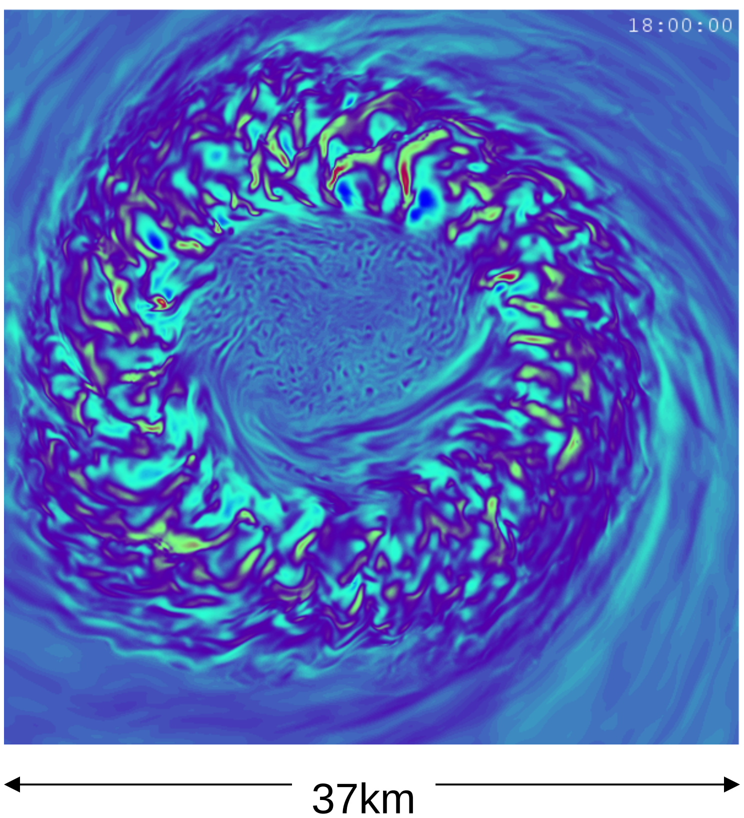
Large Eddy Simulations of an Idealized Hurricane

Yongsheng Chen, Rich Rotunno, Wei Wang,
Christopher Davis, Jimy Dudhia, Greg Holland
MMM/NCAR

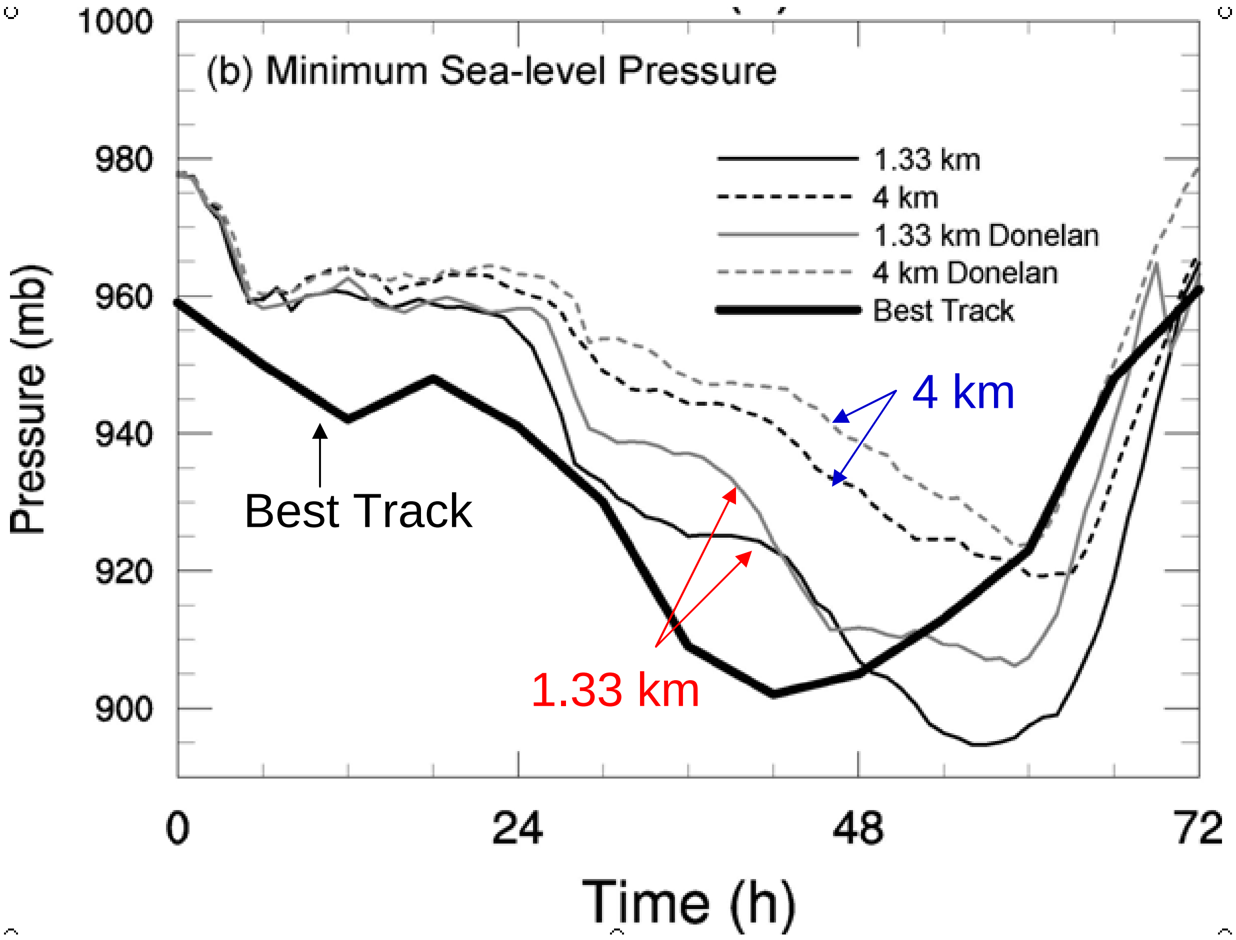


Motivation

1. Intensity sensitivity to model resolution

2. Direct computation of effects of turbulence

Motivation 1: Resolution Sensitivity



Hurricane Katrina 2005

Forecasts start at 00Z August 27, 2005.

