Effects of Hail Parameterization within the COSMO-CLM in Simulated Convective Storms

Cecille M. Villanueva-Birriel, Kwinten Van Weverberg,
Maryna Lukach, Philippe Marbaix, Jean-Pascal van Ypersele

GEORGES LEMAÎTRE CENTRE FOR EARTH AND CLIMATE RESEARCH,
UCLOUVAIN,
LOUVAIN-LA-NEUVE, BELGIUM

Tuesday, April 28, 2015

cecille.villanueva@uclouvain.be

Motivation

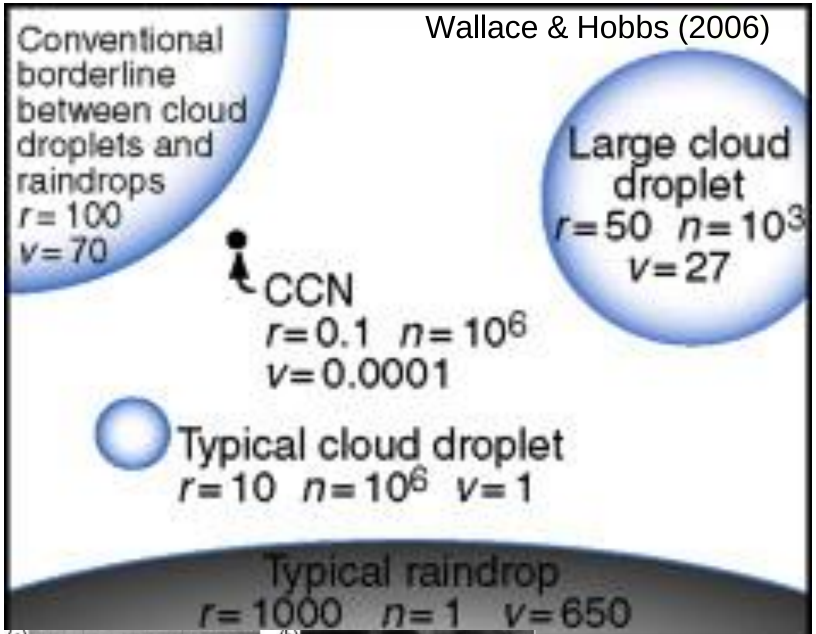
- Currently, scientists use numerical global models to predict the climate system behavior due to increases in greenhouse gases.

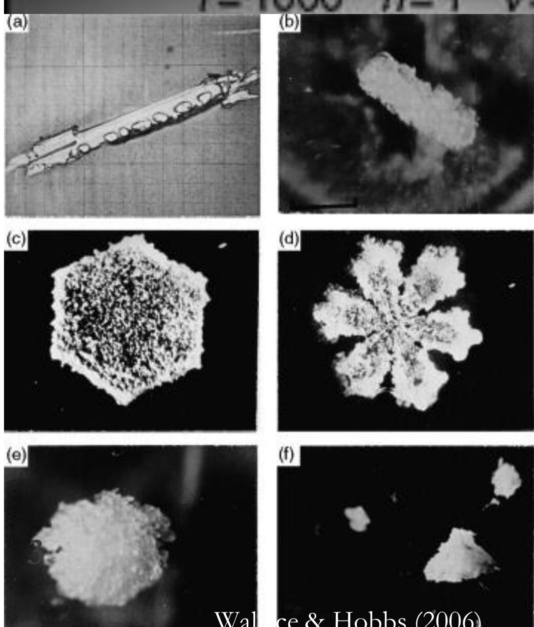
- However, models differ substantially.
  - Major uncertainties are related to model representations of clouds and precipitation (*Boucher et al. 2013, IPCC*)

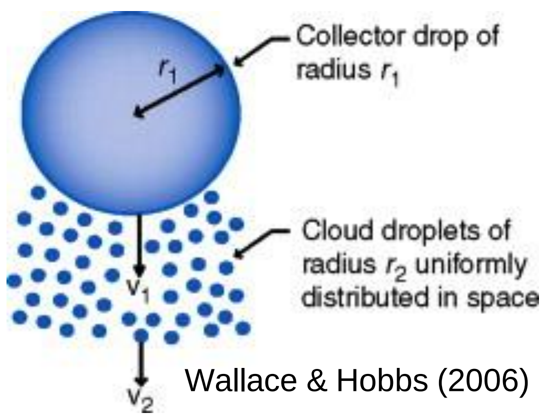
- Focus - Hailstorms known for their great economic and hazardous impact
  - Important to properly simulate hailstone sizes at the surface.

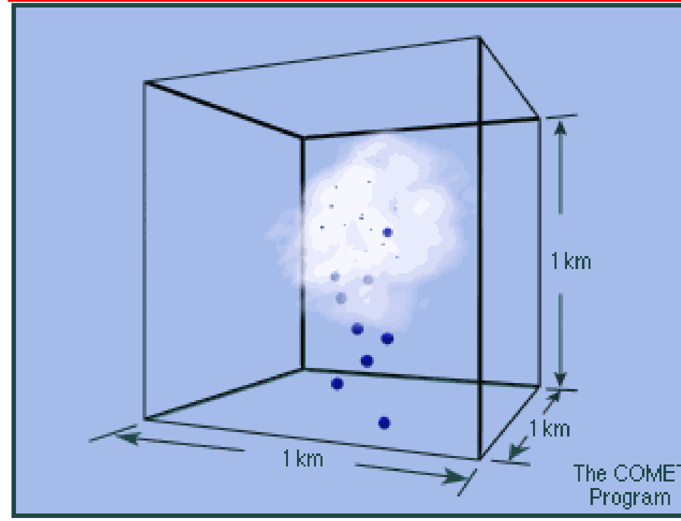
Background- Microphysical processes

Microphysical processes occur on a scale too small to be modeled explicitly in climate models

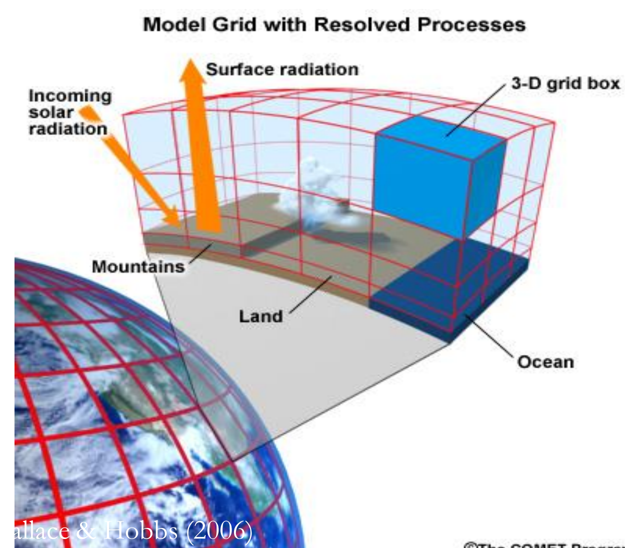








Condensation and droplet growth occurring inside a 1-km model grid box.



Microphysical Parameterization

- 2M microphysics (MP) scheme – predicts both mixing ratio (*q*) and number concentration (*N*)

MP Sources/Sinks

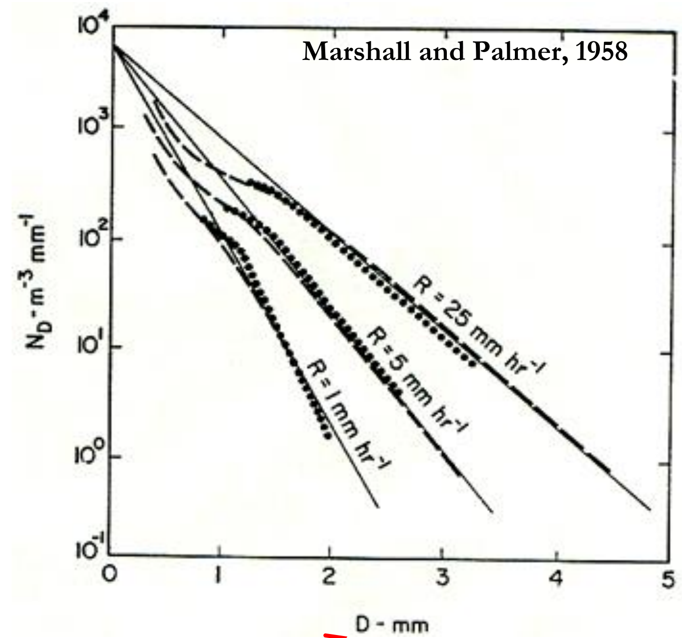
$$\frac{\partial q^x}{\partial t} + v_h \cdot \nabla_h q^x + \dot{\zeta}\frac{\partial q^x}{\partial \zeta} + \frac{1}{\rho\sqrt{G}}\frac{\partial}{\zeta}\left(\rho \upsilon_z^T q^x\right) = \underbrace{}_{}\boldsymbol{S_x} \longrightarrow$$

Similar eqn for N

- Seifert and Beheng (2006)
  - Cloud water, rain, ice, snow, graupel
- <u>Hail category</u> added (Blahak, 2008; Noppel, 2010)
  - Hail characteristics within new parameterization in COSMO-CLM model (Van Weverberg et al. 2014)
    - This study focused on rain representation.

