Spectral Habit Ice Prediction System (SHIPS) Initial Test Simulations of Orographic Precipitation

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Requirements of Microphysics Prediction

- Size Distribution
  - nucleation
  - history
- Phase (s)
  - function of particle history
- Shape
  - liquid hydrometeors: size implies shape
  - ice: particle history results in:
    - shape
    - internal structure
    - density
- Chemical and Phase Content
  - history of hydrometeor implies:
    - acidity
    - ion content
    - chemical content

Habit Variation

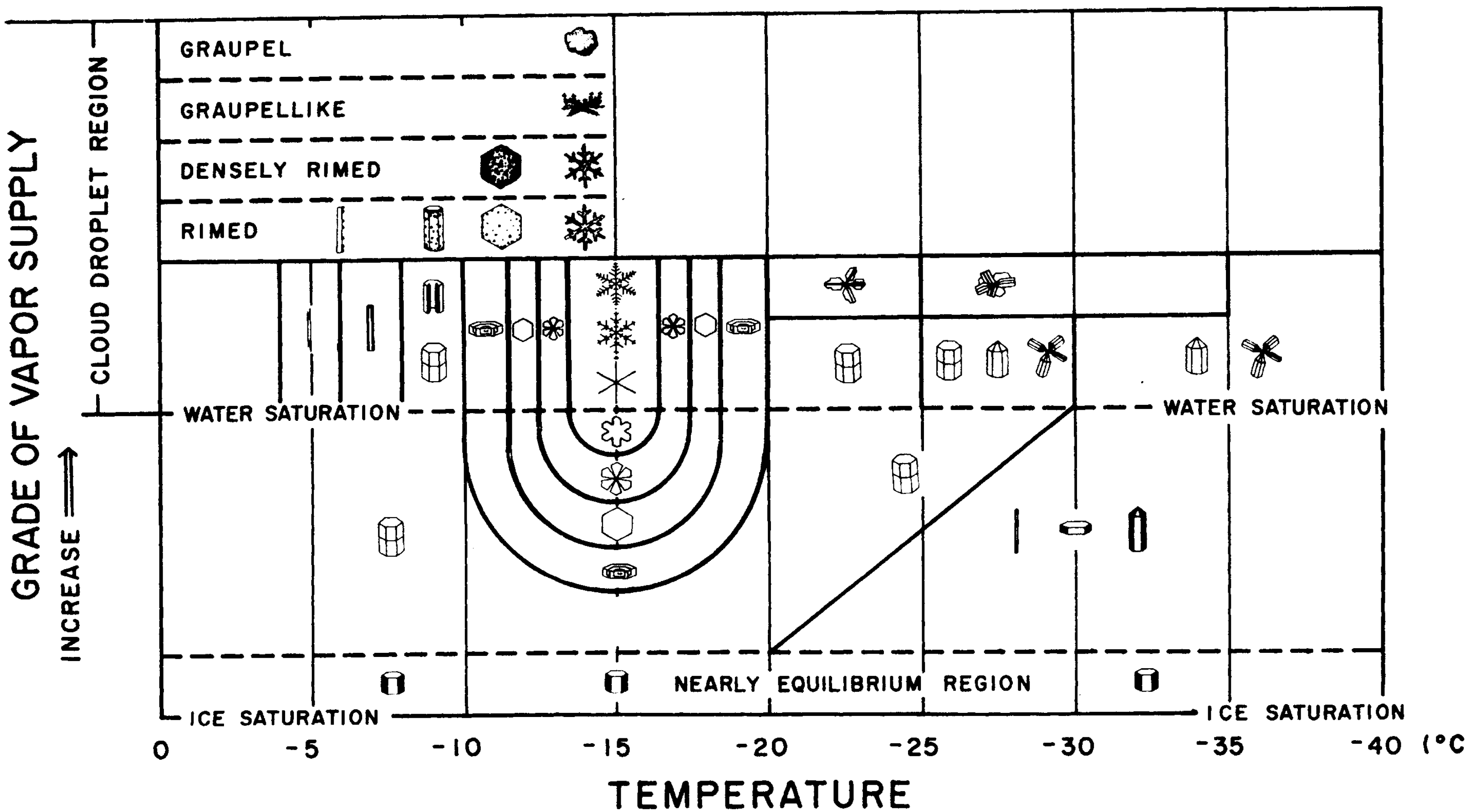
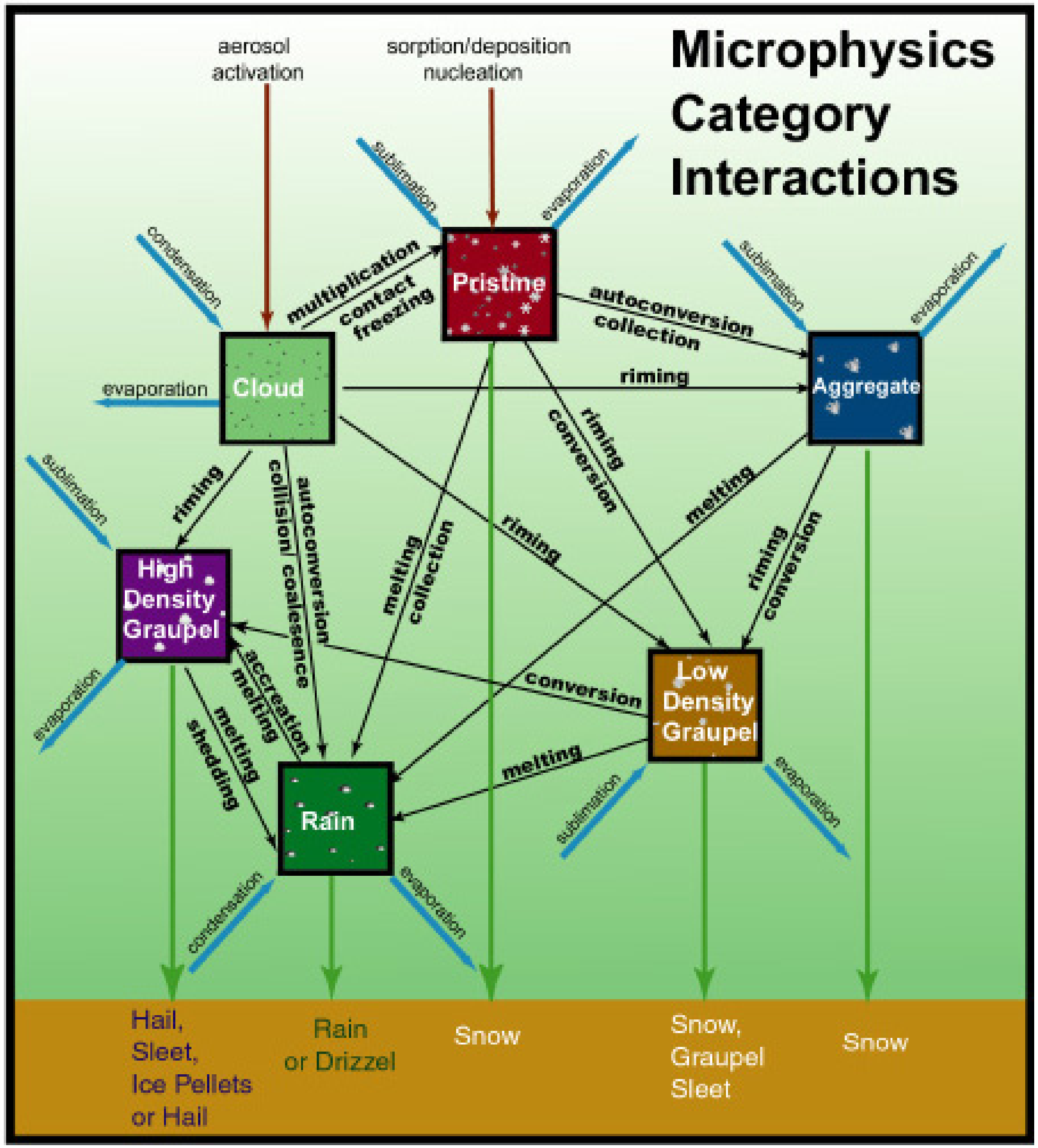


Fig. 2-37: Temperature and humidity conditions for the growth of natural snow crystals of various types. (From Magono and Lee, 1966; by courtesy of *J. Fac. Sci.*, Hokkaido University.)