(Davis et al. 2008, MWR)

Motivation 1: Resolution Sensitivity

Δ=1.67*km* Δ=5*km*

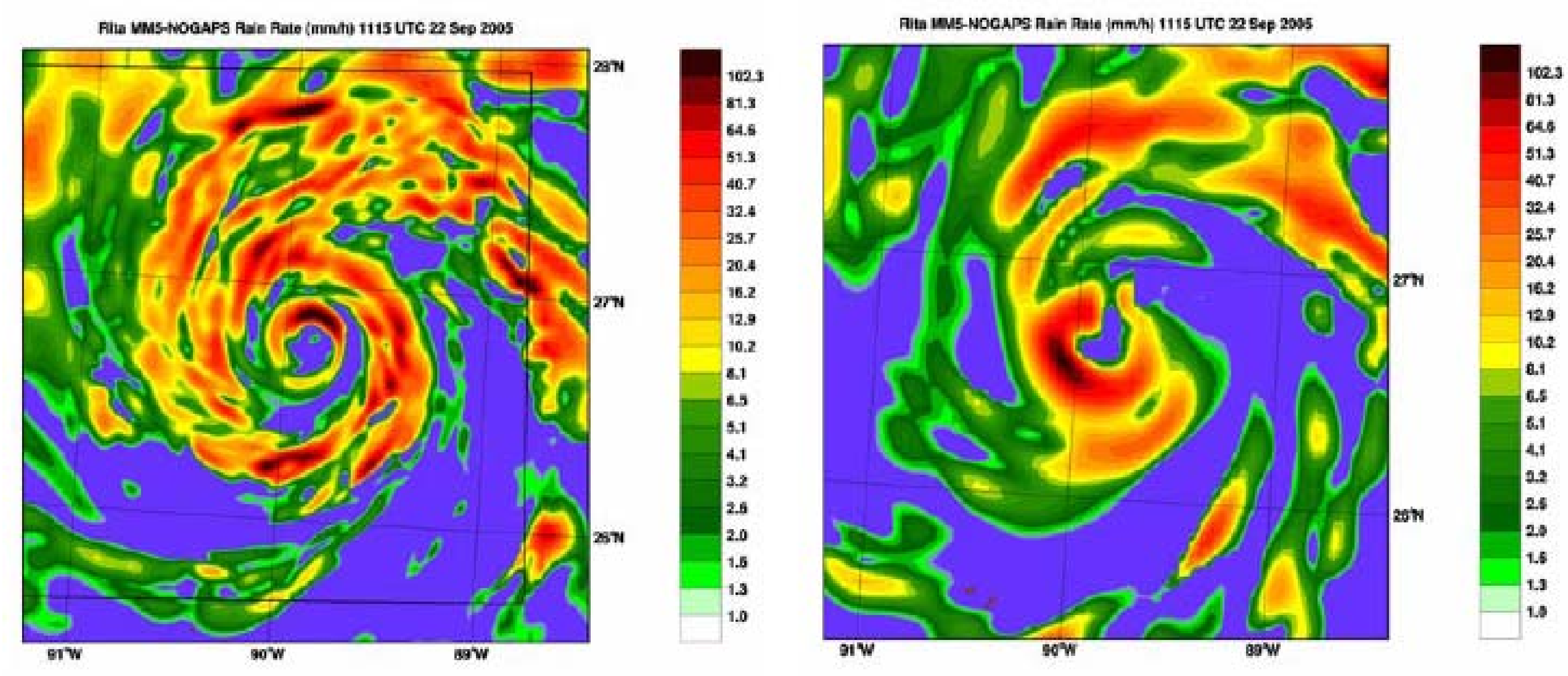
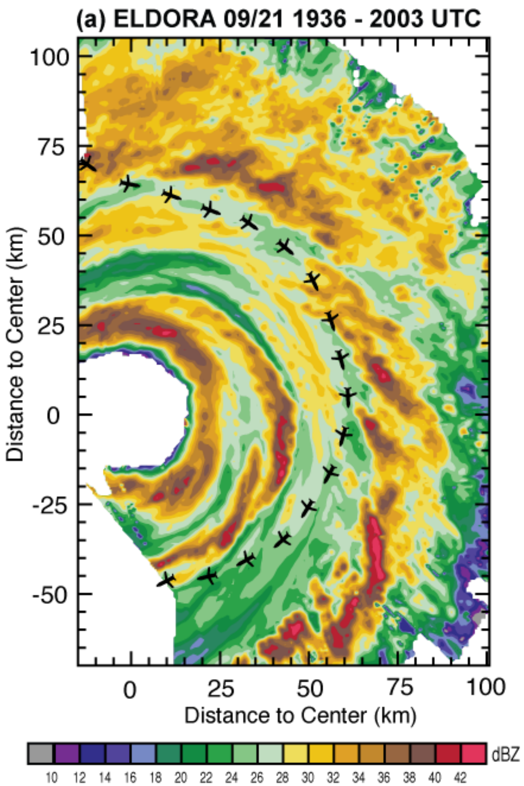


