Abstract

An adequate understanding of the turbulent structure of the atmosphere is required to model various diffusion processes in the atmospheric surface layer (ASL). Typically, most human activities and pollutant emissions occur in the ASL. This layer determines the horizontal and vertical transport of heat, moisture, momentum, and pollutants by serving as a link between the atmosphere and the earth's surface. Spectral analysis techniques are instrumental in understanding and parameterizing these turbulent processes in the models.

In the thesis, the turbulent structure of the atmosphere is studied under low and moderate wind conditions using spectral analysis techniques. The fast Fourier transform technique is applied by decomposing the turbulent data into frequency components, and the relative contribution of eddies in the low and high-frequency spectrum region is observed. The existing formulations in the literature can capture the observed behavior of the spectrum in the high-frequency region for the horizontal (u and v) and vertical wind (w). However, they cannot explain large oscillatory (meandering) behavior in the low-frequency region of the spectrum of the horizontal wind components. The extent of meandering occurring in the atmosphere is computed using the value of the significant negative lobe observed in the Eulerian Auto-correlation function (EAF) function of u and v. Various EAF formulations in the literature are tested. It is found that the computed peak of the negative lobe differs from the observed peak both in terms of position and value. Thus, modified EAF formulations are proposed, and they are seen to characterize the observed behavior of the negative lobe in a better way. With the modified formulations, RMSE (root mean square error) between the observed and computed peaks got reduced by 72–77% for the horizontal wind components (u and v) and temperature θ. Further, a direct method for computing the meandering parameter from the observed values of the

negative lobe is proposed, which works well under different wind speeds and stability conditions with an accuracy of 98%. Significant meandering is observed under low and moderate wind conditions for all three sites–Ranchi, LASPEX, and CASES-99. However, meandering effects are seen to be relatively more pronounced in the low wind than in the moderate wind. For the Ranchi dataset, around 89.46% of the low wind hours and 76.89% of the moderate wind hours lie in the significant meandering range. For the LASPEX dataset, around 85.51% of the low wind hours and 73.20% of the moderate wind hours lie in the significant meandering range. While for the CASES-99 dataset, around 97.96% of the low wind hours and 82.31% of the moderate wind hours lie in the significant meandering range. To account for these meandering effects, the proposed parametrization for EAF is utilized to compute the meandering parameters accurately for their further applications in spectrum analysis. The modified spectrum formulations work well under low and moderate wind conditions. Also, the non-dimensional frequency is found to be different under meandering and non-meandering conditions. Its values lie in the range of 0.90–3.81 under meandering conditions, with a mean of around 1.97. While under non-meandering conditions, these values lie in the range of 2.91–3.94, with a mean of around 3.58. General characteristics are observed for the turbulent parameters computed from spectra, such as eddy diffusivity (K), TKE dissipation rate (ε), and normalized dissipation length scale (l/z).

Further, they are parametrized in terms of friction velocity, and the proposed parametrizations are seen to work well under different wind speeds and stability conditions. The maximum absolute percentage error obtained in the prediction of K, ε, and l/z is around 3.52%, 3.26%, and 3.73%, respectively. The general parameterizations proposed for eddy diffusivity can be adopted to model the dispersion characteristics over tropical regions.

The physical reasoning behind the wind's meandering and non-meandering behavior is also studied by analyzing various turbulent parameters. It is found that the parameter σ_w / σ_h (ratio of standard deviations of vertical and horizontal wind) helps in differentiating wind's meandering and non-meandering behavior. The decrease in σ_w values due to the non-interaction of vertical eddies with the ground, and the increase in σ_h values due to large-scale oscillations, are attributable to the decrease in the ratio of σ_w / σ_h during meandering conditions. Further, parameterization between the meandering and turbulent parameters is proposed, which can help in differentiating the meandering and non-meandering behavior of wind.

In order to estimate the surface fluxes accurately, the observed functional behavior of the stability-correction functions for wind speed (φ_m) and temperature (φ_h) are analyzed under stable conditions for the Ranchi site. It is observed that the non-linear form with the optimized coefficients can explain the observed behavior of φ_m for the Indian region. However, a large scatter is observed in the values of φ_h as compared to φ_m. Thus, the non-linear form of φ_h (in existing form) and φ_m (with optimized coefficients) are recommended for the Indian region.

These proposed parametrizations in the thesis can be used for further applications in dispersion modeling, spectral analysis, air pollution studies, and accurate computation of surface fluxes in the Indian region.

Keywords: Autocorrelation coefficient • Low and moderate wind speed • Meandering • Stability correction functions • Surface layer • Turbulent and spectral characteristics