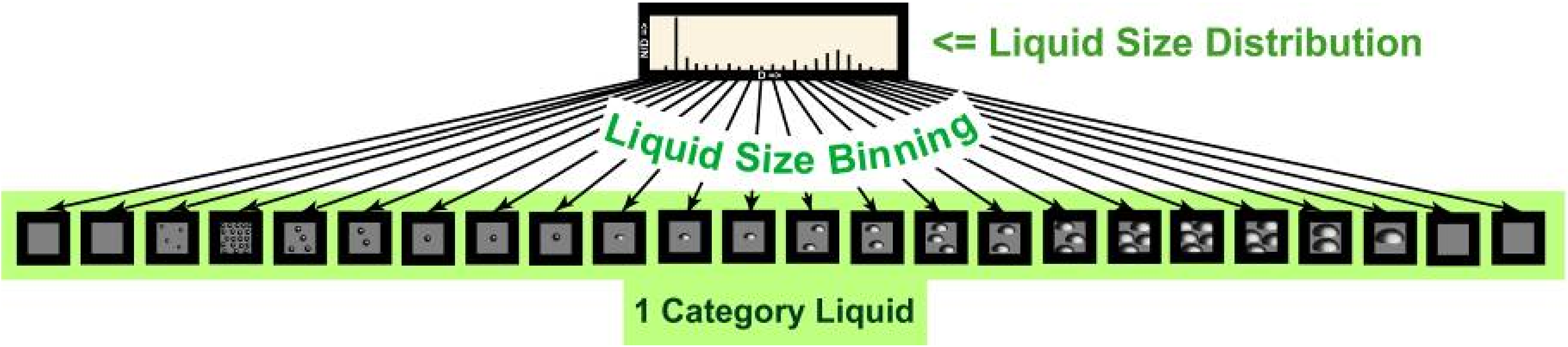
Conventional Bulk Microphysics Parameterization

Kessler-Lin/Orville Paradigm (1967)

- categories of hydrometers
- each category has one unimodal size distribution.
- density and shape are fixed for each category.
- No history of growth
- Conversions between categories based on local conditions and tendencies



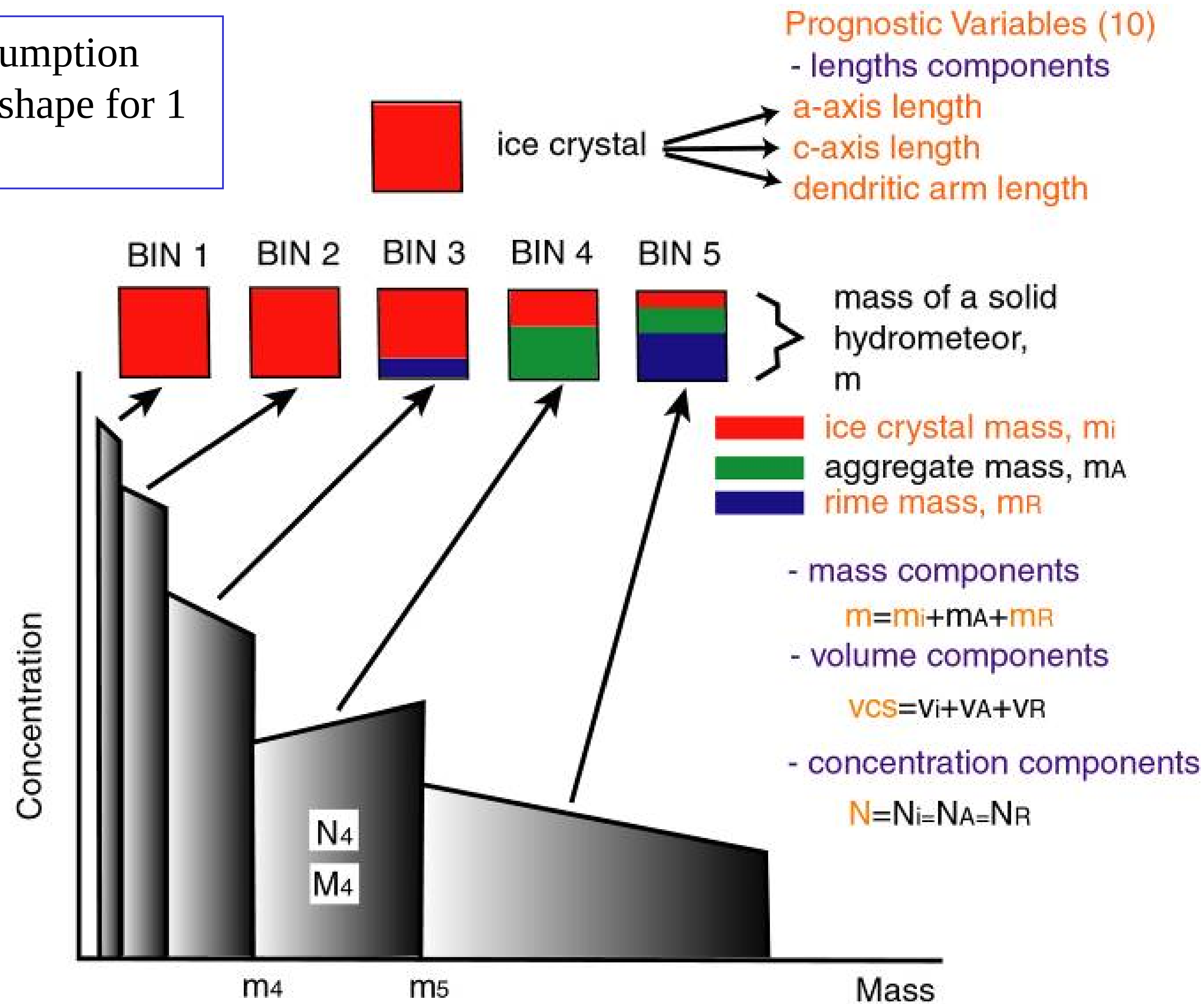
Bin Model Paradigm



- Berry (1967)
  - converts the continuous distribution to a discrete one and solve at those grid points.
  - values of the function between grid points are interpolated using Lagrange polynomials
- Gelbard and Seinfeld (1978)
  - uses finite element method
- Bleck (1970)
  - one moment method (mean mass in a bin is fixed).
  - Liquid water content is conserved, but not number concentration or other moments

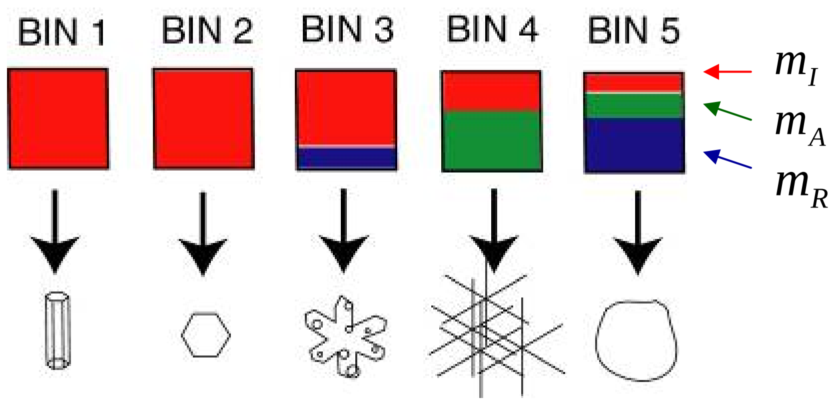
Spectral Habit Ice Prediction System (SHIPS) (1)

Mass sorting assumption
1 representative shape for 1 mass bin

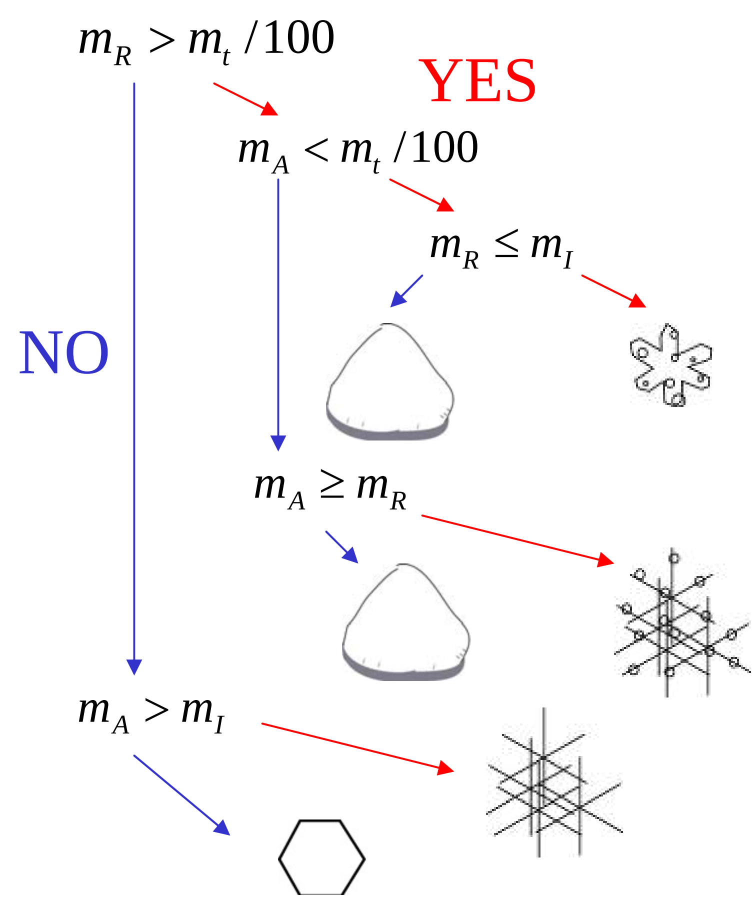


Spectral Habit Ice Prediction System (SHIPS) (2)

