# 1D.8 IMPACT OF EXPLICIT ATMOSPHERE-OCEAN COUPLING ON TROPICAL INTRASEASONAL OSCILLATIONS

Wojciech W. Grabowski*
NCAR†, Boulder, Colorado

Tropical intraseasonal oscillations concern variability of the tropical climate on time scales between several days and a few months and are the strongest mode of atmospheric variability in the tropics. Their best known example is the Madden-Julian Oscillation (MJO), which is a coherent pattern of deep convection, large-scale circulation, and sea-surface temperature that propagates toward the east across the tropical warm pool (eastern Indian and western Pacific Oceans) with a typical speed of 5 m/s (see a recent review of Zhang 2005). Intraseasonal oscillations and MJO are poorly represented in contemporary climate models (e.g., Slingo et al. 1996; Lin et al. 2005). It has been suggested that MJO is a coupled atmosphere-ocean phenomenon, where the atmosphere and the ocean work hand-in-hand to create the observed variability (e.g., Stephens et al. 2004). This conjecture is supported by simulations using traditional climate models where enhanced intraseasonal variability is typically observed when atmospheric model is coupled to the interactive ocean model (Flatau et al. 1997; Sperber et al. 1997).

A dramatically different conclusion was reached by Grabowski (2006; hereafter G2006), who discussed large-scale convective organization and MJO-like systems simulated by a numerical model applying the Cloud-Resolving Convection Parameterization (the superparameterization; Grabowski and Smolarkiewicz 1999; Grabowski 2001). The idealized modeling setup was an aquaplanet with a globally-uniform mean sea surface temperature (SST) of 30 deg C ("tropics everywhere"), with the size and rotation of Earth, in radiative-convective quasi-equilibrium. This idealized model setup was applied previously to investigate MJO-like systems by Grabowski (2003) and Grabowski and Moncrieff (2004). To simulate realistic changes of the ocean temperature, an interactive radiative transfer model was used together with a mixed-layer (or slab) ocean model with precribed (spatially and temporaly invariant) mixed layer depth. The depth was varied between 5 and 45 m in simulations with variable SST, and it was given a large value ($1.5 \times 10^4$ m) in simulations that mimic the constant-SST conditions.

G2006 discussed two sets of simulations. The first set started from $t = 0$, the large-scale atmosphere at rest, and with randomly distributed deep convection. The developing large-scale organization took the form of eastward-propagating convectively-coupled disturbances, similar to previous simulations, and argued in Grabowski and Moncrieff (2004) to result from the moisture-convection feedback mechanism. This feedback involves spatial fluctuations of deep convection causing perturbations of the free-tropospheric humidity, which in turn affect the spatial distribution of deep convection. Grabowski and Moncrieff (2004) argued that the feedback involves relatively long time scales (several days) and is key to tropical intraseasonal oscillations and MJO.

Evolution of the large-scale kinetic energy (LSKE) associated with developing convectively-coupled disturbances demonstrated that the interactive ocean *impeded* development of the large-scale organization. This was explained as the impact of the convection-SST feedback that partially negates the moisture-convection feedback. The convection-SST feedback is a process by which SST perturbations in the tropics are damped by deep convection. This is because deep convection tends to develop preferentially over warm SSTs, with the lower/higher SST regions experiencing enhanced/suppressed surface insolation and suppressed/enhanced surface heat fluxes. These processes all tend to reduce SST perturbations on time scales comparable to the moisture-convection feedback. The fact that the convection-SST feedback opposes the moisture-convection feedback explains why LSKE increases faster when SST is constant compared to when it is allowed to vary.

The coupled atmosphere-ocean system copes with the adverse impact of the convection-SST feedback by allowing coupled perturbations to propagate. G2006 refers to this process as the "cat-and-mouse" mechanism. In G2006's simulations, the large-scale organization propagates toward the east with higher/lower SSTs located to the east/west of the maximum surface precipitation

* *Corresponding author address*: Dr. W. W. Grabowski, NCAR, PO Box 3000, Boulder, CO 80307; e-mail: grabow@ncar.ucar.edu.

