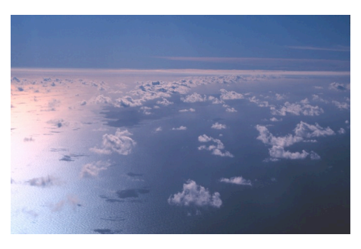
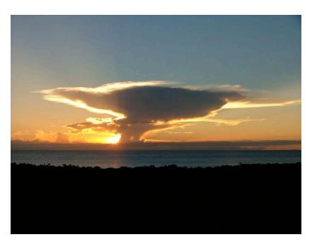
Assessment of Tropical Intraseasonal Variability in Versions 2 & 3 of the GFDL Atmosphere Model





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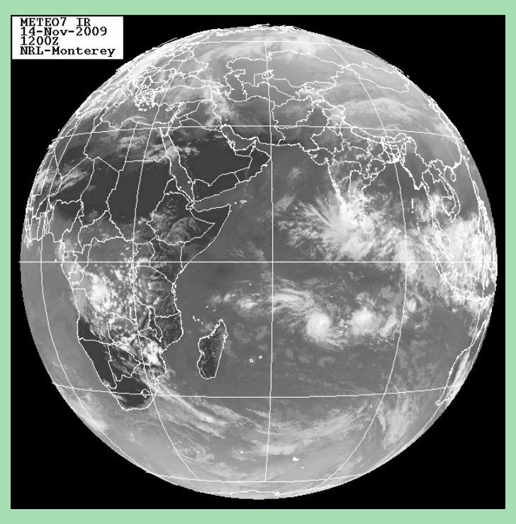
1. Background & Motivation

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 comes at the cost of tropical subseasonal features such as convectively-coupled Kelvin waves and the Madden-Julian Oscillation (MJO)[1,2].

Relative to AM2, AM3 utilizes 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. Mesoscale anvil clouds and their associated heating structure play critical roles in the accurate depiction of the MJO in some GCMs[3].

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, can we configure the AM3 such that we produce more realistic intraseasonal variability while simultaneously maintaining small mean state biases?

3. Model Settings & Preliminary Results

	AM2-climsst	AM2-climssttok1	AM3-CTL	AM3-E	AM3-I3	AM3-N
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 $\mu = 0.0002\ \mathrm{m^{-1}}$

Table 1. Both versions of the AM2 use RAS for all convective plumes, but in AM2-climssttok1 the increased minimum entrainment parameter makes is more difficult for very deep convective plumes to form. In AM2 and AM3-CTL, the closure assumption involves cumulus heating that relaxes CAPE to a specified value over a selected time scale. In the 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 represent 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.

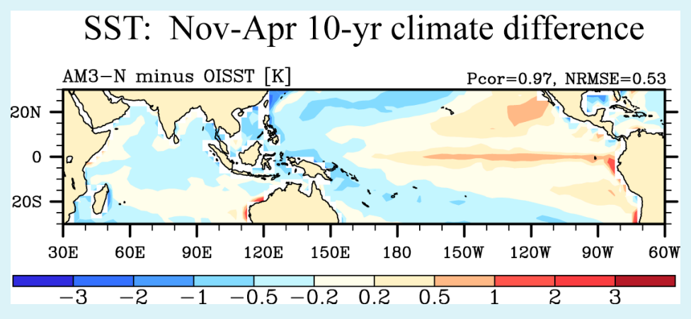


Figure 1 (left). Representative difference in Nov-Apr 10-year climatological SSTs that the prescribed SSTs for the AM2 and AM3 simulations (1980-2000 mean) had slightly stronger El Niño conditions compared to the 1999-2008 observation period.

