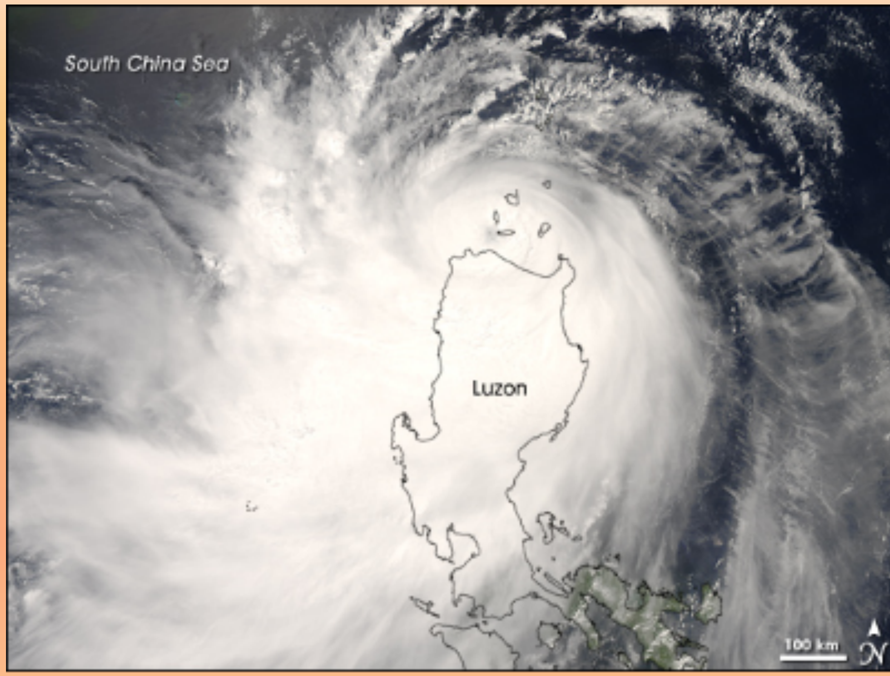
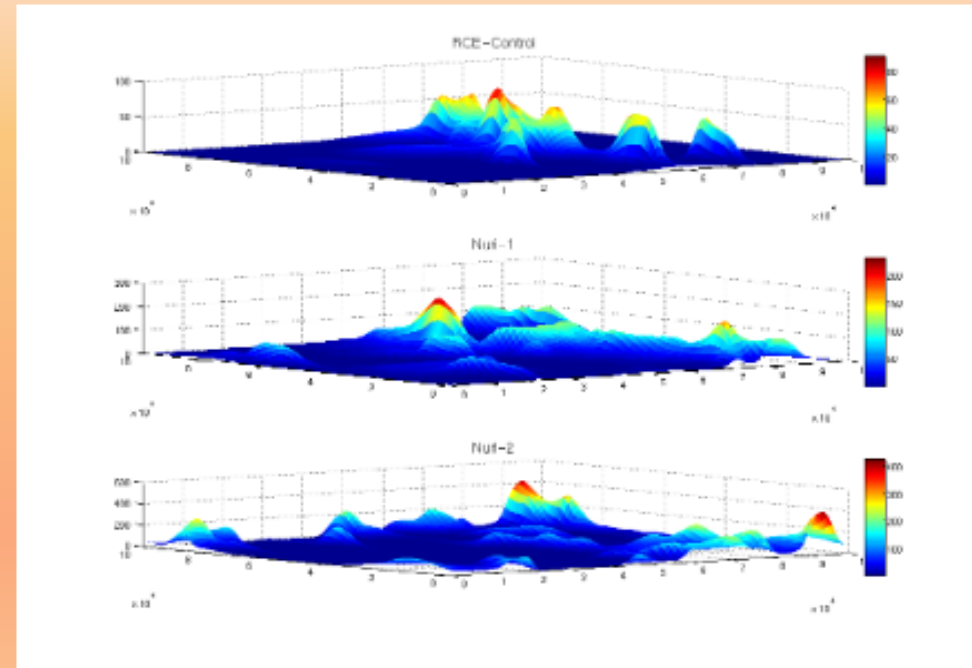
Weak Temperature Gradient Simulations For Different Convective Environments





