A conceptual framework for the resolution dependence of updraft properties in cloud system resolving models

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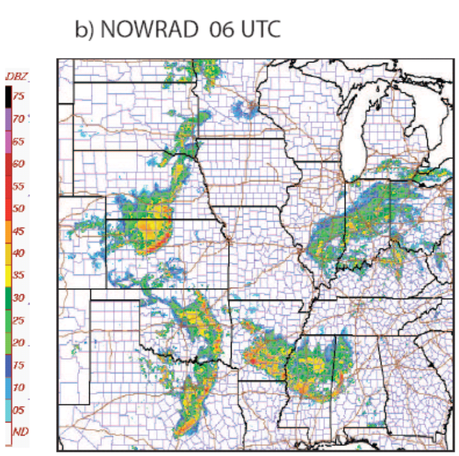
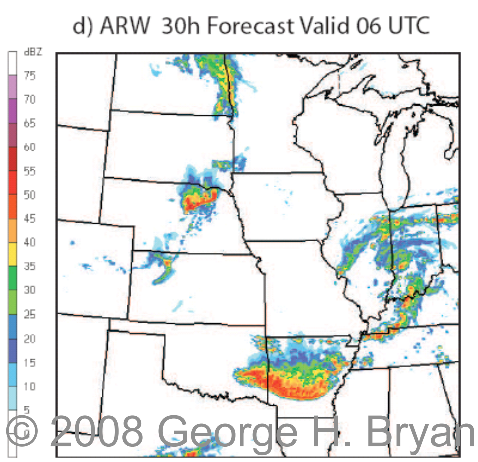
Background

- Real-time forecasts at cloud-resolving resolution (Δx = 3-4 km) have shown much success (compared to CPS):
  - accurate diurnal cycle
  - good propagation
  - good structure (squall lines, isolated cells, hurricane rainbands)
- But also some notable biases (compared to obs):
  - too much rainfall
  - delayed convective initiation
- What are the sources of these biases?

Observed radar



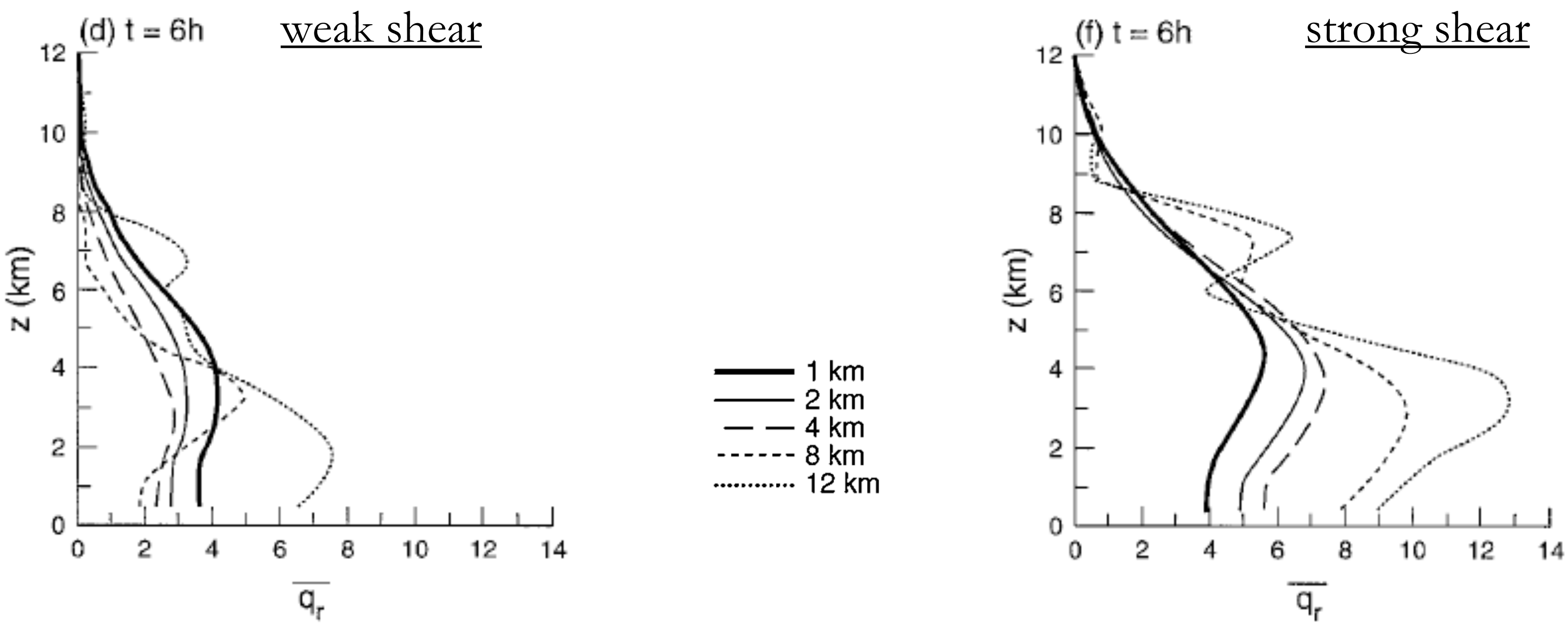
30-h forecast



Weisman et al. (2008, WAF)

Candidates for improvement

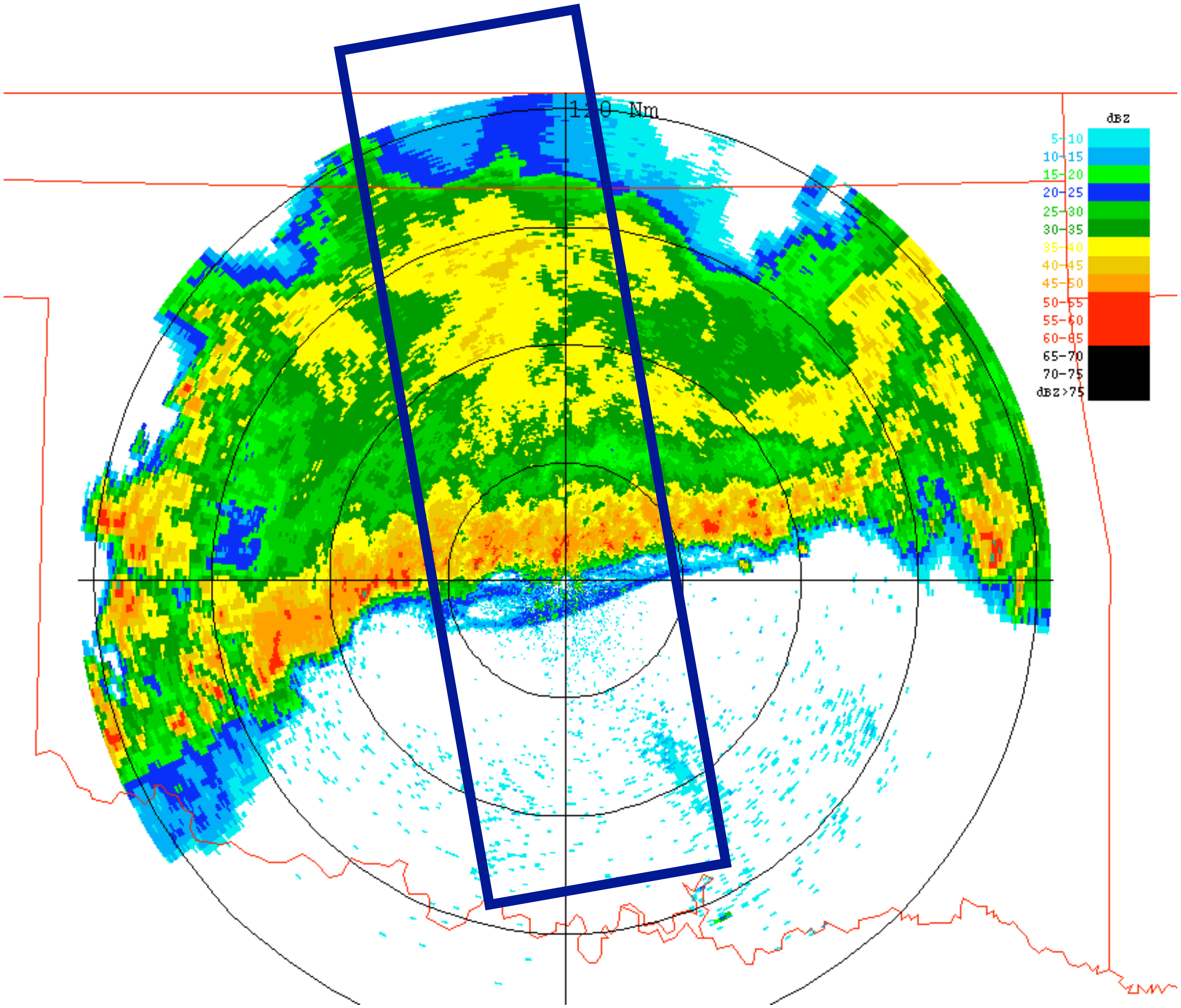
- Physical parameterizations:
  - microphysics
  - planetary boundary layer (PBL)
  - surface processes / air-surface exchange
- Initial conditions
- Boundary conditions
- Model numerics
- Model resolution



"Clearly, the 1-km solution has not converged."