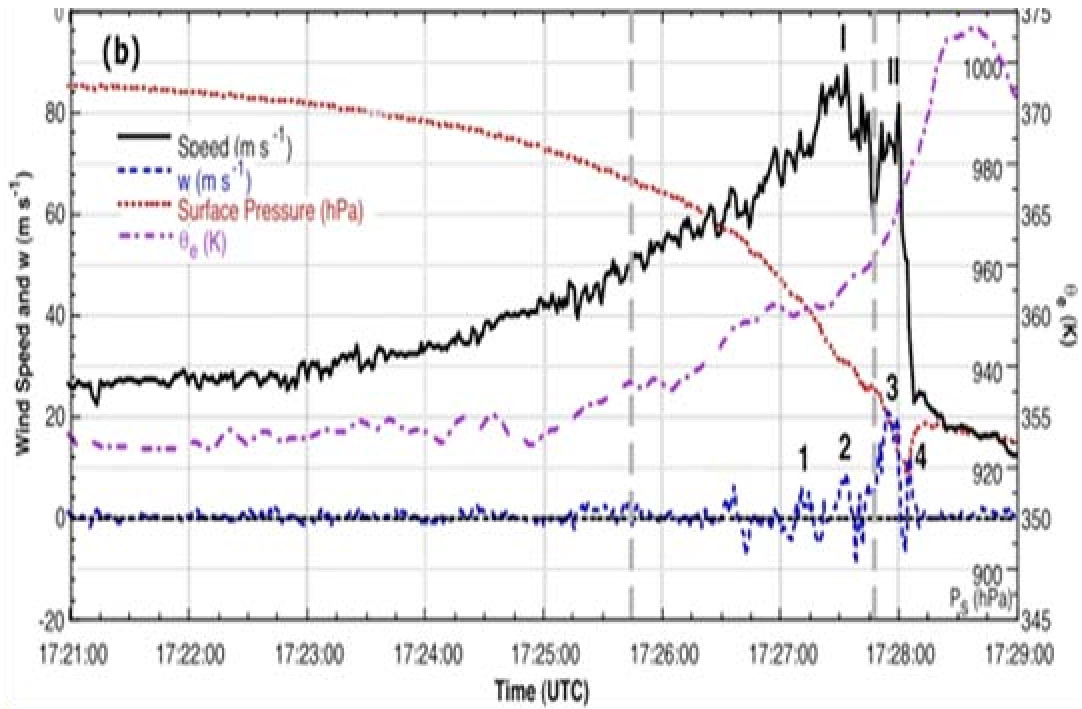
Figure 4.4b. MM5 forecasted rainrate (mm h^{-1}) in Rita at 1115 UTC 22 September using 1.67-km (left) and 5-km (right) grid resolution. The model was initialized at 0000 UTC 20 September using the NOGAPS forecast fields as lateral boundary condition. The 1.67-km forecast shows a primary and secondary eyewalls as observed, whereas 5-km does not.

(HIRWG 2006, S. Y. Chen)

Motivation 2: Effect of Turbulence



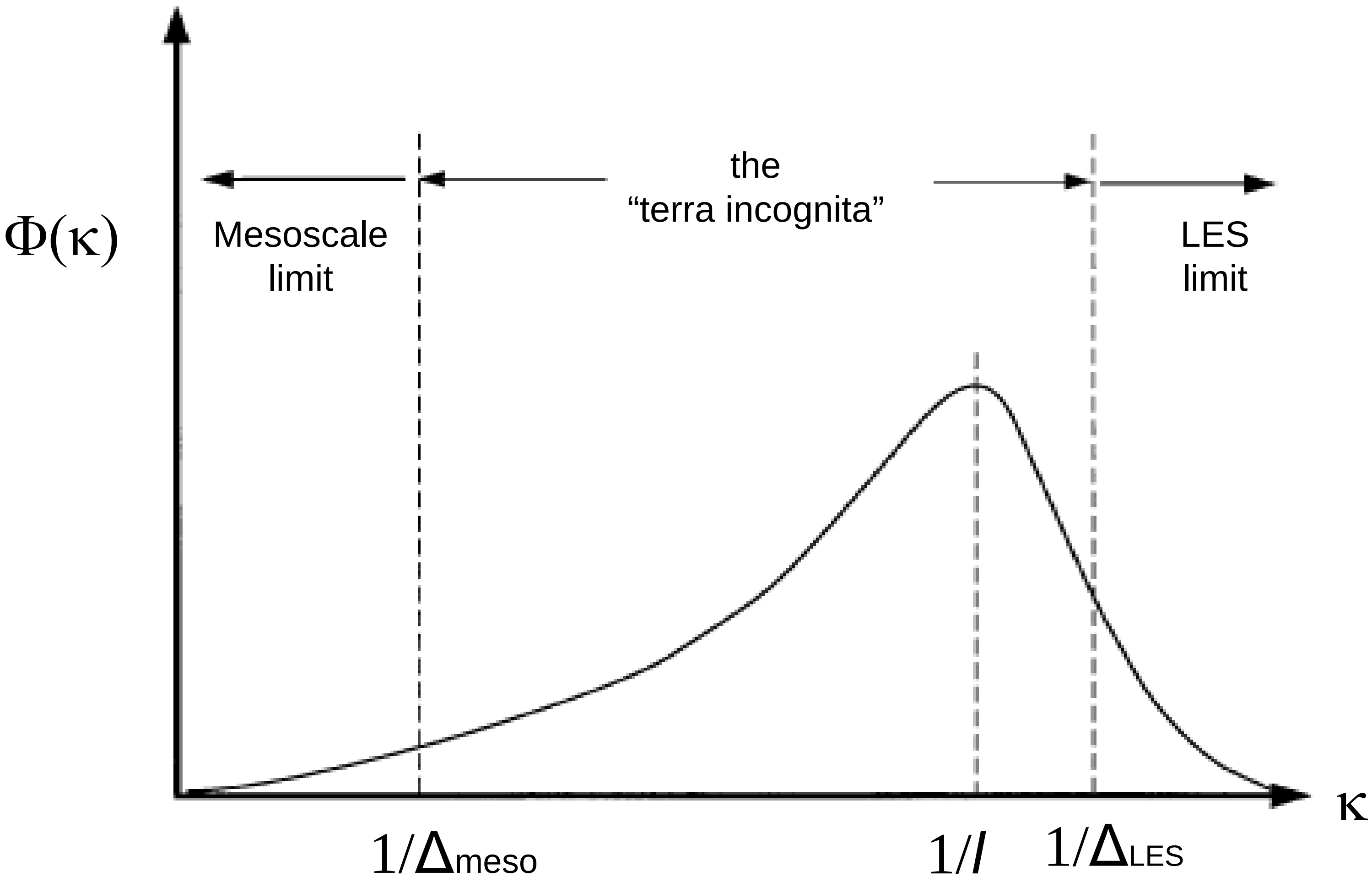
ELDORA Reflectivity in Hurricane Rita (2005)
Courtesy Michael Bell



