Diurnal Timescale Feedbacks in the Tropical Cumulus Regime

James Ruppert
Max Planck Institute for Meteorology, Hamburg, Germany

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MJO Convective Onset in the Indian Ocean

- Madden–Julian oscillation (MJO) “onset”
- Dynamics of the MJO (DYNAMO; 2011–12)

Ruppert and Johnson (2015, JAS)
MJO Convective Onset in the Indian Ocean

Afternoon cloud deepening
Vertical motion
Cloud-top frequency
Moisture (q')
Composite Diurnal Cycle in DYNAMO Shallow Cloud Regimes
MOIST
DRY
mm s$^{-1}$
10$^{-1}$ g kg$^{-1}$
%

Diurnal Composites (repeated 3x)

Cloud-top frequency from S-PolKa
Study Objective

Does the diurnal cycle of moist convection rectify* onto longer timescales?

- Simulate the cumulus diurnal cycle in a suppressed regime, isolate nonlinear (daily-mean) forcing

*Rectification: intraseasonal upper ocean warming (Webster et al. 1996; Bernie et al. 2005; Shinoda 2005)
Model Framework

• CM1 (Cloud Model 1; Bryan and Fritsch 2002) initialized from mean suppressed phase sounding

• Physics:
  – Morrison 2-moment microphysics
  – Deardorff TKE
  – Goddard LW, SW radiation
  – Surface:
    • Prescribed SST, diurnal cycle (2°C range)
    • Fixed exchange coefficients

• Model Domain:
  – $O(100 \text{ km})$ in $x,y$, 22 km in $z$
  – $\Delta x,y = 200 \text{ m}$, $50 \text{ m} < \Delta z < 350 \text{ m}$
Model Framework

• Large scale must be parameterized: “Weak Temperature Gradient” (WTG) balance:
  – Diabatic sources offset by large-scale adiabatic motion \( \rightarrow \mathbf{w}_{wtg} \)
  – \( \mathbf{w}_{wtg} \) diagnosed during runtime, used to advect \( \boldsymbol{\theta} \) and \( q \)
  – Spectral WTG relaxation: \( \theta \)-anomalies endure as an inverse function of depth (Herman and Raymond 2014)

• Diurnal cycle in \( \mathbf{w}_{wtg} \)
Experiment Rationale

- Stretch the diurnal cycle to scale nonlinearity:
  - **NODC**: diurnal forcing (shortwave, SST) fixed to daily means
  - **12H**: diurnal cycle scaled to 12 h
  - **24H**: … to 24 h
  - **48H**: … to 48 h
Day-to-day Evolution

Drying wanes, moistening takes over

Moistening accelerated for longer diurnal period \(\rightarrow\) indicative of diurnal timescale feedback
Mean Differences

Greater convective-cloud activity

Reduced large-scale subsidence

Vertical eddy buoyancy flux

48H – NODC

NODC Differences from NODC

Greater convective-cloud activity

Reduced large-scale subsidence
The Diurnal Cycle Accelerates Onset

**WITHOUT DIURNAL CYCLE**

**WITH DIURNAL CYCLE**

**Initial State**

**Final State**

Day 1

Day 7
Diurnal Cycle of $\theta_v$

- PBL warmest in the afternoon
- Aloft, signal shifted earlier due to $w_{wtg}$

Revelle soundings
- Much greater $\theta_v^*$ amplitude
Cloud-layer Humidity, Lapse Rate, and Convection

Moisture index $[q^*]$  
Stability index $\Delta \theta^*_v$  
Vertical eddy buoyancy flux $[F_\theta]$
Cloud-layer Humidity, Lapse Rate, and Convection

SST-driven peak
Cloud-layer Humidity, Lapse Rate, and Convection
Diurnal forcing agents—moisture and stability—amplify with diurnal period

Cloud-layer Humidity, Lapse Rate, and Convection
The Diurnal Cycle Accelerates Onset
Conclusions

• Co-varying diurnal cycles of lapse rate and humidity increase daily-mean convective heating (a nonlinear timescale feedback)

• This timescale feedback accelerates the onset of deep convection, assuming WTG balance
Open Questions

• A more complete treatment of large-scale dynamical coupling is required
  – Large-scale $w$ is crudely represented here $\rightarrow$ substantial amplitude bias in $\theta, w_{wg}$

• Do / how do diurnal timescale feedbacks manifest in other climate regimes?
  – Over land, where the diurnal heating cycle is much stronger
  – Over the Maritime Continent (land–sea contrast)
References


