A new approach to parameterize ice-phase cloud microphysics

The Predicted Particle Properties (P3) Scheme

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in collaboration with

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RPN Seminar Series
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NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Environment
Canada

RPN
Service through science

Development of Bulk Microphysics schemes

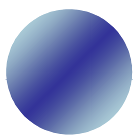
- Kessler (1969), first bulk scheme (liquid only, 1-moment)
- Ice-phase categories were introduced; over the next decades more detailed 1-moment schemes were developed
- In the early 2000s, 2-moment schemes (and one 3-moment scheme) appeared
- In the last 10 years, new schemes have been developed (and older ones have been improved)
  - e.g. WRF (community model) now has several schemes (12+)
  - in universities, research labs, etc. several innovative parameterization ideas have been (and are being) explored

From RPN Seminar Series
March 1, 2013:

Paradigm shift (in the parameterization of ice phase)

Currently under development*:

KA-ice



***ICE-PHASE HYDROMETEOR* (1 mode)**

- ρ is *predicted*
- $V = a(\rho)D^{b(\rho)}$
- Predicted rime fraction
- Predicted spectral dispersion

PROGNOSIC VARIABLES: Q_{dep}, Q_{rim}, N, B, Z

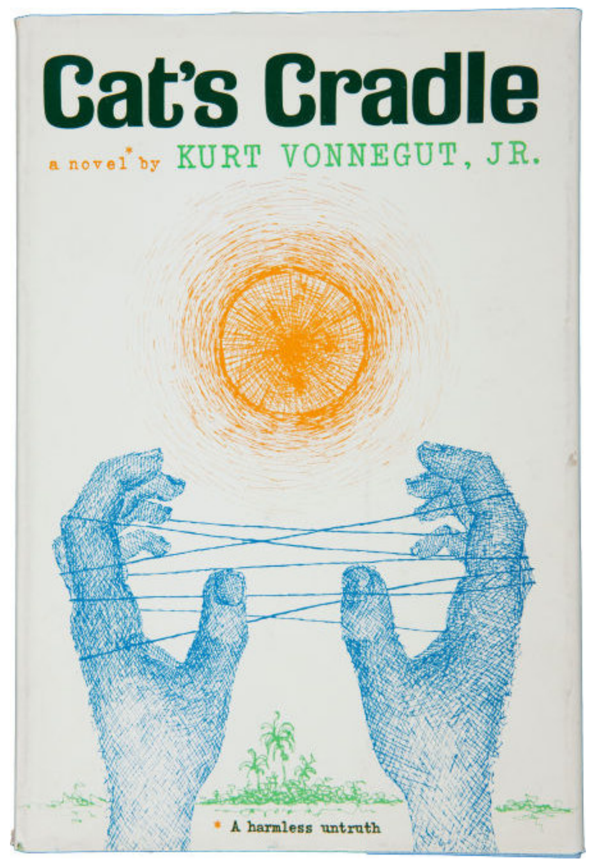
*collaboration between NCAR and RPN

OUTLINE

1. Background
2. Overview of the P3 scheme
3. Model results
4. The future …

Vonnegut's Challenge:*

"Any scientist who can't explain to an eight-year old what he is doing is a charlatan."

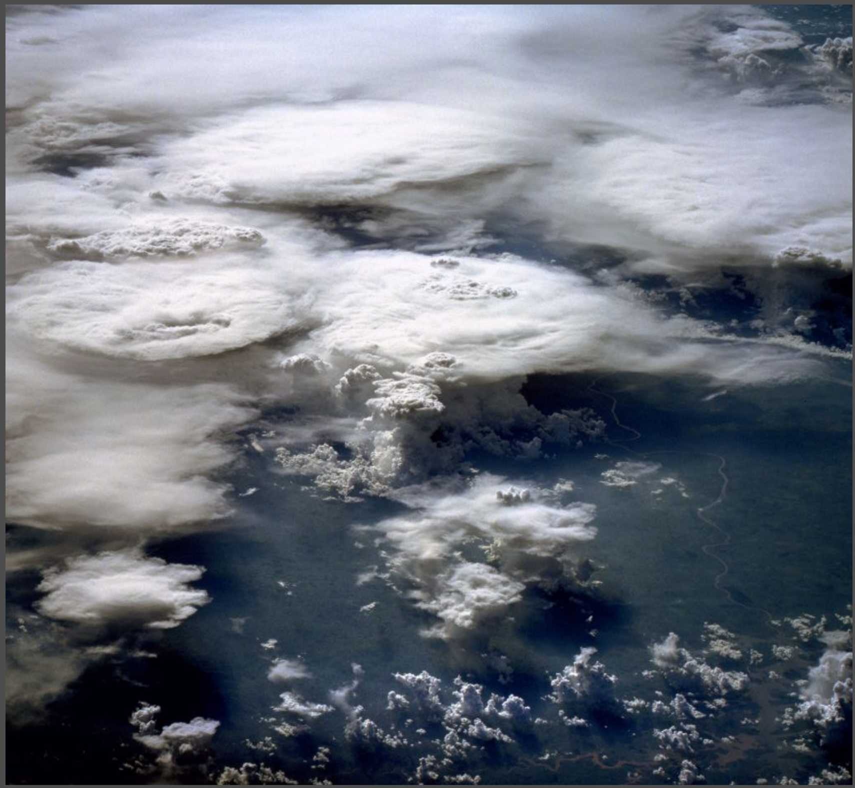


* Kurt Vonnegut Jr., "*Cat's Cradle*", 1963

1. Background

Role of Clouds in NATURE

- radiative forcing
- thermodynamical feedback
- redistribution of atmospheric moisture
- precipitation
- etc.



Representation of Clouds in MODELS

1. Radiative Transfer Scheme

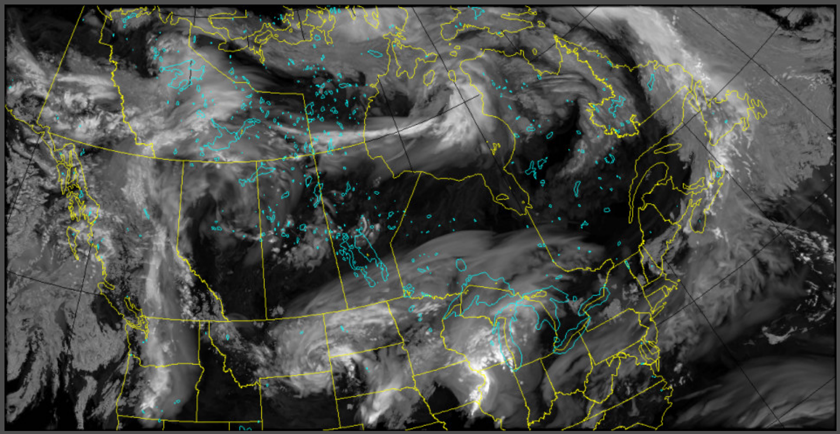
- computes radiative fluxes SW/LW

2. Microphysics Parameterization Scheme

- optical properties (for radiation scheme)
- feedback to dynamics
  - latent heating/cooling
  - mass loading
- precipitation

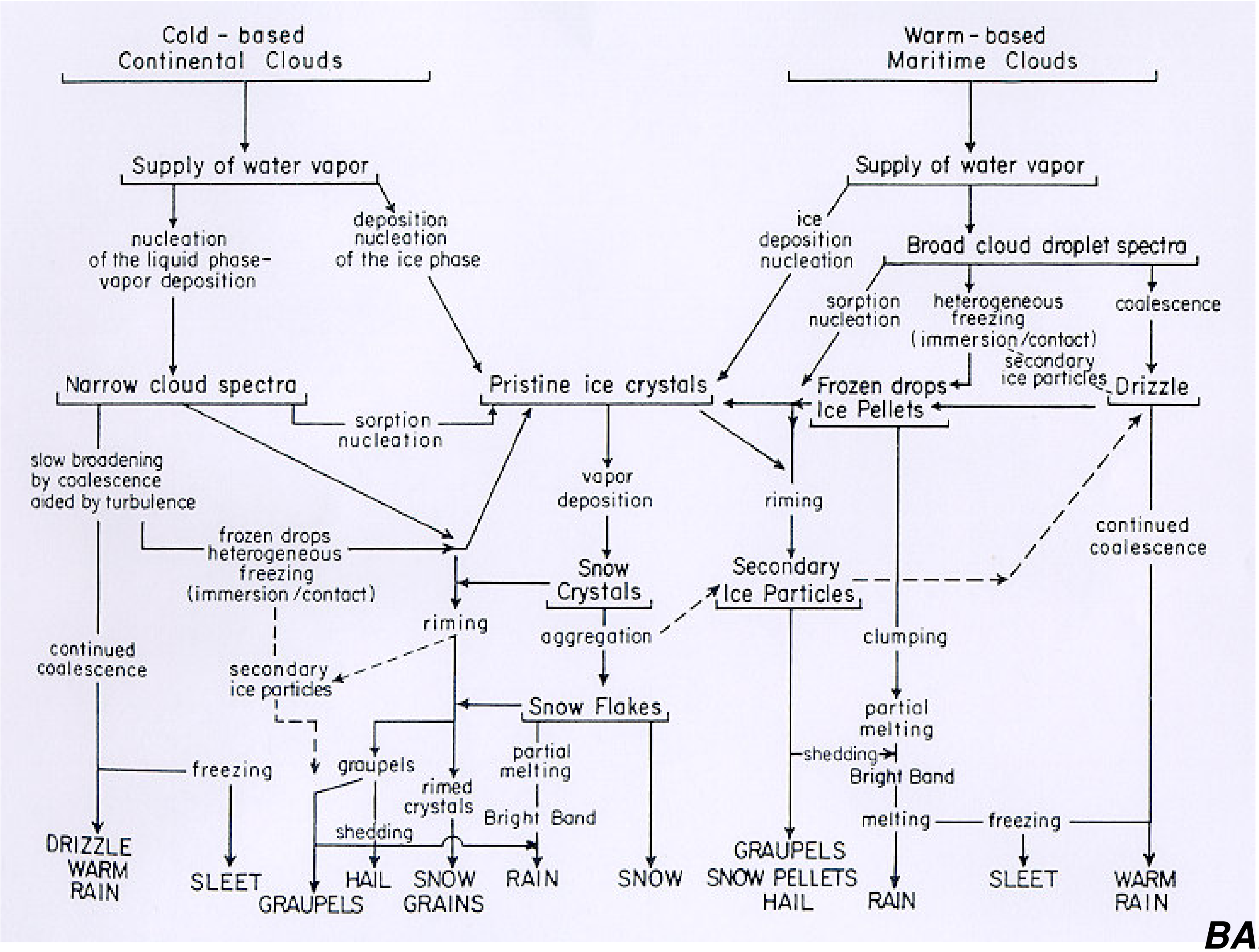
3.Subgrid-scale schemes

- e.g. shallow convection



Microphysics Parameterization Scheme

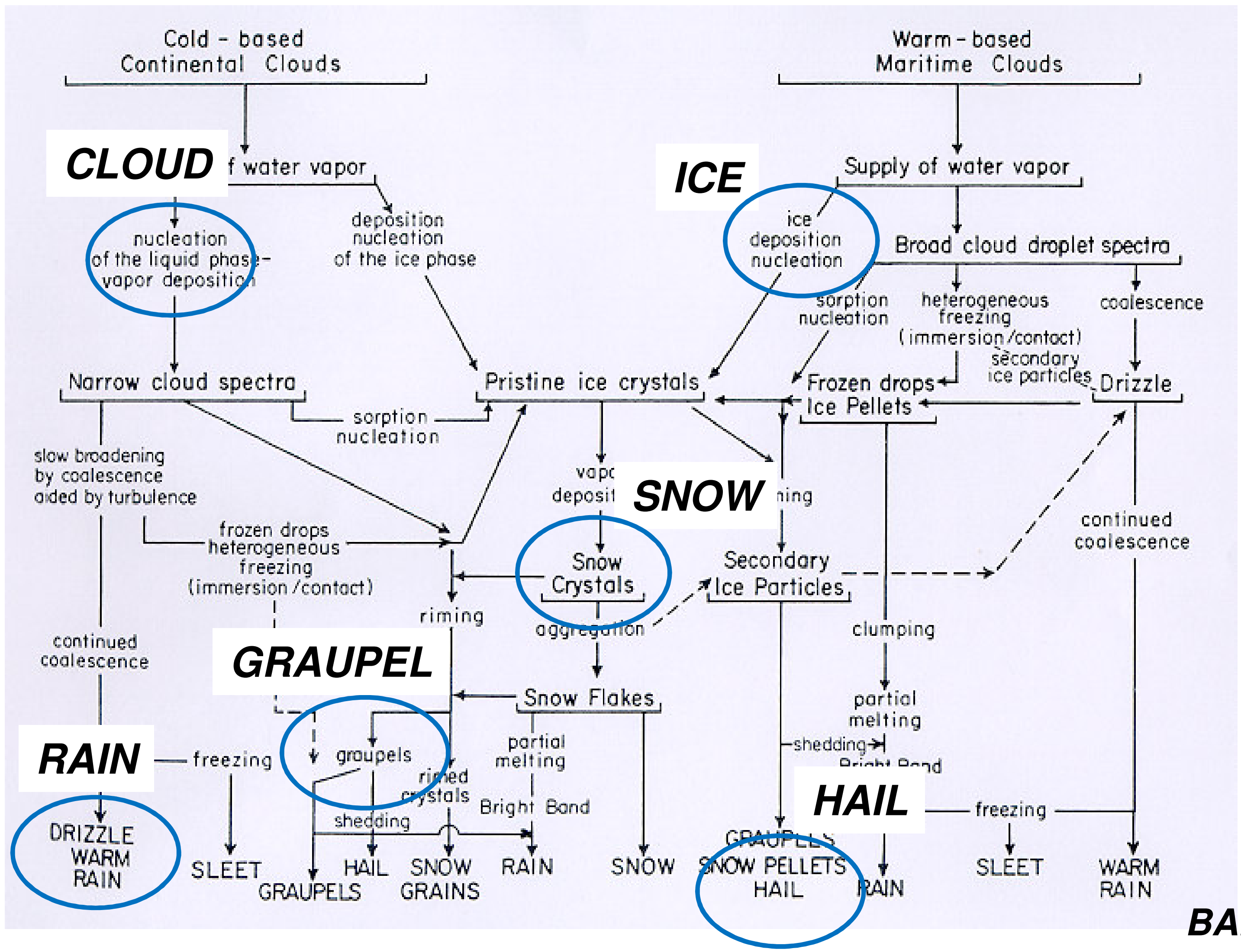
To achieve its roles, it must represent a complex set of processes



***BAMS*, 1967**

Microphysics Parameterization Scheme

Hydrometeors are partitioned into categories

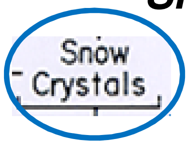


BAMS, 1967

Microphysics Parameterization Scheme

The particle size distributions are modeled

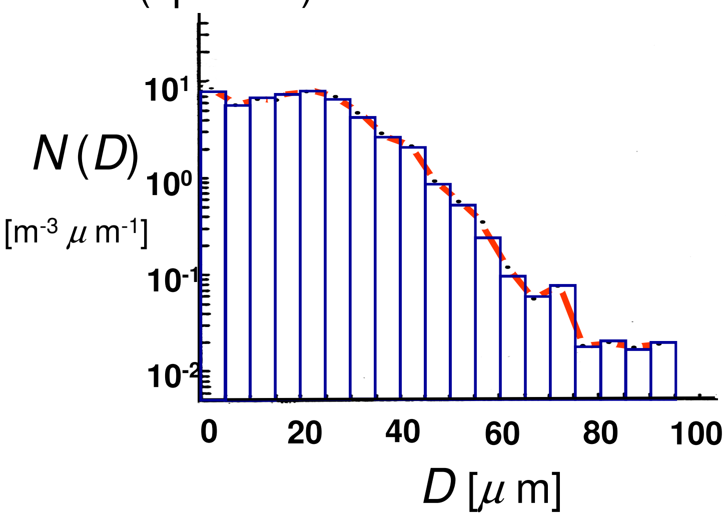
e.g. ***SNOW***



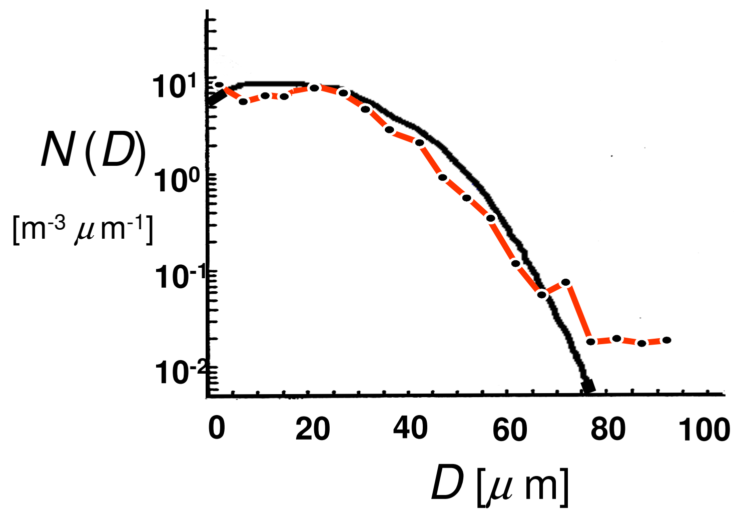
For each category, microphysical processes (initiation, growth/decay, sedimentation) are parameterized in order to predict the evolution of the *particle size distribution, $N(D)$*

TYPES of SCHEMES:

