16B.6 EXTRATROPICAL FORCING OF CONVECTIVELY COUPLED KELVIN WAVES

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1. INTRODUCTION

Convectively coupled Kelvin waves are large-scale, eastward-propagating tropical convective disturbances whose spectral characteristics in the deep cloudiness field lie along the theoretical dispersion curves for dry Kelvin waves of shallow equivalent depth (Wheeler and Kiladis 1999). Convection in these waves propagates eastward at approximately 17 m s^{-1}, with a horizontal scale of ~3000 km, and is accompanied by large-scale kinematic and thermodynamic perturbations in the troposphere and lower stratosphere. Previous studies of convectively coupled Kelvin waves have illustrated the observed horizontal and vertical structures of these waves in their developed stage (Wheeler et al. 2000), but have not addressed the mechanisms by which Kelvin waves might be initially excited. We argue here that a substantial fraction of convectively coupled Kelvin waves during austral winter (JJA) are excited through extratropical forcing originating in the Southern Hemisphere subtropical jet.

2. DATA AND METHODOLOGY

A linear regression technique is used to determine the preferred circulation and convection patterns associated with the initiation and development of a convectively coupled Kelvin wave in the central Pacific ITCZ during austral winter. Daily ECMWF reanalysis fields and total outgoing longwave radiation (OLR, a proxy for deep convection) are regressed against an index of Kelvin wave OLR, for the 15 JJA periods from 1979–1993, as a function of temporal lag. The Kelvin wave index is defined as the daily value of the space-time filtered Kelvin wave OLR [see Wheeler and Kiladis (1999)] at the point of its maximum JJA climatological variance, which is at 7.5˚N, 172.5˚W. The filtering process constrains the Kelvin wave OLR to propagate with eastward phase speeds between 8–30 m s^{-1}.

3. CLIMATOLOGY

Convectively coupled Kelvin waves are observed most frequently in the central Pacific ITCZ during austral winter. Fig. 1 shows the JJA climatological total OLR (shading), Kelvin wave OLR variance (dark contours), 200 hPa zonal wind (light contours) and 200 hPa <30 day filtered E-vectors. Total convection during JJA maximizes in the Asian monsoon region and the eastern Pacific, but Kelvin wave variance maximizes in the central Pacific, where the total convection is minimized. This suggests that Kelvin wave activity is not simply a stochastic function of the total convective activity, but that other factors may be involved in determining the distribution of Kelvin wave activity within the ITCZ. As is shown in the following section, it appears that Kelvin waves can be initated by eastward-propagating forcing originating in the Southern Hemisphere subtropical jet, which is visible in Fig. 1 as a zonal wind maximum stretching along 30˚S from 120˚E to 160˚W. Chang (1999) shows that Rossby waves excited in the subtropical jet preferentially propagate eastward and equatorward over Australia with phase speeds of 8–12 m s^{-1}, and then continue propagating eastward along 20˚S across the Pacific. The preferred propagation direction of submonthly perturbations in the jet can be estimated by the direction of the E-vectors in Fig. 1, which point northeastward over Australia and to its east.

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4. REGRESSION RESULTS

Fig. 2 shows the Kelvin wave filtered OLR and upper tropospheric circulation on Day -5 of the linear regression, when the tropical convective signal first becomes established. (Day 0 is defined as the time when the Kelvin wave filtered OLR reaches a minimum at the basepoint in the central Pacific.) Prior to Day -5, a baroclinic wavetrain in the Southern Hemisphere propagates eastward from the Indian Ocean region along 50˚S. The wavetrain then splits into two branches to the east of Australia, as seen in Fig. 2, with the stronger northern branch first propagating equatorward and then eastward along 20˚S, and the weaker southern branch propagating eastward along 50˚S. Poleward (equatorward) flow and divergence (convergence) in the subtropics is collocated with 400 hPa upward (downward) motion. These divergence and vertical motion fields spread northward and eastward as the wavetrain approaches the equator. Low (high) OLR, indicating enhanced (suppressed) deep convection in the tropics (or upper-level cirrus in the subtropics), forms to the northwest of the high (low) pressure center in the northern branch of the wave packet, and is also collocated with 400 hPa upward (downward) motion. Temperature anomalies in the subtropics are consistent with vorticity perturbations in the wavetrain, but in the tropics, temperature anomalies instead appear to be influenced more strongly by diabatic processes. Since the extratropical wavetrain exists for several days before the tropical and subtropical convective anomalies appear, it is suggested that the circulation initially forces the vertical motion and cloudiness signals associated with the tropical Kelvin wave.