Benjamin Hatchett[1] and Sharon Sessions[2]

[1] Division of Atmospheric Science, Desert Research Institute, Reno, Nevada

[2] Department of Physics, New Mexico Institute of Mining and Technology, Socorro, New Mexico

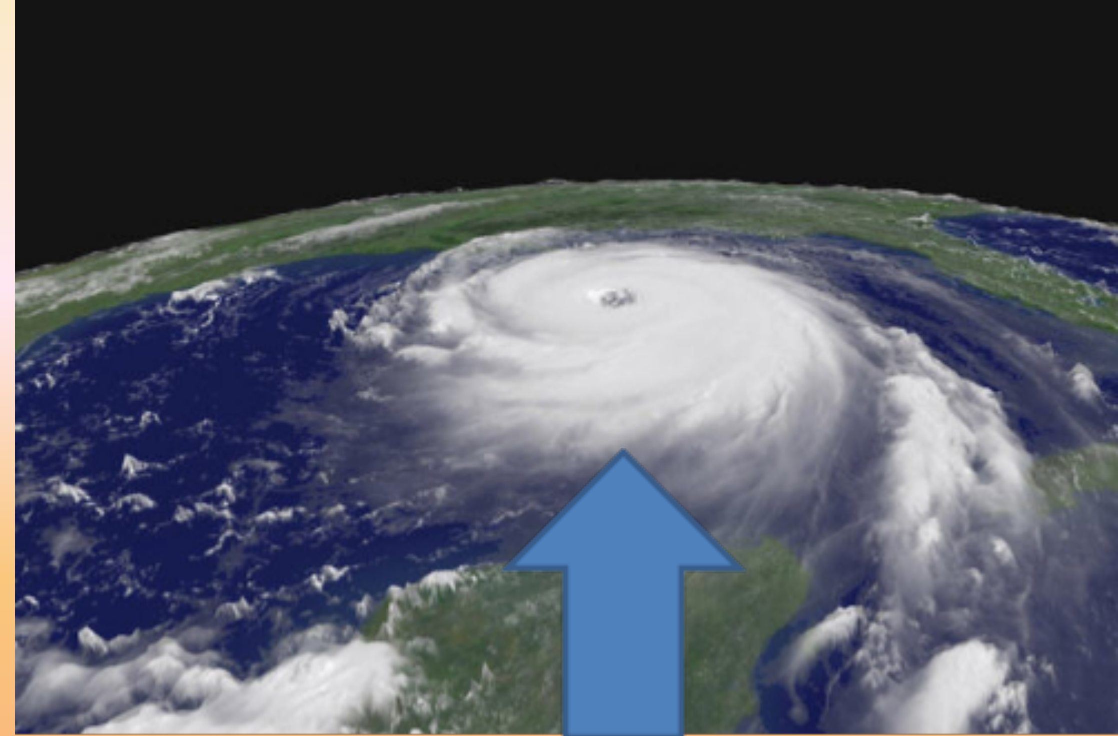
Outline

- Importance of Tropical Convection At Various Scales
- Weak Temperature Gradient Introduction
- CRM-WTG Model Outline
- Results: Evaluation of Convective Environments
- Conclusions