Bin-resolving: (spectral) $$N(D)=\sum_{i=1}^{I}N_i$$



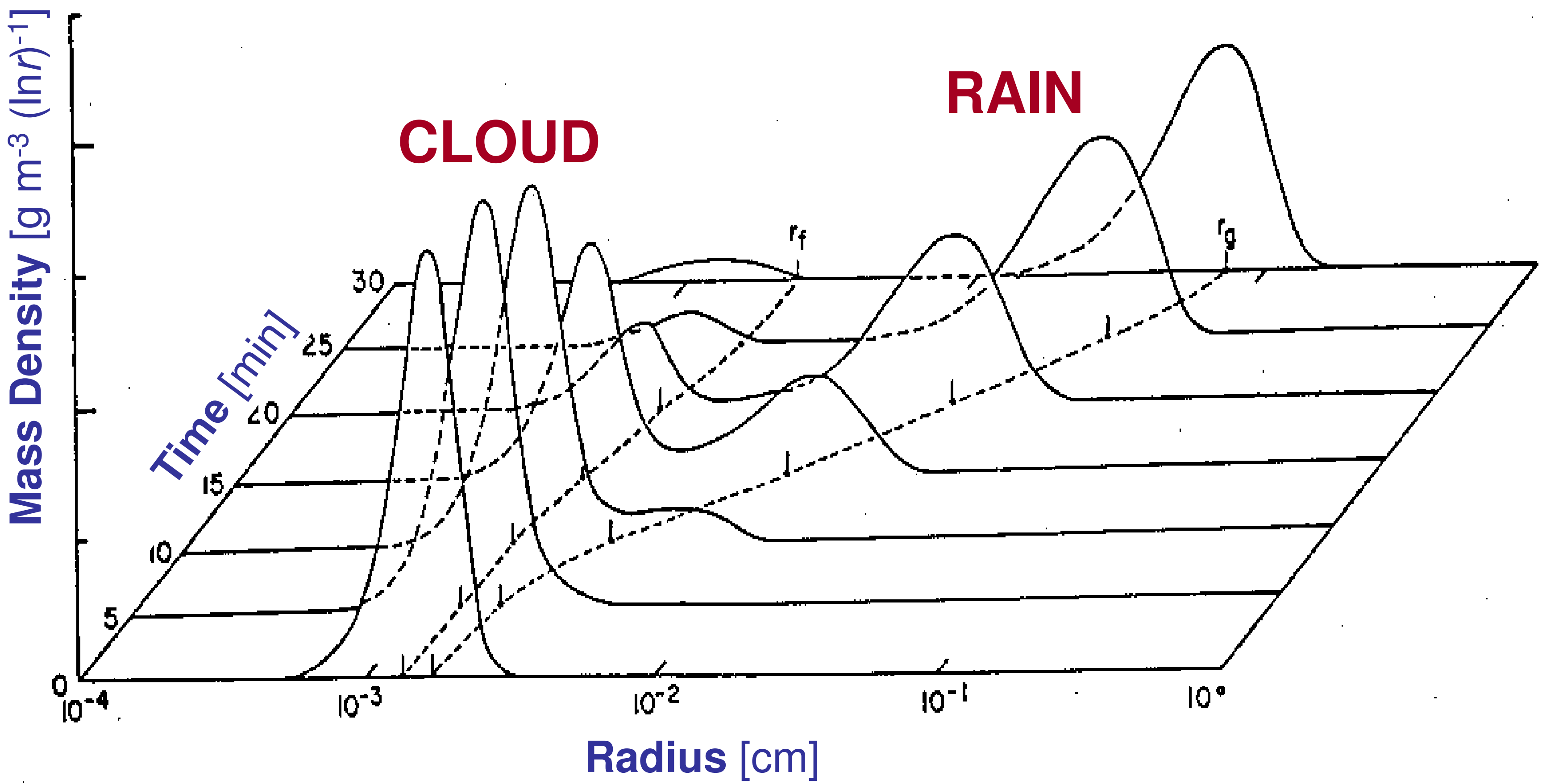
Bulk: $$N(D)=N_0 D^{\alpha} e^{-\lambda D}$$



Liquid Phase

"Warm rain" coalescence process:

→ **2-moment bulk schemes model this process very well**



Bin-resolving coalescence model
Berry and Reinhardt (1974)

Ice Phase

Traditional bulk approach:

CLOUD ICE

ρ_s = 500 kg m^{-3}

$m = (\pi/6\ \rho_s)D^3$

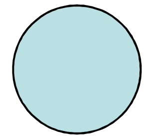
$V = a_i D^{bi}$

"SNOW"

ρ_s = 100 kg m^{-3}

$m = cD^2$

$V = a_s D^{bs}$

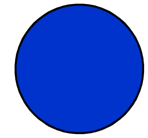


GRAUPEL

ρ_g = 400 kg m^{-3}

$m = (\pi/6\ \rho_g)D^3$

$V = a_g D^{bg}$



HAIL

ρ_h = 900 kg m^{-3}

$m = (\pi/6\ \rho_h)D^3$

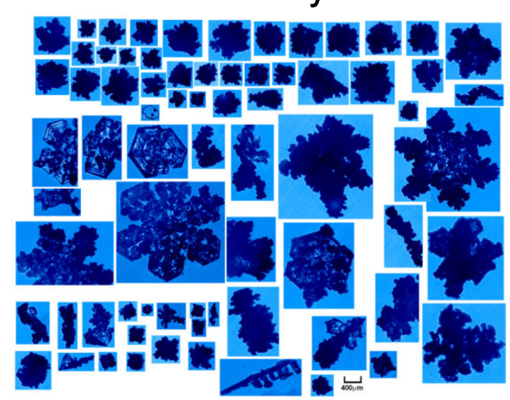
$V = a_h D^{bh}$

← abrupt / unphysical conversions

Problems with pre-defined categories:

1. **Real ice particles have complex shapes**
2. **Conversion between categories is ad-hoc**
3. **Conversion leads to large, discrete changes in particle properties**

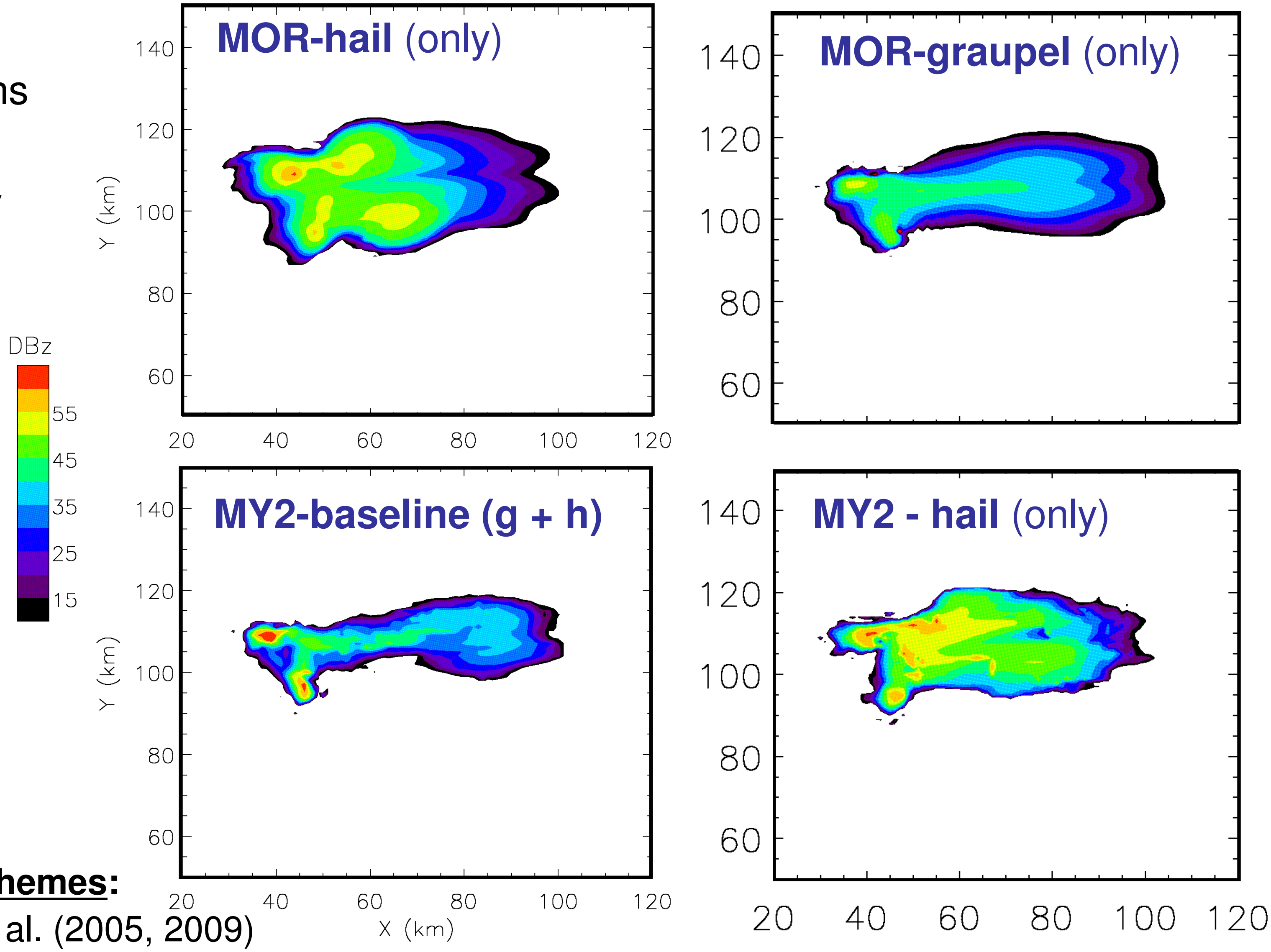
Observed crystals:



NOTE: Bin microphysics schemes have the identical problem

The simulation of ice-containing cloud systems is often *very sensitive* to how ice is partitioned among categories

- idealized 1-km WRF simulations (em_quarter_ss)
- base reflectivity



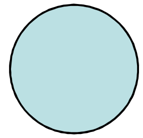
Morrison and Milbrandt (2011), *MWR*

<u>Microphysics Schemes</u>:
MOR: Morrison et al. (2005, 2009)
MY2: Milbrandt and Yau (2005)

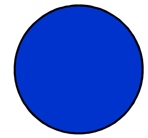
Ice Phase

TRADITIONAL:

SNOW
$\rho_s = f(D_s)$
$V = a_s D^{bs}$



GRAUPEL
$\rho_g = 400 \text{ kg m}^{-3}$
$V = a_g D^{bg}$

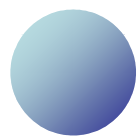


HAIL
$\rho_h = 900 \text{ kg m}^{-3}$
$V = a_h D^{bh}$

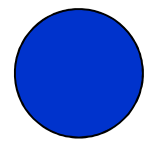
← ***abrupt / unphysical conversions***

MODIFICATION:*

SNOW
$\rho_s = f(D_s)$
$V = a_s D^{bs}$



GRAUPEL
ρ_g is *predicted* *
$V = a_g(\rho_g) D^{bg(\rho_g)}$



HAIL
$\rho_h = 900 \text{ kg m}^{-3}$
$V = a_h D^{bh}$

← ***smooth conversions***

Qs, Ns ***Qg, Ng, Bg*** ***Qh, Nh***

<u>Partial</u> mitigation to the problems with pre-defined categories

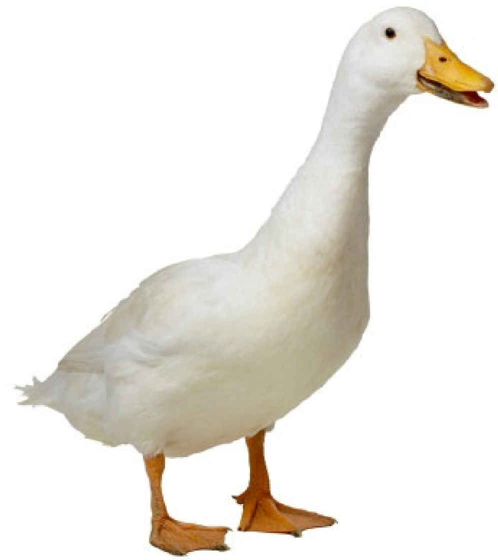
* Milbrandt and Morrison (2013), *JAS*

Which of the following is more duck-like?

DUCK

SQUEAK!

QUACK!



- **has a label that says “DUCK”**
- big, round eyes
- plastic exterior, hollow interior
- yellow, wing-like appendages
- no feet
- makes a “squeak” noise

- **has no label**
- small, round eyes
- feathery exterior, meaty interior
- white, wing-like appendages
- webbed feet
- makes a “quack” noise

IF IT QUACKS LIKE A DUCK …

2. Overview of P3

New Bulk Microphysics Parameterization:

Predicted Particle Properties (P3) Scheme*

Based on a conceptually different approach to parameterize ice-phase microphysics.

NEW CONCEPT

"free" category – predicted properties, thus freely evolving type

"fixed" category – traditional; prescribed properties, predetermined type

Compared to traditional (ice-phase) schemes, P3:

- avoids some necessary evils (category conversion, fixed properties)
- has self-consistent physics
- is better linked to observations
- is more computationally efficient

* Morrison and Milbrandt (2014)
[P3, part 1] *J. Atmos. Sci.* (in press)

Prognostic Variables: (advected)

LIQUID PHASE: 2 categories, 2-moment:

- $\boldsymbol{Q_c}$ – cloud mass mixing ratio [kg kg^{-1}]
- $\boldsymbol{Q_r}$ – rain mass mixing ratio [kg kg^{-1}]
- $\boldsymbol{N_c}$ – cloud number mixing ratio [#kg^{-1}]
- $\boldsymbol{N_r}$ – rain number mixing ratio [#kg^{-1}]

ICE PHASE: *nCat* categories, 4 prognostic variables each:

- $\boldsymbol{Q_{dep}}(n)$* – deposition ice mass mixing ratio [kg kg^{-1}]
- $\boldsymbol{Q_{rim}}(n)$ – rime ice mass mixing ratio [kg kg^{-1}]
- $\boldsymbol{N_{tot}}(n)$ – total ice number mixing ratio [# kg^{-1}]
- $\boldsymbol{B_{rim}}(n)$ – rime ice volume mixing ratio [m^3 kg^{-1}]

* $Q_{tot} = Q_{dep} + Q_{rim}$, total ice mass mixing ratio (actual advected variable)

Overview of P3 Scheme

A given (*free)* category can represent any type of ice-phase hydrometeor

Prognostic Variables:

$\boldsymbol{Q_{dep}}$ – deposition ice mass mixing ratio [kg kg^{-1}]

$\boldsymbol{Q_{rim}}$ – rime ice mass mixing ratio [kg kg^{-1}]

$\boldsymbol{N_{tot}}$ – total ice number mixing ratio [# kg^{-1}]

$\boldsymbol{B_{rim}}$ – rime ice volume mixing ratio [m^3 kg^{-1}]

Predicted Properties:

$\boldsymbol{F_{rim}}$ – rime mass fraction, $F_{rim} = Q_{rim} / (Q_{dep} + Q_{rim})$ [--]

$\boldsymbol{\rho_{rim}}$ – rime density, $\rho_{rim} = Q_{rim} / B_{rim}$ [kg m^{-3}]

$\boldsymbol{D_m}$ – mean-mass diameter, $D_m \propto (Q_{dep} + Q_{rim}) / N_{tot}$ [m]

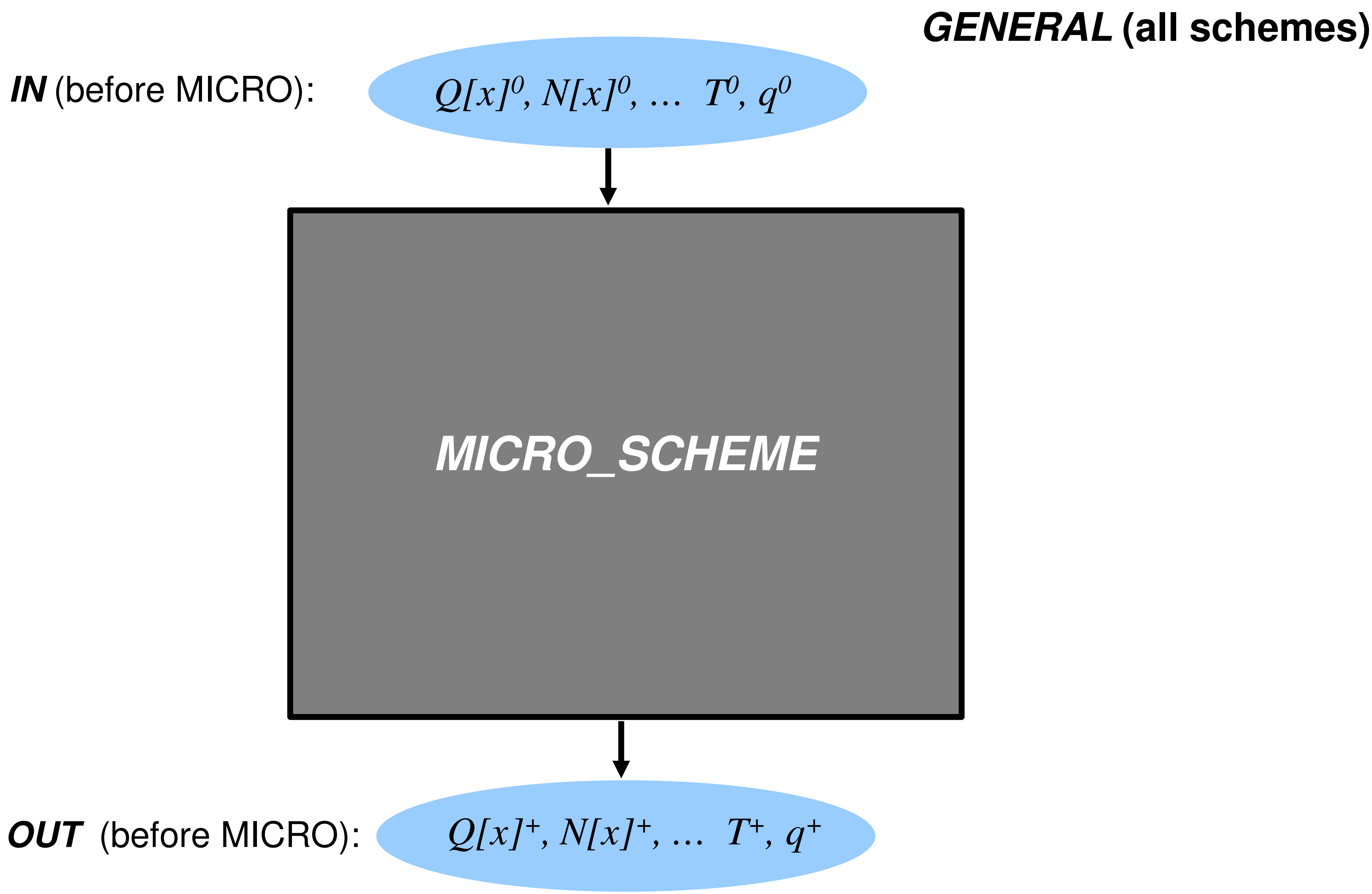
$\boldsymbol{V_m}$ – mass-weighted fall speed, $V_m = f(D_m, \rho_{rim}, F_{rim})$ [m s^{-1}]

etc.

