Evaluating theories for severe convective weather using numerical simulation

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Workshop on Severe Weather and Climate
15 March 2013

NCAR is sponsored by the National Science Foundation

Main Points

- There are reasons why global warming (as currently proceeding) could lead to *fewer* tornadoes

- Numerical modeling of tornadic storms can be used to evaluate ideas … but it requires a lot of computer resources, and hasn't been explored fully

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Details …

A Hypothesis (commonly presented to media)

- Temperature increases,
- and relative humidity stay roughly the same,
- therefore water vapor mixing ratio increases,
- therefore storms have stronger updrafts (more CAPE),

- therefore more tornadoes will occur.

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  [I don't disagree with any of these points]

- therefore more tornadoes will occur.

  [I would call this a *reasonable hypothesis* that needs evaluation]

Other Ingredients

- SPC's Significant Tornado Parameter, STP (Thompson et al 2003)

STP = (CAPE/1500 J kg-1)	
× ((2000-LCL)/1000 m)	[this term set to 1 if LCL < 1000 m, 0 if LCL > 2000 m]
× (SRH1/150 m2 s-2)	[0-1 km storm-relative helicity]
× (6BWD/20 m s-1)	[deep-layer (0-6 km) shear]

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  - "A majority of significant tornadoes (F2 or greater damage) have been associated with STP values greater than 1"

- Assuming fixed RH, increasing temperature yields higher LCL
  - Suggests *fewer* tornadoes
  - +10 m for every +1 °C (assuming fixed RH)

    (in "STP units", that's roughly equivalent to -500 J/kg CAPE)

