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Application of CALPUFF model for designing ambient air quality monitoring network

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***Abstract*— In order to comply with the regulatory requirements for air quality management, the industries operates a network of monitoring stations providing air quality data at regular interval for analysis and decision making. The site selection of monitoring station is mostly decided by the logistic constraints i.e. availability of shelter for equipment, power supply, security, safety, approach road etc. Due to these constrains, sometimes, the scientific approach are ignored. These monitoring stations are fixed stations and once a station is established as upwind station, it remains upwind even though the wind pattern changes throughout the year. The air quality monitored under these conditions may not be representative of the emission conditions and may report lower concentration of pollutants, thereby showing a false impression of healthy environment. Under these circumstances, it is required to revisit the air quality monitoring network design practice. The most important criteria i.e. ground level concentration (GLC) of pollutant needs to be incorporated in the network design practice. In this paper, *state-of-the-art* CALPUFF model is used for designing the air quality monitoring network for coal based thermal power plant at Birsinghpur Pali, M.P. The GLC obtained from the dispersion model is compared with the ambient air monitored air quality data and it found that the two set of values matches fairly well.

***Index Terms*— Air Quality, CALMET, CALPUFF, Dispersion Model, Thermal Power plant.**

I. Introduction

Realizing the potential threat due to emissions from coal combustion, regulatory compliance needs air quality monitoring around thermal power plants. The regulatory framework of EIA [1,2] requires setting up of air quality monitoring network around power plant. The pre-requisite to air quality monitoring is the design of a network which truly represents the study area. A poorly designed network having most of the stations on the upwind site or in no-impact zone may report no air pollution thereby misleading the decision makers. AP-98 document published by USEPA [3] provides details about the air quality monitoring network for surveillance purpose. The requirement of air quality stations varies with the objective of monitoring. For urban area, the station siting criteria is described by Harrison [4]. Similarly for highways, a special report was prepared by Highway Research Board [5]. Species specific (carbon monoxide) monitoring station requirement for urban area is discussed by Ott et.al. [6]. Assessment of regional air quality, the network requirement is commented by Pooler [7] in detail. Criteria required for various types of monitoring stations are documented by Ott [8]. All the consideration of safety, security, approachability, shelter, power supply, and object oriented monitoring network design is given by Kenneth et al. [9]. Besides regulatory monitoring, some monitoring is aimed towards source apportionment of PM_{10} and $PM_{2.5}$, requiring sampling of PM from all possible source in the study domain. The criteria for such sampling differs from the season based regulatory requirements and is documented by John et al. (USEPA) [10]. Wind direction based monitoring location that used a new concept of wind impact area diagram or plumerose diagram is presented by George et al. [11]. Quantifying the same plumerose diagram, the duration (month) in which sampling should be carried out for getting maximum pollutant concentration is presented by George et al. [12].

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Thus the design of air quality monitoring network is a very important step. The emission from tall stacks follow wind pattern and thereby maximum impact of air pollution is felt in the downwind side of the emission source. The emission pathway or plume is tracked using classical Gaussian Dispersion Model (GDM). USEPA has developed and approved several software that uses GDM incorporating different topographical and meteorological features. For most of the EIA studies in India, Industrial Source Complex Short Term (ISCST3) is recommended by Ministry of Environment and Forest (MoEF). ISCST3 model software considers uniform meteorology for the study area i.e. in the entire air-shed, at an instant (1 hour) wind vector is constant and uniform. In reality, uneven topography and land use (water body, green cover, built-up area) causes differential convective currents leading to a non-uniform meteorology in an air-shed, which is in contravention to the assumption of uniform meteorology in the entire domain. Better understanding and treatment of non-uniform meteorology encouraged the development of model that permit plume to break off at the boundary of meteorological grid. This lead to the development of puff model and is named as CALifornia PUFF (CALPUFF) model. Currently *state-of-the-art* model for simulating emission from tall stacks is CALPUFF which is likely to give better prediction about puff in an air-shed.

In this paper, optimal design of air quality monitoring network around Sanjay Gandhi Thermal Power Station (SGTPS), Birsingpur is carried out based on historical wind and air quality data with the help of latest *state-of-the-art* source dispersion model (CALPUFF).

II. Materials And Method

A. Modeling

The efficacy or appropriateness of air quality monitoring station can be judged by comparing the values of concentration of air pollutant obtained by field monitoring with mathematically modelled values of concentration of pollutant. Field monitored time series concentration can be obtained from the data base of monitoring stations. There are four air quality monitoring stations outside the power plant premises, which collects air quality data at regular time interval as per the standard methodology suggested by the CPCB [13].