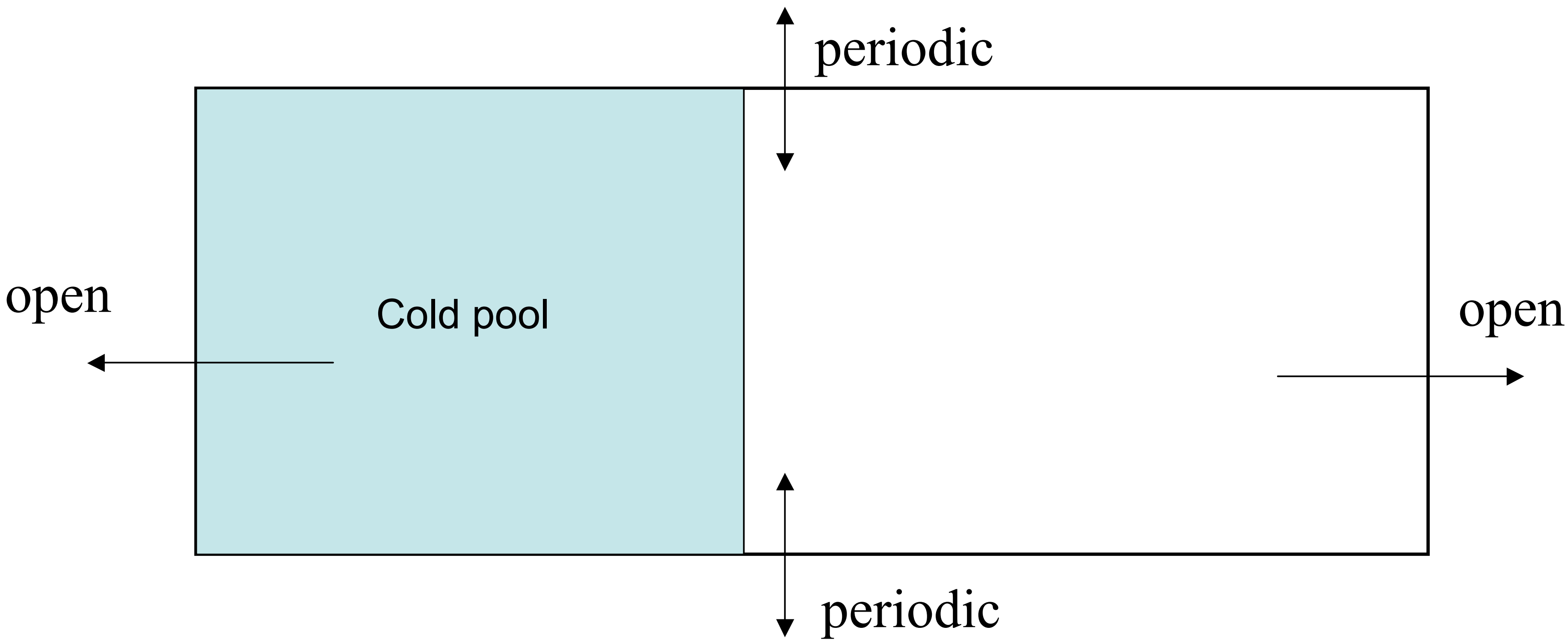
Weisman et al. (1997)

Squall line simulations: motivation



Squall-line simulations: setup

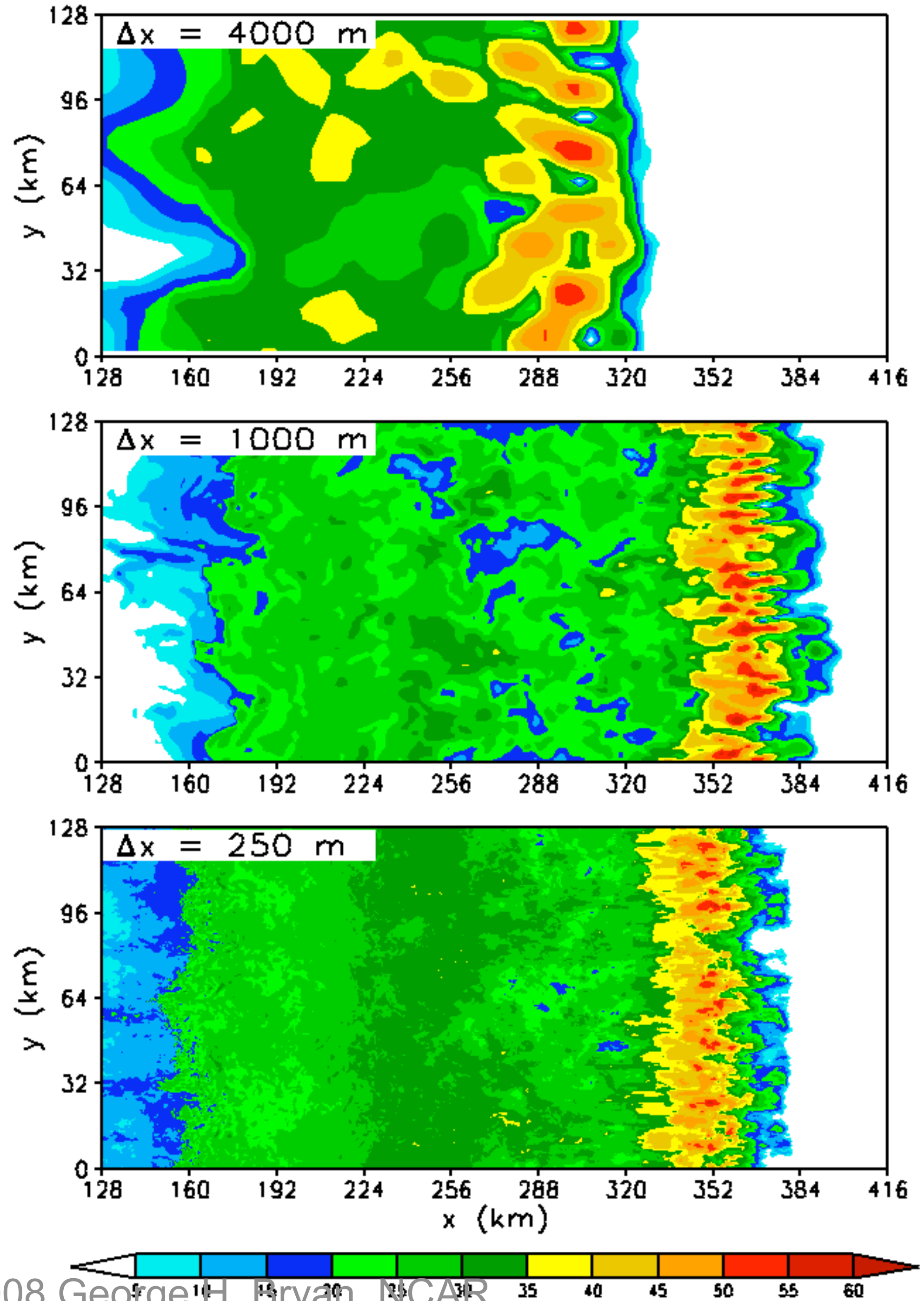
Domain: 512 km x 128 km x 18 km



- Δz = 250 m: $\Delta x,\Delta y$ = 8 km, 4 km, 2 km, 1 km, 0.5 km, 0.25 km
- Δz = 125 m: $\Delta x,\Delta y$ = 125 m
- Sounding: mid-latitude continent (CAPE = 2500 J/kg)
- Ice microphysics, no surface fluxes, no radiation

System structure:

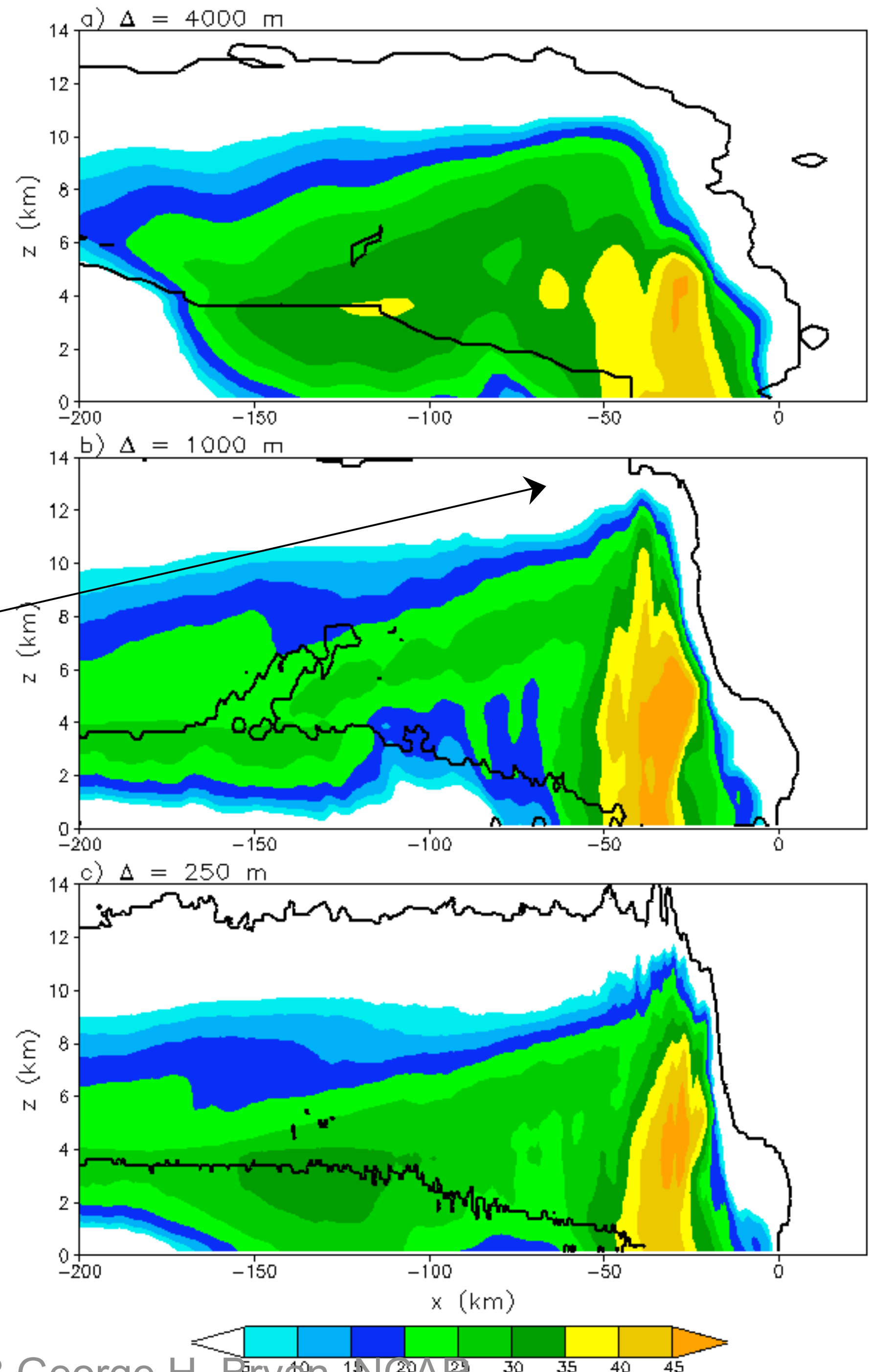
Composite reflectivity (dBZ) at t = 6 h



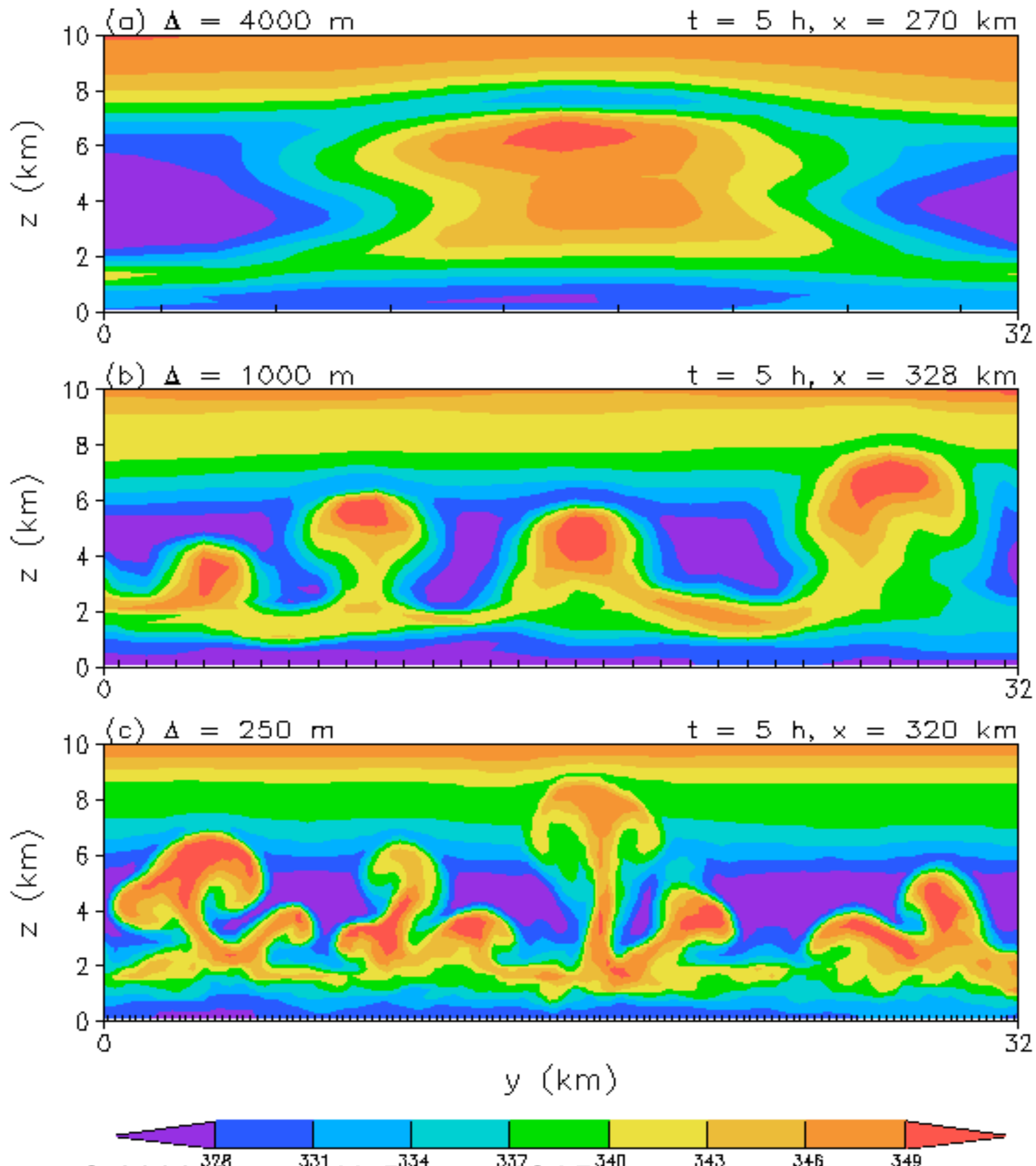
Line-averaged reflectivity (dBZ, shaded) and cloud boundary (black contour) at *t* = 6 h

NOTE: high cloud tops (> 14 km)

NOTE: better representation of stratiform region

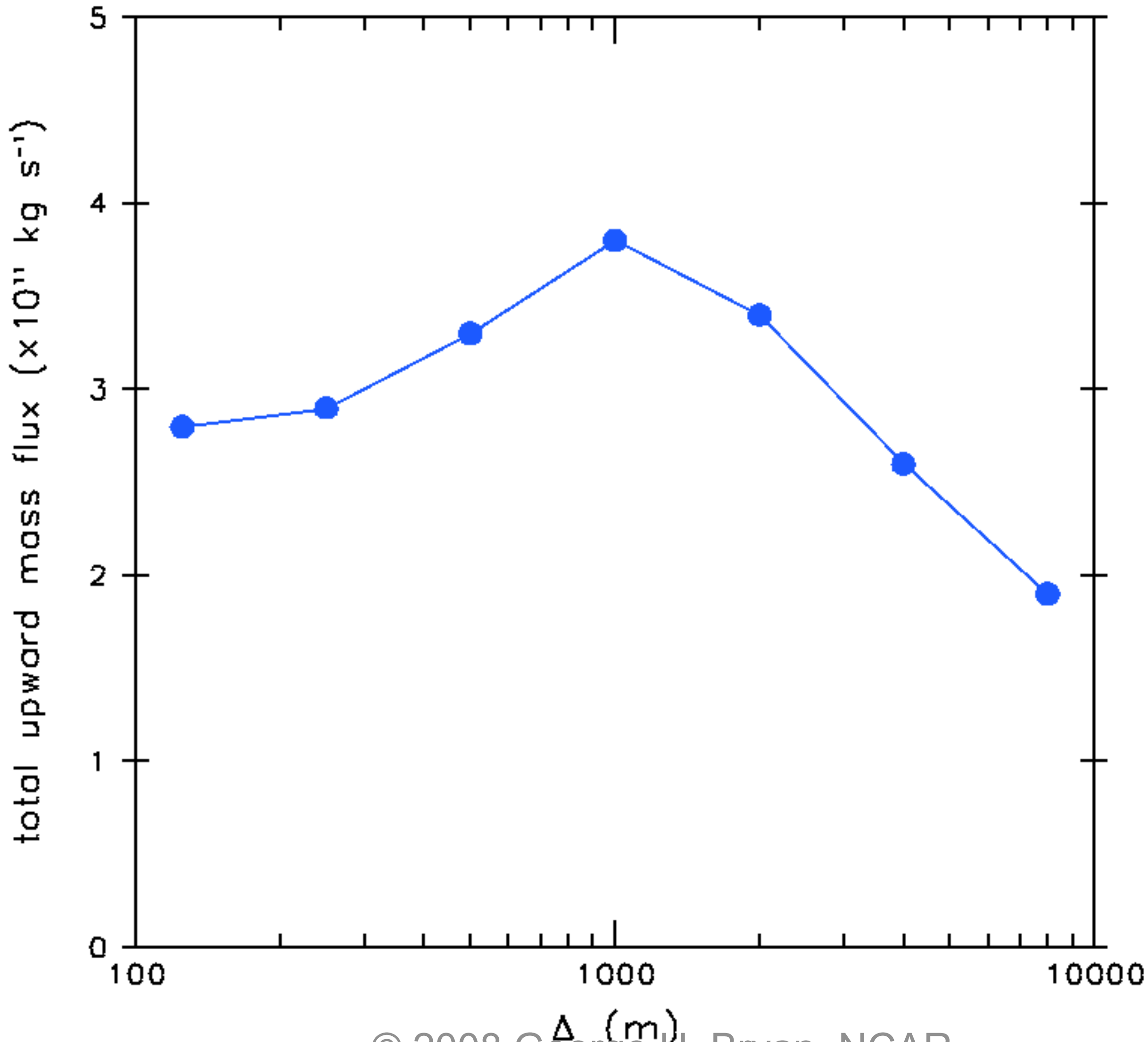


Along-line cross sections: equivalent potential temperature (θ_e), t = 5 h

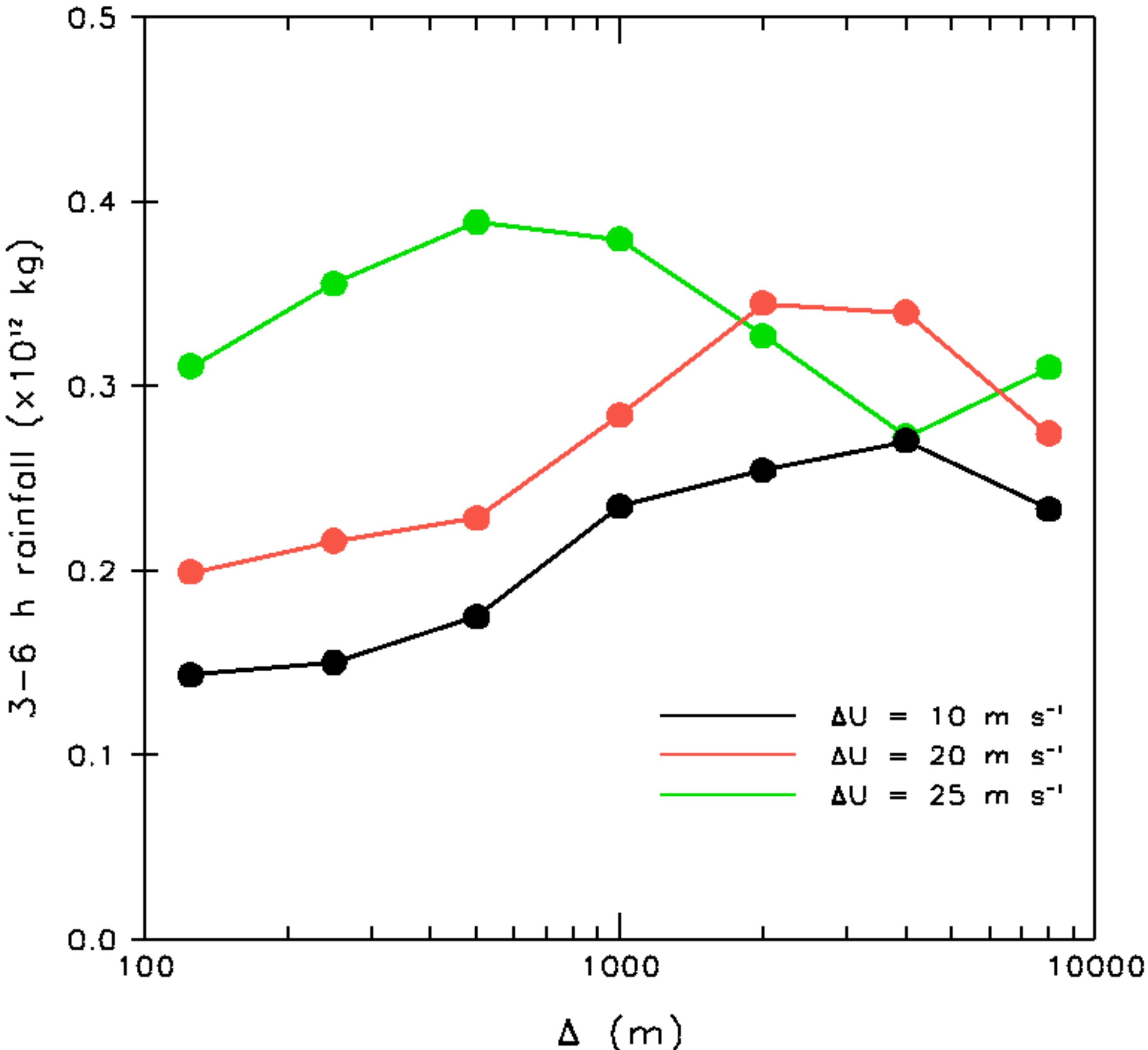


Total upward mass flux (M) (t = 6 h)