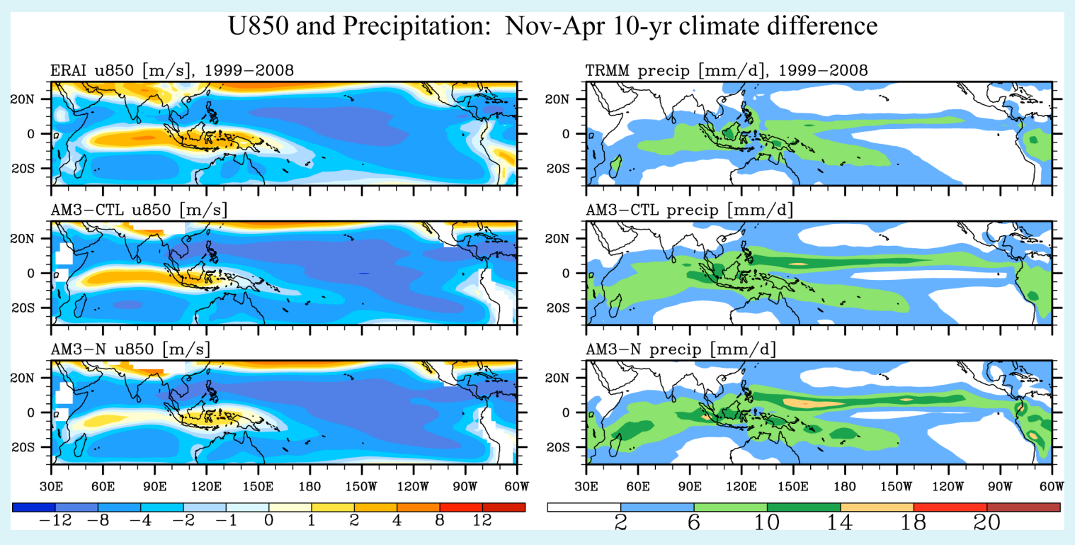


Figure 2 (left). Representative 10-year climatologies indicate that the "control" simulations (AM2-climsst not shown) had more realistic mean states for 850 hPa zonal winds and precipitation. Overestimated annual rainfall in the tropical West Pacific is a deficiency common to all GFDL AM runs examined, particularly AM2-climssttok1 (not shown).

