Draft

CMMAP MJO FOCUS THEME

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1. Introduction: Basic issues and new approaches[1]

Fundamental barriers to advancing weather and climate diagnosis and prediction on timescales from days to years are attributable to gaps in knowledge and the limited capability of contemporary operational and research numerical prediction systems to represent precipitating convection and its multi-scale organization, particularly in the tropics. In particular, the Madden-Julian Oscillation (MJO; Madden and Julian, 1972; Fig. 1) displays a multiplicity of interacting scales and strong three-dimensional transport of mass, momentum, and energy. The multi-scale organization of convection underscores the necessity to represent dynamical coherence, upscale evolution, and regime-dependent transport of organized systems in global models. Moreover, the effects of phase changes of water (the ultimate source of thermodynamic energy for deep convection) are manifested on various temporal scales: from convective-turnover and diurnal time scales (hours to a day), through the timescale of meso-convective organization (~days) to the residence time of water in the atmosphere (~2 weeks). Thus, the behavior and effect of water in the atmosphere in association with convective organization straddles the intersection of weather and sub-seasonal climate and has important implications for longer-term climate processes e.g., cloud-radiation interaction. The reader is referred to the review of Zhang (2006) for a more detailed background.

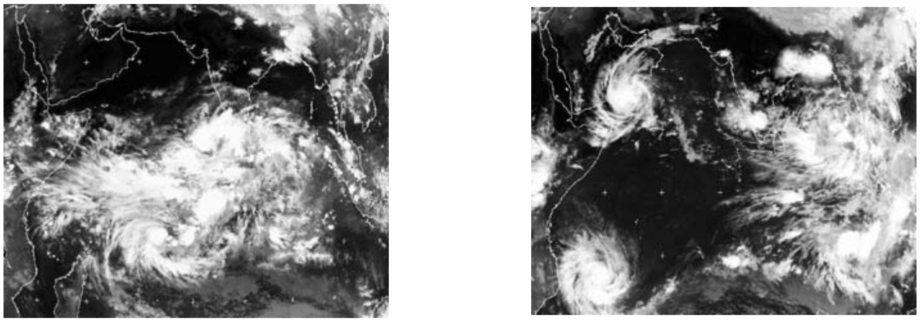

Figure 1: MJO convective organisation. An active MJO over the Indian Ocean on 2 May 2002 (left panel). A week later the MJO has moved eastwards over Indonesia, spawning two tropical cyclones in its wake (right panel). The multi-scale organisation of convection is clearly visible within the envelope of the MJO. The twin cyclones demonstrate graphically how high-impact organised weather events are associated by large-scale convective organisation and equatorial waves (Courtesy: Julia Slingo).

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[1] For the most part, this section is extracted from a manuscript: "Organized Tropical Convection and Multiscale Interaction with the Global Circulation: A THORPEX and WCRP Collaborative Research Opportunity" by M. W. Moncrieff, M.A. Shapiro, J.M Slingo, and F. Molteni.

The MJO is increasingly recognised as influencing high-impact weather events and climate variability. It is also important in the socio-economic sense and across temporal scales. For example, the MJO is associated with: i) tropical cyclones, which are particularly severe weather events as poingantly illustrated in Fig.1; ii) tropical variability on sub-seasonal timescales such as breaks in the Asian, Australian and African monsoons which has imporant implications for life, agriculture, and infrastructure across the deep tropics; iv) global influences on through tropical-extratropical interactions and subsequent effects on the storm track in midlatitudes; v) a possible influence on interannual variability through affecting the genesis of El Nino. The reader is referred to Shapiro and Thorpe (2004) for more discussion of the effects of the MJO onhigh-impact weather events in midlatitudes. Yet, adequate knowledge of the processes contributing to the initiation and maintenance of the MJO and realistic simulations and predictions of the MJO, remain major scientific challenges to the weather/climate community.