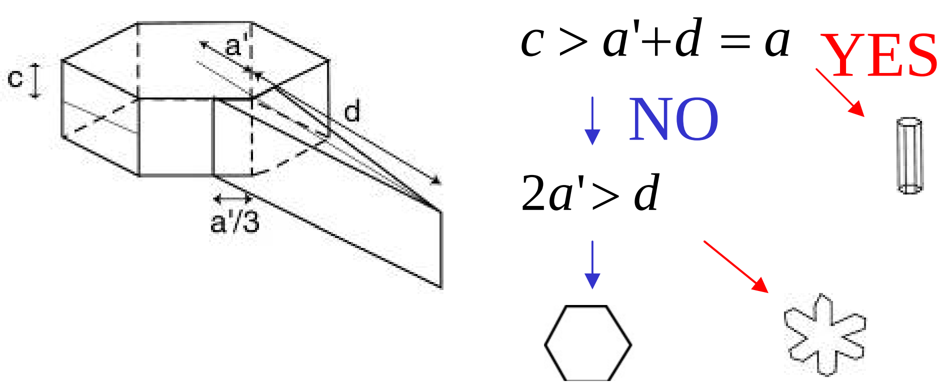
Diagnose the habit and type



Type



Habit



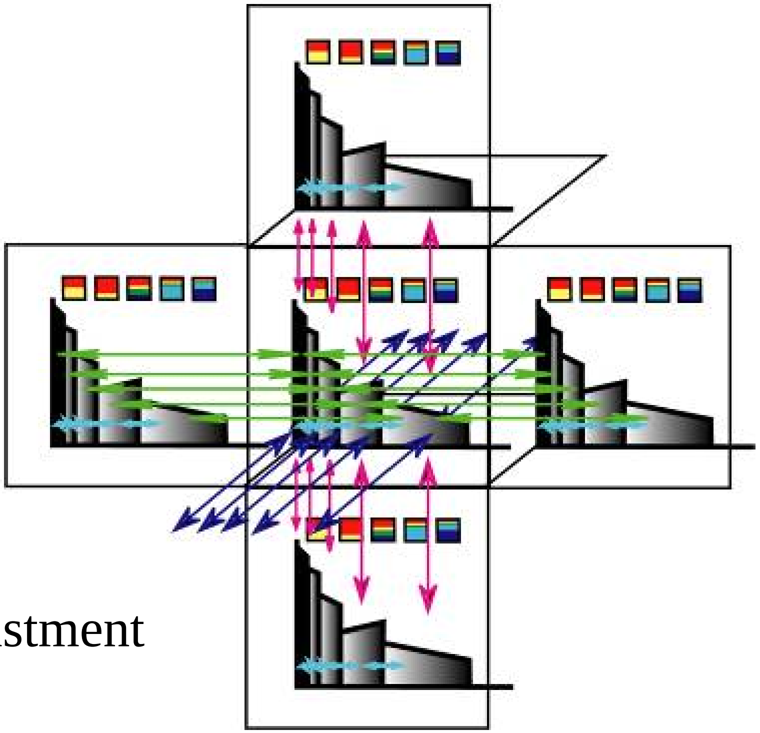
Spectral Habit Ice Prediction System (SHIPS) (3)

Simulation of microphysical processes using information on habit and type.

- vapor deposition process
- aggregation process
- riming process
- ice nucleation
- breakup process
- melting-shedding

Repair routine

Mix (advect) the hydrometeors in 3D Eulerian model



Negative adjustment
Reality check

Application to Eulerian Model

- Predict 2-3 dimensional variable
  - (1-10 parameters, # bins, # categories)
- Parameter must be an extensive variable
  - Mass => mixing ratio
  - Axis length => total length/mass of air
  - Concentration => number/mass of air
  - Charge => charge / mass of air

Predict Axis Length or Axis Mass?

- Mass => requires statistical model to determine implied axis length
- Length => requires statistical model to find axis width

Application to Cloud Resolving Model

Predictive Variables

- Dynamics core (u, v, w, p)……………..4
- Thermodynamics (θ, q_T)………….……..2
- TKE……………………………………..1
- Bulk Microphysics (7 ice, 1 liquid)…..8

- Total…………………………………..15

Application to Cloud Resolving Model

<u>Predictive Variables</u>

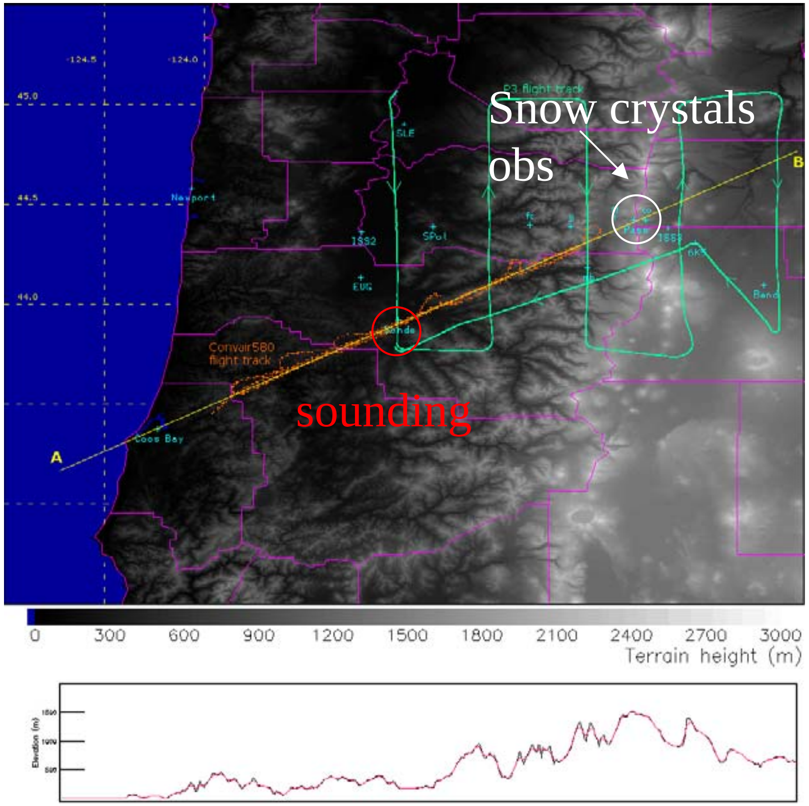
- Dynamics core (u, v, w, p)…......................4
- Thermodynamics (θ, q_T)…………..............2
- TKE………………………………………1
- SHIPS Microphysics (50 ice, 10 liquid)…60
- Spectral Liquid Prediction System…..…..10

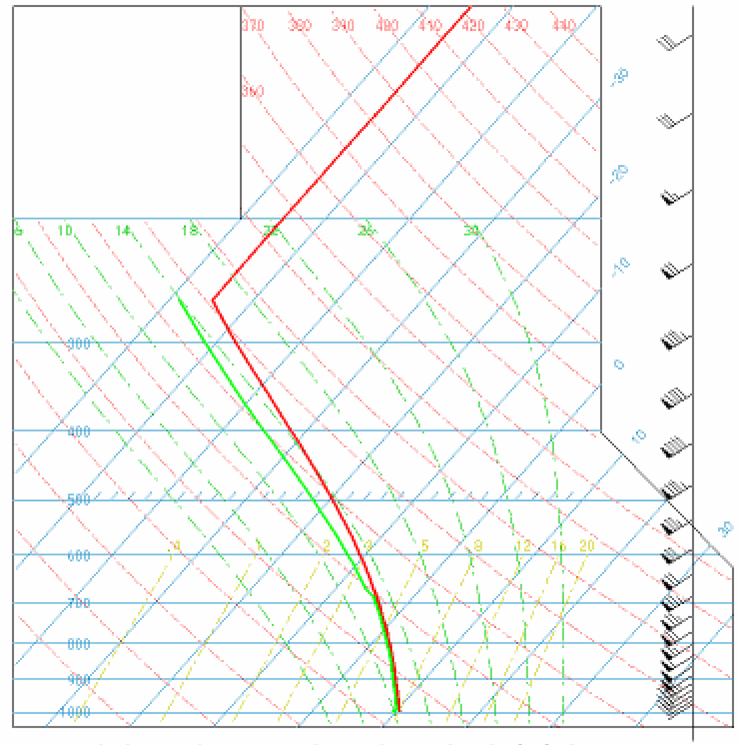
- Total……………………………….…...77

Reason for Optimism

- Large number of microphysics variables over very small percentage of domain
- Use gather/scatter technique and solve microphysics in a distributed CPU-cash contained algorithm
  - 100 % load balanced
  - limited memory references

2D Orographic Snow Storm Simulation – IMPROVE II (13-14 Dec 2001)





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From IMPROVE II website

Upper cold-front passage and orographic forcing

UW-NMS setup

- 1,000m horizontal, 100m vertical (up to 750m) resolution
- time-step is 10 second.

Vapor Deposition Process

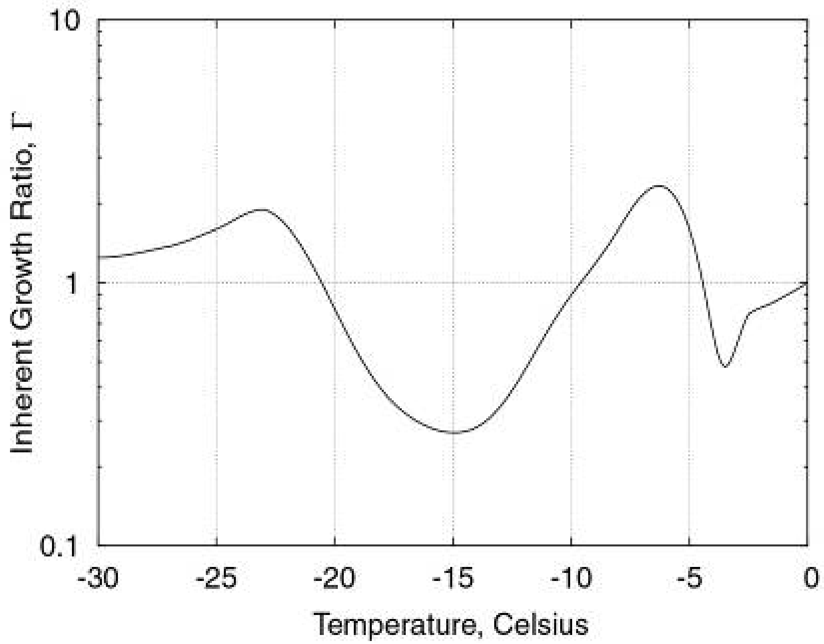
Mass Distribution Hypothesis

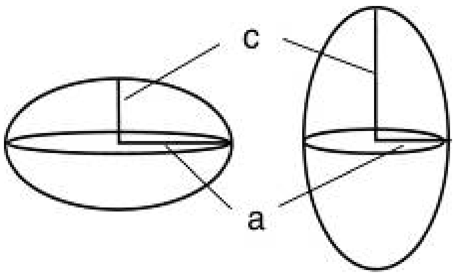
Chen and Lamb (1994a)

$$\frac{dc}{da} = \frac{\alpha_c(T)}{\alpha_a(T)} \frac{\nabla \rho_c}{\nabla \rho_a}$$

- assume spheroid shape for ice crystal to solve $\nabla^2 \rho_v = 0$
- can be used for varying ambient temperature.