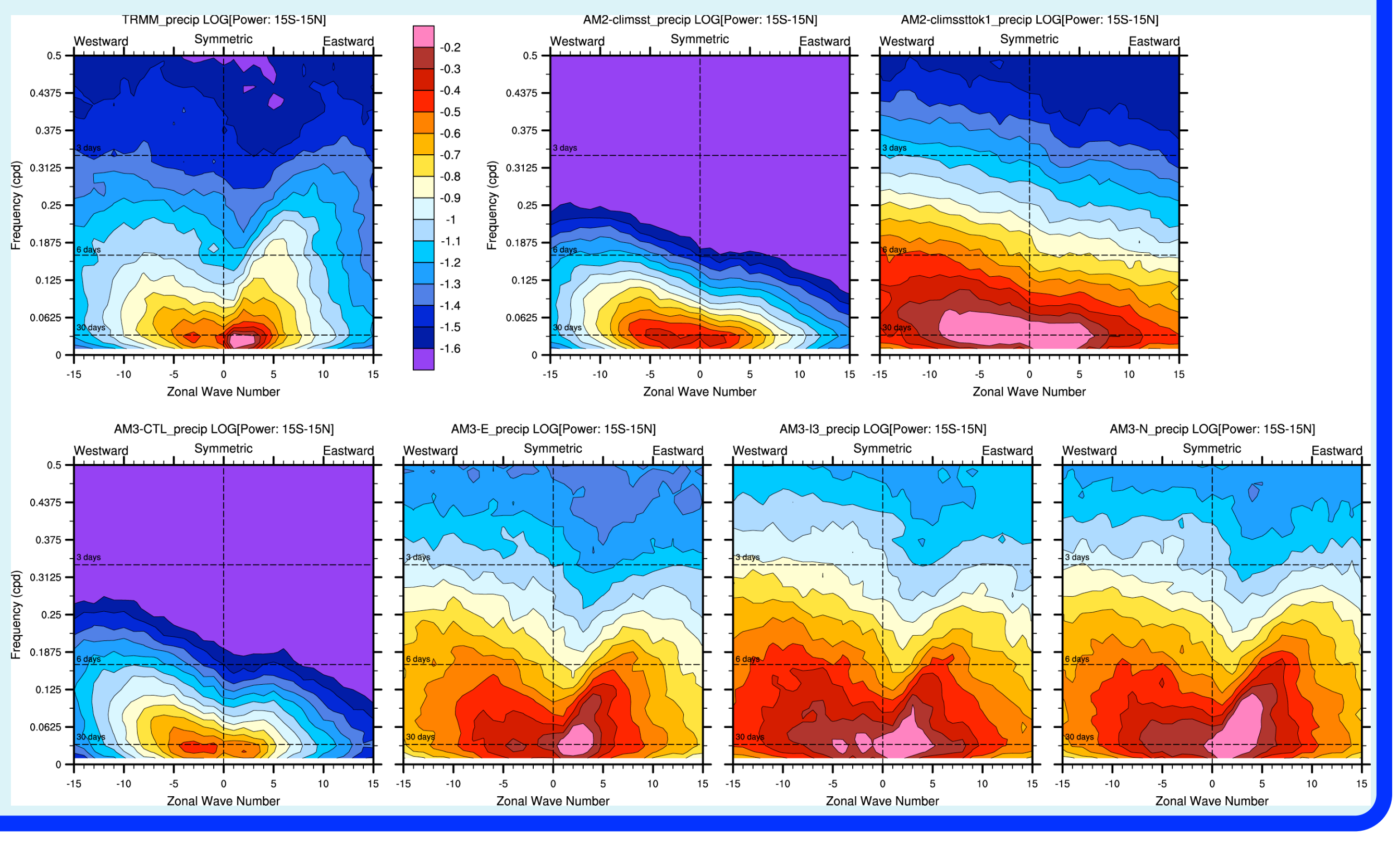


Figure 3 (right). Zonal wavenumber-frequency spectra show a dominance of westward intraseasonal rainfall disturbances in the control runs. In the modified AM2 (top right), the pattern of variability increases uniformly but Kelvin waves remain weak. In modified AM3, variability is overestimated but a clear Kelvin signal emerges.