The modeling effort would require gathering of meteorological data, emission characteristics and terrain features. The simplest analytical solution lead to steady-state Gaussian plume model was given by Turner [14]. The dispersion coefficients used in the Gaussian model is described by Turner [15]. The model of turner is further improved by Pasquill [16], which is extensively used today. Gaussian Model developed for single source is then applied for multiple sources using algorithm developed by Novak et al. [17]. Inclusion of all the features in a single model / software was done and Industrial Source Complex Model, ISC3 (USEPA) [18] was developed by USEPA for short range dispersion. Subsequently, improved algorithm for dispersion coefficient estimation using atmospheric turbulence helped developed AERMOD, which does not use Pasquill-Gifford-Turner (PGT) atmospheric stability classification system. Further, development includes consideration of non-uniform wind vector in the dispersion modeling practice, which resulted in CALPUFF model. The documentation of CALPUFF model [19] and its software (Lakes Environmental Software) [20] is available on the web.

B. Model Domain and Meteorology

For using CALPUFF, a study domain of approximately 50 km x 50 km with power plant at the centre is initially defined for the study area. A meteorological grid of 12 cells x 12 cells of 4 km x 4 km sub-grid is overlaid on the study domain with center same as the overall study domain. The overall size of meteorological domain would be 48 km x 48 km.

Emission inventory for the plant consist of parameters like physical stack height, exit gas velocity, exit gas temperature, stack top diameter and emission rate of pollutant. The terrain features for the study area includes elevation which is gathered from Shuttle Radar Tomography Mission (SRTM1) data set that provides ground elevation at 30 m resolution. Besides this, the land use type and surface roughness is also derived from the data provided on the web sites optimized for Asia at 1 km resolution.

Spatio-temporally varying Meteorological data (spatial resolution - 4 km; temporal resolution – 1 hour) is derived from Prognostic Mesoscale Model of 5th generation (MM5) for one year period and used as input to CALMET.

C. Model Parameters

Following are the primary meteorological data used in the CALMET.

Wind speed (m/s) used in estimating the boundary layer parameters; Direction (degrees) the wind is blowing from, corresponding to the wind speed; Height at which the wind above was measured (m); Temperature (K) used in estimating the boundary layer parameters; Height at which the temperature above was measured (m); Cloud cover in Oktas; Pressure (Pascal); Relative Humidity and Mixing Ratio (g/Kg).

CALMET pre-processes the primary data and generates derived parameters as given below:

Sensible heat flux, H (Watts/m^2); Surface friction velocity, u* (m/s); Convective velocity scale, w* (m/s); Convective mixing height, z_{ic} (m); Mechanical mixing height, z_{im} (m); Monin-Obukhov length, L (m).

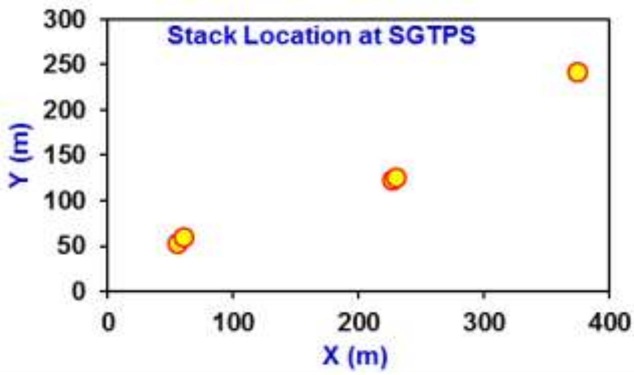
All these parameters at one-hour time-step in each of the sub-grid cell (144) becomes input to CALPUFF model.

Existing air quality monitoring stations are located on a geo-referenced map followed by setting up of CALPUFF framework. Putting all required data and its execution in CALPUFF model will generate the concentration of pollutants, which can be post-processed to generate the isopleth of pollutant concentration in the study area.

III. Result And Discussion

The Emission details are plotted on a geo-reference map and then the origin from Universal Transverse Mercator (UTM) system is shifted close to the stack so as to gauge the relative distance between stacks. Fig. 1 shows the relative distance of stacks. There are five units having three stack, of which two are twin stacks. The emission characteristics of all the stacks are shown in Table 1.

Fig. 1: Relative stack location at SGTPS, Birsingpur.



Wind: The meteorological domain and its sub-grid is shown in Fig. 2. It can be seen that there are 12 cells along X and Y direction each. The source stacks are at Cell No. 7, 7. Based on the wind pattern of all the grid cells, spatially varying wind pattern is shown in Fig. 3. For cell 7, 7 where all the

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stacks are located, the windrose diagram is plotted and is shown in Fig. 4.

