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NOTES AND CORRESPONDENCE

Chimeric Equatorial Waves as a Better Descriptor for "Convectively-Coupled Equatorial Waves"

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Abstract

The term "convectively-coupled Kelvin waves" is misleading. That is because these waves have Rossby-wave components, comparable to their Kelvin-wave components and, in fact, bear a close resemblance to the Gill solution with a moving heating source. A better alternative would be to call these waves chimeric Kelvin waves, to signify their combined nature and the fact that they are implicitly convectively-coupled. By extension, chimeric Rossby waves and chimeric mixed Rossby-gravity waves would be better alternatives to "convectively-coupled Rossby waves" and "convectively-coupled mixed Rossby-gravity waves," respectively. Collectively, these waves can be called chimeric equatorial waves. Recognizing the above misleading terms can help avoid confusion.

1. Introduction

"Convectively-coupled Kelvin waves," is a term often found in the literature; "convectively-coupled Rossby waves" and "convectively-coupled mixed Rossby-gravity waves" are terms also found in the literature (e.g., Wheeler and Kiladis 1999; Wheeler et al. 2000; Straub and Kiladis 2002, 2003a, 2003b; Majda et al. 2004). Because each of these types of waves is implicitly convectively-coupled, and because each is a composite of more than one wave type, I propose calling them, collectively, chimeric equatorial waves, and individually, chimeric Kelvin waves, chimeric Rossby waves, and chimeric mixed Rossby-gravity waves. The word "chimeric" means "composed of parts of different origin." For the sake of simplicity, the discussion will be limited to what have heretofore been called convectively-coupled Kelvin waves. However, this reasoning applies equally well to what have heretofore been called convectively-coupled Rossby, and convectively-coupled mixed Rossby-gravity waves (also known as Yanai waves).

"Convectively-coupled Kelvin waves" refer to the eastward-moving waves of about 15 ms^{-1} in the analysis of outward-going long wave (OLR) data (e.g., Wheeler and Kiladis 1999; Wheeler et al. 2000; Straub and Kiladis 2002, 2003a, 2003b; Majda et al. 2004). These waves were previously analyzed by Wallace (1971), Zangvil and Yanai (1980), and Takayabu (1994), among others, and were simply referred to as Kelvin waves. Recent authors added the modifier "convectively-coupled" to distinguish them from Kelvin waves in the dry atmosphere (e.g., Wheeler and Kiladis 1999).

"Convectively-coupled Kelvin waves" have a power spectrum in the wavenumber-frequency diagram that closely follows that of Kelvin waves in the linear shallow-water theory, with

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a small equivalent depth (Takayabu 1994)*. This is what has led to their name (e.g., Wheeler and Kiladis 1999; Wheeler et al. 2000; Straub and Kiladis 2002, 2003a, 2003b; Majda et al. 2004). However, while "convectively-coupled Kelvin waves" are, indeed, convectively-coupled, they are not Kelvin waves in the strict sense of the term. A review of a revised Gill solution will help explain why.

2. Arguments with a revised Gill solution

The revision to the Gill solution I will make use of here is such that the heating source moves zonally at a prescribed constant speed, instead of remaining stationary. Yamagata (1987) and Chao (1987; see Appendix A of Chao 1995) have provided such a solution. When the heating source is symmetric with respect to the equator, the Gill solution has two components: a forced Kelvin wave, and a forced Rossby wave. If the speed of the heating source is intermediate between the speeds of the free Kelvin wave and the free Rossby wave, a forced Kelvin wave exists within the heating region and to its east, and a forced Rossby wave exists within the heating region and to its west. These forced waves are stationary within the frame of reference that moves with the heating source. These forced waves are not the same as the normal-mode free waves presented by Matsuno (1966), in that they decay outside the heating region, and travel at the speed of the prescribed heating source. The speed of the prescribed heating source is completely independent of the speeds of the free Kelvin, and free Rossby waves. If the heating source is traveling eastward at the speed of the free Kelvin wave or faster, the forced Kelvin wave does not exist east of the heating region; and if the heating source is traveling westward at the speed of the free Rossby wave or faster, the forced Rossby wave does not exist west of the heating region. On the other hand, when the heating source is anti-symmetric with respect to the equator, and traveling at a prescribed speed, the Gill solution has no forced Kelvin wave, or forced Rossby wave, but it has a version of forced mixed Rossby-gravity wave.