4. Selected Results

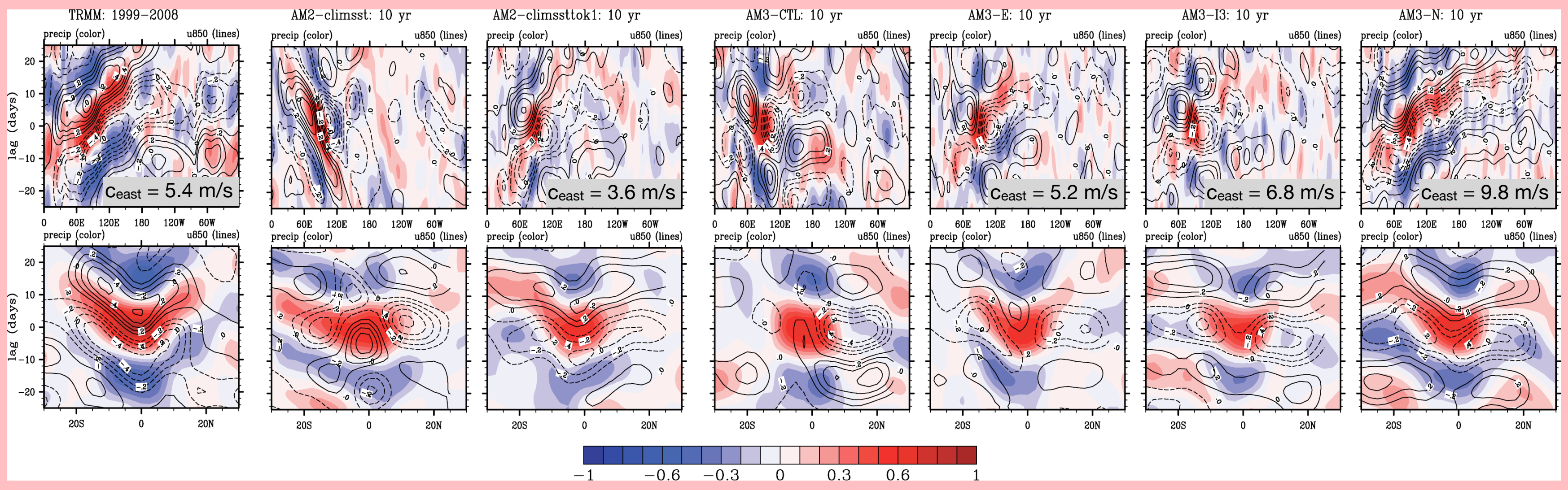
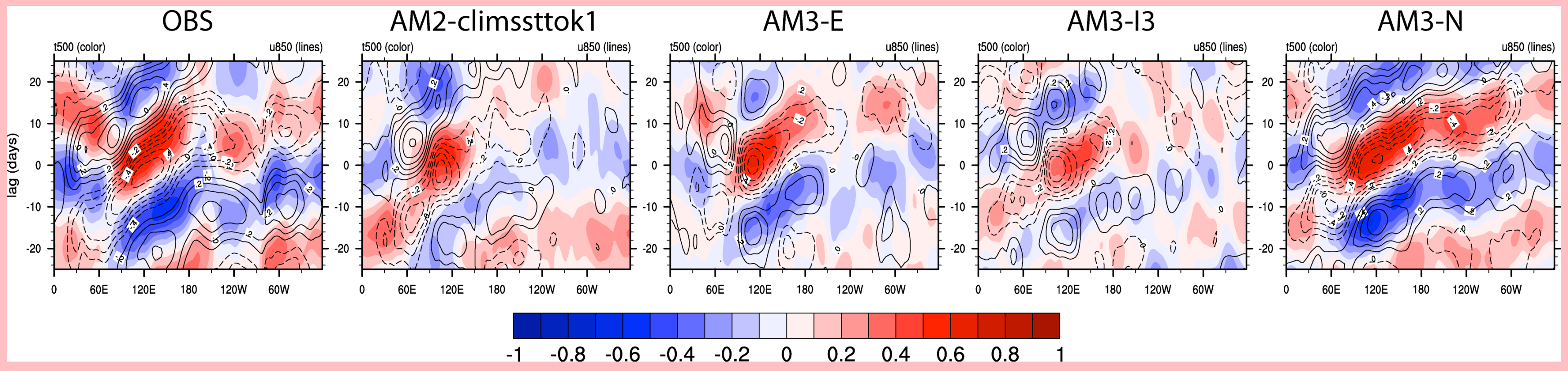


Figure 4 (above). Lag correlations between East Indian Ocean rainfall (index) and U850. Use of a minimum entrainment parameter[2,4] generates eastward intraseasonal features in AM2. Versions of the Donner convection scheme with modified deep convective trigger[1], particularly with non-zero entrainment for CAPE (AM3-N), strengthen and organize eastward intraseasonal disturbances. **Figure 5 (below).** Lag correlations between T500 and U850 (same rain index as above) suggest these disturbances have some characteristics resembling convectively-coupled Kelvin waves[5].