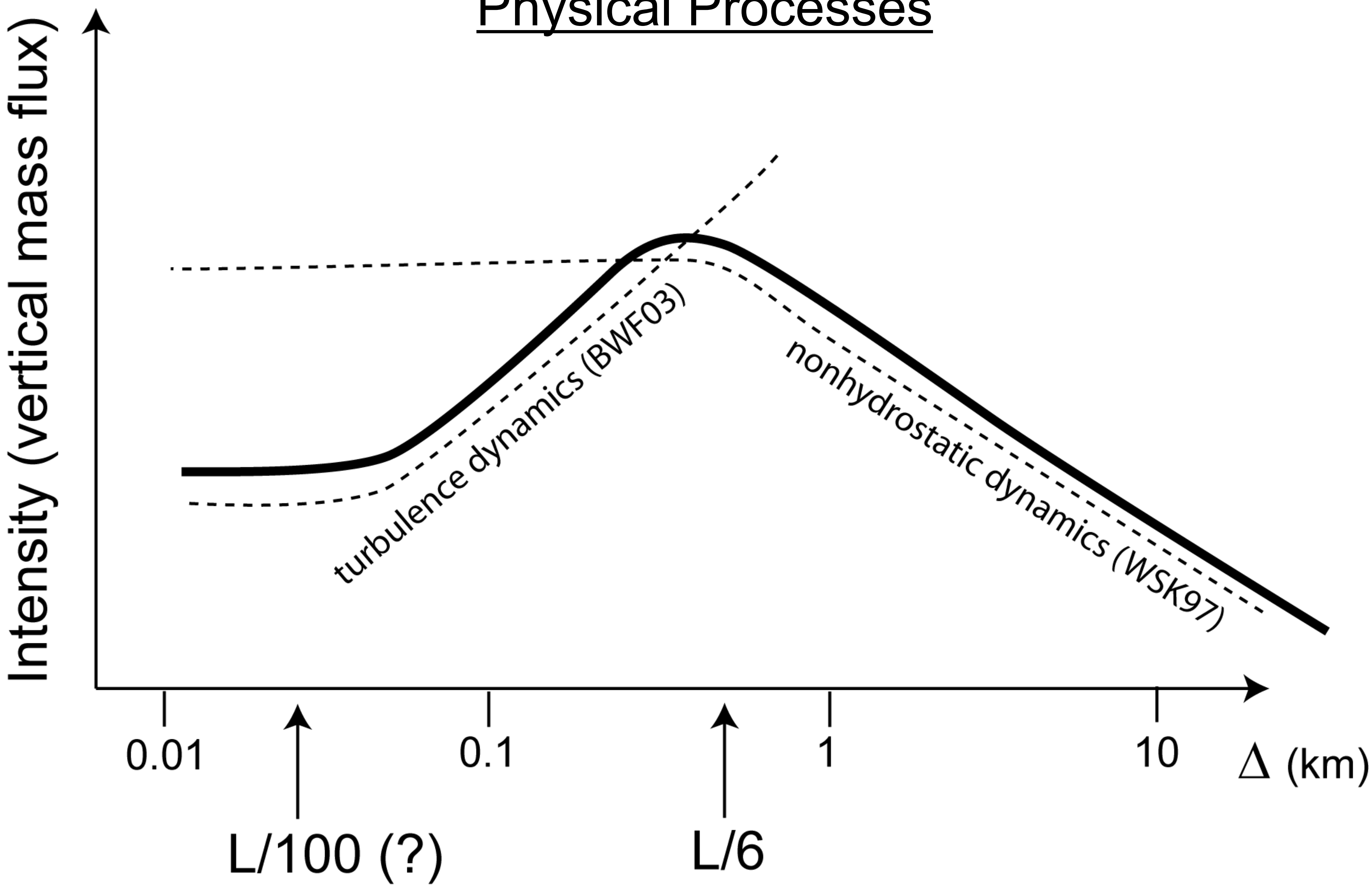
$$M = \sum \rho \max(0,w)\, \Delta x\, \Delta y$$



Total rainfall (t = 3-6 h)



Physical Processes



WSK97 = Weisman, Skamarock, Klemp (1997, MWR)

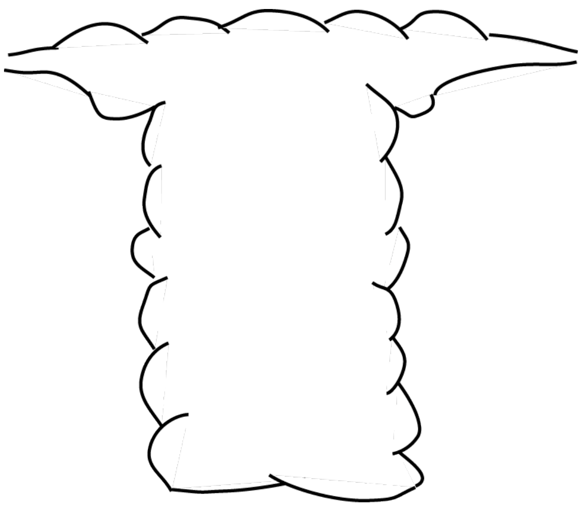
BWF03 = Bryan, Wyngaard, Fritsch (2003, MWR)

Conceptual Model

<u>Nature and LES</u>

$\Delta \approx 0.1$ km

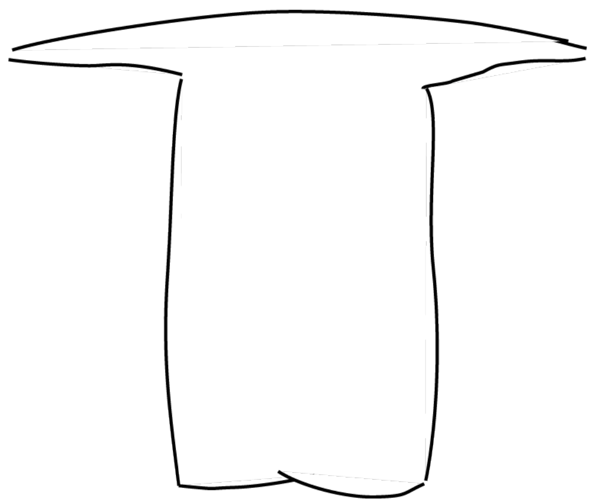
(turbulent and entraining)



<u>Cloud-resolving</u>

$\Delta \approx 0.5$ km

(laminar)



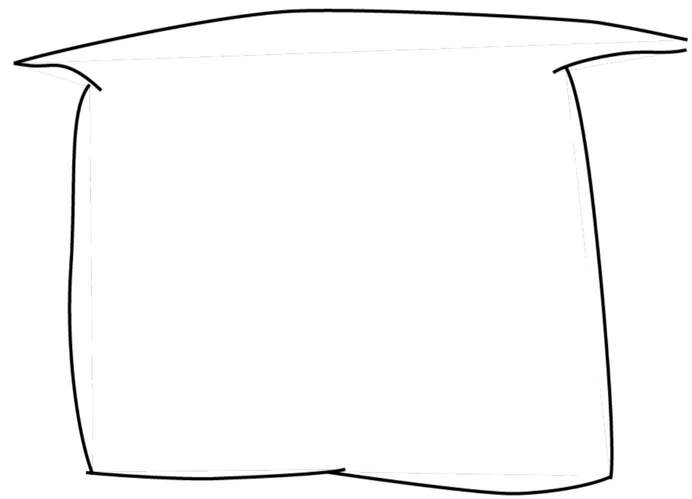
Consequences:

- too intense
- over-stabilizes

<u>Cloud-permitting</u>

$\Delta \approx 4$ km

(too large, laminar)



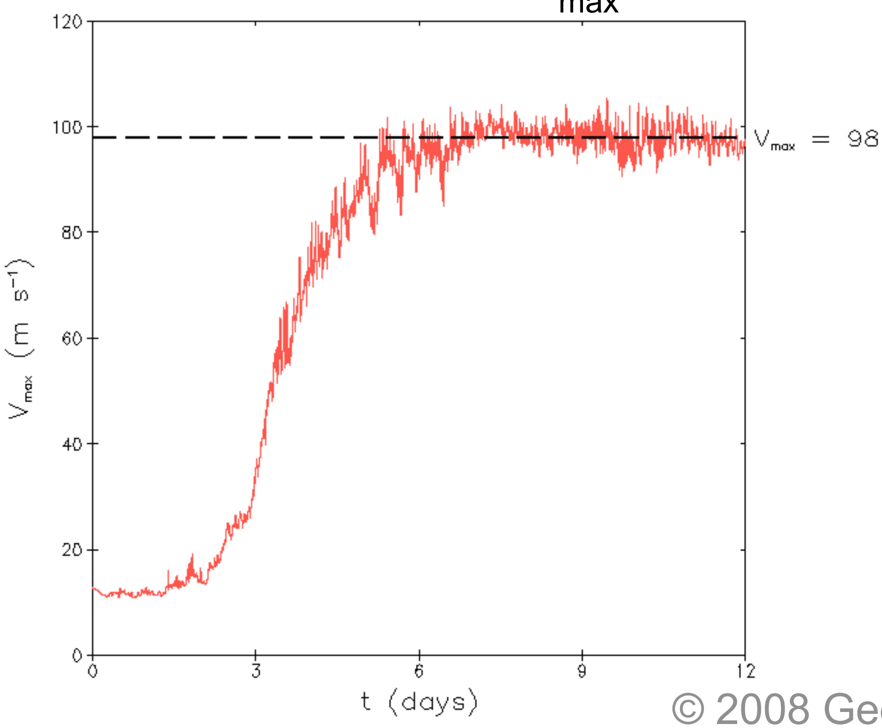
Consequences:

- too slow

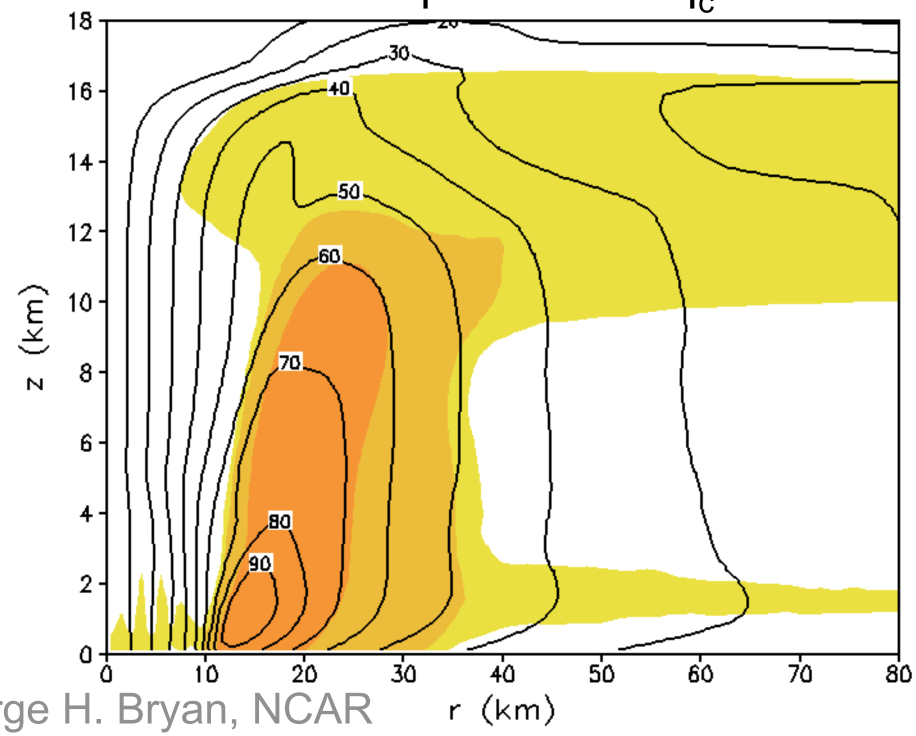
Idealized Tropical Cyclones

- Constant SST = 28 °C
- Moist-neutral sounding (CAPE = 0)
- see Bryan and Rotunno (2009, MWR, in press) for details

Time series of v_{max}

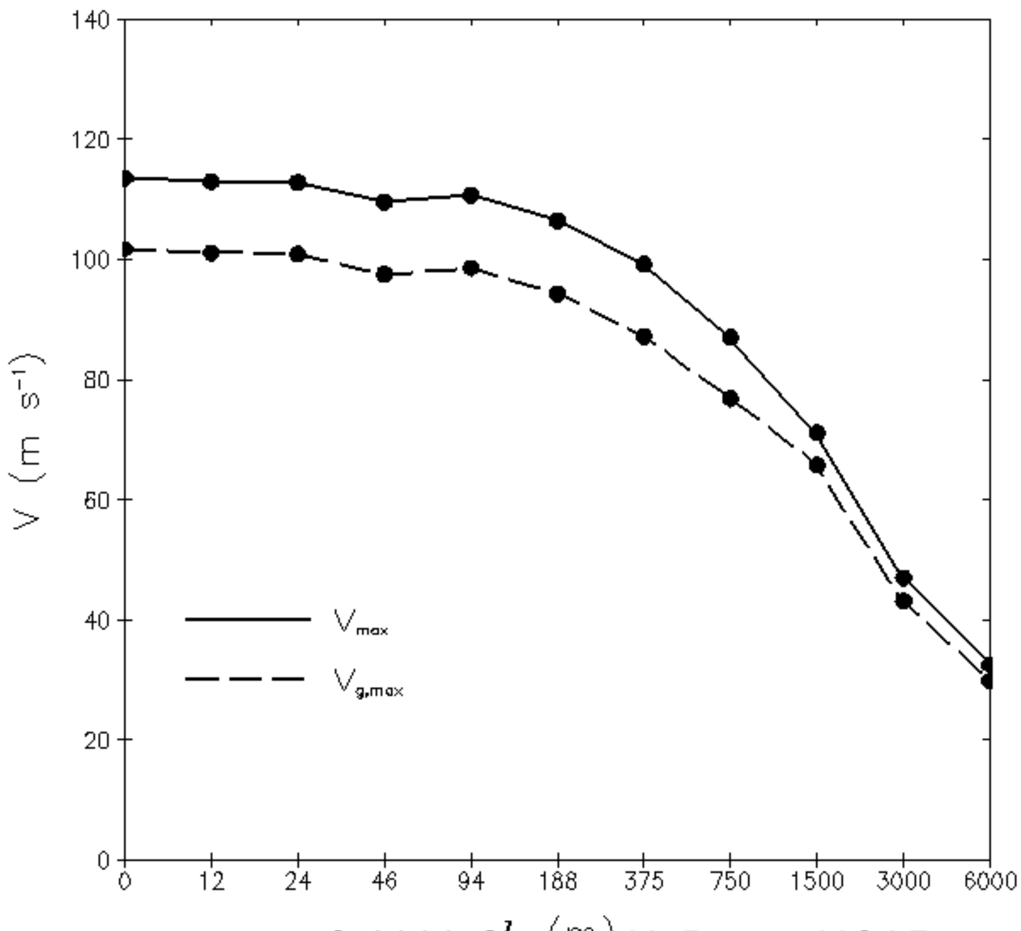


Output: v and q_c



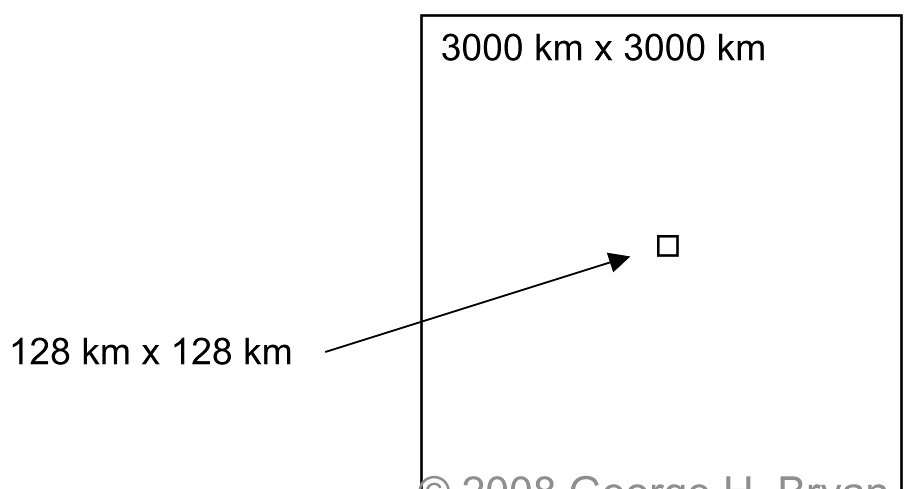
Motivation

- Bryan and Rotunno (2009, MWR) found that v_{max} is very sensitive to horizontal turbulence
- Goal: explicitly simulate turbulence (LES)

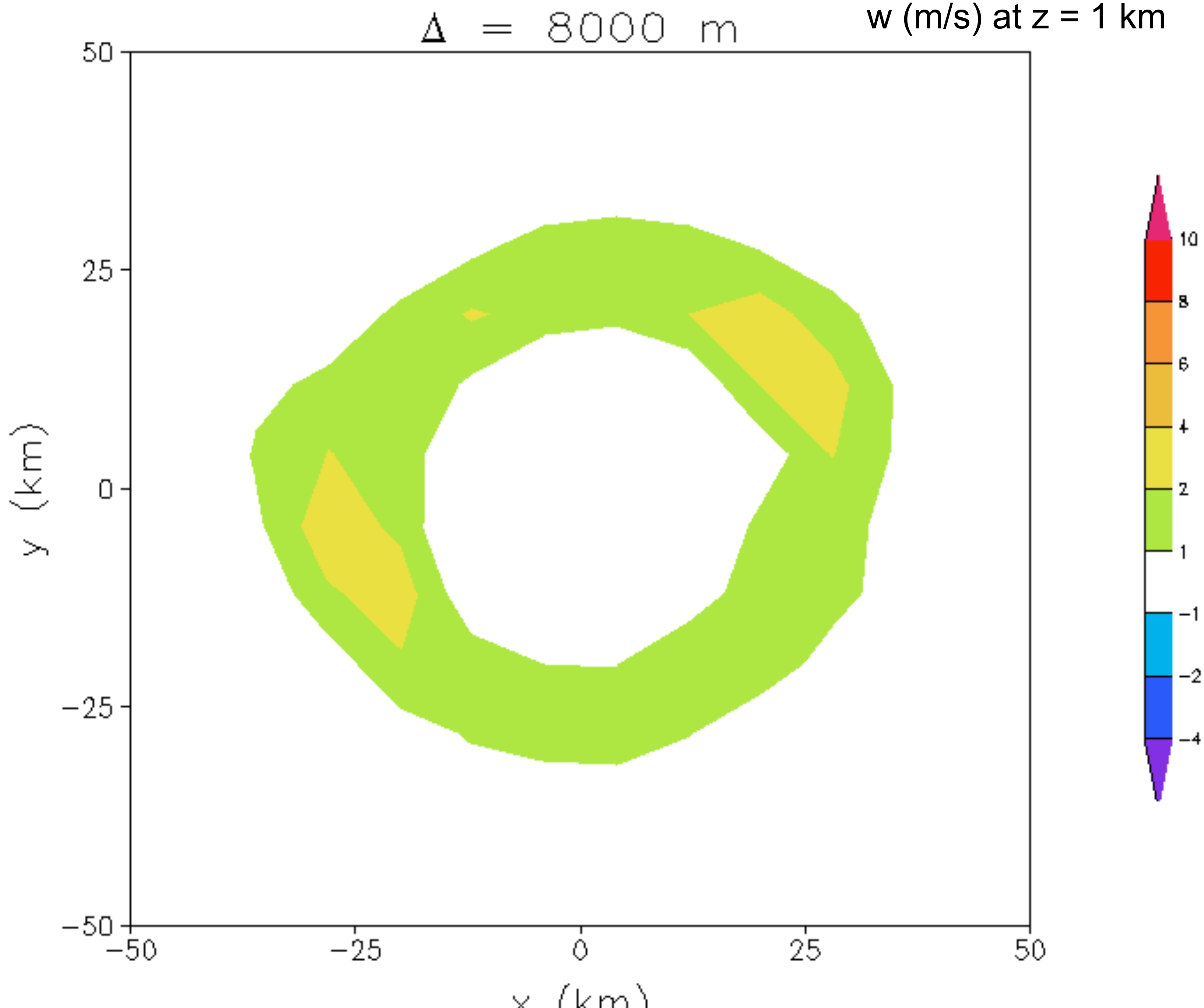


Methodology

- Initialize 3d simulation with the axisymmetric model output
  - total domain is 3000 km x 3000 km x 25 km
  - inner nest is 128 km x 128 km x 25 km
- Insert random perturbations (in u and v)
- Integrate until a new steady-state is obtained
  - requires ~12 h