Reflect the environment the ice crystal is going through.





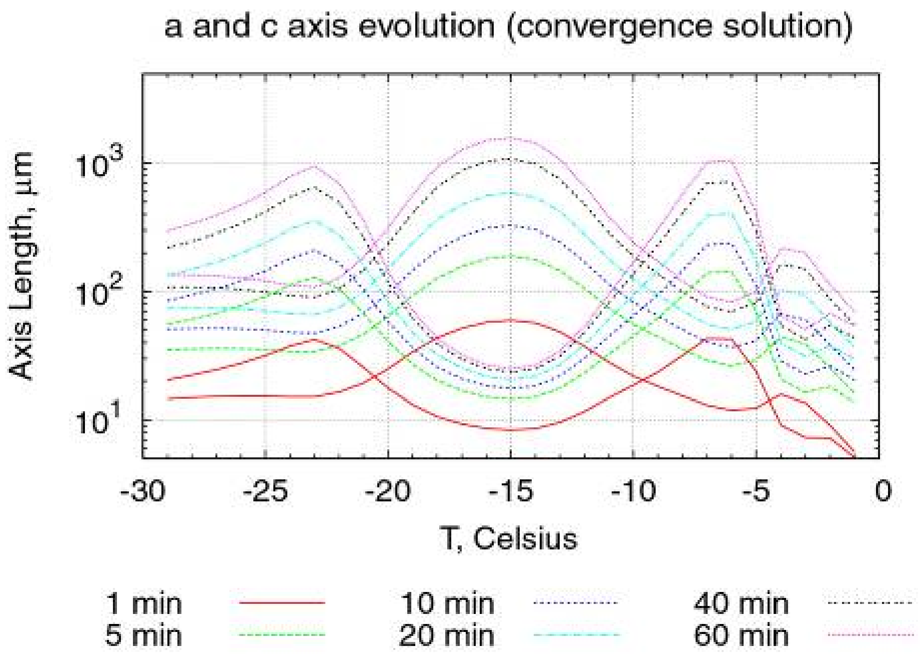
$$\frac{dc}{da} = \Gamma(T) \frac{c}{a}$$

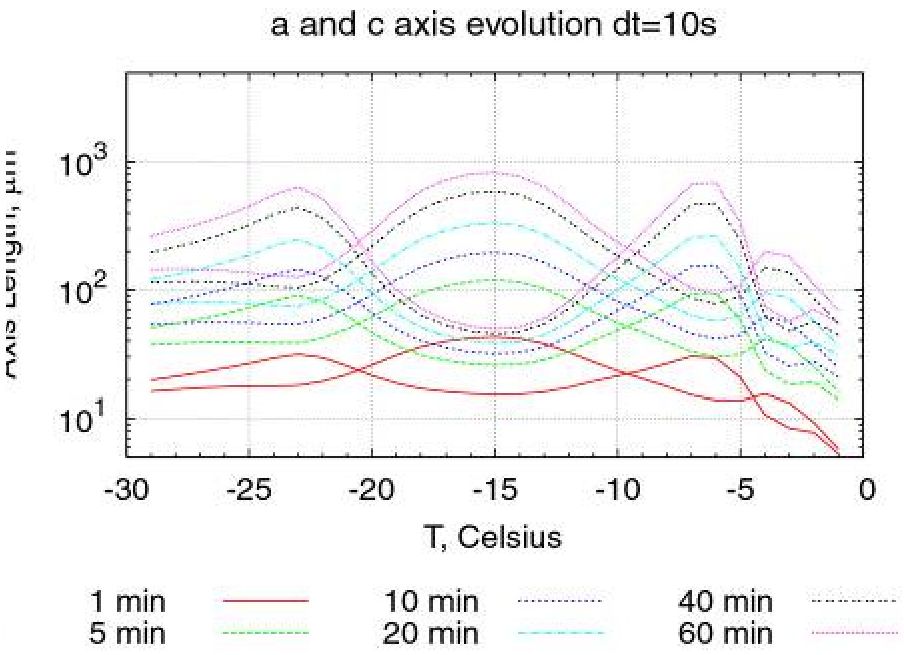
Inherent Growth Ratio

axis ratio

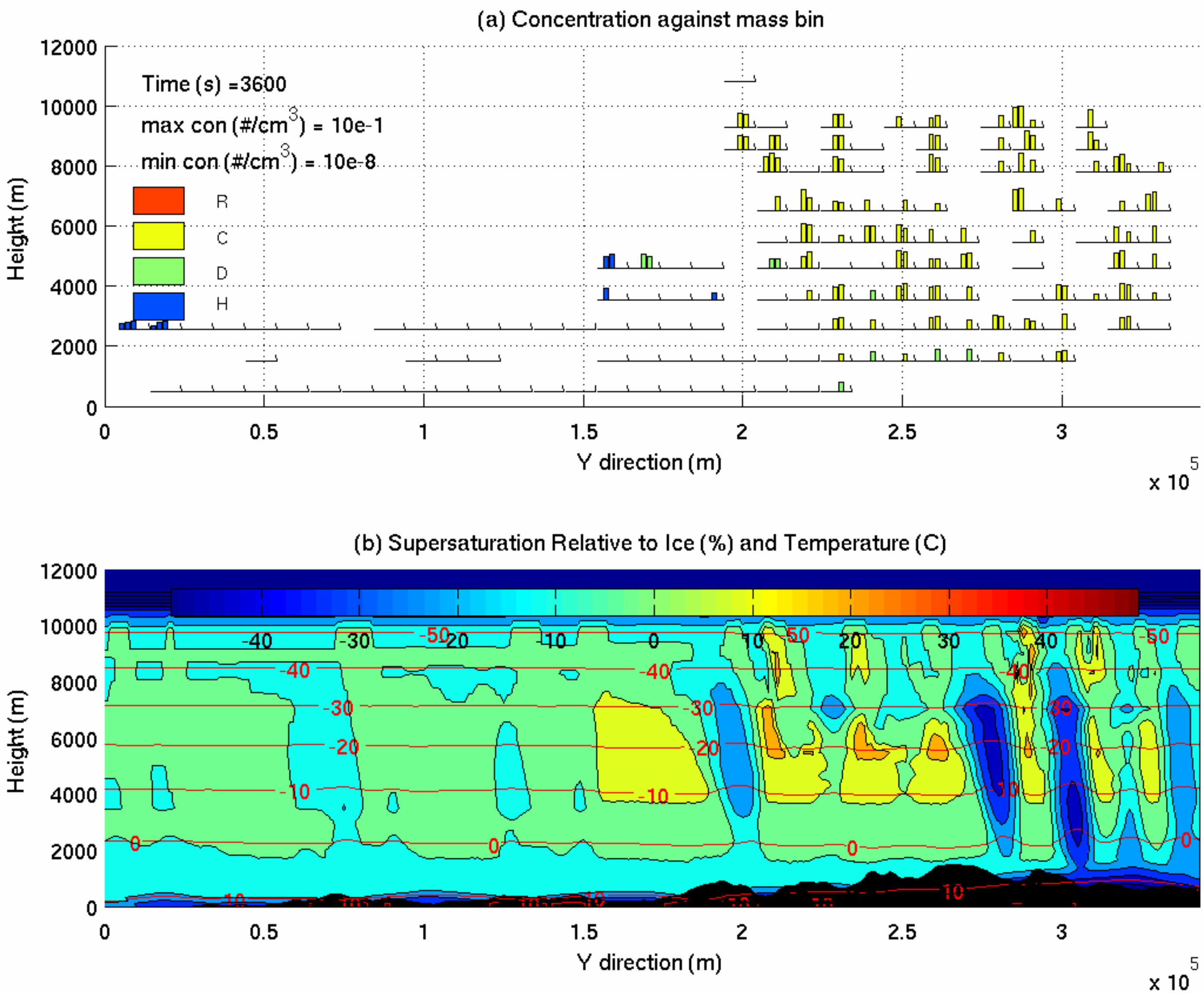
Vapor Deposition Model

Water-saturation at 700mb





Predicted Habit in 2D Model of IMPROVE II with Vapor Deposition Only



Aggregation Process (1)

