14.2

The effects of small-scale turbulence on maximum hurricane intensity

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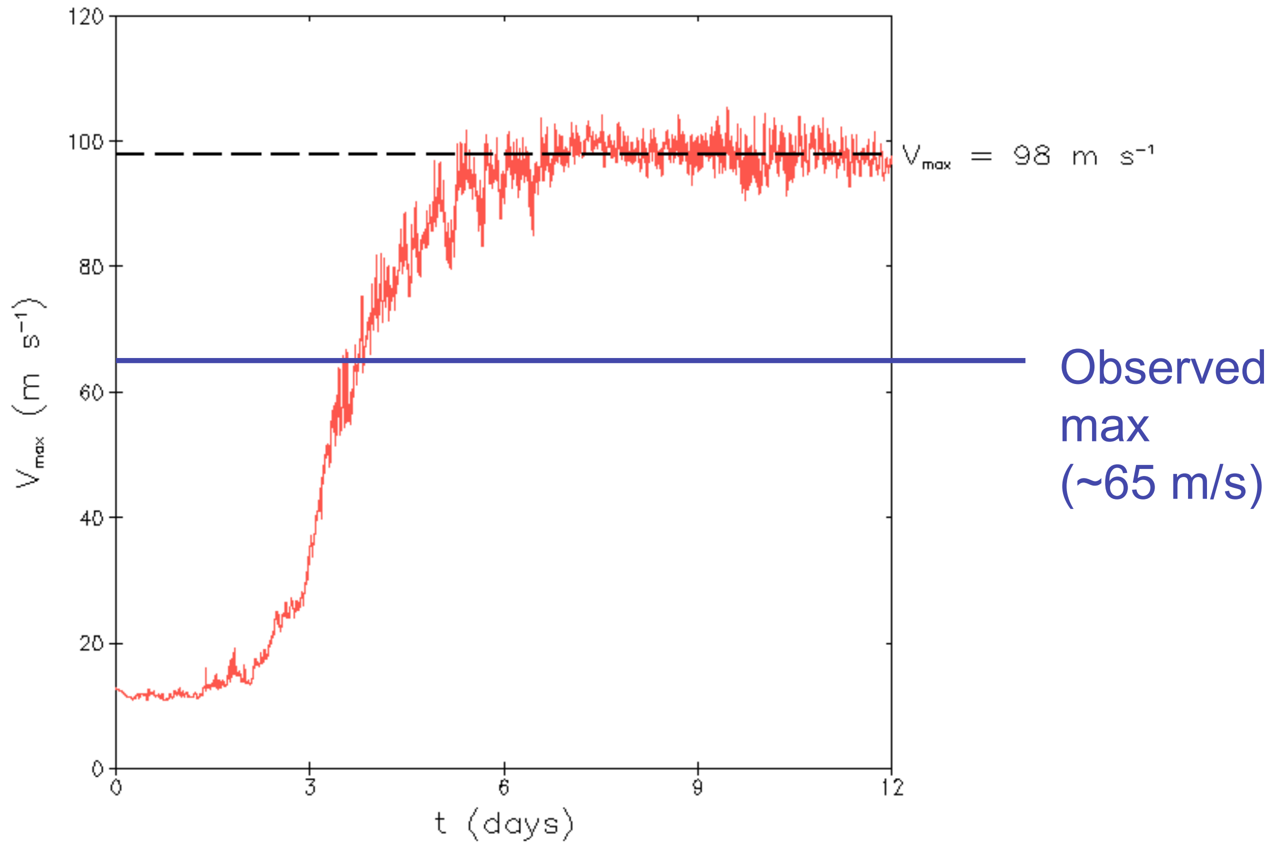
NCAR

13th Conference on Mesoscale Processes
19 August 2009

- Axisymmetric numerical model (2d: r-z)
  - Nonhydrostatic, primitive equations, time-dependent
  - See Bryan and Rotunno (2009b, MWR) for details
  - T_s = 26 °C, same setup as Rotunno-Emanuel (1987) and Persing-Montgomery (2003)

Time series of max. azimuthal velocity (m s^{-1}):



Model components investigated:

[see Bryan and Rotunno (2009b, MWR) for details]

- Resolution
- Numerics
- Initial vortex
- Governing equations
  - unique mass/energy conservation in this model
- Microphysics
  - liquid / ice processes
  - single-moment / double-moment
  - fall velocity of condensate
- Surface exchange coefficients (C_E / C_D)
- Turbulence

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- **Turbulence**

Turbulence eddy viscosities:

$$\nu_h = l_h^2 S_h,$$

$$\nu_v = l_v^2 \left(S_v^2 - N_m^2 \right)^{1/2}.$$

Bryan and Rotunno (2009b, MWR)

