

**A Radical
Dynamical Mesh Refinement
Under a Finite Volume Framework
Inspired by
Atmospheric Subgrid-Scale
Parameterization (NAM-SCA)**

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Outline (1)

Motivation: Parameterization Problem:
“Parametric” Representation of Subgrid-Scale Processes in Atmospheric Modelling

Basic Strategy: Be Simple: Upstream Flux Scheme, no adaptation in time, etc

NB: Climate System: Non-Conservative:
Strongly Forced-Dissipative System (no “shock” anticipated, subsonic flow)

Outline (2)

Basic Features: Refinement/Adaptation is Totally “Unstructured” and “Local”

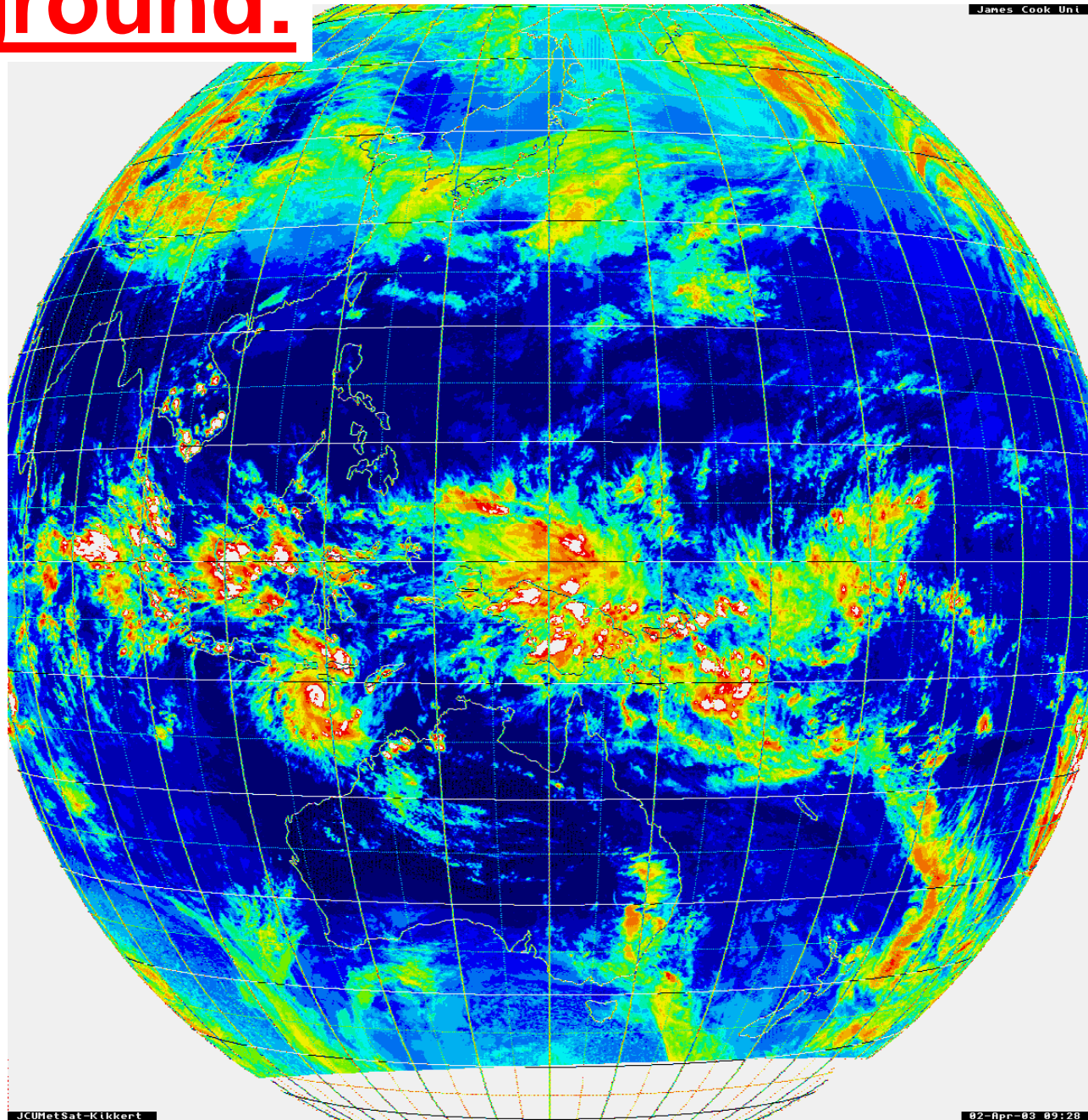
Numerics: Strict 0th-Order Finite-Volume (Horizontally): **Segmentally-Constant Approximation (SCA)**

Notes: **Exception: Poisson Pressure solver (with “full” resolution), Refinement (Degradation) Only in Horizontal, Finite Difference in Vertical System:**
Nonhydrostatic Anelastic Model (NAM)

NAM: Model System:

- **Nonhydrostatic**
- **Anelastic=Boussinesq+Mean Density (thermal) Stratification (z)**
- **Ideal Gas (or Constant Density)**
- **+**
- **Physics: Cloud (Micro)Physics, etc**

Background:

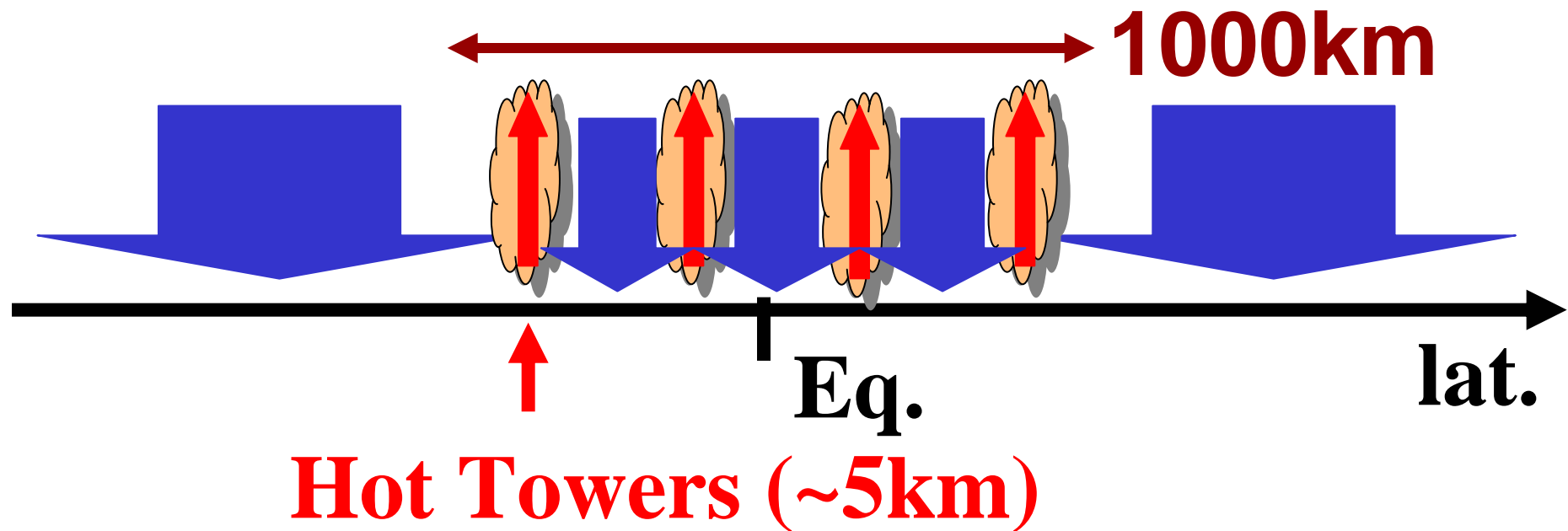


Parameterization Problem:

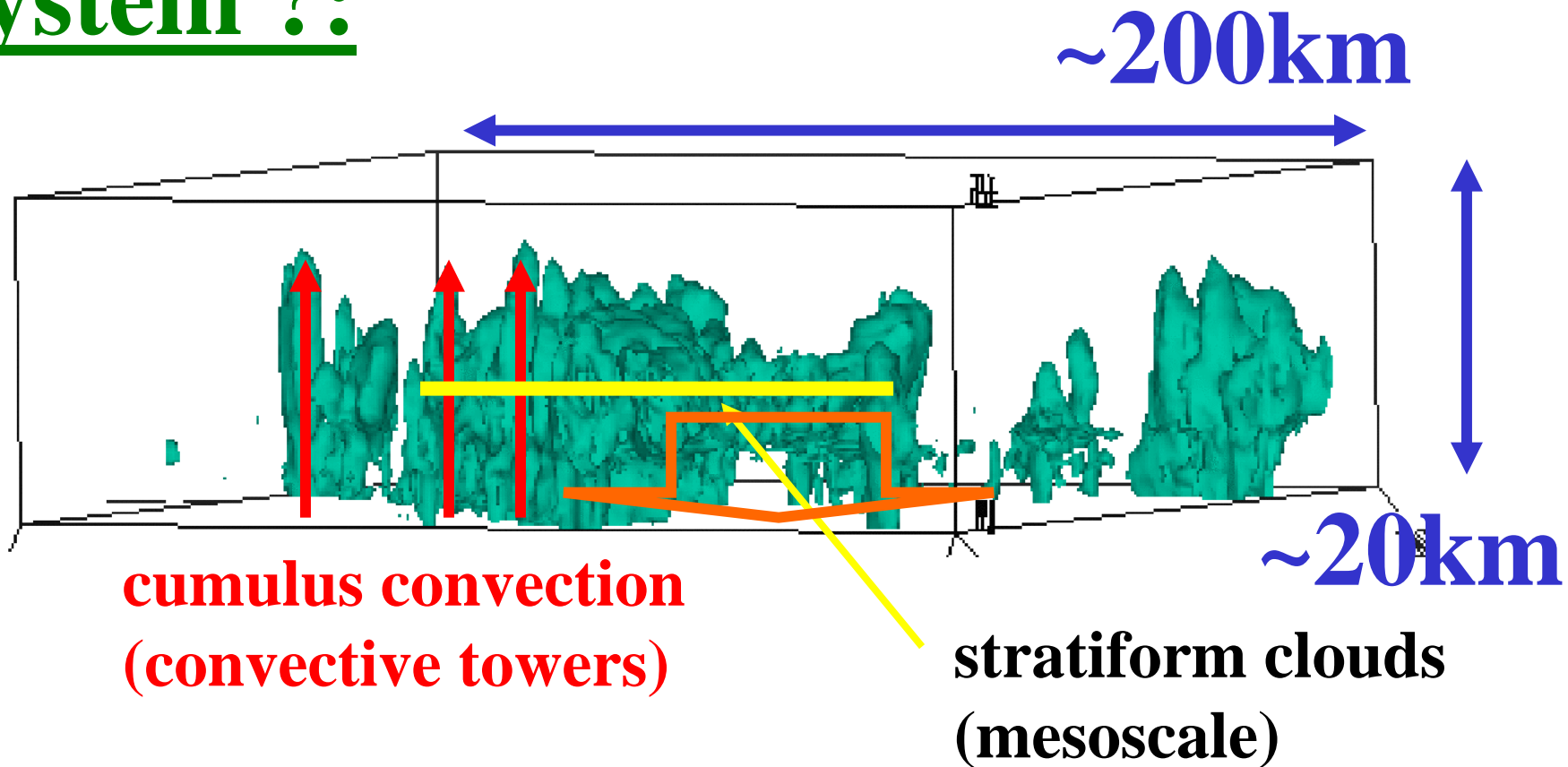
e.g., Hadley Circulation:

Hot-Tower Hypothesis

(Riehl and Malkus 1958):



What should be parameterized: A Typical Atmospheric Convective System ?:



