Impact of stratospheric temperature on hurricane intensity: An idealized modeling study

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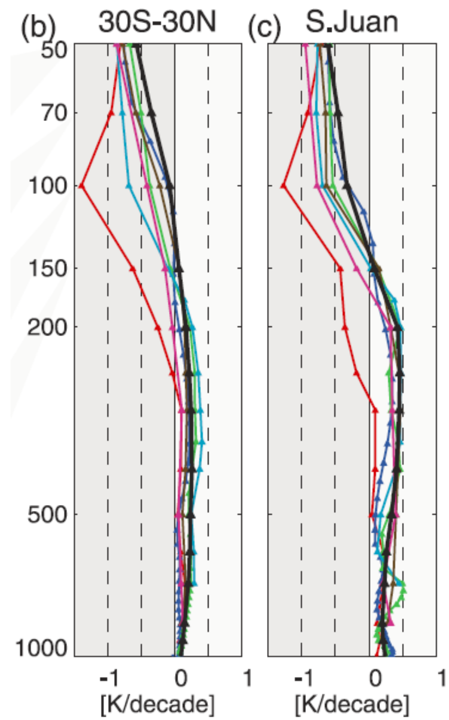
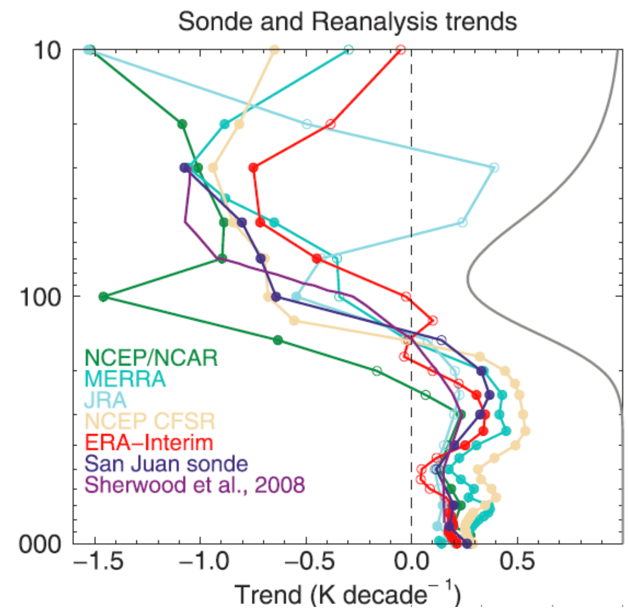
Trend in lower stratosphere and upper troposphere temperature

Randel et al 2009, Emanuel 2011, Emanuel et al 2013, Vecchi et al 2013



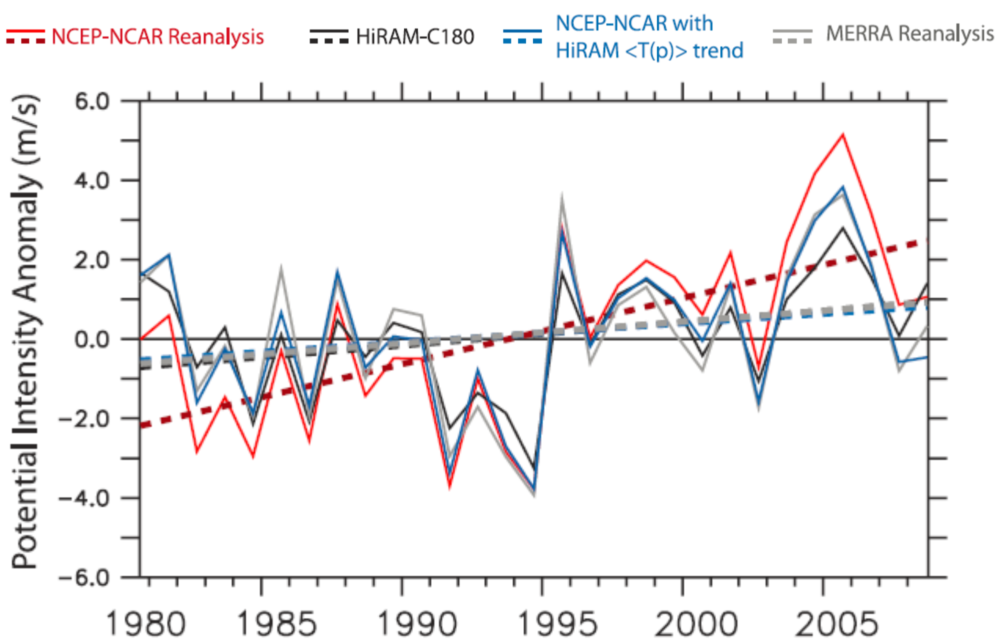
Vecchi etal 2013



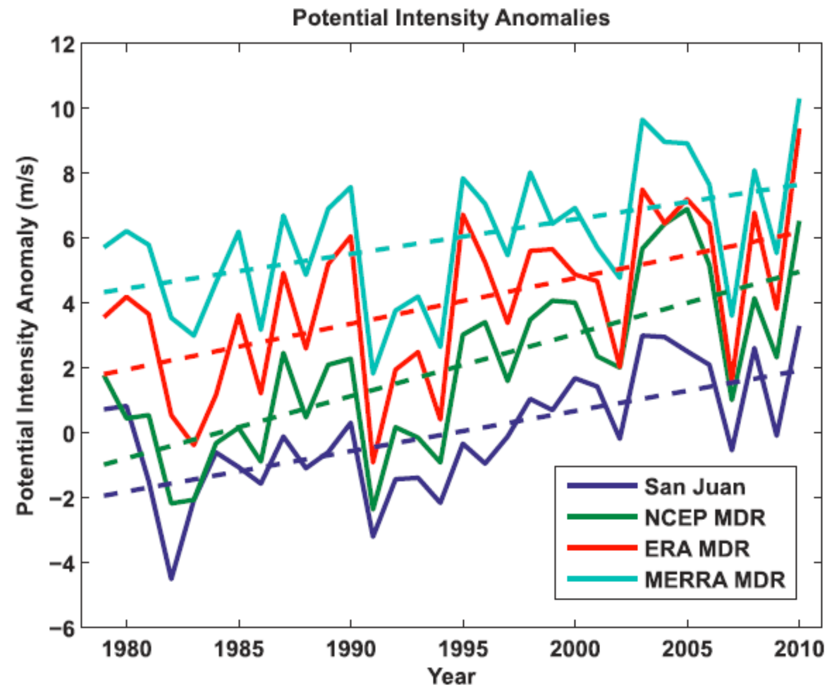
Emanuel etal 2013

Cooling trend in stratosphere temperature

Potential intensity at Atlantic MDR



Vecchi etal 2013



Emanuel etal 2013

~ 1 m/s per degree cooling (except NCEP-NCAR reanalysis)

=> Using WRF to better understand this issue

WRF model V3.0

-f=5x10^{-5} s^{-1}, two nested domain: DX=12 km, 4 km, 50 levels, no convective parameterization – Nonhydrostatic modeling

-Simple radiation: -1.25 K/day in troposphere (Pauluis and Garner 2006)

$$Q\Big|_{rad.\ cooling} = \begin{cases} -1.2 \quad K \cdot day^{-1} \quad for \quad T > 6 + T_s \\ \dfrac{T_s - T}{5 \quad days} \; for \quad T \le 6 + T_s \end{cases}$$