- Propose the collection efficiency model:

$$E_c = E_{collision} \cdot E_{coal} = 1 \cdot E_{coal}$$

$$E_{coal} = \min(1.0, E_{\text{int}} + E_{stick})$$

  - Interlocking mechanism: E_{int}
  - Sticking mechanism : E_{stick}

- Interlocking mechanism: use the approach of Chen and Lamb (1994b).

$$E_{\text{int}} = 1 - \frac{V_1\rho_1 + V_2\rho_2}{V_1\rho_i + V_2\rho_i}$$

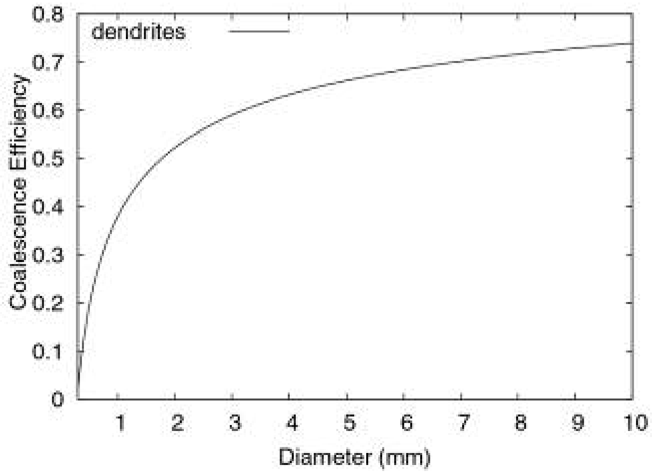
- Sticking mechanism: Hallgren & Hosler (1960).

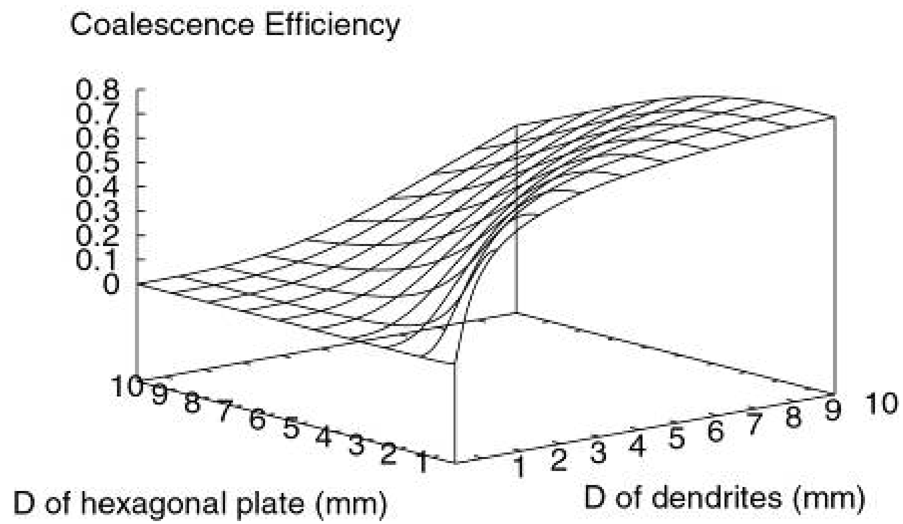
$$E_{stick} = \exp(0.38(T - 273.15))$$

- The axis ratio and maximum dimension of aggregates are diagnosed by using empirical formula by Barthazy and Schefold (2004) and Mitchell, Zhang, and Pitter (1989).

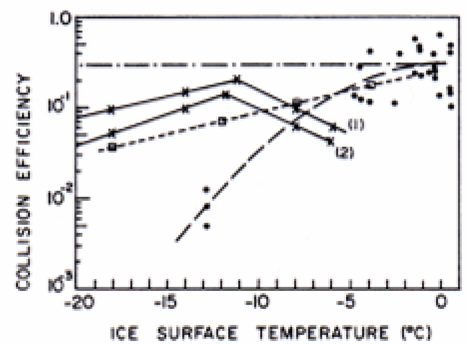
Aggregation Process (2)

- Interlocking mechanism:



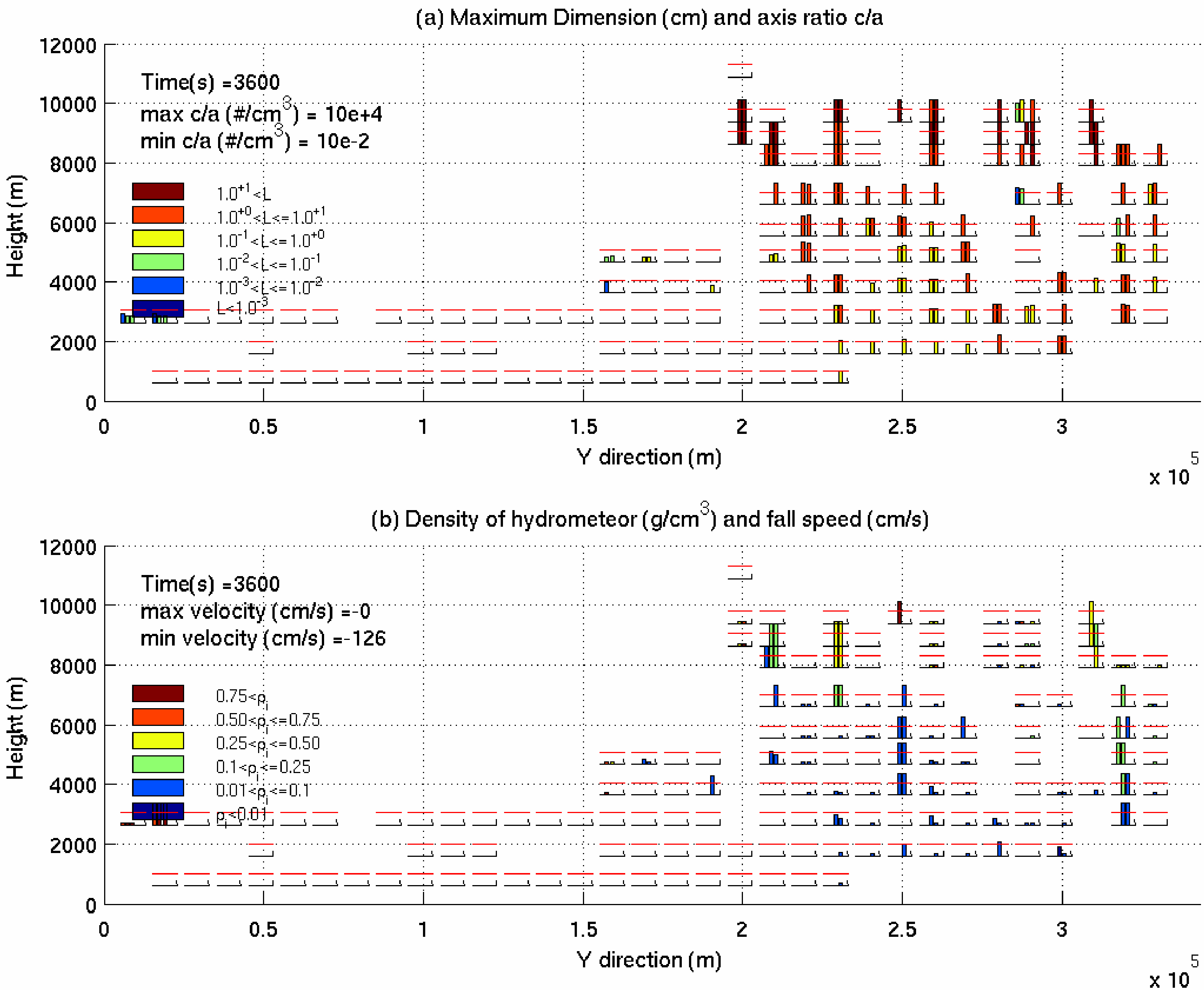


- Sticking mechanism:



From Pruppacher and Klett (1997)

Fig. 14-18: Experimentally determined efficiency with which snow crystals and ice spheres collect micron sized ice crystals, as a function of temperature of collector ice particle. (-.-.) Latham and Saunders (1970), $a = 1000\ \mu m$, spheres; (— — — — — —) Rogers (1974b), $a =$ 500 μm, snowflake; (— — —) Hallgren & Hosler (1960), $a = 85\ \mu m$ ice sphere; (×) Hosler & Hallgren (1960), $a = 180\ \mu m$ (1), $a = 63.5\ \mu m$ (2), ice spheres.



(a) Maximum Dimension (cm) and axis ratio c/a
Time(s) =3600
max c/a (#/cm^3) = 10e+4
min c/a (#/cm^3) = 10e-2
1.0^{+1}<L
1.0^{+0}<L<=1.0^{+1}
1.0^{-1}<L<=1.0^{+0}
1.0^{-2}<L<=1.0^{-1}
1.0^{-3}<L<=1.0^{-2}
L<1.0^{-3}
Height (m)
Y direction (m)
x 10^5
(b) Density of hydrometeor (g/cm^3) and fall speed (cm/s)
Time(s) =3600
max velocity (cm/s) =-0
min velocity (cm/s) =-126
0.75<ρ_i
0.50<ρ_i<=0.75
0.25<ρ_i<=0.50
0.1<ρ_i<=0.25
0.01<ρ_i<=0.1
ρ_i<0.01
Height (m)
Y direction (m)
x 10^5

Riming Processes

- Uses the collision efficiency calculated for hexagonal ice plates, broad-branch crystals, and columnar ice crystals by Wang and Ji (2000).