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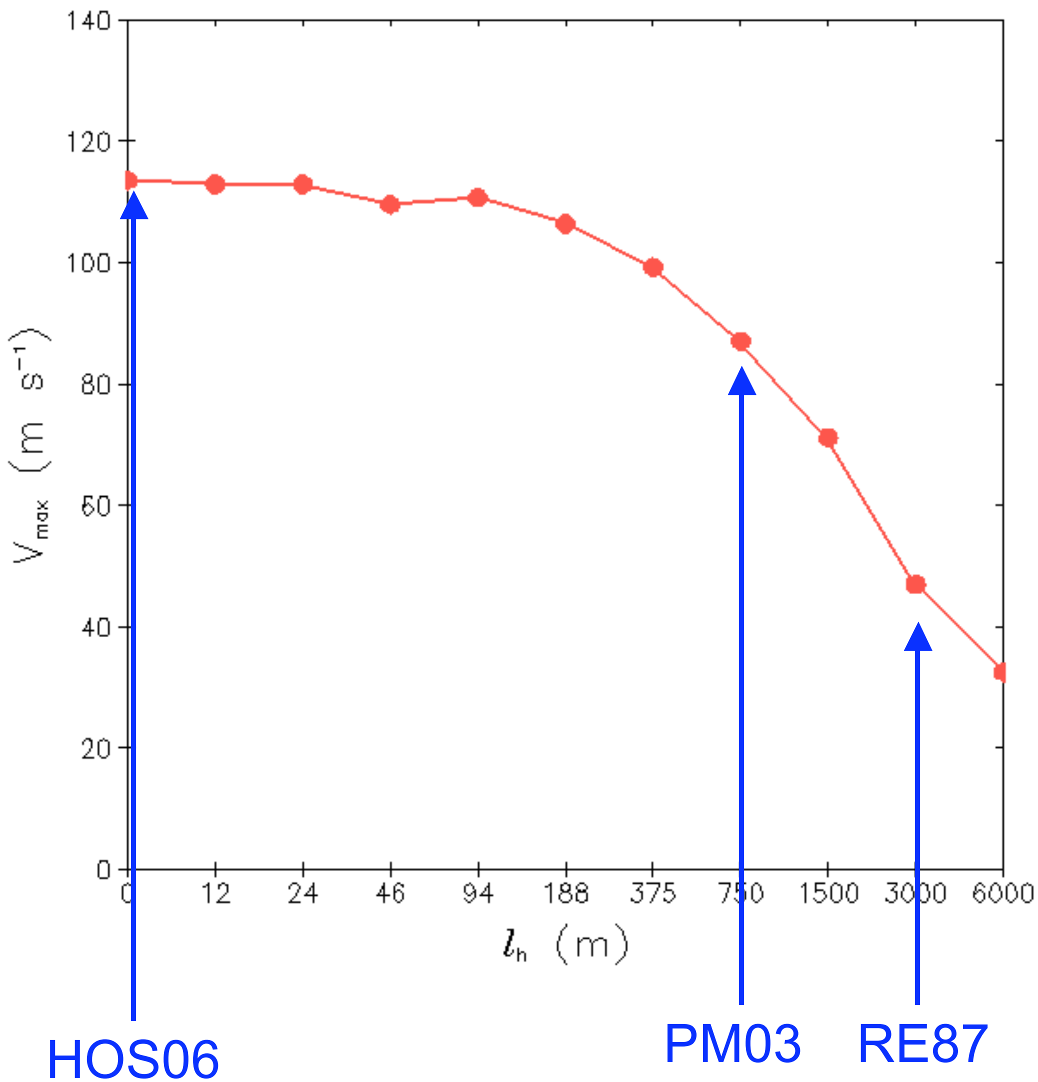
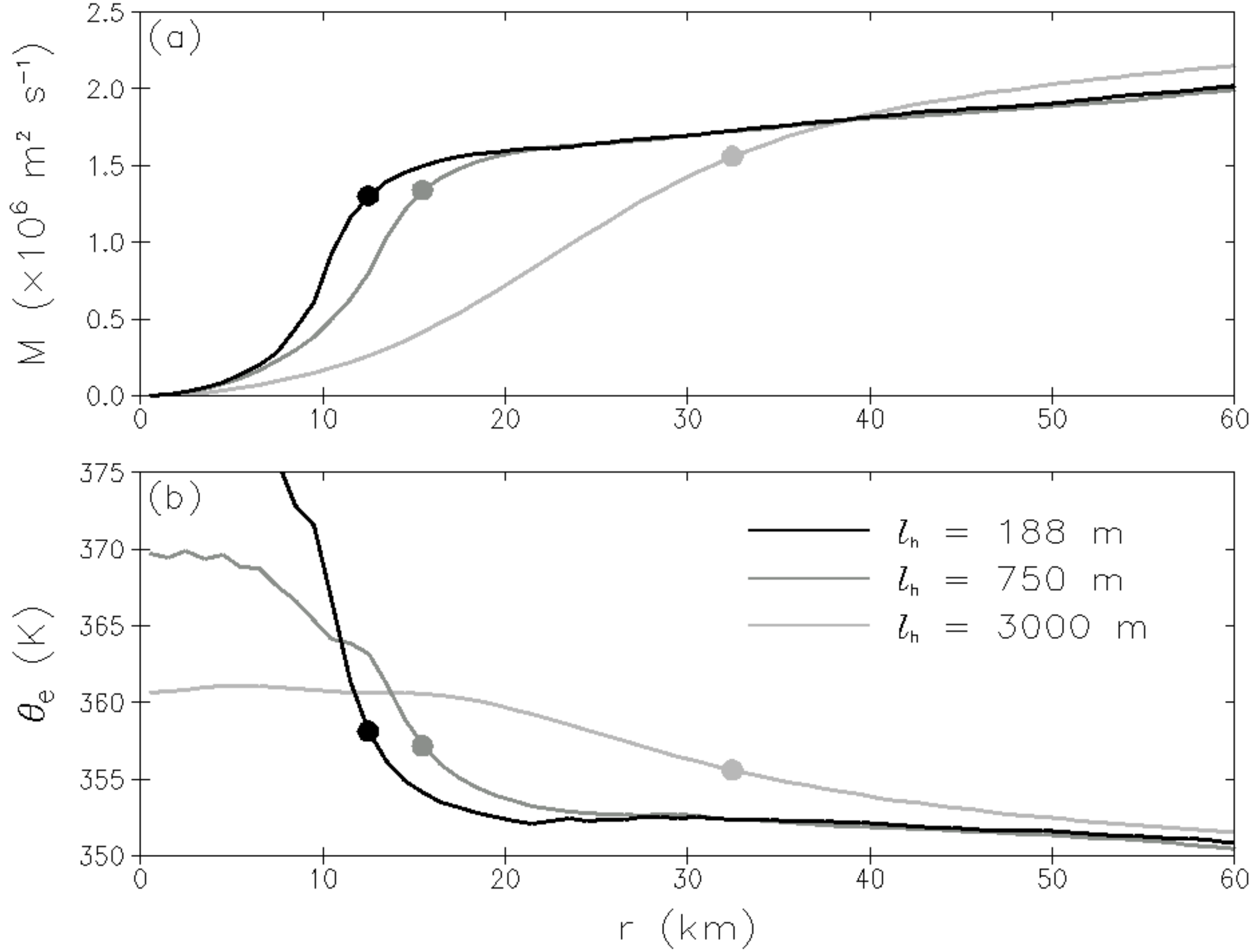


Bryan and Rotunno (2009b, MWR)

M and θ_e at $z = 1.1$ km

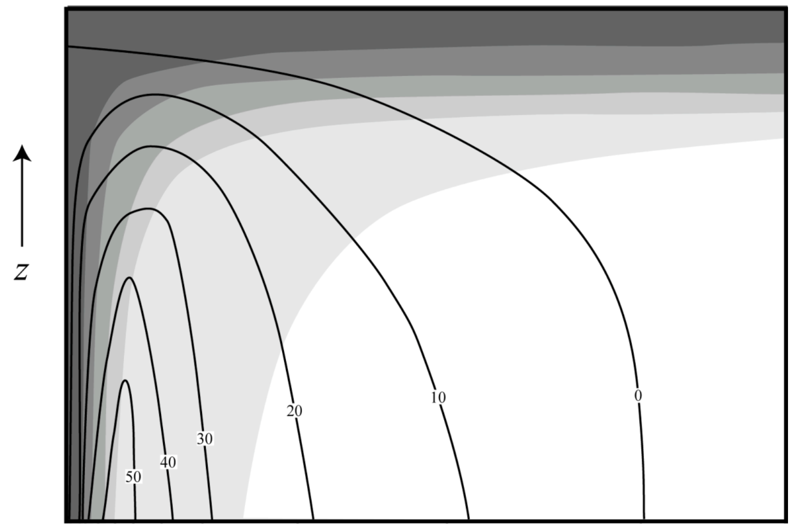


Bryan and Rotunno (2009b, MWR)