Hurricane Hugo (1989) Flight level data
Marks et al. (2008)

LES

Regimes of Numerical Modeling
(Wyngaard 2004)



Model Setup

Idealized TC

f-plane

zero env wind

fixed SST

Nested Grids

WRF Model Physics

WSM3 simple ice

No radiation

Relax to initial temp.

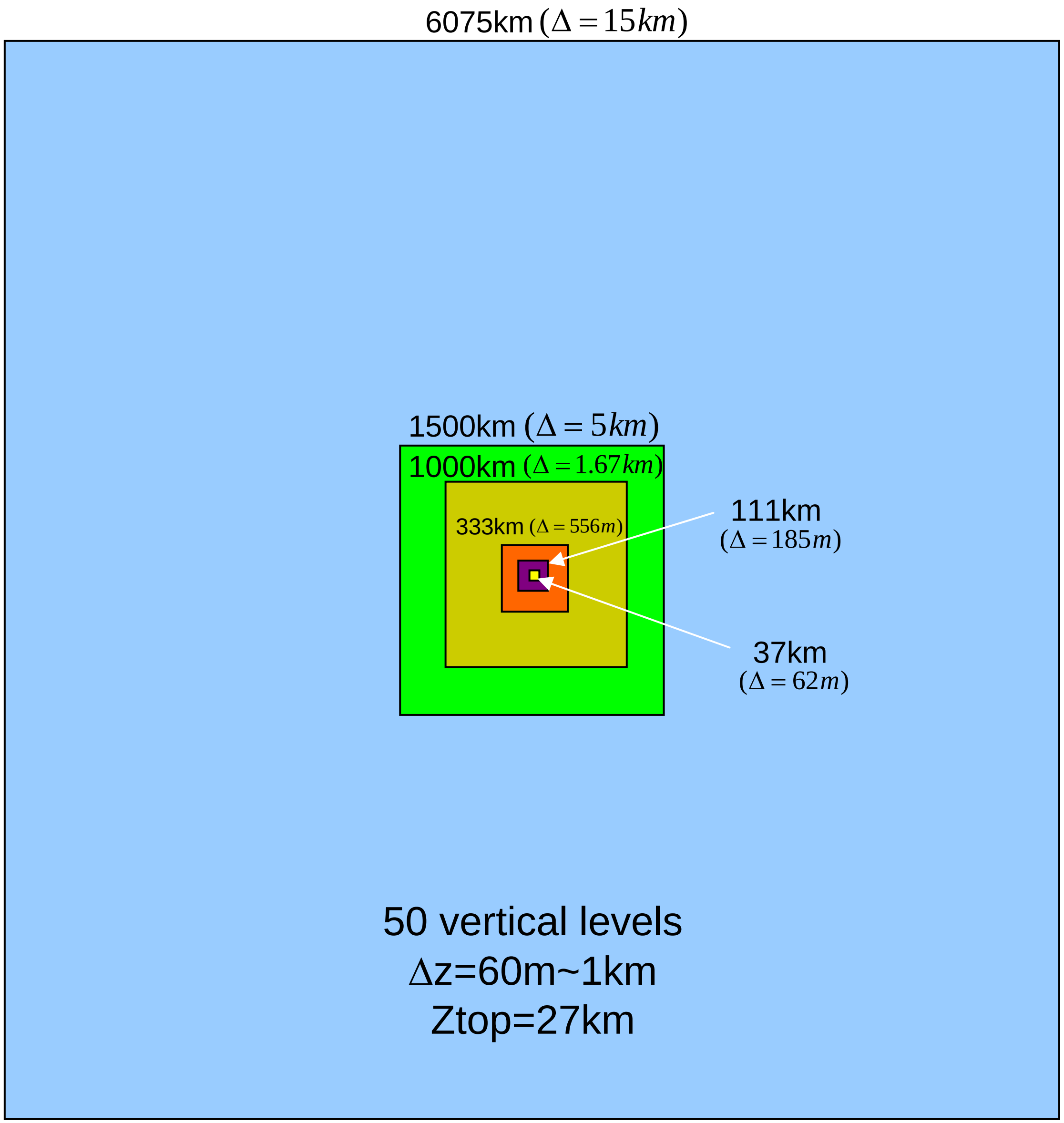
Cd (Donelan)