The equatorward-propagating branch of the wavetrain is constrained to the upper troposphere by tropical easterlies, but the poleward branch includes baroclinic features which extend to the surface and subsequently spread equatorward. Fig. 3 shows the regressed 1000 hPa geopotential height fields on Day -5, illustrating the strong connection between extratropical and tropical height anomalies and the Kelvin wave-like symmetry of the anomalies about the equator. At subsequent lags, easterlies flow from high to low heights along the equator, producing a region of low-level zonal wind convergence to the east of the developing low OLR anomaly. This converges boundary layer moisture and increases CAPE, providing additional forcing for the eastward propagation of the coupled wave.

5. CONCLUSIONS

The initiation of deep convection in a convectively coupled Kelvin wave in the central Pacific during austral winter appears to be due to a combination of two factors: first, the upper tropospheric vertical motion anomaly forced by the equatorward-propagating Rossby wavetrain, and second, the lower tropospheric moisture convergence and upward motion anomalies induced by an extratropically-generated pressure surge. The upper tropospheric divergence/convergence pair associated with the subtropical wavetrain induces vertical motion anomalies that spread toward the tropics and acquire equatorially trapped, Kelvin wave-like characteristics. At the same time, a lower tropospheric pressure surge excited by the baroclinically-developing extratropical wavetrain also produces Kelvin-like temperature and height anomalies in the equatorial region. An easterly trade surge forms as mass flows from high to low pressure at the surface, causing moisture convergence and upward motion in the lower troposphere ahead of the developing low OLR anomaly. Once a convectively coupled Kelvin wave is established, it appears that it can be self-sustaining. In many individual cases, eastward-propagating convective anomalies persist even after the initial subtropical circulation anomalies dissipate. Several recent studies suggest that convectively coupled Kelvin waves, once initiated, themselves provide the necessary internal feedbacks to maintain their convective-dynamical structure as they propagate eastward.

6. REFERENCES

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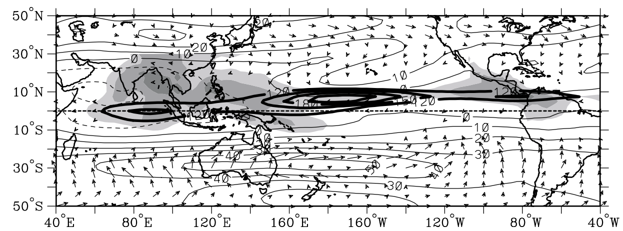

Fig. 1. JJA climatological OLR (shading, at 200, 220, and 240 W m^{-2}), Kelvin wave filtered OLR variance (dark contours, by 30 from 120 W^{2} m^{-4}), 200 hPa zonal wind (light contours, by 10 m s^{-1}), and 200 hPa <30 day filtered E-vectors (maximum 150 m^{2} s^{-2}).

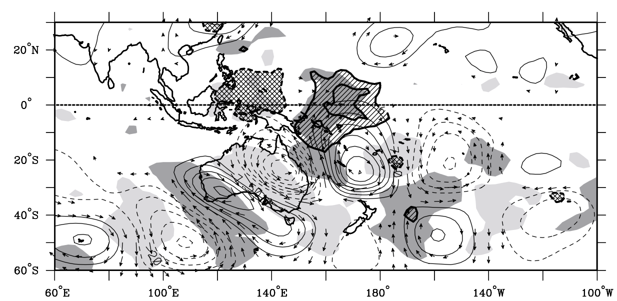

Fig. 2. Regressed OLR (hatching, cross-hatching negative, at ±6 W m^{-2}), 200 hPa streamfunction (contours, interval 7.5 m^{2} s^{-1}) and winds (vectors, maximum 10 m s^{-1}), and 400 hPa vertical motion (shading, dark negative, at ±0.2 cm s^{-1}) on Day -5, based on a -40 W m^{-2} anomaly in OLR on Day 0.

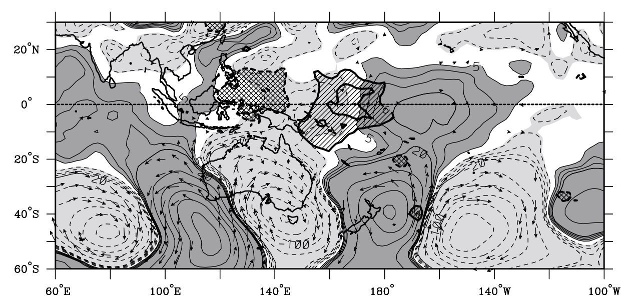

Fig. 3. As in Fig. 2 except for 1000 hPa geopotential height (contours and shading, dark positive, by ±5 m to 20 m, then by 40 m) and 1000 hPa winds (vectors, maximum 5 m s^{-1}).