w (m/s) at z = 1 km



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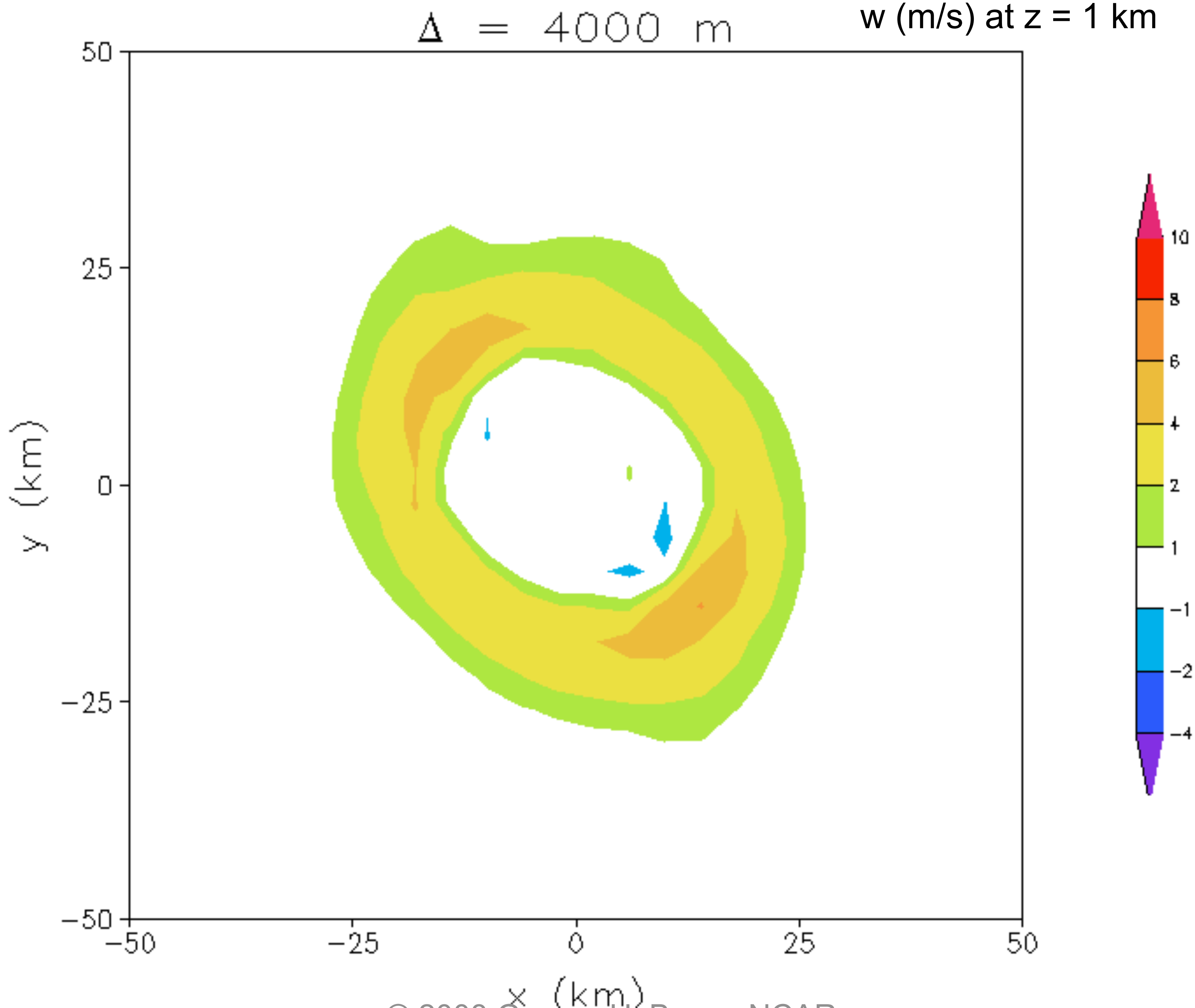
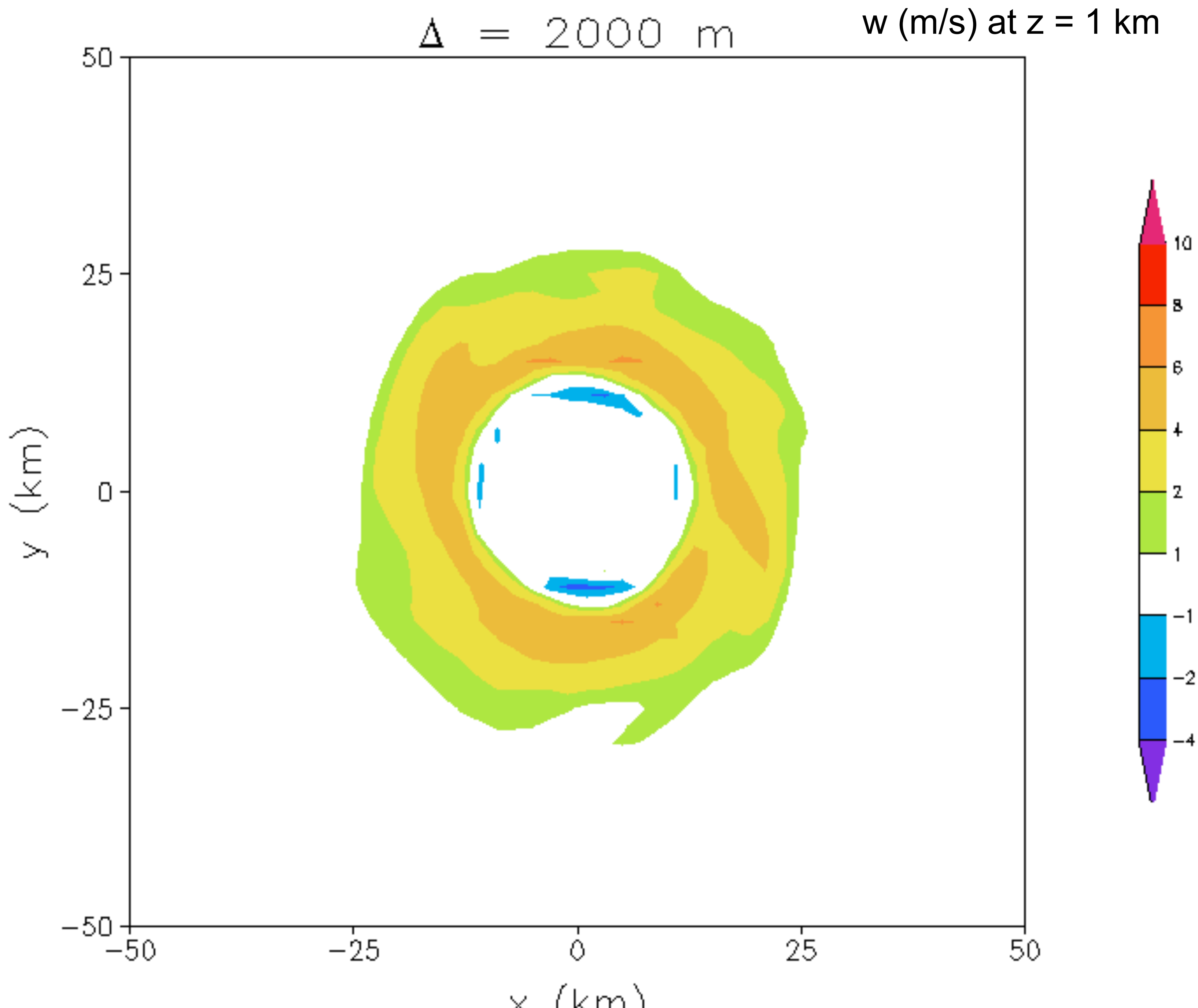
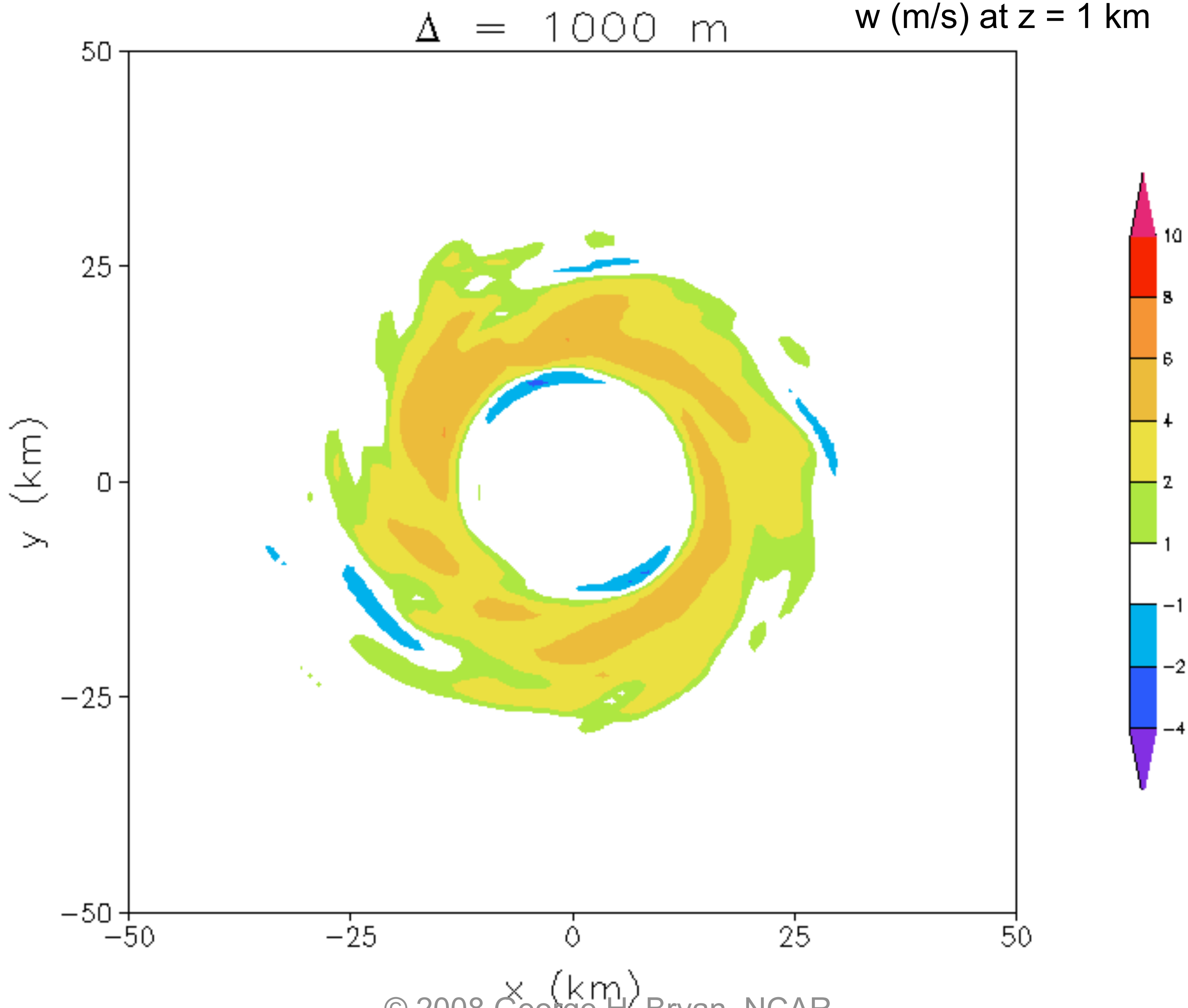