Diagnostic Particle Types:

Based on the <u>predicted properties</u> (rather than pre-defined)

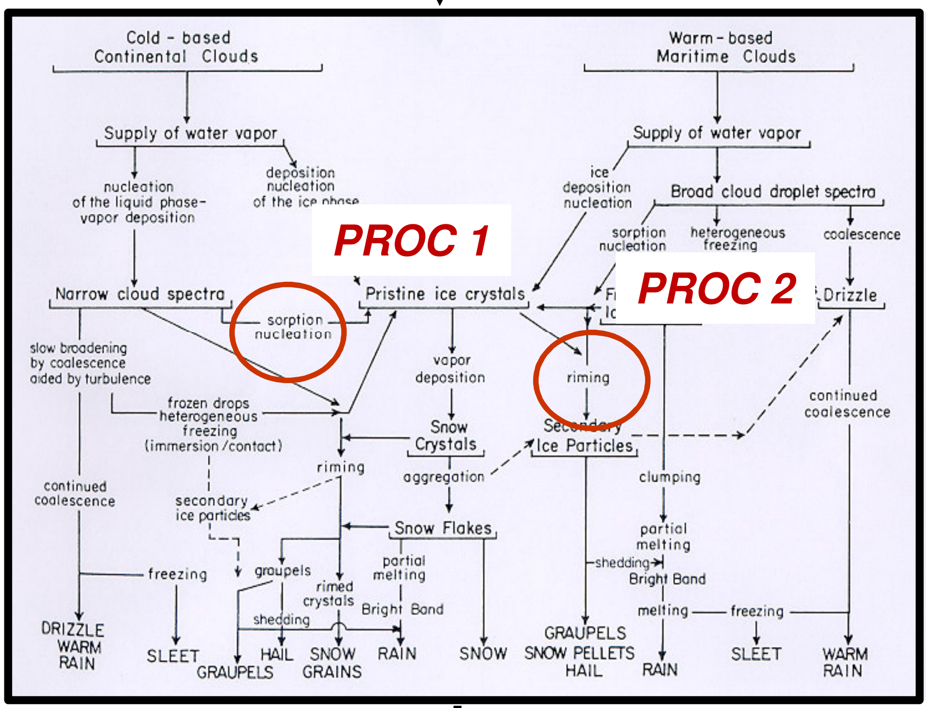
Overview of P3 Scheme



Overview of P3 Scheme

GENERAL **(all schemes)**

IN (before MICRO): $Q[x]^0, N[x]^0, \ldots\ T^0, q^0$

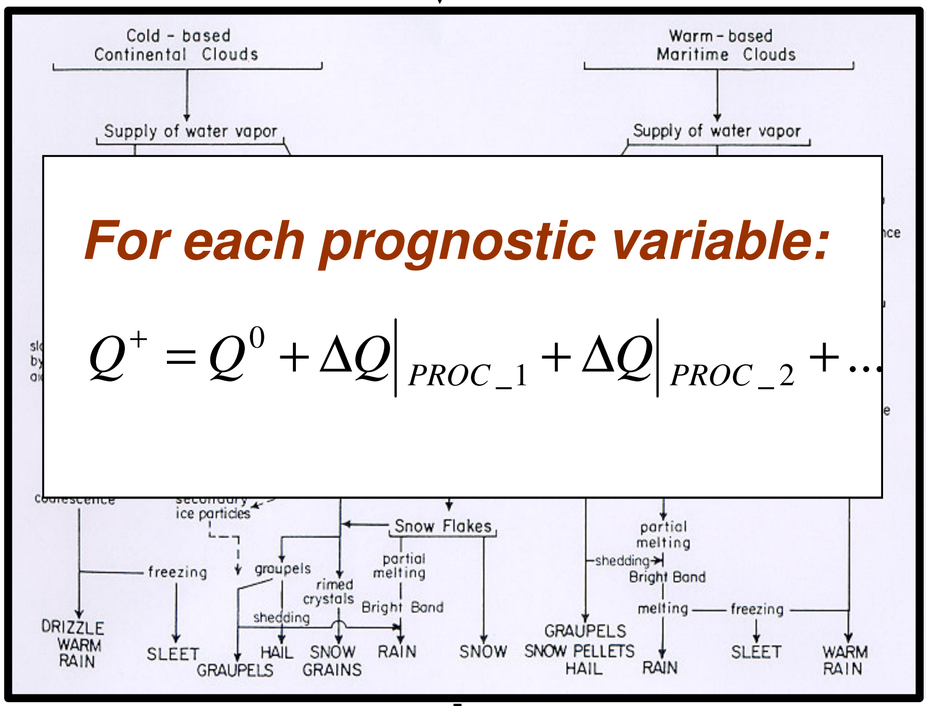


OUT (before MICRO): $Q[x]^+, N[x]^+, \ldots\ T^+, q^+$

Overview of P3 Scheme

***GENERAL* (all schemes)**

IN (before MICRO): $Q[x]^0, N[x]^0, \dots \; T^0, q^0$



For each prognostic variable:

$$Q^{+} = Q^{0} + \Delta Q\big|_{PROC\_1} + \Delta Q\big|_{PROC\_2} + \dots$$

OUT (before MICRO): $Q[x]^+, N[x]^+, \dots \; T^+, q^+$

GENERAL **(all schemes)**

$$Q^{+} = Q^{0} + \underbrace{\Delta Q\big|_{PROC\_1}} + \Delta Q\big|_{PROC\_2} + \ldots$$

$$\Delta Q\big|_{PROC\_1} = \Delta t \cdot \frac{1}{\rho} \underbrace{\int_0^\infty \frac{dm(D)}{dt}\Big|_{PROC\_1} N(D)dD}$$

$\propto M^{(p)}$ (and other moments)

Computing the tendencies for the prognostic variables (i.e. process rates) essentially amounts to computing various moments of $N(D)$

Predicting process rates for V_x **→** ***computing various*** $M_x^{(p)}$

$$M^{(p)} = \int_0^\infty D^p N(D)dD = \int_0^\infty D^{p+\mu} e^{-\lambda D} dD$$

$$N_x(D) = N_{0x} D^{\mu_x} e^{-\lambda_x D}$$

V = prognostic variable (*Q*, *N*, …)
x = category (rain, ice, …)

Predicting process rates ~ computing $M_x^{(p)}$

***TRADITIONAL SCHEMES* (e.g. 2-moment)**

$$M^{(p)} \equiv \int_0^\infty D^p N_x(D)dD = N_{0x}\frac{\Gamma(1+\mu_x+p)}{\lambda_x^{p+1+\mu_x}}$$

Fixed categories, therefore *m-D* parameters* are constants

$$Q = \frac{1}{\rho}\int_0^\infty m(D)N(D)dD = \frac{1}{\rho}\int_0^\infty \alpha D^\beta N_x(D)dD = \frac{\alpha}{\rho}M^{(\beta)} = \frac{\alpha}{\rho}N_{0x}\frac{\Gamma(1+\mu_x+\beta)}{\lambda_x^{1+\mu_x+\beta}}$$

$$N = \int_0^\infty N_x(D)dD = M^{(0)} = N_{0x}\frac{\Gamma(1+\mu_x)}{\lambda_x^{1+\mu_x}}$$

- impose assumption about μ
- 2 equations, 2 unknowns → solve for λ, N_0

→ Now, any $M^{(p)}$ can be computed analytically

* $m(D) = \alpha D^\beta$

Predicting process rates ~ computing $M_x^{(p)}$

P3 SCHEME

$$M^{(p)} \equiv \int_0^\infty D^p N_x(D)dD = N_{0x}\frac{\Gamma(1+\mu_x+p)}{\lambda_x^{p+1+\mu_x}}$$

Fixed category ⇨ constant m-D parameters

Free category ⇨ variable m-D parameters

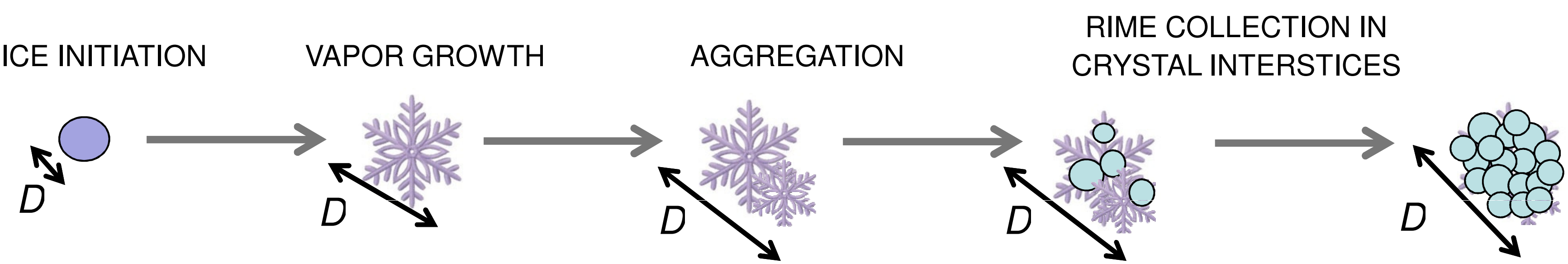
$$Q = \frac{1}{\rho}\int_0^\infty m(D)N(D)dD = \frac{1}{\rho}\int_0^\infty \alpha D^\beta N_x(D)dD = \frac{\alpha}{\rho}M^{(\beta)} = \frac{\alpha}{\rho}N_{0x}\frac{\Gamma(1+\mu_x+\beta)}{\lambda_x^{1+\mu_x+\beta}}$$

→ cannot compute Q analytically (or any other $M^{(p)}$)

Predicting process rates ~ computing $M_x^{(p)}$

P3 SCHEME – Determining $m(D) = \alpha D^{\beta}$ for regions of D:

Conceptual model of particle growth following Heymsfield (1982):



spherical ice
$\alpha = \pi/6\ \rho_{bulk\_ice}$
$\beta = 3$

unrimed crystals
$\alpha = \text{const}$
$\beta \sim 2$

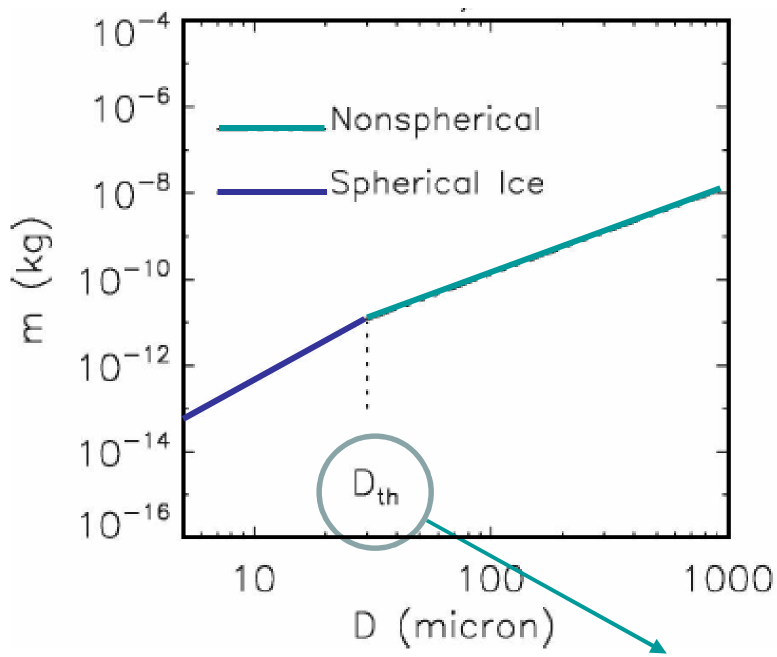
partially rimed crystal
$\alpha = f(F_{rim}, \rho_{rim})$
$\beta \sim 2$

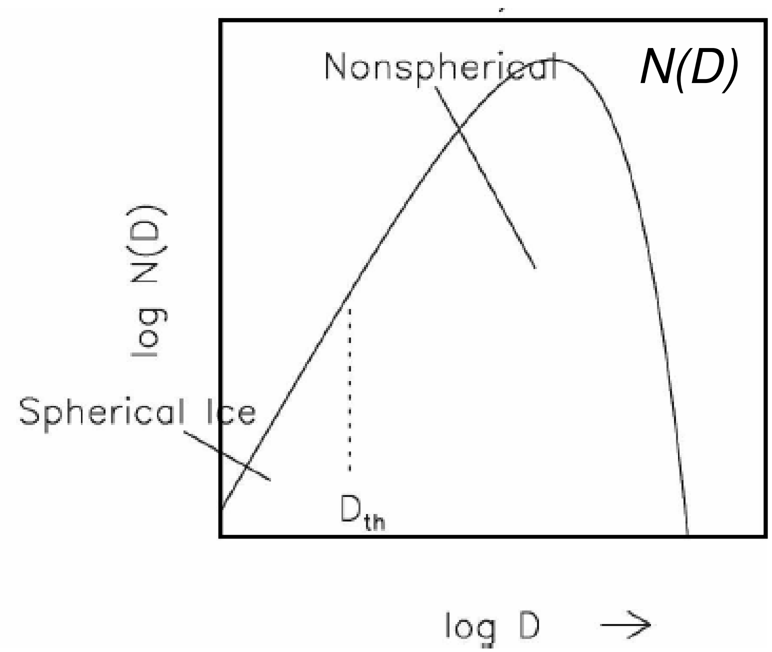
spherical graupel
$\alpha = \pi/6\ \rho_{grpl}$
$\beta = 3$

Predicting process rates ~ computing $M_x^{(p)}$

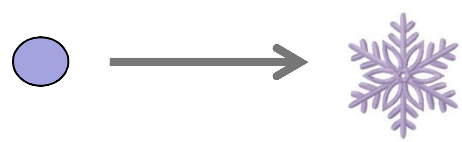
P3 SCHEME – **Determining $m(D) = \alpha D^{\beta}$ for regions of D:**

e.g. F_{rim} **= 0**





conceptual model + algebraic derivation



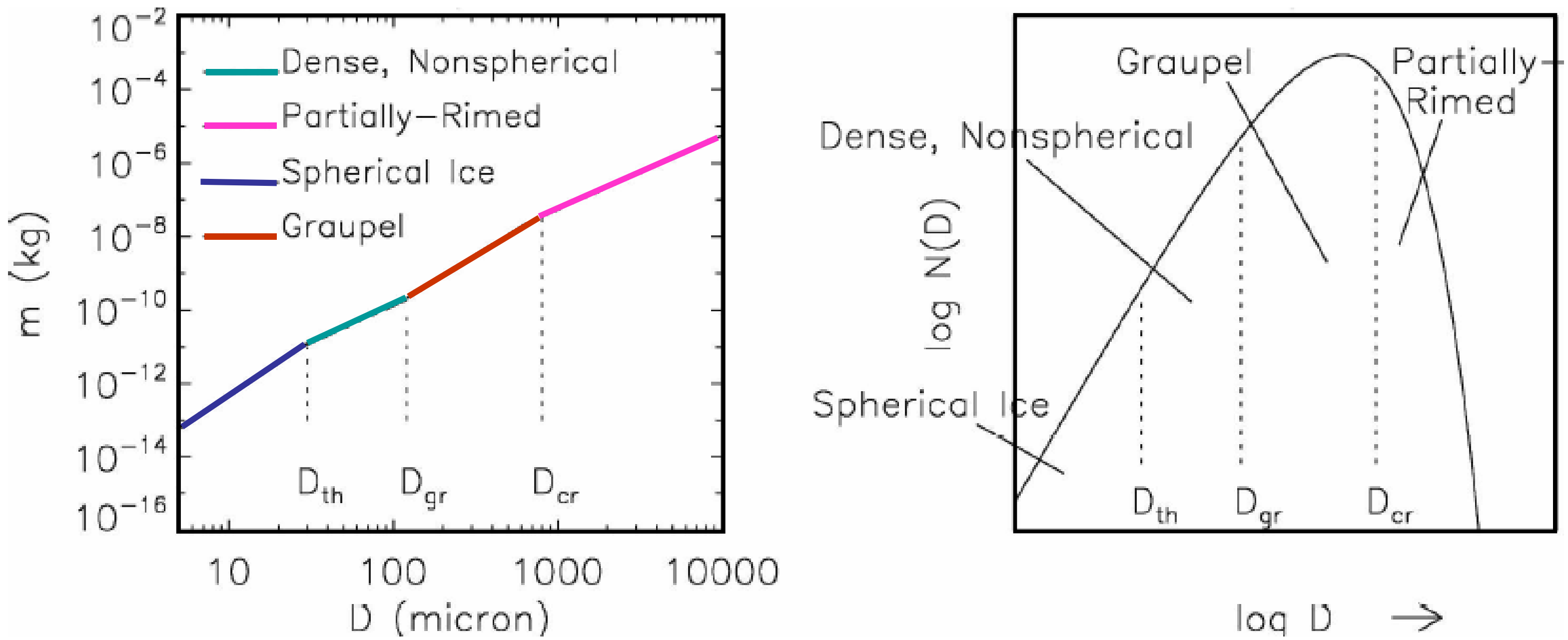
spherical ice
$\alpha_1 = \pi/6\ \rho_{bulk\_ice}$
$\beta_1 = 3$

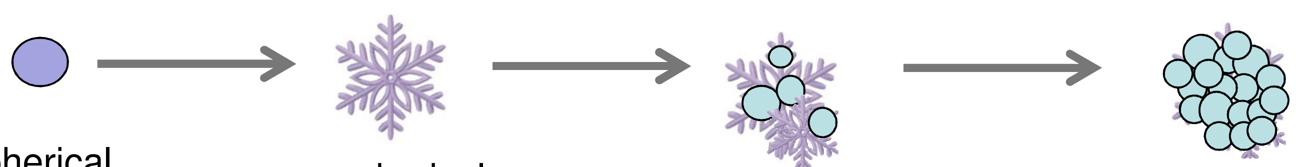
unrimed, non-spherical crystals
α_2 = const
$\beta_2 \sim 2$
} based on observed crystals

Predicting process rates ~ computing $M_x^{(p)}$

P3 SCHEME – **Determining $m(D) = \alpha D^{\beta}$ for regions of D:**

e.g. **1 > F_{rim} > 0; for a given ρ_{rim}**





spherical unrimed	non-spherical unrimed	non-spherical, partially rimed	spherical completely rimed
$m(D) = \alpha_1 D^{\beta 1}$	$m(D) = \alpha_2 D^{\beta 2}$	$m(D) = \alpha_3 D^{\beta 3}$	$m(D) = \alpha_4 D^{\beta 4}$

Predicting process rates ~ computing $M_x^{(p)}$

P3 SCHEME – Computing $N(D)$ parameters :

1. Compute properties $F_{rim} = Q_{rim}/(Q_{dep}+Q_{rim})$, $\rho_{rim} = Q_{rim} / B_{rim}$
2. Determine integral ranges, D_{th}, D_{gr}, D_{cr}
3. Determine PSD parameters (λ, N_0, μ)
   - apply definitions of Q_{tot} and N_{tot}

$$Q = \frac{1}{\rho}\left[\int_0^{D_{th}} \alpha_1 D^{\beta_1+\mu} e^{-\lambda D} dD + \int_{D_{th}}^{D_{gr}} \alpha_2 D^{\beta_2+\mu} e^{-\lambda D} dD + \int_{D_{gr}}^{D_{cr}} \alpha_3 D^{\beta_3+\mu} e^{-\lambda D} dD + \int_{D_{cr}}^{\infty} \alpha_4 D^{\beta_4+\mu} e^{-\lambda D} dD\right]$$

$$N = N_{0x} \frac{\Gamma(1+\mu_x)}{\lambda_x^{1+\mu_x}}$$

$$\mu = f(\lambda)$$

   - solved numerically (iteratively; pre-computed and stored in look-up table)

