Waves and multiscale processes in the tropics

organized by
Joseph Biello, Boualem Khouider, and George Kiladis

Workshop Summary

A multiscale system like the climate is forced on a wide variety of temporal scales: daily, seasonal, annual and secular (from anthropogenic, geological and astronomical sources). Though solar forcing occurs on the largest spatial scales of the Earth, it is communicated to the troposphere more locally, primarily through the latent heating within deep convection. The resulting storm systems and circulations that are generated organize on spatial scales ranging from individual thunderstorms on up through planetary circulations (an "upscale" process). Additionally, these organized storm systems generate large scale atmospheric waves which rapidly traverse the globe and are able to affect weather patterns, elsewhere in the tropics and in extratropical regions far from the centers of organization.

The dynamics of organised multiscale convective systems in the tropics presents one of the most challenging problems in contemporary dynamical meteorology, requiring new developments in fluid mechanics, scientific computing, and statistical physics. A comprehensive theoretical understanding of this organized, multiscale process and the resulting waves has yet to be achieved. Furthermore, numerical simulations (General Circulation Models, or GCMs) are neither able to capture the upscale organization from tropical convection nor do they faithfully represent the wave activity (Lin et al 2006). A theoretical understanding of these upscale processes and the planetary waves which they generate are essential not only for improving global weather forecasting, but also for understanding how climate change will alter the manner in which the tropics impact the extratropics.

This workshop brought together several leading researchers working on a broad range of observational, theoretical and modeling aspects of multiscale tropical interactions. The basis for much of our theoretical understanding comes from the relatively simple framework developed by Matsuno in 1966, which isolated the normal modes of the so-called shallow water system linearized about a basic state at rest on an equatorial beta plane. Though not the only topic of discussion during the workshop, the behemoth of tropical organized convection, the Madden-Julian oscillation (MJO), was a recurring theme in the presentations and the discussions. The MJO is by far the largest scale and most influential wave considered here, although it does not correspond to a Matsuno eigenfunction and therefore poses special challenges.

George Kiladis gave the first talk of the workshop presenting observations of unresolved issues in tropical waves. He highlighted the faster waves embedded in the MJO signal including the 13 m/s convectively coupled Kelvin wave and the fast, westard moving waves, which he speculated could be inertio-gravity waves. An important point was made regarding the upscale forcing of the MJO. Since various MJOs are seen to be comprised of a wide range of smaller scale disturbances from event to event, the MJO can apparently be maintained by a wide variety of convectively coupled waves. He also showed a mesmerizing visualization of observations of "atmospheric rivers"; these tongues transport enormous amounts of tropical moist air to the midlatitudes (and are realized in California as the "pineapple express").

Andrew Majda spoke about his recent work with Sam Stechmann on a skeleton model for the MJO. Vertically integrated moisture is used to construct a (conserved) moist equivalent potential temperature. However the novelty of the model consists in the introduction of a dynamic variable describing wave activity on the synoptic scales; higher wave activity implies more deep convection, and this activity need not be organized in any systematic way (in terms of waves), consistent with observations. In fact, this aspect of the closure initiated a lot of discussion in a subsequent breakout session as there was much debate on the interpretation of this variable in terms of more fundamental thermodynamic quantities. Irrespective of the interpretation, the linear theory of the model has structures which look like an MJO wave packet, exist on the planetary scales and have the dispersion characteristics of the MJO.

Sam Stechmann followed Andy's talk with a discussion of their joint work on how convection can be organized by convective momentum transport from gravity waves in a two baroclinic mode model. While this momentum transport appears to be a crucial aspect in explaining the large scale structure of the MJO, it is not generally represented well by GCMs, although cloud resolving models (CRMs) contain these processes more explicitly. A case was made that this transport could be better represented in GCMs through a stochastic parameterization.

Brian Mapes presented a wide ranging talk that brought up multiple interpretations of the observed scale interactions within equatorial waves. He showed a marked difference in the structure of the mass circulation between more "rotational" waves compared to more "divergent" waves, which seemed consistent with the enhancement of stratiform rain in the more divergent modes along with the MJO.This is also consistent with theoretical results regarding the wavelength dependence of gross moist stability, a result that was also confirmed in a cloud resolving model simulations.

