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INFLUENCE OF MEDIA INHOMOGENEITY ON THE TRANSPORT OF DISPERSIVE WAVE PACKETS

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The investigation of dispersive wave packet propagation within inhomogeneous media stands as a cornerstone of modern physical research. This area of study spans a diverse array of scientific disciplines, including but not limited to optics, acoustics, seismology, and plasma physics. In these systems, the physical properties of the medium vary spatially, while the propagation velocity of the wave is intrinsically linked to its frequency. The simultaneous presence of inhomogeneity and dispersion creates a highly intricate dynamic environment. As a wave packet traverses such a medium, it is subjected to a variety of transformative effects. It does not simply translate through space; it undergoes temporal spreading, experiences a redistribution of its internal energy, and follows curved propagation paths. Modeling these phenomena requires a sophisticated set of analytical and computational tools that can account for the non-stationary nature of the signals produced by such interactions.

Traditional approaches to wave propagation, such as ray tracing and the Wentzel-Kramers-Brillouin approximation [1], have long served as the primary methods for modeling wave behavior in media where properties change slowly relative to the wavelength. However, these classical methods encounter significant difficulties in specific physical scenarios that are common in real-world applications. They often fail to provide accurate descriptions near caustic regions where wave energy focuses intensely, or at turning points where the wave direction changes abruptly. Furthermore, when dealing with wave packets that possess a broad spectral content, these approximations struggle to maintain validity because they cannot easily handle the rapid variations in phase and amplitude. This underscores a clear requirement for mathematical methods that can effectively

capture the localization of signals in both the time and frequency domains simultaneously, providing a more granular view of the propagation process than what is available through standard asymptotic techniques.

The Continuous Wavelet Transform has emerged as a sophisticated technique that transcends the limitations inherent in traditional Fourier-based analysis. While the standard Fourier transform provides excellent frequency resolution, it loses all temporal information, making it unsuitable for non-stationary signals where frequency content changes over time [2]. The Short-Time Fourier Transform attempts to bridge this gap using a fixed-width window, but it is constrained by a uniform resolution across all frequencies.

Beyond basic tracking, the wavelet-based approach is instrumental in isolating and characterizing superimposed wave phenomena that frequently occur in inhomogeneous systems. Real-world media often produce multiple reflections, mode conversions, and precursors that overlap in the time domain. Because wavelet basis functions are localized, the transform can separate these distinct components if they possess different frequency signatures or temporal patterns. In a layered or complex medium, the arrival of a direct wave can be clearly distinguished from subsequent reflected or refracted pulses on a scalogram. This high level of resolution significantly improves the precision of travel-time tomography and various waveform inversion techniques. Additionally, the transform has been utilized to extract specific wave parameters, such as local attenuation coefficients, and to investigate how nonlinear effects influence dispersive wave packets within these systems. By offering a comprehensive time-frequency representation, the technique provides a powerful lens through which the complex physics of wave propagation can be examined and quantified.

Summary and conclusions. The computational analysis of the datasets D1 and D2 provides significant insights into dispersive wave behavior. For D1, which represents a single coherent energy packet, the results show an excellent agreement between experimental data and calculated cross-correlation signals. This correspondence confirms the validity of the mathematical model used for the simulation. From this analysis, modulated curves for phase velocity, group velocity, and attenuation were successfully extracted, offering a detailed profile of the packet propagation within the medium.

Analysis of the wavelet images suggests that the energy distribution does not follow typical modal patterns. Since no significant frequency overlap was observed between different components, the presence of standard modal structures is effectively ruled out. Instead, the data reveals two coherent packets localized within a frequency band of 50 Hz. This concentration is a direct result of the strong attenuation exhibited by the medium in this specific frequency range, which

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PHYSICS AND MATHEMATICS

effectively filters out other components and limits the spectral breadth of the signals.

For the D2 dataset, the modulus of the wavelet transforms allowed for the clear identification of two separate coherent surface waves. A filtering technique was employed to isolate these distinct events from the recorded signal. By utilizing the estimated dispersion and attenuation properties to calculate cross-correlations for each individual packet, the complete dispersive wave path was reconstructed. The summation of these signals effectively captured the dynamics of both high and low frequency components, demonstrating the ability of the wavelet framework to resolve complex wave structures in inhomogeneous media.

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