4. Also, match A-D parameters to m-D parameters for the various regions of D
   - based on geometric + empirical relations
   - for V-D (process rates and sedimentation) and r_{i_eff} (optical properties)

Predicting process rates ~ computing $M_x^{(p)}$

P3 SCHEME – Computing the process rates:

Now, have λ, N_0, μ, and integral ranges D_{th}, D_{gr}, D_{cr} (plus $\alpha_{(i)}$, $\beta_{(i)}$, …)

RECALL:

GENERAL

$$Q^+ = Q^0 + \underbrace{\Delta Q\big|_{PROC\_1}} + \Delta Q\big|_{PROC\_2} + \ldots$$

$$\Delta Q\big|_{PROC\_1} = \Delta t \cdot \frac{1}{\rho}\underbrace{\int_0^\infty \frac{dm(D)}{dt}\bigg|_{PROC\_1} N(D)dD}$$

$\propto M^{(p)}$ (and other moments)

Predicting process rates → computing various $M^{(p)}$

Predicting process rates ~ computing $M_x^{(p)}$

P3 SCHEME – Computing the process rates:

Now, have λ, N_0, μ, and integral ranges D_{th}, D_{gr}, D_{cr} (plus $\alpha_{(i)}$, $\beta_{(i)}$, …)

ACTUALLY, FOR P3:

$$Q^{+} = Q^{0} + \underbrace{\Delta Q\big|_{PROC\_1}} + \Delta Q\big|_{PROC\_2} + \ldots$$

$$\Delta Q\big|_{PROC\_1} = \Delta t \cdot \frac{1}{\rho} \underbrace{\int_0^{\infty} \frac{dm(D)}{dt}\Big|_{PROC\_1} N(D)dD}$$

$\propto X_1$ (and X_2, …)

$$X_1 = \int_0^{D_{th}} D^a N_0 e^{-\lambda D} f(\alpha_1, \beta_1, \ldots) dD + \int_{D_{th}}^{D_{gr}} D^b N_0 e^{-\lambda D} f(\alpha_2, \beta_2, \ldots) dD$$

$$+ \int_{D_{gr}}^{D_{cr}} D^c N_0 e^{-\lambda D} f(\alpha_3, \beta_3, \ldots) dD + \int_{D_{cr}}^{\infty} D^d N_0 e^{-\lambda D} f(\alpha_4, \beta_4, \ldots) dD$$

Predicting process rates → computing sums (X_n) of partial moments

Predicting process rates ~ computing $M_x^{(p)}$

P3 SCHEME – Computing the process rates:

Now, have λ, N_0, μ, and integral ranges D_{th}, D_{gr}, D_{cr} (plus $\alpha_{(i)}$, $\beta_{(i)}$, …)

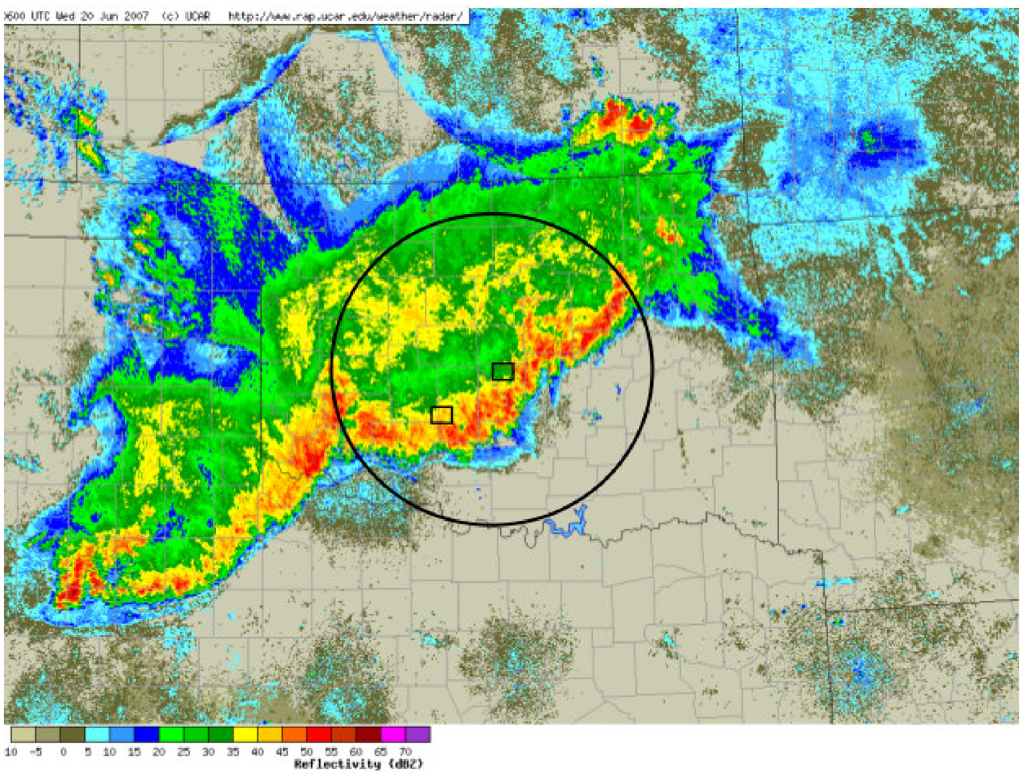
$$X_1 = \int_0^{D_{th}} D^a N_0 e^{-\lambda D} f(\alpha_1, \beta_1, \ldots) dD + \int_{D_{th}}^{D_{gr}} D^b N_0 e^{-\lambda D} f(\alpha_2, \beta_2, \ldots) dD$$
$$+ \int_{D_{gr}}^{D_{cr}} D^c N_0 e^{-\lambda D} f(\alpha_3, \beta_3, \ldots) dD + \int_{D_{cr}}^{\infty} D^d N_0 e^{-\lambda D} f(\alpha_4, \beta_4, \ldots) dD$$

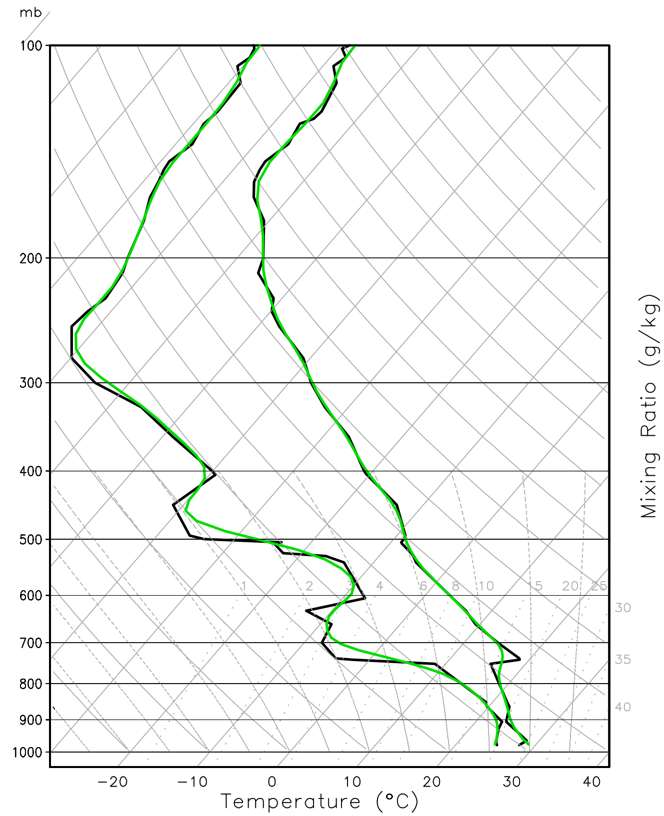
- All process rates are proportional to one or more sums (X_1) of sub-moments
- Relevant sums of sub-moments are pre-computed (accurately) and stored in a look-up table
- At run time, values of X_1, X_2,.. are accessed (quickly) via look-up table → actual computation of $\Delta Q|_{PROC\_x}$ is fast

3. Model Results

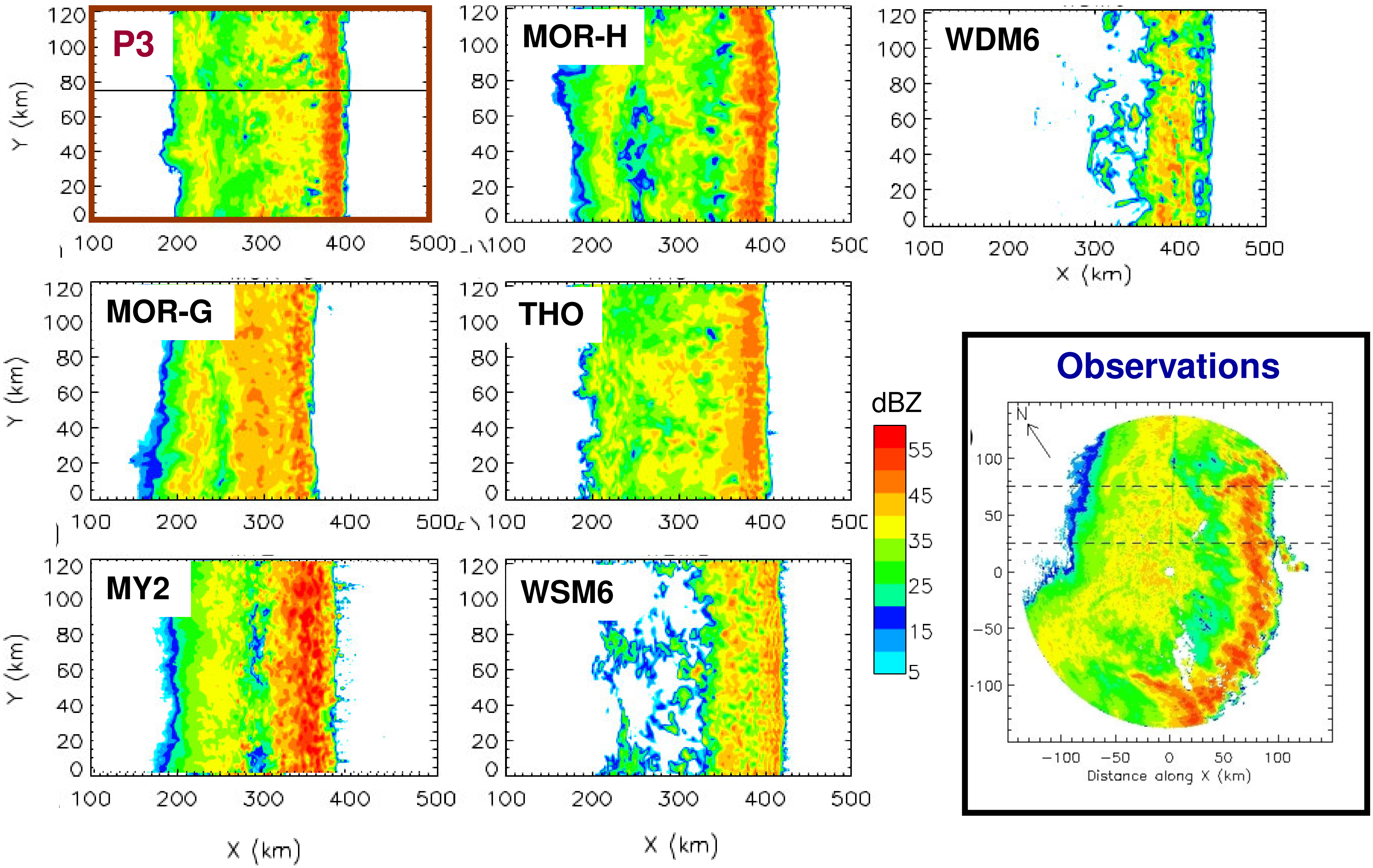
3D Squall Line case:
(June 20, 2007 central Oklahoma)

- WRF_v3.4.1, Δx = 1 km, Δz ~ 250-300 m, 112 x 612 x 24 km domain
- initial sounding from observations
- convection initiated by *u*-convergence
- no radiation, surface fluxes



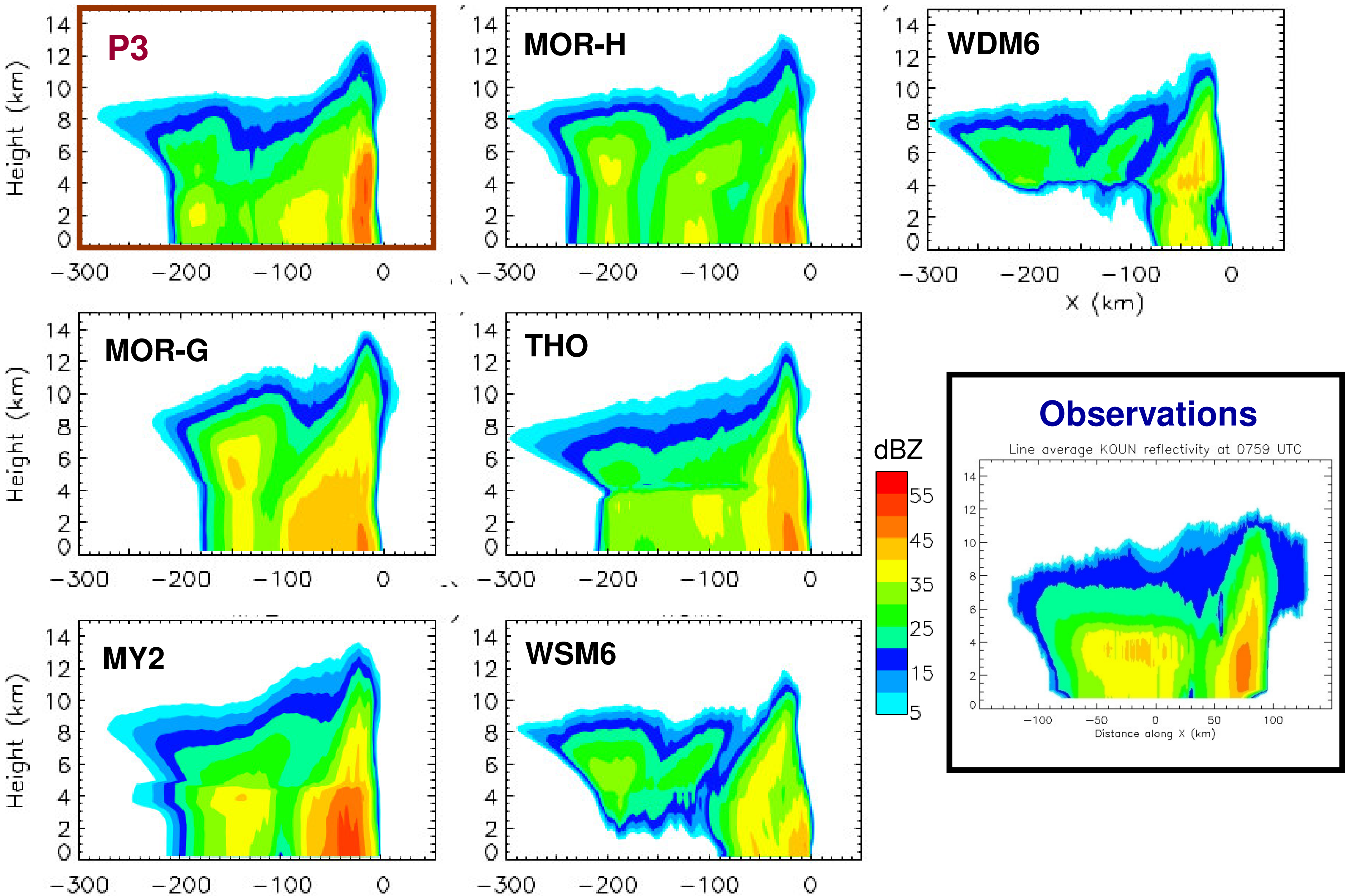


WRF Results: Base Reflectivity (1 km AGL, t = 6 h)



Morrison et al. (2014) [P3, part 2]

WRF Results: Line-averaged Reflectivity (t = 6 h)



F_r ~ 0-0.1
ρ ~ 900 kg m-3
V ~ 0.3 m s^{-1}
D_m ~ 100 µm
→ ***small crystals***

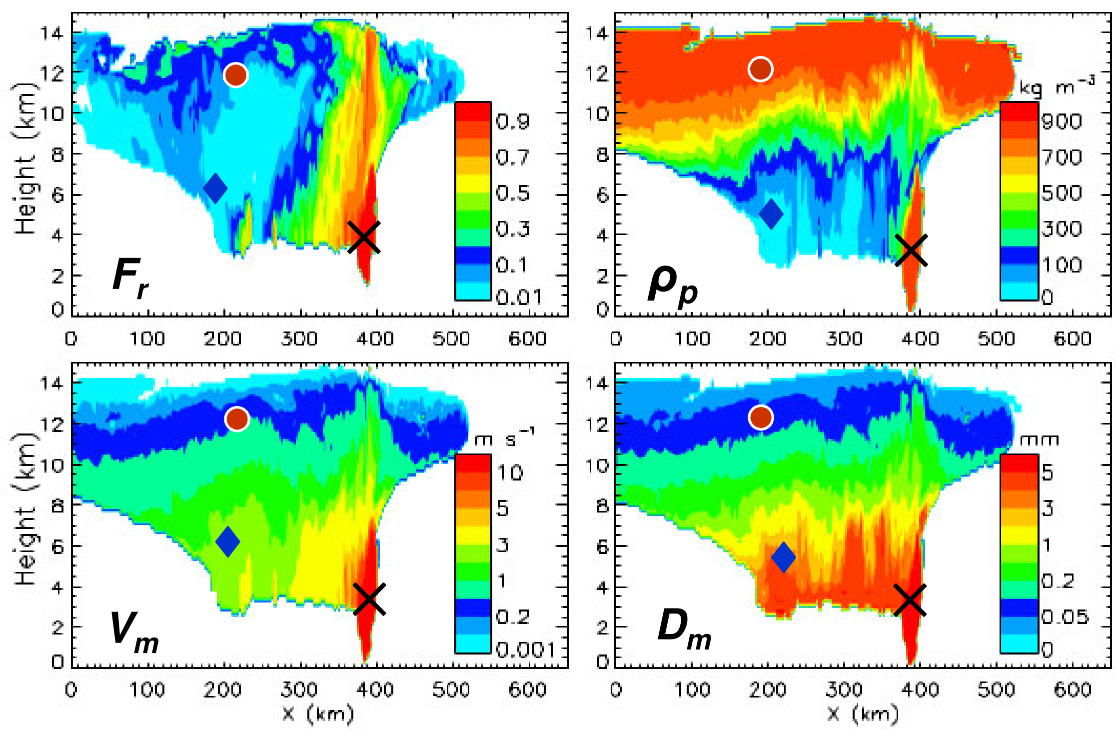
F_r ~ 0
ρ ~ 50 kg m-3
V ~ 1 m s^{-1}
D_m ~ 3 mm
→ ***aggregates***

F_r ~ 1
ρ ~ 900 kg m^{-3}
V > 10 m s^{-1}
D_m > 5 mm
→ ***hail***

etc.

