A Comparison of Simulated Hydrometeor Occurrence Profiles from the Multiscale Modeling Framework (MMF) with ARM observations as a Function of the Large-Scale Atmospheric State

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Introduction

Over the last few years a new type of global climate model (GCM) has emerged in which a two-dimensional or small three-dimensional cloud-resolving model (CRM) is embedded into each grid of a GCM. The embedded CRM removes the need for most of the cloud parameterizations used in traditional GCMs. This new approach is frequently called a Multiscale Modeling Framework (MMF).

Here we present a comparison of output from the MMF model of Khairoutidinov and Randall with ARM ground-based radar profiles of hydrometeor occurrence (that is, the relative frequency that clouds or other hydrometers, such as rain or snow, are detected by a cloud-radar at a given altitude above ground level).

MMF profiles of hydrometeor occurrence are obtained using a radar simulator (Haynes et al. 2007).

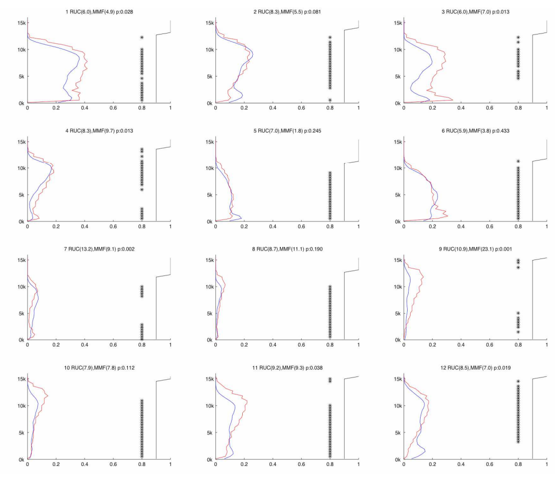
Profiles are shown as a function of atmospheric state, where the atmospheric states are determined using a neural network clustering algorithm on the large scale temperature, pressure, relative humidity and winds fields (Marchand et al. 2006).

The atmospheric state associated with the ARM observations is determined using numerical weather prediction analysis from the Rapid Update Cycle (RUC) model.

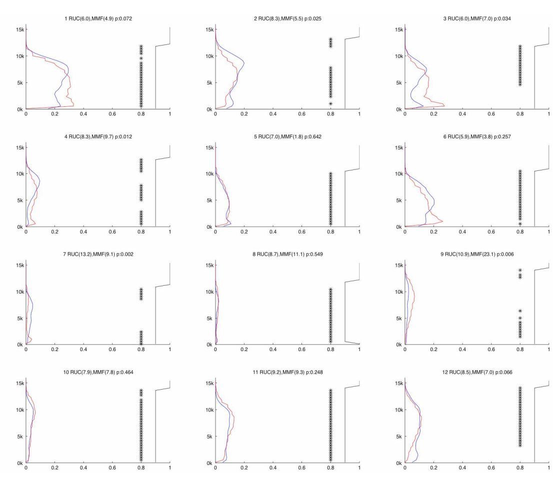
Conclusions

- For cold frontal and post-cold frontal conditions (states 5 and 6), the MMF produces profiles of cloud occurrence that compare favorably with radar observations (using either a -40 dBZe or -25 dBZe threshold). There is some indication that low-level (less than 3 km) hydrometeor fractions in post-cold-frontal conditions may be over predicted.
- For warm frontal conditions (as represented by states 1 and 3), the MMF tends to produce hydrometeor fractions that are too large. Below 7 km this is true using either a -40 or -25 dBZe reflectivity threshold.
- The MMF does not appear to correctly capture the formation of a low clouds in those states where low-level moisture is being advected from the Gulf of Mexico over the ARM site (states 2 and 12).
- In several states, including the four states which occur during June, July, and August (states 9, 10, 11 and 12), the MMF produces too much high and thin cloud, especially above 10 km. This result appears to be a common feature of the model in convective regimes..
- The percentage of time each state occupies in the RUC analysis and MMF output is shown at the top of each panel in the figures to the right. It is encouraging that the percentages are similar for most states. A statistical hypothesis test (e.g. based on a moving blocks bootstrap resampling approach) could be designed to assess to what degree these differences are significant. States 5 and 9, however, have rather large percentage differences that are almost certainly significant. State 9, the atmospheric state with the hottest surface temperatures, is particularly troubling in that this state occurs about 23% of the time in the MMF compared with about 11% of the time in the RUC analysis. Investigating possible causes of this large difference will be one focus of future research.

Comparison of occurrence profiles –40 dBZe threshold



Comparison of occurrence profiles –25 dBZe threshold



In the above plots, observations (RUC+ARM) are shown in blue while MMF simulated output is in red. The label at the top of each subplot shows the percentage of time occupied by each state, along with the p-value from the global similarity hypothesis test (Marchand et al. 2006). The thin black line on the right side of each sub-panel indicates what levels have a sufficient number of samples to make a robust comparison. Individual altitudes where the profiles do not appear to be different at the 95% level of confidence are marked with an asterisk.