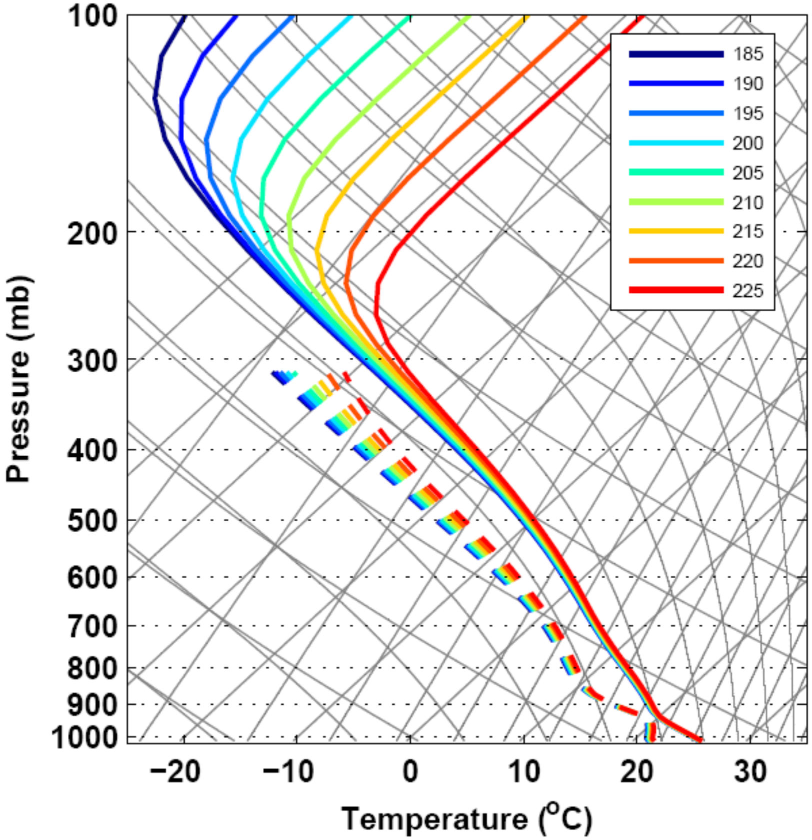
-Isothermal stratosphere, Ts = 190 – 215 K

-Homogeneous sea surface temperature: 26, 28, or 30 degree

-Physics schemes: PLin et al. microphysics, YSU PBL, surface fluxes, Smagorinsky sub-grid model - mixing length proportional to grid spacing

The RCE soundings (~400 km domain)

SST = 28 °C



A set of initial sounding with different stratospheric temperature

In RCE (at Dx=12 km)

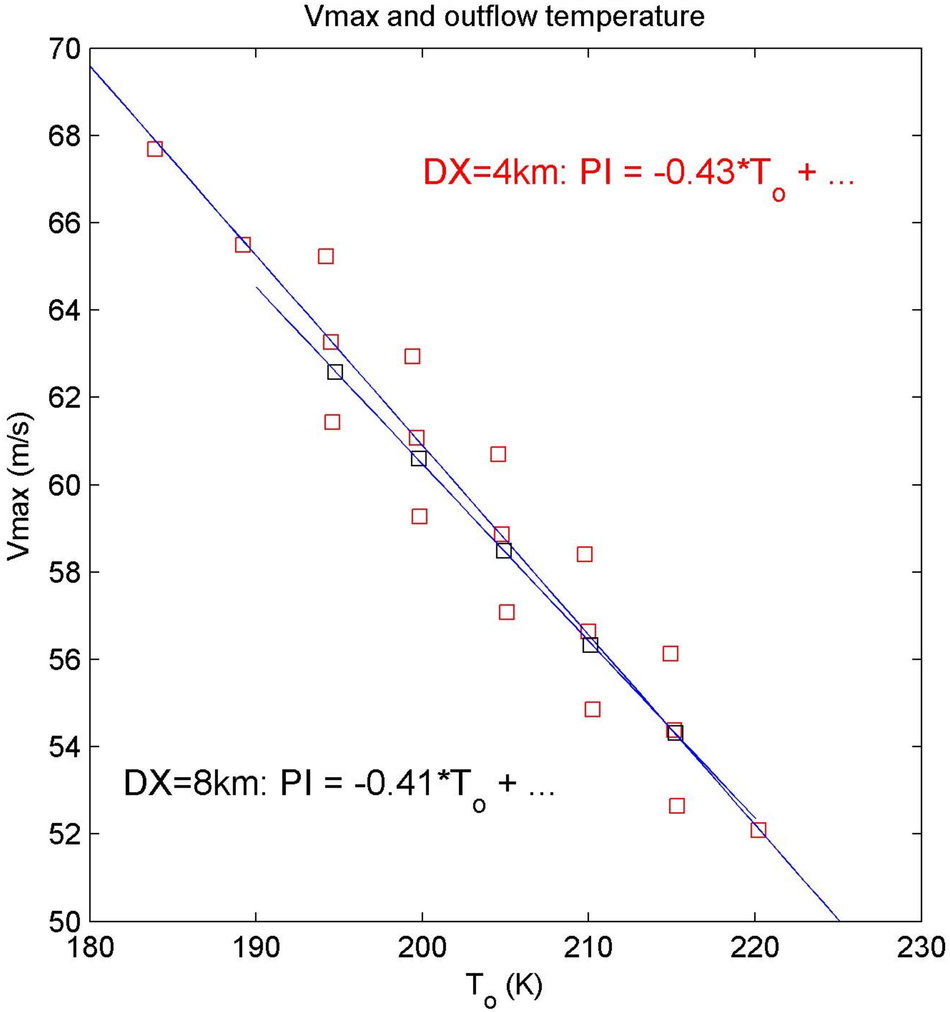
At different SST:

26, 28, and 30

Radiative cooling and surface fluxes are nearly fixed ~ 120 W/m2

Potential Intensity from the RCE soundings

Using assumptions in PI: CK/Cd=0.5,   Pseudo-adibat, no dissipative heating



Less than 0.5 K decrease in Ts

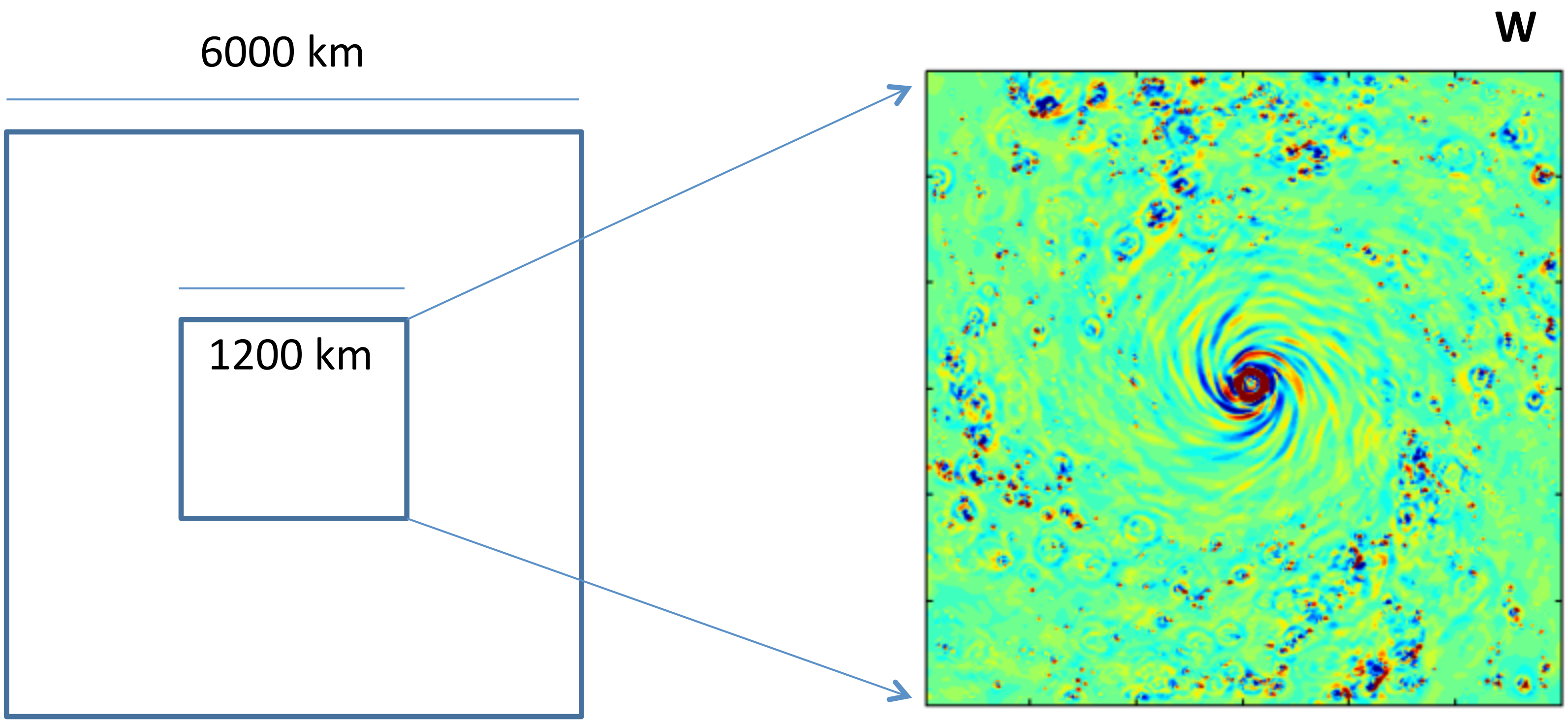
⇩

1 m/s in PI

The slope varies with different Ck/Cd. E.g., Ck/Cd=1, reversible-adibat , the slope is close to 1

WRF hurricane simulations

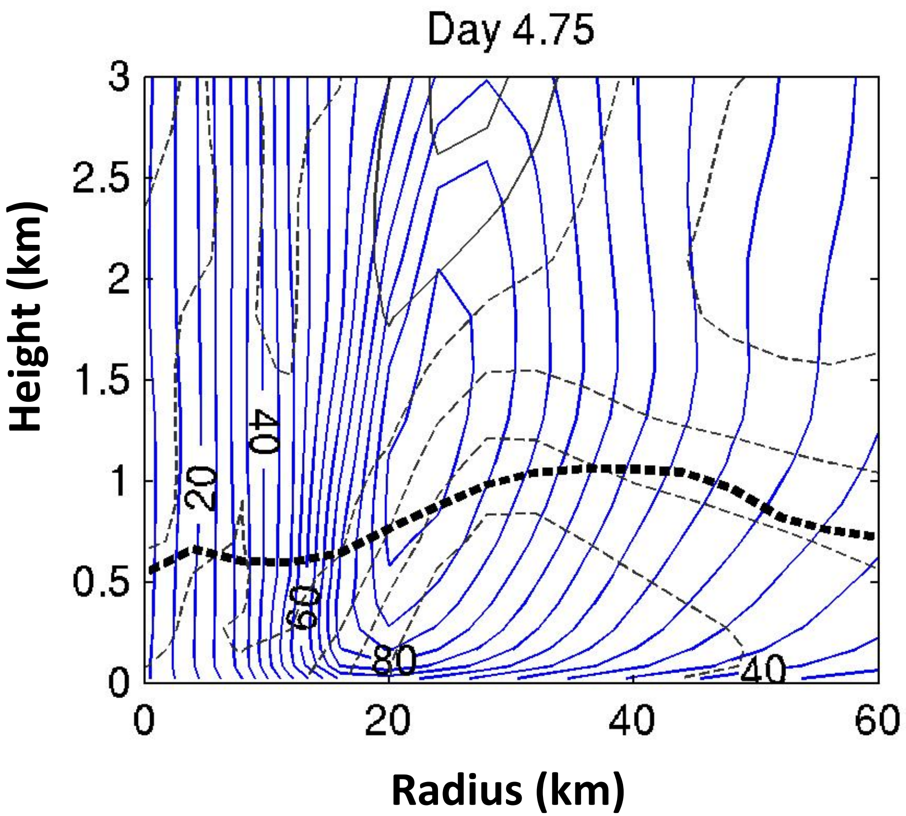
- Same physics as RCE, but in a larger, nested domain



- Idealized hurricane simulations with an initial vortex (Rotunno and Emanuel 1987), but no wind shear, no interactive radiation, no ocean mixed layer etc.