Table 1: Source emission parameters used in Source Dispersion Modeling.

Stack	Capacity (MW)	Ht. (m)	Dia. (m)	Temp. (K)	Velo. (m/s)	SPM (g/s)	SO_2 (g/s)
Unit-1	210	200	4.9	381	23.5	53	75
Unit-2	210	200	4.9	382	23.5	53	75
Unit-3	210	220	4.07	383	17.0	27	37
Unit-4	210	220	4.07	383	17.0	27	37
Unit-5	500	275	7.18	391	15.4	41	89

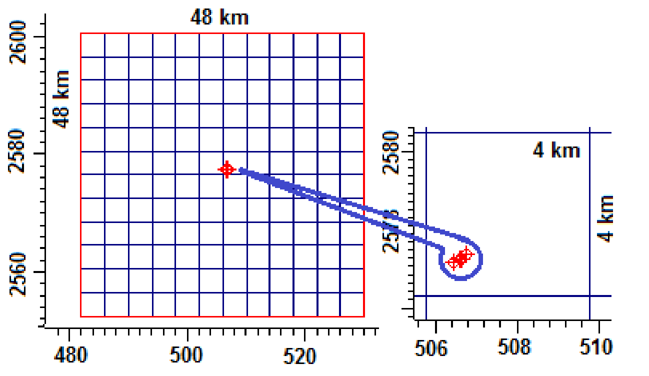

Fig. 2: Meteorological domain, Grid with location of SGTPS Stacks.

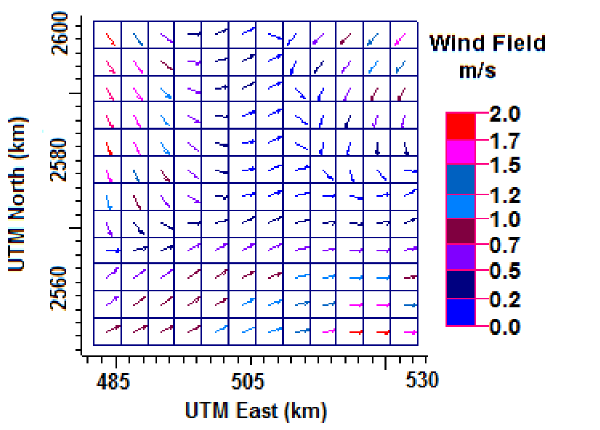

Fig. 3: Spatial non-uniform wind in the study domain.

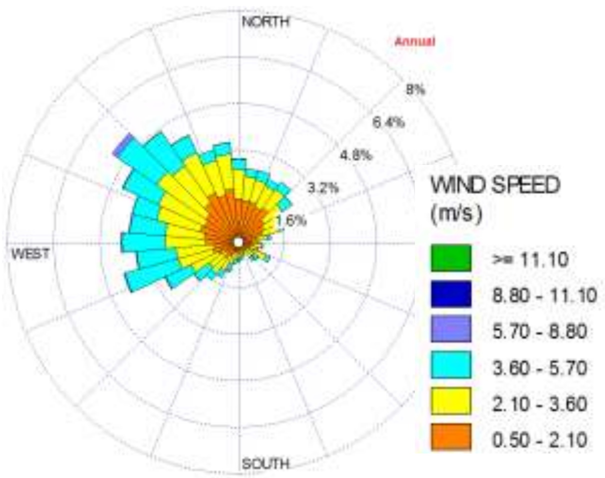

Fig. 4: Windrose diagram for the study area.

CALPUFF Predicted Ambient Air Quality: The ground level concentration (GLC) of pollutant estimated by the CALPUFF model for each receptor location is stored in tabular format. The same data is used for plotting the contour of constant GLC also called isopleth for user defined averaging time. For one year simulation, there will be 8760 (= 365 x 24) GLC values for each receptor. These GLC values of each hour, for one year, for each receptor can be arranged in descending order. The highest GLC for each receptor can be used to plot the isopleth by Kriging interpolation technique. Such a plot, where hourly values are used, are called isopleth of hourly average. Similarly, for each receptor, the GLC for each day (24 GLC values) is averaged and then arranged in descending order. This yields 365 GLC values for each receptor, which when arranged in descending order reveals daily average highest value for that receptor. Isopleth of these highest GLC values is called daily average isopleth. On the same line, different averaging time like 3 or 8 hour can be used for plotting the isopleth. If all the values (i.e. 8760 GLCs) of a receptor is averaged and then used, the isopleth is called annual average isopleth. Since the averaging period of air quality monitoring is fixed as 24 hours, the daily average isopleth of SO_2 is plotted and shown in Fig. 5.