1.1 Multi-scale convective organisation

A long-standing shortcoming of weather forecast and climate-prediction systems is their inadequate representation of subgridscale precipitation physics (Lin *et al.* 2006). The multi-scale organisation of precipitating convection and its interaction with the resolved-scale circulations is gaining prominence in the global modeling community. The issues are basic since the MJO is usually significantly different in coupled atmosphere-ocean models compared to atmosphere-only models. While there are reasons for such disparity, incomplete formulations of how boundary layers of the ocean and atmosphere interact are important issues, especially regarding the role of the MJO in the genesis of El Niño. Convective systems strongly affect surface radiative balance, evaporation, and wind stress which are key to atmosphere-ocean interaction.

Tropical convection organises on a remarkably wide range of spatial and temporal scales: i) cumulonimbus (~1- 10 km, hour); ii) meso-convective clusters (~100-500 km, day); iii) synoptic-scale superclusters (~1000-3000 km, week); iv) the MJO (~10000 km, weeks-months). A crucial unknown is how these multiple scales interact to form self-reinforcing, multi-scale organised systems. It is recognised that synoptic-meso-convective activity in the tropics is often coupled to preferred meriodinally-trapped modes of atmospheric variability described, to a first approximation, as Rossby-gravity waves and Kelvin waves.

Issues have been raised regarding: i) how convective activity is modulated by wave modes; ii) the degree to which convection forces atmospheric waves and *vice versa*; iii) feedback between convection and synoptic-scale to planetary-scale processes; iv) the upscale effects of meso-convective organisation (e.g., *via* thermodynamic and momentum transport) on large-scale atmospheric circulation; v) the effects of higher-latitude disturbances propagating into equatorial regions (e.g., cold surges originating in Siberia) on MJO genesis.

a) MJOs in parameterized global models

Figure 2 illustrates that MJOs in operational weather prediction disintegrates from the robust system in the analysis to a nonentity in a matter of days. Idealised global models (e.g., aquaplanet models) experience similar difficulty with the MJO, suggesting that the problem is fundamental.

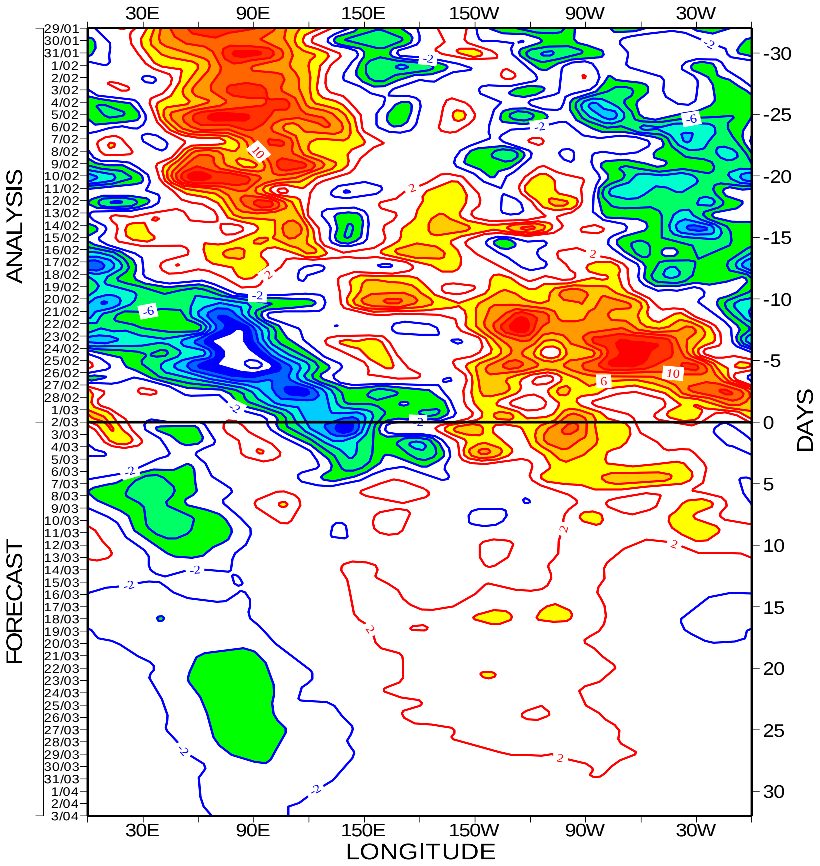

Figure 2: MJO within the ECMWF forecast system for an event in February 2006. The eastward propagating MJO is visible in the velocity potential (large-scale divergence) at 200hPa in the analyses, but the signal is lost rapidly within the forecast after 5 days (Courtesy: Adrian Tompkins, ECMWF).

