Observational Studies on Turbulence in Atmospheric Surface Layer

A thesis submitted

in partial fulfillment for the award of the degree of

Doctor of Philosophy

By

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JUNE 2024

ABSTRACT

Introduction

In the atmosphere, the atmospheric surface layer (ASL) is the layer that is directly interacting with the surface of the Earth and is located between 10 and 100 meters above ground level (a.g.l). As a consequence, surface forcings exert the greatest amount of impact in this layer, which leads to the phenomenon of persistent turbulence. Terrestrial ecosystems, bodies of water, ice fields, and oceans are all possible components of these surfaces. The surface heating and the drag or frictional forces that are exerted near the surface of the Earth are the two basic factors that are responsible for the turbulence that occurs in the boundary layer of the atmosphere. In addition to being necessary for the dispersion of air pollutants, turbulence is necessary for the transport of momentum, heat, and scalars such as CO_2, H_2O, and other trace gases. For this reason, it is absolutely necessary to have a thorough knowledge of the turbulent properties of ASL in order to make an accurate prediction regarding the flux transport of the values indicated above.Turbulence is a phenomenon that is characterized by its non-linearity and irregularity. Turbulence is also strongly rotational and three-dimensional. It is believed that the presence of coherent structures, also known as organized motions, is responsible for the intermittent nature of turbulence in Atmospheric surface layer. Even if it is not completely understood, the role that coherent structures play in the transfer of these fluxes has been recognized for quite some time because of their significance. In pure shear flows, it is common practice to suppose that heat and momentum fluxes are transported by comparable eddies. This is a concept known as the Reynolds analogy, in which the eddy diffusivities of heat and momentum are assumed to be equal. On the other hand, this comparison is commonly broken when dealing with ASL flows, which results in a dissimilarity between the transfer of momentum and heat flux transfer. The dissimilarity in flux transport is connected with atmospheric stability (ζ), which also effects the evolution of coherent structures in the ASL, according to a number of studies that have been published in the scientific literature. Because of this, we are compelled to explore the properties of coherent structures present in ASL. The intermittent nature of the dissipation rate, ϵ, provides an alternate explanation for the observed intermittency in turbulence, and also serves as the main rationale for its departure from Gaussianity and Kolmogorov's 1941 hypothesis. It has been speculated that the intermittent nature of this turbulence is due to the intermittent dissipation rate, which is also known as internal intermittency. This rate serves as the foundation for the multifractal models that are now being utilized, such as the log-normal or log-Poisson models. This gives rise to the need for more research into the multifractal properties of Atmospheric surface layer, which have been largely underexplored in earlier studies.

Objective

The main objectives of this thesis can be outlined in the following points:

- To illustrate the extent to which the ASL under consideration in this study deviates from the ideal theory, we assess the validity of the Monin-Obukhov similarity theory (MOST) for the drag coefficient (C_D), momentum, heat, CO_2 and H_2O fluxes.

- We utilize Quadrant-Hole (QH) analysis to establish that the coherent structures or motions of sweeps and ejections are the predominant type of motion responsible for flux transport in the ASL. We examine how the efficiency of flux transport and the dissimilarity in fluxes are influenced by atmospheric stability (ζ).

- In order to study the contribution of coherent structures, we partition the ASL turbulent flow into mean, coherent (large), and incoherent(small) scales using wavelet-based multiresolution analysis (MRA) and then study various properties of these high-intensity or bursting events by isolating them through event detection techniques that make use of the Mexican Hat (MHAT) wavelet and the zero-crossing method.

- Finally, we utilize the wavelet leader (WL) based technique to determine the multifractal framework of both the original and partitioned flow. This technique facilitates the estimation of scaling exponents (ξ_q), Hölder exponents (h), and the singularity spectrum ($D(h)$).

Data and Methodology

The research strategy followed in this thesis is to investigate point-measurements of turbulent data in ASL. The data analyzed consists of three wind field components (u,v,w), sonic temperature (T) collected through a Young Model 81000 ultrasonic anemometer (RM Young) and H_2O (q) and CO_2 (c) measurements collected through eddy-covariance gas analyzer (LI-7500D, LI-COR, Lincoln, Nebraska, USA) installed at 8-m height on a 50-m meteorological tower. The data is sampled continuously at the rate of 20 Hz for more than one year at two different tropical sites characterized by different topography. Site A is a coastal station on west coast of India while Site B is a rural inland station situated in a complex hilly terrain. The initial data filtering involves coordinate rotation using the double rotation technique, density adjustments, de-spiking, tilt correction, time-lag corrections and check for steady state and stationarity. After filtering, the data is subjected to Fourier, QH and wavelet analysis.

Results and Conclusions

The main results and conclusions of the thesis are summarized below :

1. The transfer efficiency of momentum and heat fluxes show dependence on atmospheric stability, while no such dependence was observed for H_2O and CO_2 fluxes. Thus, while momentum and heat flux transfer efficiency can be expressed as a function of atmospheric stability no such dependence on atmospheric stability is realized for H_2O and CO_2 fluxes.

2. Sweeps and ejections were found to contribute more than 80 % to the total flux suggesting they are the dominant motion type.

3. Wavelet based multiresolution analysis presents a promising technique for separating organized motions (large or coherent scale) from fine scale turbulence (small or incoherent scale). A cut-off frequency of $f_c = 0.0779$ Hz is found which delineate original flow into above mentioned scales. However, the velocity probability density function of streamwise, lateral, and vertical

velocity for incoherent scales show a narrower distribution as compared to the coherent scales. The probability density function of neither coherent nor incoherent scales are strictly Gaussian.

4. The frequency of occurrence and duration of detected bursting events do not show a strong dependence on stability. However, the length of the structure is found to be longer during convective conditions.

5. The underlying motion of ASL data exhibits a multifractal structure, as indicated by the broader shape of the singularity spectrum. The multifractal framework shows that scalars are more intermittent than their velocity counterparts. Regardless of whether the data is wind or scalar, the coherent scale statistics display a uniform trend that remains unaffected by terrain or stability conditions.