Vertical cross section of model fields (*t* = 6 h)

Ice Particle Properties:



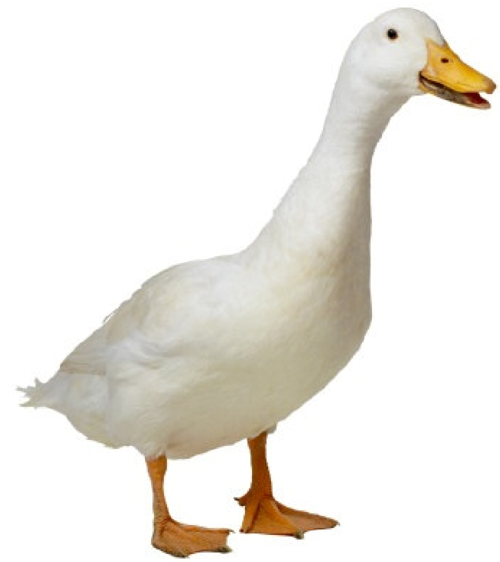
Note – only one (free) category

F_r ~ 0-0.1
ρ ~ 900 kg m-3
V ~ 0.3 m s^{-1}
D_m ~ 100 μm
→ ***small crystals***

F_r ~ 0
ρ ~ 50 kg m-3
V ~ 1 m s^{-1}
D_m ~ 3 mm
→ ***aggregates***

F_r ~ 1
ρ ~ 900 kg m^{-3}
V > 10 m s^{-1}
D_m > 5 mm
→ ***hail***

etc.

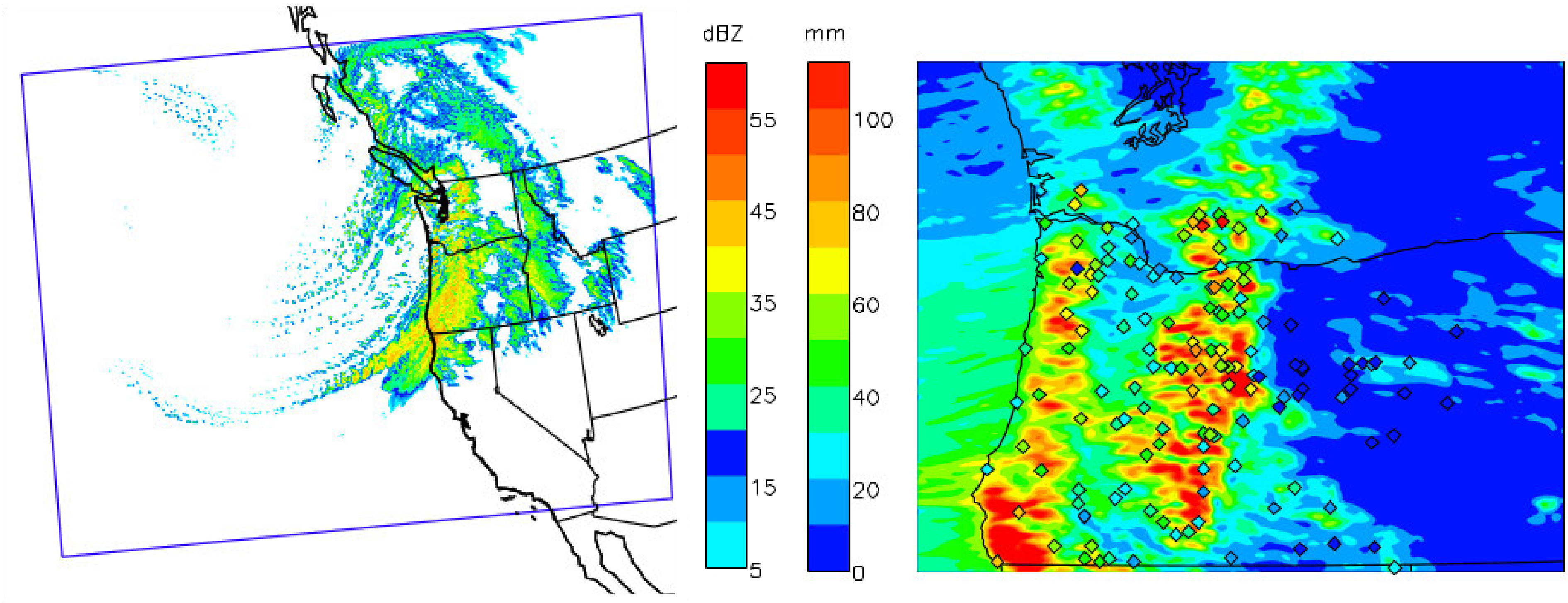


- small, round eyes
- feathery exterior, meaty interior
- white, wing-like appendages
- webbed feet
- makes a "quack" noise

→ ***duck***

Frontal/orographic case:
IMPROVE-2, 13-14 December 2001

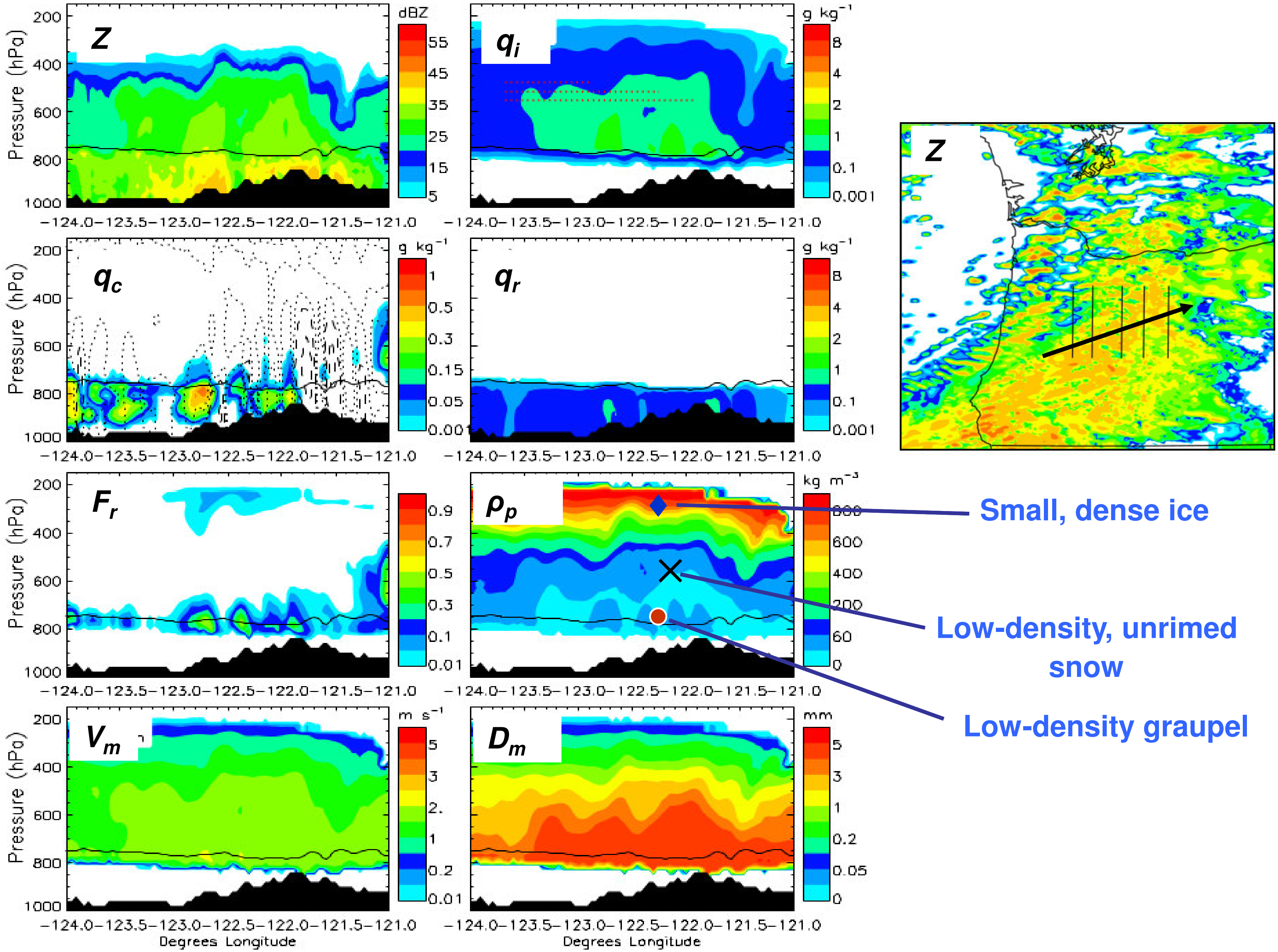
- WRF_v3.4.1, Δx = 3 km, 72 stretched vertical levels



Simulated lowest level **REFLECTIVITY**
(00 UTC December 14)

Accumulated **PRECIPITATION**
(14 UTC Dec 13 - 08 UTC Dec 14)

Morrison et al. (2014) [P3, part 2]



Z
q_i
q_c
q_r
F_r
ρ_p
V_m
D_m
Pressure (hPa)
Degrees Longitude
dBZ
g kg^{-1}
kg m^{-3}
m s^{-1}
mm
Small, dense ice
Low-density, unrimed snow
Low-density graupel

Timing Tests for 3D WRF Simulations

Scheme	Squall line case (Δx = 1 km)	Orographic case (Δx = 3 km)	# prognostic variables
P3	0.436 (**1.043**)	0.686 (**1.013**)	**7**
MY2	0.621 (1.485)	1.012 (1.495)	12
MOR-H	0.503 (1.203)	0.813 (1.200)	9
THO	0.477 (1.141)	0.795 (1.174)	7
WSM6	0.418 (**1.000**)	0.677 (**1.000**)	**5**
WDM6	0.489 (1.170)	0.777 (1.148)	8

- Average wall clock time per model time step (units of seconds.)
- Times relative to those of WSM6 are indicated parenthetically.

→ P3 is one of the fastest schemes in WRF

NOAA Hazardous Weather Testbed

2014 Spring Forecasting Experiment

05 May - 06 June 2014

The **NOAA HWT Spring Forecasting Experiment** is a yearly experiment that investigates the use of convection-allowing model forecasts as guidance for the prediction of hazardous convective weather. A variety of model output is examined and evaluated daily, and experimental forecasts are created and verified to test the applicability of cutting-edge tools in a simulated forecasting environment. The variety of model output allows us to explore different types of guidance, including products derived from both ensembles and deterministic forecasts, and to provide focused feedback to model developers.

The **2014 Spring Forecasting Experiment will be held from May 5th through June 6th** in the HWT facility at the National Weather Center in Norman. The Experiment is scheduled to run Monday through Friday from 8am to 4pm. More information about this year's Experiment can be found below in the 2014 Spring Forecasting Experiment Operations Plan (see below).

Guidance Information

- Summary of 2014 Model Guidance
- File Status: NSSL | SPC

Model Guidance Graphics

- **HWT Model Comparison Page**
- Objective Verification: 1-km Sim. Reflectivity [Images w/ Scores]
- Objective Verification: 1-km Sim. Reflectivity [Score Summary]
- Experimental Ensemble graphics - All Members
- Experimental Ensemble Proxy Severe Forecast | Verification
- Experimental Ensemble 3h Proxy Severe - Forecast | Verification

Operation Plans and Procedures

- HWT Spring Forecasting Experiment Operations Plan
- CAPS Spring Forecasting Experiment Program Plan

Evaluation Forms (internal)

- SE2014 - Evaluation of Yesterday's Forecasts: SPC Desk
- SE2014 - Evaluation of Yesterday's Forecasts: NSSL/Dev Desk
- SE2014 - Evaluation of Convection-Allowing Ensembles
- SE2014 - Evaluation of EMC Parallel CAMs
- SE2014 - HAILCAST Evaluation
- SE2014 - Microphysics comparisons
- SE2014 - NSSL-WRF UKmet comparisons

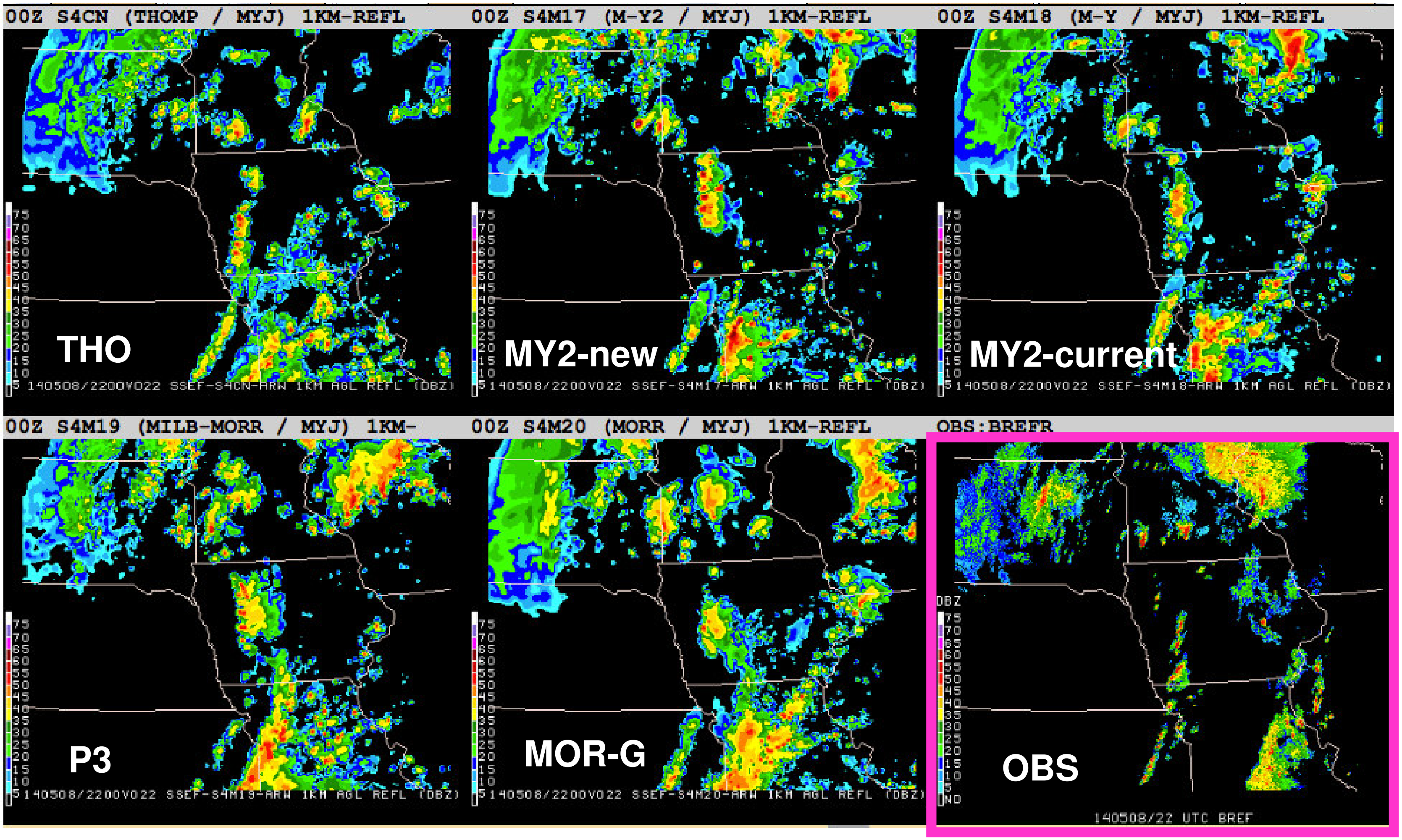
Experimental Forecasts

- 2014 Experimental Forecast Verification - Severe Convection
- 2014 Hourly Probabilistic Forecasts: NSSL/Dev Desk
- Set Forecast Centerpoint
- 2014 Experimental Forecast Generation - SPC Team (Restricted)
- 2014 Experimental Forecast Generation - NSSL Team

http://hwt.nssl.noaa.gov/Spring_2014

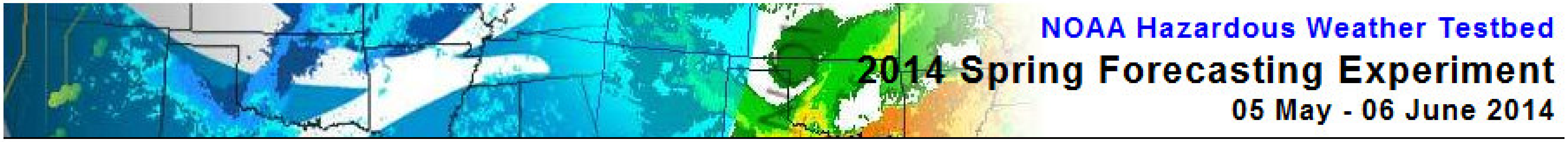
NOAA Hazardous Weather Testbed
2014 Spring Forecasting Experiment
05 May - 06 June 2014

