The Equilibration of Short Baroclinic Waves

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ABSTRACT

The life cycles of short baroclinic waves are investigated with the intention of completing a simple classification of nonlinear equilibration scenarios. Short waves become important in moist environments as latent heating reduces the scale of maximum baroclinic instability. Long-wave life cycles (wavenumber 6) were previously found to depend on details of the low-level momentum fluxes established during the earliest stages of development. These fluxes also serve as a focal point for the present study.

For a realistic, zonally symmetric jet on the sphere, the normal-mode life cycle of a short wave (wavenumber 8) under both dry and moist conditions is described. Latent heating intensifies the low pressure system and frontal zones but does not alter the broader details of the life cycle. The normal modes have predominantly equatorward momentum fluxes, in contrast to the mainly poleward momentum fluxes of long waves. The short waves are more meridionally confined. The equatorward momentum fluxes direct the waves toward cyclonic breaking. The feedback with the zonal-mean wind, the so-called barotropic governor, is less effective than in the standard long-wave life cycle, which ends in anticyclonic breaking. However, in contrast to long-wave life cycles that are ''engineered'' to produce equatorward momentum fluxes, relatively little potential vorticity and surface temperature anomaly roll up into isolated vortices. Therefore, the short wave undergoes protracted barotropic decay leading to complete zonalization. Short waves also have a brief period of baroclinic decay due to cold advection over the surface cyclones.

Eliassen–Palm cross sections for the short-wave life cycles show the usual combination of upward and meridional propagation of wave activity. However, the meridional propagation is mainly toward the pole and there is a consequent zonal-mean deceleration at high latitudes. These details are included in the proposed classification of equilibration scenarios.

1. Introduction

Recently, Whitaker and Snyder (1993) and Balasubramanian and Garner (1997, hereafter BG97) compared dry wavenumber 6 baroclinic life cycles in Cartesian and spherical geometry. They contrasted the ''anticyclonic'' behavior of spherical wavenumber 6—in which the eddies exhibit a robust SW–NE tilt and poleward momenutm flux—to the ''cyclonic'' behavior of the same wave in Cartesian geometry—where the eddies tilt NW–SE and the flux is equatorward. The more recent study (BG97) explained the drastic differences in terms of the interaction of the eddy momentum flux convergence with the zonal-mean flow. The sign of the meridional tilt and the strength of the feedback throughout the life cycle were both attributed to the characteristics of the linear mode. The wavenumber-6 normal-mode flux has an equatorward bias in Cartesian geometry and a slight poleward bias in spherical geometry. As a result of this difference, the zonal-mean flow alterations in the two geometries are sharply different.

Normal-mode experiments suggest that the fully equilibrated state of an inviscid baroclinic wave consists of either a zonally symmetric flow or a train of cyclonic vortices. Anticyclonic long-wave life cycles on the sphere [''LC1'' of Thorncroft et al. (1993), hereafter THM] fall into the first category. Cyclonic long-wave life cycles on the sphere (''LC2'' of THM) and, to a large extent, Cartesian normal modes at the same scale (BG97) belong to the second category. The same type of contrast can be seen in nature (THM) and in general circulation models (Lee and Feldstein 1996). Cyclonic long-wave development on the sphere is obtained by adding cyclonic barotropic shear across the jet in the

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