Microphysical Parameterization

- Represent sub-grid scale processes
  - Warm rain process (T > 0 °C)
  - Ice processes (T< 0°C)



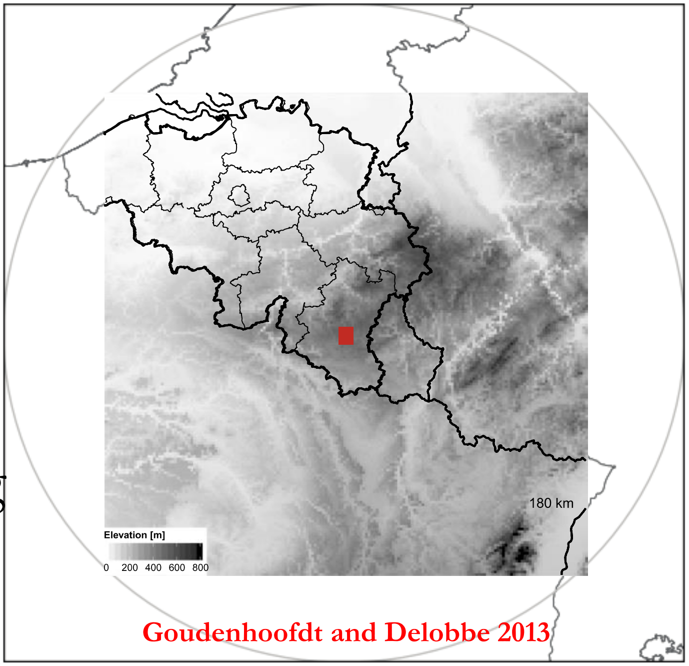
- **Bulk microphysics** – functional form of particle size distributions.
  - e.g. Gamma, Exponential (Marshall-Palmer) distributions

$$N_x(D_x) = N_{0x} D_x^{m} exp(-L_x D_x)$$

  - Negative exponential distribution when $\mu = 0$

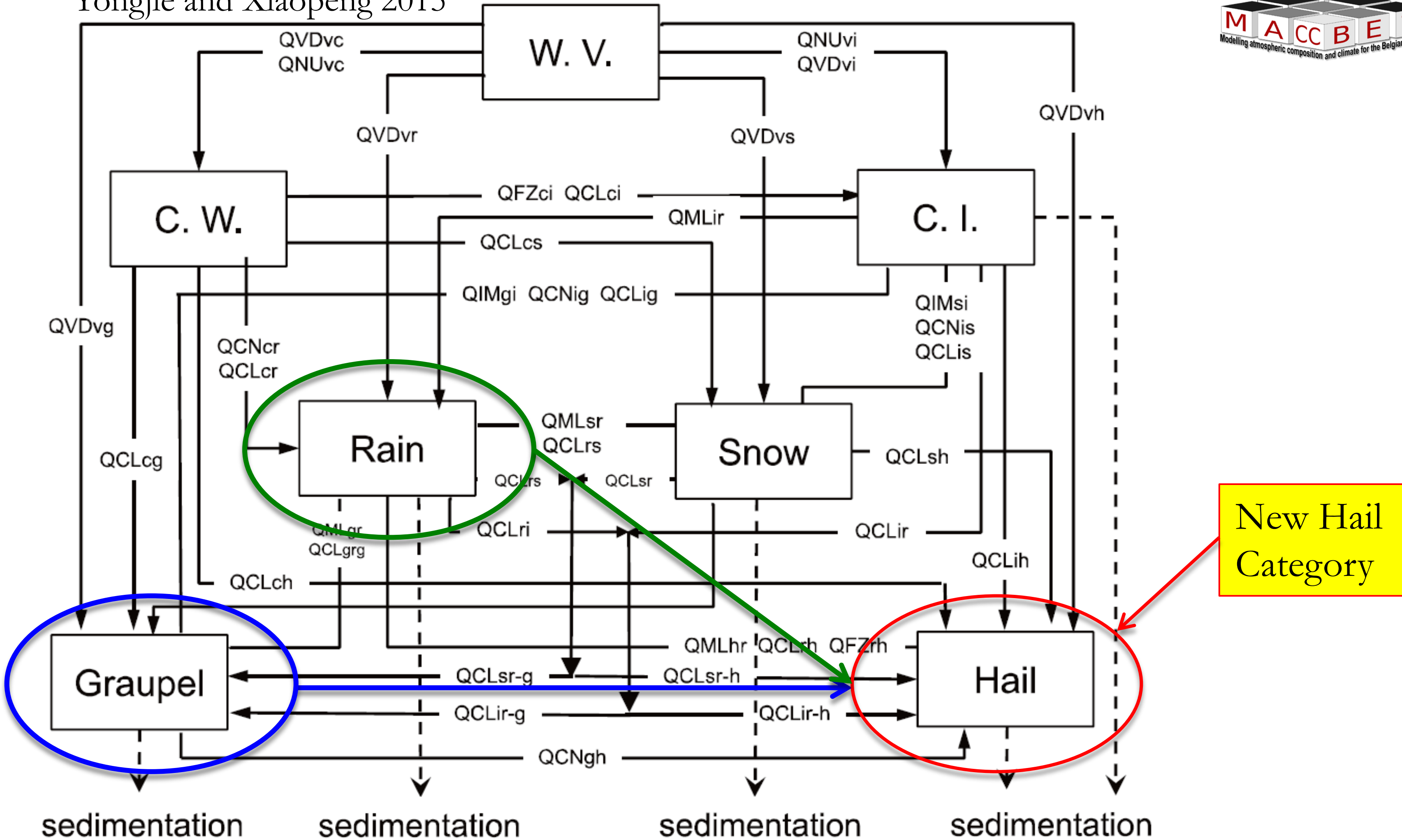
Hail Representation Within Bulk Microphysical Parameterization

- Hail model representation
  - Can substantially impact precipitation
  - Affect dynamical features within the cloud
- Evaluation of new hail parameterization using observational data in Belgium
  - 32 intense convective cases (2002-2014)
- Observations from Wideumont radar (RMI)
  - Maximum expected hail size (Witt et al. 1998)
  - Model evaluated only at 240 km range from the radar



Goudenhoofdt and Delobbe 2013

Yongjie and Xiaopeng 2015



- Focus on newest processes for hail production
  - **Raindrop freezing -> Hail**
  - **Wet Growth Process, Graupel -> Hail**
- Can the model accurately represent surface hail?