Parameterization: Caricaturization

AKIO ARAKAWA AND WAYNE HOWARD SCHUBERT

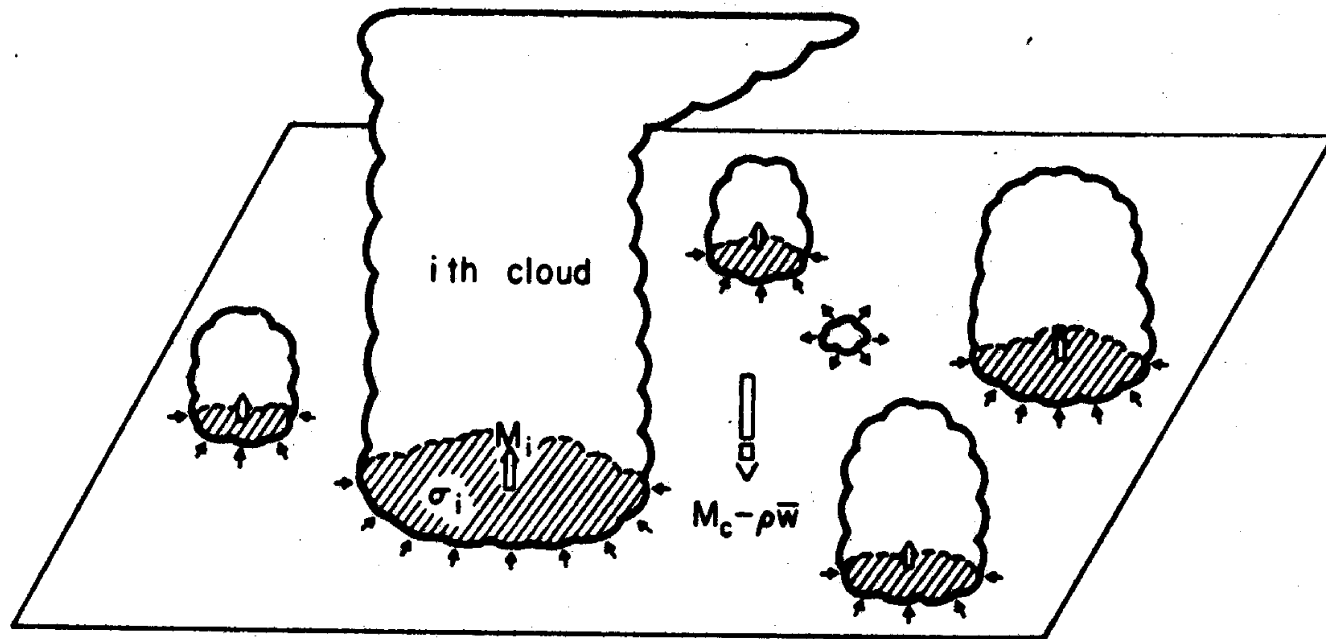
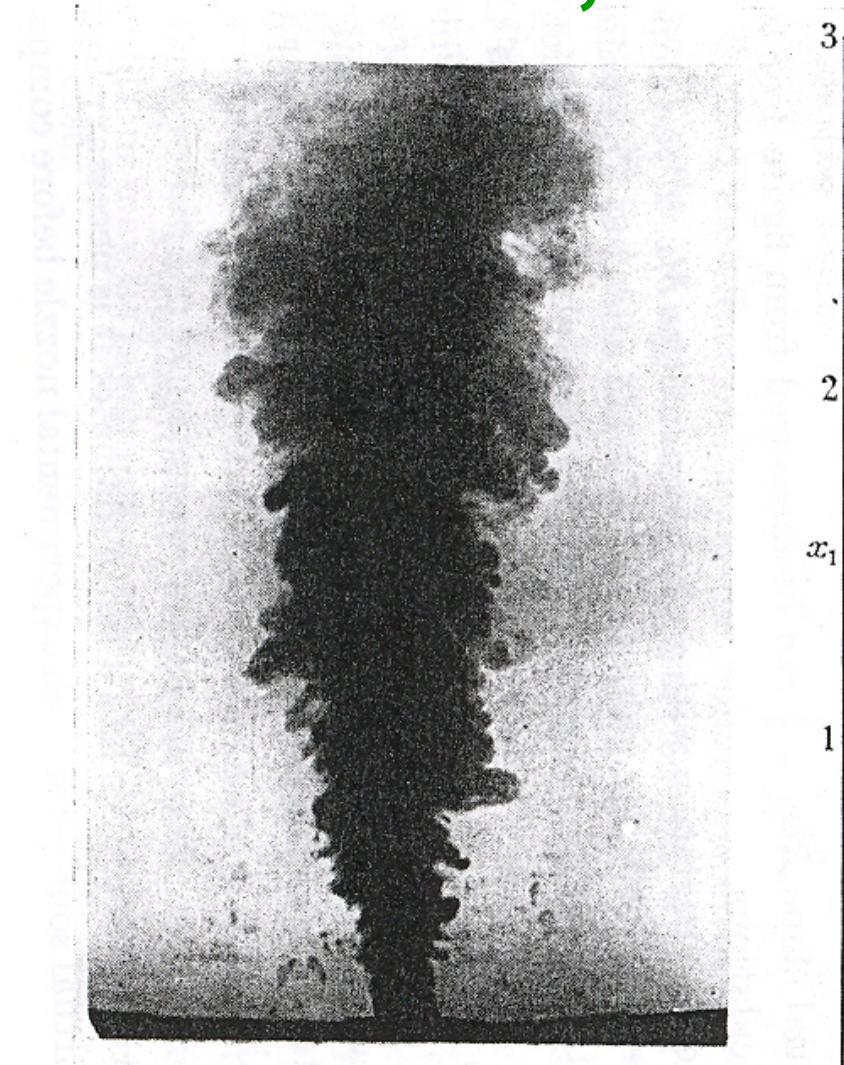


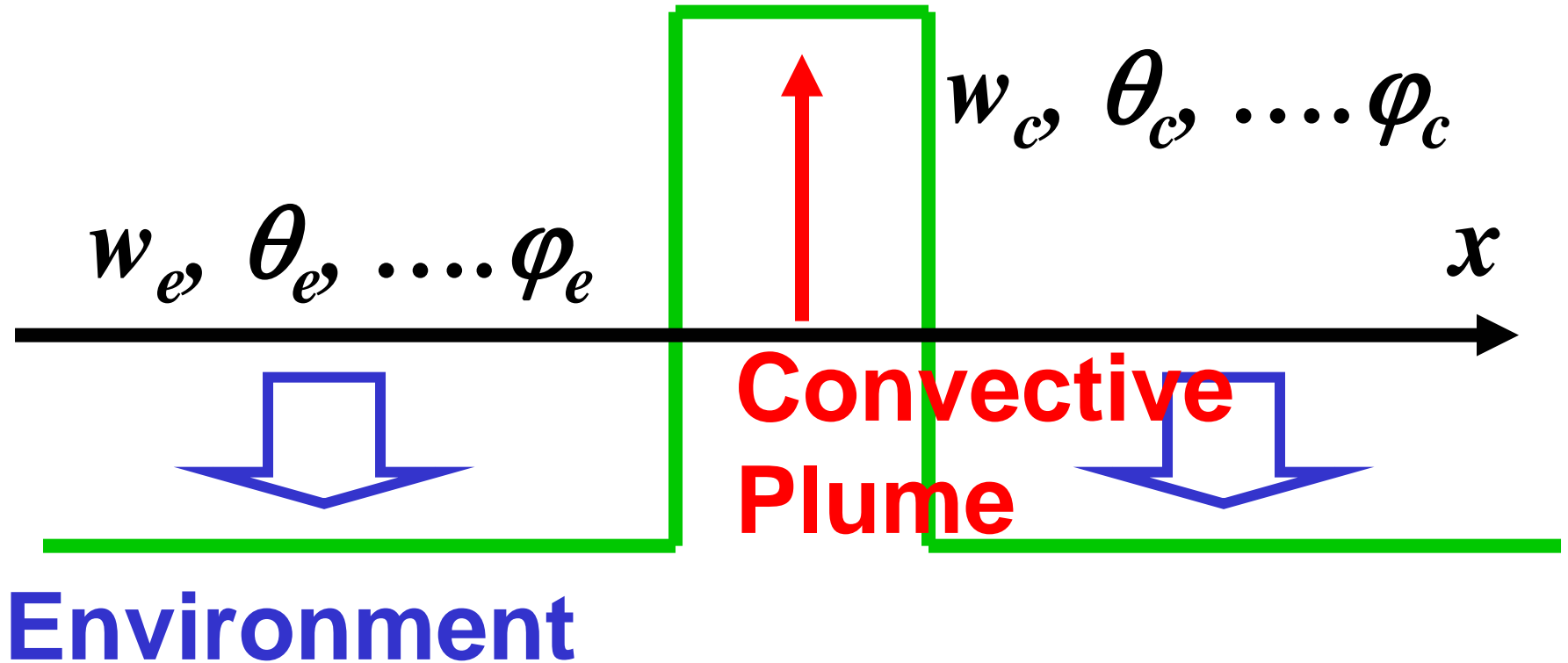
FIG. 1. A unit horizontal area at some level between cloud base and the highest cloud top. The taller clouds are shown penetrating this level and entraining environmental air. A cloud which has lost buoyancy is shown detraining cloud air into the environment.

basic element:

A Plume: Laboratory Experiments (Morton et al., 1956)



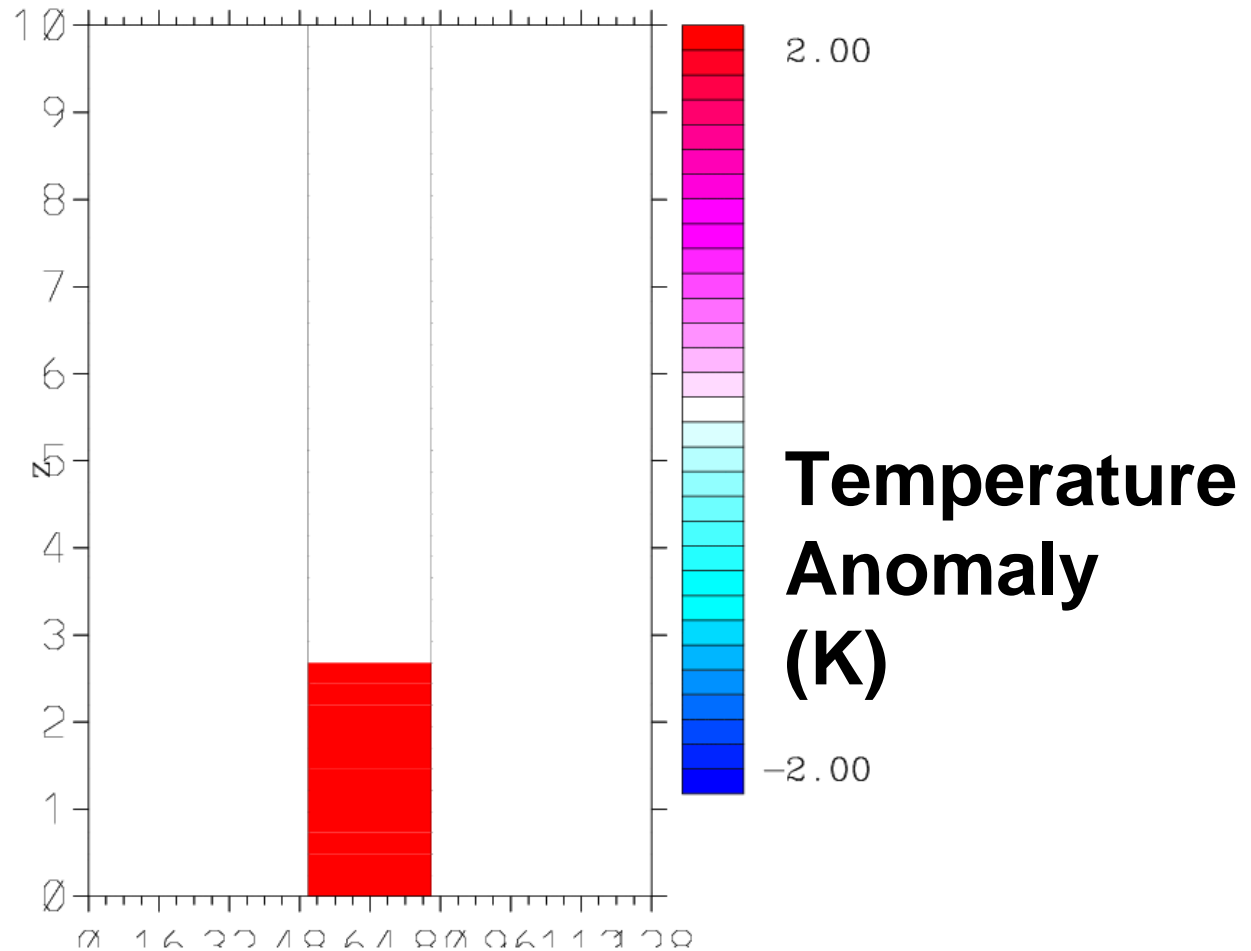
SCA: Segmentally-Constant Approximation



A Plume:

Segmentally-Constant Approximation (SCA)

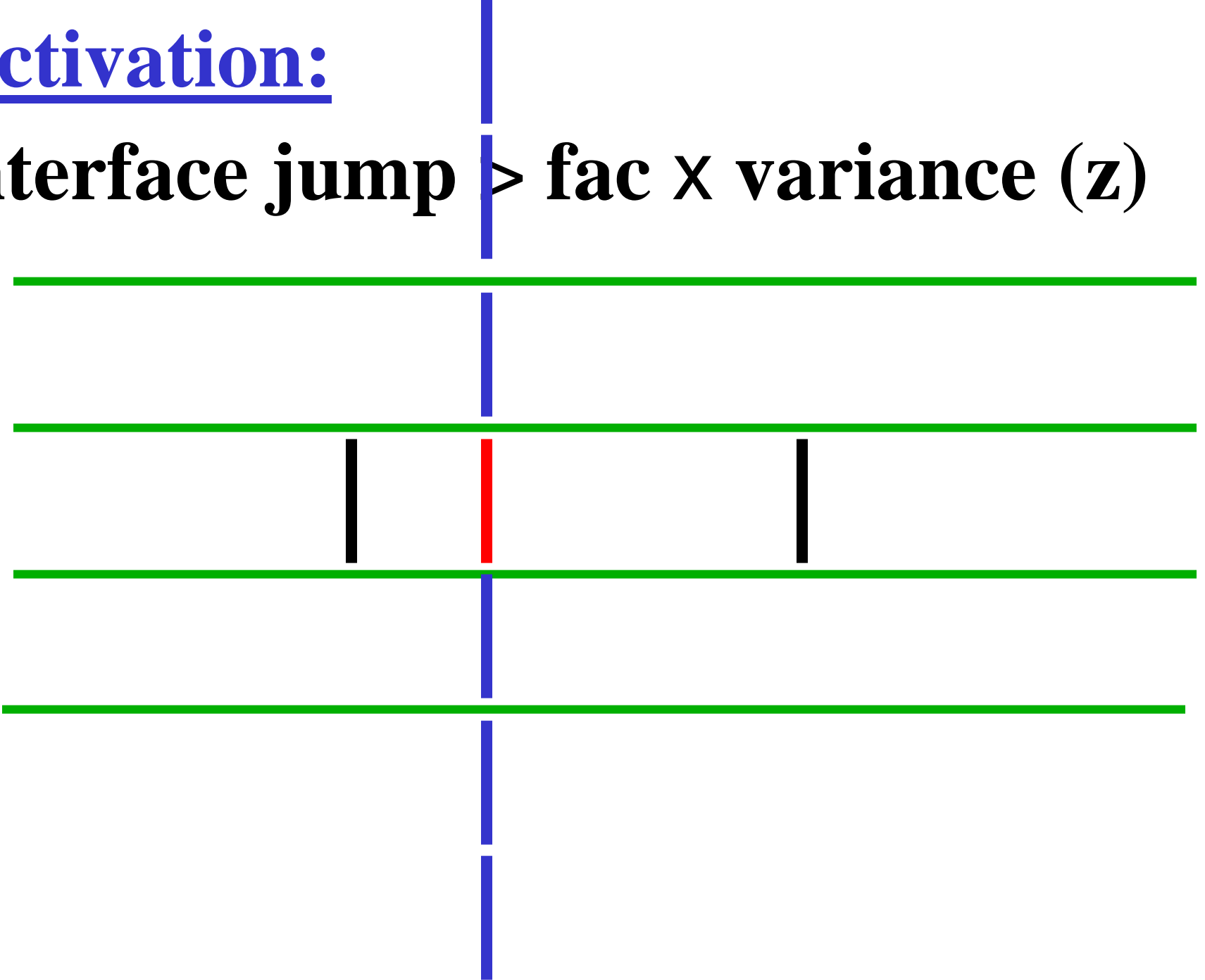
time= 0 min



Mesh Refinement/Adaptation?

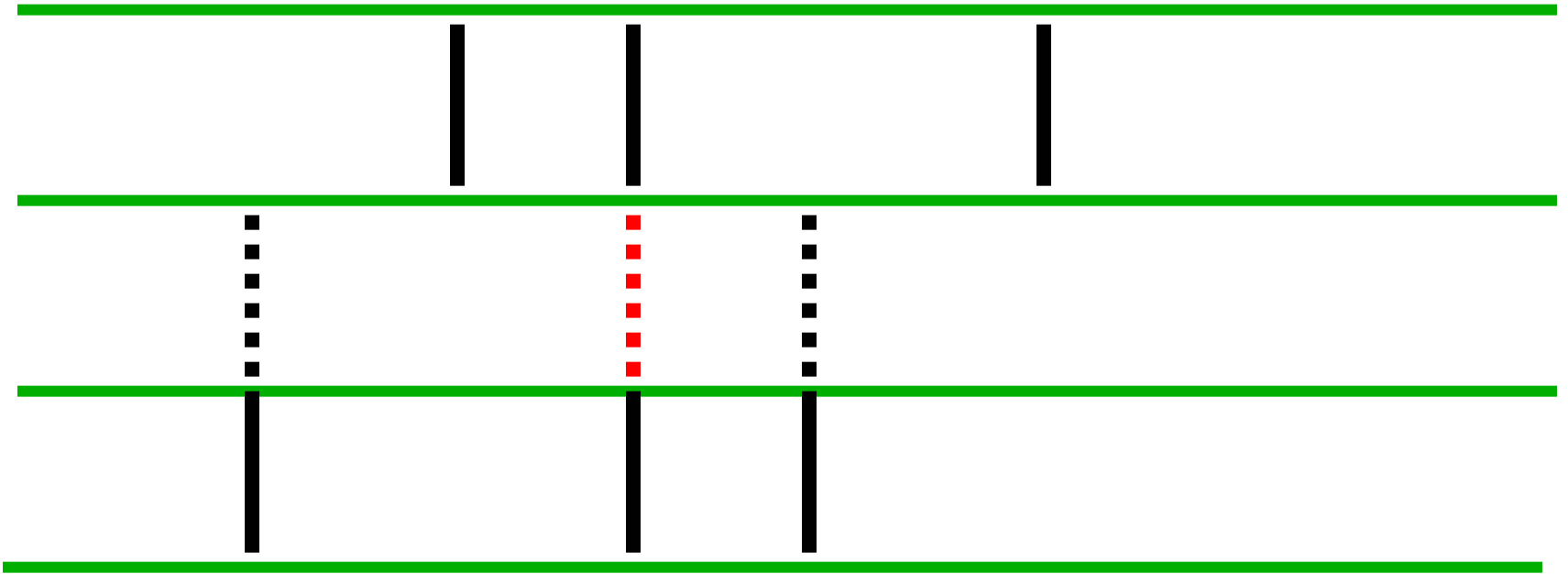
Activation:

interface jump \triangleright fac \times variance (z)



Deactivation:

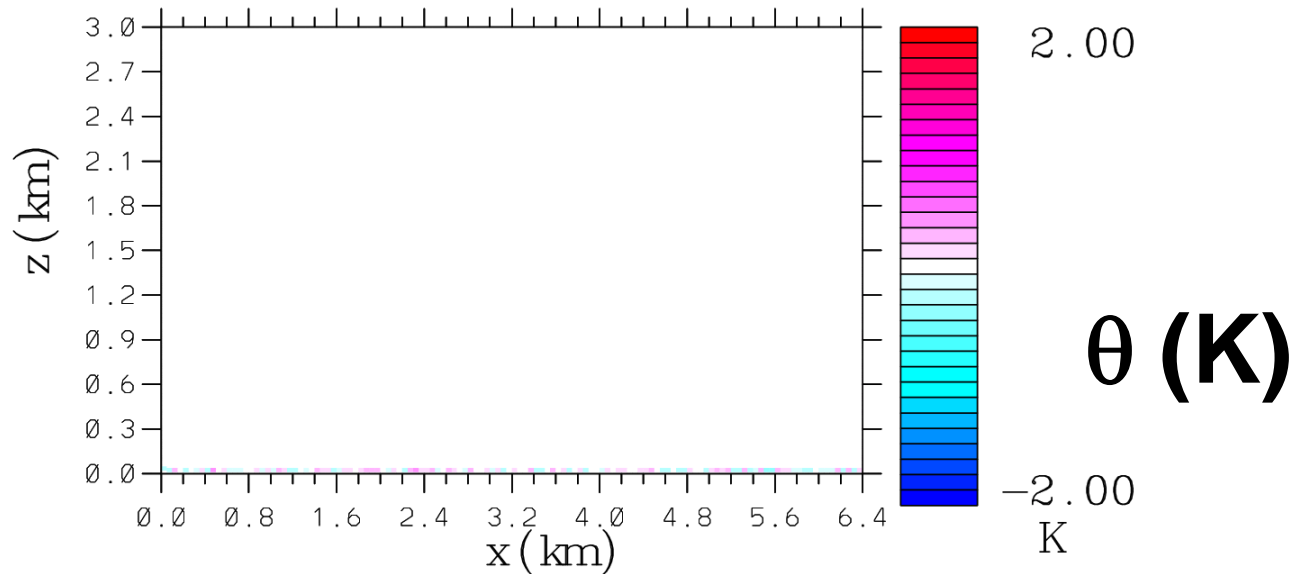
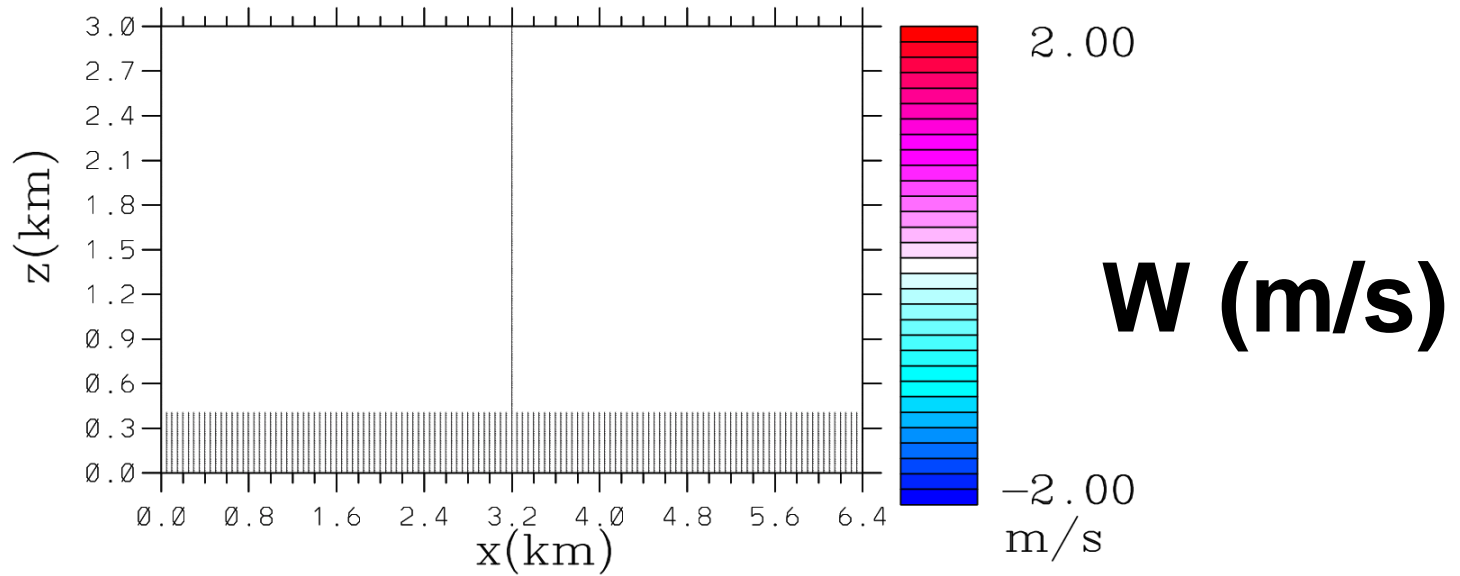
interface jump < facd x variance (z)