Dave Randall showed both some older and new numerical results using the superparameterization technique. The use of embedded cloud resolving models within a large scale GCM framework appears to solve some of the problems encountered by conventional parameterization of convection, including the ad hoc nature of closure assumptions and the necessity of "convective triggers" to generate realistic results in many cases. Dave also showed that ocean coupling to super parameterized models, while not necessary to simulate the MJO and equatorial waves, improves the details of even the high frequency modes. This was interpreted as being due to a better simulation of the basic state and its variability in the case of coupling, leading to more a realistic background mean flow and variability on both intraseasonal and interannual time scales.

On day 3, Wayne Schubert reviewed some results of his research on tropical cyclone dynamics. This ranged from the application of Rossby length and depth concepts in tropical cyclone dynamics, the radiation of inertia-gravity waves from the cyclone core, to Ekman pumping effects and shock-like structures within the boundary layer. Wayne also showed how upper troposphere potential vorticity (PV) anomalies curve isentropes in the lower troposphere and can act as a mechanism for convective triggering, and he presented some elegant analytic solutions illustrating this interpretation.

Chidong Zhang used a PV diagnostic to evaluate the the relative strength of different types of PV forcing the MJO. An exciting result confirmed the dominance of upscale fluxes in driving the MJO PV signal. Much discussion in the break out session involved the comparison of his analysis to the multi-scale models of the MJO.

Day 4 was dedicated to moisture. Olivier Pauluis provided a “Fermi-esque” discussion of moist thermodynamics, comparing the classical Carnot cycle to the steam engine. He emphasized the importance of these results in understanding the effects of deep convection building models to describe them. Boualem Khouider did describe such a model, the multi-cloud model, that he has developed with A. Majda. Their new results show large scale envelopes modulating (and counterpropagating to) synoptic and meso-scale convectively coupled waves. This model is beginning to reproduce the spectral power seen on the classic Wheeler-Kiladis diagrams for the tropics.

On the final day, Timothy Dunkerton and Carlos Raupp spoke. Tim discussed some of the history of simple modeling of equatorial waves, and convincingly demonstrated that some of the older ideas, such as barotropic and inertial instability and WISHE, should not be entirely dismissed for explaining equatorial waves. He also pointed out some still unsolved problems with regards to the vertical structure of mixed Rossby-gravity waves that he worked on in the 90’s. He then finished up with an overview of his “Marsupial Paradigm” for hurricane genesis, emphasizing the potential role of a “pouch” of dynamically isolated air that fosters deep convective growth leading to the formation of the hurricane spin-up region.

Carlos Raupp talked about his work with Pedro Silva Dias on the non-linear interactions between equatorial waves and also their interactions with the diurnal cycle. These interactions are analyzed within the framework of the diabatic equatorial beta plane primitive equations, with resonant triad interactions responsible for the growth of eigenmodes corresponding to the observed equatorial waves. The results support the idea that high frequency modes and even the diurnal cycle can force lower frequency intraseasonal variability through nonlinear interactions.

Larissa Back humbly withdrew since she felt that she gave her talk in the Diurnal cycle session of the day before.

The group was reluctantly convinced narrow the afternoon breakout sessions to

- **Tropical/Midlatitude interactions. Days 1,2**
- **Scale interactions and self similarity. Day 1,2**
- **Convective models, stochastic and deterministic. Day 1**
- **Convective Triggering. Day 2**
- **MJO Initiation. Day 3**
- **The relationship between thermodynamic fields. Day 3**.
- **Modeling and Observation of Kelvin Waves. Day 4**
- **The Diurnal Cycle. Day 4**
- **Wrap up. Day 5**

At least one new collaboration resulted from the break out discussions (we hope that Raupp and Biello will be able to complete an equatorial wave scattering theory). Overall, the workshop was well received by the participants and achieved its main goal of improving the communication between observationalists, modelers and mathematicians.