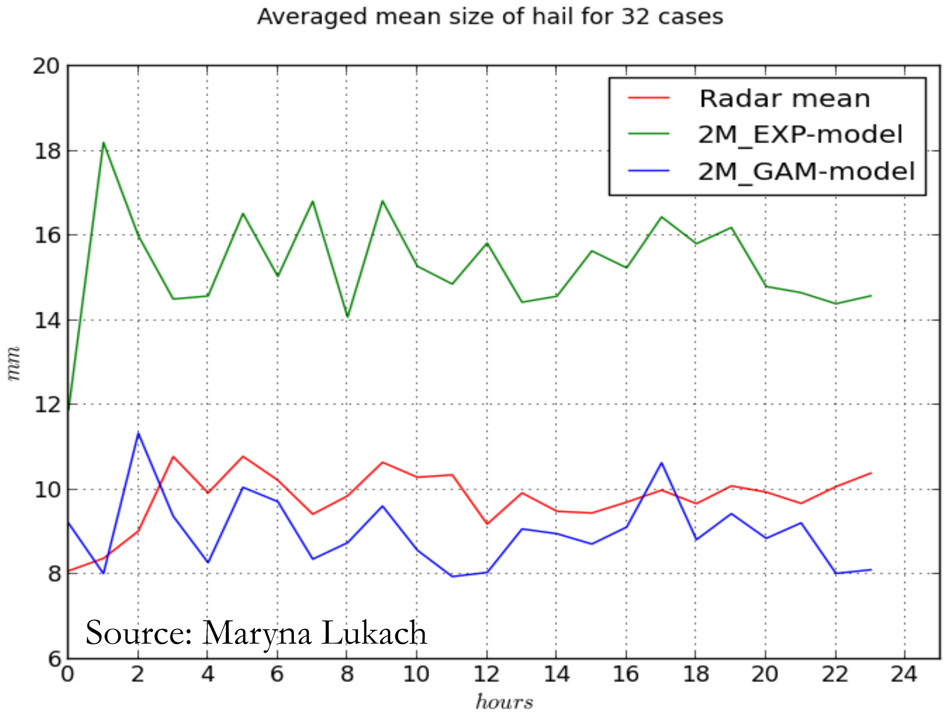
Model Setup

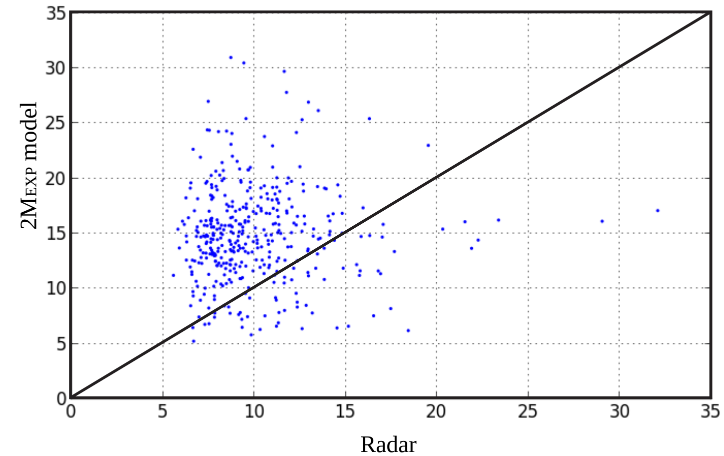
- 6-hourly boundary conditions from ERA-Interim used to drive the COSMO4.8-CLM11

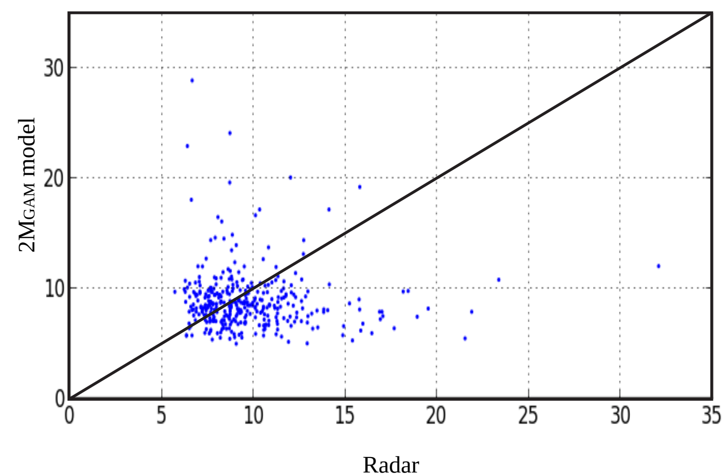
- One-way nesting approach centered over Belgium
  - 1st nest – 0.22° (~25 km) – 100×100×50 grid points
  - 2nd nest – 0.025° (~**2.8 km**) –192×175×50 grid points
    - deep convection resolved

- Sensitivity tests
  - Emulated 1M (*N* diagnosed) vs 2M MP scheme
  - Exponential (EXP) vs gamma (GAM) size distributions