fac = facd = 1

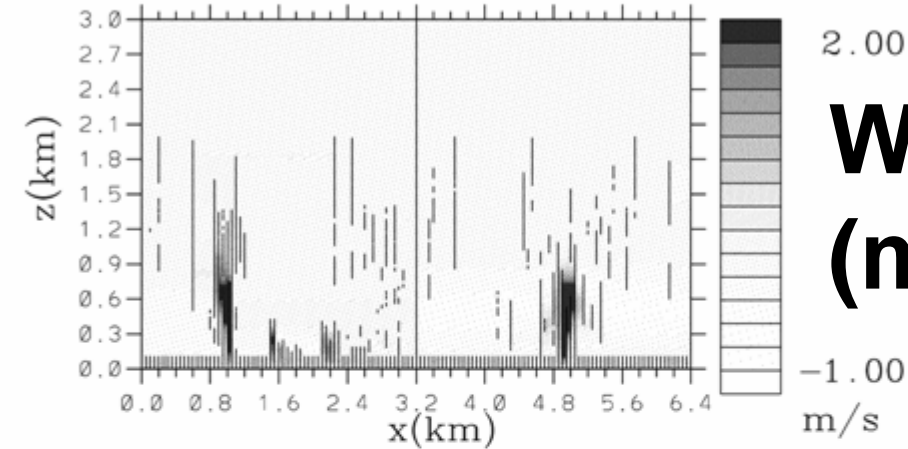
Dry Convective Boundary Layer

time= 0 min

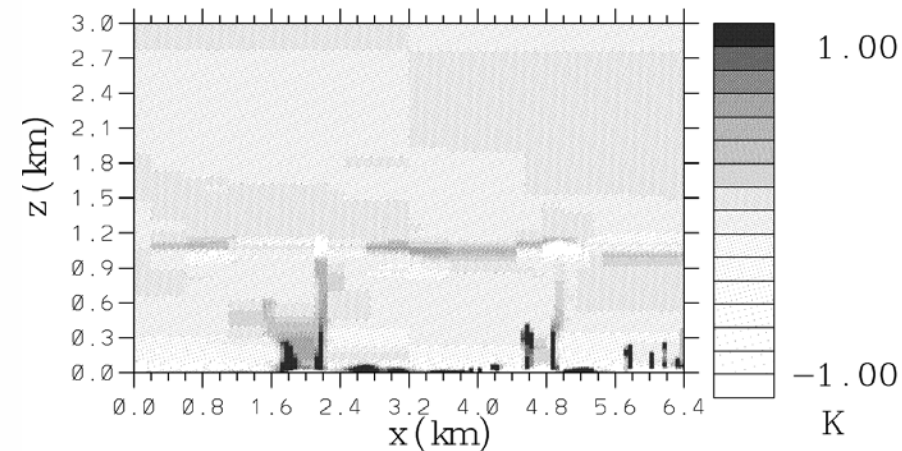
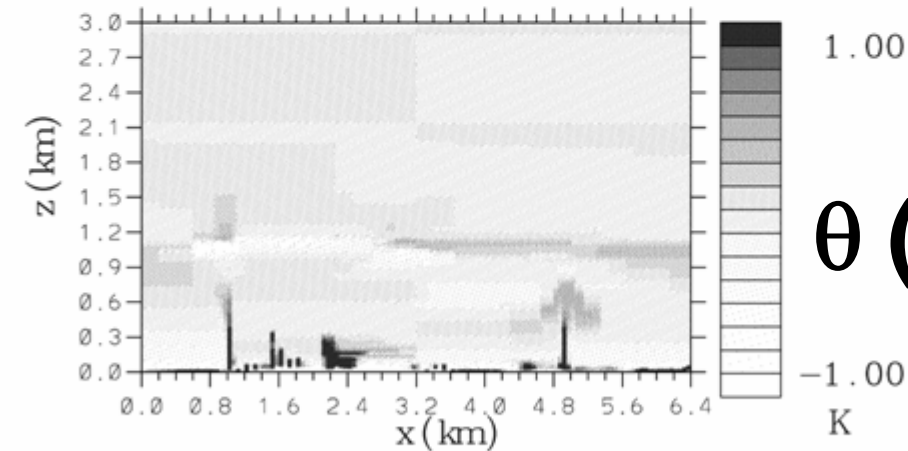
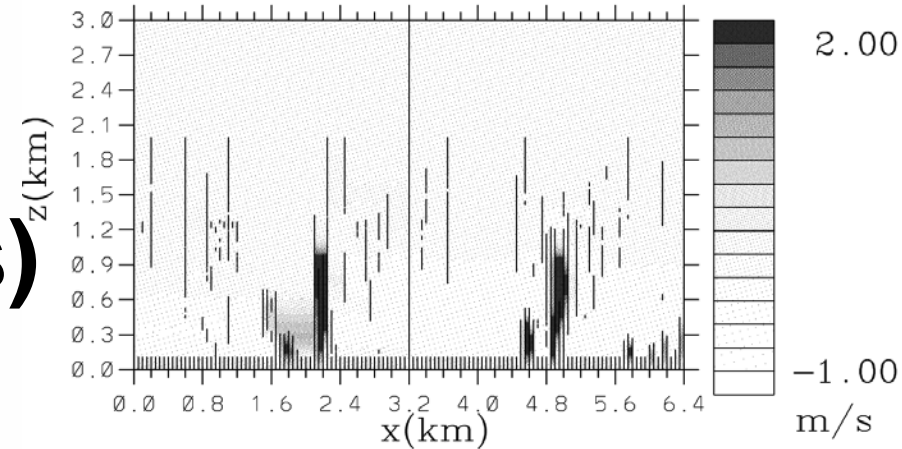


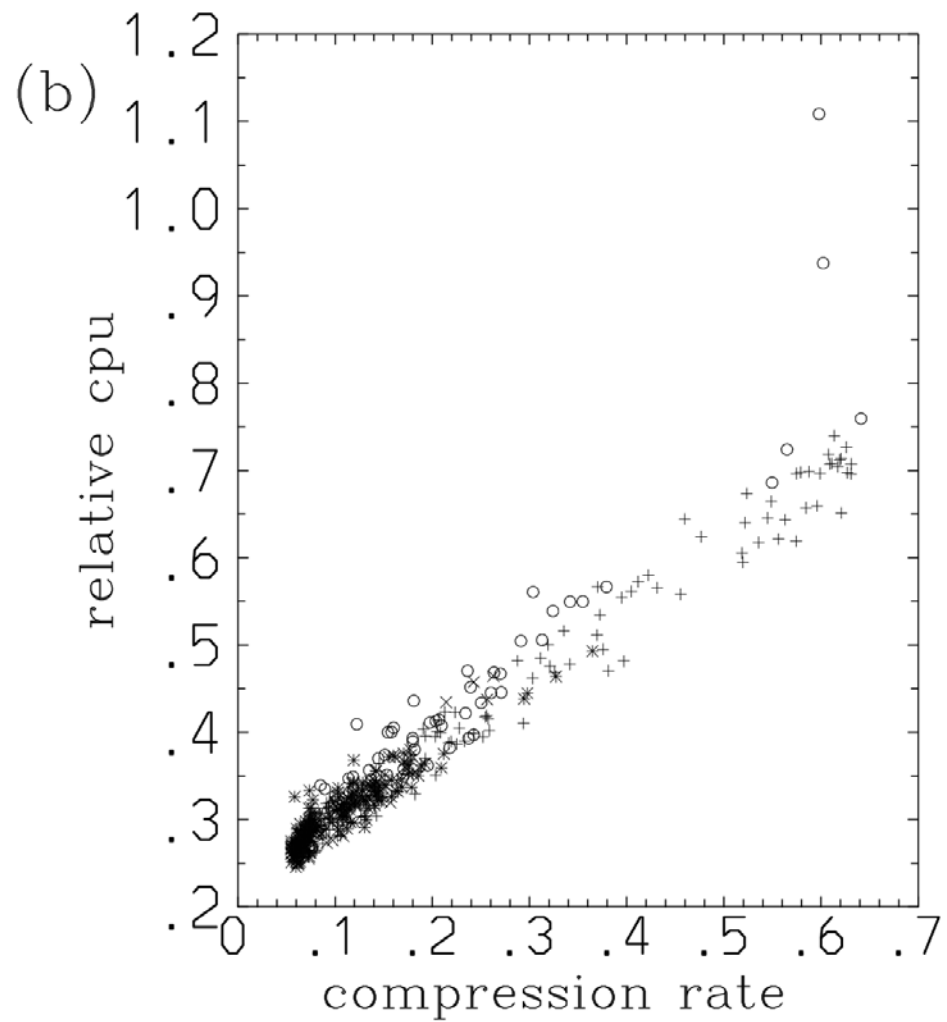
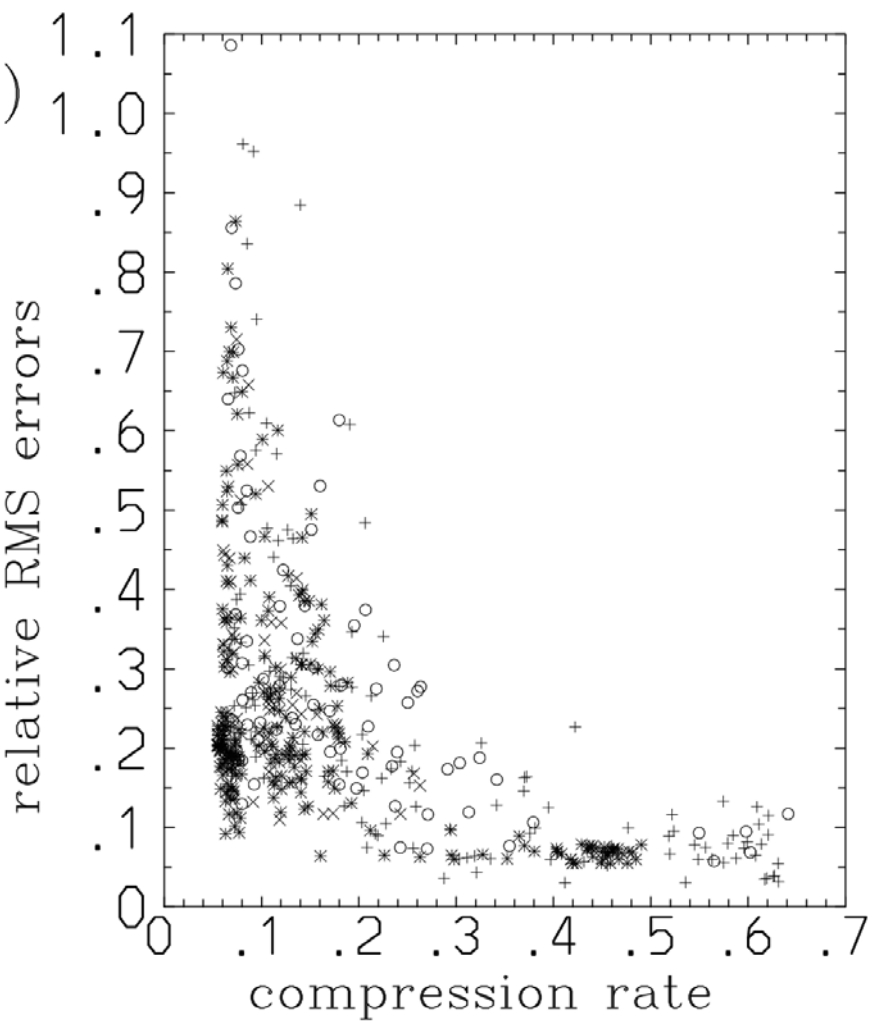
Dry Convective Boundary Layer

