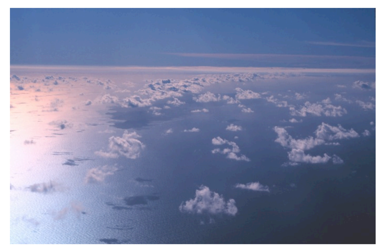
Assessment of Tropical Intraseasonal Variability in Versions 2 & 3 of the GFDL Atmosphere Model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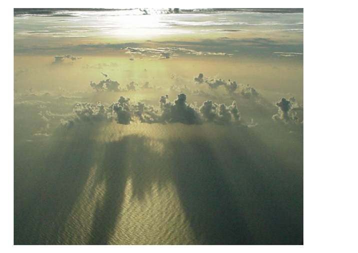
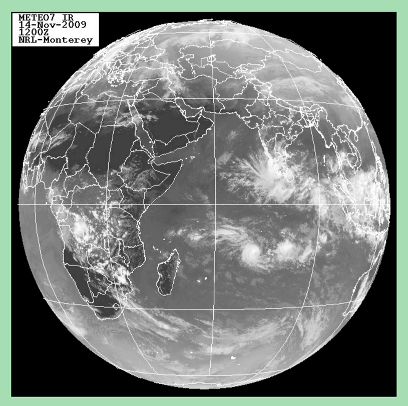


1. Background & Motivation

Versions 2 and 3 of the Geophysical Fluid Dynamics Laboratory (GFDL) Atmosphere Model (AM) will be participating models in the upcoming IPCC AR5. Both AM versions are tuned to produce a realistic mean state and ENSO variability, as is customary for many global climate models (GCMs). However, this tuning degrades tropical subseasonal features such as convectively-coupled Kelvin waves and the Madden-Julian Oscillation (MJO)[1,2].

Relative to AM2, AM3 uses a new treatment of deep and shallow cumulus convection and mesoscale cloud effects[1]. The AM3 cumulus parameterization is a mass flux-based scheme but also, unlike many other general circulation models including AM2, incorporates convective-scale vertical velocities that play a key role in cumulus microphysical processes. The AM3 convection scheme allows water vapor and condensate generated within deep cumulus plumes to be transported directly into adjacent, dynamically active mesoscale cloud systems, which can strongly impact larger-scale moisture and radiation fields. Some studies have shown that mesoscale anvil clouds and their associated "top-heavy" heating structure improve the depiction of the MJO in GCMs[3]; other studies assert that the "bottom-heavy" heating signature of shallow cumuli improves intraseasonal convective disturbances[4]. In this study, we investigate the cloud and precipitation processes that contribute to the changes seen in a series of AM3 simulations with differing convective parameterizations.

2. Key Questions



This study seeks to address the following questions:

(1) What are the space-time and spectral characteristics of intraseasonal variability in the control AM3, and how does this compare to the control and modified versions of AM2?

(2) Can we tune the AM3 to produce more realistic intraseasonal variability by making convection more inhibited (as is typical of many GCMs)? If so, does the tuning introduce larger mean state biases (again, as in the case of many GCMs)?

(3) Following #2, what mechanisms may contribute to the changes seen in the simulated intraseasonal disturbances of the modified AM3?

3. Model Experiment Settings

Table 1. Both versions of AM2 use RAS for all convective plumes, but in AM2-TOK the increased minimum entrainment parameter suppresses the deepest convective plumes. In AM2 and AM3-CTL, the closure assumption involves cumulus heating that relaxes CAPE to a specified value over a selected time scale. In modified versions of AM3, the closure balances CAPE changes due to convection with those due to large-scale processes above the PBL. The light gray-shaded parameters are empirical-based fractions of cumulus updraft (non-precipitated) condensate that evaporates within cumulus downdrafts, directly into the environment, or is entrained into an adjacent mesoscale cloud.