Surface Hail Mean Size Comparison

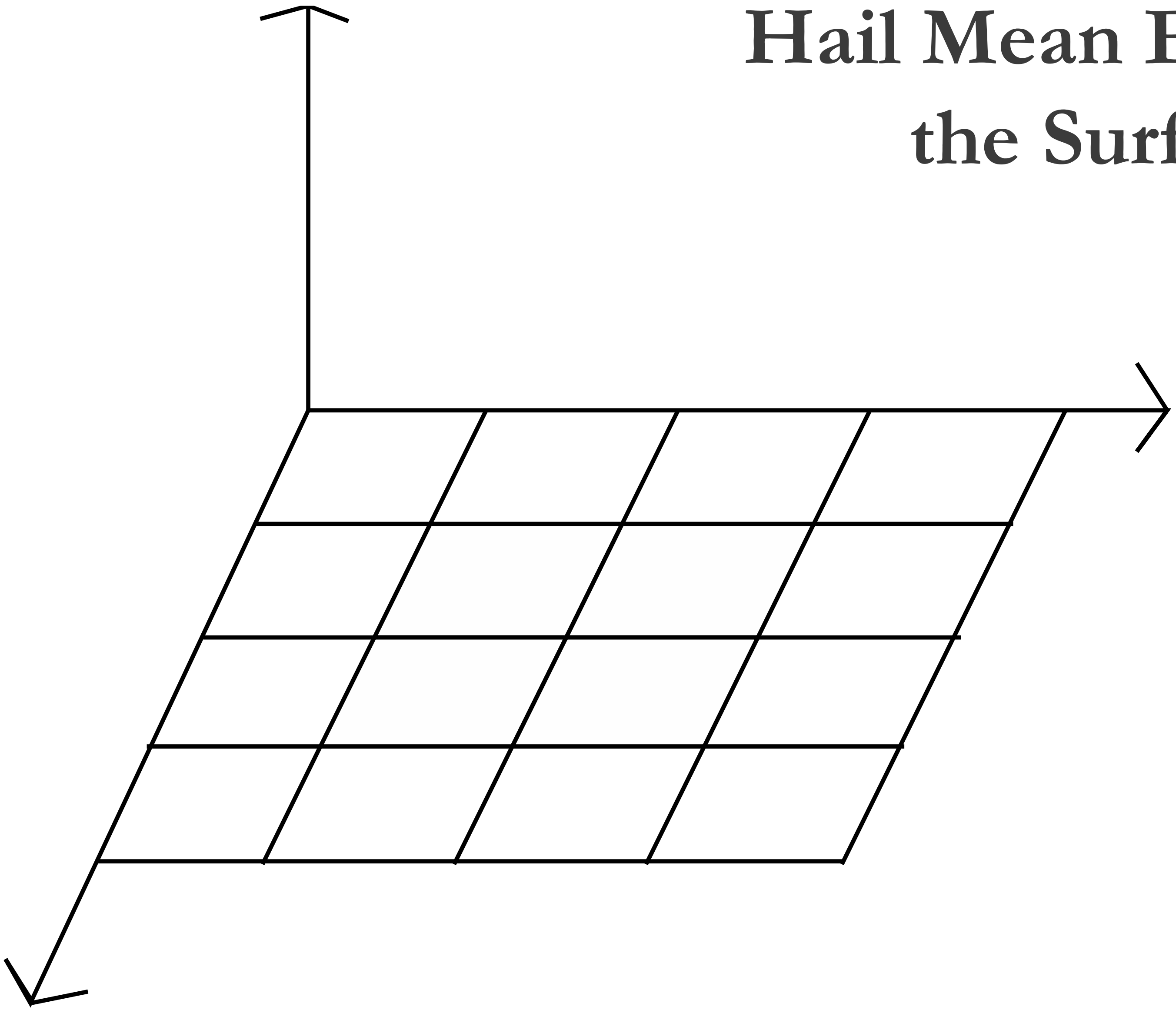




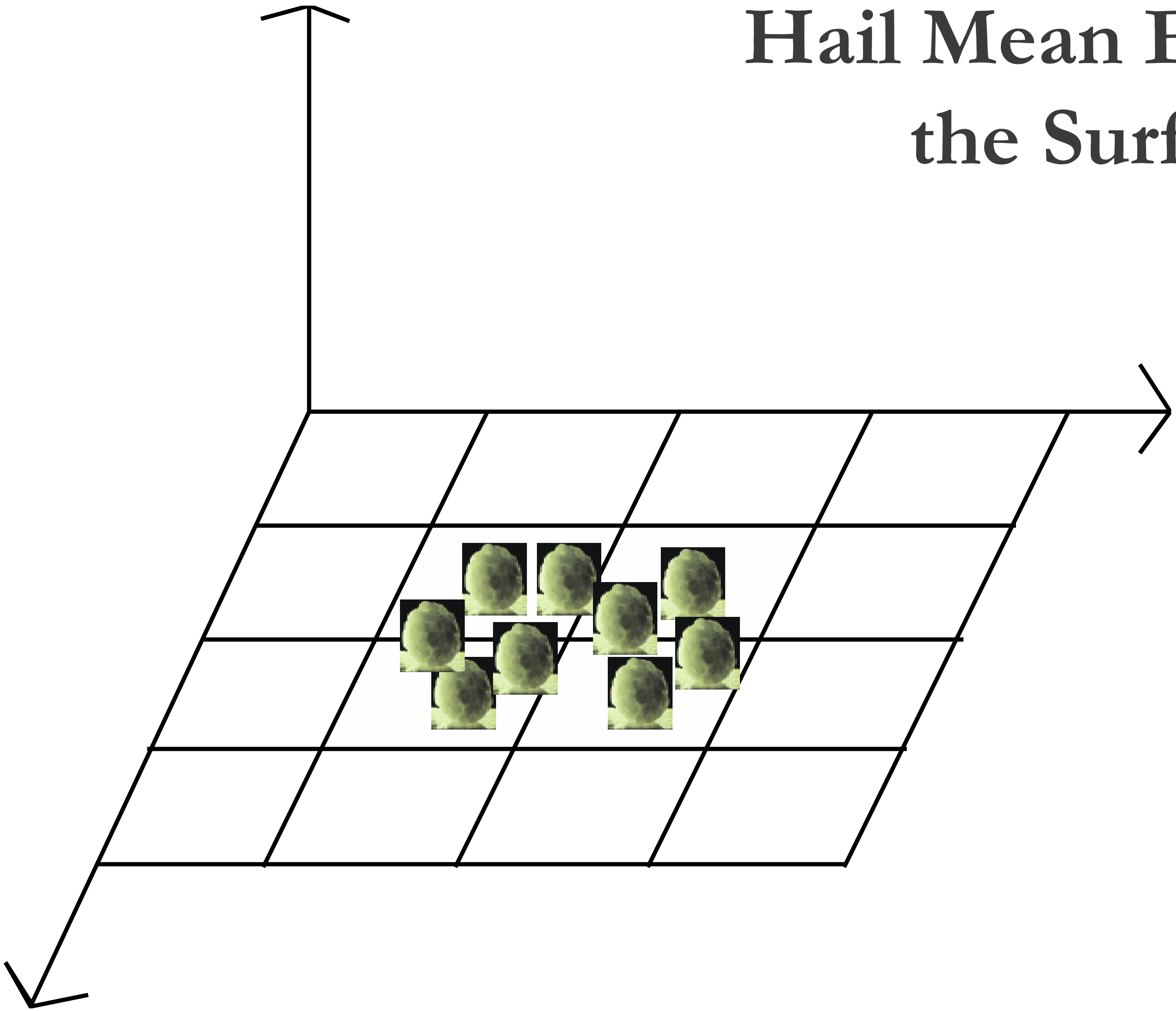


- 2M-simulations produced significant simulated hail
  - 1M-simulations produced negligible amounts
- $2M_{GAM}$ in better agreement with radar observations compared to $2M_{EXP}$
  - $2M_{EXP}$ showed larger hailstones