time = 8τ

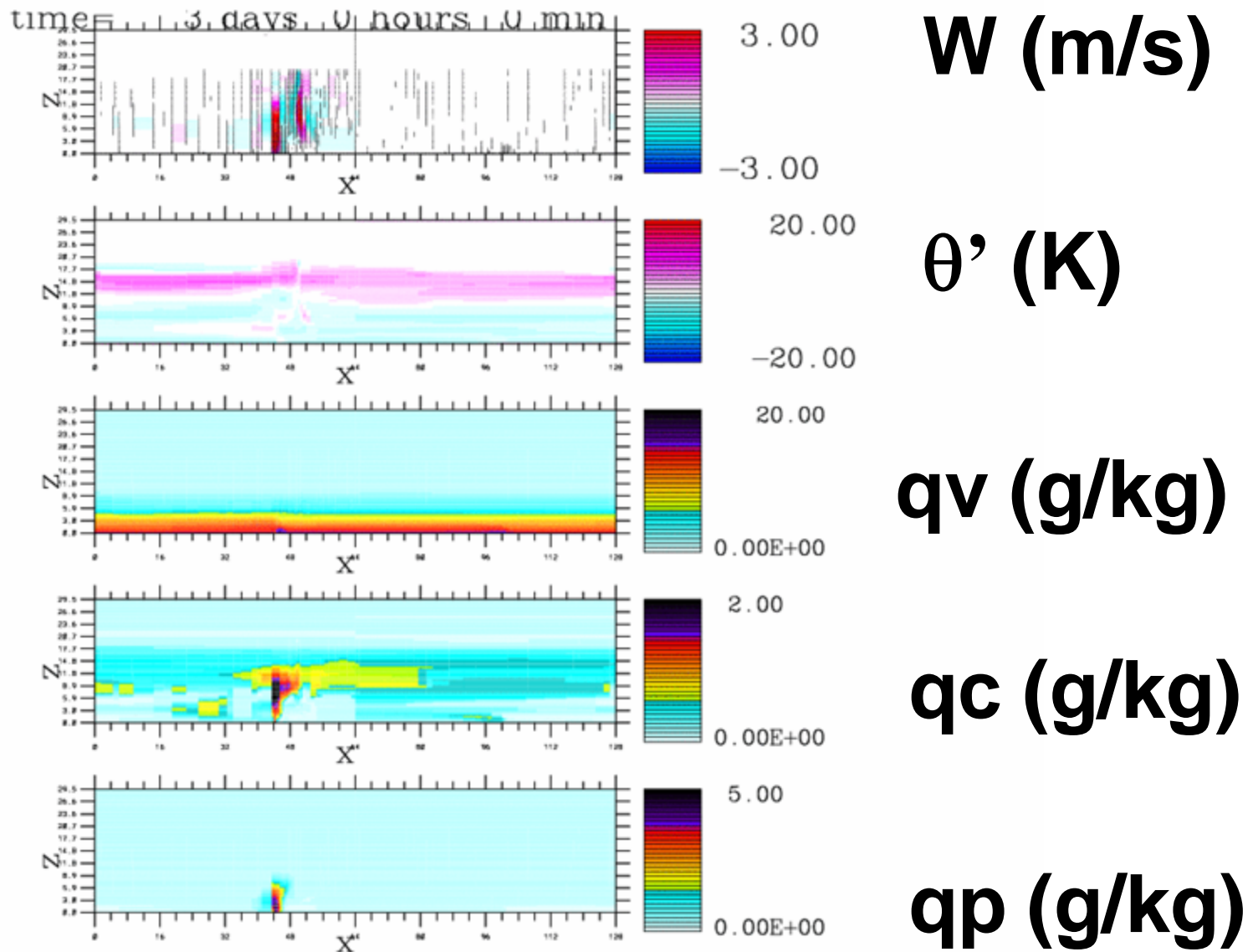


time = 9τ





Tropical Squall-line (GATE Phase III)



Further “Compression”: Organized Convection (Squall-Line)?

NAM-SCA
Framework can
numerically
generate an
organized
convection
(Archetype):
Cubism

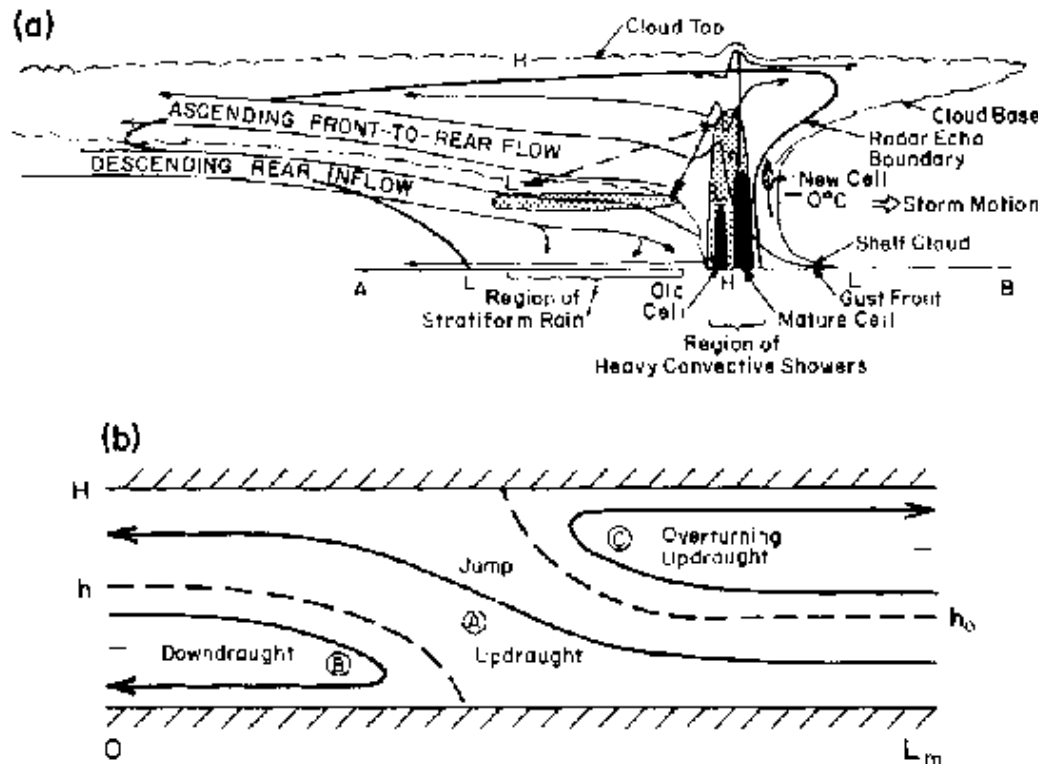
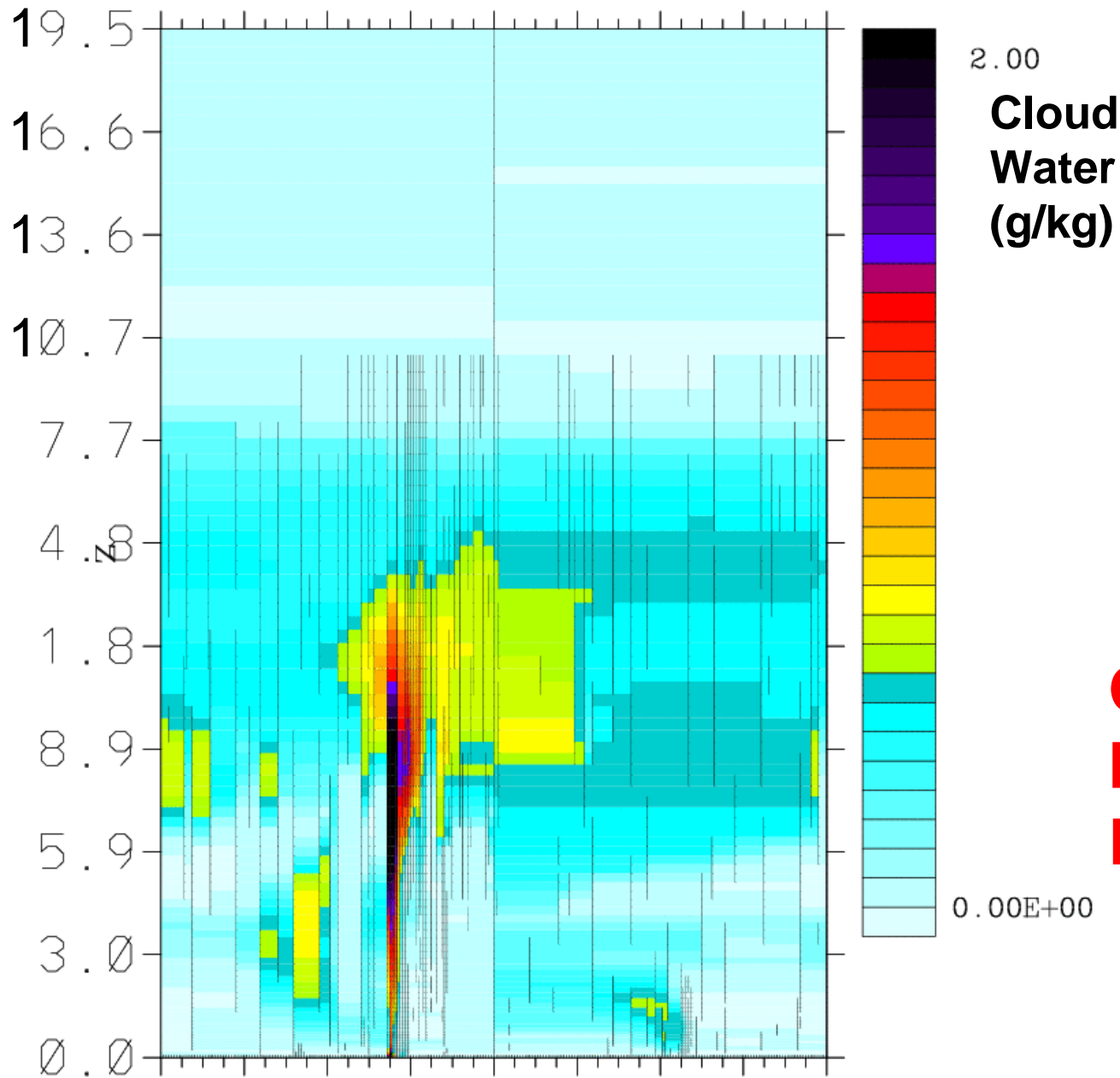
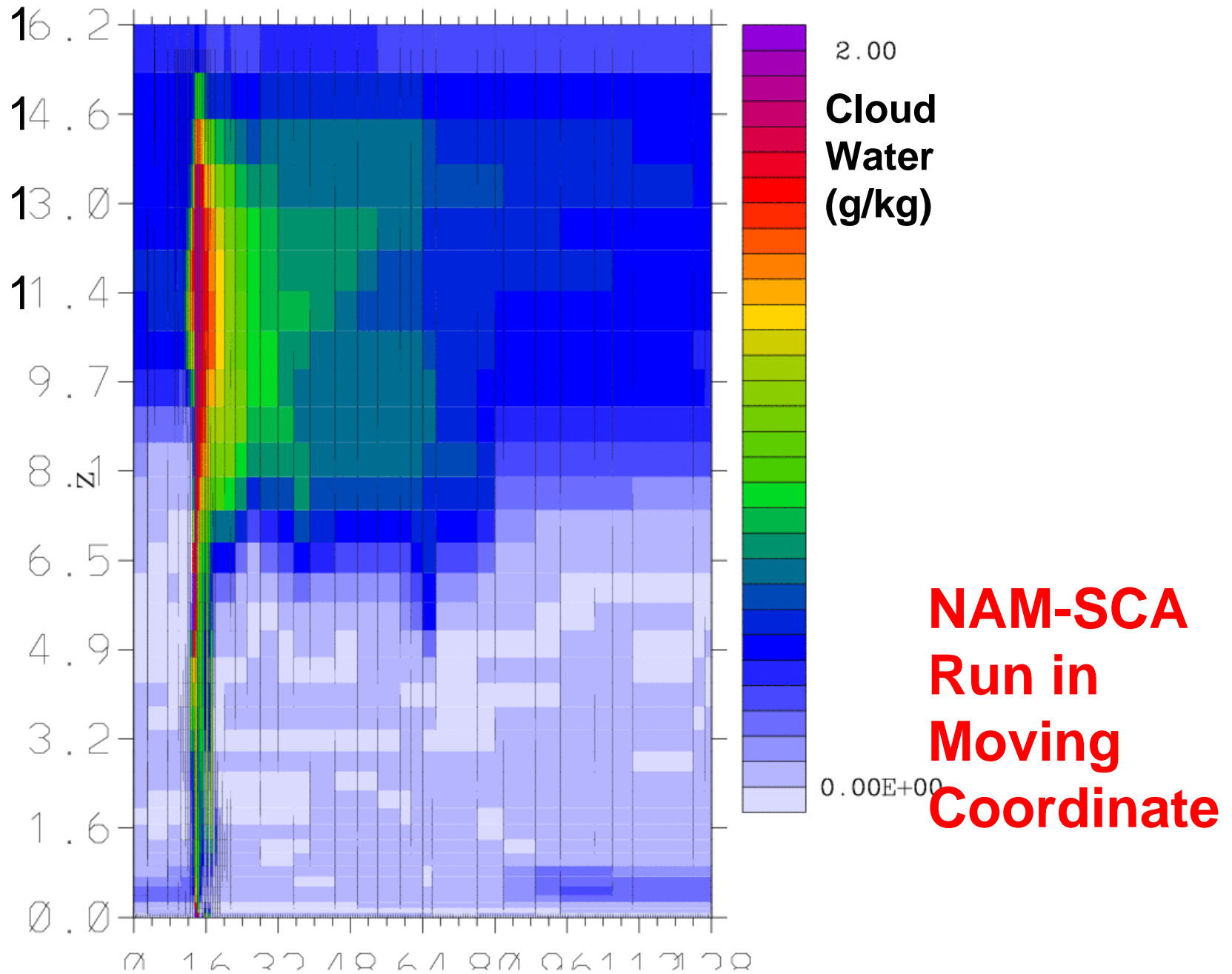