	AM2–CTL	AM2–TOK	AM3–CTL	AM3–A	AM3–B	AM3–C
Deep conv. scheme	RAS[a]	RAS[a]	Donner[b]	Donner[b]	Donner[b]	Donner[b]
Trigger/closure	tok = 0.025[c] CAPE relaxation	tok = 0.1[c] CAPE relaxation	CAPE relaxation[d]	PBL vert. velocity; Zhang (2002, JGR)	PBL vert. velocity; Zhang (2002, JGR)	PBL vert. velocity; Zhang (2002, JGR)
Dilute CAPE?	no	no	no	no	no	yes[e]
Evap. in downdrafts	0	0	0	0	0.25	0.25
Evap. in environment	1	1	0	0	0.13	0.13
Entrained into meso	N/A	N/A	1	1	0.62	0.62

[a] "Relaxed Arakawa-Schubert scheme" of Moorthi and Suarez (1991, MWR); [b] Donner (1993, JAS), Donner et al. (2001, JC), and Wilcox and Donner (2007, JC); [c] Tokioka (1988, JMSJ); [d] Wilcox and Donner (2007, JC); [e] Entrainment coefficient $\mu = 0.0002\ m^{-1}$

4. Selected Results

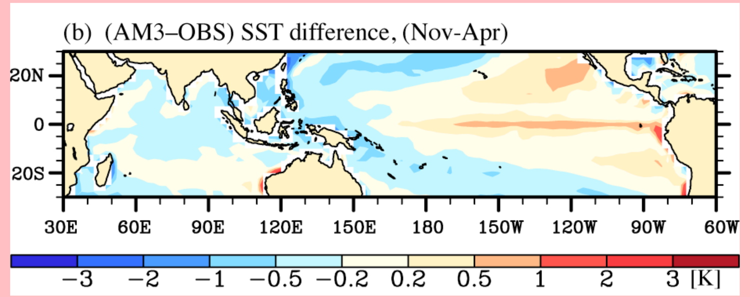


Figure 1 (l). Representative difference in Nov-Apr 10-year climatological SSTs show that prescribed SSTs for the AM2 and AM3 simulations (1980-2000 mean) had slightly stronger El Niño conditions compared to the 1999-2008 observation period.

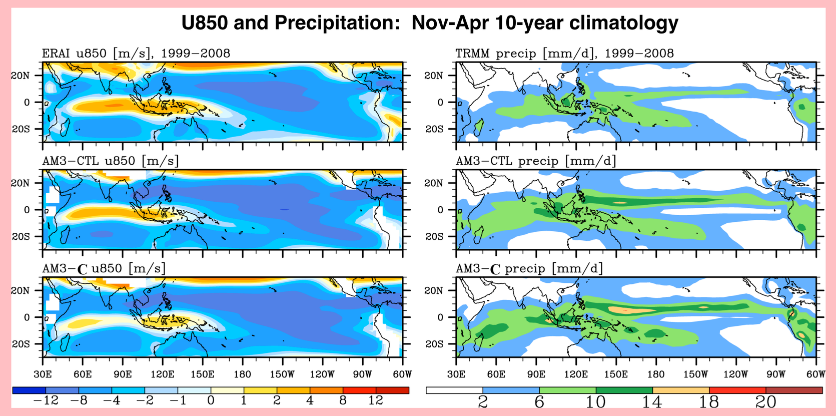


Figure 2 (r). Representative 10-year climatologies indicate that the "control" simulations (AM2-CTL not shown) had more realistic U850 and rainfall mean states. Overestimated rainfall in the West Pacific is a deficiency common to all GFDL AM runs examined, particularly AM2-TOK (not shown).