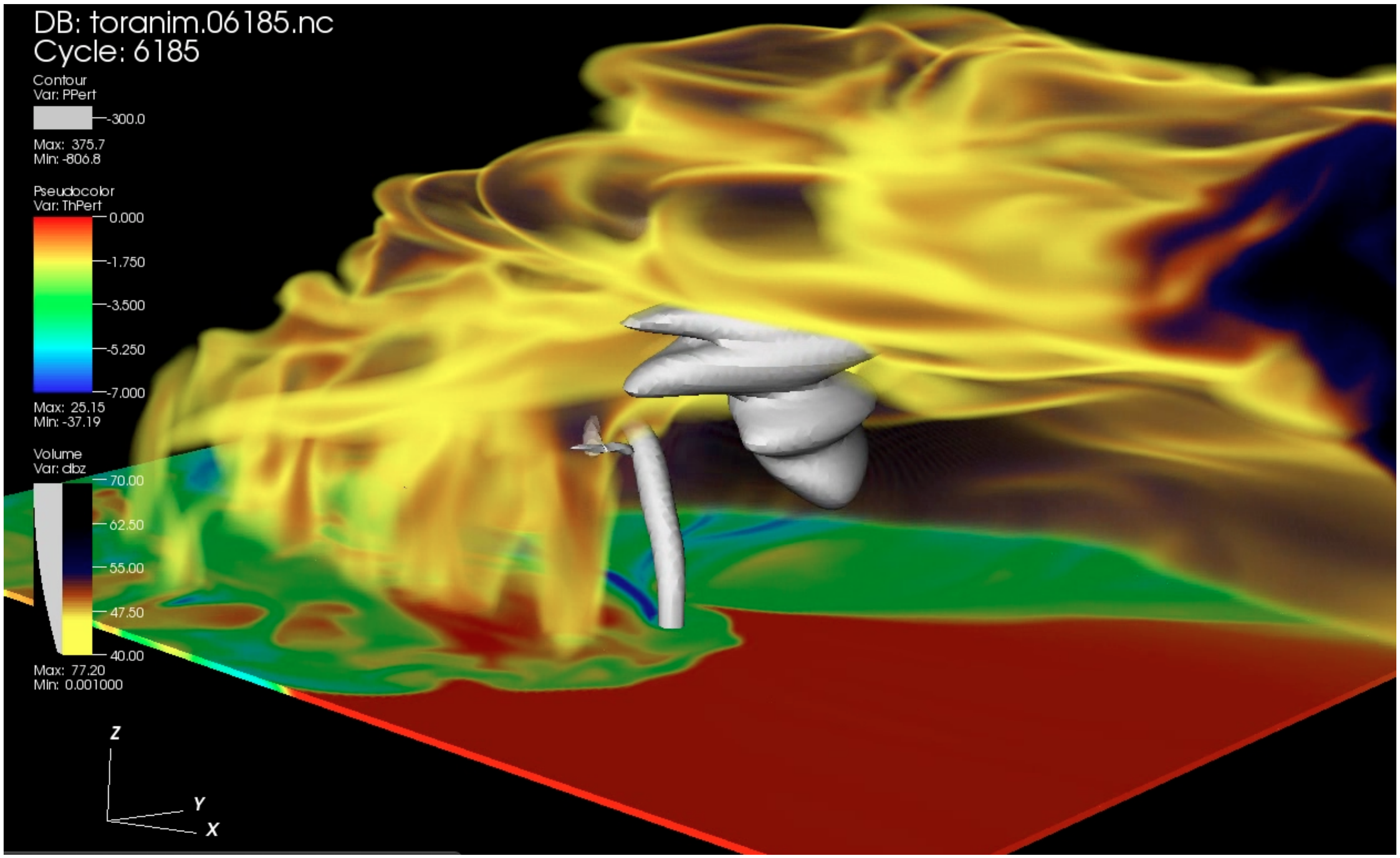
Other Counter Points

- More water vapor means more condensate (e.g., liquid water)
  - thus more evaporation, stronger "cold pools"
  - thus *fewer* tornadoes
  - perhaps more severe convective winds (e.g., derechoes)?

- Uncertain role of tornadogenesis "triggers"
  - Descending reflectivity cores (DRC) and Rear-flank gust front surges (RFGFS) occur just before tornadogenesis in well-documented events