Figure 1. (a) Schematic diagram of the relative airflow and physical processes associated with a squall line MCS. (From Rutledge 1991, adapted from Houze *et al.* 1989) (b) Schematic diagram of the airflow in the stationary dynamical model showing the three flow branches, namely jump updraught (A); downdraught (B); and overturning updraught (C). Branches have piecewise constant densities $\rho_H \approx \rho_A \approx \rho_B$ with $\rho_A = \rho_B = \rho_C$ in the archetypal model.

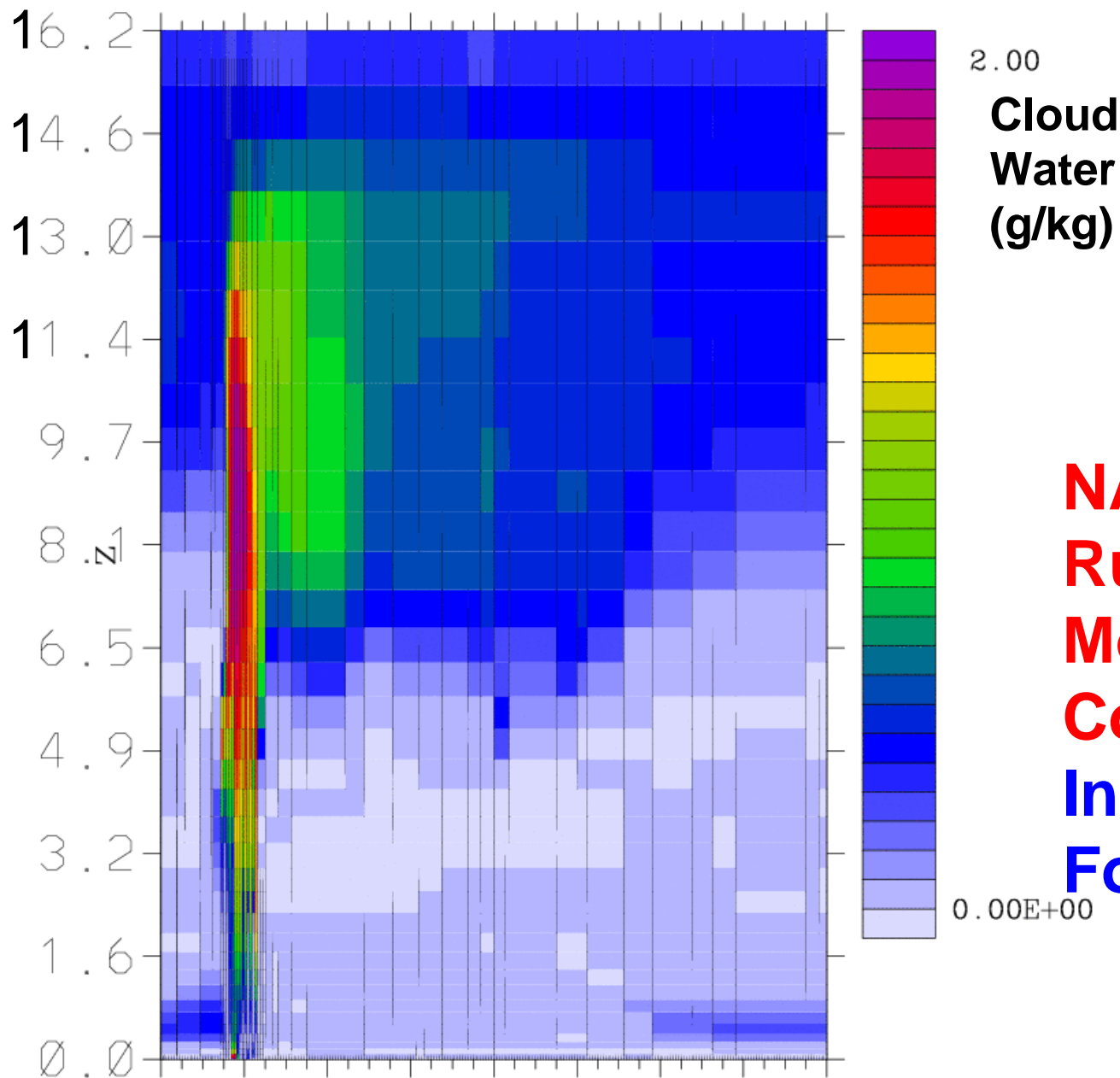
time= 3 days 0 hours 0 min



time= 3 days 0 hours 0 min



time= 3 days 9 hours 0 min

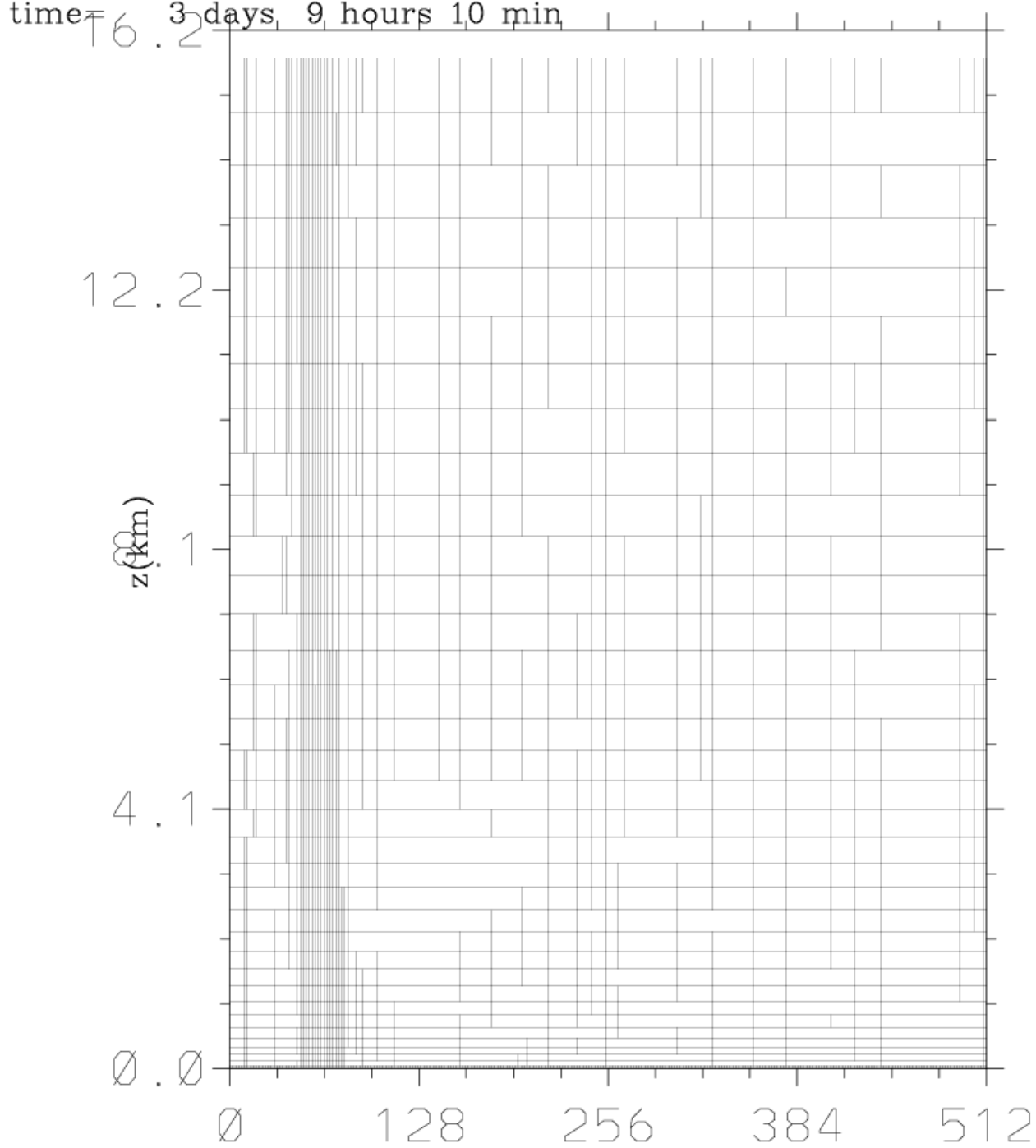


2.00
**Cloud
Water
(g/kg)**

**NAM-SCA
Run in
Moving
Coordinate:
Initial Condition
For Archetype**

0.00E+00

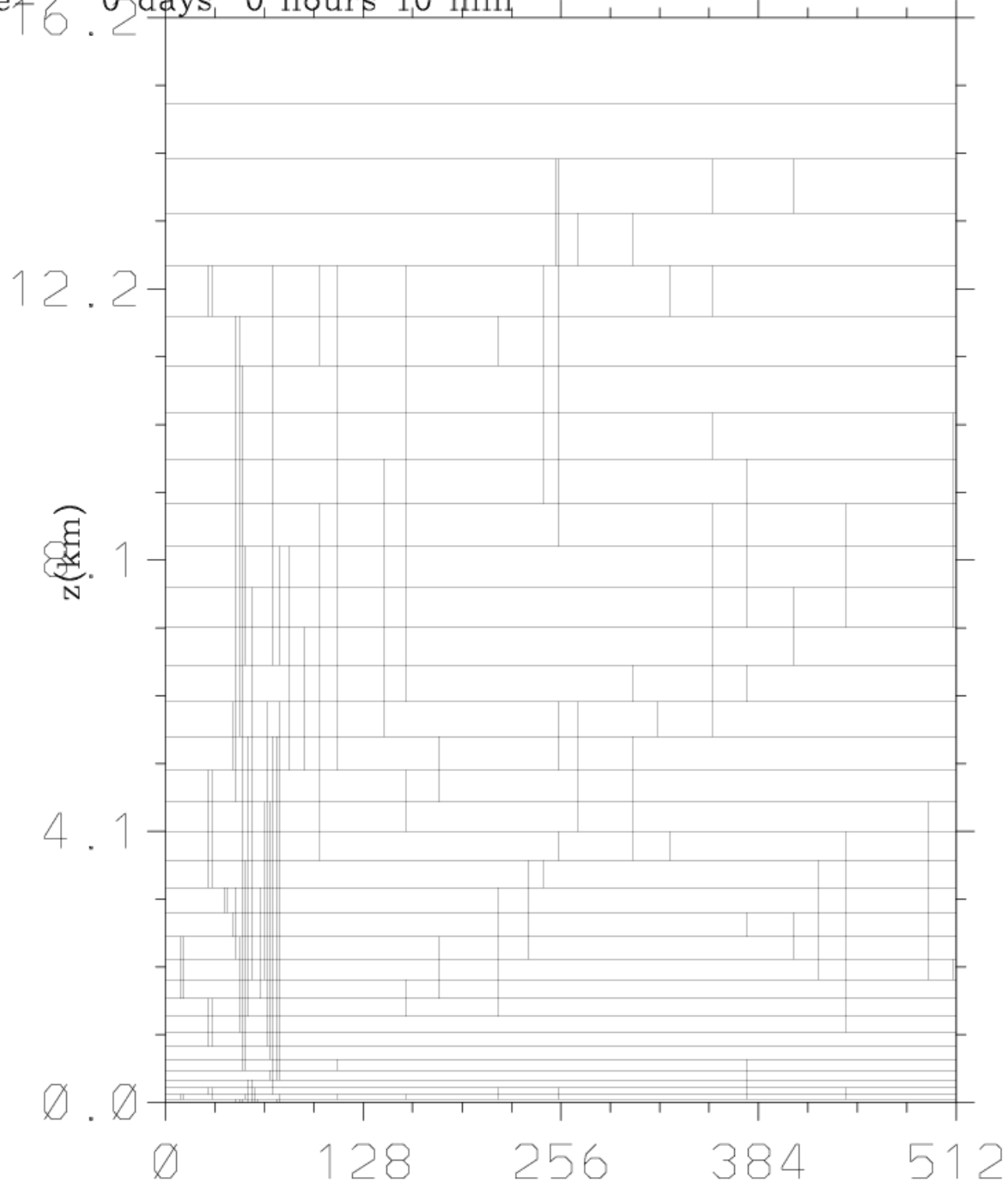
0 16 32 48 64 80 96 112 128



**Finite-Volume
Element
Distribution
(original)**

**NAM-SCA
Run in
Moving
Coordinate:
Initial Condition
For Archetype**

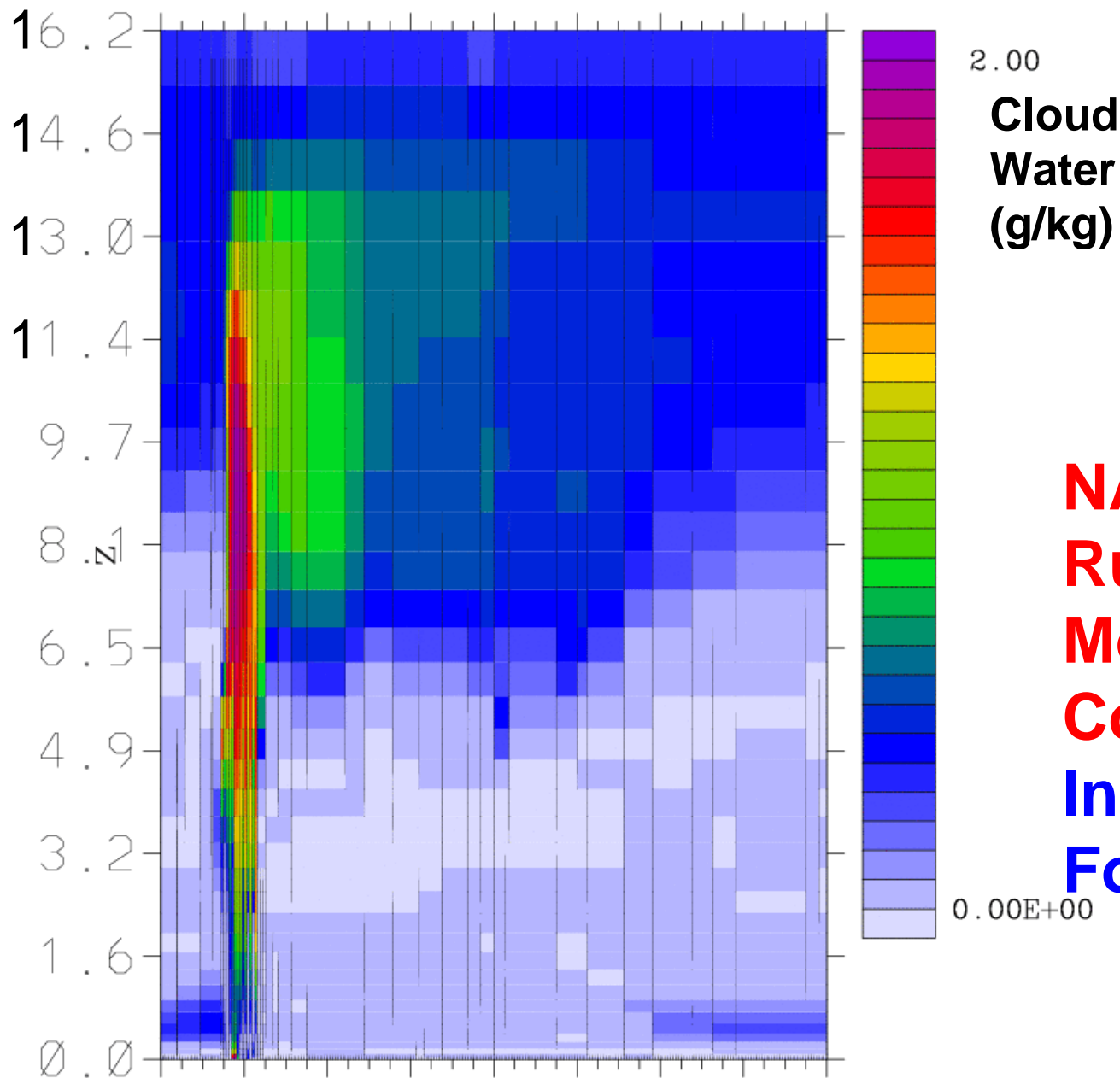
time = 6.2 days, 0 hours 10 min



**Finite-Volume
Element
Distribution
(smoothed)**

**Numerical
Archetype:
Fixed