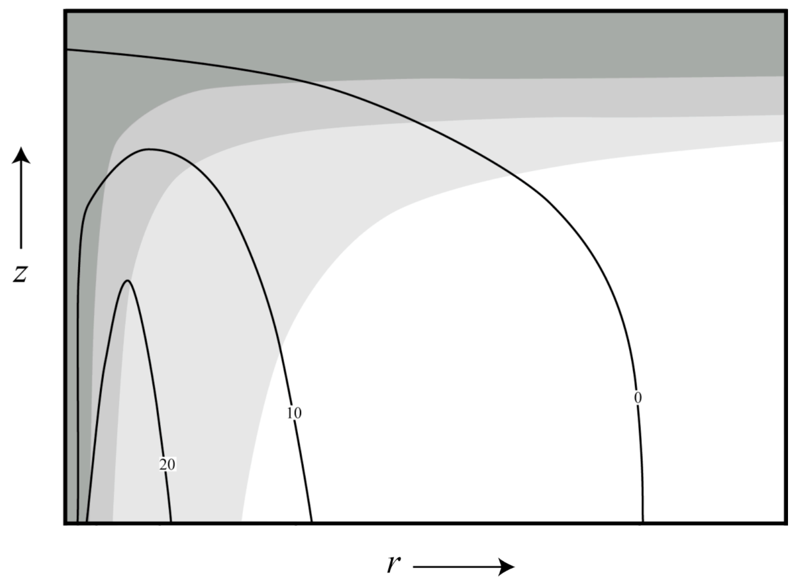
Thermal-wind balance

- vertical wind shear is proportional to the horizontal temperature (entropy) gradient

A strong vortex:



A weak vortex:



shading = entropy

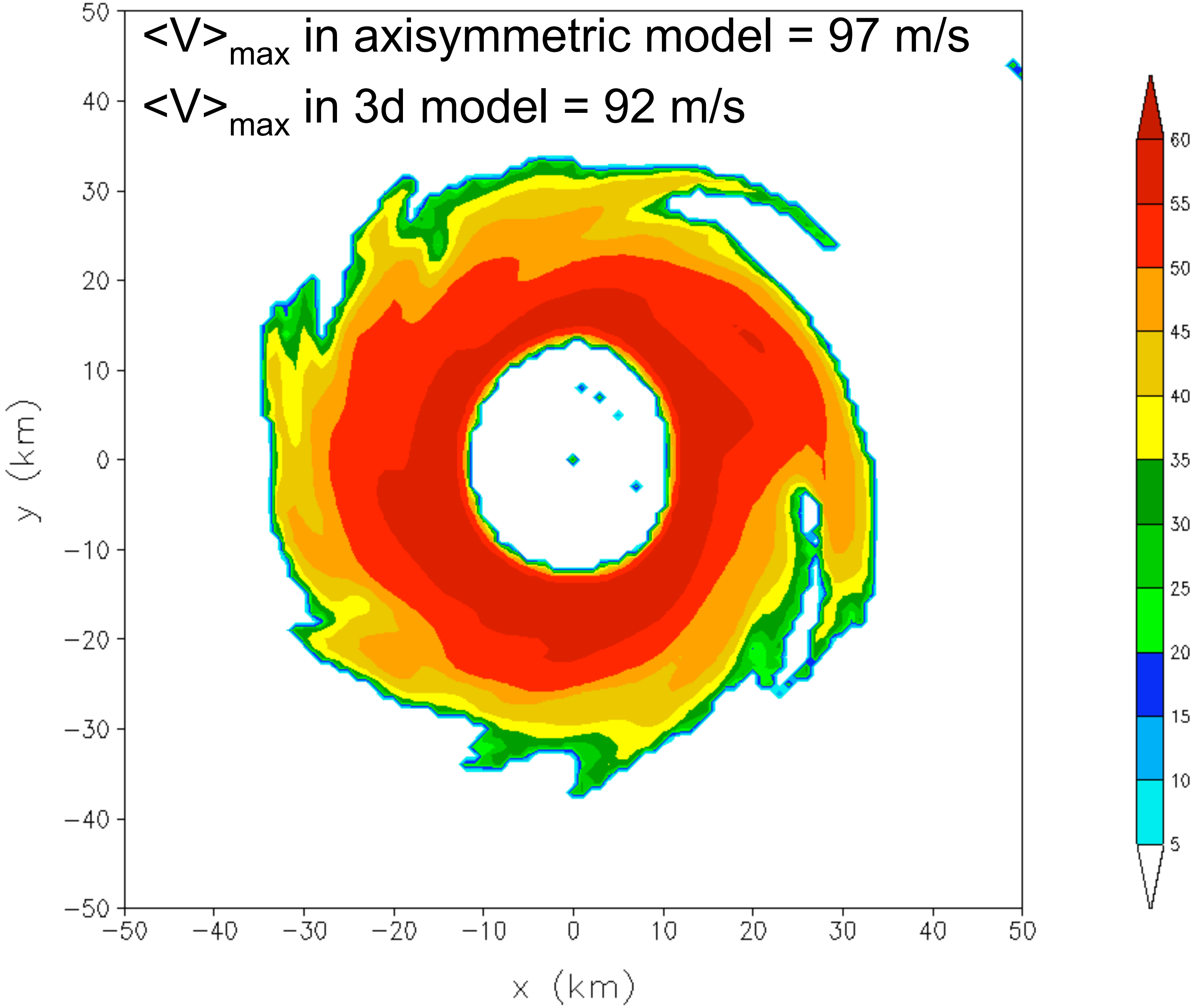
contours = v (m s^{-1})