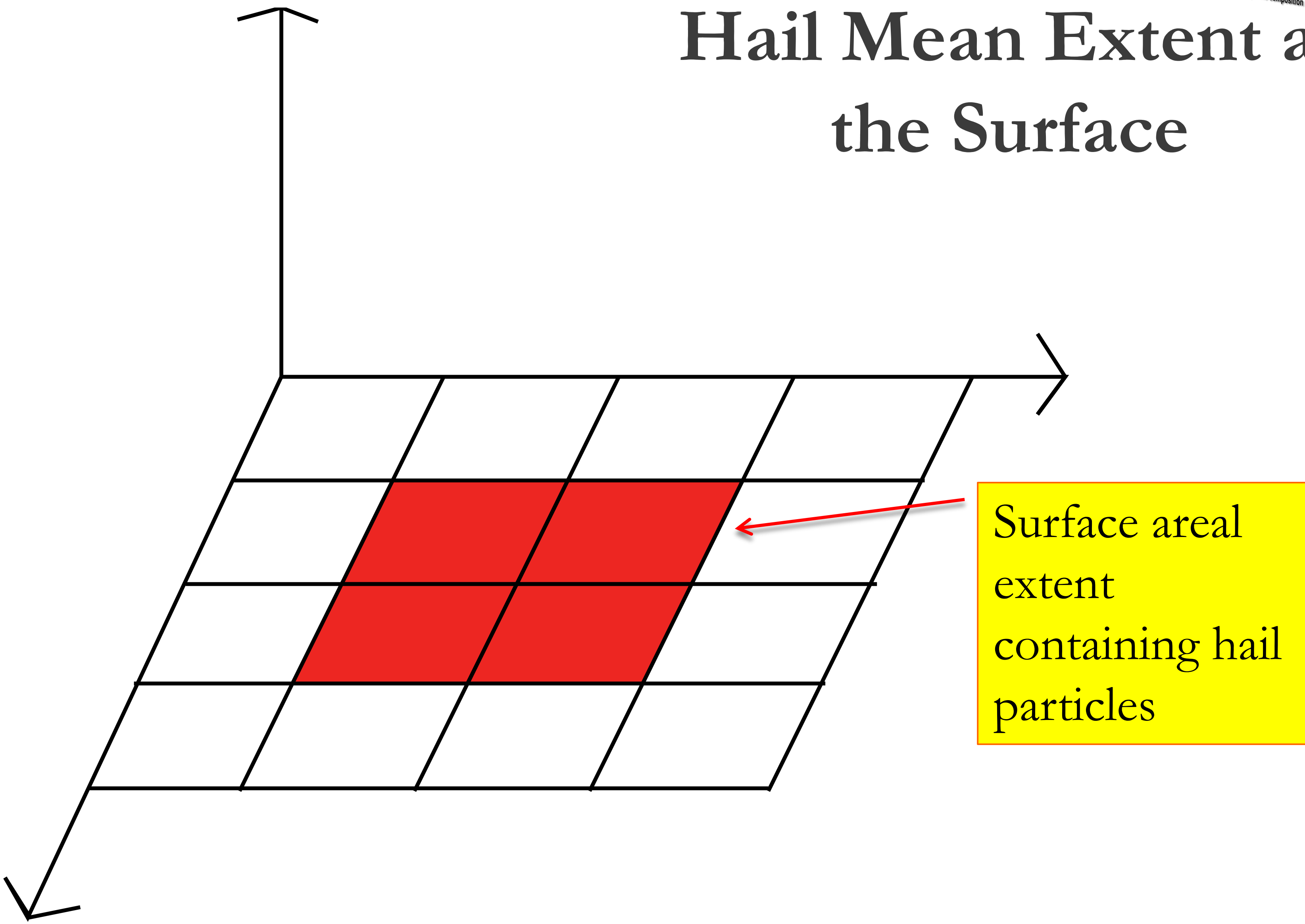
Hail Mean Extent at the Surface



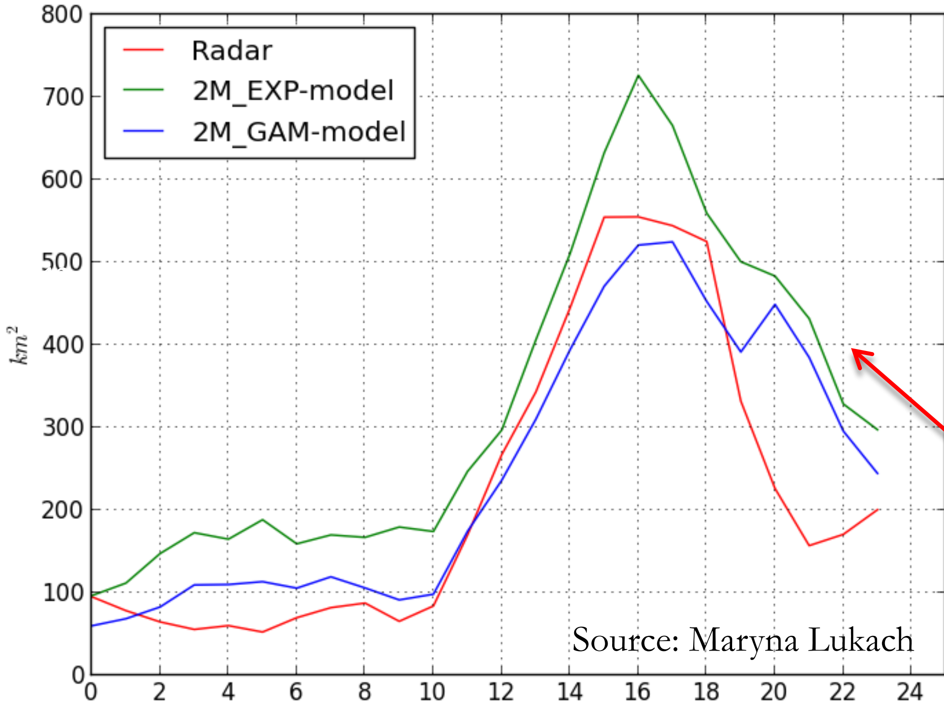
Hail Mean Extent at the Surface



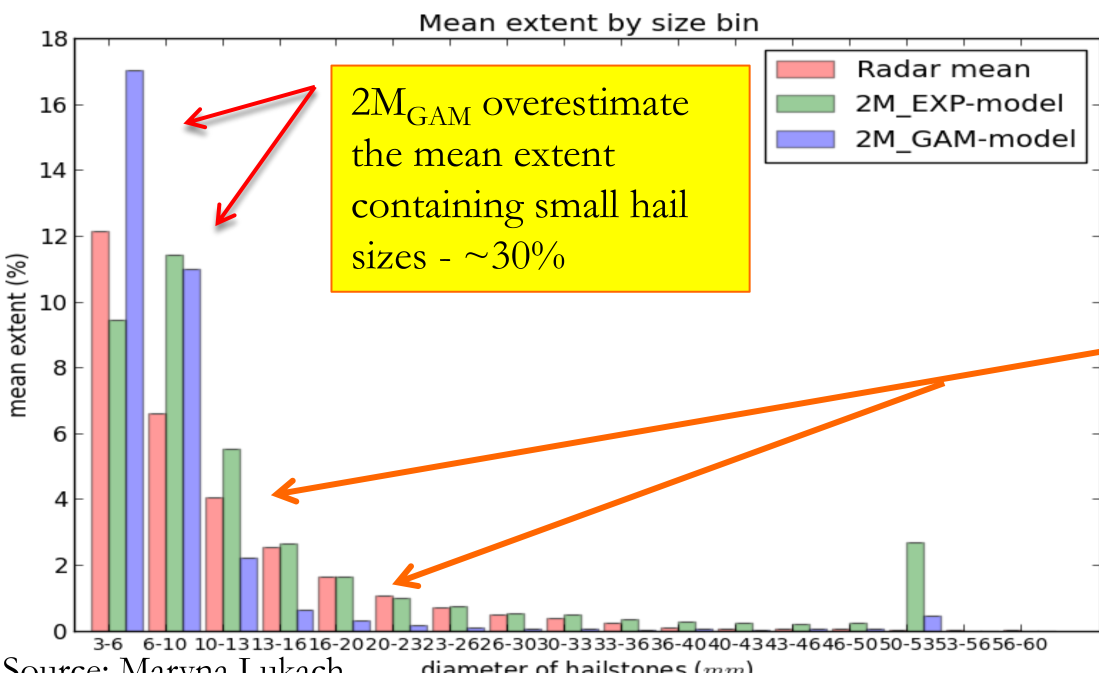
Hail Mean Extent at the Surface



Hail Mean Extent at the Surface



- Both model versions overestimate the area at the surface containing hail between 19-23h
- $2M_{EXP}$ greatest area extent



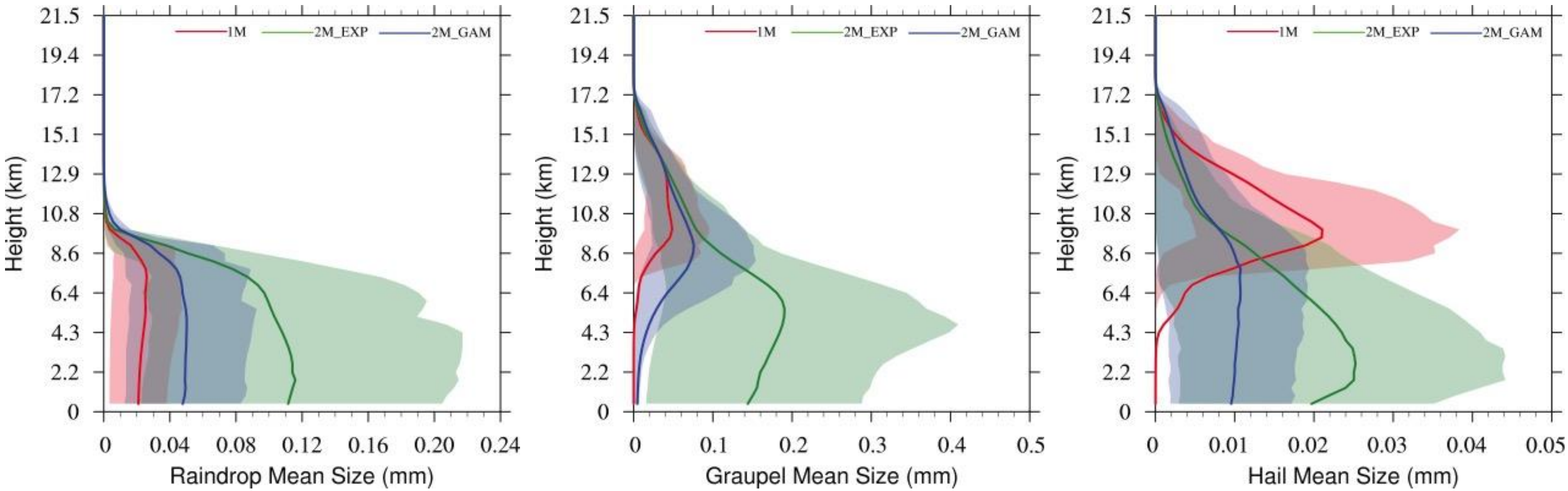
$2M_{GAM}$ overestimate the mean extent containing small hail sizes - ~30%

Underestimation of larger sizes in $2M_{GAM}$ compensates for the greater mean extent containing smaller sizes

Source: Maryna Lukach

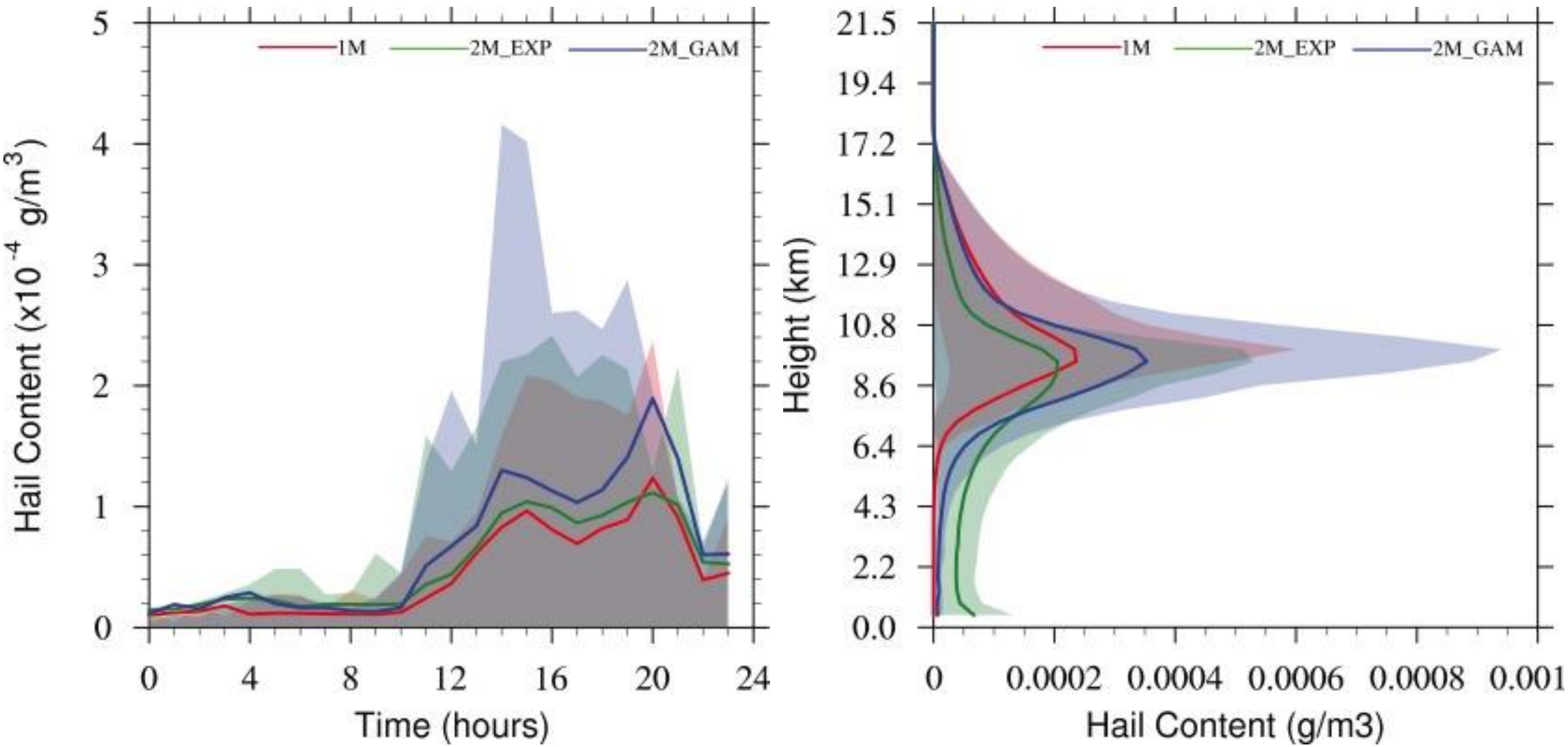
Vertical Profiles of Domain-Temporal Average Particle Size

