

**Surface Layer Turbulent and Spectral
Characteristics under Low and Moderate Wind
Conditions**

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**CENTRE FOR ATMOSPHERIC SCIENCES
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**Surface Layer Turbulent and Spectral
Characteristics under Low and Moderate Wind
Conditions**

by

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Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



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Dedicated to My Parents and Sister

Certificate

This is to certify that the thesis entitled "**Surface Layer Turbulent and Spectral Characteristics under Low and Moderate Wind Conditions**" being submitted by **Mr. Aditya Kumar Dhuria** to the Indian Institute of Technology Delhi for the award of the degree of **DOCTOR OF PHILOSOPHY** is a record of the original bonafide research carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of the thesis. The results presented in this thesis have not been submitted in part or full to any other University or Institute for award of any degree or diploma.

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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

सार

वायुमंडलीय सतह परत (एएसएल) में विभिन्न प्रसार प्रक्रियाओं को मॉडल करने के लिए वायुमंडल की संरचना की पर्याप्त समझ आवश्यक है। आमतौर पर, अधिकांश मानवीय गतिविधियाँ और प्रदूषक उत्सर्जन एएसएल में होते हैं। यह परत वायुमंडल और पृथ्वी की सतह के बीच एक कड़ी के रूप में कार्य करके गर्मी, नमी, संवेग और प्रदूषकों के क्षैतिज और ऊर्ध्वाधर परिवहन को निर्धारित करती है। मॉडल में इन अशांत प्रक्रियाओं को समझने और पैरामीटर बनाने में स्पेक्ट्रल विश्लेषण तकनीक महत्वपूर्ण हैं।

थीसिस में, वर्णक्रमीय विश्लेषण तकनीकों का उपयोग करके निम्न और मध्यम हवा की स्थिति के तहत वायुमंडल की अशांत संरचना का अध्ययन किया जाता है। फूरियर रूपांतरण तकनीक को आवृत्ति घटकों में विघटित करके लागू किया जाता है, और निम्न और उच्च आवृत्ति वाले स्पेक्ट्रम क्षेत्र में एडीज के सापेक्ष योगदान को देखा जाता साहित्य में मौजूदा सूत्र क्षैतिज (यू और वी) और ऊर्ध्वाधर हवा (डब्ल्यू) के लिए उच्च आवृत्ति क्षेत्र में स्पेक्ट्रम के देखे गए व्यवहार को पकड़ सकते हैं। हालांकि, वे क्षैतिज पवन घटकों के स्पेक्ट्रम के कम आवृत्ति वाले क्षेत्र में बड़े दोलन (विचलित) व्यवहार की व्याख्या नहीं कर सकते हैं। वायुमंडल में घटित होने वाली विसर्प की मात्रा की गणना यू और वी के ईएएफ फ़ंक्शन में देखे गए महत्वपूर्ण नकारात्मक लोब के मान का उपयोग करके की जाती है। साहित्य में विभिन्न ईएएफ योगों का परीक्षण किया जाता है। यह पाया गया है कि नकारात्मक लोब की संगणित चोटी स्थिति और मूल्य दोनों के संदर्भ में देखी गई चोटी से अलग है। इस प्रकार, संशोधित ईएएफ फॉर्मूलेशन प्रस्तावित हैं, और उन्हें नकारात्मक लोब के देखे गए व्यवहार को बेहतर तरीके से चित्रित करने के लिए देखा जाता है। संशोधित योगों के साथ, क्षैतिज पवन घटकों (यू और वी) और तापमान के लिए देखी गई और गणना की गई चोटियों के बीच आरएमएसई (मूल माध्य वर्ग त्रुटि) 72-77% कम हो गई। इसके अलावा, नेगेटिव लोब के देखे गए मानों से घुमावदार पैरामीटर की गणना करने के लिए एक सीधी विधि प्रस्तावित है, जो 98% की सटीकता के साथ विभिन्न हवा की गति और स्थिरता स्थितियों के तहत अच्छी तरह से काम करती है। रांची, लेस्पेक्स, और केसेस -99 तीनों साइटों के लिए कम और मध्यम हवा की स्थिति के तहत महत्वपूर्ण घुमाव मनाया जाता है। हालांकि, मध्यम हवा की तुलना में कम हवा में घुमावदार प्रभाव अपेक्षाकृत अधिक स्पष्ट होते हैं। रांची डेटासेट के लिए, कम हवा के घंटों का लगभग 89.46% और मध्यम हवा के घंटों का 76.89% महत्वपूर्ण घुमावदार सीमा में है। लेस्पेक्स डेटासेट के लिए, लगभग 85.51% कम हवा के घंटे और 73.20% मध्यम हवा के घंटे महत्वपूर्ण घुमावदार सीमा में हैं। जबकि केसेस -99 डेटासेट के लिए, लगभग 97.96% कम हवा के घंटे और 82.31% मध्यम हवा के घंटे महत्वपूर्ण घुमावदार सीमा में हैं। इन घुमावदार प्रभावों को ध्यान में रखते हुए, ईएएफ के लिए प्रस्तावित पैरामीट्रिजेशन का उपयोग स्पेक्ट्रम विश्लेषण में उनके आगे के अनुप्रयोगों के लिए घुमावदार पैरामीटरों की सटीक गणना करने के लिए किया जाता है। संशोधित स्पेक्ट्रम सूत्रीकरण कम और मध्यम हवा की स्थिति में अच्छी तरह से काम करते हैं। इसके अलावा, गैर-आयामी आवृत्ति घुमावदार और गैर-घुमावदार स्थितियों के तहत अलग-अलग पाई जाती है। इसका मान 0.90-3.81 की सीमा में है, जो

