An Assessment of the Warm-Season Diurnal Cycle of Convection over the Great Plains in Global Climate Models

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Overview

- Diurnal Cycle over the Great Plains – Observation and Model Intercomparisons
  - Test of Horizontal Resolutions
  - Test of Convection Trigger Functions
- Cloud-Resolving Model (CRM) Simulation
  - ARM SGP Experiments
  - Idealized Diurnal Cycle Experiments
Phase (local time) of Maximum Precipitation

Diurnal Phase (LST)

OBS (HPD)  OBS (CMORPH)

NASA (NSIPP-2)  GFDL (AM2)  NCEP (GFS)
NARR Reanalysis vs NCEP GFS

Diurnal cycle of precipitation and 925mb winds (anomaly)
NARR Reanalysis vs NASA GCM
Diurnal cycle of precipitation and 925mb winds (anomaly)
What cause the model dependency?

<table>
<thead>
<tr>
<th>Model</th>
<th>Version</th>
<th>Resolution</th>
<th>Cumulus Convection</th>
<th>Shallow Convection</th>
<th>Grid-scale condensation</th>
<th>PBL</th>
<th>Land surface</th>
</tr>
</thead>
</table>

The convection scheme is primarily responsible:

- Closure assumptions are all based on Arakawa and Schubert (1974)
- Differences in the details of the convection scheme seem to be critical in introducing different behaviors among the models, i.e., Convection trigger /inhibition functions
Diurnal Cycle Modeling

Too-early development of deep convection over land indicates too-strong coupling of deep convection with near-surface boundary layer heating.

1) Coupling with the boundary layer (the choice of the convection starting level)

Diurnal variation of moist static energy (from ARM observations at SGP)

(Unit: kJ/kg)
2) Convection Adjustment (Relaxation) Timescale

\[ M_B \sim -\frac{dA}{dt} = \frac{(A - A_c)}{\tau} \]

- \( M_B \): mass flux at cloud base
- \( A \): cloud work function (~ CAPE)
- \( A_c \): critical cloud work function
- \( \tau \): relaxation time scale

Rather than “quasi-equilibrium” achieved at each time step, only the fraction of the cumulus mass flux relaxes the state toward equilibrium (RAS), assuming certain time-scale.

Current: 30 minutes for all cloud types

Sensitivity runs: vertically increasing function from 2 - 12 hrs
Phase of Diurnal Cycle of Precipitation
(NASA Model Exp)

CWF with parcel lifting with PBL-mean property + Increase of relaxation timescale
Role of Convection Trigger Functions (NCEP GFS)

Model simulation varies substantially by implemented convection trigger function, even in the same convection scheme (a test from the NCEP GFS model).

Lee et al. (2008, J. Geophys. Res.)
3) Convective Trigger/inhibition in NCEP GFS at Great Plains

(Equivalent to the “Lifting depth trigger” in meso models)

Daytime:
- Bigger CWF but no convection trigger

Nighttime:
- Smaller CWF but trigger

\[ h^* \leq 150 \text{ hPa} \]
Buoyancy ($h_{\text{max}} - h^*$)
GFS Simulations

“LFC is higher in Great Plains”
• The GCMs exhibit substantial biases in the diurnal cycle of warm season precipitation.

• Increased horizontal resolution has a limited impact - suggesting the importance of model physics, especially the convection scheme.

• The diurnal cycle of precipitation, particularly the phase, is quite sensitive to the very detail of convective parameterizations (e.g., the convection starting level, convective trigger functions, and relaxation time scale of CAPE).

• The “lifting depth trigger” in the NCEP GFS tends to produce a realistic nocturnal rainfall over the Great Plains.
Cloud-Resolving Model (CRM) Simulation

- GCE (Goddard Cumulus Ensemble) model by W.-K. Tao (1993)
- Non-hydrostatic
- 2-D (x-z) Experiments over 130 km domain in 1-km resolution
- Vertical resolution: about 20km, stretched grid (43 grids)
- Time step: 6 seconds

Diurnal Variation of the large-scale forcing (advection tendency) and the surface flux – IOP averages (IOP95+IOP97, 46 days)
**GCE Idealized Forcing Experiments**

### Forcings

- **EXP1**: Diurnally-varying large-scale advection and surface flux
- **EXP2**: Diurnally-varying surface flux with no large-scale advection
- **EXP3**: Diurnally-varying large-scale advectons with no surface flux
- **EXP4**: Constant large-scale advection and surface flux

100-day integrations with the same diurnal cycle of large-scale forcing and surface fluxes
Life Cycle of Storms (selected case)
Impact of cloud-longwave radiation interaction

• The cloud optical thickness is assumed zero in the longwave radiation calculation.
• The nocturnal peak in EXP3 is gradually flattened without cloud-longwave feedback.
Summary 2 (from CRM Experiments)

• Two different forcings for diurnal convection in GP:
  o Daytime boundary layer heating/moistening vs. the nighttime large-scale advection
  o Cloud-longwave radiation feedback in the nighttime

• Free-atmospheric destabilization mechanisms resolved in the CRM simulation must be adequately parameterized in current GCMs, many of which are overly sensitive to the parameterized boundary layer heating.