Tutorial Review

Middle atmosphere dynamics with gravity wave interactions in the numerical spectral model: Zonal-mean variations

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ARTICLE INFO

ABSTRACT

It is generally accepted that small-scale gravity waves (GW) produce the observed reversals in the zonal circulation and temperature variations of the upper mesosphere (e.g., Lindzen, 1981). There is evidence that GW also play an important role in the quasi-biennial oscillation (QBO) of the lower stratosphere, which can be generated by planetary waves (Lindzen and Holton, 1968). In the present paper, we summarize the modeling studies with the mechanistic numerical spectral model (NSM), which incorporates the Doppler spread parameterization for GW (Hines, 1997a, b). Our studies illuminate the importance of GW filtering and momentum deposition associated with critical level absorption and wave braking. Numerical results from the 2D and 3D versions of the NSM show how these wave interactions generate in the zonal-mean: (a) annual and semi-annual oscillations, (b) QBO with related semi-decadal oscillation and solar cycle effects, and (c) monthly intra-seasonal oscillations.

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Contents

1. Introduction

The propagation of small-scale gravity waves (GW) and their interactions with the background atmosphere has been the subject of analytical and numerical studies discussed in comprehensive reviews (e.g., Francis, 1975; Fritts, 1984, 1989; Hocke and Schlegel, 1996; Fritts and Alexander, 2003). We deal here with global-scale phenomena under the influence of GW interactions, first addressed by Lindzen (1981) in an application to the seasonal variations of the middle atmosphere. In that seminal paper, Lindzen proposed that wave interactions with the zonal circulation, combined with wave breaking, could generate the anomalous temperatures in the upper mesosphere, which are lower in summer than in winter. Lindzen also developed a GW parameterization for application in global-scale models, and his mechanism has been verified in numerous modeling studies that simulate the observations (e.g., Holton, 1982; Holton and Zhu, 1984; Garcia

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