- Large drops collecting small crystals: Lew and Pruppacher (1983) and Lew et al. (1985)

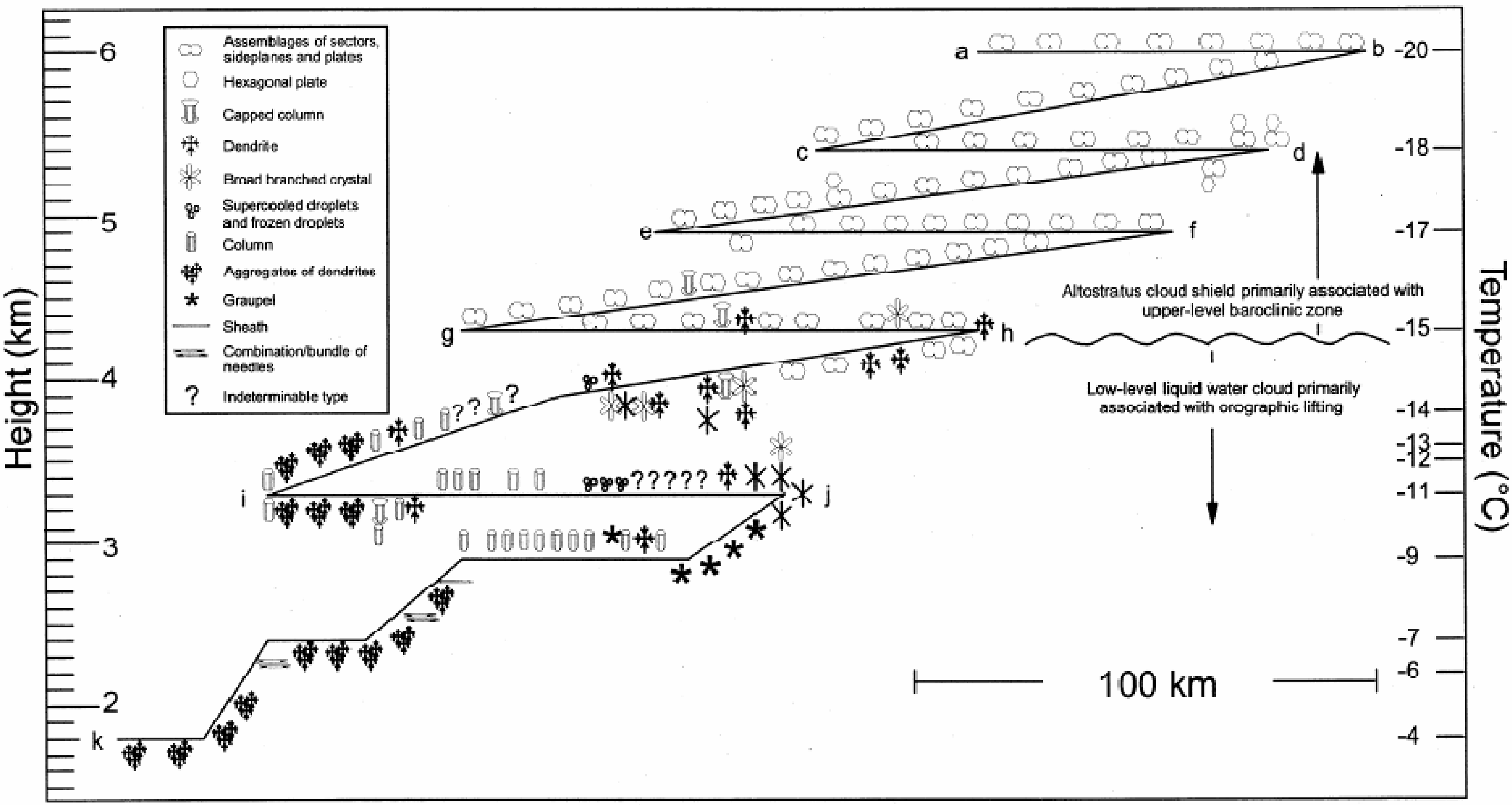
- For the collision between graupel (or hailstones) and cloud drops Pinsky et al. (2001) have calculated the efficiency which depends on the ambient pressure.

- The shorter axis is increased (Chen and Lamb,1994b).

- Rime density is calculated according to impact speed and surface temperature of ice (Hymsifield and Pflaum, 1985)

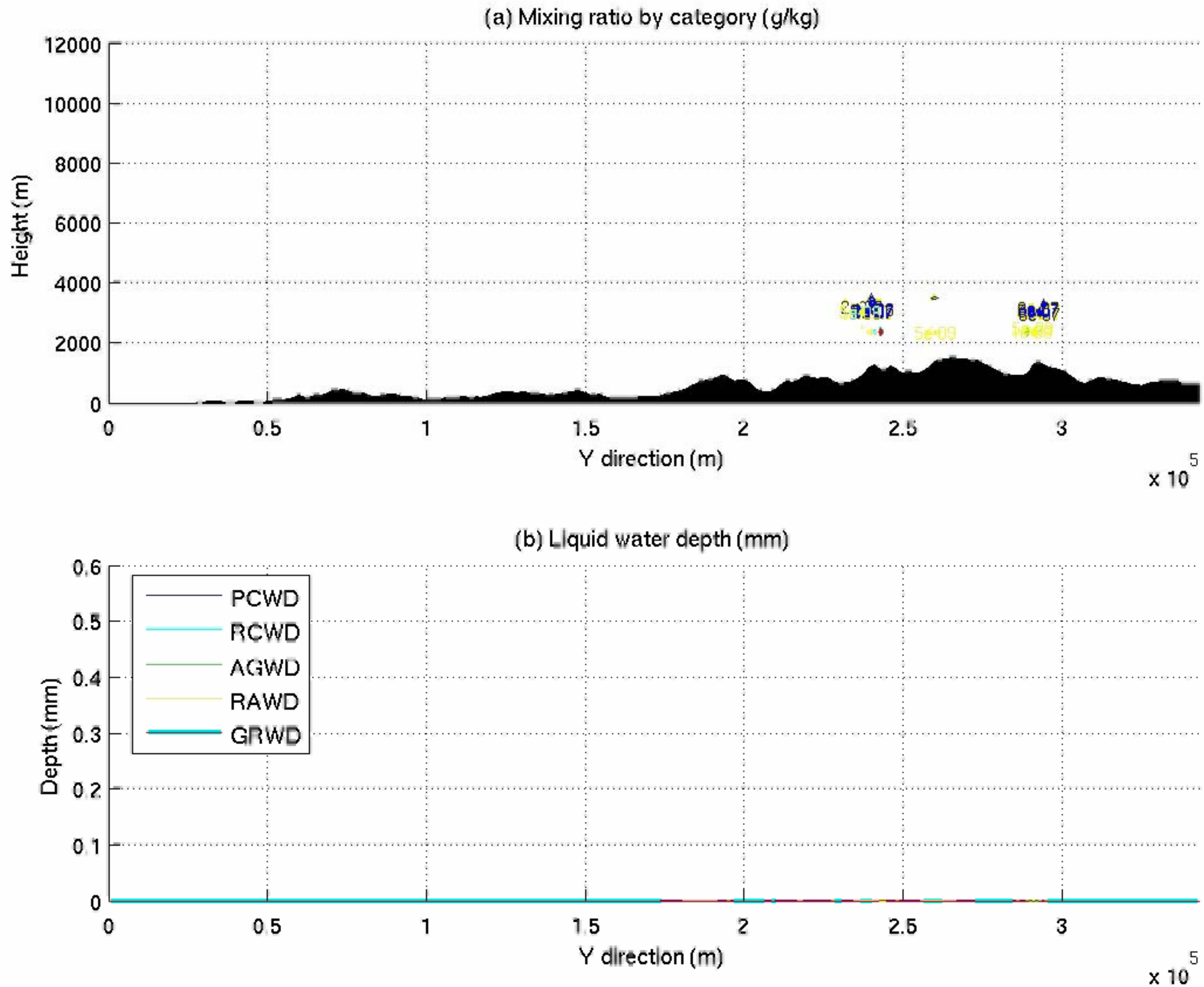
- Once it is considered as graupel or hail, the aspect ratio is assumed to be 1. Then the diameter can be calculated from mass and volume.

