Trapped lee waves as a source of low-level drag on the atmosphere

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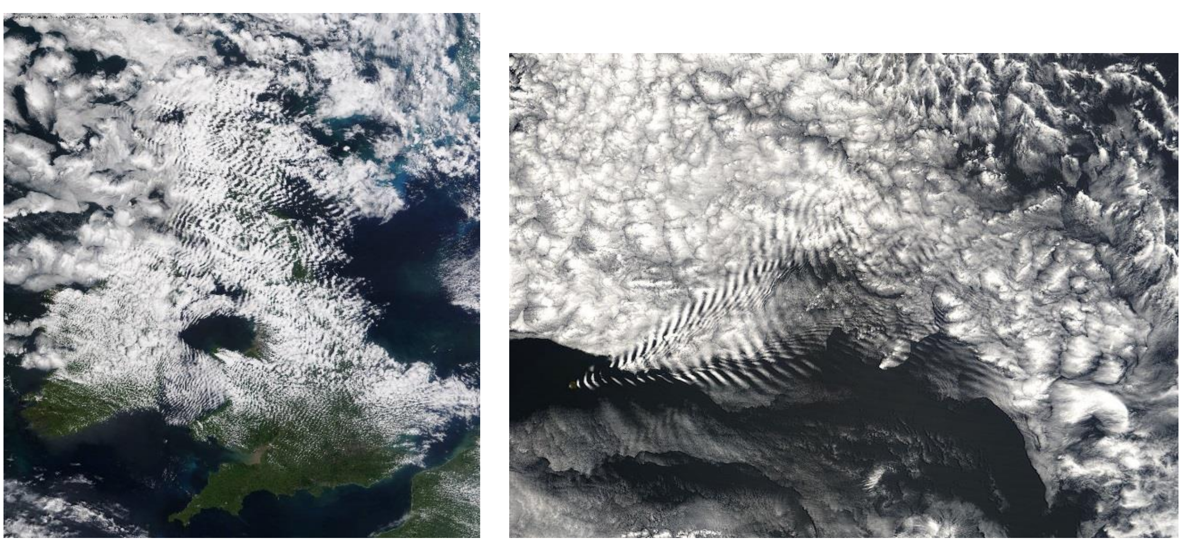
Atmospheric models used for numerical weather prediction and climate modelling have large uncertainties in their representation of small-scale processes that contribute to uncertainties in the large-scale movement of air termed the atmospheric circulation. Indeed, the latest report from the Intergovernmental Panel on Climate Change (IPCC) emphasizes that uncertainties in circulation changes under global warming scenarios, deduced from atmospheric models, are very large. One particular process which both contributes significantly to the atmospheric circulation and is not fully represented in atmospheric models is the drag (i.e. frictional) force produced by small-scale mountains.

When the atmosphere flows over mountains, internal atmospheric waves (known as orographic gravity waves) are generated, which exert a drag force on the atmosphere, acting to decelerate the large-scale circulation both locally and remotely. A large proportion of this drag is caused by mountains at horizontal scales that are either partially or totally unrepresented in models typically used for weather forecasting or climate projection, so their influence on the circulation is accounted for through approximations called parameterizations. Existing parametrizations focus on the drag produced by vertically propagating orographic gravity waves, which typically acts within wave breaking regions at high altitudes, sometimes reaching as high as the stratosphere (the atmospheric layer above about 10 km altitude) or even above. However, other orographic gravity waves, known as trapped lee waves, which have even smaller horizontal scales and propagate horizontally at lower levels (being made visible by cloud alignments – see figure below), are also known to exert a drag on the atmosphere, but are not parametrized in weather and climate models.



Approximately 2D trapped lee waves over the UK (left), 3D trapped lee waves emanating from an isolated island (right).

In strongly stably stratified atmospheric boundary layers (common at high latitudes over land), turbulence co-exists with gravity waves, and in an effort to minimize errors in the predicted surface temperature and surface wind angle (which affects, for example, the decay rate of extratropical cyclones), turbulence mixing is often unrealistically increased, which has the negative side-effect of overestimating the boundary layer depth and the height of the low-level jet by factors as large as two, and can result in biased predictions of minimum and maximum temperatures. A likely reason for these problems is the omission of trapped lee wave drag and its misrepresentation as turbulent form drag, which necessarily degrades forecasts, as the dependence of each of these processes on the flow parameters is different.

This project aims to clarify the contribution of trapped lee waves to low-level drag exerted on the atmosphere using theory, numerical simulations and observations. Theory assuming atmospheres with a representative layered structure will be used to establish the rough dependence of the drag on basic flow parameters. Very high-resolution (≤1km grid spacing) numerical simulations using the Met Office's operational weather forecast model (the Unified Model, MetUM) will be used to test the theory in idealized and realistic cases, and improve the representations of trapped lee waves suggested by theory for weather and climate forecasts. Lower-resolution simulations will be used to test these ideas in an operational context. A ground-truth for verification of results from theory and numerical simulations will be provided by available observations of trapped lee waves, including recent (2014-15) aircraft observations made in the UK by the FAAM research aircraft. The ultimate aim is to make progress in the development of a new trapped lee wave drag parametrization for the MetUM, with a view to improvements in weather and climate predictability.

Training opportunities:
This project will provide skills in numerical and mathematical modelling and data analysis. It will offer opportunities to attend postgraduate modules and summer schools (e.g., Summer School on Fluid Dynamics of Sustainability and the Environment). The student will have CASE support for an internship at the Met Office (Exeter), where two of the co-supervisors are based. This will not only allow experience of work with models used operationally for atmospheric forecasts, but also contact with a professional environment. It will also provide additional opportunities for training, via training courses, workshops and seminars.

Student profile:
This project is suitable for students with a good (1st class or upper 2nd class) degree in physics, mathematics or a closely related environmental or physical science. Good computational skills are essential. Experience in numerical modelling and in applied mathematics would be preferred, but is not essential. The student should be enthusiastic, eager to learn, and have a keen interest in physical aspects of atmospheric dynamics.

Funding particulars:
CASE support from the Met Office for this project is confirmed.

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