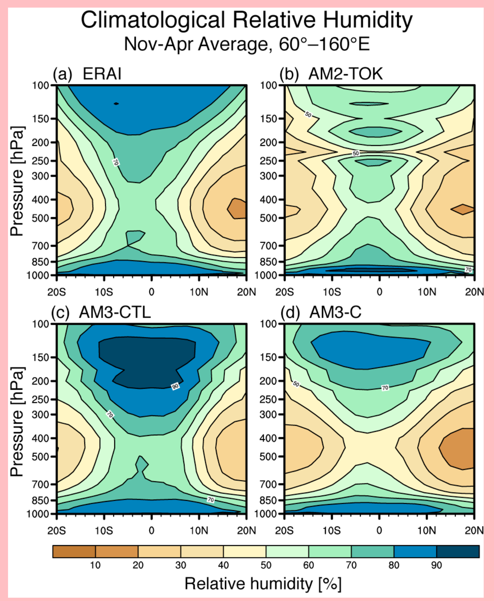


Figure 3 (above). Modified AM3 versions produce a cooler (not shown) and drier in the mean tropical troposphere, suggesting a strong suppression of deep convection.

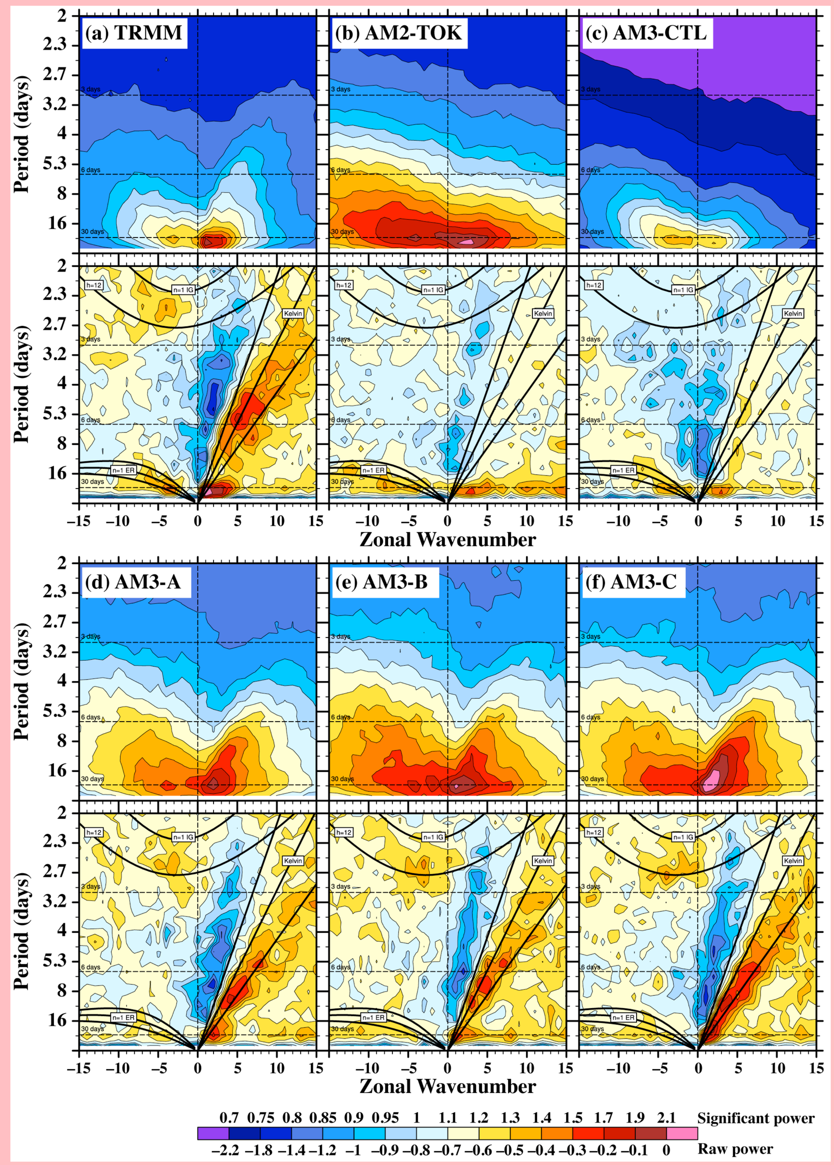
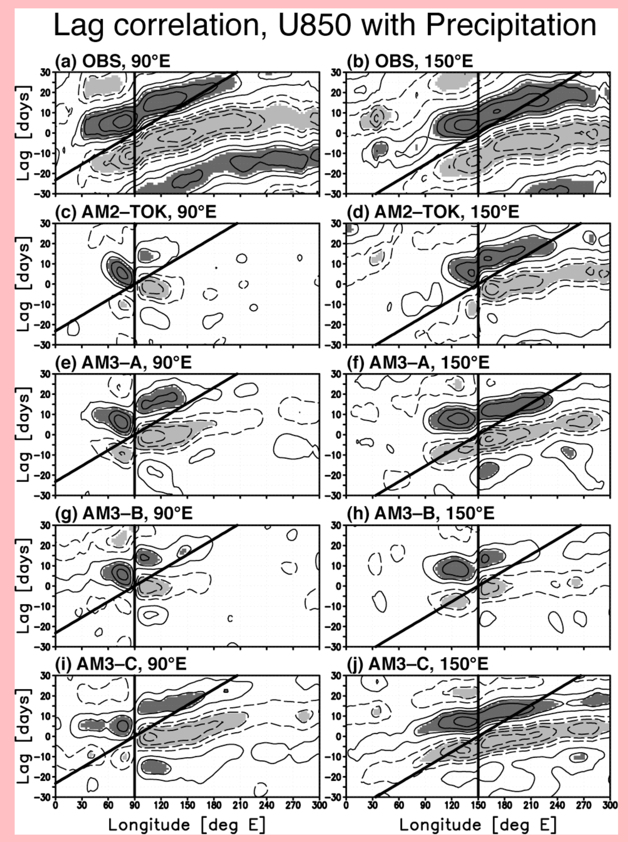