As shown in Fig. 5 of Wheeler et al. (2000), and Fig. 16 of Straub and Kiladis (2002), the composite wind fields associated with "convectively-coupled Kelvin waves" have sizeable meridional wind components, especially in the convective region. If one examines the Gill solution, modified such that it has a heating source moving eastward at a constant speed instead of being stationary—i.e., a heating source that approximates the heating source found through the composite method used by Straub and Kiladis (2002)—one gets a wind field that is a combination of forced Kelvin waves, forced Rossby waves, and forced mixed Rossby-gravity waves, all traveling eastward at the speed of the observed composite convective heating. Since such a Gill solution approximates well the composite wind fields associated with "convectively-coupled Kelvin waves," "convectively-coupled Kelvin waves" are not exclusively Kelvin waves, but are a combination of forced Kelvin, Rossby, and mixed Rossby-gravity waves. Thus, "convectively-coupled Kelvin waves," per se, is misleading. Similarly, the terms "convectively-coupled Rossby waves" and "convectively-coupled mixed Rossby-gravity waves" are not correct, either, because these waves are not exclusively Rossby and mixed Rossby-gravity waves, respectively.

It is important to point out here that the Rossby-wave component in the Gill solution is comparable, in terms of maximum wind speed, to the Kelvin-wave component, whether the heating source is stationary, or whether it is allowed to move eastward at one-third the speed of the Kelvin wave (i.e., at the speed of observed "convectively-coupled Kelvin waves). Figure 1a illustrates the non-dimensional wind field (relative to a stationary observer) of the Gill solution, with a symmetric heating source, as specified by Gill (1980), moving eastward at

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* Chimeric mixed Rossby-gravity waves also have a power spectrum in the wavenumber-frequency diagram that closely follows that of the mixed Rossby-gravity waves in the linear shallow-water theory, with the same equivalent depth as that for the chimeric Kelvin waves. Such coincidence with the linear theory has remained a mystery. A speculative explanation for the chimeric Kelvin waves is that they are a nonlinear solitary envelope wave, with internal carrier waves in the form of cloud clusters moving at a different speed. However, the exact nonlinear mechanism that creates the solitary wave is unknown. There have been attempts to explain the chimeric mixed Rossby-gravity waves in terms of middle-latitude forcing (e.g., Itoh and Ghil 1998; Magana and Yanai 1995), and nonlinear wave-interaction (Raupp and Dias 2005), but the question remains.

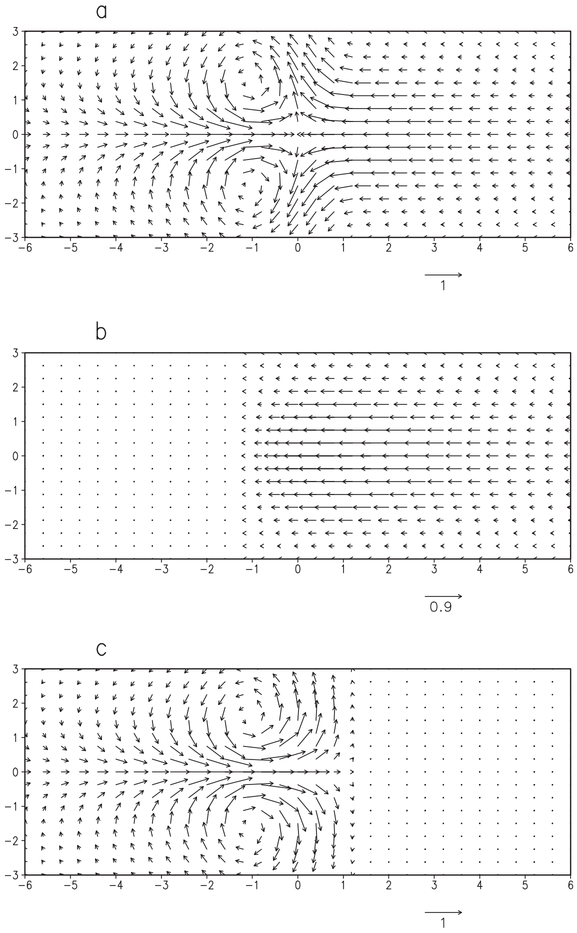

Fig. 1. a) Non-dimensional wind field of the Gill solution with a symmetric heating source moving eastward at one third of the Kelvin wave speed, with $L = 1.5$, $\varepsilon = 0.2$. Notations follow those of Gill (1980). b) the Kelvin-wave component of a). c) the Rossby-wave component of a).

