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Towards a seamlessly diagnosable expression for the energy flux associated with both equatorial and mid-latitude waves

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A feature of many phenomena in the equatorial oceans is the role played by equatorial Kelvin waves (KWs), examples being El Nino Southern Oscillation and the so-called Atlantic Nino. KWs propagate along the equator and are partially redirected into coastal KWs at the eastern boundary, where they can influence off-equatorial latitudes as well as excite extratropical Rossby waves (RWs) that subsequently propagate into the ocean interior (Matsuno, 1966). A striking example of this behavior is the equatorial basin mode. For the gravest basin mode, the time scale is set by the time taken for an equatorial KW to propagate across the basin and for the reflected gravest long Rossby wave to return to the western boundary (that is $4L/c$ where L is the basin width and c is the phase propagation speed for KWs). In addition to waves that are trapped on the equator, equatorial basin modes also feature coastal KWs that propagate along the eastern boundary and extratropical RWs that are excited by these KWs and refocus on the equator. There is growing evidence that equatorial basin modes play an important role in equatorial ocean dynamics. For example, basin modes have been associated with the equatorial deep jets and with the semi- annual and annual cycles in the equatorial Atlantic. However, the energy cycle associated with equatorial basin modes has received little attention and is an important factor when considering the forced/dissipative basin modes that one can relate to observations. A particularly interesting example is the upward energy propagation associated with the Atlantic equatorial deep jets. Yet, the detailed energy cycle associated with the jets remains largely unknown.

One way to approach the energy flux is to use ray theory. However, ray theory is linked to the dispersion relation of a single type of wave and is not suitable for investigating the sequential connection of different types of waves that are associated with a basin mode. Likewise, a Fourier analysis is not suitable for the investigation of waves near the coastal boundaries of the ocean. In fact, it is only for mid-latitude inertia-gravity waves (IGWs) that the flux of wave energy has been diagnosed from oceanic model output. On the other hand, in the atmospheric literature, the model diagnosis of pseudomomentum (or wave activity) flux has been more popular than the model diagnosis of the energy flux.

Aiki et al. (2017) have performed an analytical investigation that leads to a general expression for the energy flux that can indicate the exact profile of the group velocity times wave energy for both equatorial and mid-latitude waves. The utility of the universal expression of energy flux as a model diagnostic is illustrated for a forced/dissipative equatorial basin mode simulated by a single-layer model (Fig. 1). The model diagnosis is achieved by introducing an inversion for the linearized version of Ertel's potential vorticity (EPV). This is a novel aspect for considering the energy flux in the presence of a coastal waveguide that connects the equatorial and mid-latitude regions. For ease of diagnosis from a model, an approximate version of the universal expression is explored and illustrated for a forced/dissipative equatorial basin mode simulated by a single-layer oceanic model that includes both mid-latitude RWs and equatorial waves. Equatorial KWs propagate eastward along the equator, are partially redirected poleward as coastal KWs at the eastern boundary of the basin, and then shed mid-latitude RWs that propagate westward into the basin interior. The connection of the equatorial and coastal waveguides has been successfully illustrated by the approximate expression of the group velocity based energy flux of the present study.

To summarize, Aiki et al. (2017) have derived a general expression that can be used to diagnose the energy flux associated with linear shallow water waves at all latitudes from model output. This will allow for tropical-extratropical interactions in oceanic and atmospheric model outputs to be diagnosed in terms of an energy cycle in a future study.

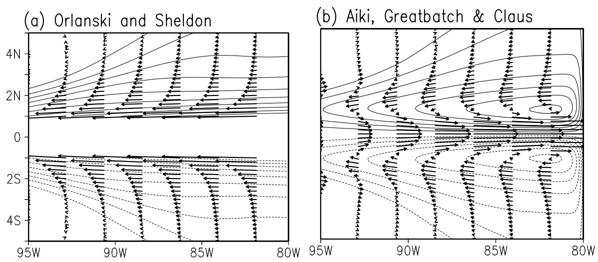

Fig. 1 Energy flux (vector) and streamfunction (dotted contour) based on (a) the previous study and (b) the present study.

References

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