Raindrop **Graupel** **Hail**



- Larger mean sizes overall for rain, graupel and hail categories in the $2M_{EXP}$ experiment.
- This will affect directly the rate of microphysical processes within the model.
  - e.g. raindrop freezing, wet growth process

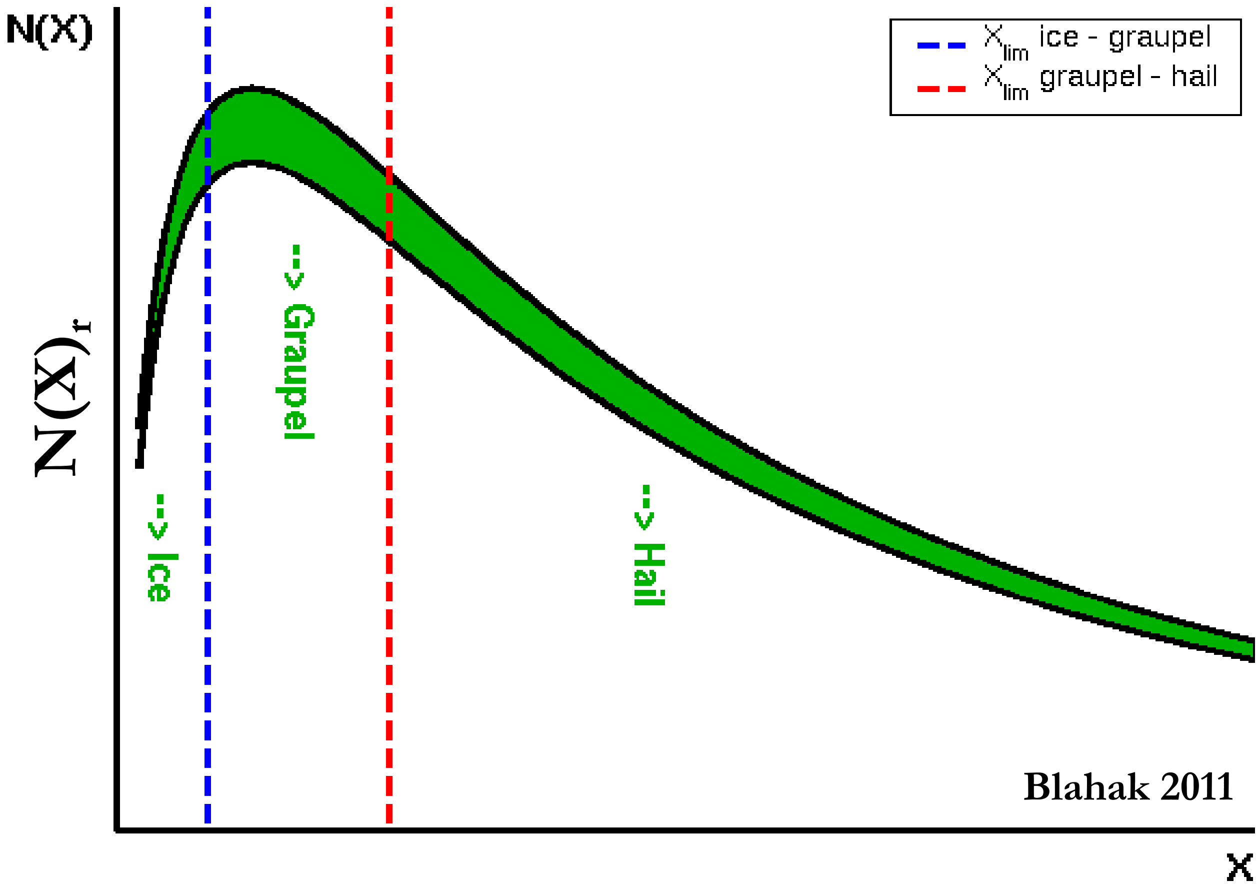
Domain Average of Hail Amount for All Cases



- Higher hail amount produced in $2M_{GAM}$ despite a smaller mean size compared to $2M_{EXP}$
  - Larger number concentration of hail in $2M_{GAM}$

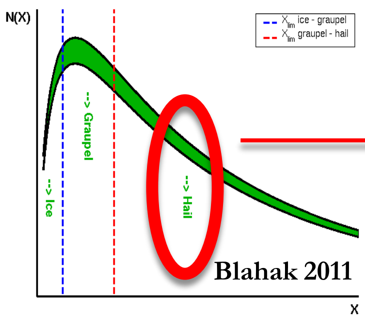
Contribution of Raindrop Freezing to Hail