Figure 3 illustrates the minimal consistency in MJO convective organisation among aqua-planet climate models applying different convective parameterisations; some systems propagate eastward, others westward; most likely, none of these realizations is truly a MJO. Another fundamental problem is the disparate spatial and temporal scales of the simulated convective organization.

b) Explicit representation of cloud-systems in global models

The explicit representation of precipitating convection by cloud-system resolving models (CRMs) is shedding new light on convective organisation, since the meso-convective organisation therein is more realistic than in contemporary parameterised global models.

This class of modeling provides the prospect for improved representation of the MJO in weather/climate models. The *global* CRM is the state-of-the-art in explicit representation of multi-scale organization.

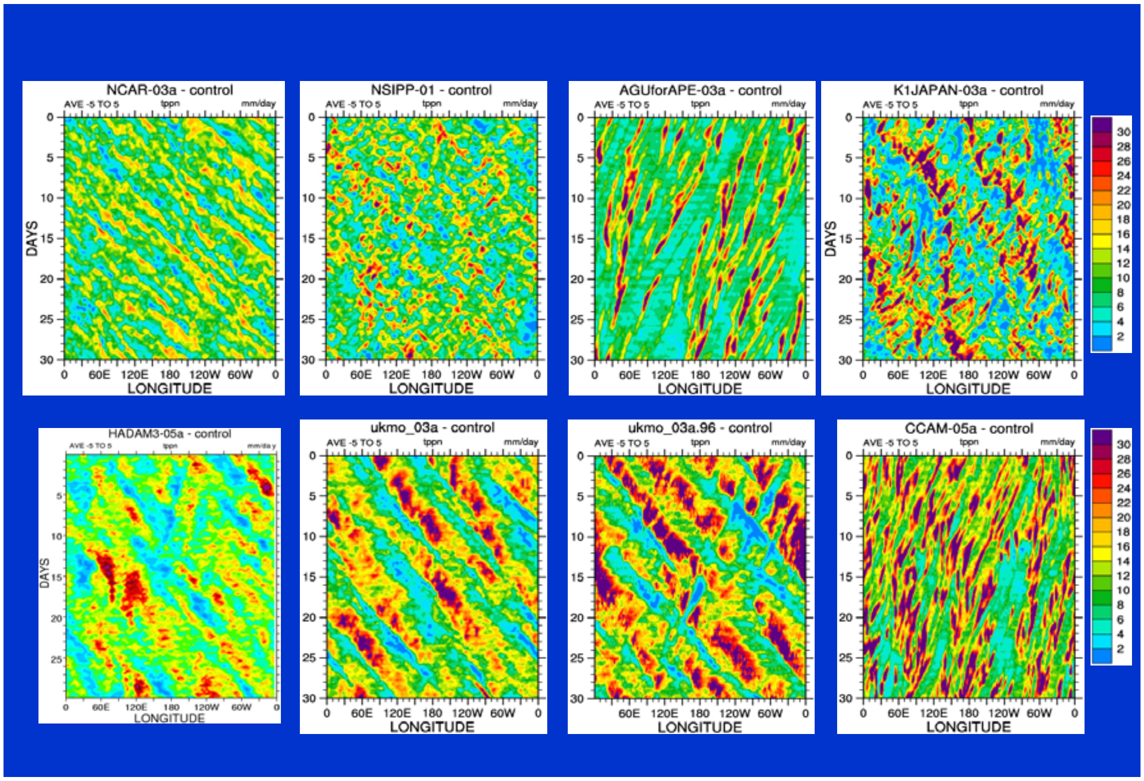

Figure 3: Large-scale organisation of tropical convection (precipitation) in climate models occurring some of the models participating in the Aqua-Planet Model Inter-comparison Project (http://www-pcmdi.llnl.gov/projects/amip/ape/). (Courtesy: Mike Blackburn, University of Reading, and Dave Williamson, NCAR.)