Figure 4 (r). Spectral diagrams show a shift to eastward-moving waves and more realistic Kelvin waves when a new closure and trigger are used in the AM3. Total low-frequency variability increases as well. With the dilute CAPE approximation (AM3–C; AM3–B has zero CAPE dilution), MJO and Kelvin waves are strengthened but their separation in spectral space becomes poorly defined.



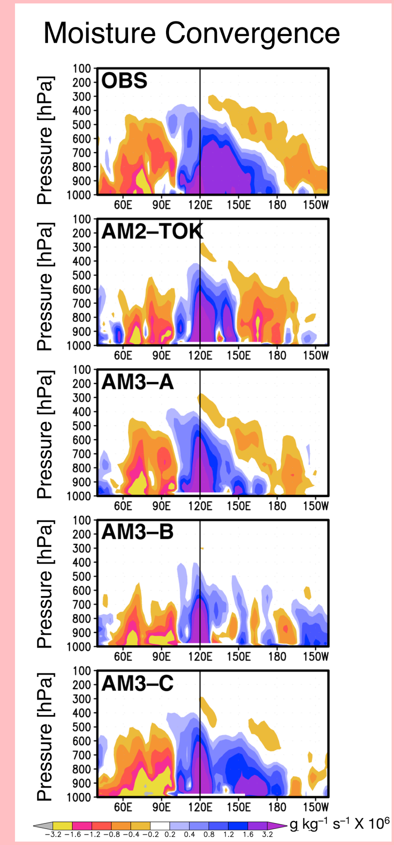
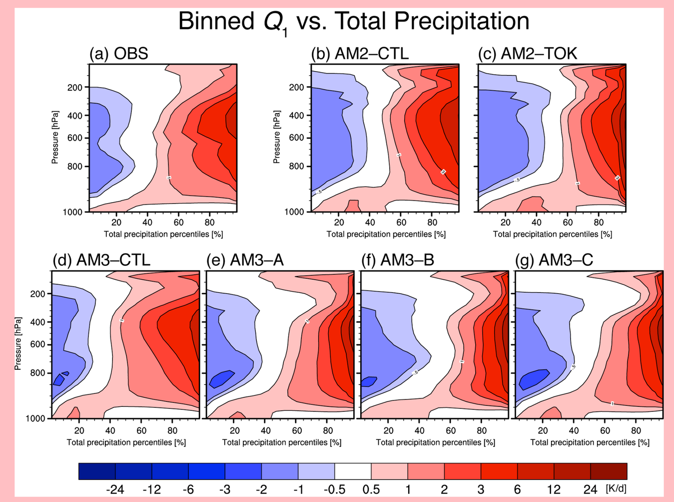