  - Note: both are related to condensate (which is increasing)

Numerical Simulations

- Nonhydrostatic, cloud-resolving models (e.g., WRF) run with grid spacing of O(10 m), can produce tornadoes:

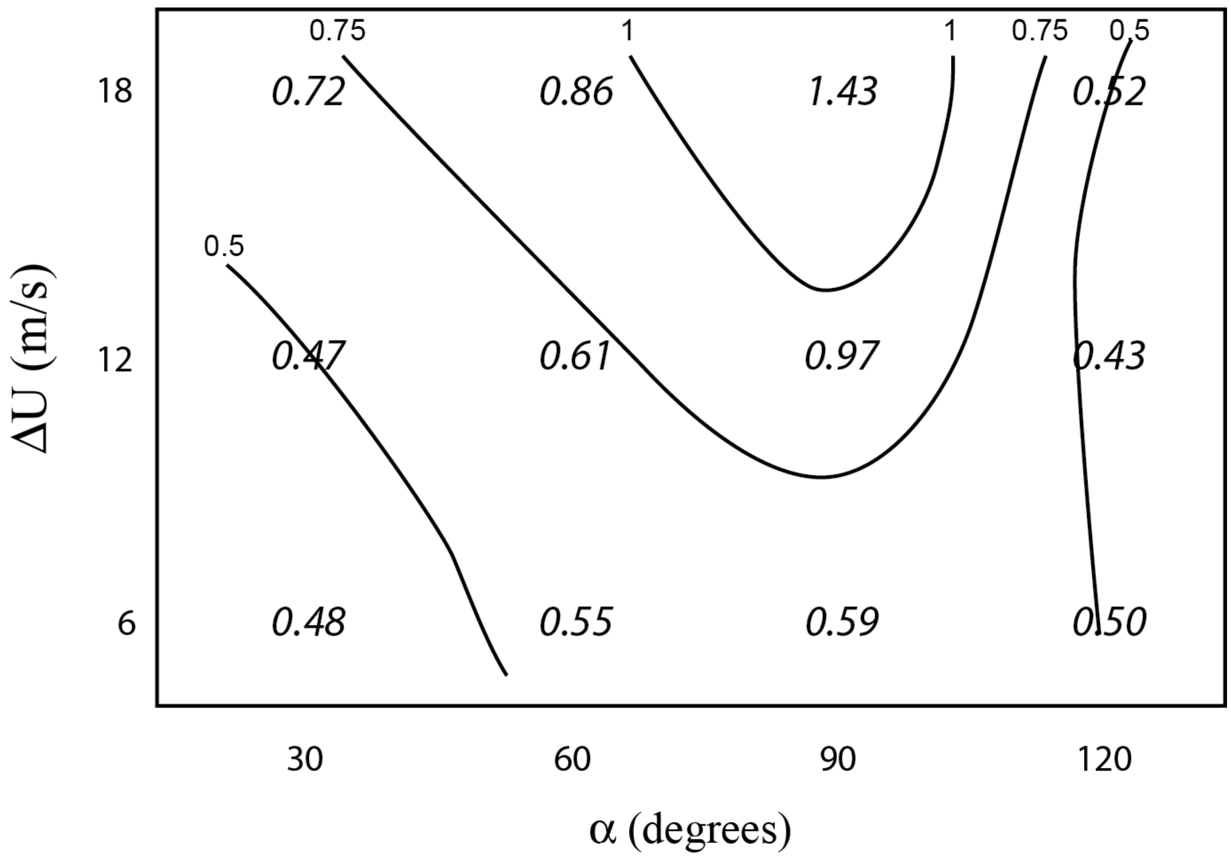


Gray shading: pressure perturbation; Color volume shading: reflectivity; Color at surface: θ perturbation