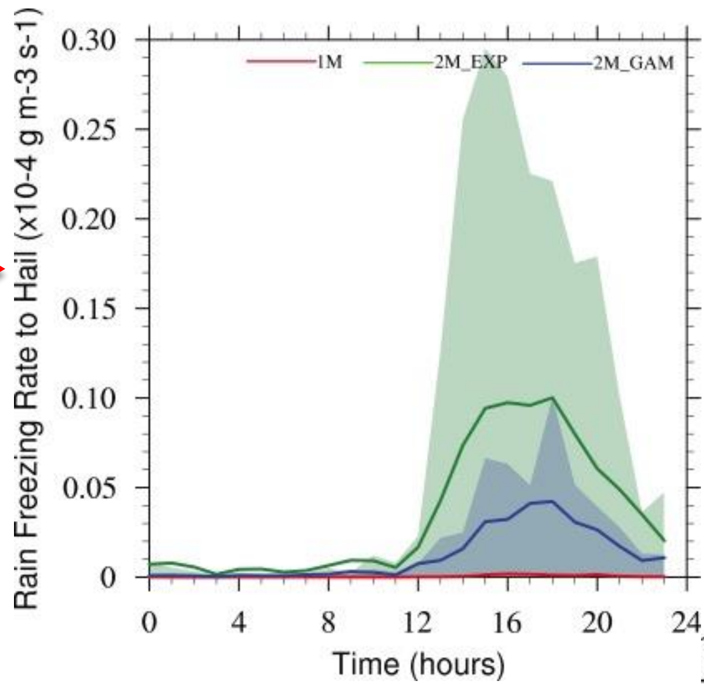
Rain ->Hail

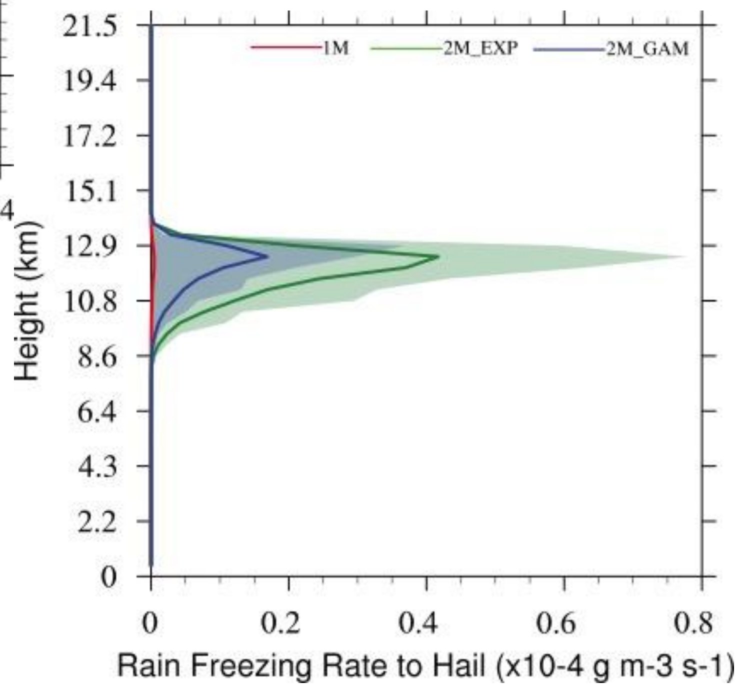


Contribution of Raindrop Freezing to Hail

Rain ->Hail

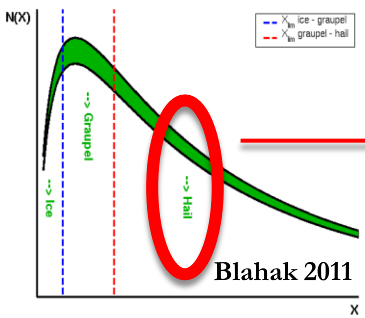


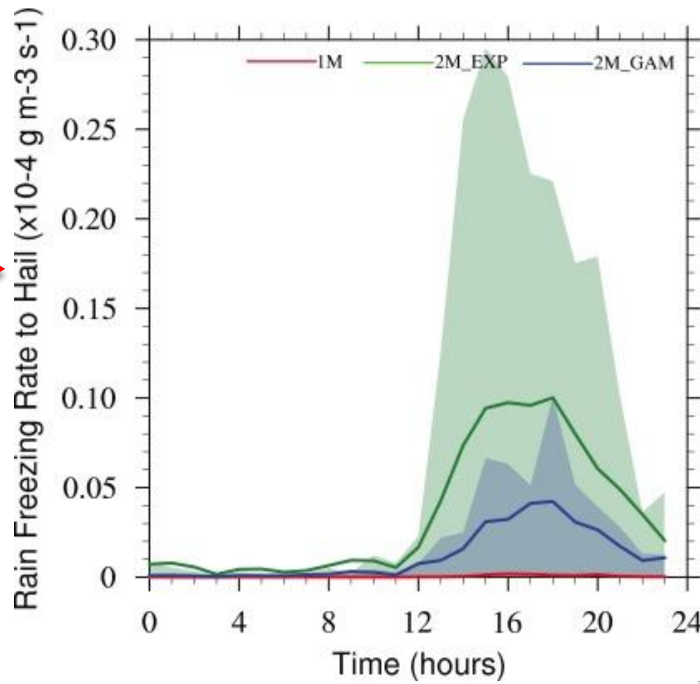




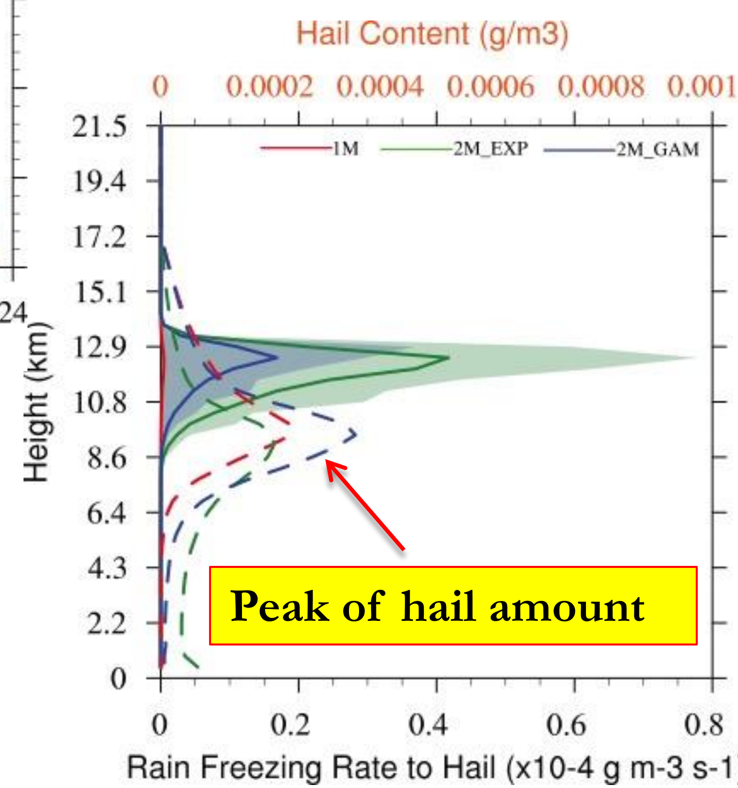
Contribution of Raindrop Freezing to Hail

Rain ->Hail





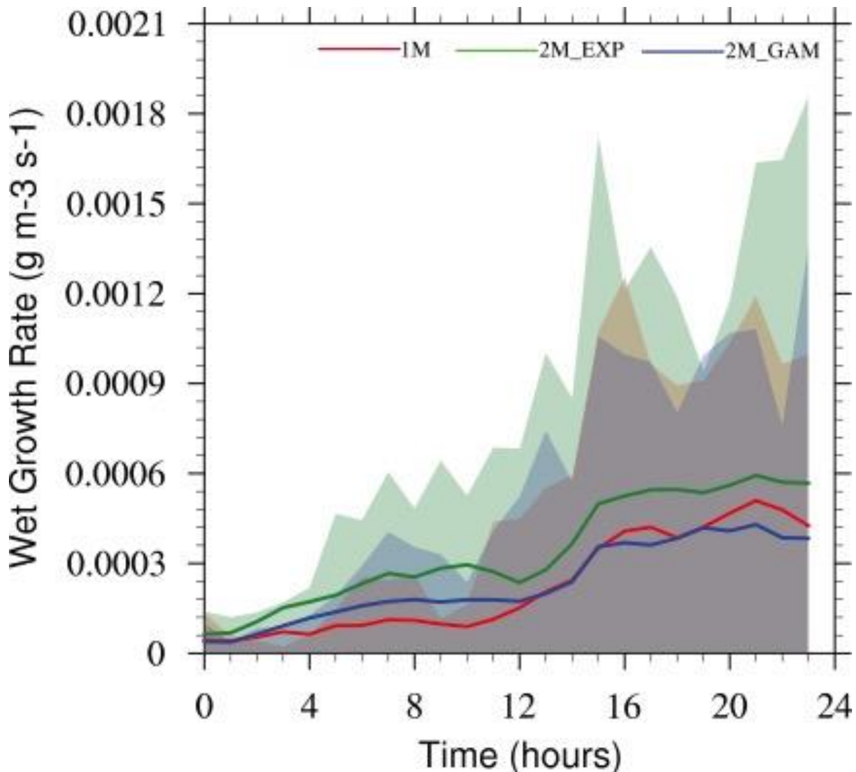
- Raindrop freezing serve as initial hail embryos
  - Subsequently hail grows by different MP mechanisms

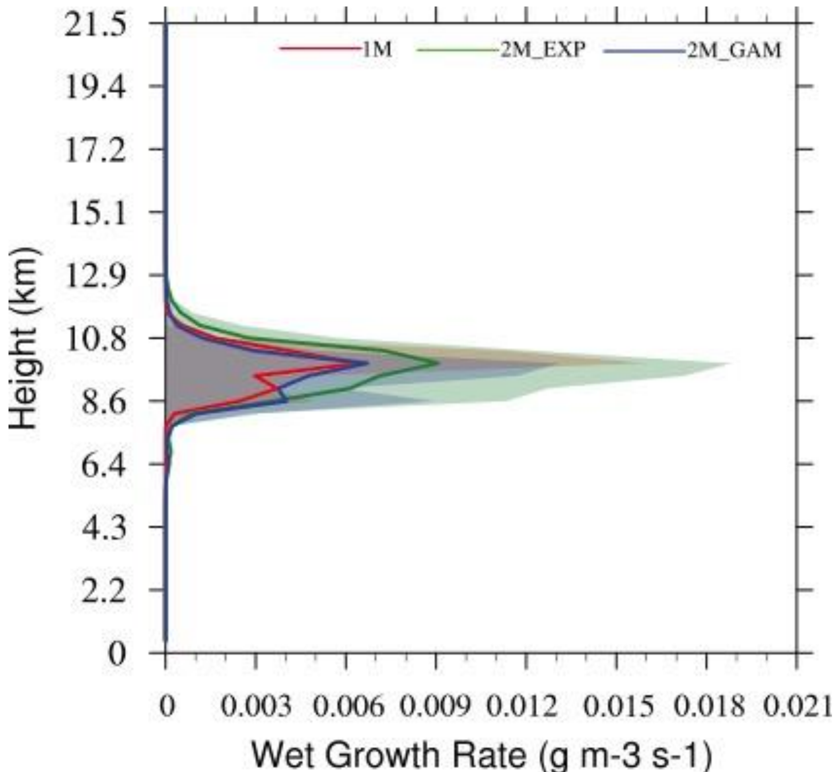


Wet Growth Process

Graupel ->Hail

- Ice particle located in high concentration of supercooled liquid water.
  - $D_g > D_{wg}$ – graupel in wet growth regime.