Distribution of
Finite-Volume
Elements**

time= 3 days 9 hours 0 min

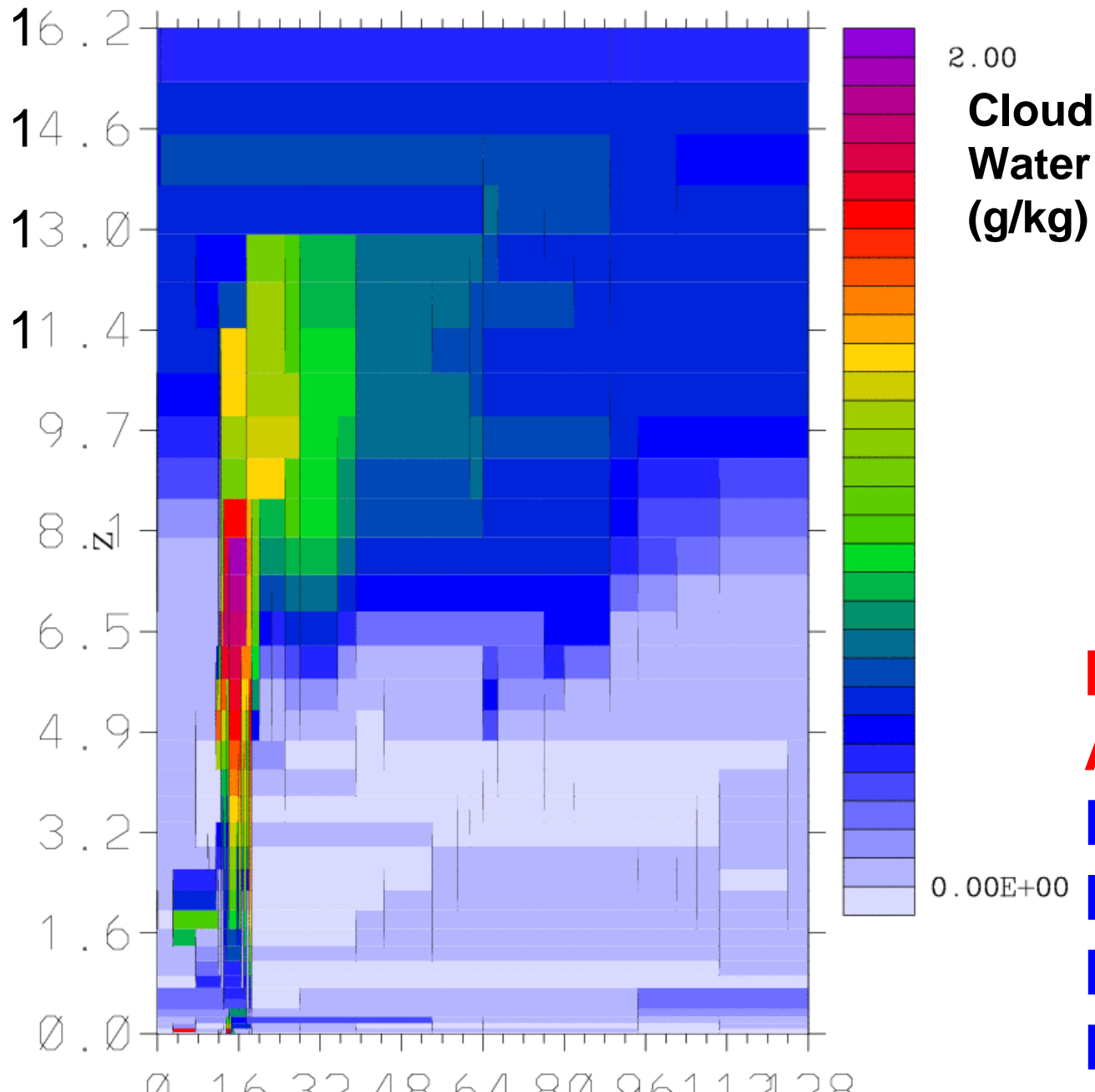


2.00
**Cloud
Water
(g/kg)**

**NAM-SCA
Run in
Moving
Coordinate:
Initial Condition
For Archetype**

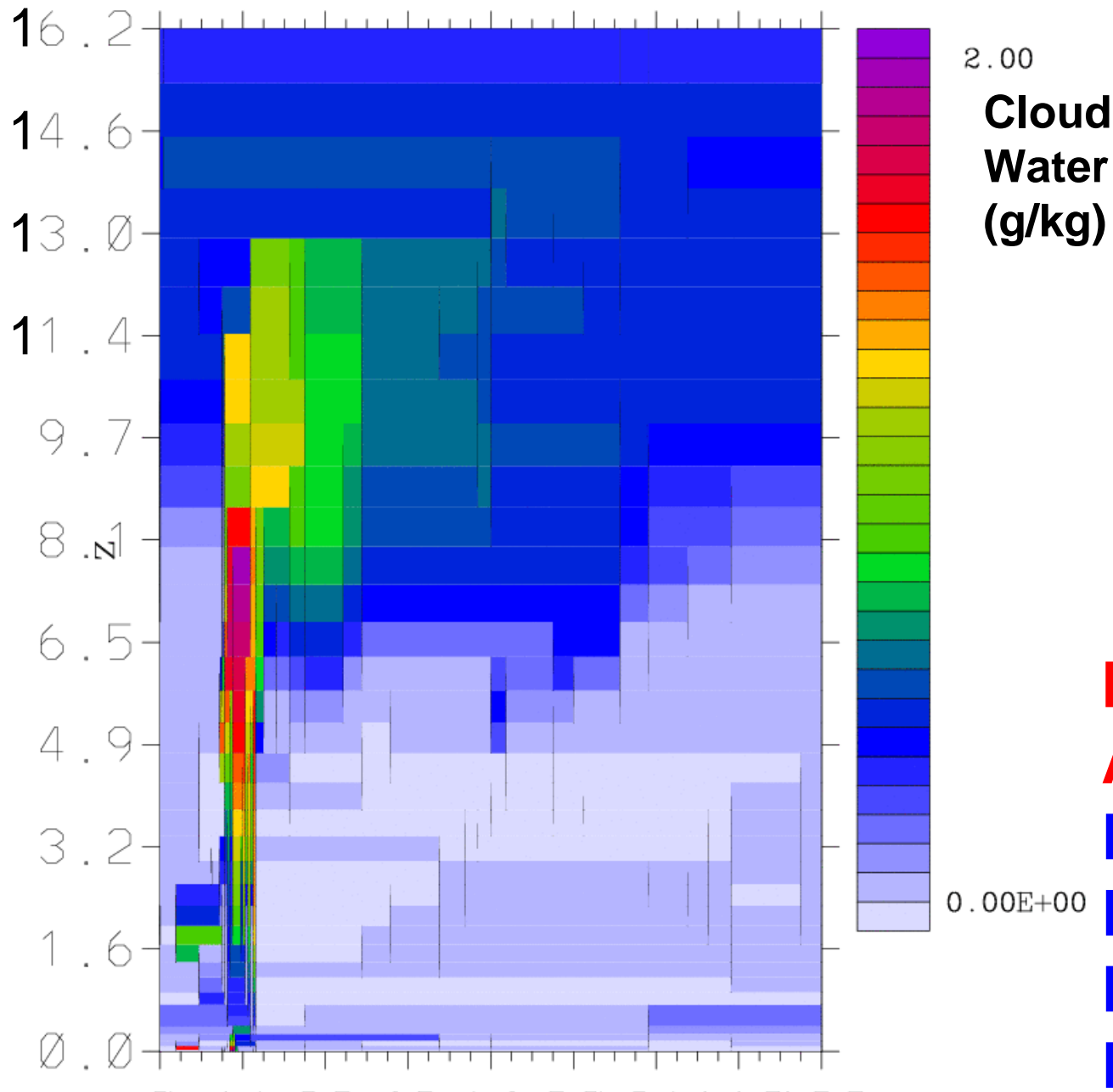
0.00E+00

time= 0 days 0 hours 0 min



**Numerical
Archetype:
Fixed
Distribution of
Finite-Volume
Elements**

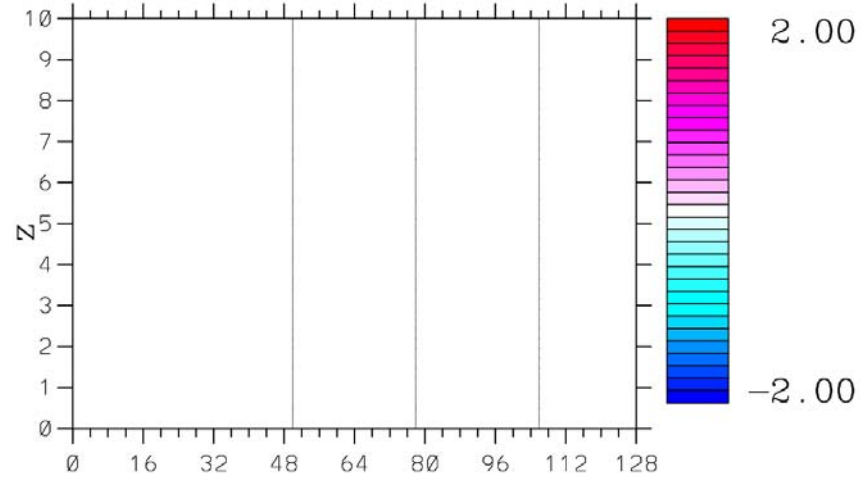
time= 0 days 0 hours 0 min



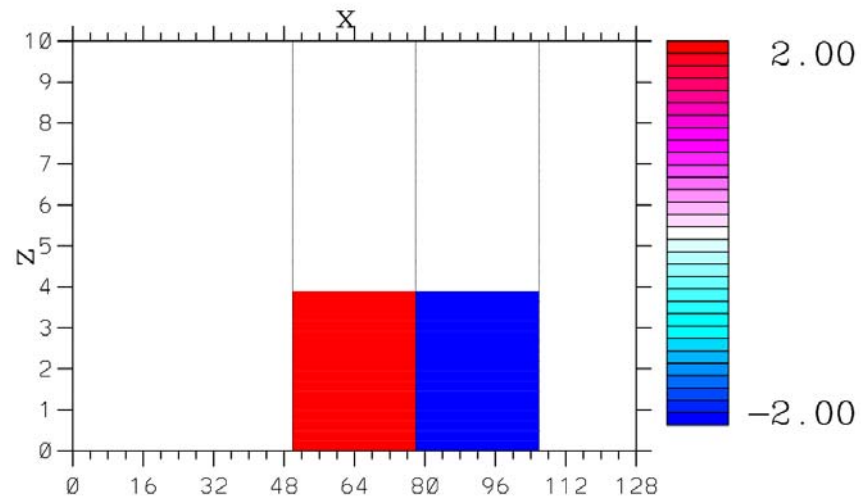
Numerical Archetype: Fixed Distribution of Finite-Volume Elements

Updraft + Downdraft:

time= 0 min

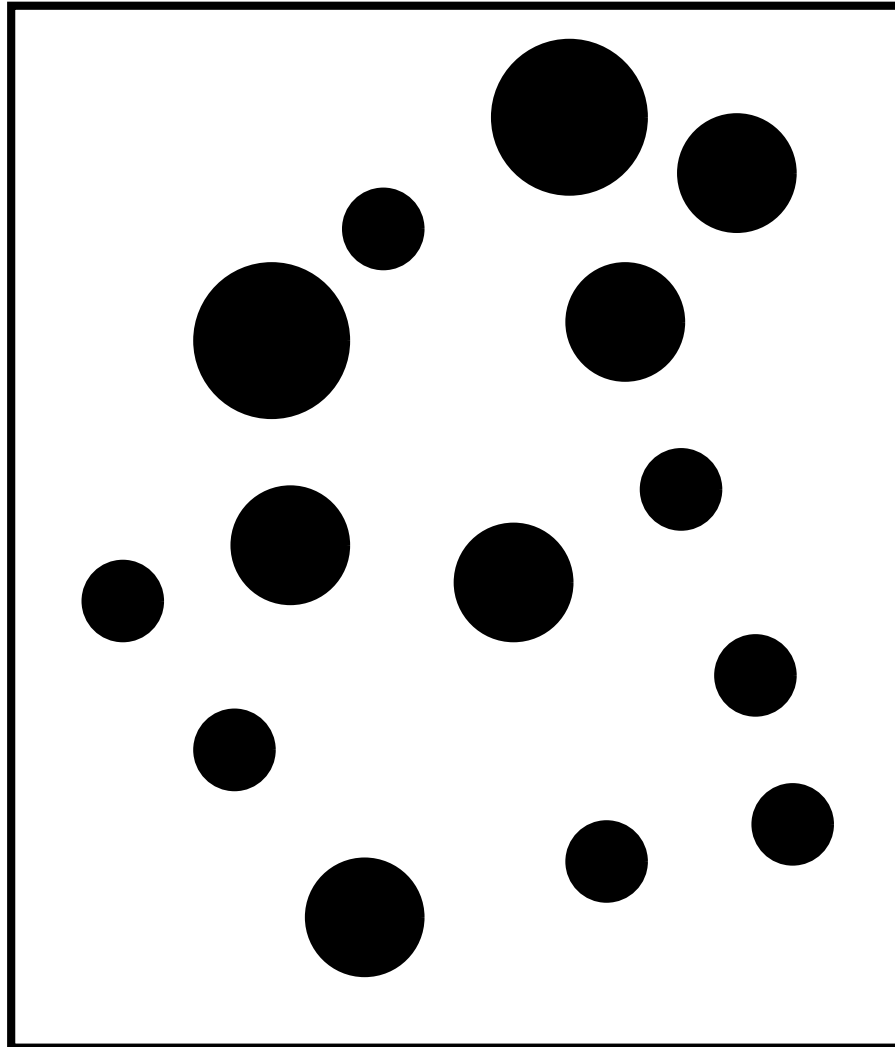


w (m/s)



θ (K)

• SCA (Segmentally-Constant Approximation)



2D SCA-CRM: Basic Formulation

The full system:

$$\frac{\partial}{\partial t}\varphi + \frac{\partial}{\partial x}u\varphi + \frac{1}{\rho}\frac{\partial}{\partial z}\rho w\varphi = F$$

Apply SCA over a segment $[x_{j,b}, x_{j+1,b}]$:

$$\int_{x_1}^{x_2} \left[\frac{\partial}{\partial t}\varphi + \frac{\partial}{\partial x}u\varphi + \frac{1}{\rho}\frac{\partial}{\partial z}\rho w\varphi \right] dx = \int_{x_1}^{x_2} F dx$$

or

