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From Ocean to Ionosphere: Gravity Waves in a Complex Atmosphere

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LONG-TERM GOALS

Fundamental theoretical and numerical study generation of large fast internal waves in the troposphere, their propagation through a complex atmosphere, and their detectable impact in the ionosphere. Special emphasis on atmospheric acoustic and internal waves generated by Tsunamis.

OBJECTIVES

Discern key features of these wave problems that are missed by standard ray-tracing methods for internal waves in atmospheric science. Examples include wave reflection at the tropopause, precise causal solution of the inititial-value problem, incorporating acoustic effects for very fast precursor waves, formation of caustics. Interactions of incoming waves with the electro-magnetic dynamics of the ionosphere.

APPROACH, WORK COMPLETED, and RESULTS

In May 2015 the dedicated PhD student funded under this grant, Chen Wei, graduated successfully from NYU and has since left the Department for work in the private sector. In his thesis work he completed a comprehensive modelling study of the two-dimensional initial-value problem for internal and acoustic waves generated by a Tsunami. The key results are described in the following paper, which has been published in the June 2015 issue of the Journal of Atmospheric Sciences:

Evolution of Tsunami-Induced Internal Acoustic–Gravity Waves
By Chen Wei, Oliver Bühler, and Esteban G. Tabak. JAS, 72, 2303-2317.

This paper contains a detailed mathematical and numerical exploration of the initial-value problem for the waves using both the anelastic and the fully compressible set of fluid equations. We highlight the importance of using the correct boundary conditions for vertical propagation at the ionosphere and of allowing for vertical back-reflection of waves at the tropopause. Our model improved on the previous state of the art in both these respects.

Now, for the last year of the project, we are switching focus from the mechanics of upward wave propagation to the development of mathematical techniques for the analysis of data, with a view to their application to the identification of tsunamis by their ionospheric signal. For this, we hired a postdoctoral fellow, Giulio Trigila, who will be partially supported by this grant.

Jointly with Giulio, we will use and extend ideas from the mathematical theory of optimal transport to identify and filter variability factors from data. For instance, the ionospheric signal depends not only on the presence of upward wave propagation, but also on a broad array of external factors, such as the season, the time of the day, the solar conditions and the prevailing winds. In order to disentangle these various sources of variability, we propose to perform maps in the space of observed variables that filter each of these factors, while leaving the remaining variability unaffected. Optimal transport provides the right language and concepts to perform this task: each map pushes forward the distribution corresponding to one value of the factor under consideration to a ``mean'' distribution, corresponding to the barycenter of the distributions for all values of the factor. Thus, after these maps, the effect of this particular factor has been eliminated from the data and, because of the maps' optimality, all remaining variability has been left as unaffected as the constraints allow.

IMPACT/APPLICATIONS

Our project aims to provide a firm theoretical groundwork for enabling high-fidelity mapping of wave sources near the ocean to high-altitude observables in the ionosphere, especially over very short time periods that could potentially be used for real-time monitoring of large-scale ocean disturbances. Potential applications include using the detailed acoustic and internal wave pattern at the ionosphere to detect a Tsunami whilst it is still in the open ocean, long before it reaches a shore. Apply statistical methods related to optimal transport theory to disentangle external factors from the wave-induced signal in the ionosphere.