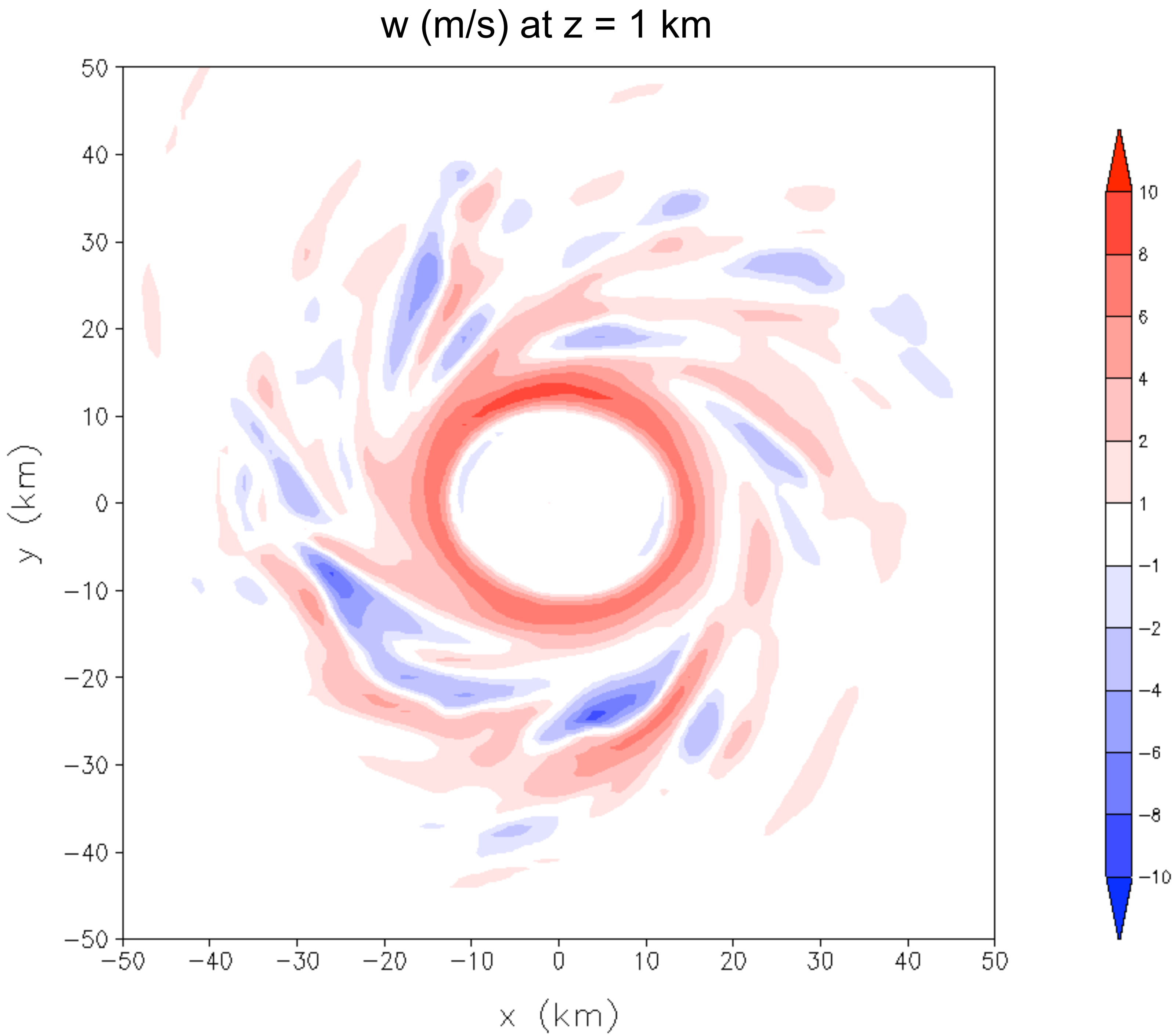
Outstanding question:

- What happens in 3d numerical simulations?

- Setup:
  - Same initial conditions, physics, etc
  - 3d geometry (Cartesian grid)
  - $\Delta x = \Delta y = 1$ km, $\Delta z = 250$ m
    (same as axisymmetric simulations)