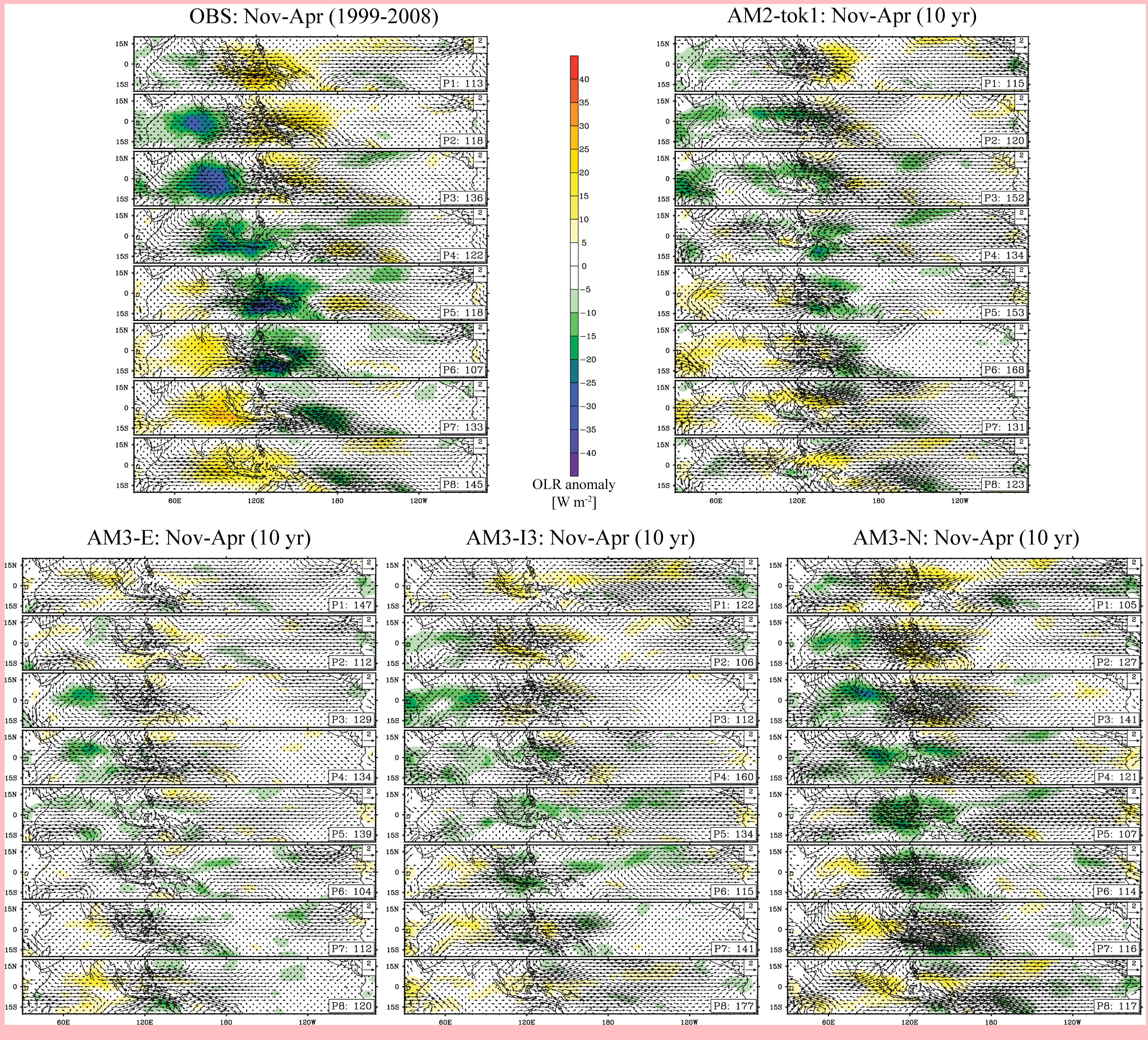


Figure 6. Phase composites[6] of OLR and 850 hPa wind anomalies indicate the most realistic and robust eastward intraseasonal disturbances are obtained with the "Donner-full" scheme that includes dilute CAPE calculations (AM3-N). AM3-N also has the most realistic OLR-U850-U200 combined EOF structures (not shown). In all versions of the GFDL AM analyzed, horizontal wind structure is qualitatively similar to observations but convective variability—especially convection progression along the equator in the West Pacific—is poorly simulated.

5. Summary

Our analyses indicate that:

(1) Both the "control" versions of AM2 and AM3 simulate the mean state relatively well (Fig. 2). However, these two versions produce eastward-propagating intraseasonal disturbances that are much too weak (Fig. 3).

(2) In general, modifications to the convective trigger and closure assumption and the use of a more sophisticated convection scheme increase tropical intraseasonal variability (particularly for eastward-moving features) in the AM3 (Figs. 3 and 4).

(3) Requiring non-zero entrainment for CAPE calculations produces more organized intraseasonal variability in the AM3. This variability exhibits characteristics common to convectively-coupled Kelvin waves (Figs. 3-6). And, like many other GCMs, mean state biases become larger when the AM is tuned to produce stronger intraseasonal variability.

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