WRF hurricane simulations

- Axis symmetric view of tangential wind, radial wind, and boundary layer height



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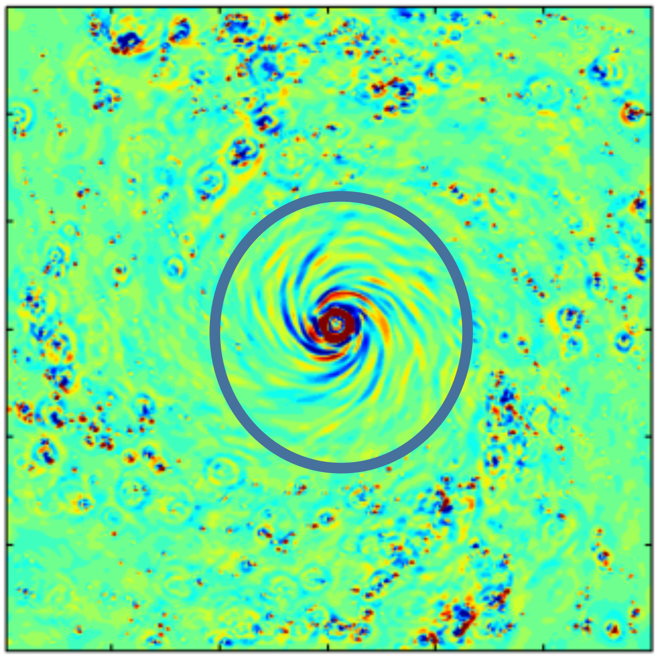
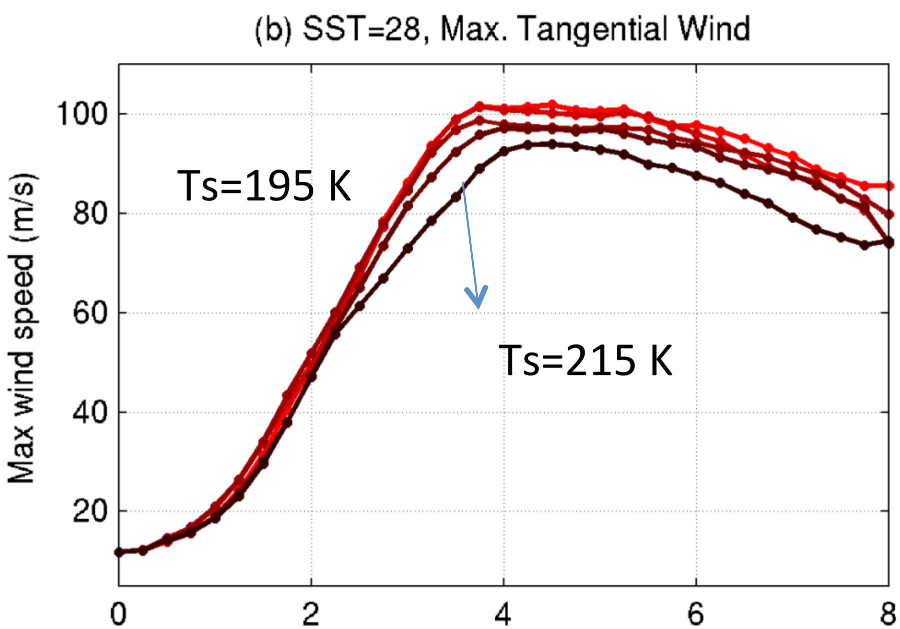
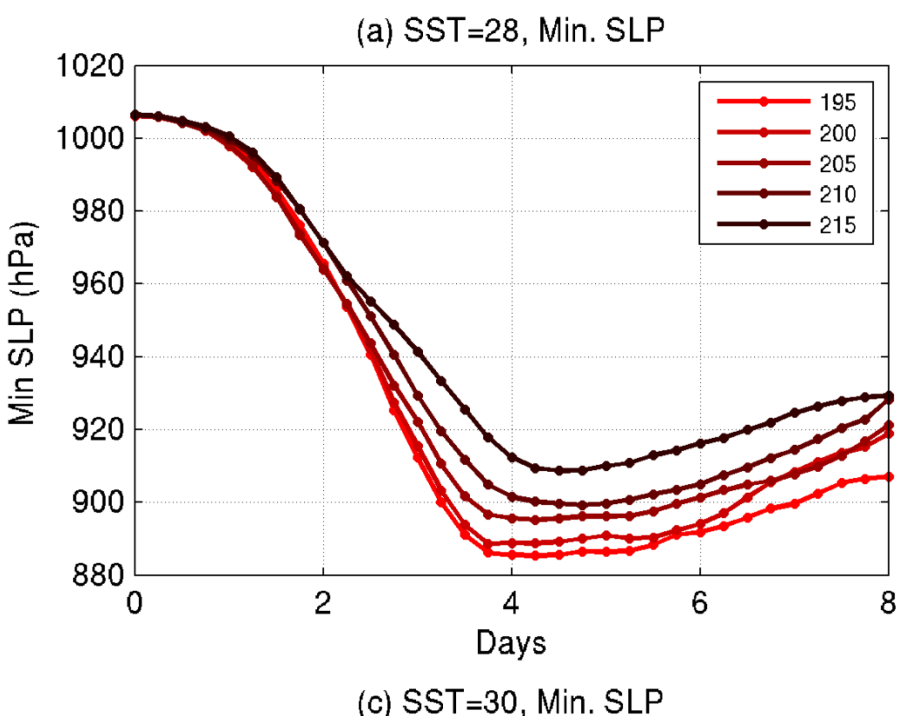
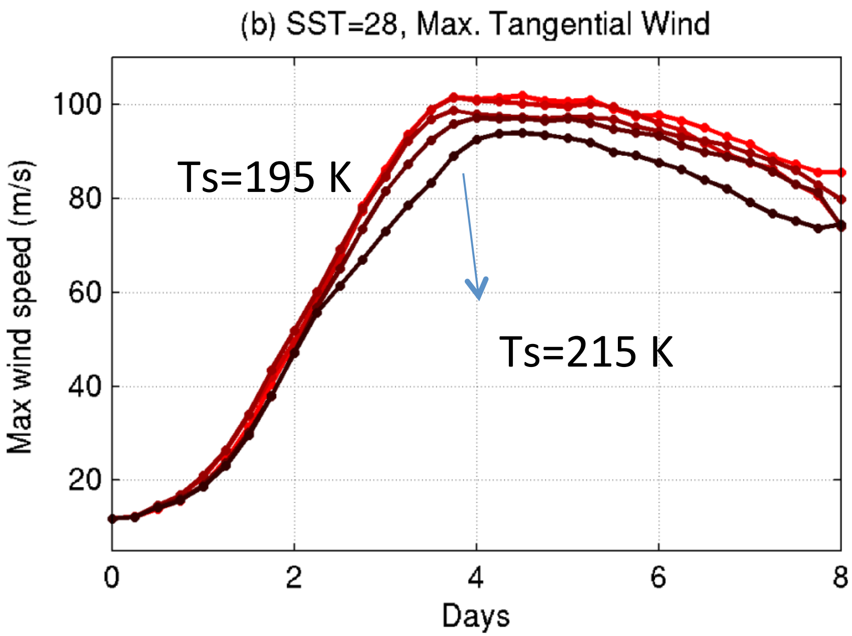