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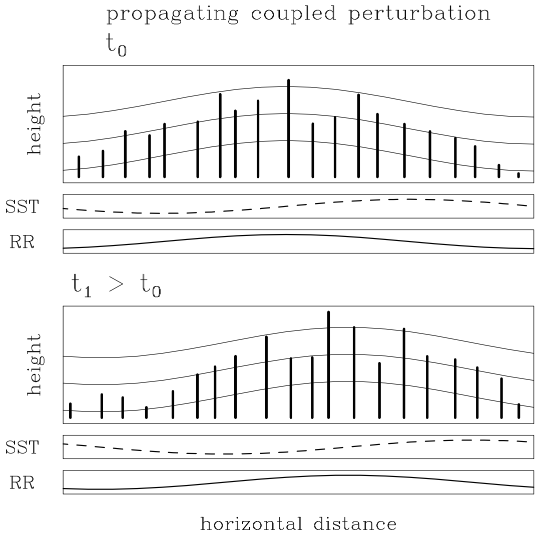


Figure 1: Schematic representation of the interaction between the positive moisture-convection feedback and the negative convection-SST feedback resulting in the eastward-propagating coupled atmosphere-ocean perturbation. Horizontal lines represent contours of water vapor mixing ratio and vertical thick lines depict convective clouds at different stages of their development. Distributions of the SST and the surface rainfall rate (marked as RR in the figure) are shown beneath. The upper and lower panels show perturbations at earlier and later times, respectively.

that coincides with the large-scale ascent. This is illustrated in Fig. 1. Such a pattern is well documented in observations of MJO on Earth (e.g., Stephens et al. 2004). For the optimum coupling between the atmosphere and the ocean, the propagation speed of coupled perturbations needs to be consistent with the intraseasonal time scales of the moisture-convection feedback in the atmosphere and the convection-SST feedback in the ocean, as well as with the horizontal scale of the large-scale organization. It follows that the pattern needs to propagate several thousands of kilometers in about 10 days, which is in the range of 5 to 10 m $s^{-1}$. This is the range characterizing both developing convectively-coupled perturbations and mature MJO-like systems in aquaplanet simulations.

As far as mature MJO-like coherences are concerned, G2006 concluded that the interactive SST has virtually no effect on their strength. This implies that the upper ocean merely responds to the atmospheric forcing with a minimal feedback on atmospheric processes. This conclusion contradicts speculations that the MJO is a coupled mode of climate variability. It also contradicts most studies using traditional climate models, which typically show enhanced intraseasonal signal when coupled to the interactive ocean.

The key question then is why traditional climate models demonstrate a drastically different impact of the atmosphere-ocean coupling on the strength of intraseasonal oscillations. Grabowski (2003) argued that a plausible explanation for the low intraseasonal variability in the tropics, simulated by traditional climate models, results from the lack of sensitivity of traditional convective parameterizations to the free-tropospheric humidity, as documented in Derbyshire et al. (2004). Naturally, the moisture-convection feedback can operate only if a convective scheme employed is sensitive to environmental humidity. (See Grabowski and Moncrieff 2004 for a detailed discussion).

In contrast to the moisture-convection feedback, the convection-SST feedback is relatively easy to capture using traditional convective parameterizations. This is because the enhanced/suppressed surface insolation in regions of suppressed/enhanced convection, the key element of this feedback, should operate even when simple convective and cloud schemes are applied. It follows that a plausible explanation of the impact of the atmosphere-ocean coupling on the intraseasonal oscillations in traditional climate models may stem from *the weakness of the moisture-convection feedback and the strength of the convection-SST feedback* in these models. With prescribed SSTs, in agreement with the discussion in Grabowski and Moncrieff (2004), the intraseasonal oscillations would be weak because of the suppression of the moisture-convection feedback. With interactive SSTs, on the other hand, the convection-SST feedback will likely induce propagating intraseasonal-time-scale coupled perturbations, in line with the “cat-and-mouse” mechanism. As a result, an enhancement of intraseasonal variability is to be expected compared to a prescribed-SST simulation.

The above conjecture is supported by additional simulations of developing disturbances but with suppressed moisture-convection feedback (cf. section 5c in Grabowski 2003; Grabowski and Moncrieff 2004). In these simulations, a relaxation term is added to the water vapor equation of the global model that relaxes the water vapor towards the value given locally by the globally-averaged relative humidity and the local temperature. The relaxation time scale is one day, as in Grabowski and Moncrieff (2004), and the relaxation is only applied for model levels above 2 km. Simulations with the depth of the oceanic mixed layer $D = 15$ m (variable SST) and $1.5 \times 10^4$ m (constant SST) are performed. The development of large-scale organization in these simulations is similar to other simulations described in G2006, but the large-scale perturbations are stronger in the variable SST simulation. This is illustrated in Fig. 2 which shows evolution of the LSKE near the equator. As the figure shows, LSKE is larger in the simulation with variable SST, with the mean value for days 21 to 30 in $D = 15$ m almost twice as large as in the constant-SST simulation. This implies about 40% stronger winds. Hence, stronger intraseasonal oscillations are expected in a coupled model when the moisture-convection feedback is suppressed compared to the model with constant SSTs.

