions (Brooks et. al., 2009). Although in a large number of fogs, the distinction between un-activated and activated droplets is not as straightforward as for other clouds types (Hudson, 1980). The properties of aerosols in the ambient air thus play an important role in fog onset due to the activation of fog droplets. Laboratory experiments have indicated that pollution/aerosol has strong effect for fog formation in favorable meteorological condition. Frank et al., (1998) studied the effect of the aerosol mass present in the fog and varied it by a factor of 4(25-100µgm^{-3}). It was found that the aerosol mass load strongly influenced the microstructure of the fog. Certain meteorological parameters alone or in combination with some air pollutants trigger fog formation in the urban area. In a metropolitan city like Delhi, with over 15 million inhabitants contributing towards the anthropogenic aerosols, coupled with the desert dust aerosols from the north-western region (Singh et al., 2006), a very high level of ambient aerosol loadings is always expected. During past one decade, Delhi has witnessed increased frequency of fog in winter season. Analysis of six years (1996-2001) of meteorological data for the winter season shows that occurrence of fog is more than 50% of the time in this mega-city (Mohan and Payra, 2008). The pollution levels in Delhi environment, especially Respiratory Suspended Particulate Matter (RSPM) concentrations are significantly high. Ali et al., (2004) reported that the anthropogenic species are higher during winter period. Despite of all the possible control measures Delhi has significant concentration of RSPM often exceeding national ambient air quality standards and therefore it is expected that increased aerosols would have an important role in the fog formation.

The main objective of the present study is thus to find the relationship with aerosol content and meteorological parameters in influencing fog formation during winter period over Delhi based on observations during winter (Nov. to Jan.) that included severe dense fog episodes.

2. Sampling Site and Techniques

Delhi ($28^0$35'N; $77^0$12'E, 218 m asl) experiences a severe weather swing between different seasons: from hot and humid weather in summer to cold and dry weather during winter. Apart from such swings of weather, the entire northern part of India, especially the Indo-Gangetic Plain, experiences a thick foggy weather during winter. During such conditions, pollutants could not be dispersed and mix with free troposphere due to trapping canopy of low boundary layer. Such conditions ultimately results in poor visibility and high levels of pollutants.

The ambient sampling of aerosols for this study was carried out at about 15m above the ground level, on the rooftop of a building situated in the thoroughly urbanized central part of Delhi. The area is primarily a residential area, and no large pollutant source exists nearby which could have influenced the sampling site directly. Sampling location is given on the road map of Delhi in Figure 1.

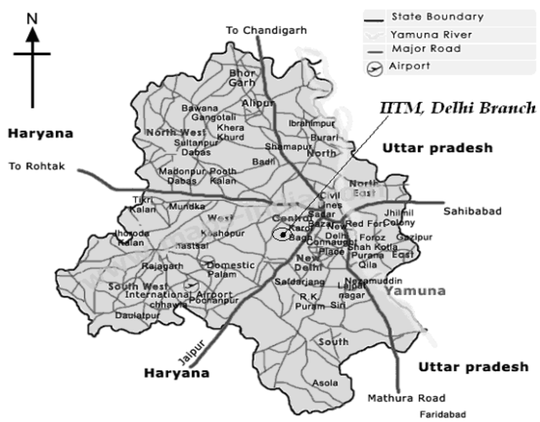

Figure 1. Sampling location (marked as dot) in the road map of Delhi

The GRIMM optical particle counter (GRIMM Aerosol Technich, model 1.108) - a 16 channel aerosol spectrometer was used to measure the total mass concentration of particles in the defined 16 different size ranges (Sciare et al., 2007). Counting of aerosol is measured by light scattering with the help of laser ray. Simultaneous constant flow rate (1.2 litre/min) is maintained throughout the measurements. All meteorological data for this study (2007-2008) are taken from India Meteorological Department (IMD). Aerosol concentration was taken for every minute and meteorological data was taken in every 30 min temporal resolution.

3. Results and Discussion

3.1 Total Aerosol mass concentrations and visibility

The hourly variations in Aerosol Mass Concentration (AMC) for a weeklong data in November, 2007 along with the visibility are shown in Fig. 2.

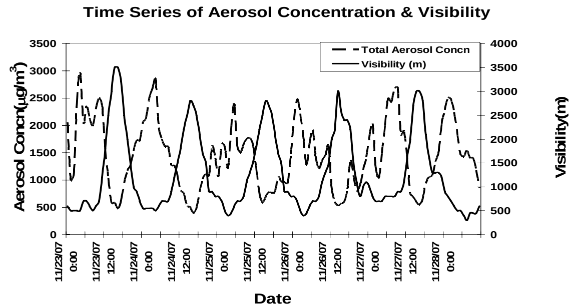

Figure 2. Time series of Visibility and Aerosol Mass Concentration (November, 2007)

The minimum and maximum values of hourly mean mass concentration of aerosols are 394.85 μg/m^3 (24th November, 4 p.m.) and 2980.34 μg/m^3 (23rd November, 4 a.m.), respectively. The corresponding visibilities are 2700m and 500m, respectively. Minimum visibility is less than 300m occurred on 28 November at 7 a.m. with mass concentration of about 1541 μg/m^3. The aerosol mass concentrations follow out of phase relationship with respect to visibility (Fig. 2). The correlation between these two shows a negative value of -0.7 which infers that more the aerosols load, less will be the visibility. This result is not surprising because the sampling site encounters almost all the times the foggy conditions with increasing aerosols concentration supporting the lesser visibility during winter.