Figure 4 shows equatorial large/meso-convective organisation in a global CRM. Evident in this diagram are the eastward-propagating convective envelope and the embedded westward-propagating cloud clusters, resembling the multiscale organisation in nature e.g., Nakazawa (1988). Interestingly, MJOs occurring in global CRMs are usually too intense and persistent -- exactly the opposite from parameterised models. This behavior poses a new set of problems, arguably more amenable to solution than problems associated with contemporary parameterisation.

The explicit representation of convective organization is the basis of the superparameterisation approach: CRMs are applied in place of contemporary convective parameterisation. Superparameterisation was originally applied in the aquaplanet model of Grabowski (2001) and recently applied in full climate models (e.g., Khairoutdinov and Randall 2006).

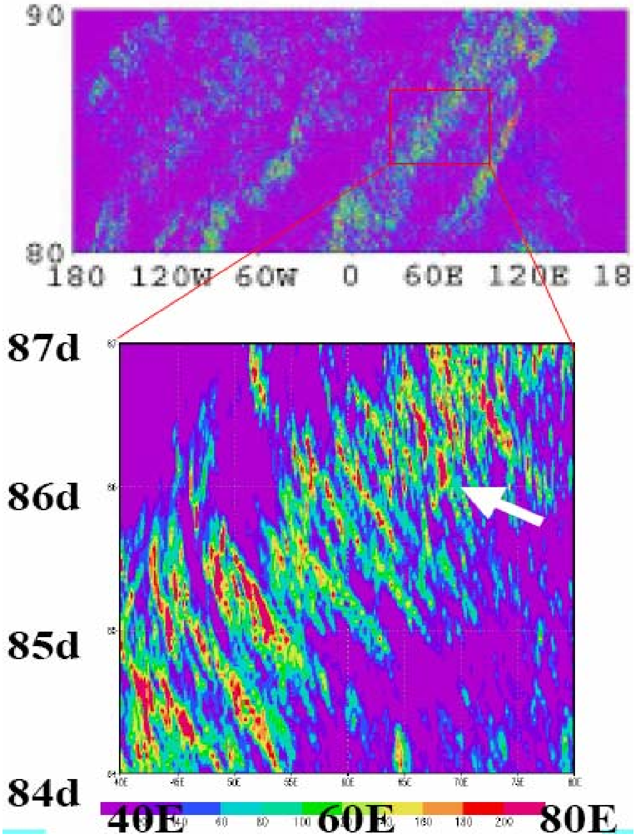

Figure 4: Simulated multiscale convective organisation in a global aquaplanet CRM at 3.5 km grid-spacing. Top, eastward-traveling convective envelopes and, bottom, a blow-up of the westward-traveling mesoscale convective systems (e.g., white arrow) in the top plate. (Courtesy: Satoh, Frontier Research Center for Global Change, Yokohama, Japan).

c) Dynamical models of multi-scale convective organization

The problem of quantifying the multi-scale organisation of precipitating convection and its interaction with the global circulation is unlikely to be solved through enhanced-resolution numerical simulations alone. Idealised models are useful for quantifying important issues, such as upscale transport associated with meso-convective organisation and mechanisms at work in numerically simulated multiscale systems. For example, the nonlinear mechanistic dynamical model of Moncrieff (2004) interlocks meso-convective organisation with Rossby-gyre dynamics and represents the morphology and upscale momentum transport properties. This model also simulates the vertical and meriodional transport and super-rotation properties of MJO-like systems generated by superparameterisation in Grabowski (2001). The quasi-linear multi-scale model of Biello *et al.* (2006), based on the systematic asymptotic perturbation theory of Majda and Klein (2003), shows that MJO-like systems can be intiated and maintained by organised upscale momentum and heat fluxes. Three categories of heating are represented: deep convection, stratiform, and congestus. Figure 5 illustrates: i) westward-tilted meso-synoptic eddies; iii) vertically and horizontally coupled cyclonic and anticyclonic gyres;

iii) a westerly-wind burst in the lower troposphere. These are the characteristic signatures of observed MJOs, giving plausible support for the hypotheses that MJO systems can be generated by upscale momentum transport in the vertical and horizontal.