Observations

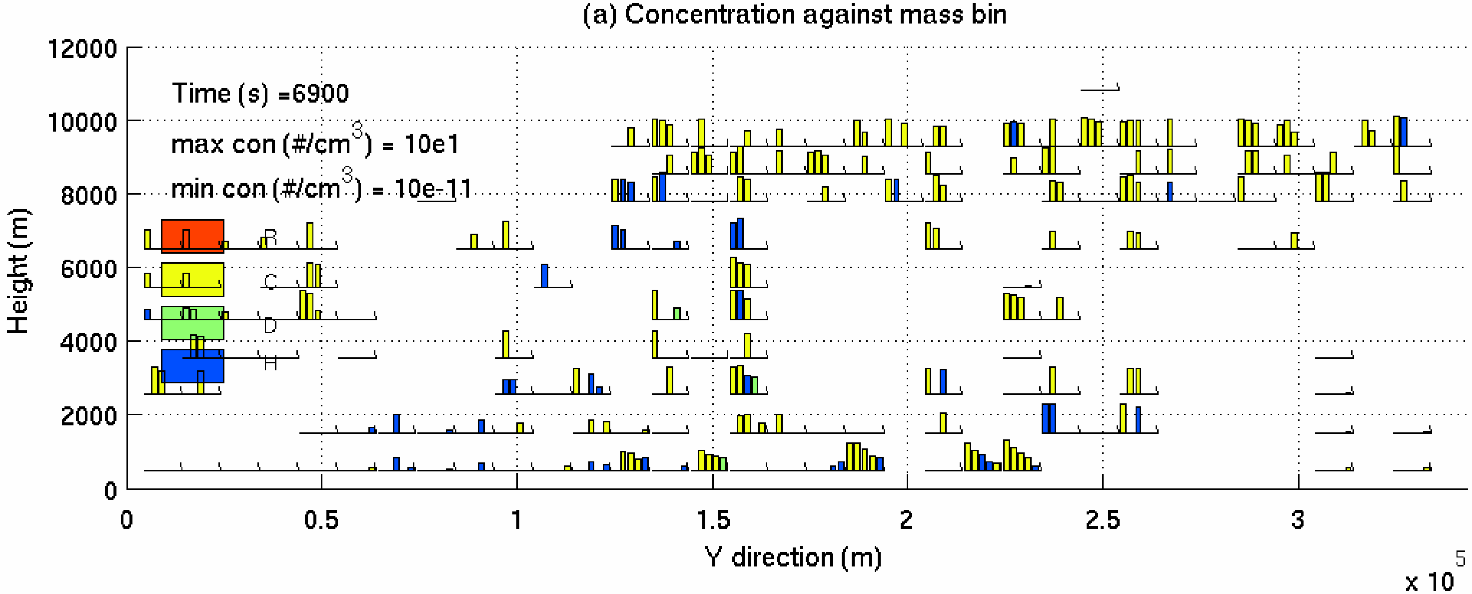


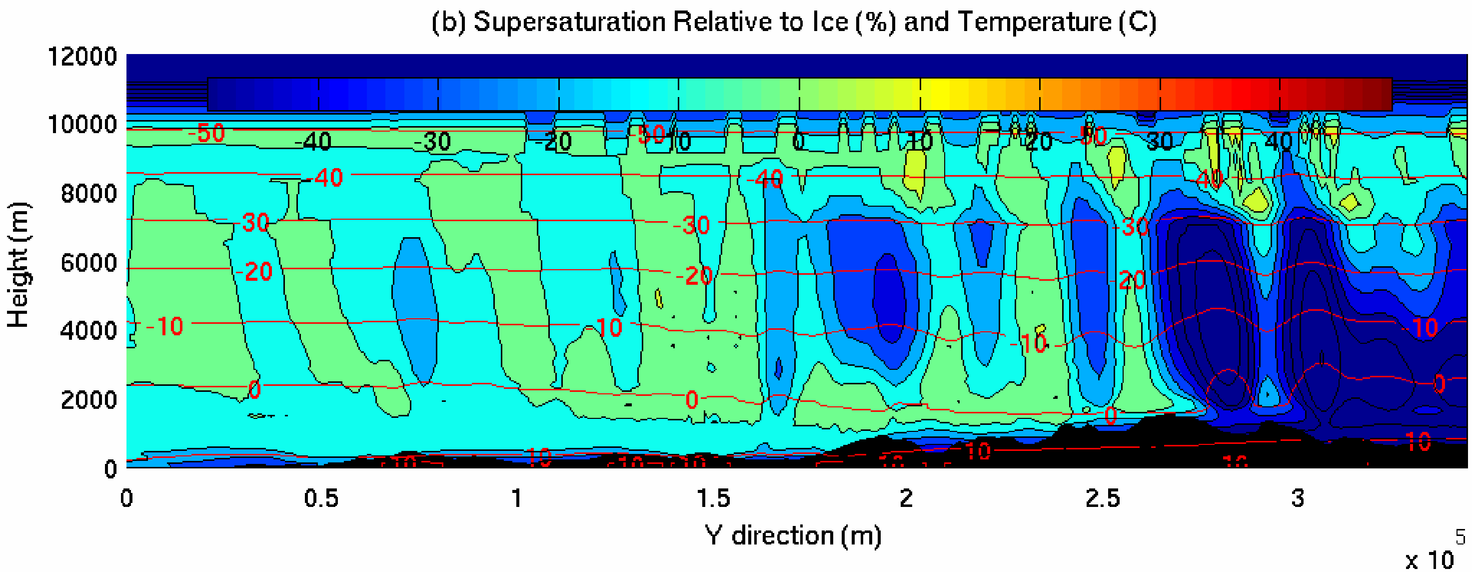
Woods et al. Figure 10

2 Hour Model Simulation (All Ice Processes)

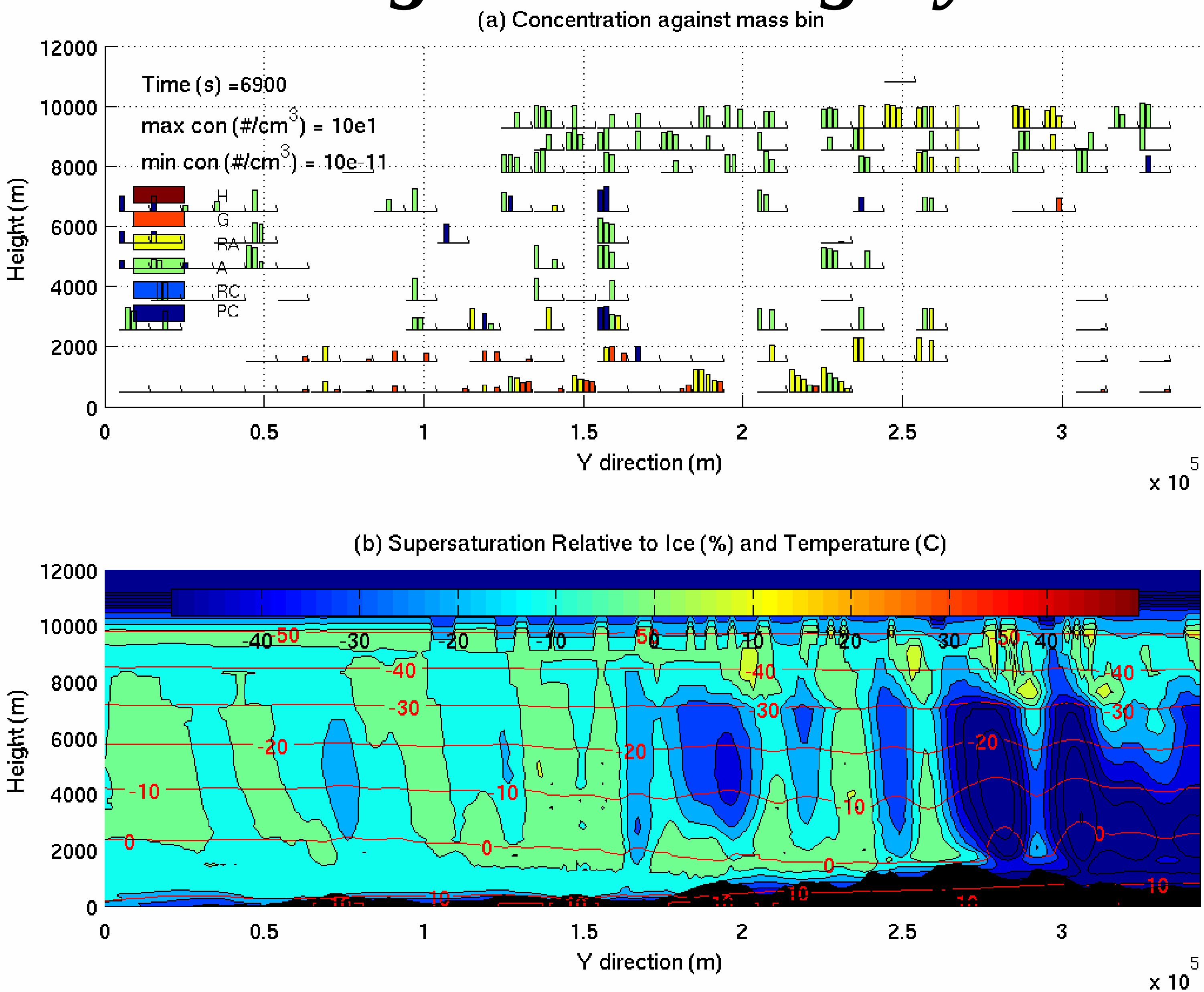


Diagnosed Habit

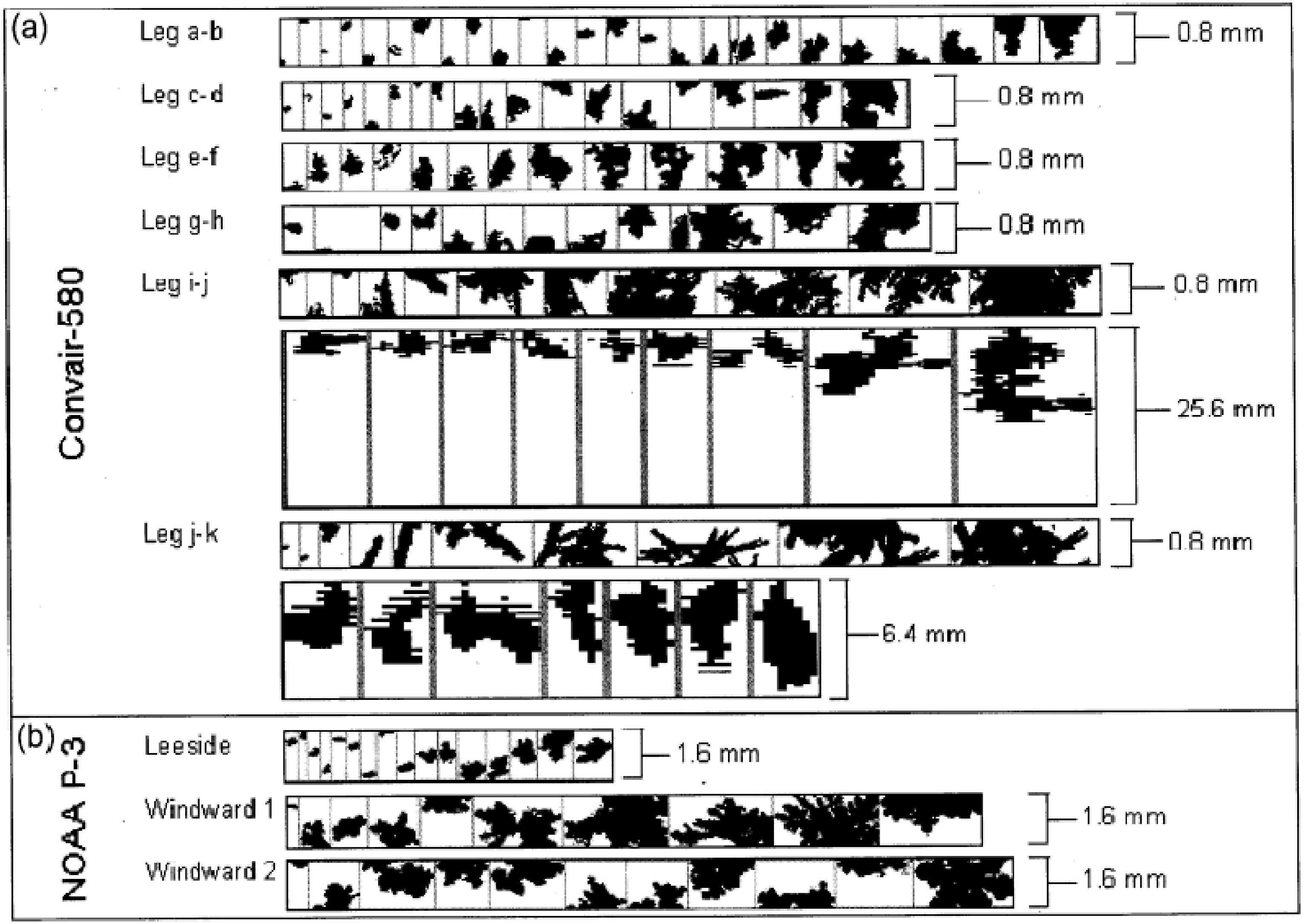




Diagnosed Category



Are Maximum Dimension & Density Correct?



Woods et al. Figure 11

6km

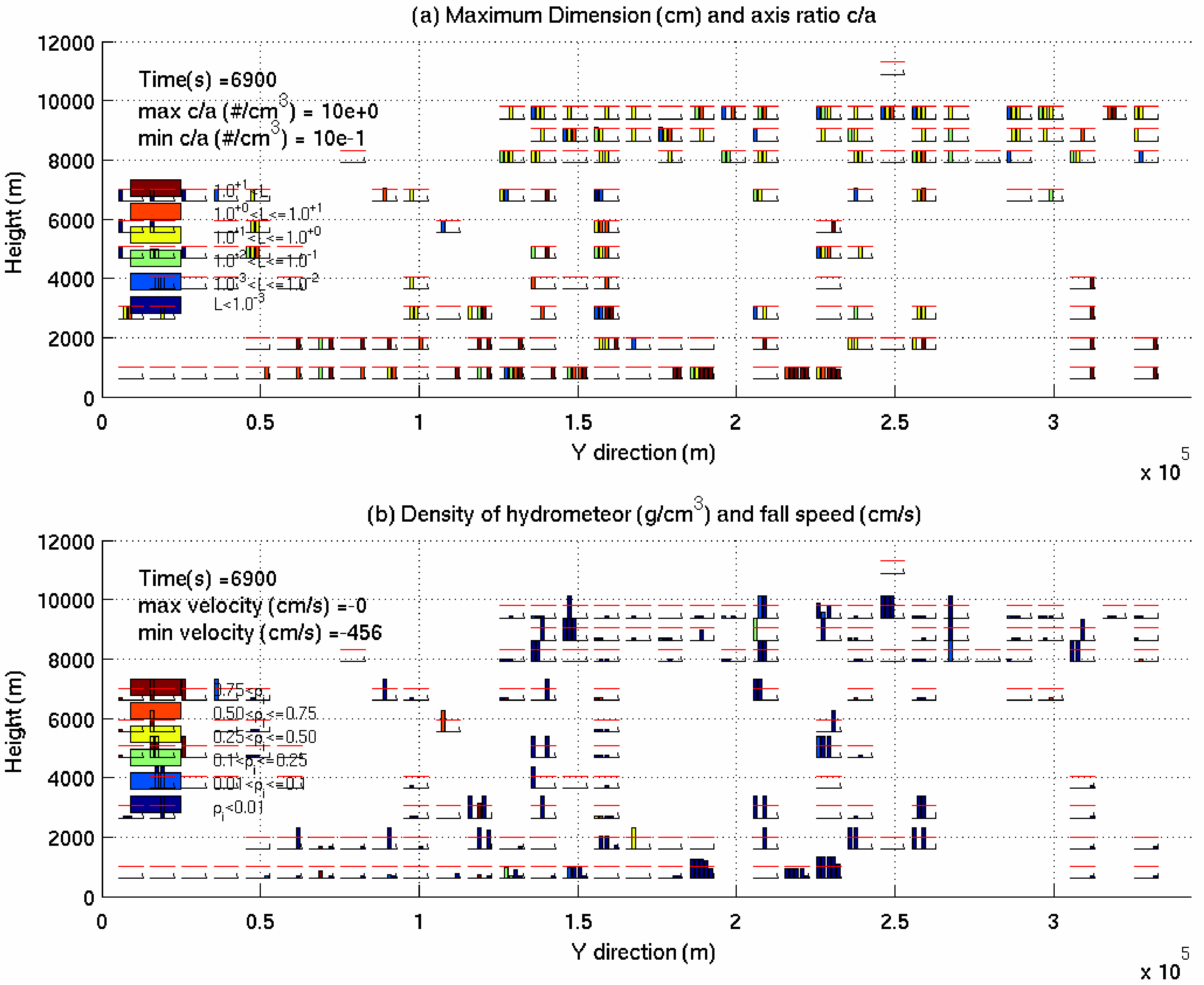
5.3km

5km

4.2km

3.2km

2-3.2km


(a) Maximum Dimension (cm) and axis ratio c/a
Time(s) =6900
max c/a (#/cm3) = 10e+0
min c/a (#/cm3) = 10e-1
Height (m)
Y direction (m)
x 10^5
(b) Density of hydrometeor (g/cm3) and fall speed (cm/s)
Time(s) =6900
max velocity (cm/s) =-0
min velocity (cm/s) =-456
0.50<ρi<=0.75
0.25<ρi<=0.50
0.1<ρi<=0.25
ρi<0.01
Height (m)
Y direction (m)
x 10^5

Radiative Transfer

Kwo-Sen Kuo and Eric A. Smith are developing new RTE model that adapts to details inherent in NMS modelÕs new microphysics parameterization.

This involves solving three key problems:

PROBLEM 1: Adapting to hydrometeors of variable density and phase.

SOLUTION 1: Single scatter model assumes *fully arbitrary layering of dielectric properties* -- thus allowing for multiple interfaces of complex refractive index. [operable]

PROBLEM 2: Adapting to hydrometeors of variable shape.

SOLUTION 2: Single scatter model uses *consummate solution* for several (7) collections of interacting spherical particles (thus avoiding far-field assumption) to form building block (kernel) shapes -- then used to generate arbitrary hydrometeor shapes. Similar to but faster than Discrete Dipole Method (DDM) for representing optical properties of complex shaped particles -- but yet to be shown to represent characteristic phase functions and volume attenuation coefficients. [in progress]

