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Mountain waves produced by a stratified shear flow with a boundary layer: transition from downstream sheltering to upstream blocking

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A non-hydrostatic theory for mountain flow with a boundary layer of constant eddy viscosity is presented. The theory predicts that dissipation impacts the dynamics over a an inner layer which depth δ is predicted by viscous critical level theory. In the near neutral case, the surface pressure decreases when the flow crosses the mountain to balance an increase in surface friction along the ground. This produces a form drag which can be predicted quantitatively. With stratification, internal waves start to control the dynamics and produce a wave drag that can also be predicted. For weak stratification, upward propagating mountain waves and reflected waves interact destructively and low drag states occur, whereas for moderate stability they interact constructively and high drag states are reached. In very stable cases the reflected waves do not affect the drag much.

The sign and vertical profiles of the Reynolds stress are profoundly affected by stability. In the neutral case and up to the point where internal waves interact constructively, the Reynolds stress in the flow is positive, with maximum around the top of the inner layer, decelerating the large scale flow in the inner layer and accelerating it above. In the stable case, the opposite occurs, and the large scale flow above the inner layer is decelerated as expected for dissipated mountain waves. These opposed behaviors challenge how mountain form drag and mountain wave drag should be parameterized in large-scale models.

The structure of the flow around the mountain is also strongly affected by stability: it is characterized by non separated sheltering in the neutral case, by upstream blocking in the very stable case, and at intermediate stability by the presence of a strong but isolated wave crest immediately downstream of the ridge.