लगभग 1.97 के औसत के साथ विकट परिस्थितियों में है। जबकि गैर-अस्थिर परिस्थितियों में, ये मान लगभग 3.58 के औसत के साथ 2.91-3.94 की सीमा में हैं। स्पेक्ट्रा से गणना किए गए अशांत मापदंडों के लिए सामान्य विशेषताओं को देखा जाता है, जैसे कि एडी डिफ्यूसिविटी, टीकेई अपव्यय दर, और सामान्यीकृत अपव्यय लंबाई स्केल। इसके अलावा, वे घर्षण वेग के संदर्भ में पैरामीट्रिज्ड हैं, और प्रस्तावित पैरामीट्रिजेशन को विभिन्न हवा की गति और स्थिरता स्थितियों के तहत अच्छी तरह से काम करने के लिए देखा जाता है। K , ϵ , और u_z की भविष्यवाणी में प्राप्त अधिकतम पूर्ण प्रतिशत त्रुटि क्रमशः 3.52%, 3.26% और 3.73% है। उष्णकटिबंधीय क्षेत्रों पर फैलाव विशेषताओं को मॉडल करने के लिए एड़ी विसारकता के लिए प्रस्तावित सामान्य पैरामीटर को अपनाया जा सकता है। विभिन्न अशांत मापदंडों का विश्लेषण करके हवा के घुमावदार और गैर-घुमावदार व्यवहार के पीछे भौतिक तर्क का भी अध्ययन किया जाता है। यह पाया गया है कि पैरामीटर / (ऊर्ध्वाधर और क्षैतिज हवा के मानक विचलन का अनुपात) हवा के घुमावदार और गैर-घुमावदार व्यवहार को अलग करने में मदद करता है। इसके अलावा, घुमावदार और विक्षुब्ध मापदंडों के बीच मानकीकरण प्रस्तावित है, जो हवा के घूमने वाले और गैर-घुमावदार व्यवहार को अलग करने में मदद कर सकता है।

सतह के फ्लक्स का सटीक अनुमान लगाने के लिए, रांची साइट के लिए स्थिर परिस्थितियों के तहत हवा की गति और तापमान के लिए स्थिरता-सुधार कार्यों के देखे गए कार्यात्मक व्यवहार का विश्लेषण किया जाता है। यह देखा गया है कि अनुकूलित गुणांकों के साथ गैर-रैखिक रूप भारतीय क्षेत्र के लिए देखे गए व्यवहार की व्याख्या कर सकता है। हालाँकि, की तुलना में के मूल्यों में एक बड़ा बिखराव देखा गया है। थीसिस में इन प्रस्तावित पैरामीट्रिजेशन का उपयोग फैलाव मॉडलिंग, वर्णक्रमीय विश्लेषण, वायु प्रदूषण अध्ययन और भारतीय क्षेत्र में सतह के प्रवाह की सटीक गणना में आगे के अनुप्रयोगों के लिए किया जा सकता है।

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Certificate

Acknowledgments

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