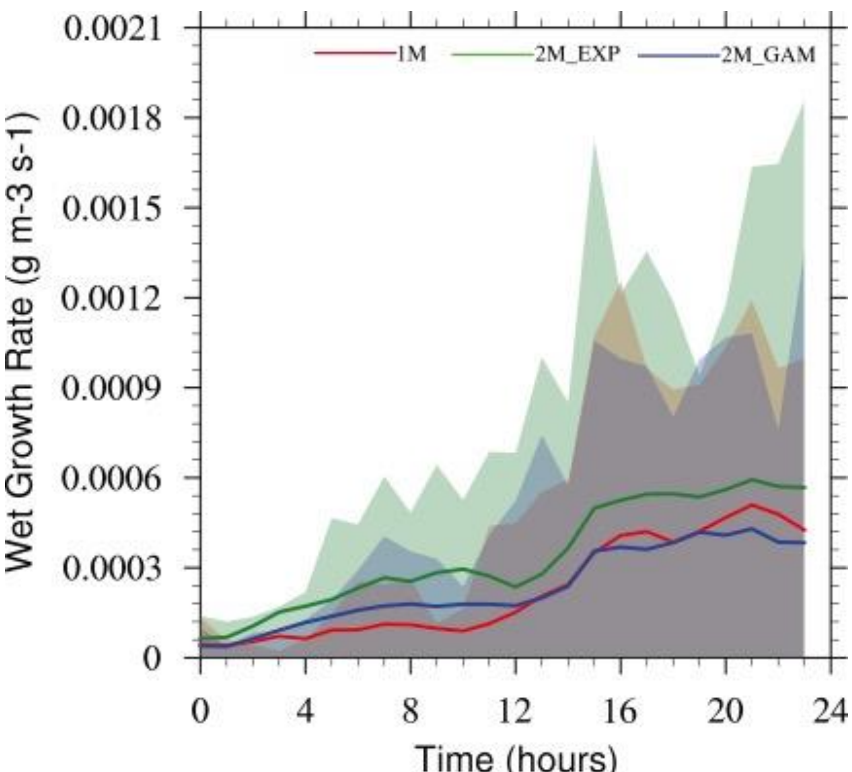


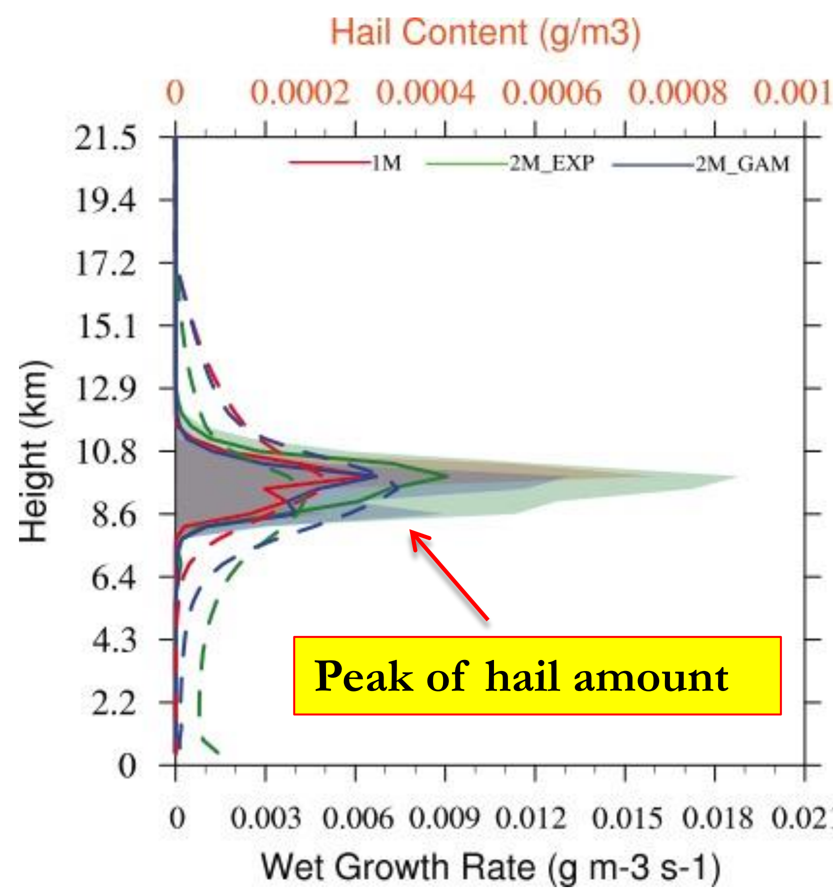


Wet Growth Process

Graupel ->Hail

- Ice particle located in high concentration of supercooled liquid water.
  - $D_g > D_{wg}$ – graupel in wet growth regime.





Summary

- 2M-simulations produced significant simulated hail at the surface
  - 1M-simulations produced negligible amounts

- $2M_{GAM}$ in better agreement with radar observations compared to $2M_{EXP}$
  - $2M_{EXP}$ showed larger hailstones
  - $2M_{GAM}$ overestimates (underestimates) the mean size of smaller (larger) hail particles at the surface

- Raindrop freezing may serve as initial hail embryos
  - Subsequently grows by MP processes? Contributing to hail amount within the storms.

- Wet growth process also important for further hail production,
  - however other MP processes also responsible for the greater hail amount in $2M_{GAM}$ at higher levels

Questions?

Acknowledgements

- Jean-Pascal van Ypersele
- Philippe Marbaix
- Kwinten Van Weverberg
- Maryna Lukach
- Modeling Atmospheric Composition and Climate for the Belgian Territory (MACCBET)
- Belgian Science Policy Office (Belspo)
- CLM-community

Model Setup

- Time-split integration with a third-order Runge-Kutta scheme.
- Horizontal and vertical turbulent diffusion are calculated using a 1.5-order turbulent kinetic energy (TKE) scheme.
- Radiation was parameterized using a δ two-stream approach following Ritter and Geleyn (1992).
- Tiedke (1989) deep convection scheme in coarser domain
  - Reduced version of this parameterization used to represent shallow convection in the high-resolution domain

Particle Size Distribution

$$N(\chi_x) = N_0 \chi_x^{\mu m} \exp\left(-\Lambda \chi_x^{\gamma m}\right)$$

Changing from size descriptor *D* to mass of particle (χ)

$$\mu_m = b_m\left(\mu_d + 1\right) - 1 \qquad \gamma_m = b_m \gamma_d$$

Emulated 1M

$$N_x = \frac{N_{0x}}{\gamma_m}\left(\frac{\Gamma\left(\frac{\mu_m+1}{\gamma_{mx}}\right)}{\Lambda_x^{\frac{\mu m+1}{\gamma m}}}\right)$$

Shape parameter in gamma distribution

$$\mu = \begin{cases} 6\tanh\left[c_1\left(D_m - D_{eq}\right)\right]^2 + 1, & D_m \le D_{eq} \\ 30\tanh\left[c_2\left(D_m - D_{eq}\right)\right]^2 + 1, & D_m > D_{eq} \end{cases}$$

	Negative Exponential				Generalized Gamma			
	Rain	snow	graupel	hail	rain	Snow	graupel	hail
γ_m	0.333	0.526	0.323	0.333	0.333	0.526	0.323	0.333
μ_m	−0.666	−0.474	−0.677	−0.666	Eq. (5)	Eq. (5)	Eq. (5)	Eq. (5)
γ_d	1	1	1	1	1	1	1	1
μ_d	0	0	0	0	Eq. (5)	Eq. (5)	Eq. (5)	Eq. (5)
a_m	0.124	8.160	0.190	0.128	0.124	8.160	0.190	0.128
b_m	0.333	0.526	0.323	0.333	0.333	0.526	0.323	0.333
N_0 (m)	3.3×10^5	5.6×10^8	2.5×10^5	1.7×10^3	-	-	-	-
N_0 (D)	8×10^6	3×10^6	4×10^6	4×10^4	-	-	-	-

Van Weverberg et al. 2014