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A Review Paper: Contributions from the Gravity and the Kelvin Modes for the Vertical Motion Response

Uma Revisão: Contribuições dos Modos de Gravidade e de Kelvin para a Resposta do Movimento Vertical

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Resumo

Uma série de integrações do Modelo da Comunidade Climática do Centro Nacional de Pesquisas Atmosféricas com uma fonte anômala tropical de calor mostra regiões de pronunciada subsidência e de seca localizadas a 3000 km a oeste da fonte de calor em direção aos pólos para casos do Atlântico e do Pacifico leste tropicais aquecidos.A alta predictabilidade do movimento descendente e estabelecida dentro dos cinco primeiros dias destas integrações. Os modos normais do conjunto de equações primitivas não lineares para uma atmosfera: Adiabática, hidrostática, incompressível, seca, sem atrito e viscosidade são linearizadas com relação ao estado básico em repouso e usadas para a partição da resposta do modelo em modos de inércia gravidade e de Rossby. A ênfase desta revisão e dada para as contribuições dos modos de gravidade e de Kelvin para a resposta do movimento vertical.
Palavras-chave: clima; dinâmica global; modelagem atmosférica; ondas atmosféricas

Abstract

In earlier papers of a series of real data integrations of the National Center for Atmospheric Research (NCAR) Community Climate Model (CCM) with tropical heat anomalies display regions of pronounced subsidence and drying located several thousand kilometers westward poleward of the heating for cases of tropical Atlantic heating and tropical east Pacific heating. This highly predictable sinking response is established within the first five days of these integrations. The normal-modes of a set of nonlinear primitive equations for an atmosphere: Adiabatic, hydrostatic, incompressible, dry, without friction and viscosity are linearized about a basic state at rest and used to partition model response into gravity-inertia and Rossby modes. The emphasis of this review is given upon the contributions of the gravity and Kelvin modes for the vertical motion response.
Keywords: climate; global dynamics; atmospheric modeling; atmospheric waves

1 Introduction

A series of earlier simulations using real data were performed with NCAR CCM (a set of nonlinear primitive equations for an atmosphere: Diabatic, compressible, hydrostatic, wet, with friction and without viscosity) see Williamson *et al.* (1987). These studies simulations above were developed by Buchmann *et al.* (1986), Paegle *et al.* (1987), Buchmann *et al*. (1990) and Buchmann *et al*. (1995a) where they investigated the teleconnections between tropic-extratropic to heating source anomalies located at the tropical region.

The purpose of the present study is to explore the dynamical basis of the tropic-extratropic connections noted in our earlier studies based only in the contributions of the gravity and Kelvin waves see Wallace & Kousky (1968) and Madden & Julian (1972) that in this study using cross-espectral analyses suggests an eastward-moving wave in the equatorial region.

Gill (1980) and Buchmann *et al.* (1986) studied the Kelvin modes response for heating source anomalies. Buchmann (2000) studied the gravity and Rossby modes for vertical motion response and found that the most important contribution comes from the gravity waves.

Section 2 describe the contributions from the gravity and Kelvin modes for the vertical motion response. Section 3 presents the conclusions.

2 Partitioning Vertical Motion Response into Contributions from the Gravity and Kelvin modes

The numerical integrations discussed in this section were done with 9-level NCAR CCM truncated at rhomboidal 15, as described by Paegle *et al.* (1987) and Ramanatham *et al.* (1983) have documented characteristics of this version of the NCAR CCM, wich included convective adjustment, solar and infrared radiation, as well as surface drag and heat and moisture fluxes.

The experiments and controls were projected onto the vertical and horizontal structure functions, as done by Paegle & Mo (1988), these functions are obtained by separating the solution of the nonlinear primitive equations for an atmosphere with the same physical hypothesis as mentioned above in the abstract and linearized about a basic state at rest studied and proposed by Kasahara & Puri (1981) and Buchmann (2008) that can also be seen in the papers of Kasahara & Qian (2000) and Qian & Kasahara (2003) with less restrictives suppositions (for an atmosphere: Adiabatic, compressible, nonhydrostatic, dry, without friction and viscosity) when compared with physical considerations formulated by Kasahara & Puri (1981).

The vertical and horizontal structure functions are similar for those used in a normal-modes initialization for filter in especial the gravity-modes with high-frequencies in particular this is made more common at the operational meteorological centers. The heights and the winds are projected onto these vertical and horizontal structure functions at 9 sigma-levels separating the contribution from the external (barotropic equivalent) vertical mode and 2, 3, 4, 5, 6, 7, 8 and 9 internal (baroclinic) vertical modes that constitute a Sturm Liouville problem Kasahara & Puri (1981) and the horizontal structure function has as solution for each equivalent depth the Hough functions Kasahara (1976) and Kasahara & Puri (1981) that are given approximeted as a serie of associated Legendre polinomials Kasahara (1976). The fields can be recomposed into sigma space for the Rossby, gravity (eastward and westward), Kelvin and Rossby-gravity modes separately and added for all vertical modes or for each vertical mode separately as seen in Kasahara & Puri (1981), Buchmann (1995b) and Buchmann (2008) and for determination of normal modes has been used the software of Errico (1987) available at NCAR . These future results for gravity and Kelvin modes will be shown more further in this section. Vertical motions are computed from the continuity equation Williamson *et al*. (1987). The results are analyzed for a level where sigma is equal .5, corresponding approximately to 500 mb over the oceans.