(Visualization by Leigh Orf, Central Michigan Univ)

- Hypotheses can be tested in controlled conditions
- For example, an evaluation of 0-1 km wind-vector difference (ΔU):

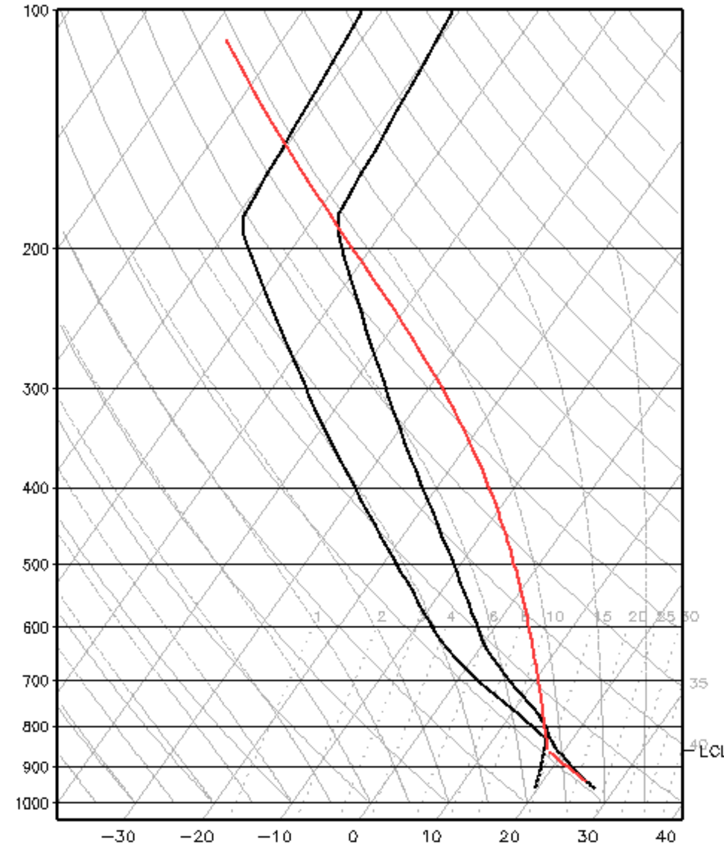
<u>Maximum Circulation at z = 1 km (60-90 min average)</u>



Experimental Setup

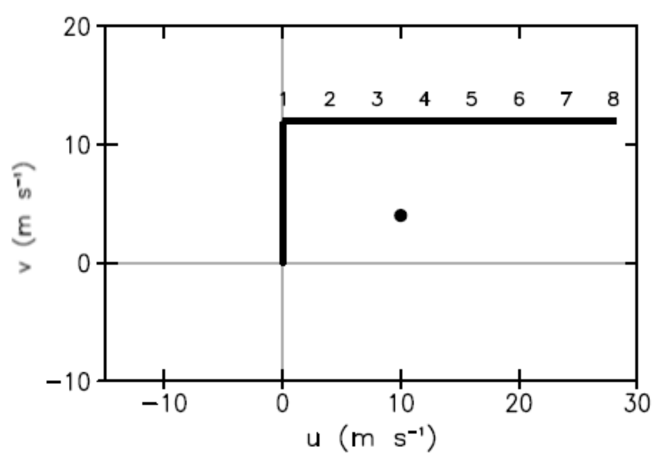
The Control environment:
(based on North American climatology)

CAPE: 2500 J/kg
CIN: 20 J/kg
Surface T / Td: 27 °C / 20 °C
Surface θ_e: 350 K
$\Delta\theta_e$: 25 K
LCL: 1025 m
LFC: 1500 m



Wind profile: "L-shaped"

