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Rossby-Haurwitz wave perturbations under tropical forcing

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RESUMEN

Este trabajo explora el flujo zonal en forma de polinomios de Legendre. El flujo básico se divide en un flujo zonal simétrico y una onda de Rossby-Haurwitz (RH). Varias características (más realistas) de este flujo zonal lo hacen particularmente interesante, como las corrientes en chorro con dirección oeste en latitudes medias y un viento con dirección del este alrededor del ecuador, muy similar al flujo medio horizontal del periodo diciembre-enero a 200 mb. El flujo zonal se combina con la onda RH para evaluar las etapas tempranas del mecanismo de acciones de bloqueo en el Pacífico nororiental. Se llevó a cabo una simulación numérica utilizando un modelo barotrópico lineal con forzamiento tropical y disipación para analizar la respuesta extratropical del mecanismo de reforzamiento de torbellinos en los sistemas de alta presión a lo largo de la costa occidental de Norteamérica.

ABSTRACT

This study explores the zonal flow in the form of Legendre polynomials. The basic flow is divided into a zonally symmetric flow and a Rossby-Haurwitz (RH) wave. Several features of this (more realistic) zonal flow make it particularly interesting, such as the midlatitude westerly jet streams and an easterly wind around the equator, which closely resembles the mean horizontal flow at 200 mb of the December-February period. The zonal flow is combined with the RH wave, in order to test the blocking formation mechanism on early stages for the northeastern Pacific. A numerical simulation has been performed using a linear barotropic model with tropical forcing and damping to check the extra-tropical response of the mechanism of eddies reinforcement of the ridge along the western coast of North America.

Keywords: Rossby-Haurwitz wave, Legendre polynomials, normal mode stability, northeastern Pacific blocking formation mechanism, tropical forcing, Pacific-North American pattern.

1. Introduction

During the period from December 2009 to February 2010, the sea surface temperature (SST) in the central Pacific was anomalously warm. The Northern Hemisphere winter of 2009-2010 was notable for its low-frequency anomalous behavior because it was extremely cold in many places (Pérez-García *et al.*, 2010; Wang *et al.*, 2010; Kim *et al.*, 2011; Ratnam *et al.*, 2012). Figure 1 shows the 200-hPa geopotential height, a meridional dipole-like structure in its incipient stages that extended from the western North America to the southwest of Mexico on January 27, 2010. A convective heating over the tropical central and eastern Pacific linked to a teleconnection called the Pacific-North American pattern (PNA) (Wallace and Gutzler, 1981), is known to have influenced the extratropical circulation over the northeastern Pacific, Canada, and the southeastern USA.

Many theories have been proposed to understand the onset and maintenance of the teleconnection patterns and the synoptic blocking events in the atmosphere (Hoskins and Karoly, 1981; Haines and Marshall, 1987). The PNA manifests itself as a warm ridge (southerly flow) along the western

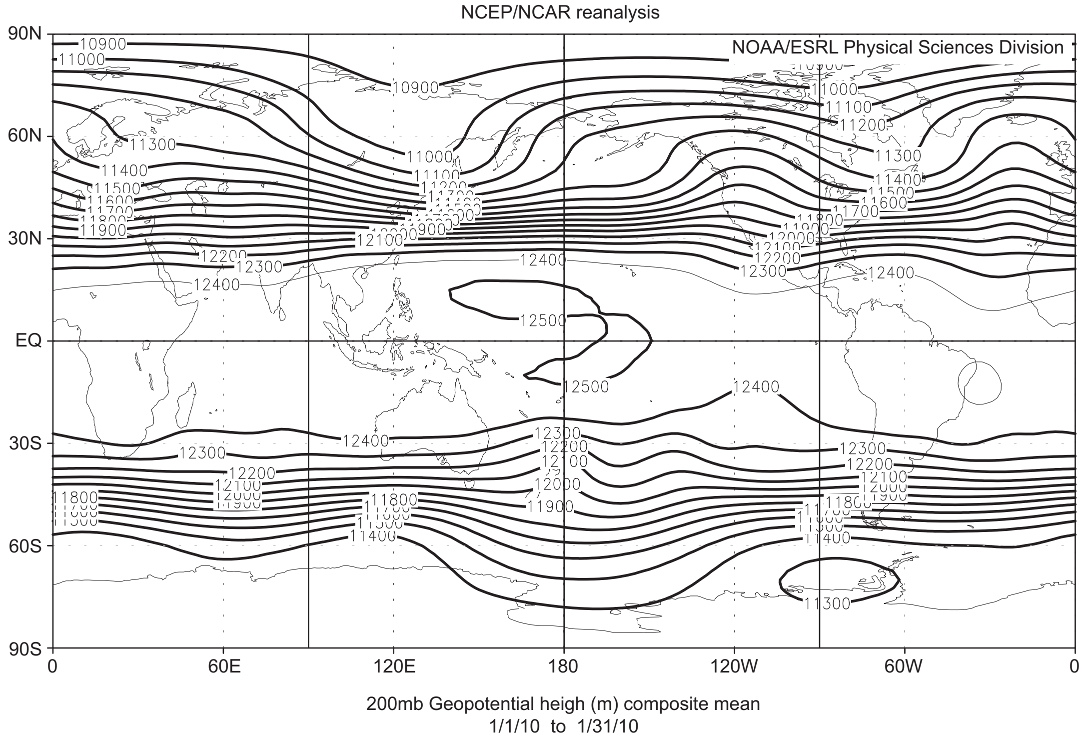

Fig. 1. Time-mean flow of geopotential height at 200 hPa for the period January 1-31, 2010. The extended jet stream is shaded.

coast, and a cold trough over eastern North America (Rex, 1950; Lejenas and Okland, 1983). The use of a one-level barotropic model to simulate the extra tropical response to a fixed tropical heating has been reported in several studies (Simmons, 1982; Branstator, 1983; Held and Kang, 1987; Sardeshmukh and Hoskins, 1988; Grimm and Silva-Dias, 1995), which found that the remote response to (steady) tropical forcing has an equivalent barotropic structure, and that energy propagation is influenced by both zonal and meridional variations of the basic-state flow. Simmons *et al.* (1983) show structures similar to the observed PNA when the barotropic model is linearized about the zonally varying flow (300 hPa mean of January flow). These flow patterns are related to the more unstable normal mode associated with barotropic instability. Hoskins and Ambrizzi (1993) examine the most frequent trajectories of the Rossby waves in a longitudinally varying flow, and found that the jet stream can act as waveguides in the atmosphere.

This study aims to increase the understanding of the northeastern Pacific blocking formation mechanism in its incipient stages, in connection with the Rossby-Haurwitz (RH) wave. Due to its importance, numerical simulations were performed with a barotropic model on a basic flow regarded as the sum of a zonally symmetric flow and an RH wave component. Midlatitude westerly jet streams are embedded within the zonally symmetric flow. In addition, linearized barotropic models through the zonally symmetric state are easier to simulate than those observed in the zonally asymmetric flow, because time-averaged basic flows generally do not satisfy the steady barotropic vorticity equation (BVE). Section 2 of this paper highlights some previous research related to the BVE on the sphere with forcing and damping, and also a brief description of the up-to-date solutions to the normal mode instability. In Section 3, the basic flow is constructed analytically; the selection of such basic flow allows for the application of analytical methods, which increase its potential use in persistent anomalies and low-frequency variability studies. The non-divergent vorticity equation for the vorticity perturbations, which is numerically time-integrated and has a steady tropical divergence forcing and damping, is addressed in Section 4. In