$$\begin{aligned} \frac{\partial}{\partial t}\sigma_j\varphi_j + \frac{1}{L}[(u_{j+1,b} - \dot{x}_{j+1,b})\varphi_{j+1,b} - (u_{j,b} - \dot{x}_{j,b})\varphi_{j,b}] \\ + \frac{1}{\rho}\frac{\partial}{\partial z}\rho\sigma_j(w\varphi)_j = \sigma_j F_j \end{aligned}$$

Mass continuity:

$$(u_{j+1,b} - u_{j,b}) + \frac{1}{\rho}\frac{\partial}{\partial z}\rho L_j w_j = 0$$

doc/crm-sca/massflux/note/massflux_note.tex

Hierarchy (3): SCA: segmentally-constant approximation

$$\frac{\partial}{\partial t} \sigma_j \varphi_j + \frac{1}{\rho} \frac{\partial}{\partial z} \rho \sigma_j (w \varphi)_j + \frac{1}{S} \oint_{\partial S_j} \varphi (\mathbf{v}_H^* - \dot{\mathbf{r}}_b) \cdot d\mathbf{r}. = \sigma_j F_j \quad (3.1)$$

where

$$\varphi_j = \frac{1}{S_j} \int_{S_j} \varphi dx dy, \quad (3.2a)$$

$$\mathbf{v}_H^* = \mathbf{v}_H - w \frac{\partial \mathbf{r}_{j,b}}{\partial z}. \quad (3.2b)$$

$\mathbf{r}_{j,b}$: the segment boundary position

$\sigma_j = S_j/S$: the fractional area occupied by the j -th segment

NB: two major approaches are possible:

i) bulk: a single plume + environment : $N = 2$

ii) spectrum: $N > 2$