Atmospheric States

State	Srf. Temp	Srf. Pres. Anomaly	Srf. Winds	500 hPa flow	375 hPa RH	Other/Notes
1	Cold to Cool (5°-10° C) to north, warmer (~20° C) and moist to south	Strong low in/to SW of domain	Confluent flow, easterly or southeasterly over much of domain	Strong SW flow, very moist, approaching trough	Very moist, RH 60% to 80% over most of domain	Warm front Easterly flow at srf and strong southerly flow at 875 hPA over ARM site Occurs: Nov – Apr
2	Warm (~25° C) and Moist	Low in west part of domain	Southerly, strong in S and E, weaker in W of domain.	SW flow, Strong moisture gradient from N/NW (RH ~60%) to S (RH 30% to 40%)	30% to 75%, similar moisture gradient as at 500 hPa.	Strong S/SW winds at 875 hPa over ARM site and east half of domain Occurs: Feb – May Oct – Nov
3	Cold to north (<5° C), warmer (15-20° C) and moist along Gulf coast	Low pressure NW of domain.	Weak confluent	Strong W/SW flow, RH less than 50% over most of domain (drier than 375 hPA except along north edge of domain)	Moist, RH near 60% over most of domain.	Cold season warm front Occurs: Nov – Apr
4	Cool (~ 15-25° C)	High in SE, low in NW	Southerly	Strong W/NW flow in N of domain (jet stream). Dry south of jet (RH 20% to 30%)	30% to 50 % south of jet, 50% to 70% in jet.	ARM site on the south side of the 500-hPa jet Occurs: Oct – May
5	Cold to cool in north (<10° C), warmer and moister to south (~20° C)	Low	Confluent flow	W/SW flow (strong in southern half of domain).	High RH, 60 to 80%, north of front, lower RH in south	SW-NE oriented cold/stationary front. Occurs: Nov – May
6	Cold to cool (<10° C), except along southern boundary.	High over most of domain, lower in south	Northerly	Convergent SW flow, Moist (especially in eastern half of domain)	Moist, 60% to 80%	Post cold frontal passage at ARM site. Cold front S/SE of domain Occurs: Oct – Mar
7	Cold (<0° C in NW, <10° over most of domain)	Very High	Northerly, weak over much of domain, except in northwest of domain	Strong W/NW, Dry (RH over most of domain less than 40%), approaching ridge.	40% to 60%	Anticyclonic flow at low levels (centered W or NW of domain) with weak northerly flow over most of domain. Occurs: Oct – Apr
8	Cool (~ 10-20° C)	High	Northerly	Weak W/NW flow, Dry (RH less than 30% over most of domain)	Dry, RH 30% to 50%	Occurs: Oct – Apr
9	Very Hot (> ~35° C) over entire domain.	High in western third of domain, Neutral elsewhere.	Southerly at ARM site (weak along E and W boundaries)	Weak flow, except along north boundary where westerly. Dry (RH ~ 30%) in east half of domain. RH 50-60% in NW (along the Rockies)	Dry (RH ~ 30%) except along west / north boundary where RH ~ 50%	SW 875 hPa jet over ARM site (flow over Texas) Occurs: July – Sept.
10	Hot and Humid (~30° C), hotter in west than east.	High in western third of domain, Neutral elsewhere.	Southerly at ARM site (weak along E and W boundaries)	NW flow in north half of domain, weak flow associated with building ridging in the SE. Dry (RH ~ 30%) in east half of domain, but RH 50-70% in NW (along the Rockies)	Dry (RH ~ 30%) except along N/NW boundary where RH ~ 50%	S/SW 875 hPa jet largely west of ARM site (flow over Texas) Occurs: May – Sept
11	Warm to Hot (25° – 30° C), warmer in W/SW	High in NW, low to neutral in SE.	Weak	NW/W flow in north half of domain, weak flow elsewhere. RH 30 to 50 %.	30 to 50 %	Occurs: May – Oct (infrequent during July/August)
12	Hot and Humid (~30° C) hotter in southwest	Low in east	Southerly	W flow (RH 30 to 50% over most of domain, 60% along north domain boundary.	RH pattern similar to 500 hPa.	Strong S/SW winds at 875 hPa at ARM site (flow from Gulf) Occurs: May – Oct (infrequent during July/August)

Future Work

- In the near future we hope to investigate running SAM (the cloud resolving model in the MMF) using the atmospheric states - or more precisely using composite forcing conditions constructed from the MMF output. If running SAM with such composites is able to reproduce the MMF occurrence profiles, then the atmospheric states can likely be used as test-beds to further understand and correct the model shortcomings shown here.