one-third the speed of the Kelvin wave (i.e., at the speed of observed "convectively-coupled Kelvin waves"). The solution is for $L = 1.5$, $\varepsilon = 0.2$ (see Gill 1980 for notations). The Kelvin-wave component is shown in Fig. 1b, and the Rossby-wave component is shown in Fig. 1c. Figure 1a is a good representation of observed "convectively-coupled Kelvin waves." Likewise, Figs. 1b and 1c are good representations of the Rossby-wave and Kelvin-wave components of the observed "convectively-coupled Kelvin waves," respectively. Since Figs. 1b, and 1c show that the Rossby-wave component is comparable, in terms of maximum wind speed, to the Kelvin-wave component, these figures show that the "convectively-coupled Kelvin waves," do not just slightly deviate from Kelvin waves, but greatly deviate.

As an aside, the speed of the "convectively-coupled Kelvin waves" cannot be equated with that of any Kelvin wave, and the meaning of the corresponding equivalent depth based on their speed (e.g., Takayabu 1994; Wheeler and Kiladis 1999) should be re-assessed. Some authors (e.g., Wheeler and Kiladis 1999) also refer to the "convectively-coupled Kelvin waves," as the "moist Kelvin waves" (which is another misnomer), and refer to the equivalent depth, computed from their speed, as the equivalent depth for the moist atmosphere. Now that we know that the "convectively-coupled Kelvin waves" cannot be identified as the Kelvin waves, per se, the equivalent depth, computed from their speed, does not really have any clear meaning.

3. A proposal

One may give a phenomenon any name; what is wrong with continuing to use the term "convectively-coupled Kelvin waves?" In this case, since the Rossby-wave component, within the "convectively-coupled Kelvin waves" is comparable to the Kelvin-wave component, people may think these waves have a Kelvin-wave structure only, and hence, may make some serious errors. This is because the name Kelvin wave implies that the wave is symmetric, and has no meridional wind component. One may tolerate a small meridional wind component, and still use the name Kelvin wave; but the "convectively-coupled Kelvin waves" that Straub and Kiladis (2002) studied in the eastern Pacific have obvious anti-symmetric components—with heating on only one side of the equator—and a sizeable meridional wind component; also, the eastward-moving "convectively-coupled Kelvin waves" that Wheeler et al. (2000, see its Fig. 5) studied in the western Pacific and in the Indian Ocean, although fairly symmetric, have a large meridional wind component. Therefore, the term "convectively-coupled Kelvin waves" is not appropriate for these waves.

A more precise term for the "convectively-coupled Kelvin waves" would be the "convectively-coupled nonlinear 15 ms^{-1} eastward-moving combined Kelvin-Rossby waves." The modifier "nonlinear" is used to recognize the fact that the westward-moving meso-scale systems in these waves are the integral parts of the waves, and that any explanation for the cause of these waves must take into account the nonlinear interaction between the meso-scale waves, and the waves as a whole. The modifier "15 ms^{-1}" is used to distinguish these waves from the Madden-Julian oscillation, which also has both Kelvin- and Rossby-wave components. For brevity, however, one can simply use the term chimeric Kelvin waves. The adjective "chimeric" signifies the combined nature of these waves, and the name "Kelvin" is retained to acknowledge their eastward movement. Since these waves are commonly-known to be convectively-coupled, this modifier can be dropped. By extension, one can call the "convectively-coupled Rossby waves" chimeric Rossby waves, and the "convectively-coupled mixed Rossby-gravity waves" chimeric mixed Rossby-gravity waves.

By recognizing the above misnomers, and by changing the terminology, one can gain a better understanding of these waves and lessen confusion.

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