Figure 5 (far left). Lag correlations suggest that AM3–A and AM3–C produce a stronger and more organized coupling between convection and dynamics compared to AM3–B. Disturbances in the West Pacific move too quickly (~10 m s^{-1}) in AM3–A,B,C. AM2–TOK has a more realistic MJO in the West Pacific but not in the Indian Ocean.

Figure 6 (above right). Lag regressions of $-\nabla \bullet r\mathbf{v}_h$ (r is vapor mixing ratio) onto a 20-100-day filtered rainfall index at 120°E clearly indicate a more robust lower-tropospheric moisture convergence signal ahead of peak convection for AM3–A and C compared to AM3–B. Moisture convergence promotes convective development and is an important component of realistic MJO simulations[5].



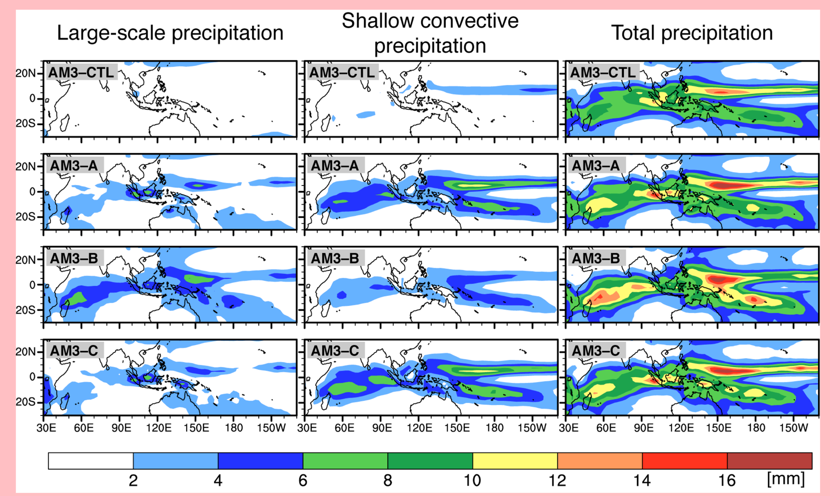


Figure 7 (above left). All-season binned (based on total rainfall) convective heating Q_1 shows a shift from "top-heavy" to "bottom-heavy" heating between the control and modified AM3, indicating a suppression of cumulonimbi and an enhancement of shallow cumuli.

Figure 8 (above right). Mean Nov-Apr rainfall confirms that shallow convective processes are more active in AM3–A and C than in AM3–B. The larger stratiform rain in AM3–B is likely associated with a weaker deep convective suppression in that model. Thus, stronger organization of intraseasonal convective disturbances is linked to increased shallow heating and low-level moisture convergence in AM3 versions in which deep convection is artificially suppressed. This result is consistent with previous GCM studies[4].

5. Summary

Our analyses indicate that:

(1) Both "control" versions of AM2 and AM3 simulate the mean state relatively well (Fig. 2) but produce very weak eastward-propagating intraseasonal disturbances (Fig. 4).

(2) In general, our modifications to the convective trigger and closure in AM3 suppressed deep convection and degraded the mean state but also increased tropical intraseasonal variability (notably eastward-moving waves) in the AM3 (Figs. 3-5). Use of the dilute CAPE approximation produces more robust intraseasonal disturbances that have characteristics similar to convectively coupled Kelvin waves[6].

(3) In the modified AM3 simulations with suppressed deep convection, an improved organization of intraseasonal convective disturbances is associated with an enhancement of shallow heating rather than a greater contribution from stratiform processes.