Parametrization of tropical coastal nonstationary gravity waves robustizing QBO

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The most dominant mode of cloud-rainfall generation in the equatorial troposphere is the diurnal cycle, which is seen typically in the world's longest coastlines surrounding major islands of the Indonesian maritime continent (IMC). Under the linear theory the coastal diurnal-cycle (so-called sea-land breeze) circulation is given by a sum of wave solutions, of which the dispersion relation is a cubic equation for vertical wavenumber squared m^2. Near the surface with large eddy viscosity/diffusivity (m^6 term) balancing the buoyancy (m^0 term), the velocity field is almost similar to a steady horizontal-convection cell, of which the intensity and horizontal scale (inverse horizontal wavenumber k^{-1}) are governed by the land-sea temperature contrast $k\Delta T$. Above this cell, with decreasing the viscosity/diffusivity, the acceleration (m^2 term) balances the buoyancy, which gives a combination of up/down-ward propagating gravity waves. Because $k\Delta T$ is reversed between day and night (with frequency $\omega = 2\pi/1$ day), the horizontal phase velocity $c = \omega/k$ directs land- and sea-ward, respectively. They are observed actually along the coastline of a major island larger than k^{-1} of a few hundreds of kilometers. They are longer and slower ($c \simeq 1\text{–}3\times10^2$ km/10 h $\simeq$ 3–7 m/s) than waves excited with an individual cloud convection, but shorter than intraseasonal scales (Kelvin or mixed Rossby-gravity waves).

With increasing altitude, the upward-propagating component of gravity waves is amplified to compensate the density decrease. Because the coastline is a closed curve, there are waves with c of all directions. However, waves with c of meridional directions may be filtered out by the Hadley meridional circulation, except for a calm zone along the equator (the ITCZ). The intraseasonal variations (Madden-Julian oscillations) with zonal (Walker-like) circulations pare down usually before landing the IMC (and the two true continents of Africa and South America). Therefore, waves with c of zonal (both east- and west-ward) directions are transmitted upward beyond the tropopause along the equator, which resembles Plumb's (1977) model considering waves with two discrete (equal but opposite) zonal c. If the velocity amplitude $|u|$ (with c of either east- or west-ward) reaches the magnitude of intrinsic phase velocity $|c - U|$ in a mean wind U, the wave breaks and U is accelerated (east- or west-ward, dependent on c), as parameterized for the middle atmospheric circulation since Lindzen (1981). Both east- and west-ward gravity waves are emitted upward from the tropical coasts every day, and their interactions with the middle-atmospheric circulation may induce the robust features of the stratospheric QBO. The wave amplitude $|u|$ and resulting acceleration (periodicity and amplitude of the QBO) are dependent on $k\Delta T$, which may be varied also with interannual variations of sea-surface temperature and much longer time-scale variations of the land distribution.

Keywords: diurnal-cycle sea-land breeze circulations, internal gravity waves, wave-mean flow interaction, quasi-biennial oscillation