0-6 km ΔU = 24 m s^{-1}
0-1 km SRH = 116 m^2 s^{-2}

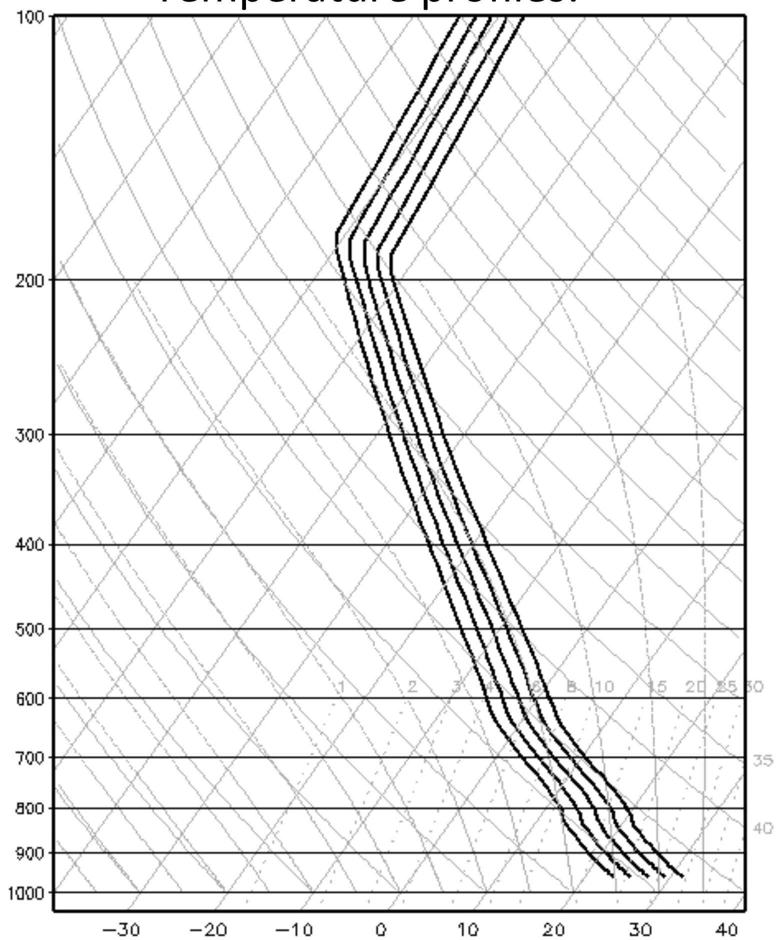


Note: STP = 1.5

Experiment: Change entire temperature profile by a fixed value (-4, -2, 0, +2, +4 K)

Use the same RH profile

Temperature profiles:



CAPE: varies from 1300 to 4500 J/kg

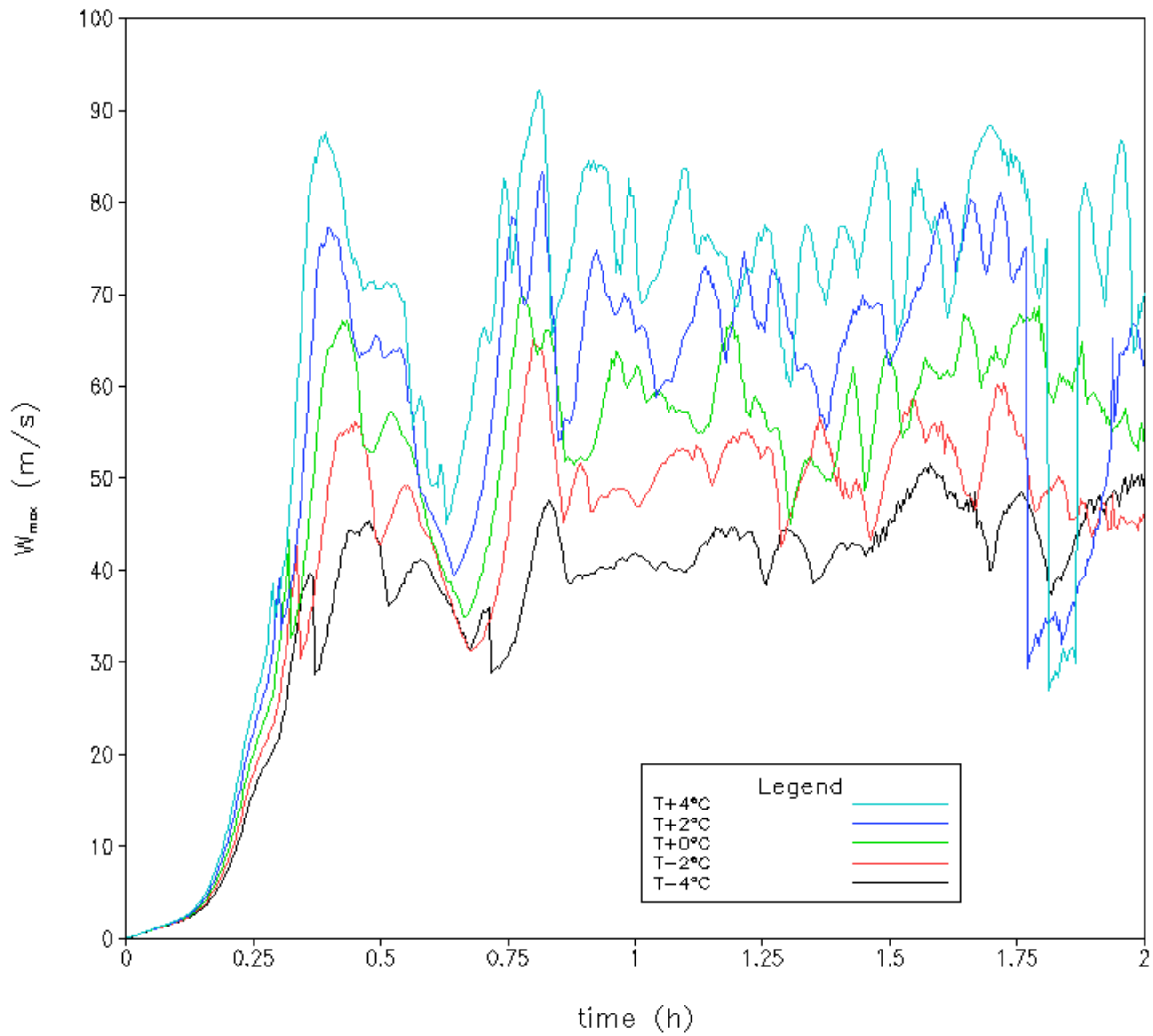
LCL: varies from 990 to 1050 m

STP: varies from 1.6 (coldest sounding)
to 0.8 (warmest sounding)

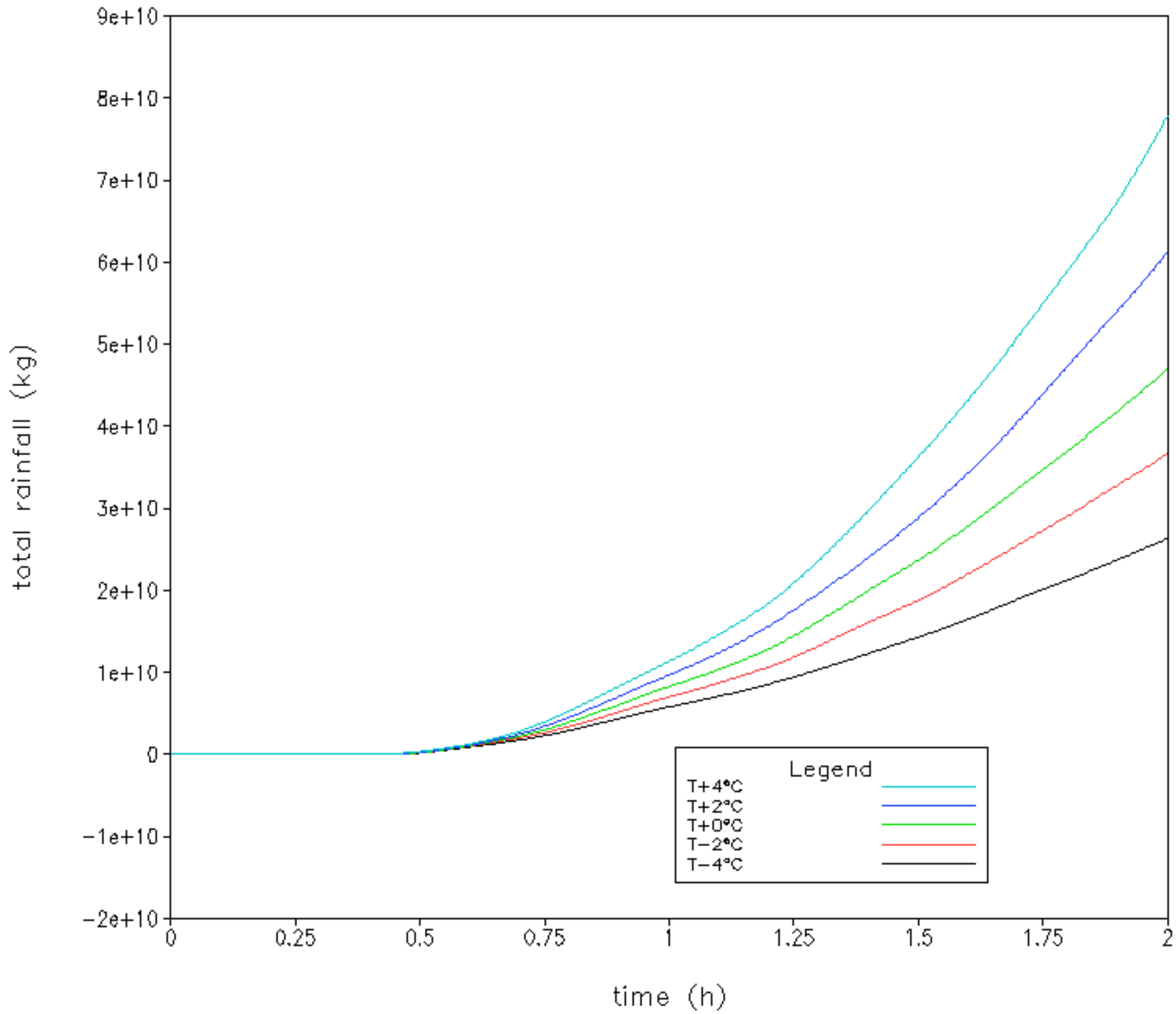
Other details:

- Δx = Δx = 250 m
- Δz varies from 25 m to 500 m
- Morrison double-moment microphysics
- roughness length z_0 = 10 cm

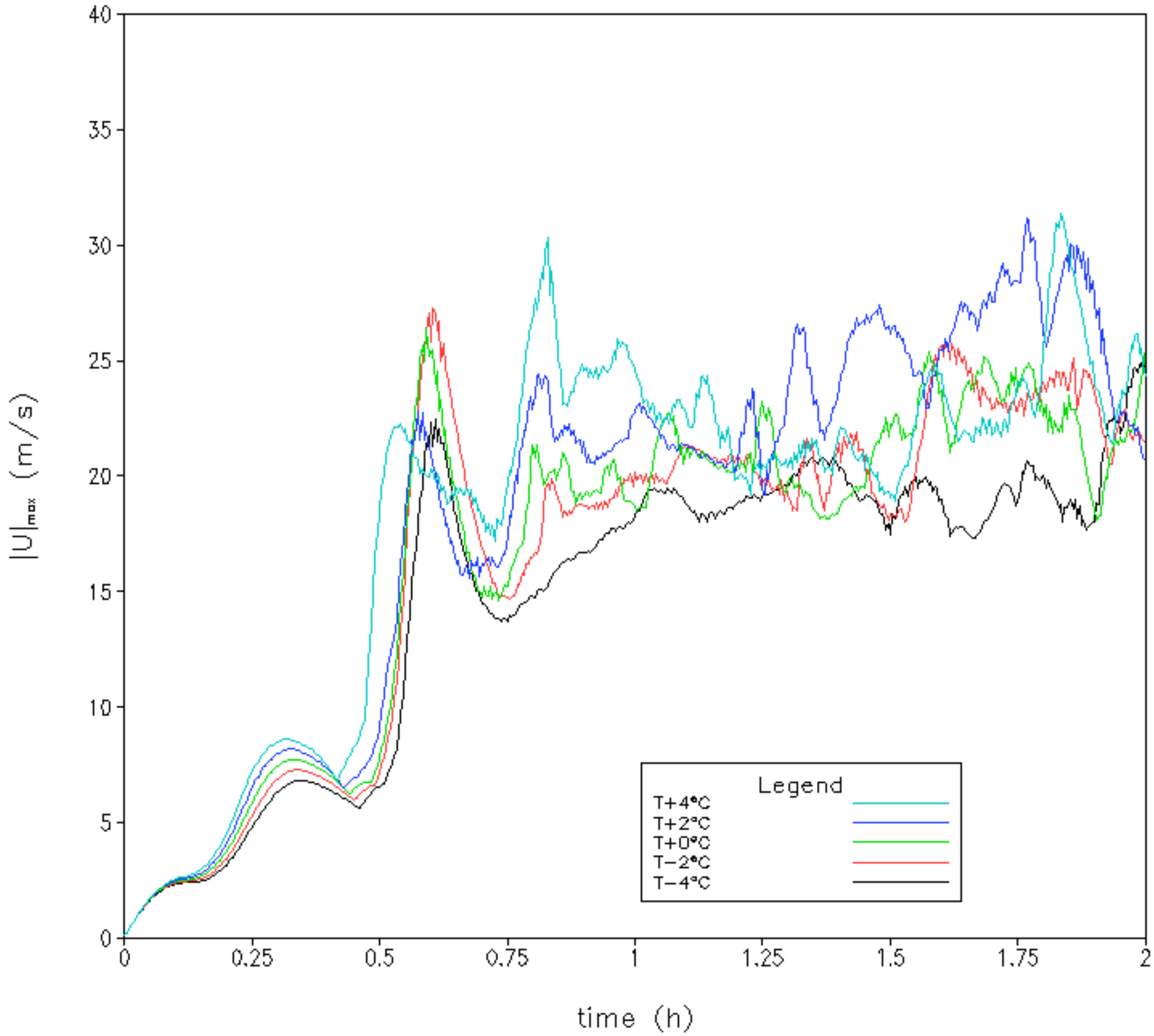
Maximum vertical velocity



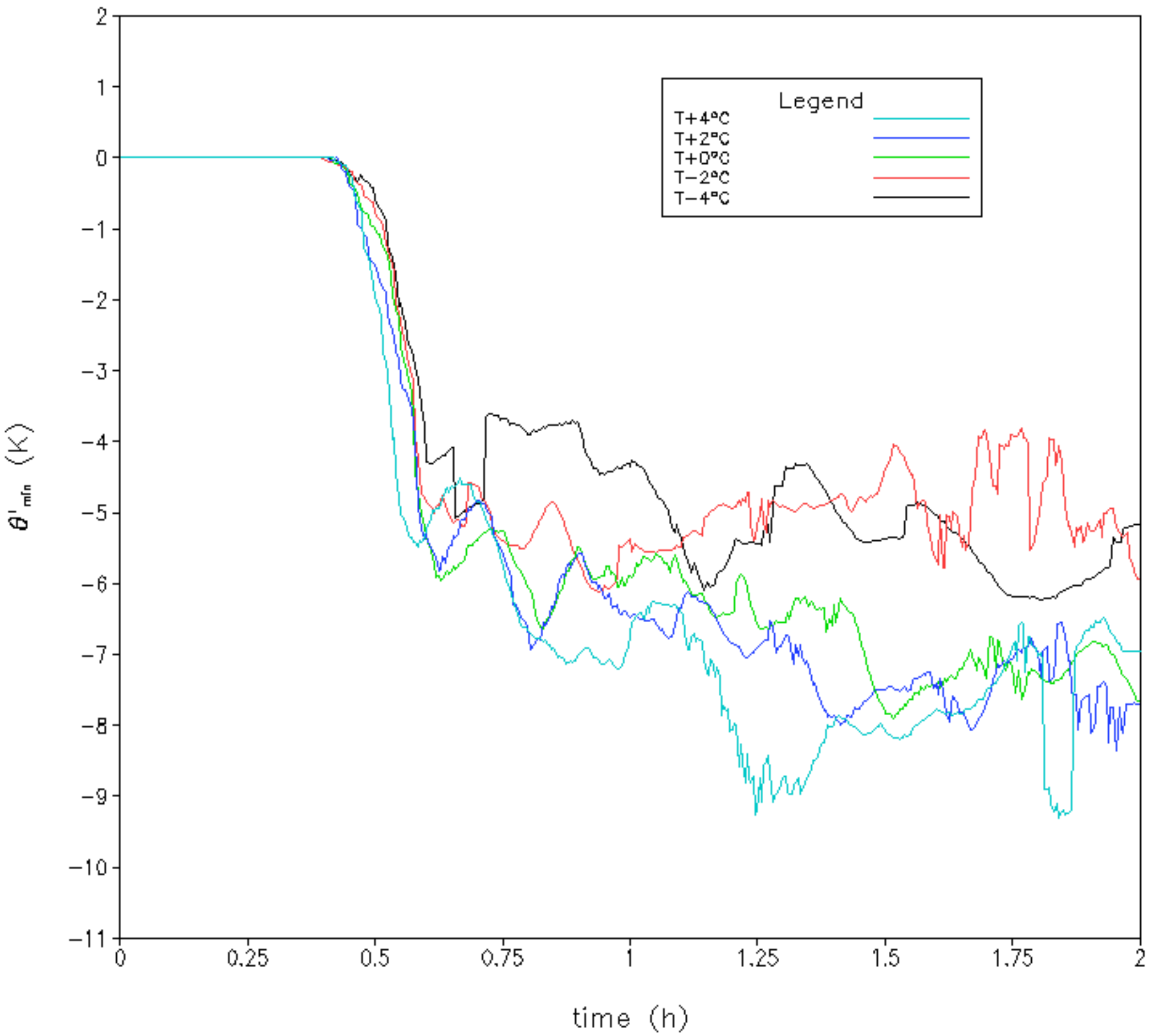
Total surface rainfall



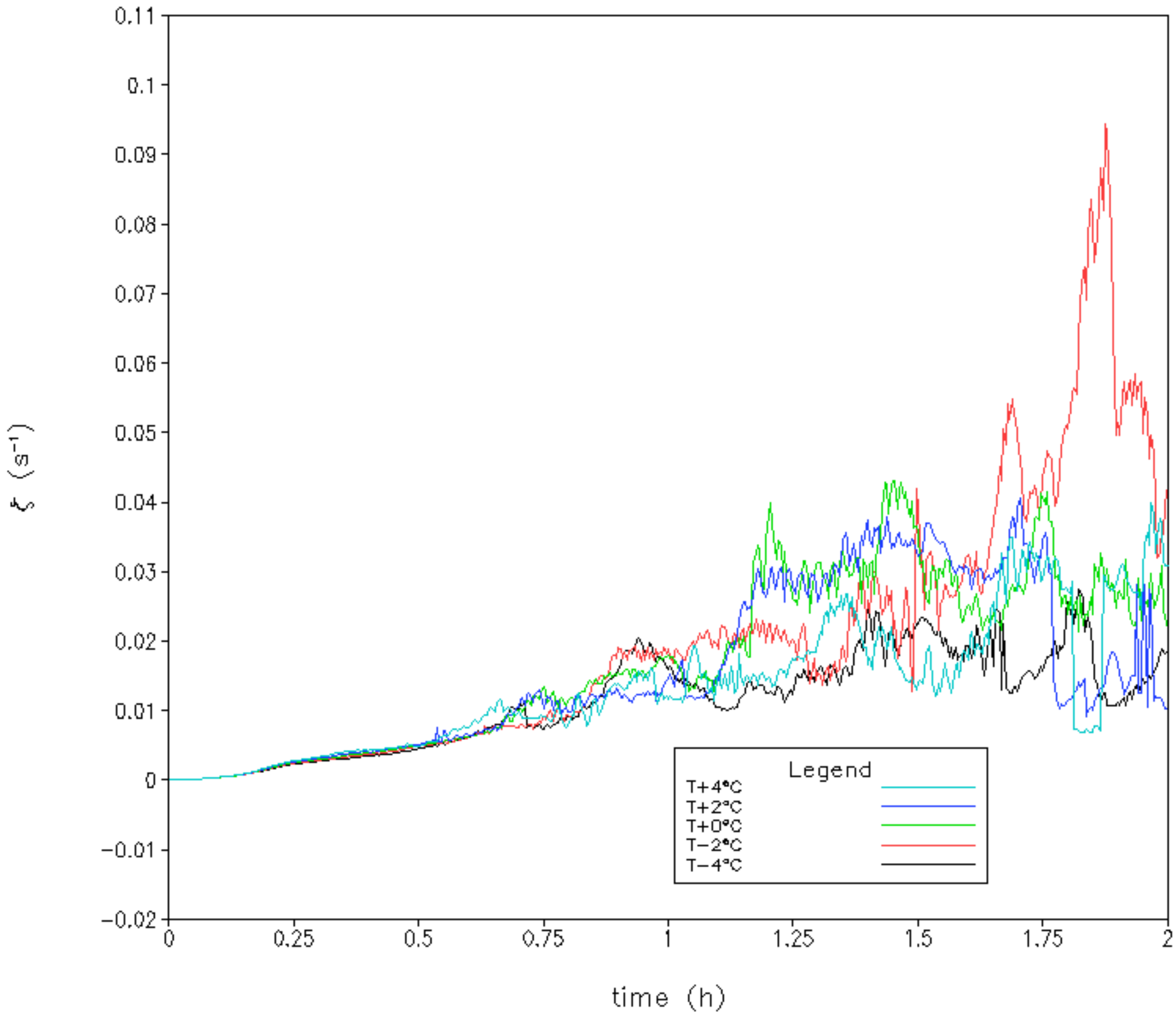
Maximum surface windspeed



Minimum potential temperature perturbation



Maximum near-surface vertical vorticity



Work to be Done

- True tornado-resolving resolution (~10 m)

- An "ensemble" of simulations would be best
  - Vary initial conditions to get different realizations
  - Vary some "physics" parameters (e.g., raindrop breakup, surface roughness)

Summary

- Increasing temperature, with constant RH, might lead to *fewer* tornadoes
  - more condensate, higher LCL, stronger cold pools

- Numerical model simulations are a tool that can sort out the pros (greater CAPE) and cons (higher LCL)
  - these simulations confirm more rain, stronger convective winds
  - tornadoes: inconclusive (so far)