Surface reflectivity

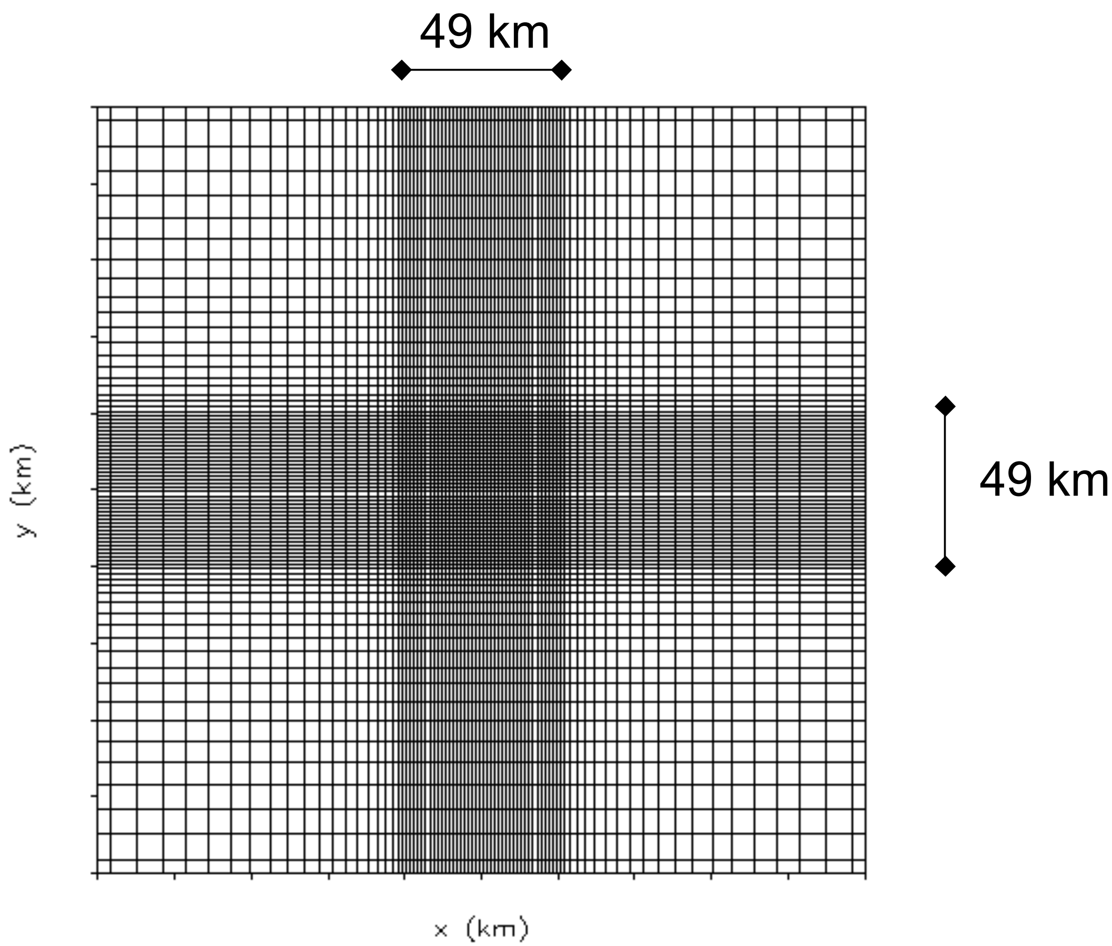


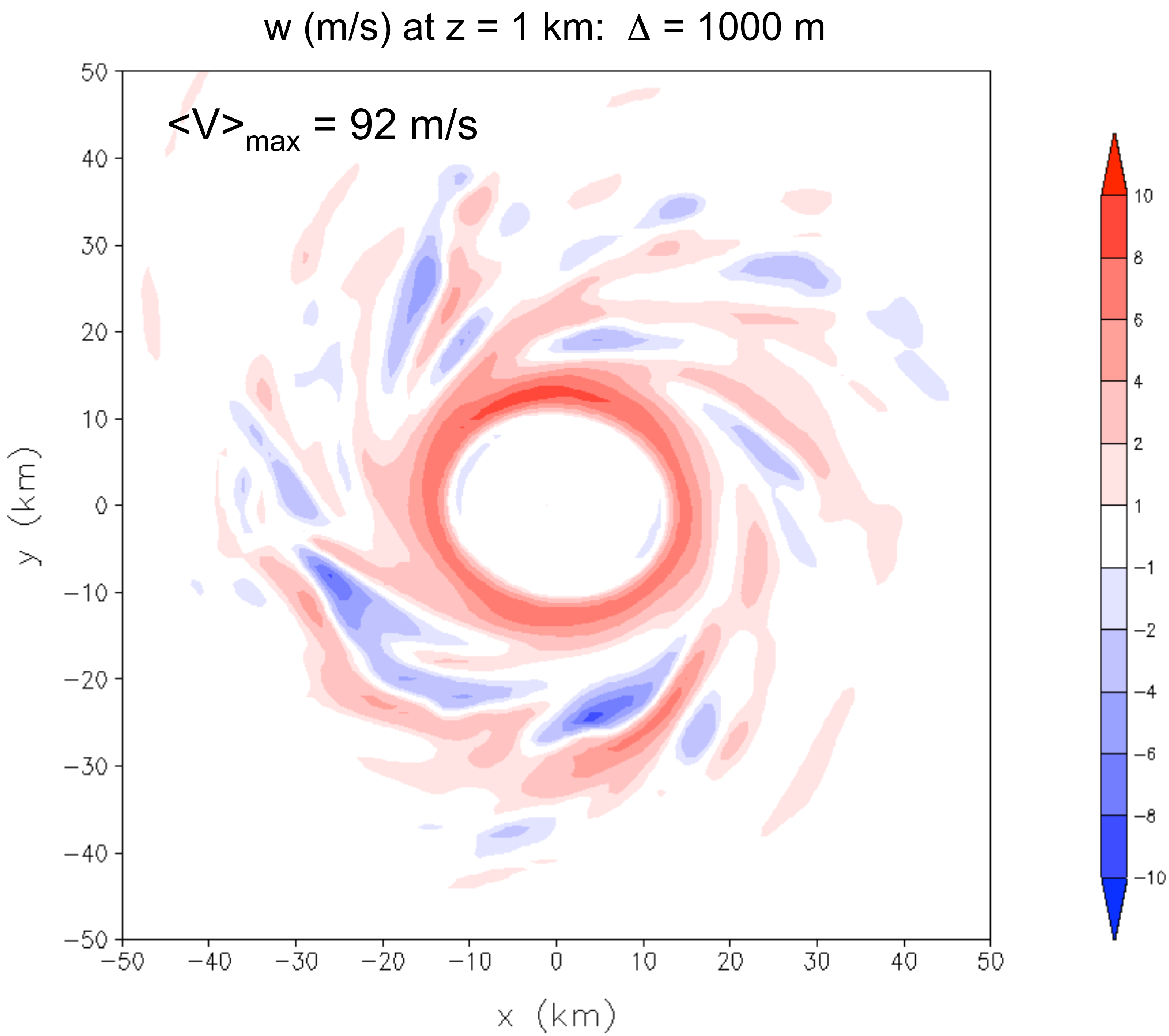


w (m/s) at z = 1 km
y (km)
x (km)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−50
−40
−30
−20
−10
0
10
20
30
40
50
10
8
6
4
2
1
−1
−2
−4
−6
−8
−10

