SENSITIVITY OF SIMULATED NOCTURNAL CONVECTIVE SYSTEMS TO GRAUPEL SEDIMENTATION

Frederick Iat-Hin Tam, Ming-Jen Yang

National Taiwan University
Weaker low-level lifting in nocturnal environments

Circulations for daytime storms -> driven from lower levels
Weaker low-level lifting in nocturnal environments

What contributes to the maintenance/strengthening of nocturnal MCS?
Our hypothesis

Circulations for nocturnal storms -> partially driven from mid-levels?
Target process: Graupel sedimentation

Updraft intensification: Mid-level latent heat release when smaller particles re-entrained into updrafts by RTF flow

Downdraft intensification: Stronger evaporation / sublimation cooling behind convective updrafts

Adapted from Siegel and van den Heever (2013)
Target case: PECAN IOP30

Increased system organization during northeast propagation during nocturnal hours
Scientific Questions

1. Could graupel sedimentation impact the system’s mid-level kinematics (i.e. updraft strength)?

2. If such impact exists, what is the physical mechanism behind it?
Microphysical Sensitivity Experiments

<table>
<thead>
<tr>
<th>Experiment Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FULL</td>
<td>Baseline experiment</td>
</tr>
<tr>
<td>GNSS</td>
<td>Graupel size sorting disabled</td>
</tr>
<tr>
<td>RNSS</td>
<td>Rain size sorting disabled</td>
</tr>
<tr>
<td>GRNSS</td>
<td>Both size sorting disabled</td>
</tr>
</tbody>
</table>

WRF V3.9 | 27km-9km-3km horizontal resolution | 41 vertical layers | K-F cumulus scheme | YSU boundary layer scheme | NSSL two-moment microphysics
Updraft Statistics for Simulated Systems

- More dramatic updraft weakening from developing to mature phase for the GNSS
- Mature phase updraft strength for the RNSS was similar to the FULL
Criticalness of updrafts above the melting level

![Graph showing updraft intensity and height](image)

- **Introduction**
- **Observations**
- **Methodology**
- **WRF simulations**
- **Concluding Remarks**

**CFAD for strong updrafts**

- Frequency = 0.135 contours

- Approximate height with $T=0^\circ C$
Line-averaged cross section analysis

- **FULL**: 04:00 UTC
- **RNSS**: 05:00 UTC
- **GNSS**: 04:00 UTC

- **w > 1 ms\(^{-1}\)** contours
- **Line-averaged system-relative wind speed**
- **Wind vectors**

Reflectivity (dBZ)

AGL Height (km)

Distance relative to Convective Edge (km)
Line-averaged cross section analysis

- Line-averaged Latent Heating Rate
- Line-averaged Latent Cooling Rate
- Reflectivity=25 dBZ contours
Line-averaged cross section analysis

**FULL-GNSS**

**Kernel Density**

- Joint distribution of Graupel Number Concentration and Air Temperature
- Frequency = 0.025 contours

**FULL-RNSS**

**Kernel Density**

- Joint distribution of Graupel Number Concentration and Air Temperature
- Frequency = 0.025 contours
Line-averaged cross section analysis

- Vapor Increase Tendency in 1 hour (g kg\(^{-1}\) hr\(^{-1}\))
- Latent Cooling Rate (Plotted every 0.3 K [5 mins]\(^{-1}\))
- Melting Level Height
Conclusions

- Identified a sensitivity between mid-level circulation strength and graupel sedimentation
- Overall updraft strength impacted more by the mid-level processes than low-level ones
- For **FULL (RNSS)**, stronger and more expanded RTF flow favors mid-level updraft intensification through riming
- Graupel melting crucial in intensifying the latent cooling
- Role of evaporation and sublimation might be less important
- Stronger thermodynamic gradient for the **FULL (RNSS)** could enhance and expand the RTF flow
Acknowledgement

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- Many thanks to the PECAN science team and students in collecting the valuable data.
Pressure perturbation analysis

\[ \frac{1}{\rho_0} \nabla^2 P' = - \nabla \cdot (V \cdot \nabla V) + \frac{\partial B}{\partial z} \]

\[ \frac{1}{\rho_0} \nabla^2 P'_{\text{dynamic}} = - \nabla \cdot (V \cdot \nabla V) \]

\[ \frac{1}{\rho_0} \nabla^2 P'_{\text{buoyancy}} = \frac{\partial B}{\partial z} \]
Simulation results - IV. Buoyancy pressure perturbation

- Negative $P_B'$ (low pressure anomaly) located immediately behind the updraft axis in FULL while negative $P_B'$ weakened and shift rearward in GNSS.
Simulation results - IV. Rear-to-front pressure gradient force

- Negative $P_B'$ (low pressure anomaly) located immediately behind the updraft axis in FULL while negative $P_B'$ weakened and shift rearward in GNSS.
Microphysical and environmental controls on nocturnal MCS maintenance

Rationale

Methodology

Results
1. Statistical analysis on kinematic properties
2. Structural and precipitation characteristics
3. Line-averaged Microphysical-kinematic properties: Generation of RIJs
4. Dynamical inference

Concluding Remarks

Filled: Buoyancy dynamic pressure perturbation (hPa);
Black dashed: Convective updraft axis

Filled: Buoyancy dynamic pressure perturbation (Pa);
Gray dashed: Convective updraft axis
Black dashed: Descending Inflow layer
Group I: On mixed-phase hydrometeor size-sorting (Disable -> $V_q = V_N$)

\[
V_N = \frac{\int_{0}^{\infty} \gamma c D^d n(D) dD}{\int_{0}^{\infty} n(D) dD}
\]

\[
V_q = \frac{\int_{0}^{\infty} \gamma c D^d m(D) n(D) dD}{\int_{0}^{\infty} m(D) n(D) dD}
\]

Number-concentration-weighted terminal velocity

Mixing-ratio-weighted terminal velocity

Group II: On assumed terminal velocity-diameter relationship

Group III: On dominant mixed phase type
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Size-sorting in our simulation

\[ D_{Vx} = \left( \frac{6 \rho_a q_x}{\pi \rho_x N_{Tx}} \right)^{\frac{1}{3}} \]

Filled: FULL line-averaged \( D_{Vg} \);
Contours: \( q_g \) (black), \( N_g \) (lime)

below the melting level

\( q_g \) falls quicker than \( N_g \) near system edge
[Indication of graupel size sorting in model]

\( q_g \) falls at the same rate compared to \( N_g \)
[No indication of size sorting for graupel]
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Filled: Line-averaged buoyancy (m s\(^{-2}\)); Gray contours: 20, 40 dBZ contours
Vectors: Storm-Relative wind