w (m/s) at z = 1 km
Δ = 2000 m
50
25
0
−25
−50
y (km)
−50
−25
0
25
50
x (km)
10
8
6
4
2
1
−1
−2
−4

w (m/s) at z = 1 km



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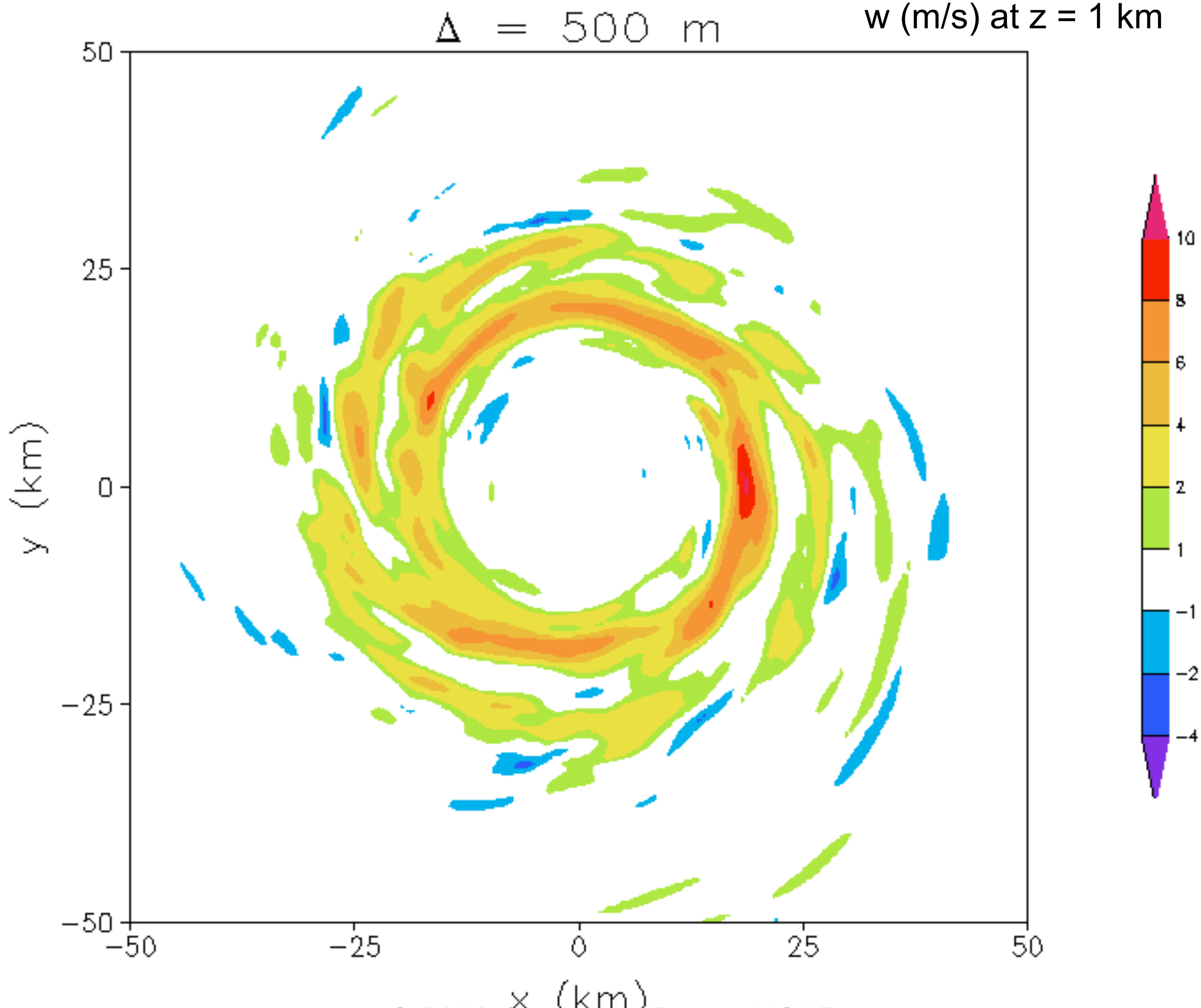