In summary, the impact of the atmosphere-ocean coupling on intraseasonal oscillations and MJO in traditional climate models is argued to be consistent with the suppression of the moisture-convection feedback in those models (because of the use of convective schemes that are not sensitive to the free-tropospheric humidity) and the presence of the convection-SST feedback, with the latter supporting propagating coupled atmosphere-ocean perturbations (the "cat-and-mouse" mechanism) characterized by intraseasonal time scales.

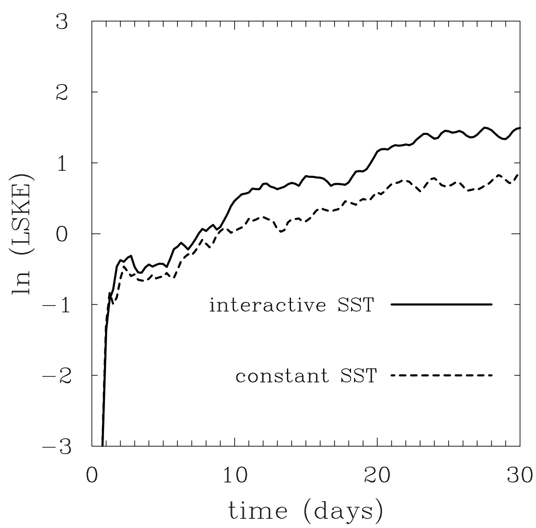


Figure 2: Evolution of the tropospheric large-scale kinetic energy (LSKE) near the equator in simulations with moisture relaxation which suppresses the moisture-convection feedback using $D = 15$ m (interactive SST) and $D = 1.5 \times 10^4$ m (constant SST).

## REFERENCES


Derbyshire, S. H., I. Beau, P. Bechtold, J. Y. Grandpeix, J. M. Piriou, J. L. Redelsperger, and P. Soares, 2004: Sensitivity of moist convection to environmental humidity. *Quart. J. Roy. Met. Soc.*, **130**, 3055-3079.

Flatau, M., P. J. Flatau, P. Phoebus, and P. P. Niiler, 1997: The feedback between equatorial convection and local radiative and evaporative processes: The implications for intraseasonal oscillations. *J. Atmos. Sci.*, **54**, 2373-2386.

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

Grabowski, W. W., 2003: MJO-like coherent structures: Sensitivity simulations using the Cloud-Resolving Convection Parameterization (CRCP). *J. Atmos. Sci.*, **60**, 847-864.

Grabowski, W. W., 2006 (G2006): Impact of explicit atmosphere-ocean coupling on MJO-like coherent structures in idealized aquaplanet simulations. *J. Atmos. Sci.* (in press).

Grabowski, W. W., and M. W. Moncrieff, 2004: Moisture-convection feedback in the tropics. *Quart. J. Roy. Met. Soc.*, **130**, 3081-3104.

Grabowski, W. W., and P. K. Smolarkiewicz, 1999: CRCP: A Cloud Resolving Convection Parameterization for modeling the tropical convecting atmosphere. *Physica D*, **133**, 171–178.

Lin, J.-L., and Coauthors, 2005: Tropical intraseasonal variability in 14 IPCC AR4 climate models. Part I: Convective signals. *J. Climate* (in press).

Slingo, J., and Coauthors, 1996: Intraseasonal oscillations in 15 atmospheric general circulation models: Results from an AMIP diagnostic subproject. *Climate Dyn.*, **12**, 325-357.

Sperber, K. R., J. M. Slingo, P. M. Innes, and W. K.-M. Lau, 1997: On the maintenance and initiation of the intraseasonal oscillation in the NCEP/NCAR reanalysis and in the GLA and UKMO AMIP simulations. *Clim. Dyn.*, **13**, 769-795.

Stephens, G. L., P. J. Webster, R. H. Johnson, R. Engelen, and T. L'Ecuyer, 2004: Observational evidence for the mutual regulation of the tropical hydrological cycle and tropical sea surface temperatures. *J. Climate*, **17**, 2213-2224.

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