Ck (Carlson-Boland)

Ck/Cd ~ 0.65

YSU PBL $(\Delta \geq 1.67 km)$

LES PBL $(\Delta < 1.67 km)$



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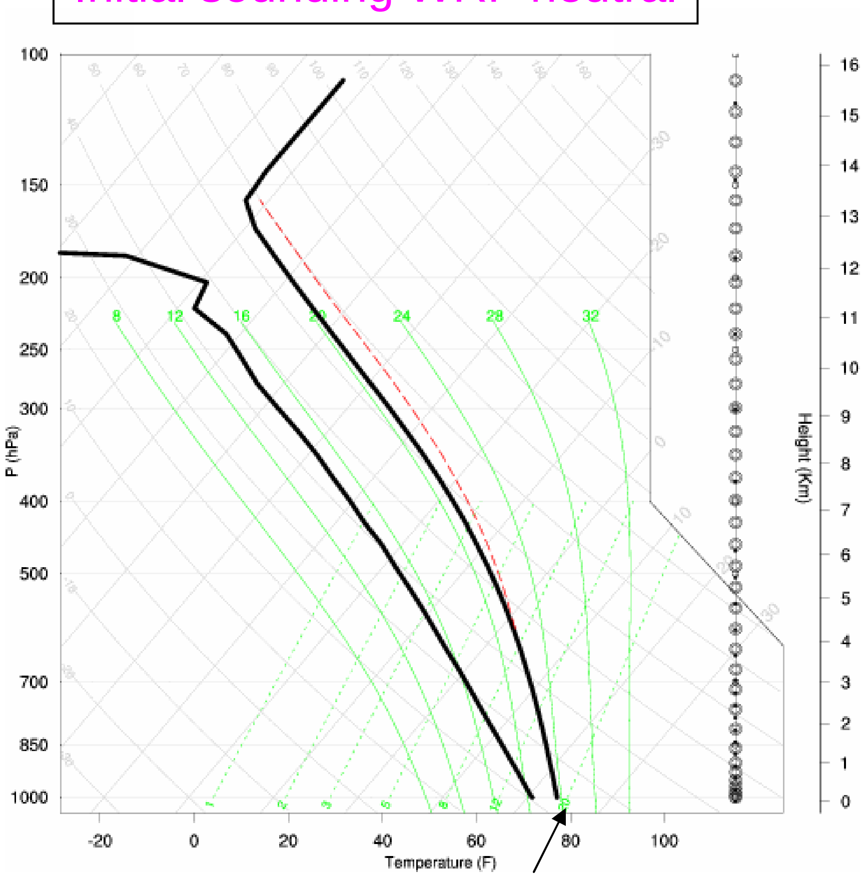
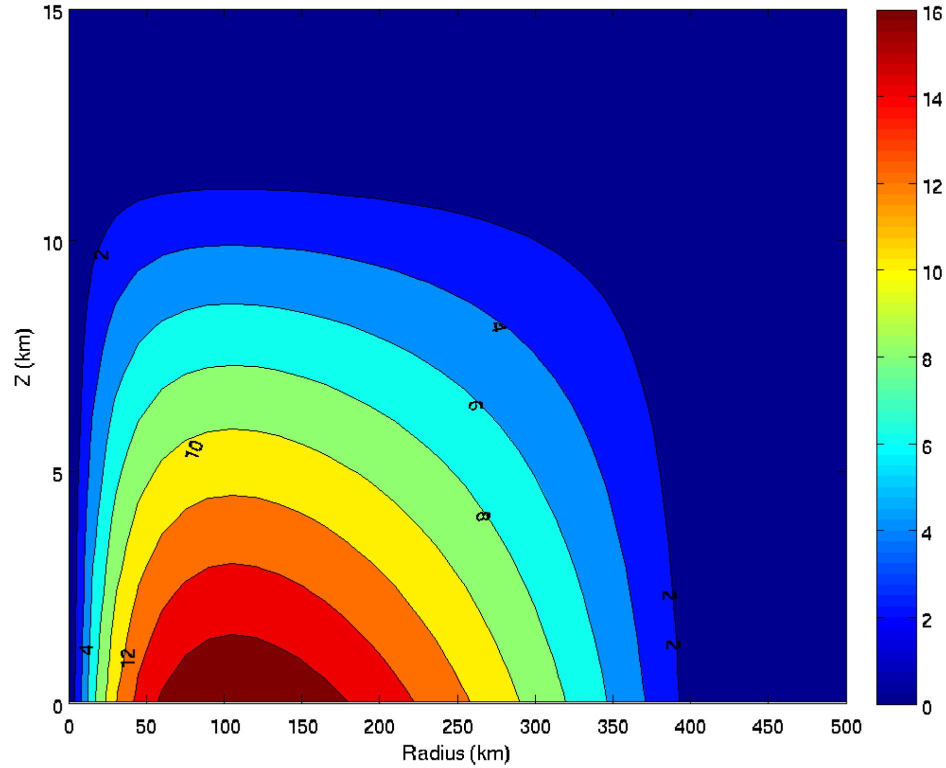
Initial Condition

Initial sounding WRF neutral



$$SST = 26.3^{o}C$$

Initial vortex (m/s)