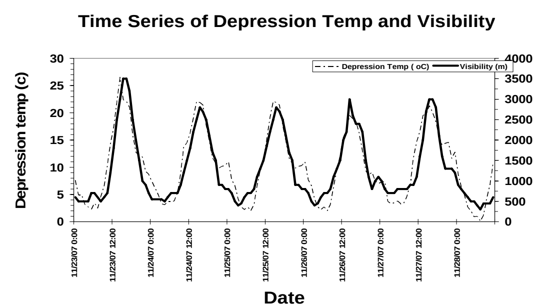

Figure 3. Time Series of Visibility and Depression Temperature (Novemeber,2007)

Figure 3 shows the time series of depression temperature and visibility during November 2007.

Most of the pure meteorological models initially considered a depression temperature less than 1^0C as fog occurrence criteria. However, it is argued that if the pollution load increases rapidly then fog may occur with a depression temperature greater than 1^0C. This study clearly shows this synergic effect of pollution and meteorological condition. The depression temperature and visibility parameter follow in-phase relationship with a high positive correlation of 0.91. The minimum depression temperature (0.1) occurs on 28 November at 7 a.m. when the visibility is the lowest (300 meter).

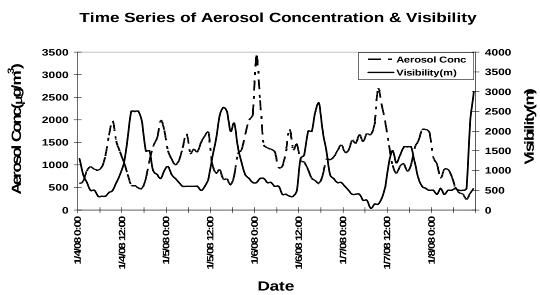

Figure 4. Time series of Visibility and Aerosol Mass Concentration (January 2008)

Hourly variations in aerosol mass concentration for a weeklong data in January 2008 along with the visibility are shown in Fig. 4. The minimum and maximum values of hourly mean mass concentration of aerosols are 233.86 $\mu g/m^3$ (8^{th} January 2008, 9 a.m.) and 3418.65 $\mu g/m^3$ (6^{th} January 2008 Midnight), respectively with corresponding visibilities as 550 m and 700 m, respectively. Minimum visibility is less than 50 m on 7 January at 7 a.m. with mass concentration 1670.72 $\mu g/m^3$. Like November 2007, the January 2008 data also show a negative trend between aerosols concentration and visibility with a negative correlation of -0.5. Thus the visibility trends in Fig. 2 and Fig.4 for a sampling location shows that more aerosols loading is one of the important factors for fog formation.

The time series of depression temperature for January 2008 has been shown in Fig. 5. The correlation of depression temperature with visibility is very high (0.87). The minimum depression temperature (0.9^0C) occurred on 7 January at 7 a.m. when the visibility is the lowest (50 meter). The results from winter shown in Figs. 2 to 5, for 2007 and 2008, respectively stems out that increase in pollution level (aerosol mass concentration) and less depression temperature are favorable for fog formation data.

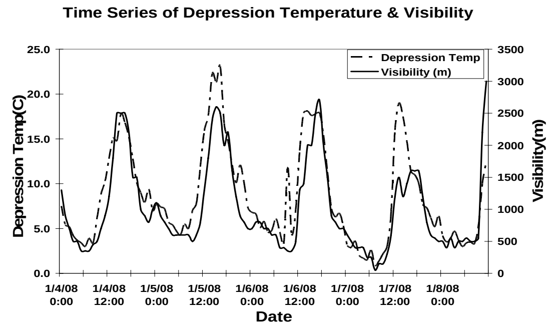

Figure 5. Time Series of Visibility and Depression Temperature (January 2008)

3.3 Linear regression model for estimating fog.

Further investigation shows that the fog formation criteria using hourly average data from 23-28 November 2007 to find linear regression amongst various parameters by due consideration of significance value. The result satisfies the precondition for using these relations even in limited data set. The model explained the variation in visibility due to depression temperature and aerosol mass concentration by the following equation:

Visibility = 545.417 - 0.214 * AMC + 103.082 * DT

Where AMC = Total Aerosol Mass Concentration

DT = Depression Temperature = Dry bulb – Dew point temp

This equation is used on 4-8 January 2008 data for validation. A visibility value of less than 1000 meter is considered as fog occurrence criteria. The predicted and observed fog occurrence is plotted in Figure 6. The estimation of fog occurrences is satisfied for 96 hours out of observed 109 hours.