2014 OU CAPS Ensemble (4-km WRF)*

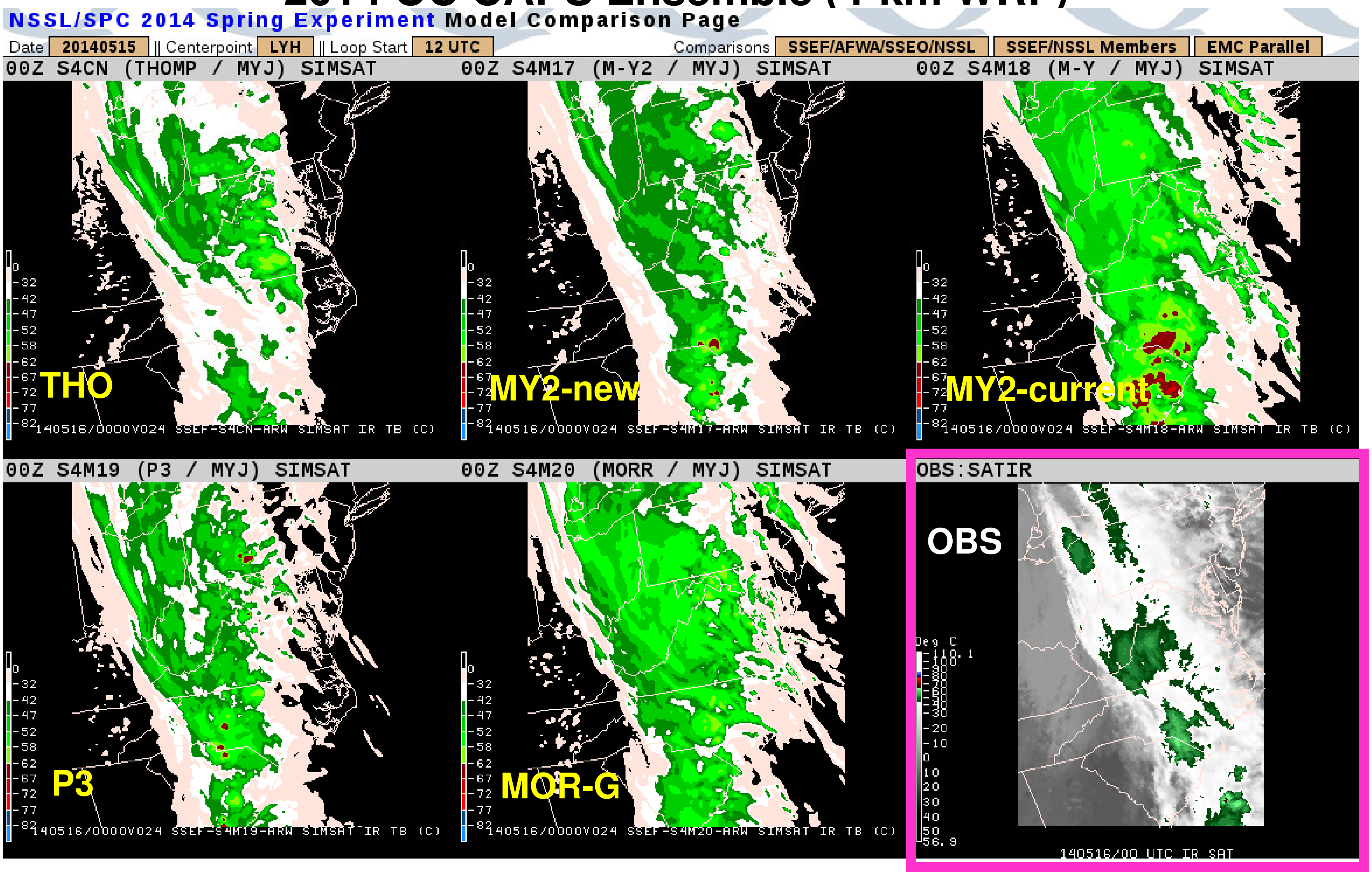


22-h FCST, 1-km Reflectivity, 22 UTC 8 May, 2014

* c/o Fanyou Kong



2014 OU CAPS Ensemble (4-km WRF)*



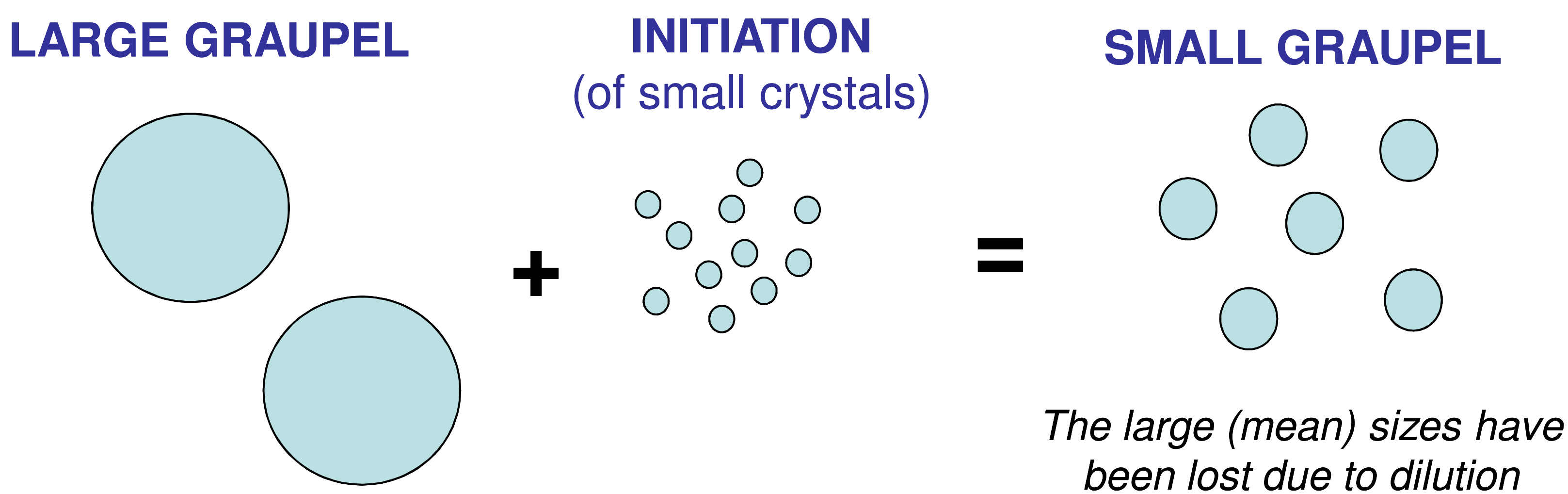
Simulated 10.7 MICRON Brightness Temperatures

* c/o Fanyou Kong

So far – despite using only 1 ice-phase category, P3 performs remarkably well compared to detailed, established (well-tuned), traditional bulk schemes

However – with 1 category, P3 has some intrinsic limitations:

- it cannot represent more than one type of particle in the same point in time and space
- As a result, there is an inherent "***dilution problem***"; the properties of populations of particles of different origins get averaged upon mixing



Single-Category Version

Morrison and Milbrandt (2014) [P3, part 1]
(in press)

All ice-phase hydrometeors represented by a single category,
with Q_{dep}, Q_{rim}, N_{tot}, B_{rim}

Processes:
1. Initiation of new particles
2. Growth/decay processes
   - interactions with water vapor
   - interactions with liquid water
   - self-collection
3. Sedimentation

Multi-Category Version

Milbrandt and Morrison (2015) [P3, part 3]
(in preparation)

All ice-phase hydrometeors represented by a ***nCat* categories**,
with Q_{dep}**(n)**, Q_{rim}**(n)**, N_{tot}**(n)**, B_{rim}**(n)** [n = 1..$nCat$]

Processes:
1. Initiation of new particles → **determine destination category**
2. Growth/decay processes
   - interactions with water vapor
   - interactions with liquid water
   - self-collection
   - **collection amongst other ice categories**
3. Sedimentation

Multi-Category Version

Initiation of new particles → **Determining destination category**

OBJECTIVE: To select the destination category of new ice such that the overall *dilution is minimized*

1. Determine category *n* with minimum *D_diff* = |*D_(n) - D_new*|
2. IF *D_diff* < *diff_Thrs* THEN
   n_Dest = *n*
   ELSE
   n_Dest = next empty category (if one is available)

NOTE: diff_Thrs = f(nCat)

diffThrs	*D_new*	D_1^0 (diff)	D_2^0 (diff)	D_3^0 (diff)	*n_Dest*	D_1^+	D_2^+	D_3^+
500	10	--	--	--	1	10	--	--
500	10	15 (5)	--	--	1	14.9	--	--
500	10	600 (590)	--	--	2	600	10	--
500	10	600 (590)	400 (390)	--	2	600	46.6	--
300	10	600 (590)	400 (390)	--	3	600	400	10
300	700	600 (100)	400 (200)	--	1	600.7	400	--
300	10	600 (590)	400 (390)	350 (340)	3	600	400	46.5
300	700	500 (100)	400 (300)	350 (350)	1	501.1	400	350

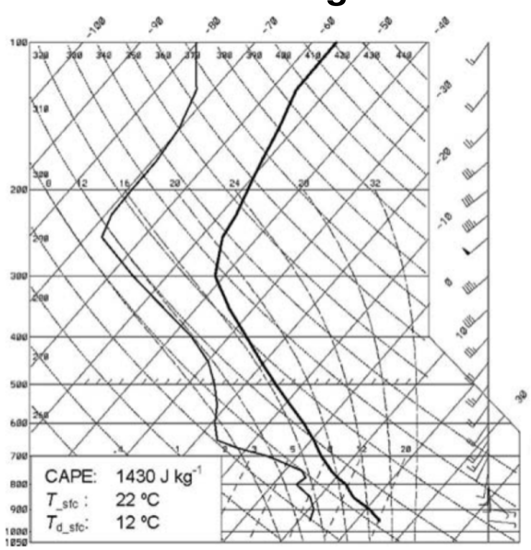
All sizes in μm

P3 – Effects of multiple categories:

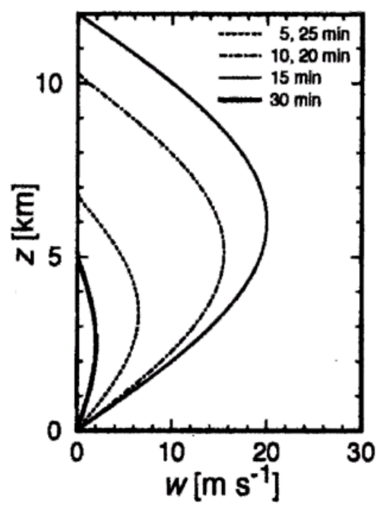
1D Kinematic Model*

- user-specified number of vertical levels
- reads in a sounding to initialize $T(p)$ and $T_d(p)$; interpolates/converts to $T(z)$ and $q_v(z)$
- during integration:
    - time-varying updraft profile (and corresponding divergence)
    - advection of T, q_v, and all hydrometeor tracers
    - call to microphysics scheme
    - output: profiles of prognostic and diagnostic variables

Initial Sounding:



Time-Varying Updraft Profile:

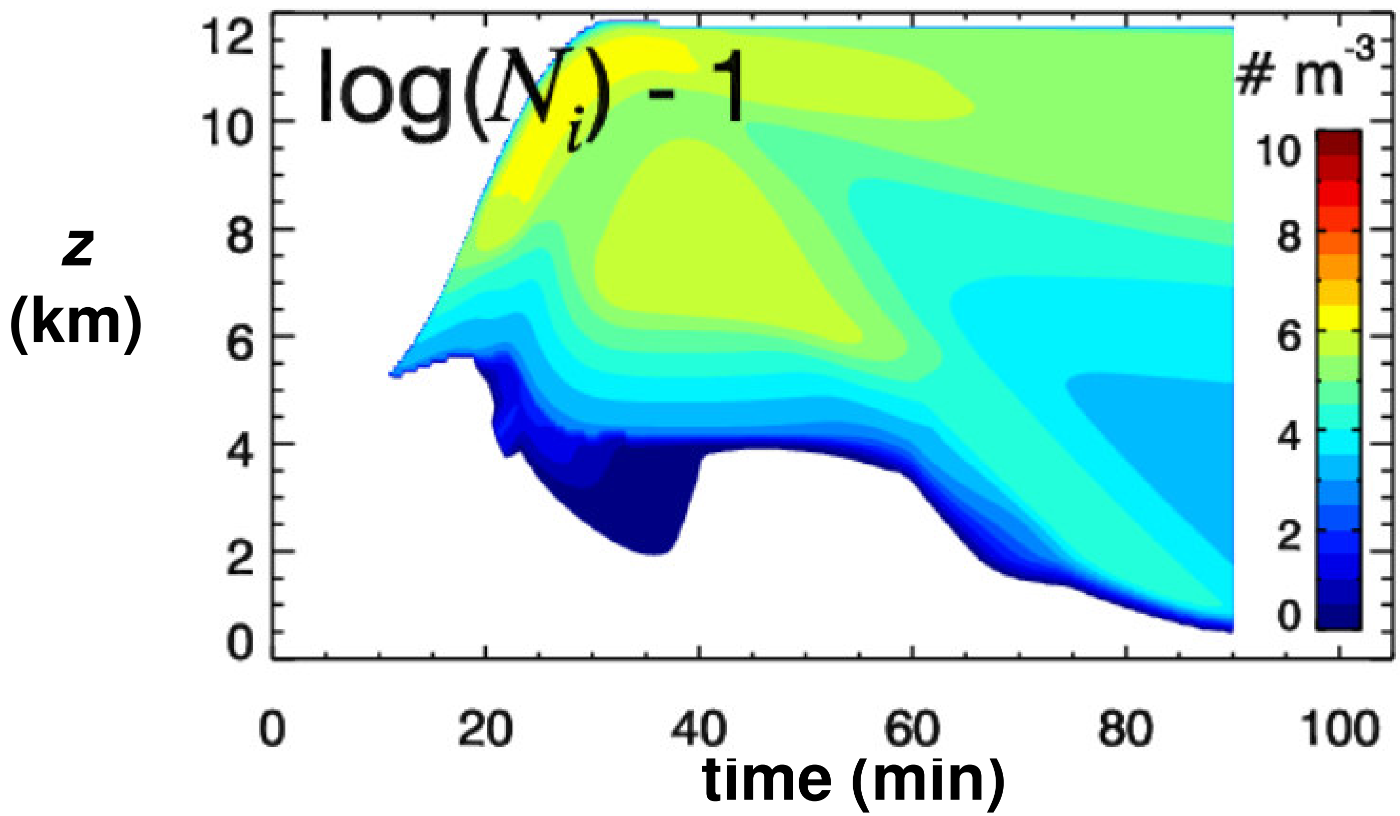


* described in Milbrandt et al. (2012)

P3 – Effects of multiple categories:

For the next few slides …

Time-height plots of output from 1D model



w_{max} = 10 m s^{-1}
$nCat$ = 1

Q_{tot}

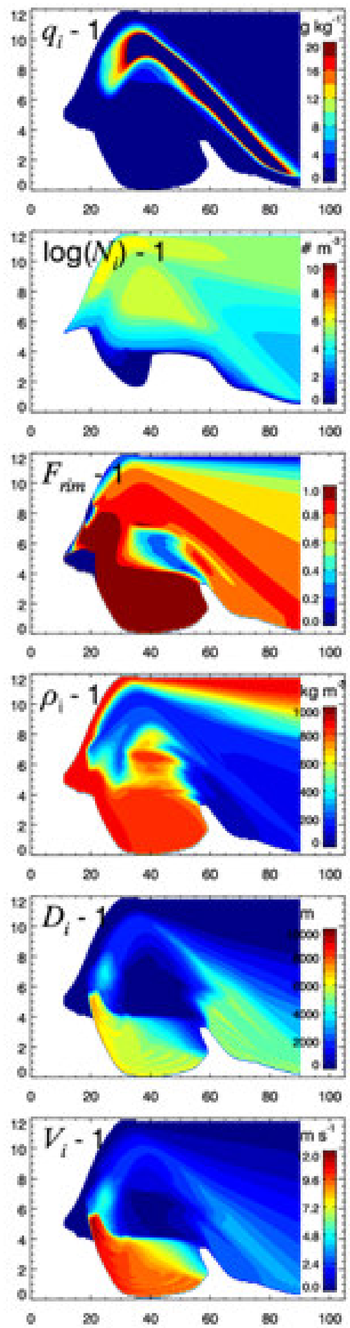
N_{tot}

F_{rim}

ρ_{ice}

D_m

V_m



w_{max} = 10 m s^{-1}
$nCat$ = 2

n = 1 | **n = 2**

$Q_{tot}(n)$

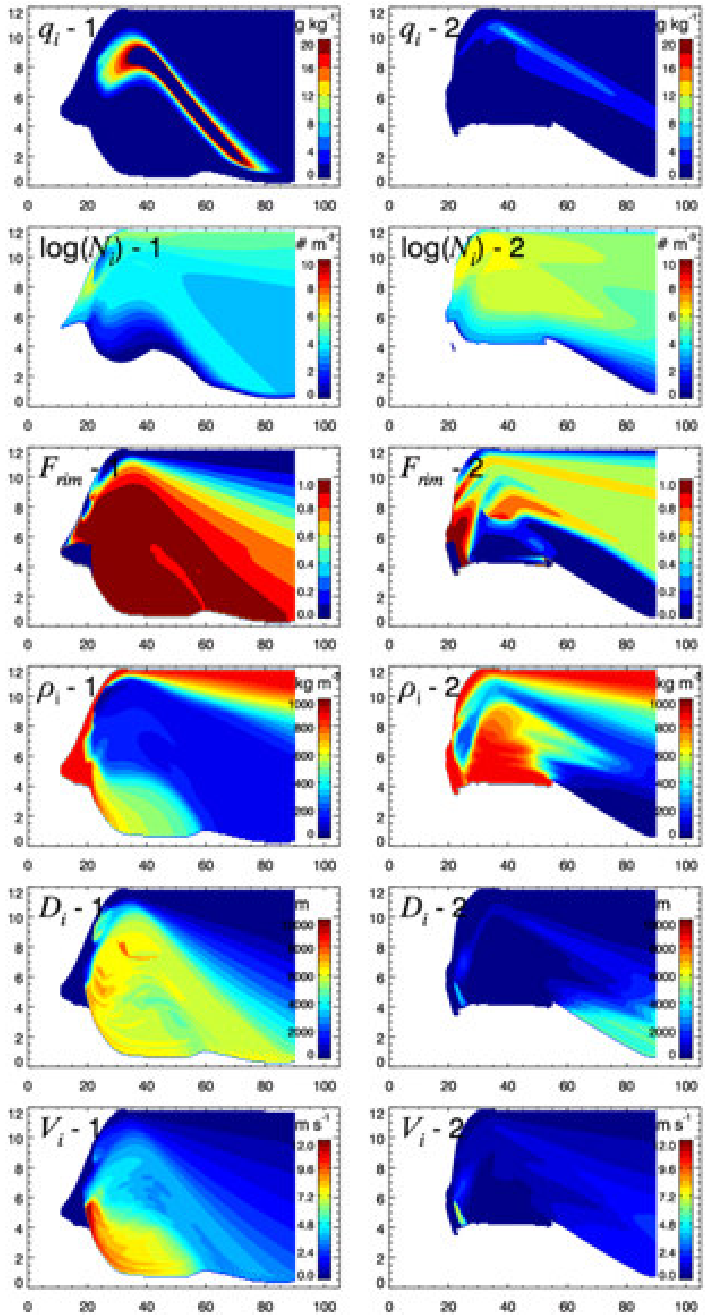
$N_{tot}(n)$

$F_{rim}(n)$

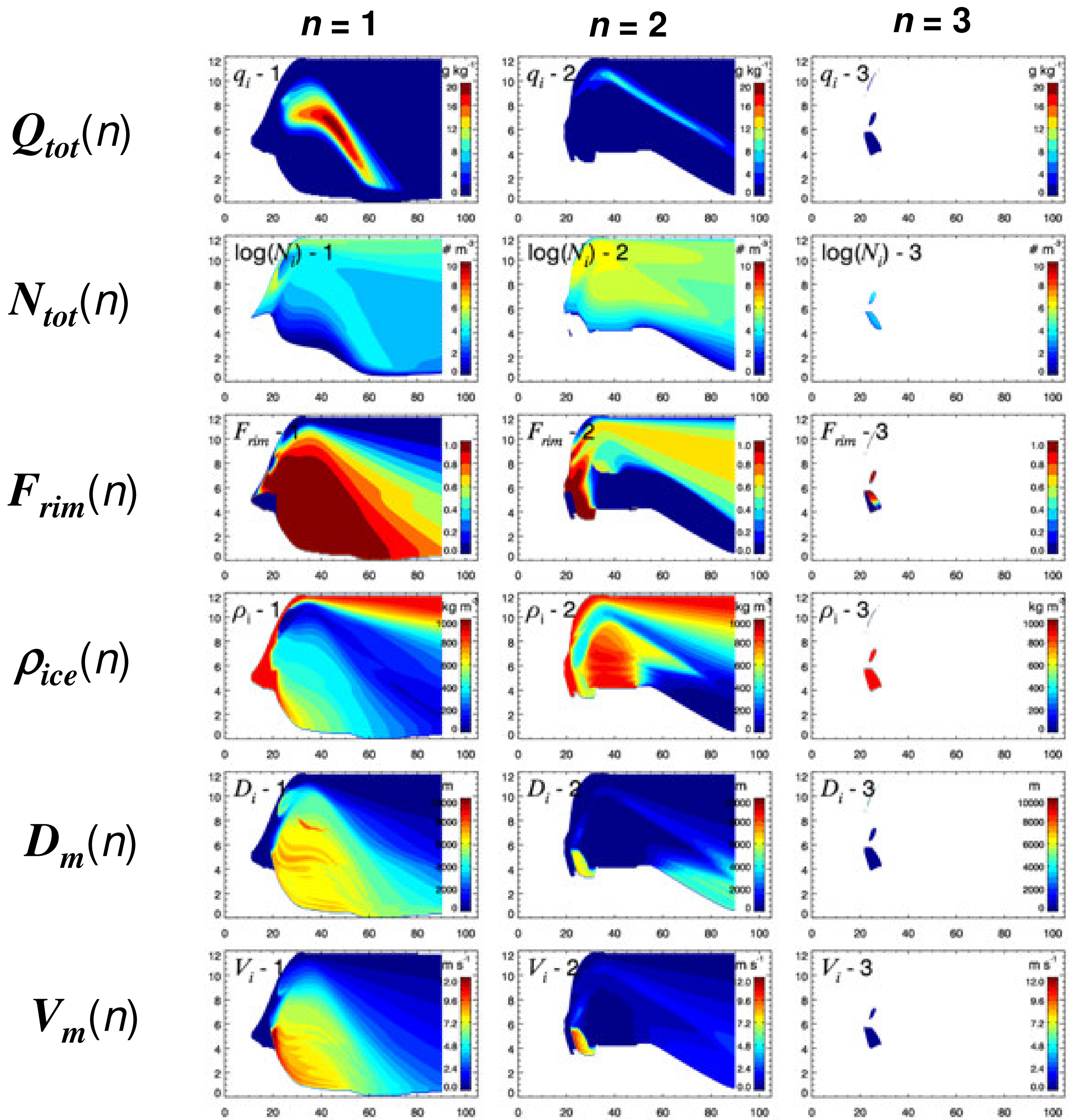
$\rho_{ice}(n)$

$D_m(n)$

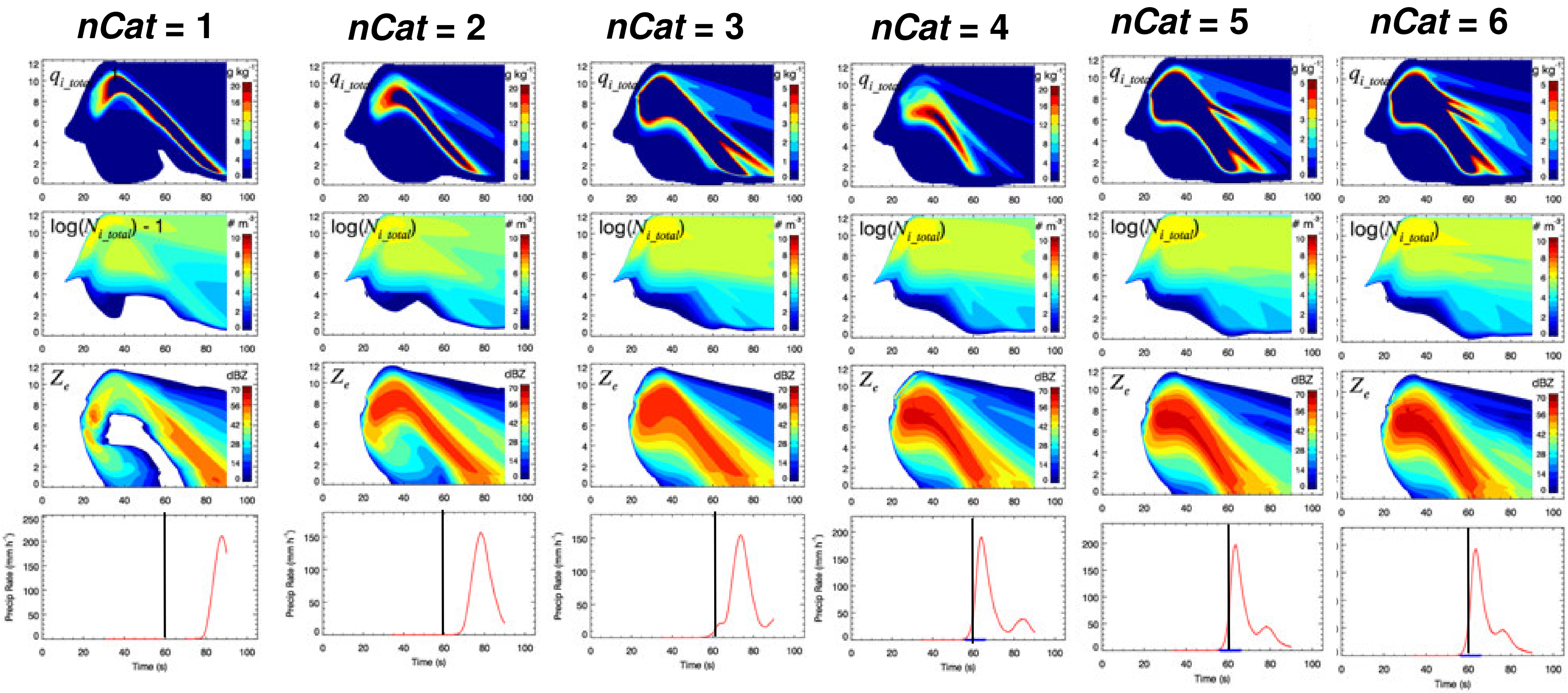
$V_m(n)$



w_{max} = 10 m s^{-1}
$nCat$ = 3



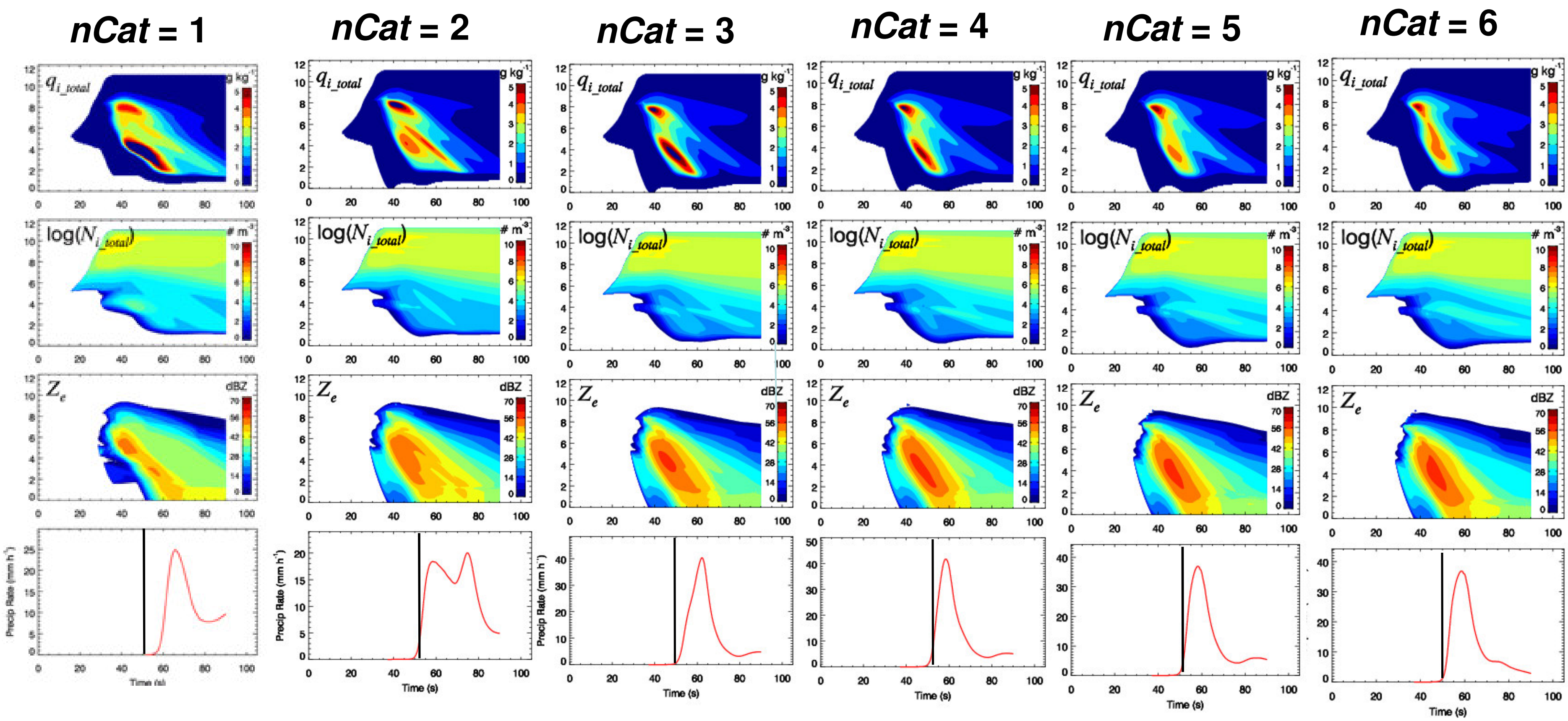
w_{max} = 10 m s^{-1}



↑

CONVERGENCE

$w_{max} = 3\ m\ s^{-1}$



↑

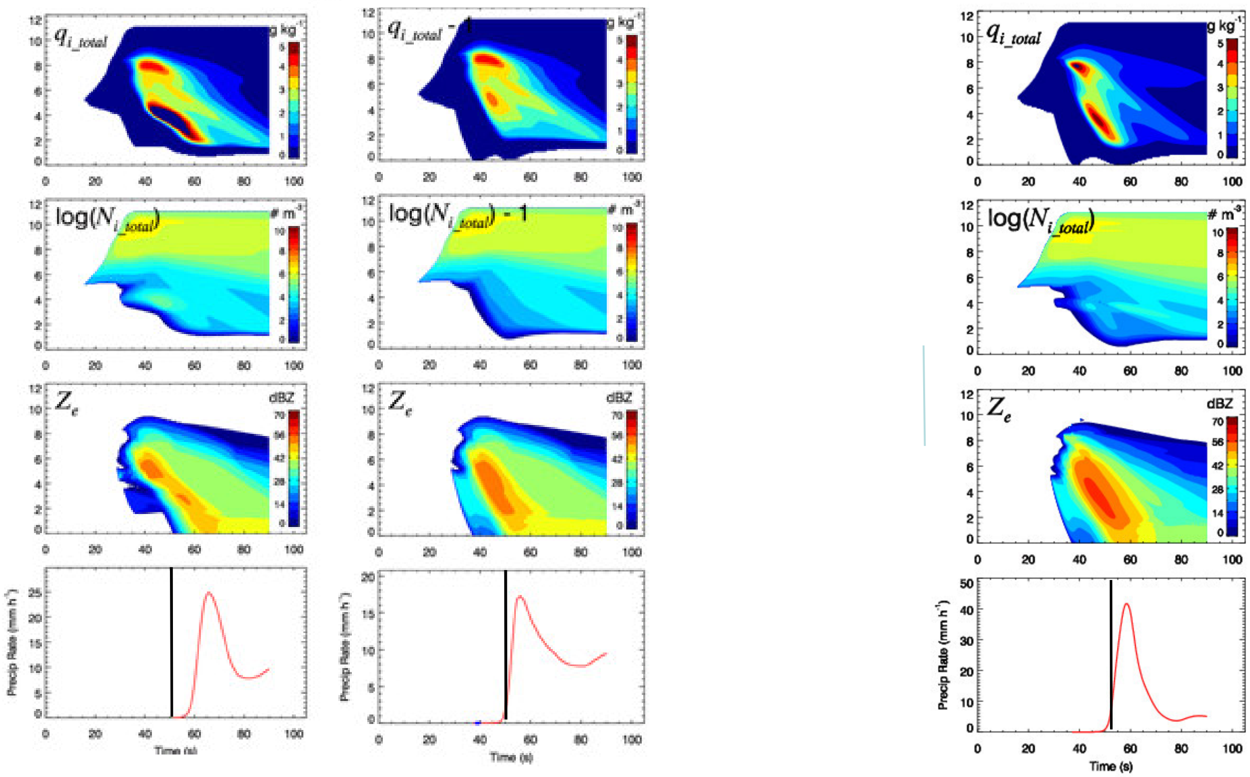
CONVERGENCE

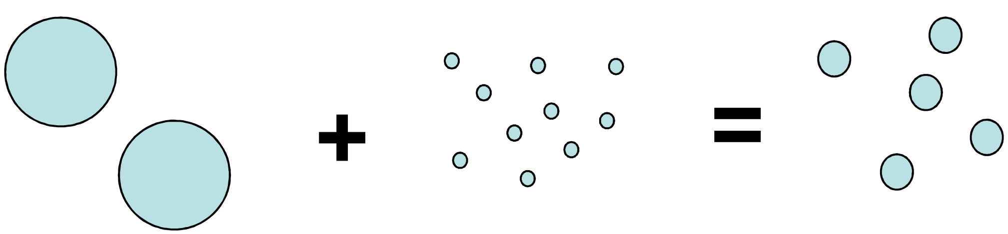
Inclusion of Hallet-Mossop (rime splintering) process

with *nCat* = 1

H-M *on* | H-M *off* | H-M *on*

***nCat* = 1** | ***nCat* = 1** | ***nCat* = 4**





→ With *nCat* = 1, the Hallet-Mossop process results in excessive dilution

P3 – Effects of multiple categories

Comments from 1D simulations:

- increasing the number of categories

  + reduces the "dilution" effect

  + results in earlier precipitation at the ground

- the number of categories to reach convergence increases with the amount of forcing

→ the multi-category version behaves as expected in 1D; ready to test in 3D

P3 Scheme – Interface in GEM (4.7.0)

Two main pieces of code:

- create_lookup_table.F90
- mp_p3.F90

subroutine create_lookup_table	→ Creates multidimensional look-up table of pre-computed moments (used for process rates)
module mp_p3	
subroutine p3_init	→ Reads in look-up table; computes various quantities (called on first time step only)
subroutine p3_wrapper_wrf	→ Main interface for WRF
subroutine p3_wrapper_gem	→ Main interface for GEM (called by CONDENSATION)
subroutine p3_main	→ Main s/r (called by wrapper)

P3 Scheme – Interface in GEM (4.7.0)

```
subroutine p3_main(Qitot, Qirim, Nitot, Birim, ncat, …

  real, dimension(ni, nk, ncat)  ::  Qitot, Qirim, Nitot, Birim
```

```
&physics_cfgs

stcond     = mp_p3
p3_ncat  = 2
```

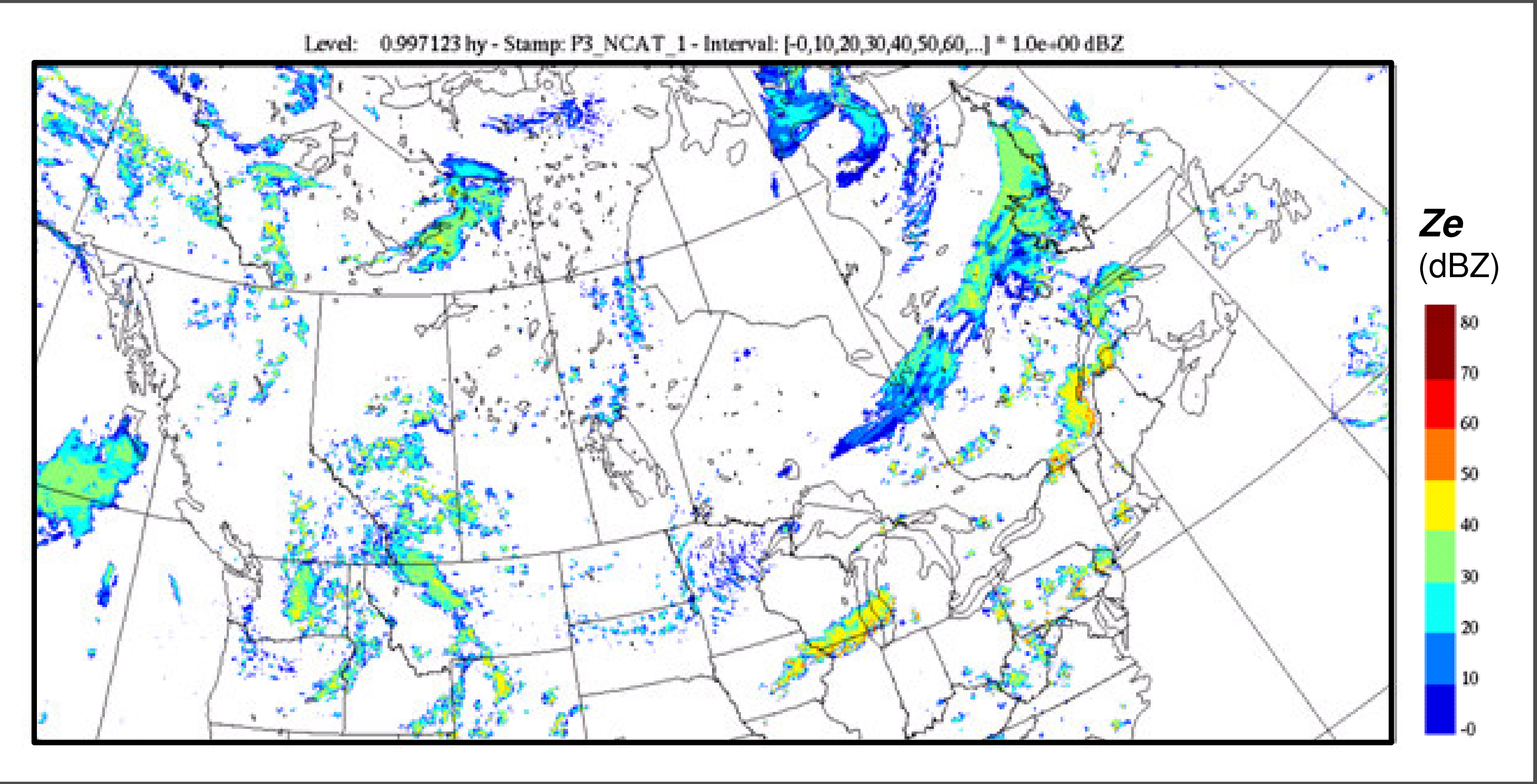
in s/r *condensation*:

```
IF (stcond .eq. 'mp_p3') THEN

   IF (p3_nCat .eq. 1) THEN
     nCat = 1
     call p3_wrapper_gem(Qitot_1, Qirim1, Nitot_1, Birim_1, nCat, …)
   ELSEIF (p3_ncat .eq. 2) THEN
     nCat = 2
     call p3_wrapper_gem(Qitot_1, Qirim_1, Nitot_1, Birim_1, &
                         Qitot_2, Qirim_2, Nitot_2, Birim_2, nCat, …)
   ELSEIF (p3_ncat .eq. 3) THEN
     nCat = 3
     call p3_wrapper_gem(Qitot_1, Qirim_1, Nitot_1, Birim_1, &
                         Qitot_2, Qirim_2, Nitot_2, Birim_2, &
                         Qitot_3, Qirim_3, Nitot_3, Birim_3, nCat, …)
     etc. …

ENDIF
```