Model simulated maximum azimuthal wind speed reaches ~ 100 m/s

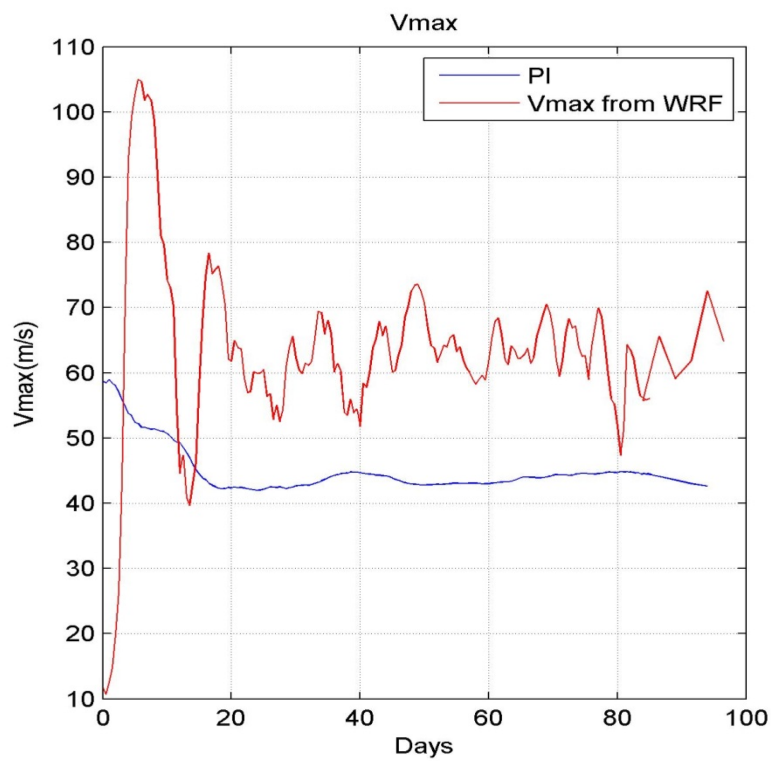


Minimum sea level pressure

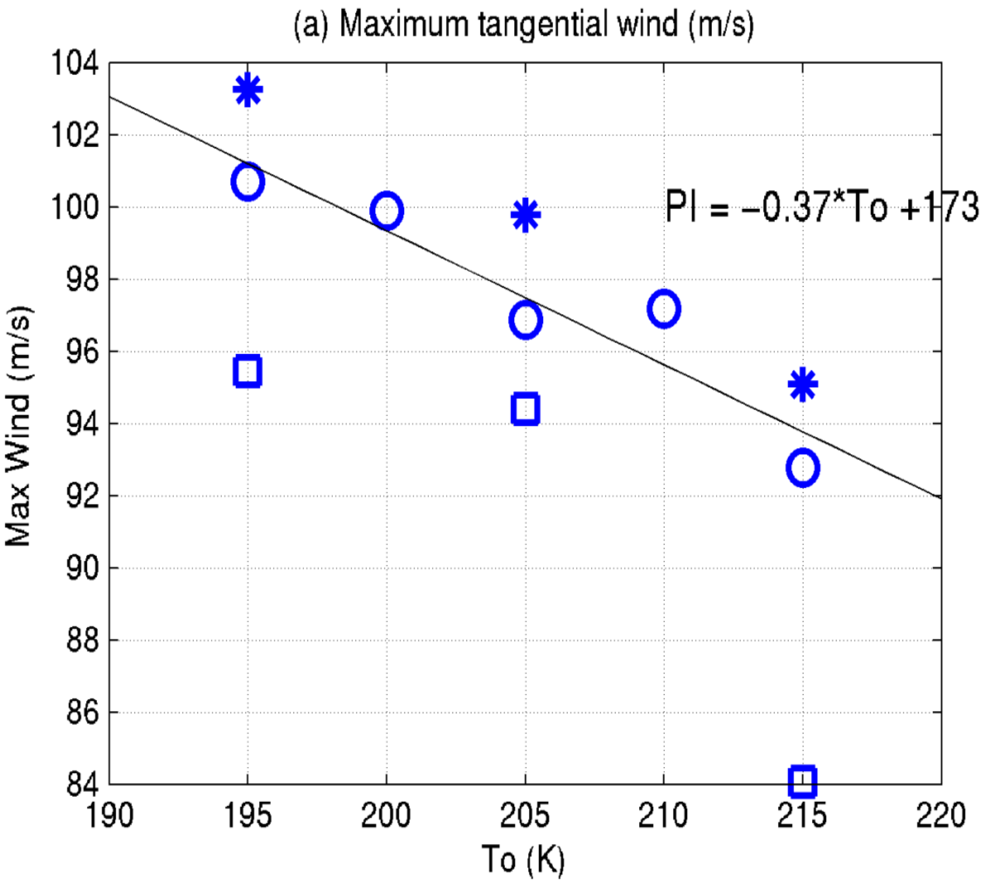


Model simulated maximum azimuthal wind speed reaches ~ 100 m/s

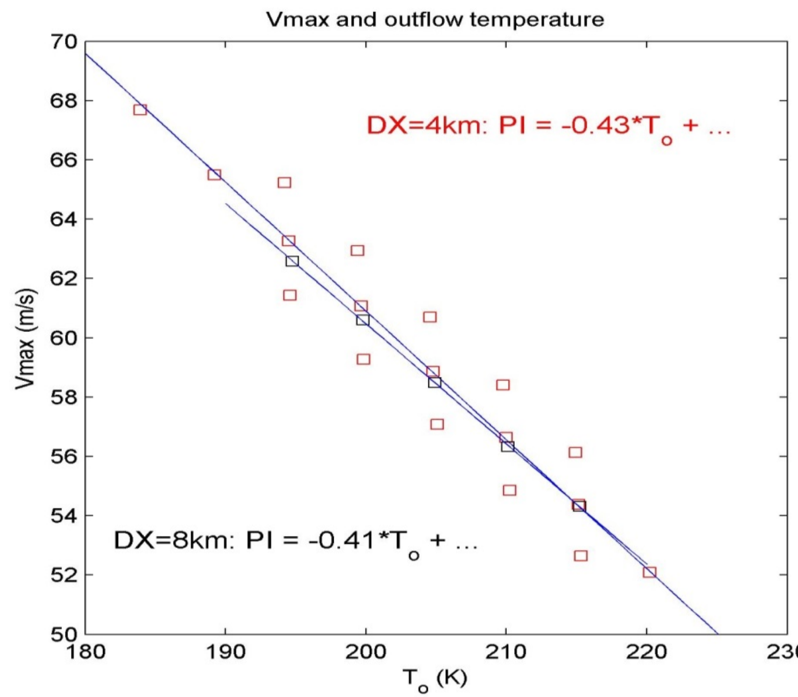
Model runs for longer time (lower resolution, smaller domain, no nesting)



