Observational-based Stochastic Convection Parameterization

Jesse Dorrestijn (CWI Amsterdam)

In cooperation with:
Pier Siebesma (KNMI, TU-Delft)
Daan Crommelin (CWI, UvA)
Harmen Jonker (TU-Delft)
Frank Selten (KNMI)

ECMWF/WWRP Workshop: Model Uncertainty, Reading, 11-15 April 2016
Outline

1. Motivation for stochastic convection;
2. High-resolution data or observations?
3. A multi-cloud model;
4. SPEEDY.
Introduction

• GCM resolutions tend to increase and are getting close to the Grey Zone;
• To be able to capture the increased variability related to convection, its representation should be stochastic;
Introduction

• We make use of a stochastic multi-cloud model; This model is based on the multi-cloud model of Khouider et al. (2010);
• Transitions between cloud types are modeled with Markov chains that are conditioned on the large-scale state and the transition probabilities are estimated from data; Crommelin and Vanden-Eijnden (2008);
• Convective area fractions serve as a closure for the mass flux at cloud base;
High-resolution simulation

High-resolution observations
Classification

<table>
<thead>
<tr>
<th>CTH [km]</th>
<th>rain rate [mm h⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 12</td>
<td>&gt; 12</td>
</tr>
<tr>
<td>≥ 6.5</td>
<td>stratiform (m = 5)</td>
</tr>
<tr>
<td>≤ 3</td>
<td>deep convective (m = 4)</td>
</tr>
<tr>
<td>∈ [1.5, 6.5)</td>
<td>moderate congestus (m = 2)</td>
</tr>
<tr>
<td>&lt; 1.5</td>
<td>strong congestus (m = 3)</td>
</tr>
<tr>
<td></td>
<td>clear (m = 1)</td>
</tr>
</tbody>
</table>
Stochastic multi-cloud model

Cloud types:
- 1 = clear sky
- 2 = moderate congestus
- 3 = strong congestus
- 4 = deep convective cloud
- 5 = stratiform cloud

**Diagram Description:**
- **Radar Data:** Image of radar data showing cloud patterns.
- **Statistical Inference:** Arrow pointing from radar data to a grid.
- **GCM Grid:** Grid with numbers indicating cloud types.
- **Micro Grid:** Smaller grid showing cloud distribution with numbers 1 to 5.

**Grid Representation:**
```
5 2 1 2 2
4 5 5 2 2
4 5 5 5 5
1 1 1 1 1
1 1 1 1 1
1 1 1 1 1
1 1 1 1 1
1 1 1 1 1
```
Stochastic multi-cloud model

- Transition probability matrix
- $\Delta T = 10$ min
- Compensated for advection

Cloud types:
1 = clear sky
2 = moderate congestus
3 = strong congestus
4 = deep convective cloud
5 = stratiform cloud

$$\hat{M} = \begin{pmatrix}
0.8987 & 0.0668 & 0.0006 & 0.0011 & 0.0329 \\
0.4147 & 0.4707 & 0.0033 & 0.0026 & 0.1086 \\
0.2563 & 0.2686 & 0.2177 & 0.0545 & 0.2029 \\
0.1757 & 0.0284 & 0.0124 & 0.4295 & 0.3540 \\
0.1185 & 0.0779 & 0.0010 & 0.0091 & 0.7935
\end{pmatrix}$$
Stochastic multi-cloud model

- Transition probability matrix
- $\Delta T = 10 \text{ min}$
- Compensated for advection
- Cloud type area fractions calculated for each GCM column

Cloud types:
1 = clear sky
2 = moderate congestus
3 = strong congestus
4 = deep convective cloud
5 = stratiform cloud

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8987</td>
<td>0.0668</td>
<td>0.0006</td>
<td>0.0011</td>
<td>0.0329</td>
</tr>
<tr>
<td>2</td>
<td>0.4147</td>
<td>0.4707</td>
<td>0.0033</td>
<td>0.0026</td>
<td>0.1086</td>
</tr>
<tr>
<td>3</td>
<td>0.2563</td>
<td>0.2686</td>
<td>0.2177</td>
<td>0.0545</td>
<td>0.2029</td>
</tr>
<tr>
<td>4</td>
<td>0.1757</td>
<td>0.0284</td>
<td>0.0124</td>
<td>0.4295</td>
<td>0.3540</td>
</tr>
<tr>
<td>5</td>
<td>0.1185</td>
<td>0.0779</td>
<td>0.0010</td>
<td>0.0091</td>
<td>0.7935</td>
</tr>
</tbody>
</table>

\[ \sigma_m(t) = \frac{1}{N} \sum_{n=1}^{N} 1[Y_n(t) = m], \]
Cross-Correlation analysis

\[ CCF(\tau) = \int_{-\infty}^{\infty} \tilde{X}(t+\tau)\tilde{\sigma}_4(t)dt \]

\[ \tilde{X}(t) = \frac{X(t) - \mu_X}{\sigma_X} \]

\[ \langle \omega \rangle := \frac{1}{p_0 - p^*} \int_{p^*}^{p_0} \overline{\omega}(p)dp \]
Relation omega sigma
Conditioning on the large-scales variables
Convective area fractions

(a) Darwin observations 2007
(b) 10x10 CMCs 25 clusters
(c) 10x10 CMCs 25 clusters
(d) Darwin observations 2007
10x10 CMCs 25 clusters
Deep convective area fraction [%]
Scale-adaptivity

(a) Darwin observations 2007

(b) 69x69 CMCs 25 clusters <\omega>

(c) 10x10 CMCs 25 clusters <\omega>

(b) 69x69 CMCs 25 clusters <\omega>
Cloud type area fractions

(a) Observations
10x10 CMCs 25 clusters <omega>
Expected values of CMC

(deep convective)

(b) strong congestus

(c) stratiform

(d) moderate congestus

(e) clear sky
Implementation in SPEEDY

- SPEEDY is a GCM of intermediate complexity;
- It is a hydrostatic spectral model solving the primitive equations on the entire globe;
- T30 resolution or 3.75 x 3.75 degree; 8 z-levels;
- SSTs are prescribed;
- Seasonal cycle; no daily cycle;
- Shallow convection: vertical diffusion;
- Convection: simplified Tiedtke mass flux scheme; Use convective area fractions as a closure for the mass flux at cloud base.

\[ M_b = \rho \omega c \sigma c, \]
Mass flux at cloud base
Mass flux at cloud base

(a) Darwin

(b) Gott15
Hovmöller-diagrams
Wheeler-Kiladis diagrams
Kelvin and MJO power
Summary

- The stochastic multi-cloud model captures variability related to convection;
- Observations more useful than LES (at the moment);
- Multi-cloud model is scale-aware;
- The large-scale vertical velocity omega displays the largest correlation with deep convection;
- By conditioning on omega, realistic time-series of the mass flux at cloud base are generated in SPEEDY;
- The scheme similar to Gottwald et al. (2016) improves the PDF of the daily accumulated precipitation and the ACF;
- The average strength of the mass flux at cloud base affects the simulation of MJO and Kelvin waves;
- By calculating the average wave power, the skill of simulation of equatorial waves can be expressed in a single scalar; this method can be used to tune models.
References