PROBLEM 3: Adapting to 3-dimensional heterogeneous mix of hydrometeors of arbitrary orientation which multiple scatters imposed radiation field across, solar, infrared, and microwave spectrums.

SOLUTION 3: Multiple scattering model uses *Picard iteration to produce fully analytic radiative transfer solution in 3-dimensional framework*. [operable]

Conclusions

- **Qualitatively SHIPS/SLiPS appears to reproduce reasonable habit and size distributions.**
- **More investigation on optimal parameter to represent axis growth history in Eulerian framework is needed.**
- **Initial computational efficiency promising, but further development is necessary.**
- **Radiative transfer model is being developed which will seize upon responding to new details in microphysical properties.**

Future Research

- Determination of optimal number of parameters.
- More case studies to validate SHIPS.
- Introduce hollow crystal + rosette bullets crystal for cirrus clouds, and capped columns.
- Verify maximum dimension and density prediction with empirical relationship and then with satellite observations through forward calculations.
- 3D orographic simulation.
- Sensitivity analysis:
  - fixed CCN concentration -- does it need to be predicted instead of diagnosed?
  - collision efficiency (demonstration of habit and type effect)?
  - cloud seeding experiment?
- Mass component approach.
- RTE experiments to demonstrate efficacy of consummate solution scheme.