WRF 3D run

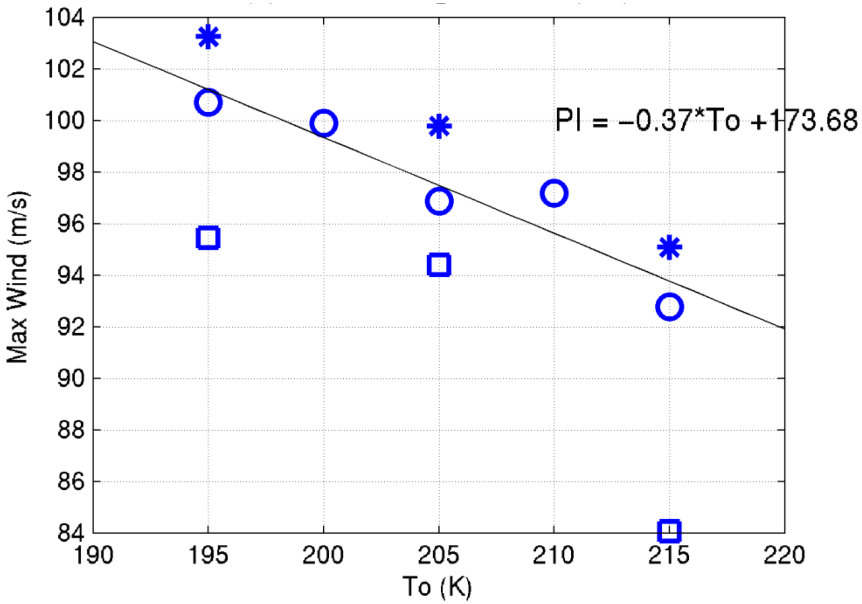


PI calculation

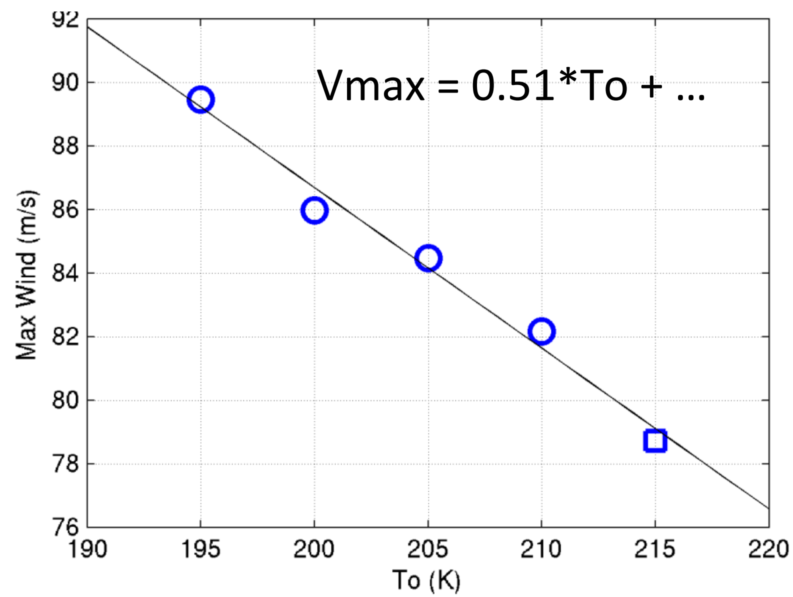


Resolution dependence

Dx=4 km, Slope ~ 0.37



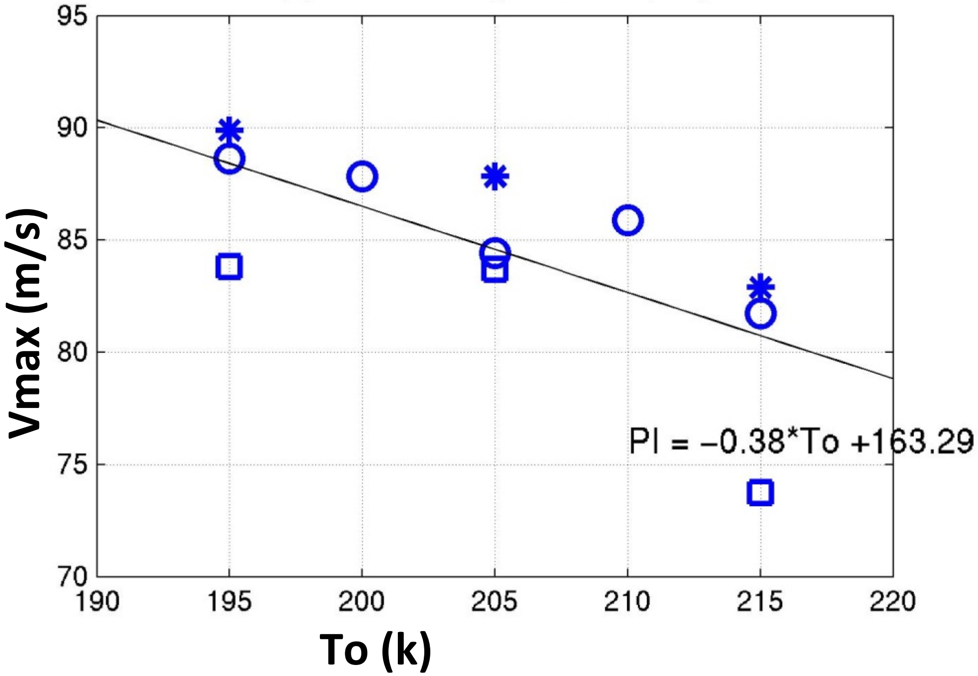
Dx=8 km, Slope ~ 0.51

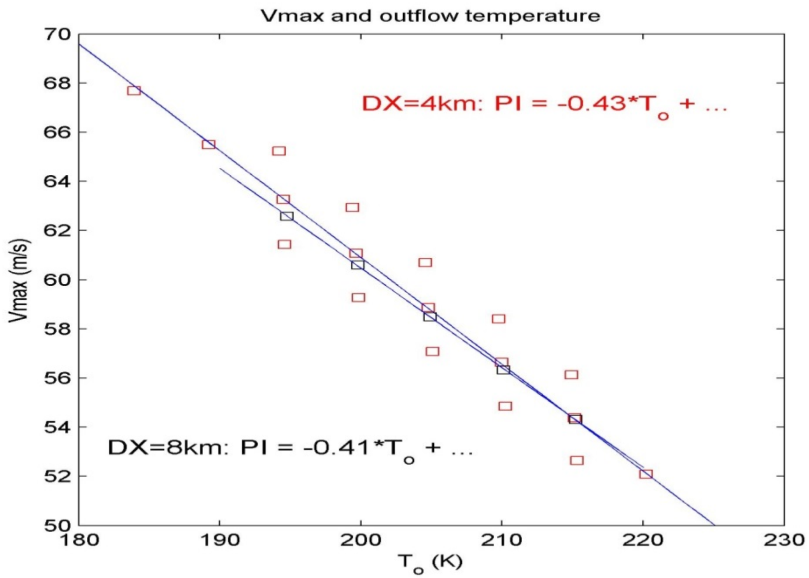


higher resolution, smaller slope

WRF maximum gradient wind

PI calculation





$$v_g = -\frac{fr}{2} + \left(\frac{f^2r^2}{4} + rc_p\theta_v\frac{\partial\pi}{\partial r}\right)^{1/2}$$

Still significantly larger than PI values

Hurricane intensity in high-resolution models

- Hakim 2011, 2D model, initial strong wind ~ 120 m/s, then 66 m/s at steady state.
- Hausman et al 2006, > 90m/s
- Bryan and Rotunno 2009, PI ~ 60 m/s for initial sounding, substantial sensitivity of of Vmax to turbulence length scale, Vmax from 30 -108 m/s, and sensitivity to moist adiabats, 40-104 m/s,
- Persing and Montogomery 2003,

- Yang et al., 2007, cd/ck~0.55, PI=58 m/s, Vmax=88m/s in 2D model, 78m/s in 3D model
- Nolan et al 2007, WRF model, surface wind ~70% of PI
- Wang and Xu 2010, 3D model, wind about 25-40% stronger than PI (40-50 m/s)