A very high-resolution simulation

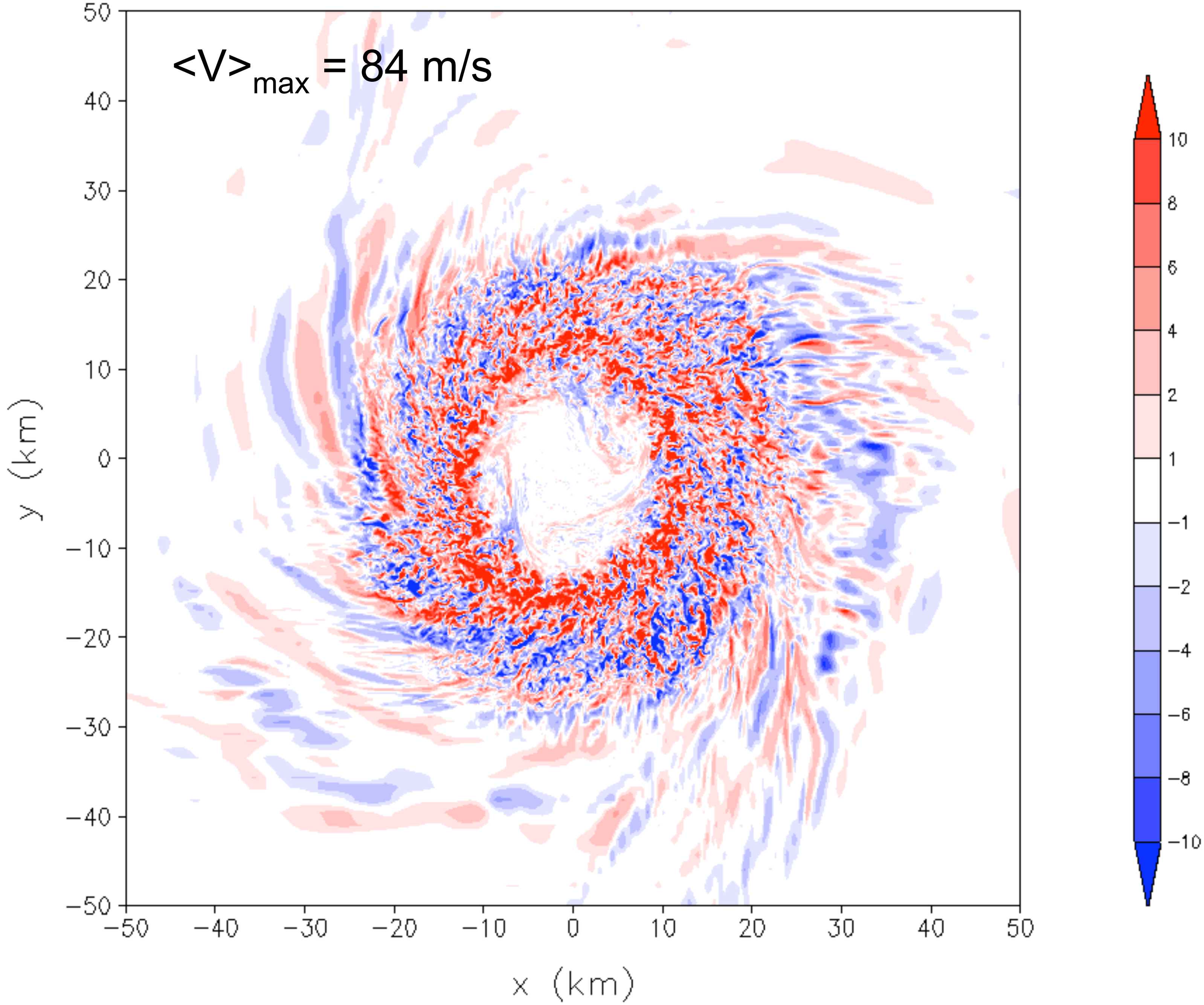
- Motivated by Rotunno et al. (2009, BAMS, in press)
- In center: $\Delta x = \Delta y = \Delta z = 62.5$ m
- (stretched structured grid)
- Initialized from 1-km simulation





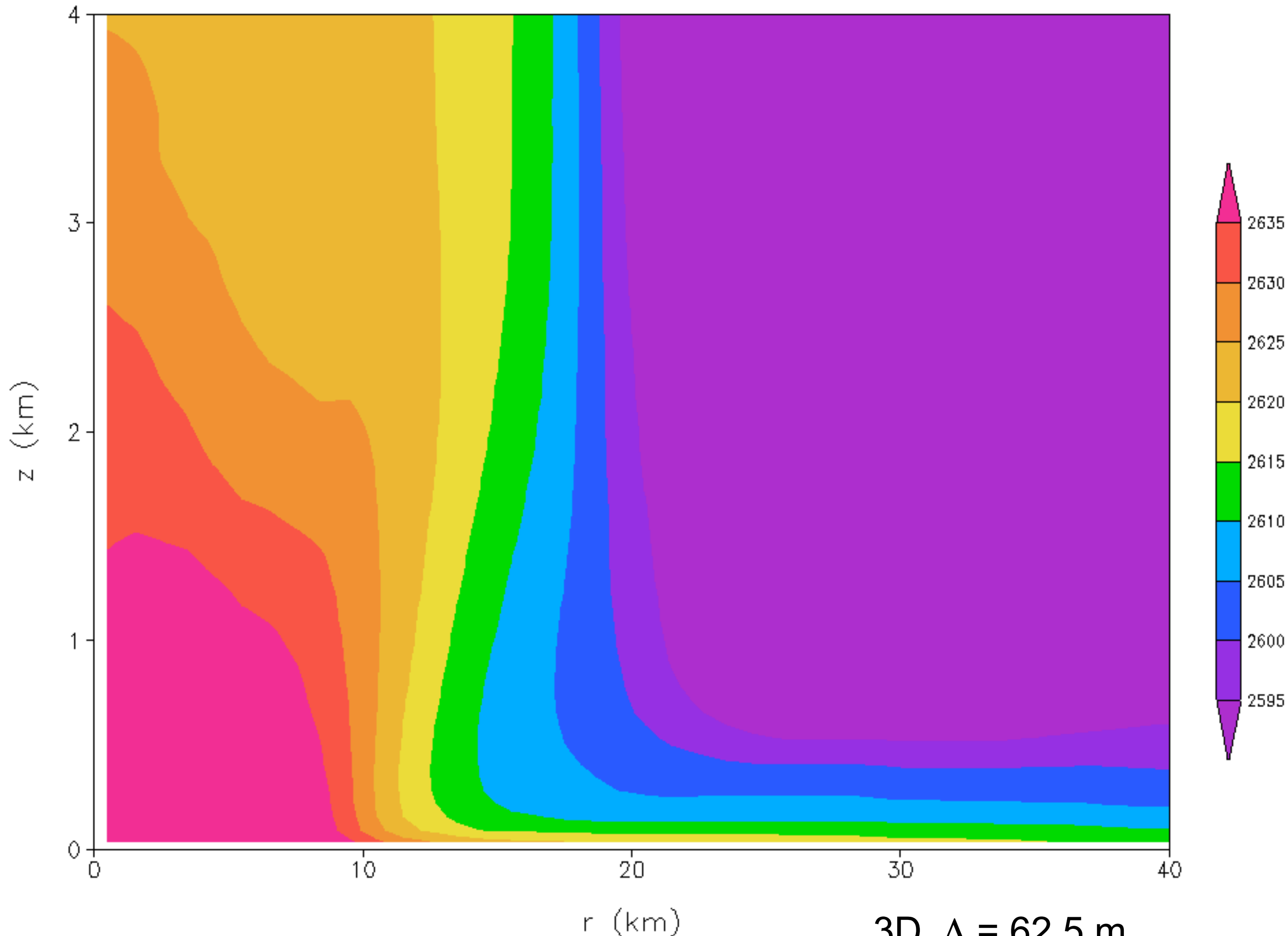
w (m/s) at z = 1 km: Δ = 1000 m
<V>max = 92 m/s
x (km)
y (km)
−50
−40
−30
−20
−10
0
10
20
30
40
50
10
8
6
4
2
1
−1
−2
−4
−6
−8
−10

w (m/s) at z = 1 km: Δ = 62.5 m



Let $\alpha(r,\phi,z) = \langle\alpha\rangle(r,z) + \alpha'(r,\phi,z)$

$\langle s\rangle$ (shaded)