P3_MAIN is generalized (nCat categories)

P3_WRAPPER_GEM constructs / deconstructs array of (ni, nk, nCat) from nCat arrays (ni, nk) for each variable

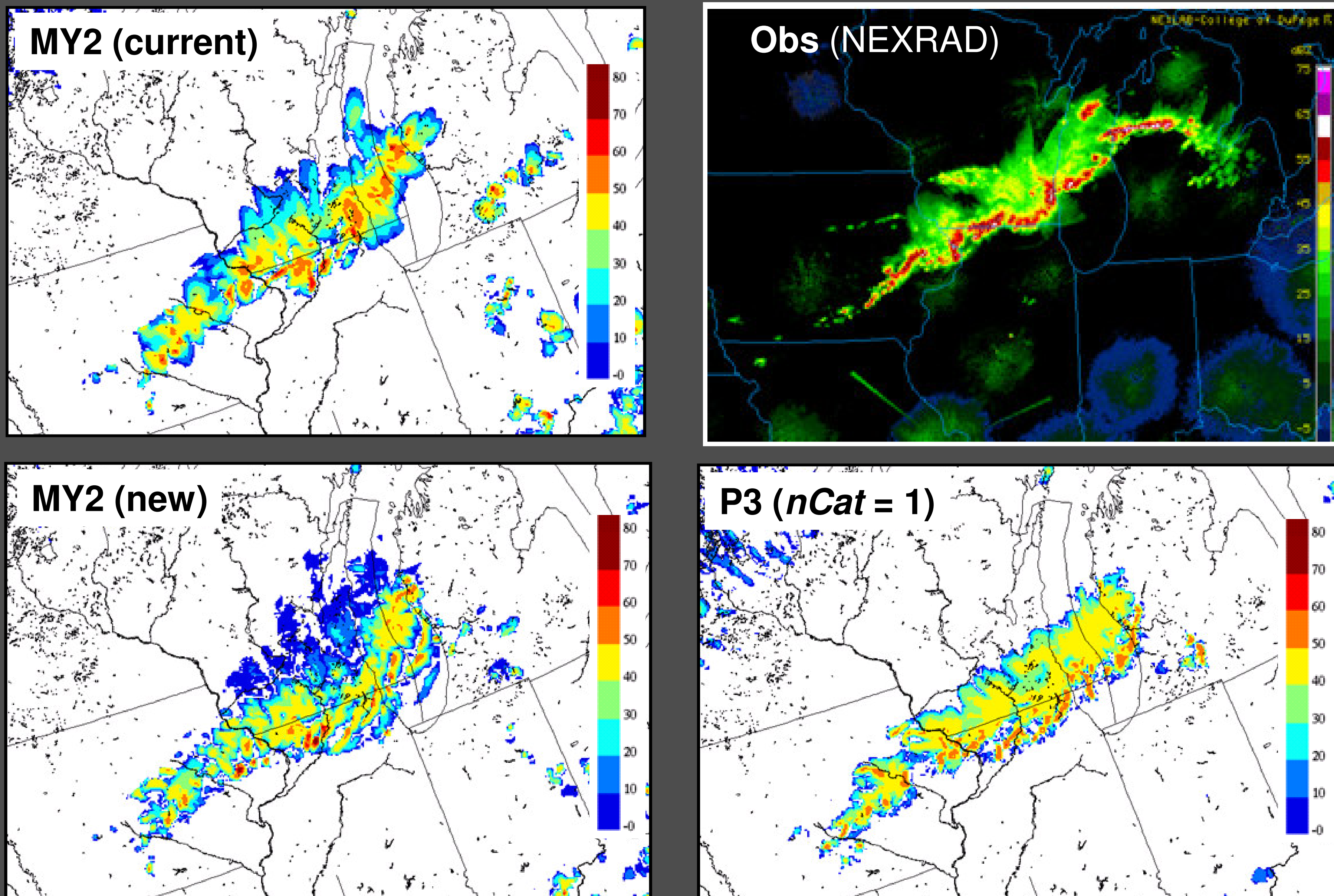
GEM simulation with P3 (*nCat* = 1)
on HRDPS (pan-Canadian) domain



12-h FCST (valid 00 UTC 9 June 2011)

GEM (2.5 km)

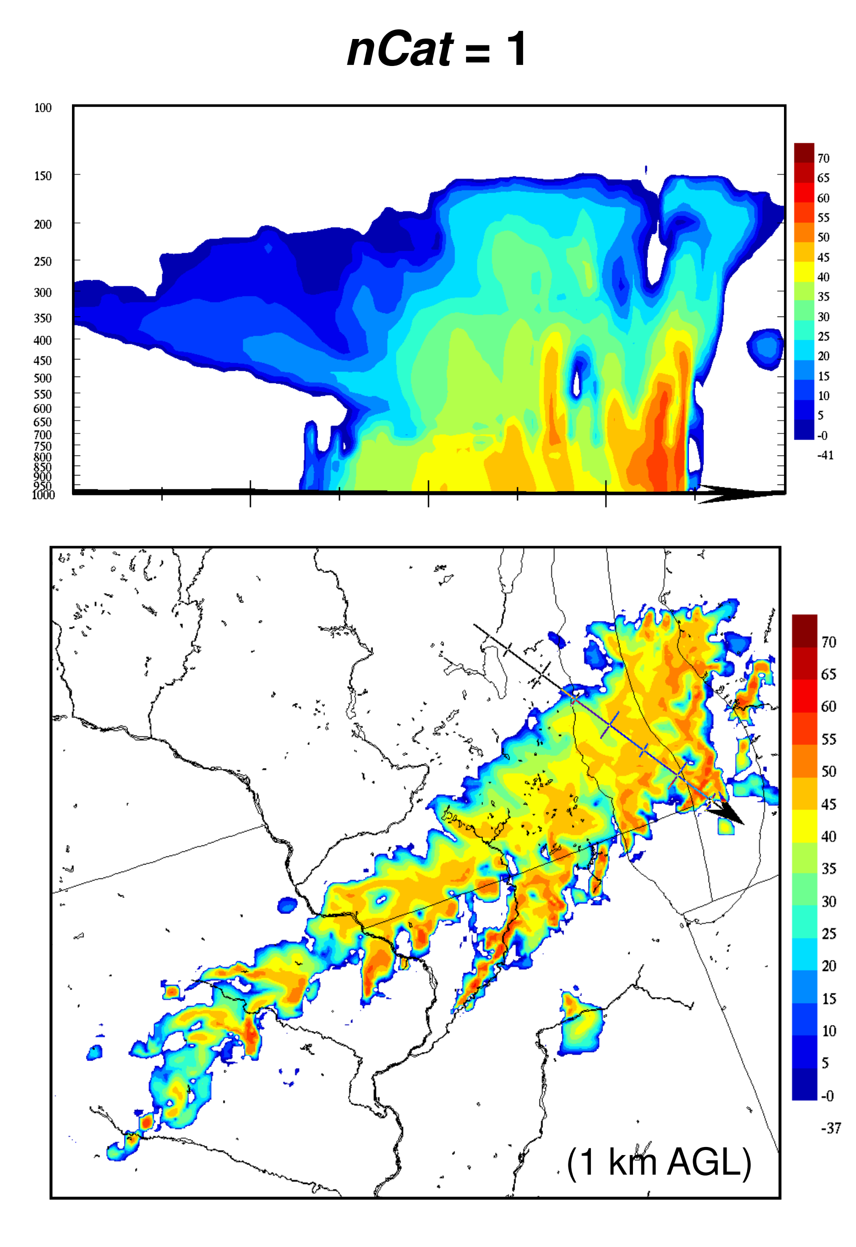
Reflectivity (1 km AGL)

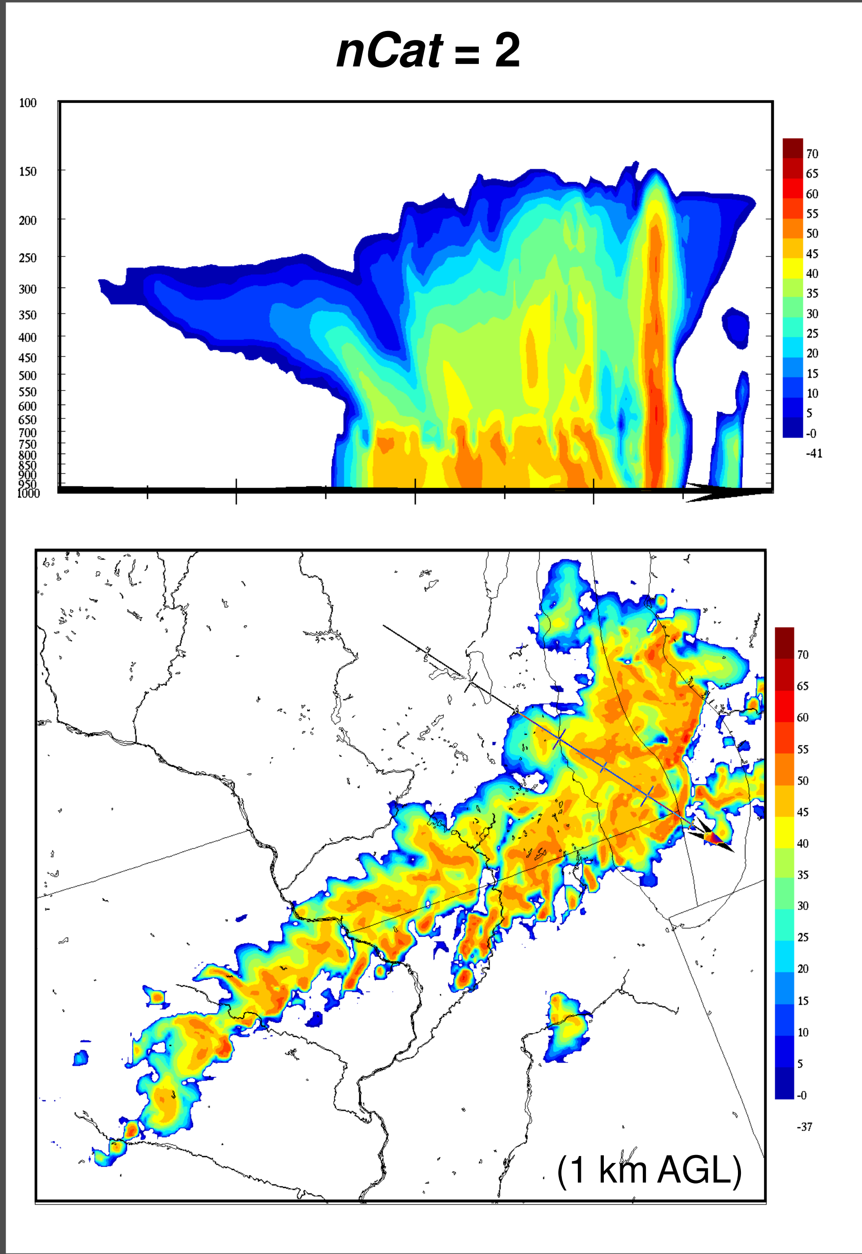


12-h FCST (valid 00 UTC 9 June 2011)

GEM (2.5 km), P3

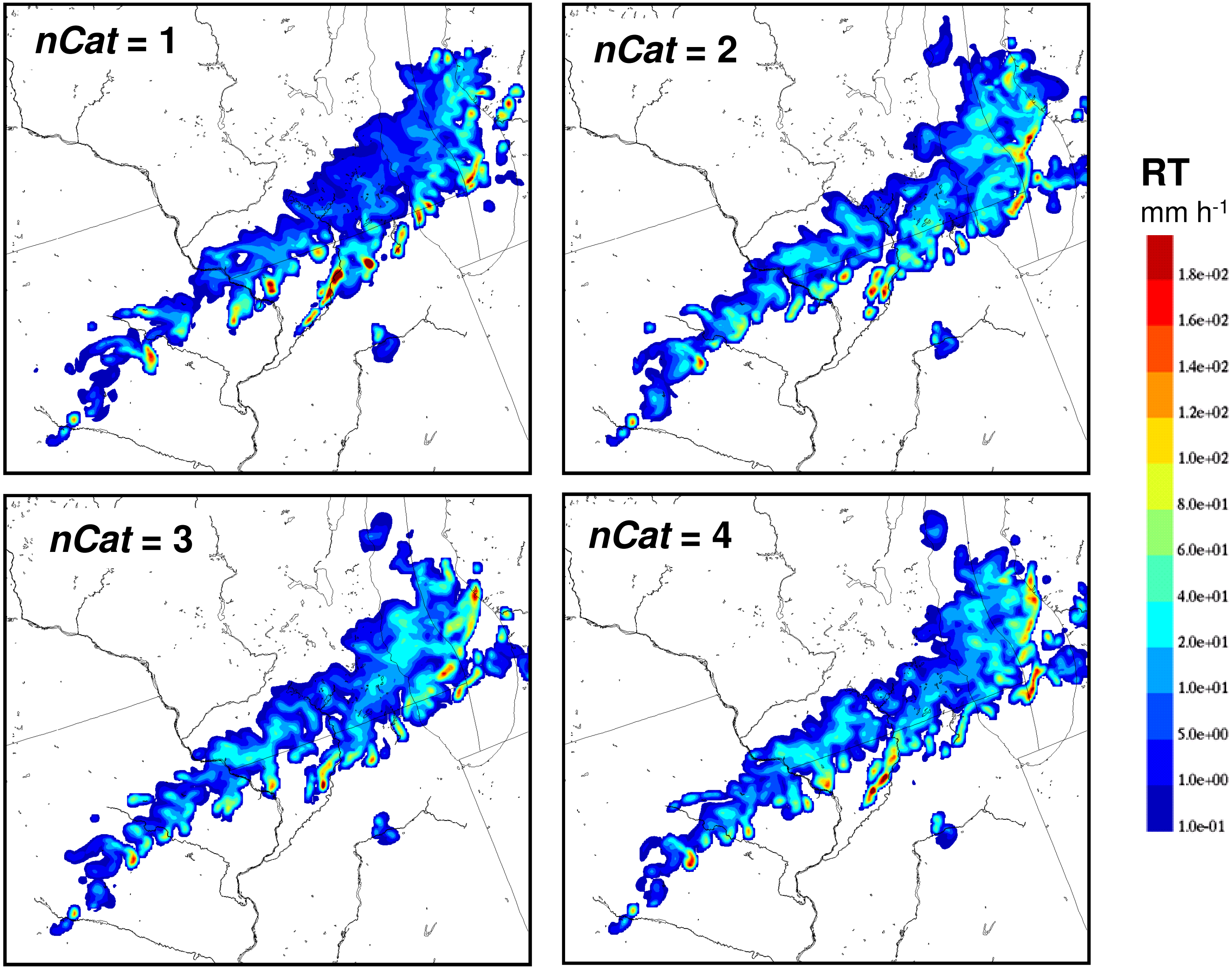
Reflectivity





GEM (2.5 km), P3

Precipitation Rate



Convergence with *nCat* = 2?

4. The Future…

Further Development of P3

1. Tuning in operational context
2. Additional predicted properties
    - Liquid fraction
    - Spectral dispersion (triple-moment)
    - others…
3. Subgrid-scale cloud fraction

P3 in GEM

1. Implementation into GEM_4.7.0
2. Consideration for HRDPS
   - P3 (*nCat* = 1) vs. P3 (*nCat* = 2)
   - P3 vs. MY2_new

Everything has a shelf-life.

EXTRA

Timings from 3D GEM runs:

- full pan-Canadian HRDPS grid
- topology 10 x 32 x 1

Run	CP SECS	GEMDM	DYNSTEP	ADW	PHYSTEP	#tracers
(MY2_orig)	7587	9069	4637	3356	4018	12
(MY2_new)	6641	7927	3685	2470	3891	12
(P3_1cat)	5925	7058	3258	2091	3430	7
(P3_2cat)	6681	7980	3659	2433	3914	11

(MY2_orig) **1.**
(MY2_new) **0.87** (NOTE: with 10 x 32 x 4, ratio is about 0.84)
(P3_1cat) **0.78**
(P3_2cat) **0.87**

Extra cost of ADW for extra tracers (vs Run 1)

Run
4 (3356-1656)/11 = 154 s/tracer, 154/4689 = 3.3%, 154/5062 = 3.0% extra total time (per tracer)
6 (2470-1656)/11 = 74 s/tracer, 74/4689 = 1.6%, 74/5062 = 1.4%
7 (2091-1656)/6 = 73 s/tracer, 73/4689 = 1.6%, 73/5062 = 1.4%
8 (2433-1656)/10 = 78 s/tracer, 78/4689 = 1.7%, 78/5062 = 1.5%