Surface fluxes for PI

$$V^2 \sim \frac{T0 - Ts}{T0} \frac{Fs}{C_d \rho |Vs|}$$

Fs: surface fluxes, Vs: surface wind speed

RCE: Fs = Radiative Cooling = ~120 W/m2

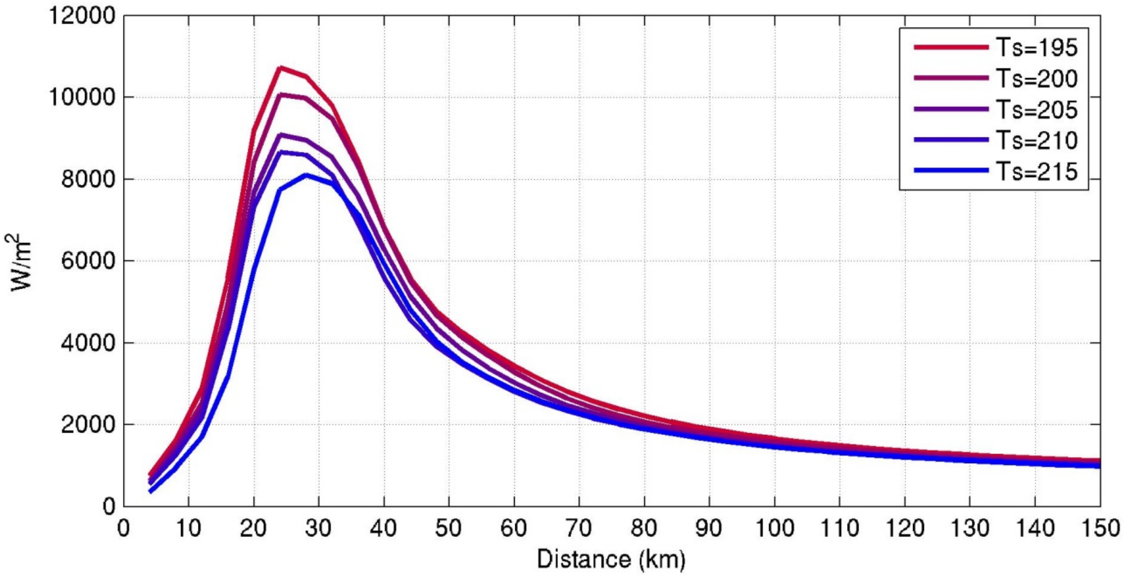
Assume that Vs ~ 70% of Vmax, estimate of Vmax can be made:

Vmax ~ 40 m/s, varies little with Ts

Surface fluxes

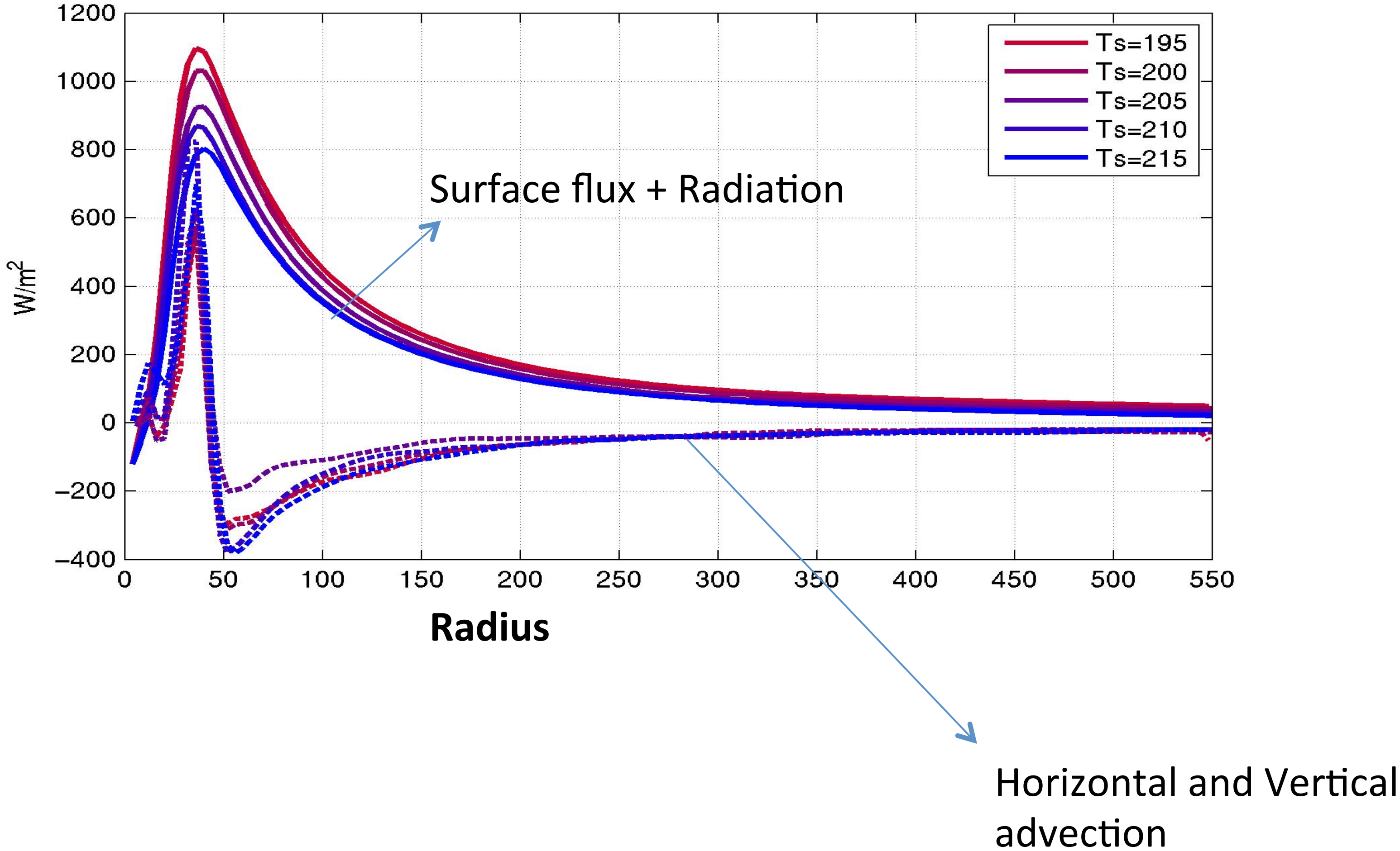
$$V^2 \sim \frac{T0 - Ts}{T0} \frac{Fs}{C_d \rho |Vs|}$$

Fs: surface fluxes, Vs: surface wind speed



If we use these numbers, Vmax will be too large: 140 m/s

Surface fluxes + radiative cooling = Horizontal + vertical advection of moist static energy

