THE ENERGY CYCLE OF THE TROPICAL MADDEN-JULIAN OSCILLATIONS SEEN THROUGH WAVELETS

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Summary
The Madden–Julian Oscillations (MJO) are probably the most notable planetary-scale convective equatorial waves in the tropical atmosphere, which propagates around the globe eastwards with 30–60 day period. The MJO constitute a good example among the complex phenomena associated with geophysical flows. Their understanding and simulations remain a challenging fluid mechanics problem with complex interactions between planetary–scale flows and small-scale moist deep convection. Even their basic mechanism is hard to identify by conventional Fourier–based analyses due to strong nonlinearities in cloud physics associated with moist deep convection. Here, the wavelet is proposed as a general methodology for analyzing complex geophysical flows, and this method is used in order to identify the maintenance mechanism of MJO under an energy cycle. The analyses of the simulation results from global models show that this system is not necessarily maintained by moist deep convection in a simple manner as expected from the current dominant view.

INTRODUCTION

The geophysical phenomena are often complex with many physical processes associated together. Thus, lucid applied mathematical approaches must be called for in order to clearly identify their mechanism by untangling these many processes. The Madden–Julian Oscillation (MJO) is such a major example.

Phenomenologically, MJO is initiated in the Indian Ocean as a convective anomaly associated with a low–level convergence, an upper–level divergence and a pressure anomaly. The whole structure, which scales 5000–10000 km, corresponding to the longitudinal wavenumbers 1–3 in the wavenumber space, propagates eastwards as it enhances. Its activity reaches its peak over the Western Pacific, and its convective component almost dissipates out as it crosses the Dateline, although the dry dynamical component is observed to circulate around the globe. The whole cycle takes 30–60 days.

The numerical simulation of this phenomenon remains challenging due to its complex and intrinsic coupling with moist–convective processes of 10–100 km in horizontal scales. With limited horizontal scales of the current standard global models, the latter process must be somehow “parameterized”, along with many other physical processes. These parameterizations not only remain overall *ad hoc*, but their existence make the identification of the basic physical mechanism in global climate–model simulations far more difficult, although these models often generate MJO–like features. In other words, no theory is easy tested by these global models due to the complexity of the latter.

Identification of the mechanism is further hindered by the current dominant thinking assuming these phenomena as oscillatory waves. The actual MJO is dominated by an isolated pulse–like structure both in convective precipitation fields and winds. By emphasizing this aspect, the wavelet is employed in order to extract MJO more efficiently as a pulse-like feature, and the energy cycle of MJO is analyzed by identifying it by its most dominant wavelet mode in a coordinate moving with MJO.

THE ANALYSIS METHOD

The adopted energy cycle (Fig. 1) is identical to the so–called Lorenz’s four boxes, but both the kinetic (K) and the potential (P) energies are decomposed into a MJO mode (a single wavelet mode, designated by the subscript MJO)) and all the remaining wavelet modes (non–MJO mode, designated by the subscript $\overline{MJO}$), instead of zonal mean and eddies.

The current dominant view for MJO assumes that it is driven by moist–convective heating. Thus, energetically, its potential energy (P_{MJO}) is generated by diabatic heating associated with moist convection (G); the generated potential energy is converted into the kinetic energy (K_{MJO}) by the buoyancy forcing (C); then the kinetic energy is dissipative by frictional processes (D). The energy components for the non–MJO mode are expected to be not playing a major role in this domiant view.

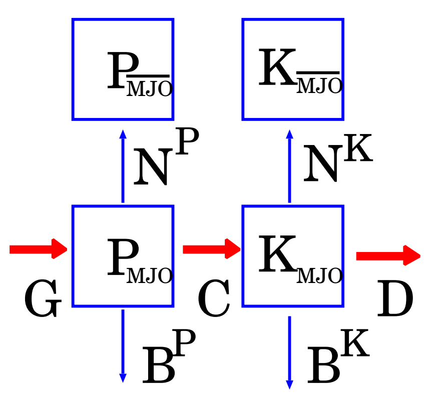

Figure 1: Schematics of the energy cycle used in the analysis, also indicating the prediction from standard theories by thick arrows.

RESULTS

This analysis method is applied to the MJO–like features simulated by two global climate models, designated by abbreviations LMDZ and ECMWF in the followings. MJO–like features in both models propagate eastwards with the phase speeds of 1.5 m/s and 7 m/s, and the dominant wavelet mode has the wavenumber band 8 and 4, respectively. The MJO–like features simulated by the LMDZ model are too slow in phase speed, and too small in scale, whereas those in the ECMWF model is reasonable.

However, MJO–like features of both models are maintained by qualitatively very different mechanism than that of the dominant view.

In the case of LMDZ (Fig. 2), diabatic heating effect (G) is not efficient enough for generating the potential energy (P) for the MJO mode. Instead, the potential energy for this mode is generated by nonlinear transfers (N^P) of potential energy from different scales ($P_{\overline{MJO}}$). Our preliminary analysis implies that the distortions of the zonal–mean temperature field by meridional advections generate the potential energy for the MJO mode. Nevertheless, the generated potential energy is used for maintaining the kinetic energy for MJO, as the standard theories predict.

The energy cycle identified from an ECMWF simulation (Fig. 3) is again, qualitatively different from the standard theories, and also in different manners than LMDZ. In the case of the ECMWF simulation, the potential energy is mostly generated by diabatic heating, but the generated potential energy is not much converted into the kinetic energy. It is simply transfered into the different scales. More surprisingly, the kinetic energy for MJO is mostly supplied by the subgrid–scale "dissipation" ($i.e.$, negative dissipation). If this is literally correct (emphasizing a preliminary nature of the analysis), MJO in ECMWF model is dynamically generated by inverse cascade of energy from the subgrid scales.

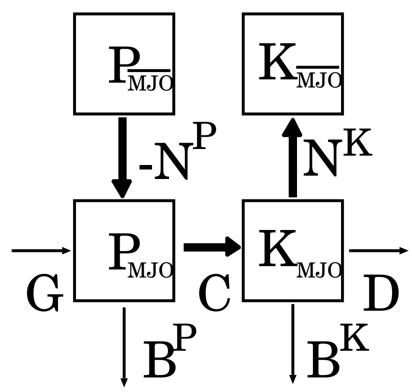

Figure 2: The schematics of the energy cycle identified for MJO in the LMDZ simulation.

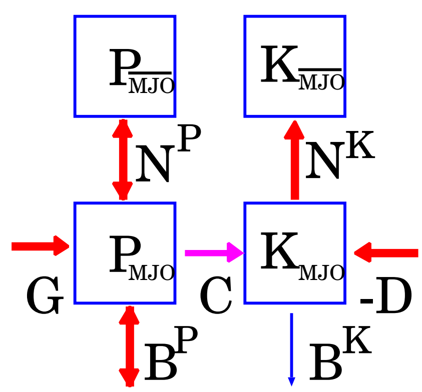

Figure 3: The schematics of the energy cycle identified for MJO in the

CONCLUSIONS

The present work demonstrates how the wavelet can be used in order to efficiently capture coherent structures in complex geophysical fbws and identify their basic maintenance mechanism. Our analysis shows that MJO–like features simulated in two global climate models are not maintained by moist deep convection, but suggest importance of various nonlinearities.