6. Summary and Conclusions

Delhi is a mega-city with very high air pollution concentration levels. The increasing particulate pollution in urban areas is responsible for fog formation. The field experiments for the measurement of aerosol mass concentrations along with meteorological parameters and visibility were conducted and data analyses were performed in various ways.

Our study over a sampling location at Delhi clearly shows that high aerosols load is one of the important factors for fog formation. The result of linear regression model depicts that increase in pollution

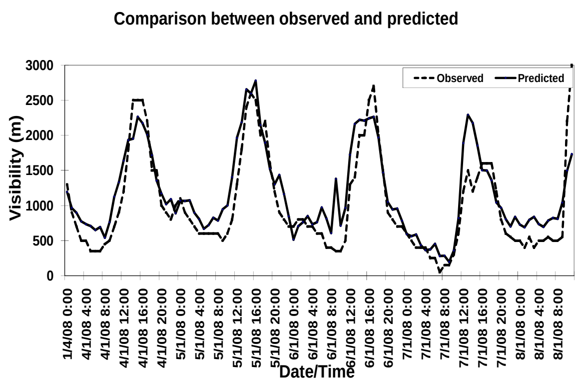

Figure 6. Comparison between of observed and predicted visibility

level (aerosol mass concentration) and less depression temperature are favorable for fog formation over sampling site in Delhi. This is a noble approach for making an idea about the dependency of pollution in favorable meteorological condition. The conclusions of the above study can be used to substantiate the future campaigns at different sites and conditions.

Acknowledgements

Authors thank India Meteorological Department, Govt. of India for providing Meteorological data during the study period. The authors are extremely thankful to Prof. B. N. Goswami, Director, IITM and Dr. P. C. S. Devara, Scientist G and Head P. M. & A. Division for their guidance and unstinted support throughout the study. Authors are also thankful to Mr. Manish Soni for his kind assistance

References

[1] Ali, K., Momin, G..A., Tiwari, S., Safai P. D. Chate, D. M., and Rao, P. S. P., 2004. Fog and precipitation chemistry at Delhi, North India. *Atmospheric Environment* 38, 4215-5422.

[2] Bergot, T., Guedalia, D., 1994. Numerical Forecasting of radiation fog. Part I : Numerical model and sensitivity tests" *Monthly Weather Review* 122, 1218-1230

[3] Brooks, S.D., Gonzales, M., and Farias, R., 2009. Using surface tension measurements to understand how pollution can influence cloud formation, fog, and precipitation. *Journal of Chemical Education 86 (7)*, 838-841.

[4] Bott, A., Sievers, u., Zdunkowski, W., 1990:A Radiation Fog Model with a Detailed Treatment of the Interaction between Radiative Transfer and Fog Microphysics, *Journal of Atmospheric Science* 47, 2153-2166.

[5] Frank, G., Martinsson, B.G., Cederfelt, S., Berg, O.H., Swietlicki, E., Wendisch, M., Yuskiewicz, B., Heintzenberg, J., Wiedensohler, A., Orsini, D., Stratmann, F., Laj, P., 1998. Droplet formation and growth in polluted fogs, *Contribution to Atmospheric Physics* Vol. 71, No. 1, 65-85.

[6] Hudson, J. G., 1980. Relationship between fog condensation nuclei and fog microstructure, *Journal of Atmospheric Sciences* 37, 1854–1867

[7]Mircea M., Facchini, M.C., Decesari, S., Fuzzi, S., Charlson, R. J., 2002. The influence of the organic aerosol component on CCN super saturation spectra for different aerosol types, *Tellus* 54B, 74-81.

[8] Mohan, M., Payra, S., 2008, Influence of aerosol spectrum and air pollutants on fog formation in urban environment of mega city Delhi, India. *Environmental Monitoring and Assessment* 151, 265 - 277

[9] Sciare, J., Cachier, H., Sarda-Estève, R., Yu, T., 2007 Semi-volatile aerosols in Beijing (R.P. China): characterization and influence on various $PM_{2.5}$ measurements, *Journal of Geophysical. Research* **112** , p. D18202 10.1029/2006JD007448.

[10] Singh, S., Nath, S., Kohli, R., Singh, R., 2006. Aerosols over Delhi during pre-monsoon months: Characteristics and effects on surface radiation forcing, *Geophysical Research Letter* 32, L13808, doi:10.1029/2005GL023062.

[11] Stoelinga, M. T., Warner., T. T., 1999. Nonhydrostatic, mesobeta-scale model simulations of cloud ceiling and visibility for an east-coast winter precipitation event. *Journal of Applied Meteorology* 38, 385-404.

[12] Toon O.B., Tabazadeh, A., Browell, E.V., Jordan., J., 2000. Analysis of lidar observations of Arctic polar stratospheric clouds during January, 1989. *Journal of Geophysical Research* 105, 20589-20616.