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# Wave number refraction and frequency modulation of medium scale gravity waves in 3-dimensional time-dependent background flows

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Going beyond the frame of classical vertical column thinking the inclusion of horizontal gradients of a background flow in the description of gravity waves (GWs) can have important impacts on GW propagation and its action back on that type of flows. The horizontal wave number and the wave-related horizontal pseudo-momentum can be refracted to different scales and azimuth directions which may lead to substantial changes in regions of dissipative pseudo-momentum deposition and therefore mean flow forcing. In this sense wave number refraction can have a remote effect in a distant dissipation region. Additionally, the time dependence of a background flow may lead to changes in the absolute, or sometimes called ground-based, frequency of the GWs moving through it. For periodic background flows a periodic frequency modulation is excited. Beside the conservative transient forcing the periodicity of frequency also changes the background flow forcing in dissipation regions. This effect does not appear in the commonly used approximation of an instantaneously adjusting GW train.

In our contribution we use a sophisticated ray tracing method to infer the effects of the time dependence and horizontal gradients of diurnal solar-thermal tides plus a realistic 3-dimensional steady mean flow on the propagation of medium scale gravity waves in the middle atmosphere. Strongest wave number refraction and frequency modulation effects occur for slowly propagating GWs. Due to large tidal wind variations in the upper mesosphere most parts of the assumed GW spectrum are slowed down in critical layer type regions. Then, the combined action of horizontal wave number refraction and frequency modulation induce changes in the horizontal phase speed which may exceed orders of magnitude compared to the initial phase speed. The phase speed variations have the tendency to follow the shape of the tidal background wind. This effect leads to less critical layer filtering of GWs and therefore decreased periodic background flow forcing due to momentum flux divergences as compared to a classical vertical column parametrization of instantaneously adjusting GW trains.