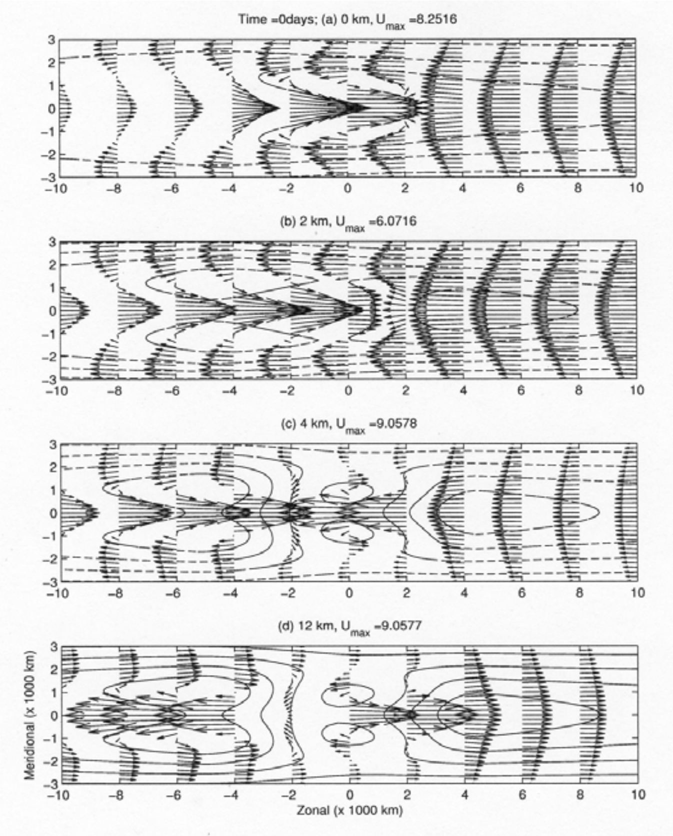

Figure 5: Horizontal velocity at selected heights in the troposphere, along with contours of the perturbation pressure in a multi-scale dynamical model forced by vertical fluxes of synoptic-scale heating and zonal momentum. Courtesy: Biello, Majda and Moncrieff (2007).

Another approach to idealised simulation of the MJO incorporates a dynamically active troposphere, a passive planetary boundary layer, and simple parameterisations of deep convection, surface heat exchange, and radiative cooling. This analog has crude vertical resolution, typically one or two baroclinic vertical modes described by $\sin(\pi z)$ and $\sin(2\pi z)$, respectively. Multi-scale convective organisation does occur in the first-baroclinic or 'shallow-water' versions of these models (Yano *et al.* 1995). However, the second-baroclinic mode results in more realistic MJO-like organisation (Khouider and Majda, 2006). This quantifies the importance of upper-tropospheric stratiform heating behind and low-to-mid tropospheric cumulus congestus heating in front of such systems, in agreement with the observed "tri-modal" characteristics of tropical convection; Johnson *et al*. (1999).

An important requirement for advancing the predictive skill of global weather/climate models is to derive parameterisations to allow the proper development of convective organization. This is a necessary requirement, since: i) convective organization is not realistically captured by present convective parameterisations; ii) the explicit approach to convection is too computationally intensive for inclusion in contemporary climate models. Idealised models quantify properties of multi-scale convective organization, e.g., vertical structure, transports, and propagation, and are therefore testbeds for the development of organized convection parameterisations.

2. MJO in CMMAP MMF models

Realizations of the MJO in CMMAP MMF models are an excellent opportunity to: i) evaluate the role of multi-scale organized convection in the genesis and maintenance of the the MJO; ii) improve the representation of MJOs in superparameterized models; iii) develop parameterizations of the MJO in coarse resolution climate models used in long simulations (e.g., IPCC assessments) where it is impractical to use superparameterization. Since global CRMs are the closest analog to superparameterization, they offer a promising conduit, along with idealized models.

The too-intense precipitation and over-active MJO in both superparmeterized globnal models and global CRMs suggests an underlying basic explanation to be explored.

