Simulation of Atmospheric Pollution Dispersion over Complex Terrain Region of Jharkhand with FLEXPART-WRF, incorporating improved turbulence intensity relationships

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Highlights
- Boundary layer turbulence intensity relationships developed for Ranchi
- Incorporated the new turbulence intensity relationships in the Hansen scheme of FLEXPART-WRF
- Ground level concentrations of nitrogen oxides (NOx) and suspended particulate matter (SPM) over Patratu, Jharkhand in southern Chota Nagpur of eastern India simulated using FLEXPART-WRF
- Modified Hansen scheme considerably improved NOx and SPM concentrations over default Hansen scheme
- Study demonstrate utility of turbulent observation in air quality modeling

Abstract
The complex terrain region of Patratu, Jharkhand in southern Chota Nagpur of eastern India has high air pollution problems besides complex mesoscale flow and meteorology. The FLEXPART-WRF mesoscale Lagrangian Particle dispersion model is used to simulate the dispersion of elevated effluent releases of nitrogen oxides (NOx) and suspended particulate matter (SPM) from Patratu thermal power plant over Patratu at a high resolution of 1 km. The WRF is integrated with nested domains (27, 9, 3 km resolutions, 51 vertical levels). The relationships for turbulent intensities in the default diffusion parameterization of the Hansen scheme of FLEXPART is modified with new empirical relationships derived as a function of atmospheric stability from one year fast response turbulence measurements from a nearby observational site at Ranchi. The pollutant dispersion simulated by FLEXPART is evaluated with modified version of the model and using the WRF simulated atmospheric field and thermodynamical structure with three alternative PBL schemes (INM, Yonsei University (YSU), Asymmetric Convective Model version 2 (ACM2) and Mellor-Yamada Nakanishi and Niino Level 2.5 PBL (MYNN2)). Results indicate that the new turbulence intensity relationships in FLEXPART provide better comparisons for concentrations of NOx and SPM with available observations relative to the default relationships. Further, the meteorological parameters simulated using YSU significantly reduces the bias in modelled pollutant concentrations in terms of less mean absolute error (MAE), root mean square error (RMSE), normalized mean square error (NMMSE), fractional bias (FB) and FAC2 (Factor of 2). These parametric tests enabled to fine tune and validate the FLEXPART-WRF dispersion model with YSU PBL physics and improved Hansen relationships to realistically simulate pollution dispersion over complex terrain of the study region. The study demonstrates the utility of high quality turbulence measurements in pollution dispersion model for better diffusion parameterization needed in air quality modeling.

Study region, data and quality checks

Study Region
The study region, Patratu (23° 40′ N, 85° 16′ E), is located in southern part of the Chota Nagpur plateau which forms the eastern edge of the Deccan plateau system. It has a hilly southern part of the Chota Nagpur plateau region was examined, simulations using 3 km grid spacing provided better results for PBL vertical structure and surface meteorological variables.

Surface Layer Turbulence Data
The turbulence intensity relationships needed in FLEXPART model for the Ranchi region are developed from one year fast response (10 Hz) measurements of wind and temperature at 10 m height acquired using a Ultra Sonic Anemometer from an observational site at Ranchi.

Air Pollution emission data
The present study sources of emissions i.e., elevated effluent releases of NOx, and suspended particulate matter (SPM) from Patratu thermal power plant. Air concentration data from the monitoring location located at DM Plant is considered for FLEXPART model validation.

Description of Models
The off-line air quality modeling system FLEXPART-WRF (Fast and Easter, 2006) used in the present study consists of two components, a) meteorology and b) dispersion.

Atmospheric model
The atmospheric model to simulate the meteorological fields over Ranchi in the present study is ARW (version 3.2).

Dispersion model
The FLEXPART Lagrangian Particle Dispersion model (LPDM) computes the mesoscale transport, diffusion, dry and wet deposition of emissions released from point, line, area or volume sources by computing trajectories of fluid particles (Stohl et al., 2005).

Results and discussion

The dispersion model FLEXPART-WRF uses the gridded meteorological fields form ARW model given in a latitude/longitude coordinate system.

In our earlier study (Srikant et al., 2014) the impact of horizontal resolution in ARW for simulating the mesoscale flow over Ranchi region in Chota Nagpur plateau region was examined. Simulations using 3 km grid spacing provided better results for PBL vertical structure and surface meteorological variables.

Srikant et al., (2015) studied sensitivity of ARW simulated flow-field and PBL parameters over Ranchi region to different PBL schemes and have shown that the non-local ACM2 followed by the TKE closure MYNN2 and non-local YSU PBL turbulence parameterizations in ARW performed better in simulating surface meteorological variables.

In the present study we have adopted these tested model grid and physics configurations in ARW model and we are not showing any ARW model analysis.

Non-dimensionalised standard deviation of wind components
The exchange of momentum, heat and moisture between the Earth’s surface and atmosphere happens in atmospheric surface layer (ASL) where the frictional drag force of the Earth and turbulent forces are predominant.

These relationships are being fitted by considering 50% bin quartile values. Horizontal fluctuations of winds are following 1/3 power law in both unstable and stable stratification (Tyagi and Satyanarayana, 2006).

Atmospheric stability classification based on high frequency turbulence measurements at Ranchi during 2009.

Conclusions

In this study long-term surface layer turbulence data gathered using fast response Sonic Anemometer observations of wind and surface meteorological variables.

In this study the derived relationships are introduced in the Hansen diffusion scheme in FLEXPART-WRF model.

Negative bias of the model is reduced with the modified Hanna scheme using new turbulence intensity empirical relationships and using ARW simulated atmospheric parameters with all PBL physics schemes.

Significant improvement in the modelled pollutant concentrations are noticed with the combination of YSU derived PBL parameters with modified Hanna schemes over the study region.

The useful outcome of the present study is formulation of empirical diffusion relationships for Ranchi region for their application in atmospheric dispersion model.

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References