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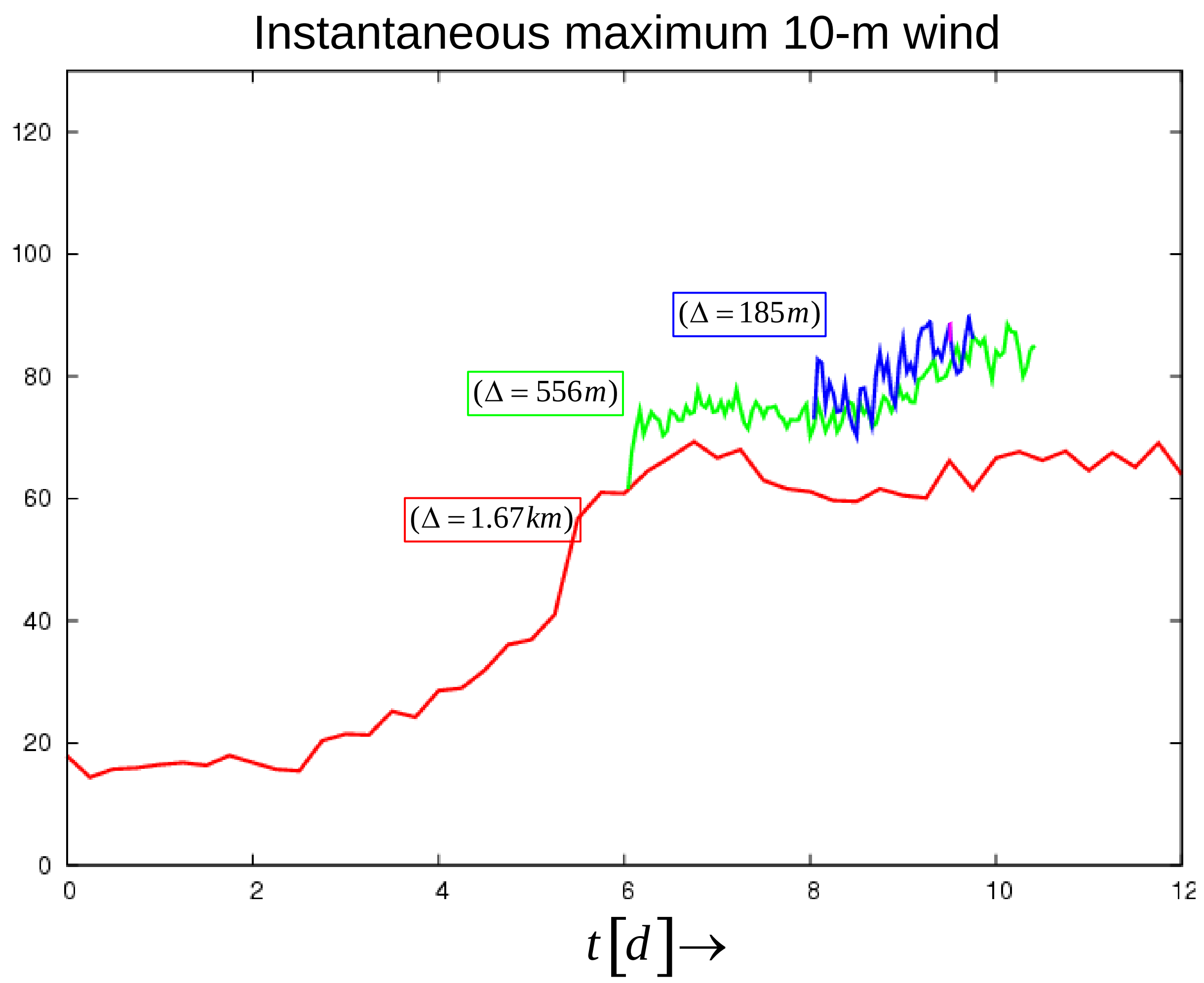
*After Rotunno and Emanuel (1987)