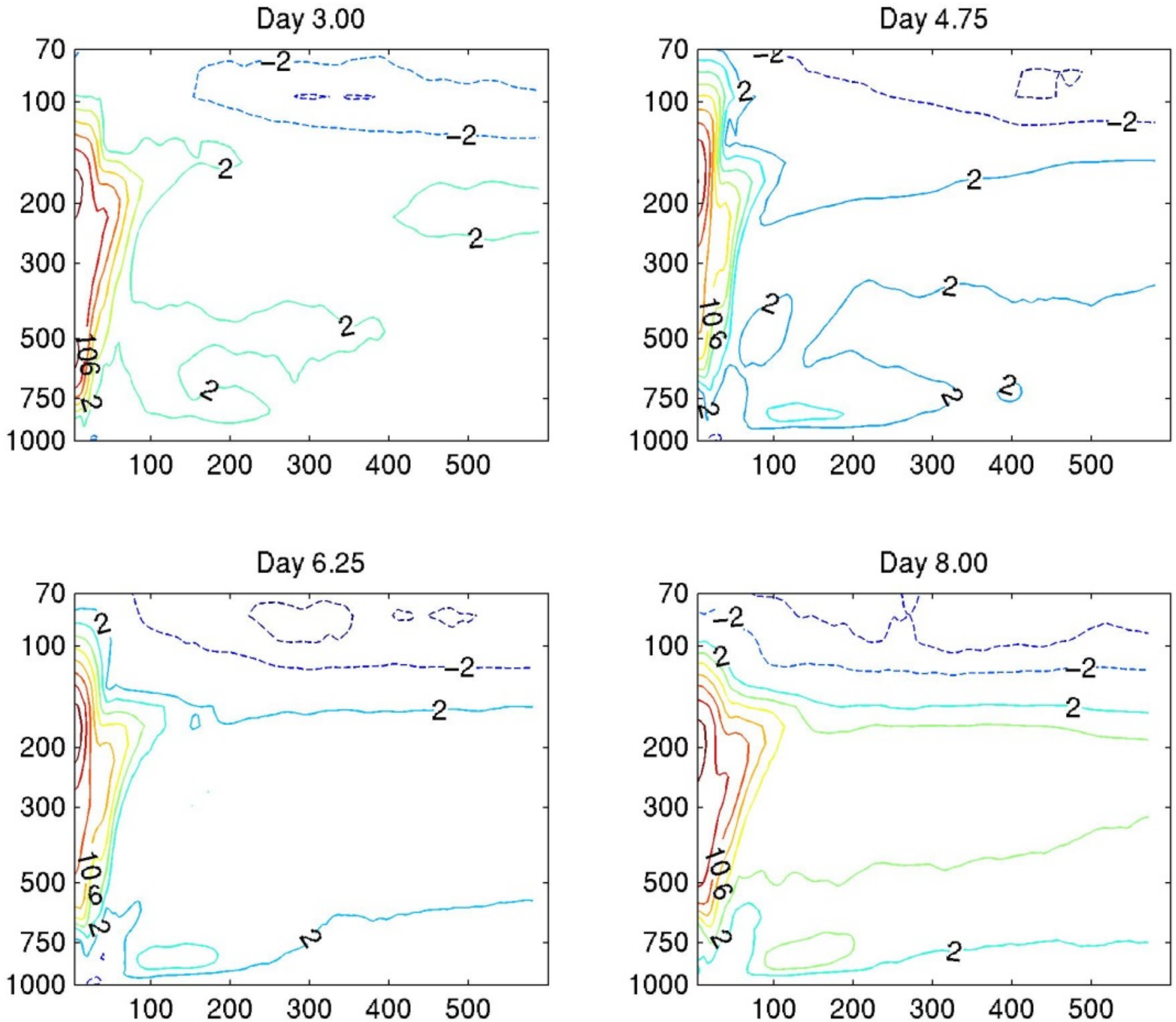


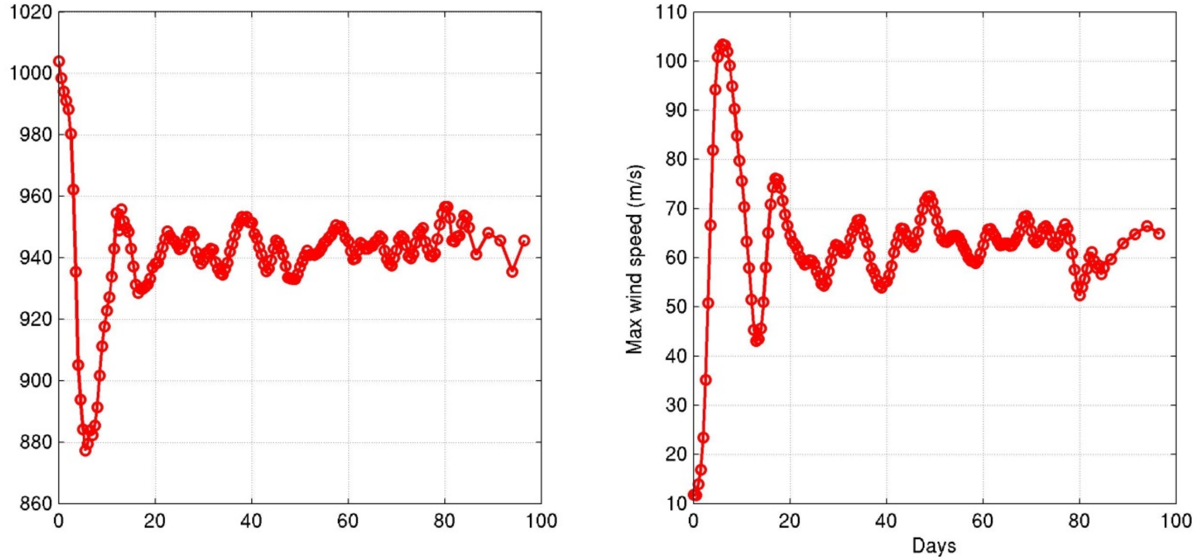
Conclusion

- WRF simulated RCE soundings: ~0.5 m/s per degree cooling in the stratosphere, but this is sensitive to assumptions in the PI code

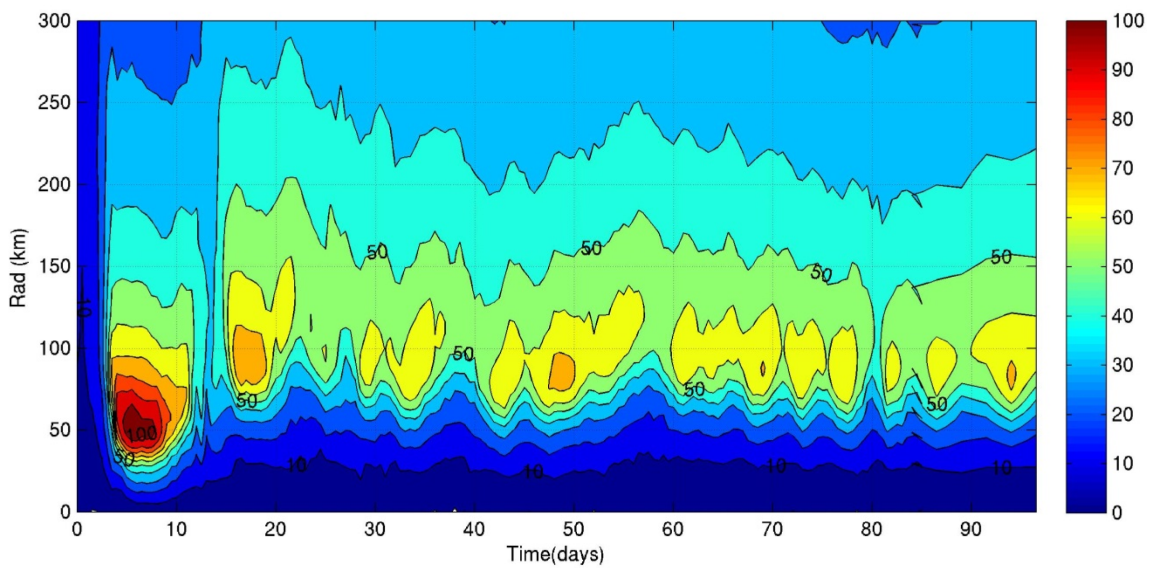
- Similar results from 3D simulations of transient hurricanes using the RCE soundings as initial state, but much stronger hurricanes

- Issues in model simulations: resolution, domain size, no dissipative heating, fixed radiation etc.


Day 3.00
Day 4.75
Day 6.25
Day 8.00
70
100
200
300
500
750
1000
100
200
300
400
500
2
−2
10
6



Max wind speed (m/s)
Days



Rad (km)
Time(days)
50
100
10