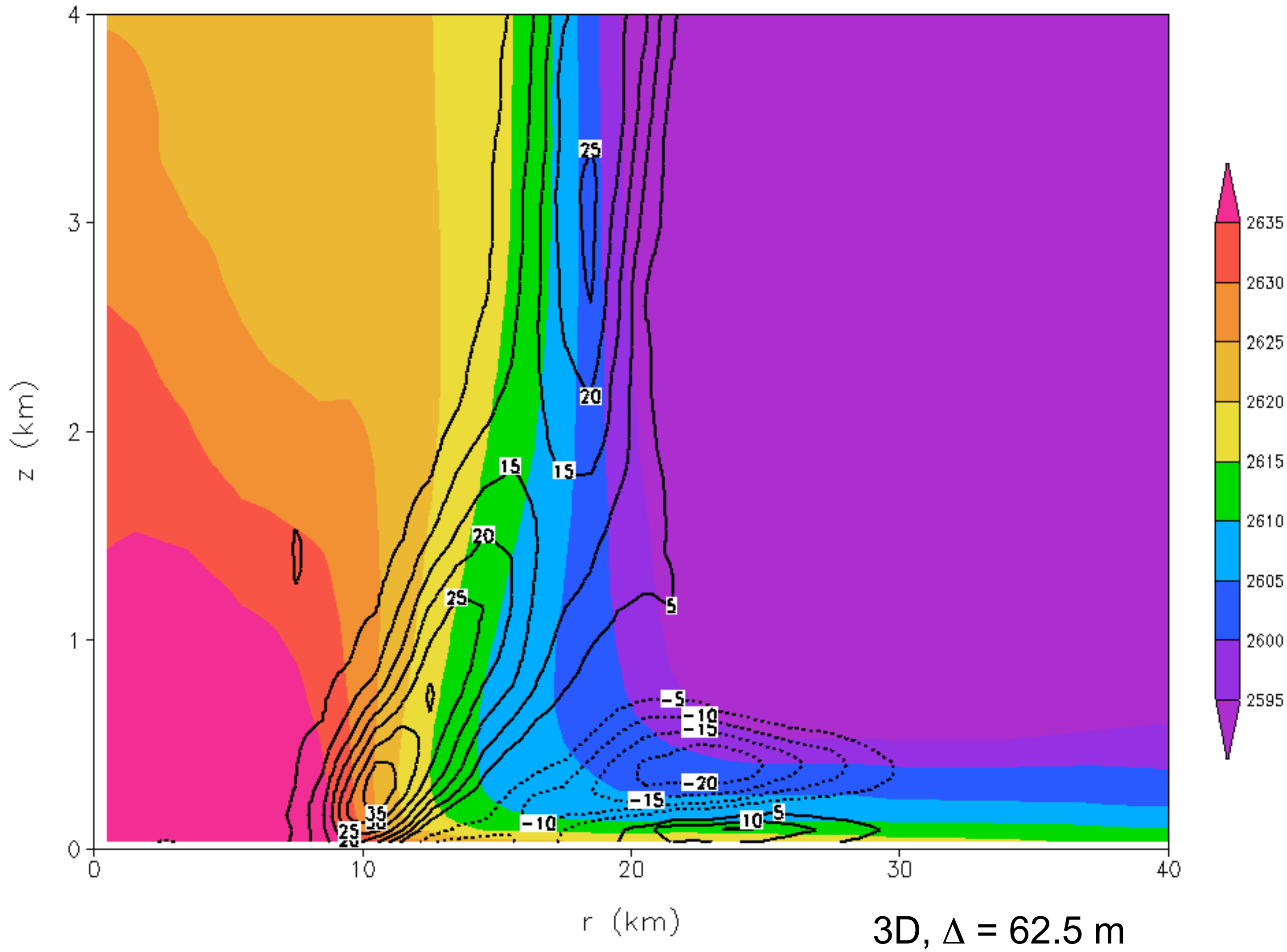


3D, Δ = 62.5 m

Let $\alpha(r,\phi,z) = \langle\alpha\rangle(r,z) + \alpha'(r,\phi,z)$

$\langle s \rangle$ (shaded)

and turbulent flux of s in radial direction, $\langle u's' \rangle$ (contours)



3D, Δ = 62.5 m

total moist entropy, <*s*>:

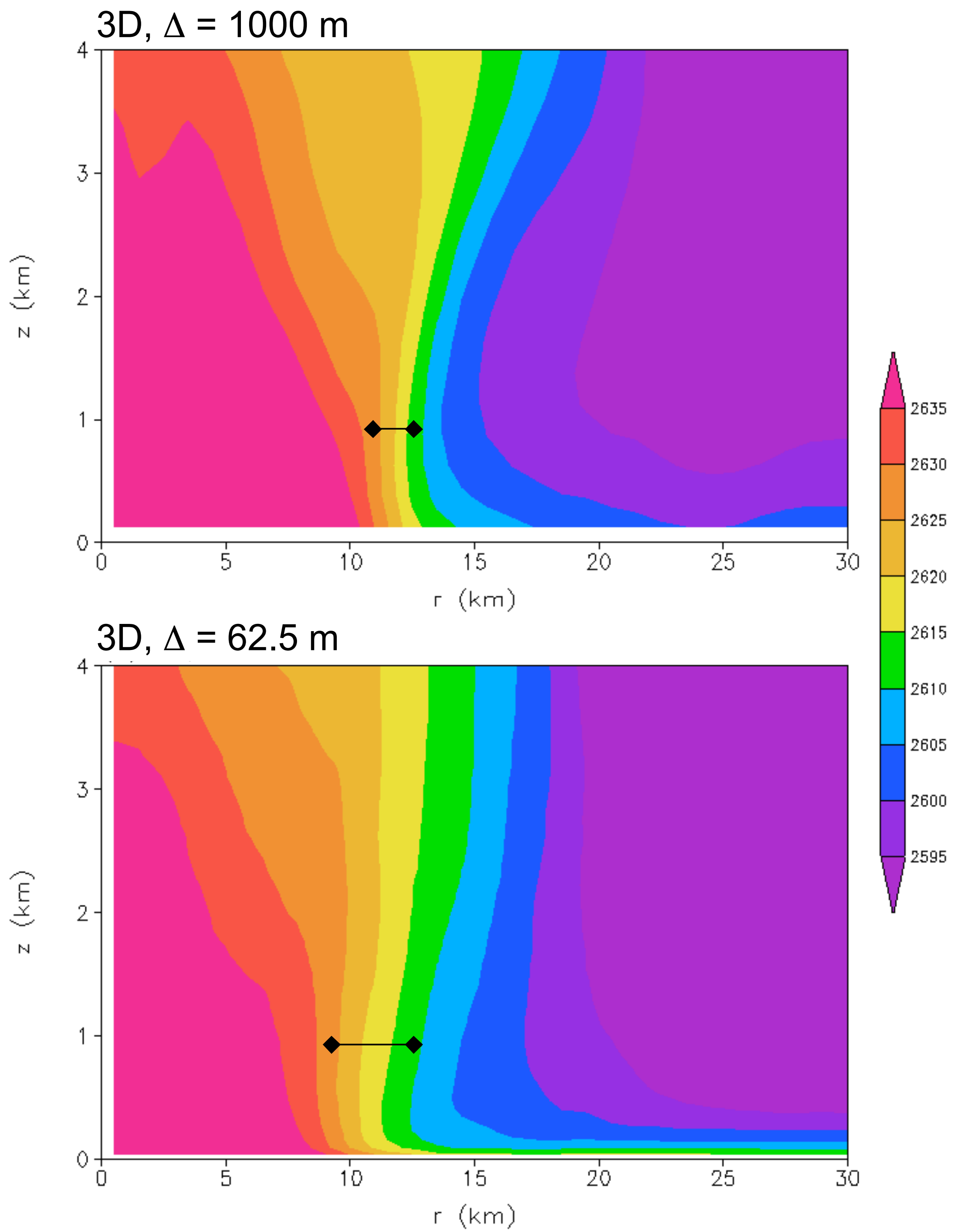
$$\frac{\partial \langle s \rangle}{\partial r} = -8.8 \times 10^{-3} \text{ m s}^{-2} \text{ K}^{-1}$$