Intensity Evolution



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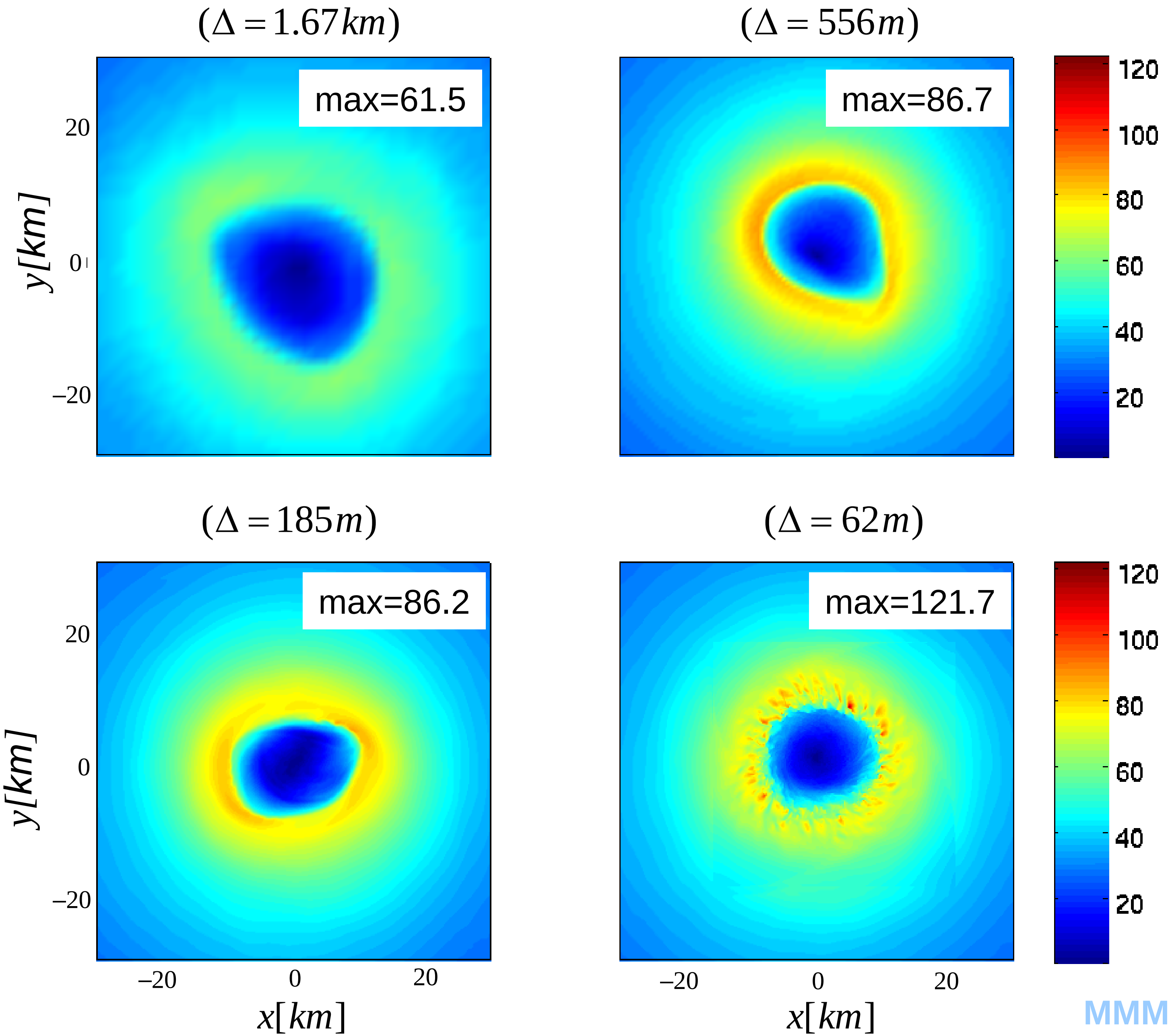
Surface Wind ~ Resolution



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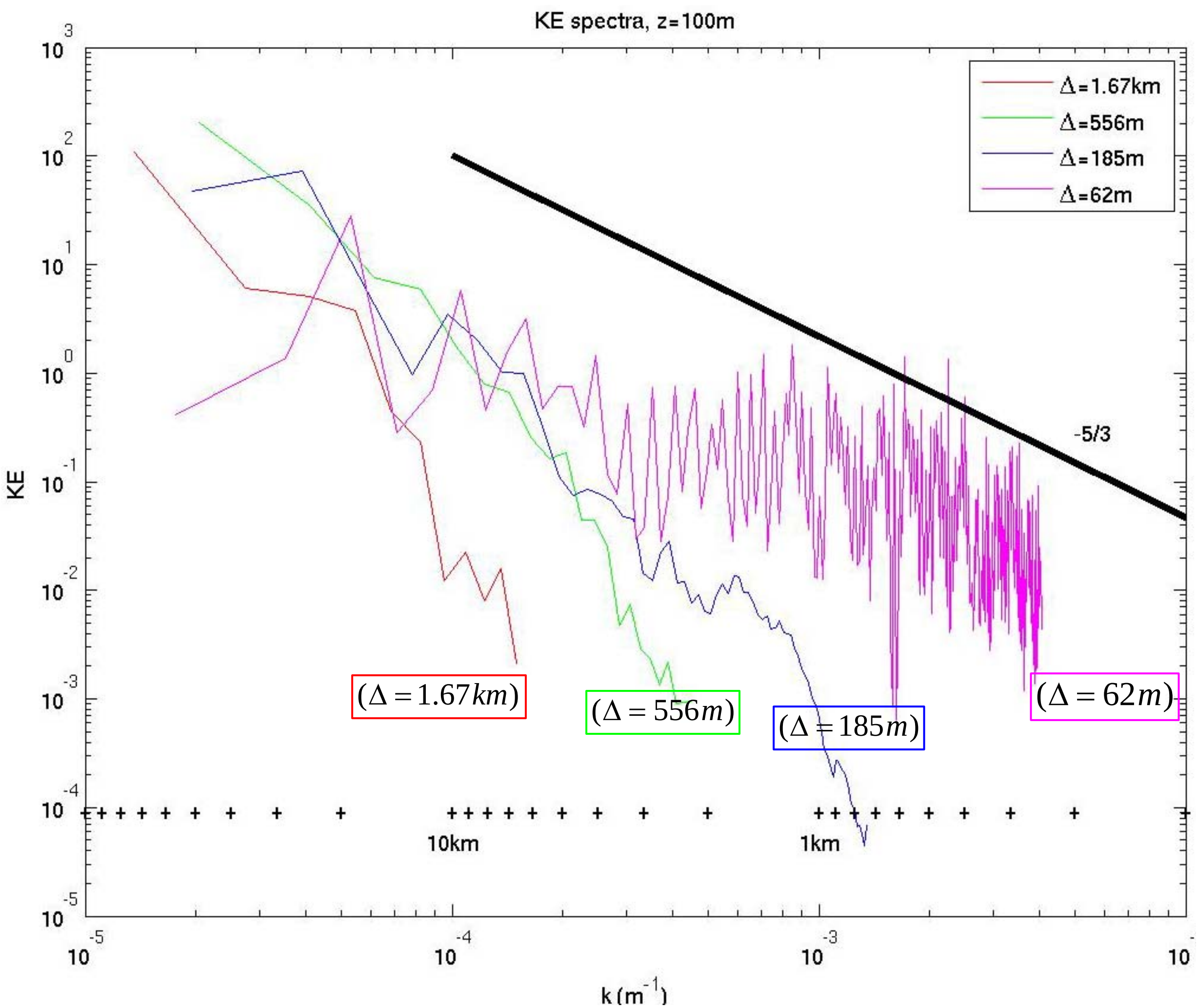
Eddy Kinetic Energy Spectra