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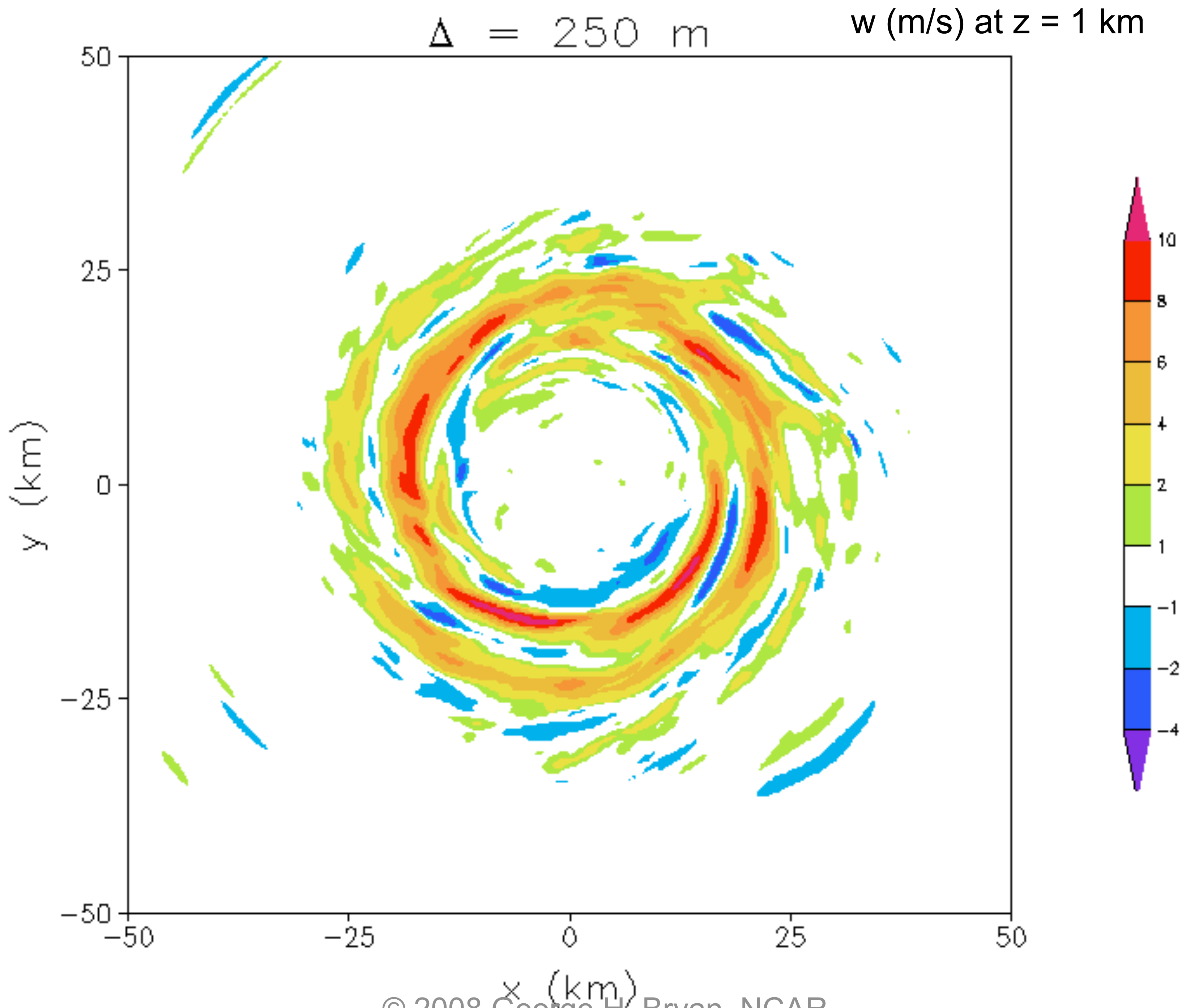
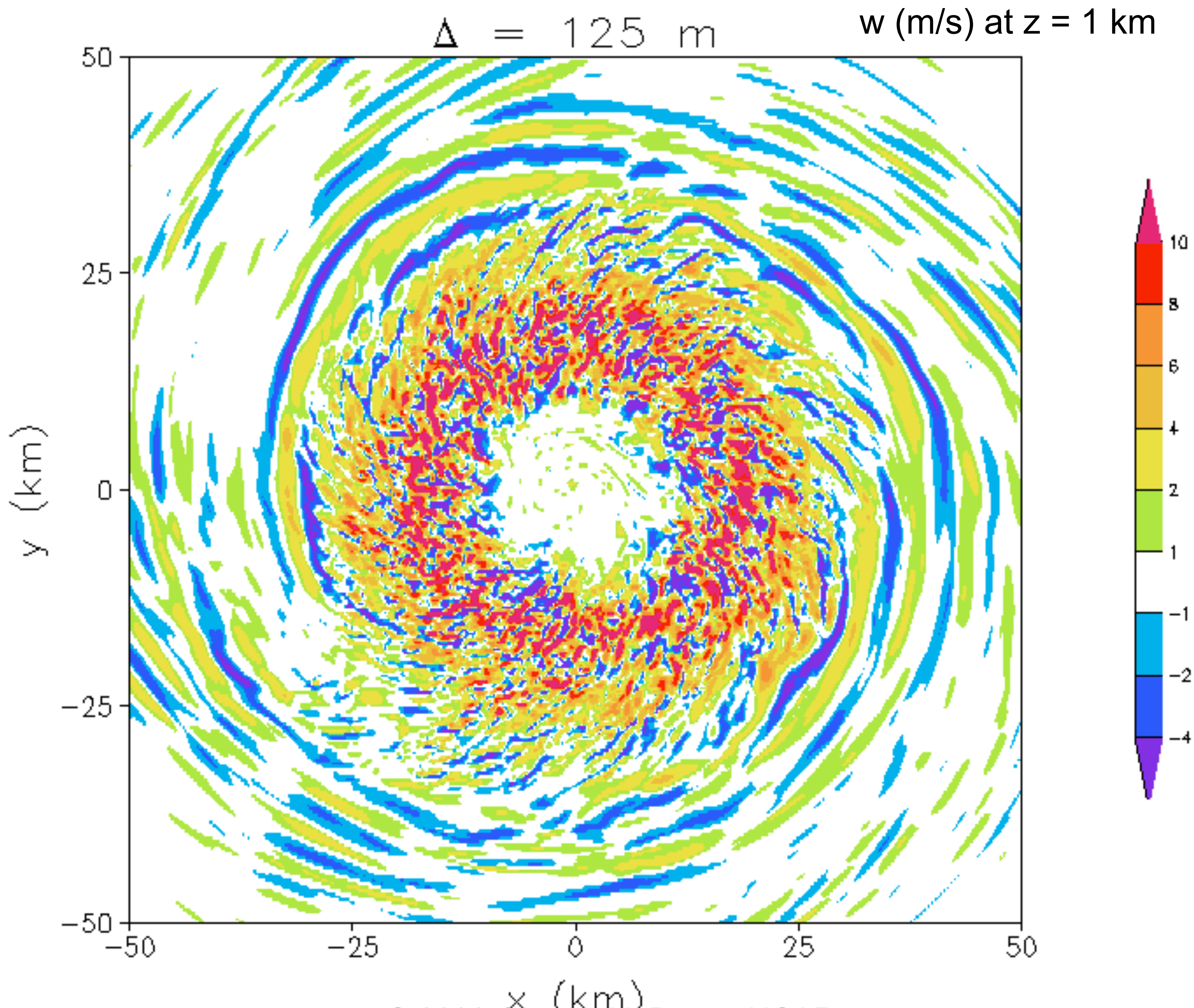
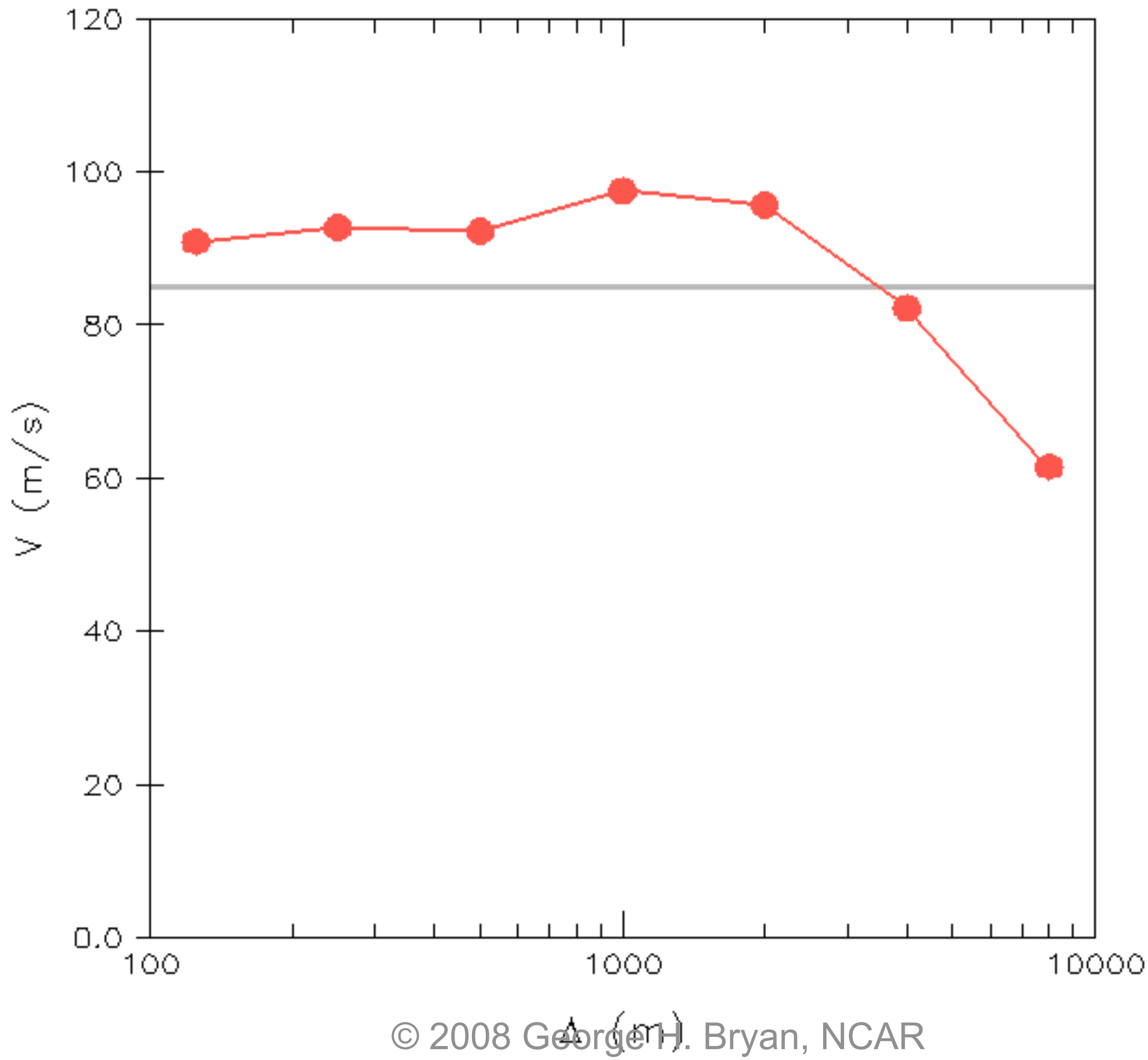



w (m/s) at z = 1 km
Δ = 125 m
y (km)
x (km)
50
25
0
−25
−50
−50
−25
0
25
50
10
8
6
4
2
1
−1
−2
−4

Maximum azimuthally-averaged v



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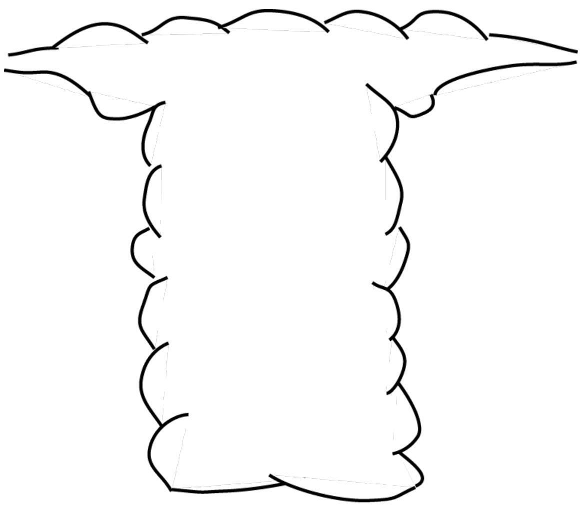

<u>Cloud-resolving</u>

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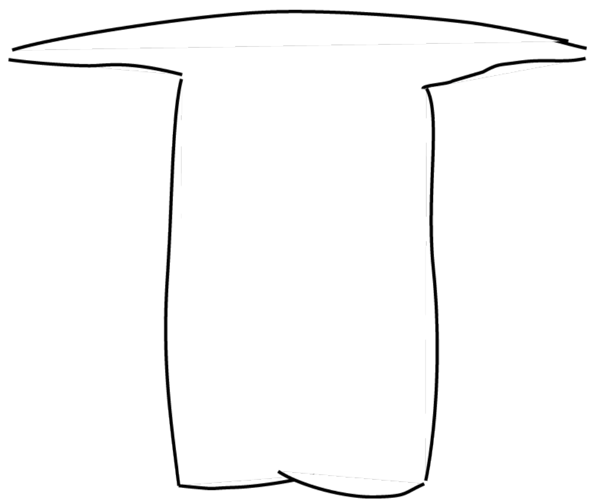
(correct size, laminar)



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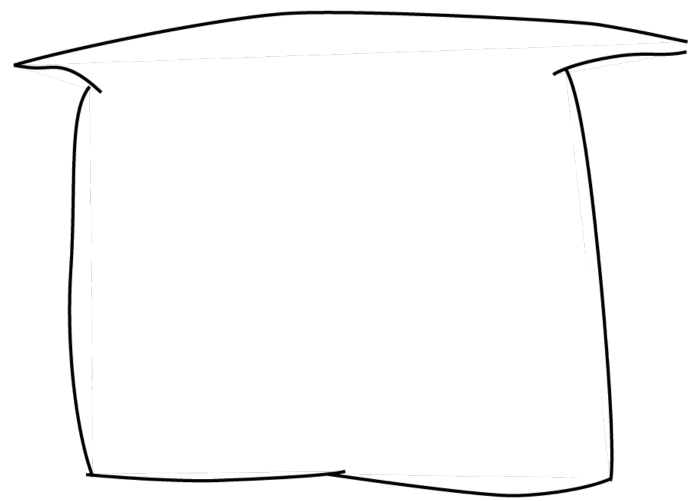

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