$$\frac{\partial \langle s \rangle}{\partial r} = -4.3 \times 10^{-3} \text{ m s}^{-2} \text{ K}^{-1}$$

Hurricane Isabel (2003):

[from Montgomery et al. (2006, BAMS)]

$$\frac{\partial \langle s \rangle}{\partial r} = -1.7 \times 10^{-3} \text{ m s}^{-2} \text{ K}^{-1}$$



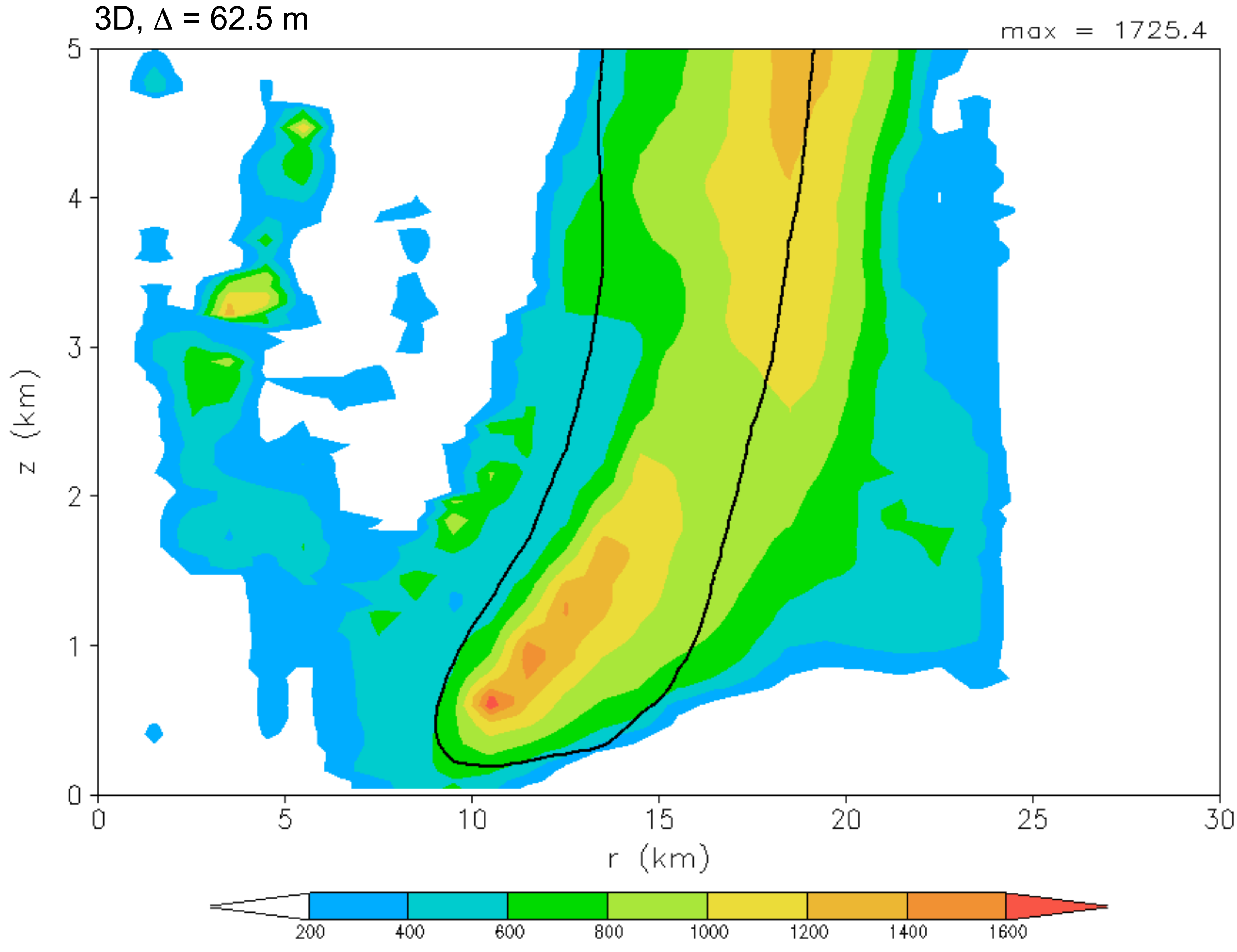
turbulence length scale:

$$\langle u's' \rangle = -K \frac{\partial \langle s \rangle}{\partial r}$$

where:

$$K = l_h^2 \left[2 \left(\frac{\partial \langle u \rangle}{\partial r} \right)^2 + 2 \left(\frac{\langle u \rangle}{r} \right)^2 + \left(\frac{\partial \langle v \rangle}{\partial r} - \frac{\langle v \rangle}{r} \right)^2 \right]^{1/2}$$

turbulence length scale (l_h):



Summary

- Turbulence in the eyewall of hurricanes *<u>reduces</u>* hurricane intensity

- Very high resolution (Δ < 100 m) in three dimensions is required to simulate turbulent processes (see also Rotunno et al. 2009, BAMS, in press)

… otherwise, turbulent processes must be *parameterized* (even with $\Delta \approx$ 1 km)

… $l_h \approx$ 1000 m

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