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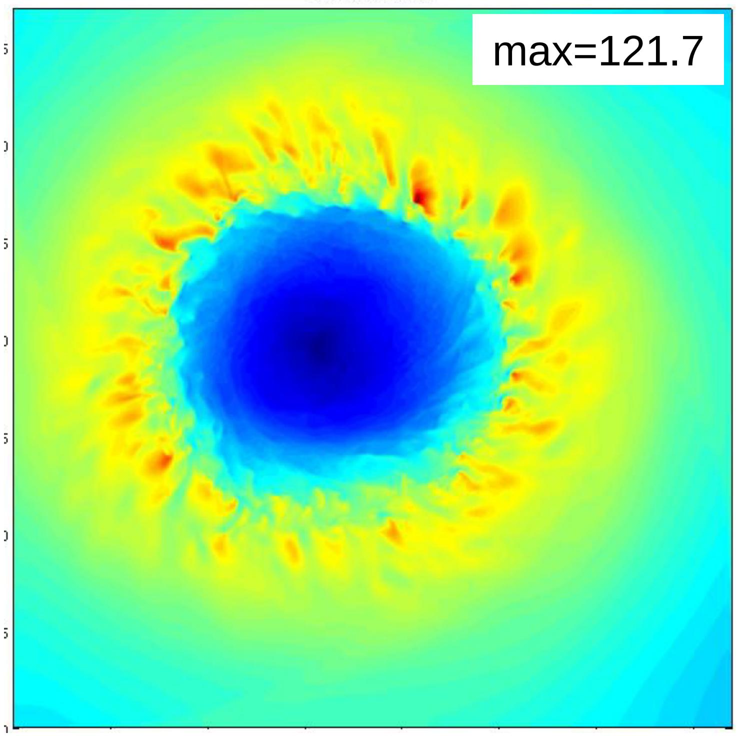
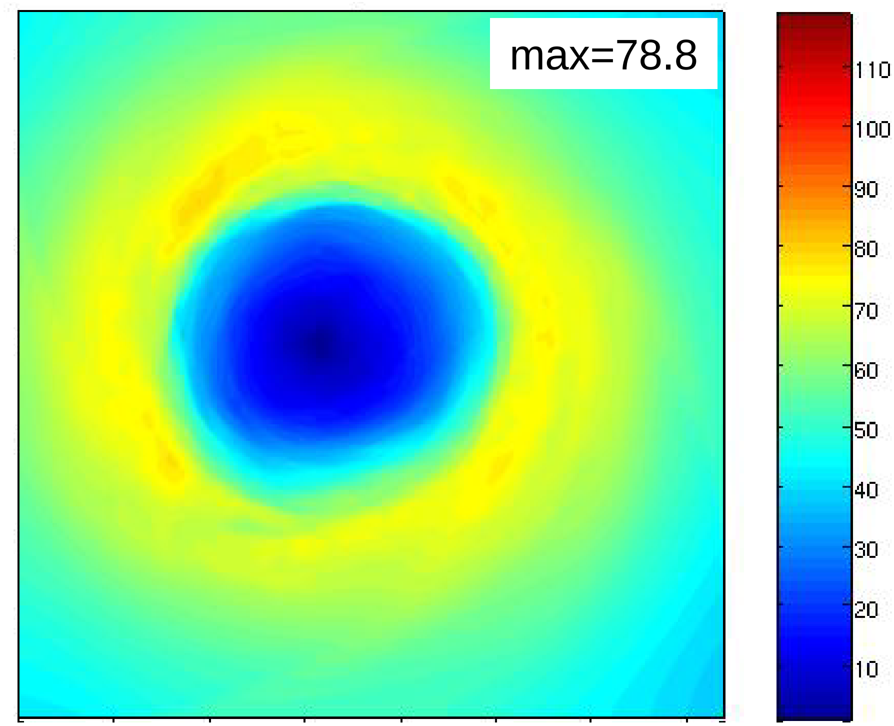
1-min Averaged Surface Wind

instantaneous



37km

1-min average



37 km

LES

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Max. Azimuthal-Mean Wind ~ Resolution

Resolution	$<\|u_{10}\|>_{max}$ (m/s)
1.67 km	53.4
556 m	73.2
185 m	77.1
62 m	72.0

Large Eddy Simulation

$$\frac{\partial\overline{\theta}}{\partial t} = -\frac{\partial}{\partial x_i}\left(\overline{u}_i\overline{\theta}\right) - \frac{\partial}{\partial x_i}\left(\overline{u_i'\theta'}\right)$$

grid-scale grid-scale subgrid-scale

$$\overline{u_i'\theta'} = -K_{LES}\frac{\partial\overline{\theta}}{\partial x_i} \quad ; \quad K_{LES} = \left(c_s\Delta\right)^2\left|Def\right|$$

When resolution increases (Δ decreases)

- K_{LES} decreases => subgrid-scale flux decreases
- Grid-scale flux is small until the LES resolution threshold is crossed!

Lessons Learned from LES

- Modeled intensity increases with decreasing grid size (decreasing turbulent mixing length) until…
- LES threshold crossed, however…

  It's not clear that Δ=62m is small enough for statistically converged result
- In high-resolution models treatment of turbulence as important as other factors (e.g. ocean coupling, ocean-wave drag, cloud physics, sea spray…)