[To be completed]

3. Analysis strategy for MMF

Discuss at Kauai

4. Numerical experimentation strategy

Discuss at Kauai

5. Summary

WEB SITES:

ICTP Workshop on organized tropical convection and the MJO:

http://cdsagenda5.ictp.trieste.it/full_display.php?ida=a04205

CLIVAR Sub-seasonal MJO Working Group:

http://www-pcmdi.llnl.gov/projects/amip/ape/

AMIP-type Aqua-Planet Model Inter-comparison Project:

http://www.usclivar.org/Organization/MJO_WG.html

REFERENCES

Biello, J.A., A.J. Majda, and M.W. Moncrieff, 2007: Meridional momentum flux and superrotation in the multi-scale IPESD MJO model. *J. Atmos. Sci.,* in press.

Ferranti, L., T.N. Palmer, F. Molteni, and E. Klinker 1990: Tropical-extratropical interaction associated with the 30-60 day oscillation and its impact on medium and extended range prediction. *J. Atmos. Sci*., **47**, 2177-2199.

Grabowski, W.W., 2001: Coupling cloud processes with large-scale dynamics using the Cloud-Resolving Convection parameterization (CRCP). *J. Atmos. Sci*., **58**, 978-997.

Johnson, R.H., T.M. Rickenbach, S.A. Rutledge, P.E. Ciesielski, and W. H. Schubert, 1999: Trimodal characteristics of tropical convection. J. Climate. 2397-2407.

J.-L. Lin and Co-authors, 2006: Tropical Intraseasonal Variability in 14 IPCC AR4 Climate Models. Part I: Convective Signals *J. Climate,* **19**, 2665–2690.

Khairoutdinov, M and D. Randall, 2007: Evaluation of the simulated interannual and subseasonal variability in an AMIP-style simulation using the CSU Multi-scale Modeling Framework. *J. Climate,* submitted.

Khouider, B. and A.J. Majda, 2007: Multicloud models for organizes tropical convection: Enhanced congestus heating. *J. Atmos. Sci.,* submitted.

Kiladis, G.N., 1998: Observations of Rossby waves linked to convection over the eastern tropical Pacific. *J. Atmos. Sci*., **55**, 2321-339.

Lin, J.L.,and co-authors, 2006. Tropical intraseasonal variability in 14 IPCC AR4 climate models. Part I: Convective signals. *J. Climate,* **19**, 2665–2690

Madden, R.A., and P.R. Julian, 1972: Description of global-scale circulation cells in the Tropics with a 40–50 day period. *J. Atmos. Sci.,* **29**, 1109–1123.

Nakazawa, T, 1988: Tropical superclusters within intraseasonal variations over the western Pacific. *J. Meteor. Soc. Japan*, **66**, 823-839.

Majda, A.J., and R. Klein, 2003: Systematic multi-scale models for the tropics. *J. Atmos. Sci.,* **60**, 393-408.

Moncrieff, M.W., 2004: Analytic representation of the large-scale organization of tropical convection. *J. Atmos. Sci.,* **61**, 1521-1538.

Moncrieff, M.W., M.A. Shapiro, J.M. Slingo, and F. Molteni, 2007: Organized tropical convection and multi-scale interaction with the global circulation: A THORPEX and WCRP collaborative research opportunity. Manuscript.

Newman M., P. D. Sardeshmukh, C. R. Winkler, and J.S. Whitaker, 2003: A study of subseasonal predictability. *Mon. Wea. Rev.*, **131**, 1715–1732.

Shapiro, M.A.., and A. J. Thorpe 2004: THORPEX International Science Plan. WMO/TD-No.1246, WWRP/THORPEX, No.2, 51 pp.

Yano, J.-I., J.C. McWilliams, M.W. Moncrieff, and K.A. Emanuel, 1995: Hierarchical tropical cloud systems in an analog shallow-water model. *J. 32Atmos. Sci.*, **52**, 1723-1742.

Zhang, C, 2005: Madden-Julian Oscillation, 2005: Rev. Geophys., **43**, doi: 10.1029/2004RG000158.