Convectively Coupled Equatorial Waves in the Hadley Centre Climate Models

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Introduction:

Tropical convection and equatorial waves, and their coupled behaviours, are fundamental components of the tropical climate system. In Yang et al. (2003) we developed a new methodology for identifying and isolating equatorial waves. As indicated in the horizontal structures provided by basic theory (Fig.1), for a 'first internal' vertical mode, if the low-level convergence provides the organization for convection, then this convection would occur in the blue-green shaded regions. In addition, Yang et al. (2003) and others have suggested that wind-dependent surface fluxes of moist entropy may play an important organizational role for convection, particularly where the SSTs are sufficiently warm to support convection. Such conditions potentially occur in the Kelvin and *n*=1 Rossby (R1) waves which have maximum zonal winds on the equator, shown as the blue and red ovals. The methodology developed in Yang et al. (2003) is applied to output from Hadley Centre climate models (HadAM3 and HadGAM1). Structures of tropical convection and equatorial waves and their coupled behaviour in the models are examined and evaluated, based on a comprehensive study of observed convectively coupled equatorial waves using ERA-15 reanalysis and satellite observed brightness temperature for 1992 summer

Reference: Yang G. -Y, B. Hoskins, and J. Slingo, 2003: Convectively coupled equatorial waves: A new methodology for identifying wave structures in observational data. *J. Atmos. Sci.*, 60,1637-1654.

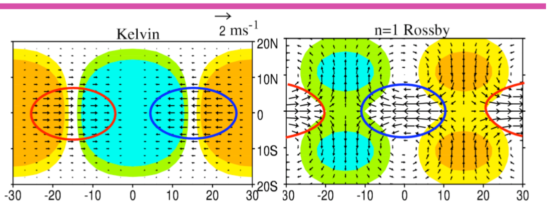

Figure 1. Horizontal wind (vector) and divergence (colour) for theoretical equatorially trapped Kelvin and the n=1 Rossby (R1) waves. Colour circles indicate the possible convection region induced by wind-dependent surface energy fluxes.

The Kelvin wave with equatorial convection

Figure 2 shows convectively coupled Kelvin wave in the EH for observation and models. In observation, the upper level zonal wind divergence is just above intensified convection; whereas the lower level strong westerlies are in phase with the convection. This is the case shown by the red oval in Fig.1 and in accord with the mean low level westerly in this warm water hemisphere, suggesting the possible importance of convective organisation by wind-dependent surface energy fluxes. Vertical structures of the observed Kelvin wave (Fig.2c) show that the convectively coupled Kelvin wave is not that of a simple first internal mode as might be speculated from the upper and lower level structures only. In addition to the two peaks in the upper and lower troposphere, the Kelvin wave has another peak in the middle troposphere, so that the vertical structure could be interpreted as having a second internal mode component. Further more, the upper tropospheric wave has an eastward tilt with height and a significant wave signal extends upward into the lower stratosphere, an indication of a coupled Kelvin wave propagating into the lower stratosphere. However, in both models, convectively coupled Kelvin waves are poorly simulated, with only very local coupling between convection and winds, and with a wave-amplitude weaker than observed. In addition, convection tends to locate over the lower level convergent region instead of in westerly region as observed, suggesting that the observed mechanism, in which surface energy fluxes play an important role in organizing equatorial convection, is potentially missing in the models. It is obvious that the Kelvin wave in the HadGAM1 has a very different vertical structure from that of observed. It is basically a first internal vertical mode, with no peak in the middle troposphere and no sign of wave upward propagating into the lower stratosphere as seen in observations.

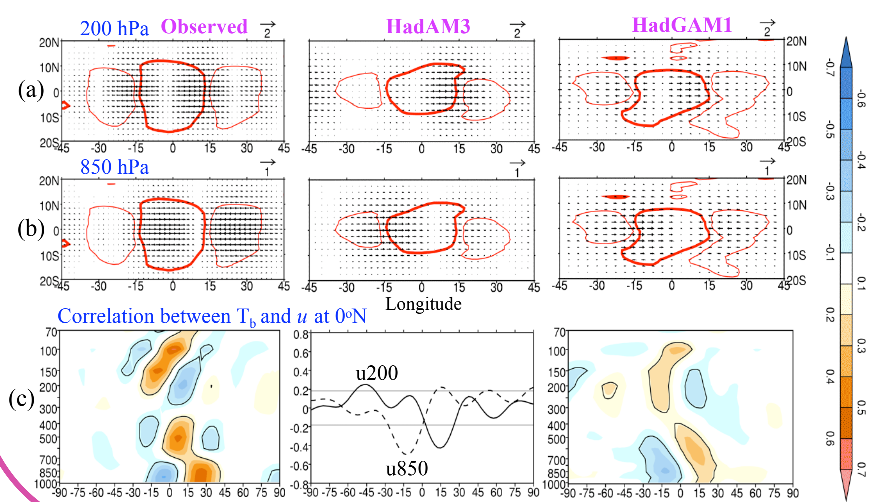

Figure 2. (a)-(b) Horizontal structures of the Kelvin wave at the upper and lower levels and associated eastward-moving brightness temperature (T_b), regressed on equatorial T_b extrema in the EH, taken to be located at 0° longitude, for observation and models. The thick (thin) red contour shows region of regressed negative (positive) T_b exceeding 95% significant level. (c) Correlation coefficients between convective extrema and equatorial u of the Kelvin wave, as a function of longitude and pressure levels (for HadAM3,the data are only available at the two levels). Solid contour denotes correlations exceeding the 95% significance level.

R1 waves with equatorial convection

The observed lower tropospheric *n*=1 horizontal winds regressed on equatorial … shows a coherent R1 wave structure. Like the Kelvin wave, the EH R1 wave ten… equatorial convection in the region of enhanced lower level westerlies. The westerl… the wave are much stronger than the easterly winds. The westerly wind anomali… strengthened by a positive feedback between the convection and the wind field. It i… this key connection of observed R1 wave with equatorial convection is entirely mis… HadAM3. In the HadGAM1 this association is present with its correlation similar… observed, but is much weaker. In addition, the wind amplitude is weak and the west… associated with the intensified convection are not significantly stronger than th… counterparts as seen in observations. Therefore, the potential role of wind-depend… fluxes in triggering equatorial convection which can then modify and possibly a… waves is not present in the models. These missing links may partly explain the weak … convection over most of the near equatorial region in the models.

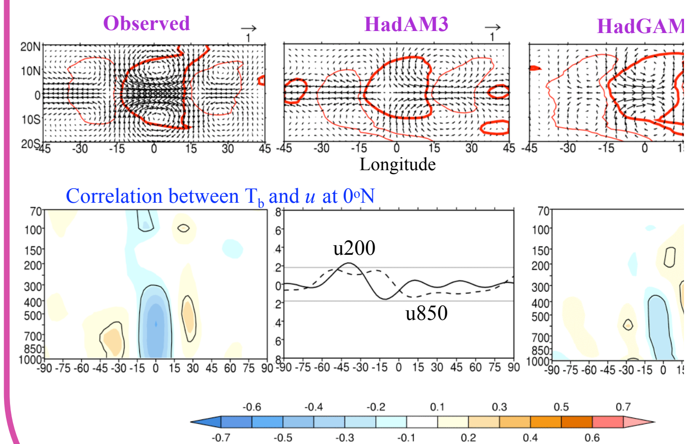

Figure 3. As in Fig. 2 but for westward-moving R1 wave at 850 hPa and equator…