The response of the vertical motion presents three regions of subsidence. Two located westward poleward of the heating and the third region located over South America as seen in Buchmann *et al*. (1995b).

(Figure 1) displays the vertical motion response associeted with gravity modes at selected times.

These display rising motion centered on the heating anomaly in the Pacific Ocean and descending movement surrounding of this source over South America and in the regions westward poleward of the heating in the Northern and Southern Hemispheres. (Figure 2) displays the vertical motion response of the Kelvin modes at selected times. These display rising motion centered on the heating anomaly in the Pacific Ocean with magnitudes slightly less than one half the contribution of the gravity modes of (Figure 1), as can be seen in Buchmann *et al*. (1995b).

Its important emphasize here now that similar figures shown below, appear in Buchmann *et al*. (1995b), with incorrections in case of the (Figure 3) from that paper. In this review the (Figure 1) mend these mistakes.

In the (Figures 1, 2) the chain and continouos lines are associated with regions of (ascendant) and (descendant) movements, respectively.

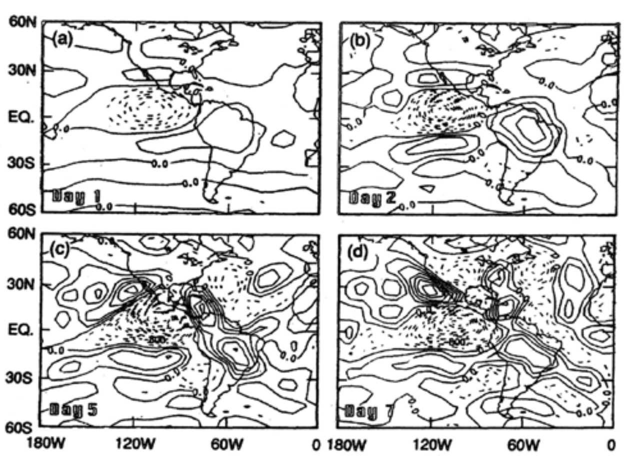

Figure 1 Vertical motion response associated with gravity modes at indicated times averaged over the 10 cases of the ensemble. The contour interval is 2 x 10^{-4} mb s^{-1} .

Buchmann (2000) studied the contributions from the gravity and Rossby waves related with the sum of all vertical modes for the vertical motion response. Where the gravity waves compared with the Rossby waves show similar results but not equal with that was found in the (Figures 1,2) for the cases of gravity and Kelvin waves.

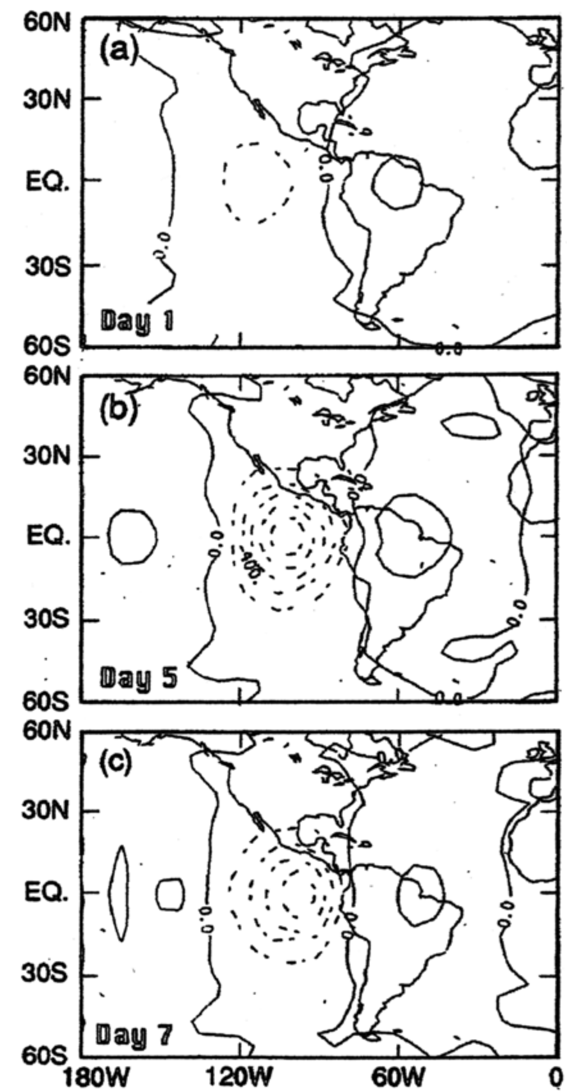

Figure 2 Ensemble-averaged vertical motion response associated with Kelvin modes at indicated times. The contour interval is 2 x 10^{-4} mb s^{-1}.

3 Conclusions

The results from the normal-modes decomposition has shown that the most important contribution for the vertical motion response comes from the gravity modes when compared with Kelvin modes (both modes added for all vertical modes) as can be seen in the (Figures 1,2) above, in Buchmann *et al*. (1995b) and also in Buchmann (2008) specifically for the second and the third gravity modes (not shown here) compared with the Kelvin modes at the Figure 2 in this review. Buchmann *et al*. (1986) simulated

Kelvin waves propagating eastward trapped around the equator and that are consistent with the results found by Gill (1980), Geisler (1981) and Silva Dias *et al*. (1983).

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