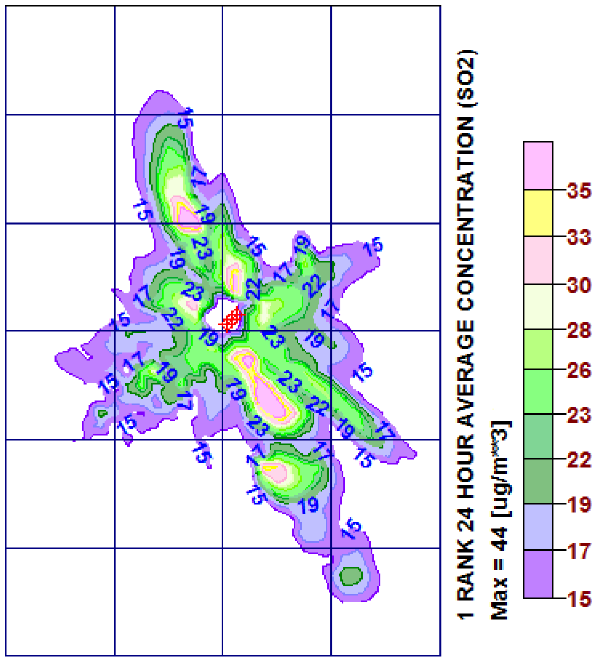

Fig. 5: Isopleth of GLC of SO_2 on daily average basis.

Comparison of monitored and predicted GLC of SO_2 and SPM: The aim of air quality management study is to know the resulting ambient air pollutant concentrations. Thus air quality monitoring not only acts as initiation of the work but also the verification at the end of the work. Besides the prediction exercise using mathematical models, air quality is also monitored to validate the results of prediction. Sources of irregular geometry are not usually well represented in source dispersion modeling. Therefore, the monitored values (at various monitoring stations established around SGTPS) need not necessarily match with the predicted values due to several unaccounted source in the vicinity of the receptor.

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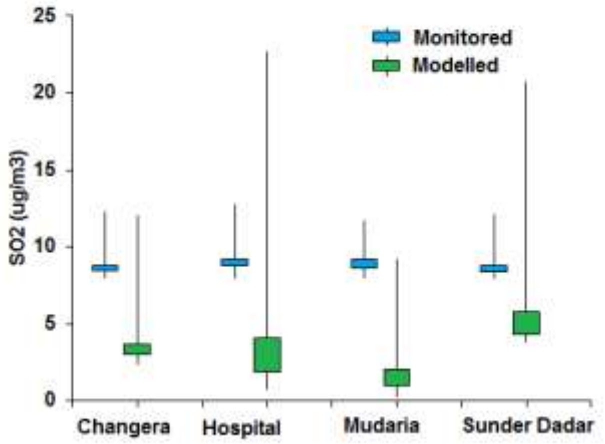
For comparing the monitored and modelled values, the ambient air quality monitored around the SGTPS power plant as per the regulatory needs from January to December, 2010 is collected and analysed. There are four monitoring stations namely Hospital, Mundaria, Changera and Sunder Dadar in the vicinity of power plant, outside the plant premises. Four parameters namely SPM, RSPM, SO_2 and NOx are monitored as per the regulatory requirements. Among the four parameters, the SPM and RSPM cannot be considered to be only contributed by power plant emission as local sources like road dust re-suspension can also contribute to the receptor. NOx undergoes chemical transformation by interacting with volatile organic compounds (VOC) in the presence of sunlight and get converted to Ozone (O_3) and therefore not considered for comparison with monitored values. SO_2 gets depleted from the atmosphere by transformation to particulates and by wet deposition and is considered to be relatively more conservative parameter compared to PM or NOx. Therefore, monitored and modelled SO_2 is used for comparison. There can be possibly two



sources of SO_2, one is emission from stack and the other is coal combustion in local activity like cooking in homes or hotels etc.

Fig. 6: Comparison of monitored and modeled GLC of SO_2 at four stations

Fig. 6 shows the box plot of monitored and modelled daily average GLC of SO_2 at four monitoring stations. It can be seen that except Mudaria, the box-whisker of monitored GLC values are within the box-whisker of modelled GLC values. Since the monitored GLC values are a subset of the complete annual data, it can be stated that the monitored values at three stations fully agree with the modelled values. At Mudaria station, the monitored GLC of SO_2 is higher than the modelled values and the station can be considered to be impacted by additional nearby sources emitting SO_2 due to ground level combustion in hotels near railway station and residential area around the station.

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