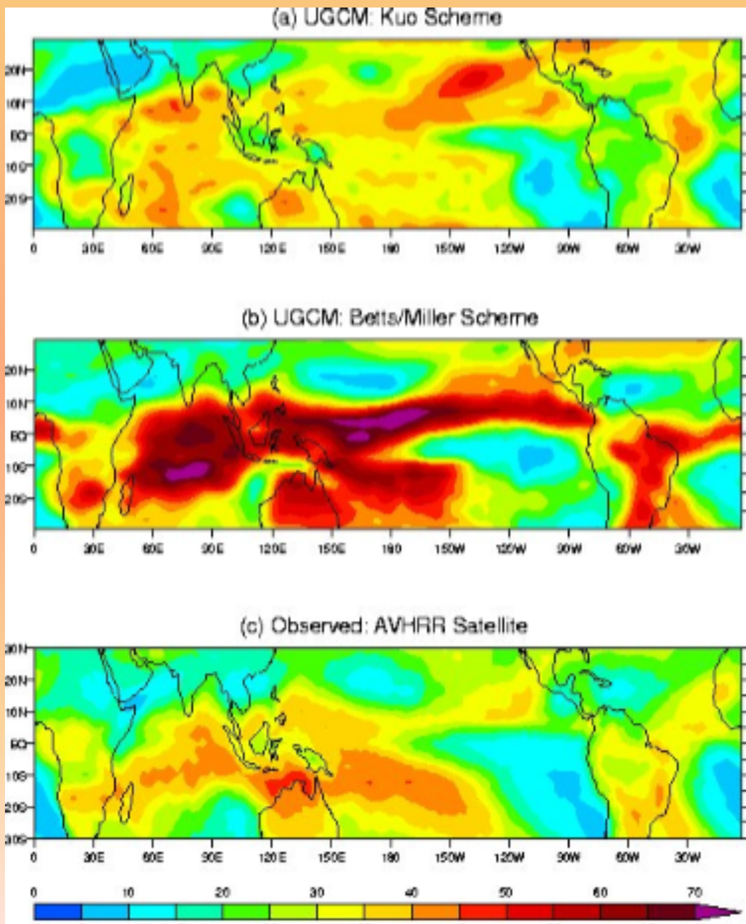
http://ntlapp.nt.gov.au/tracy/basic/Met/cyclones.html

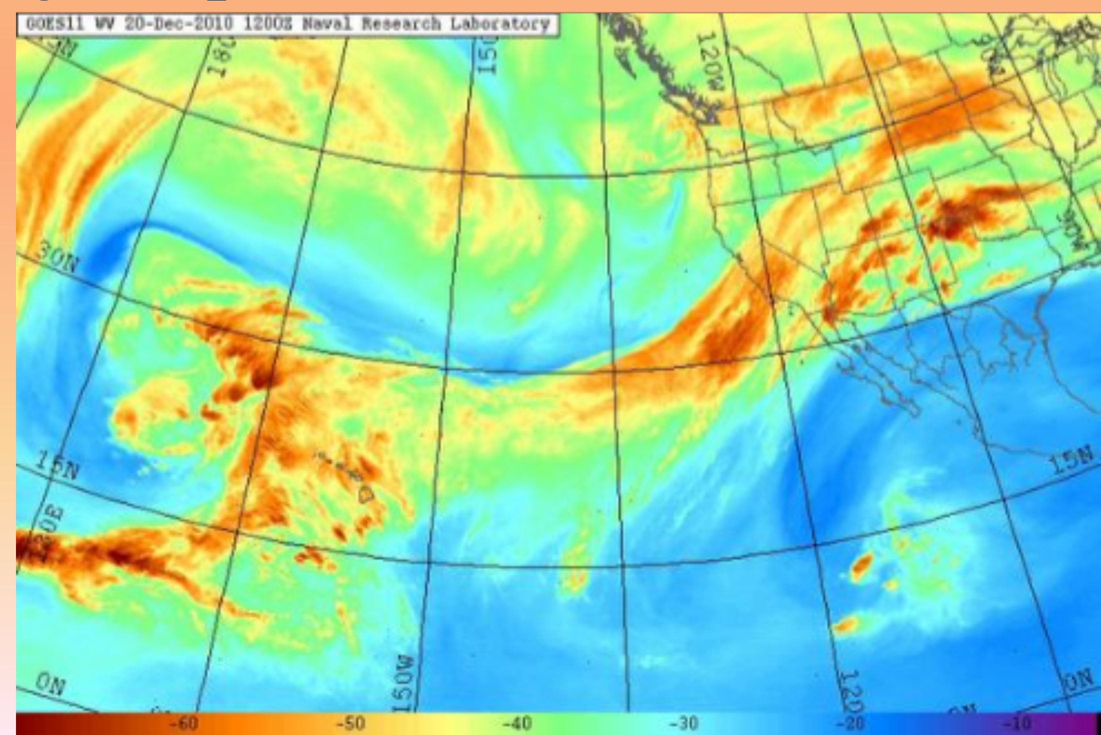
Why study the tropics?

Implications for ALL timescales of weather and climate!



“***Among the most spectacular and deadly geophysical phenomena***” (Emanuel 2003)



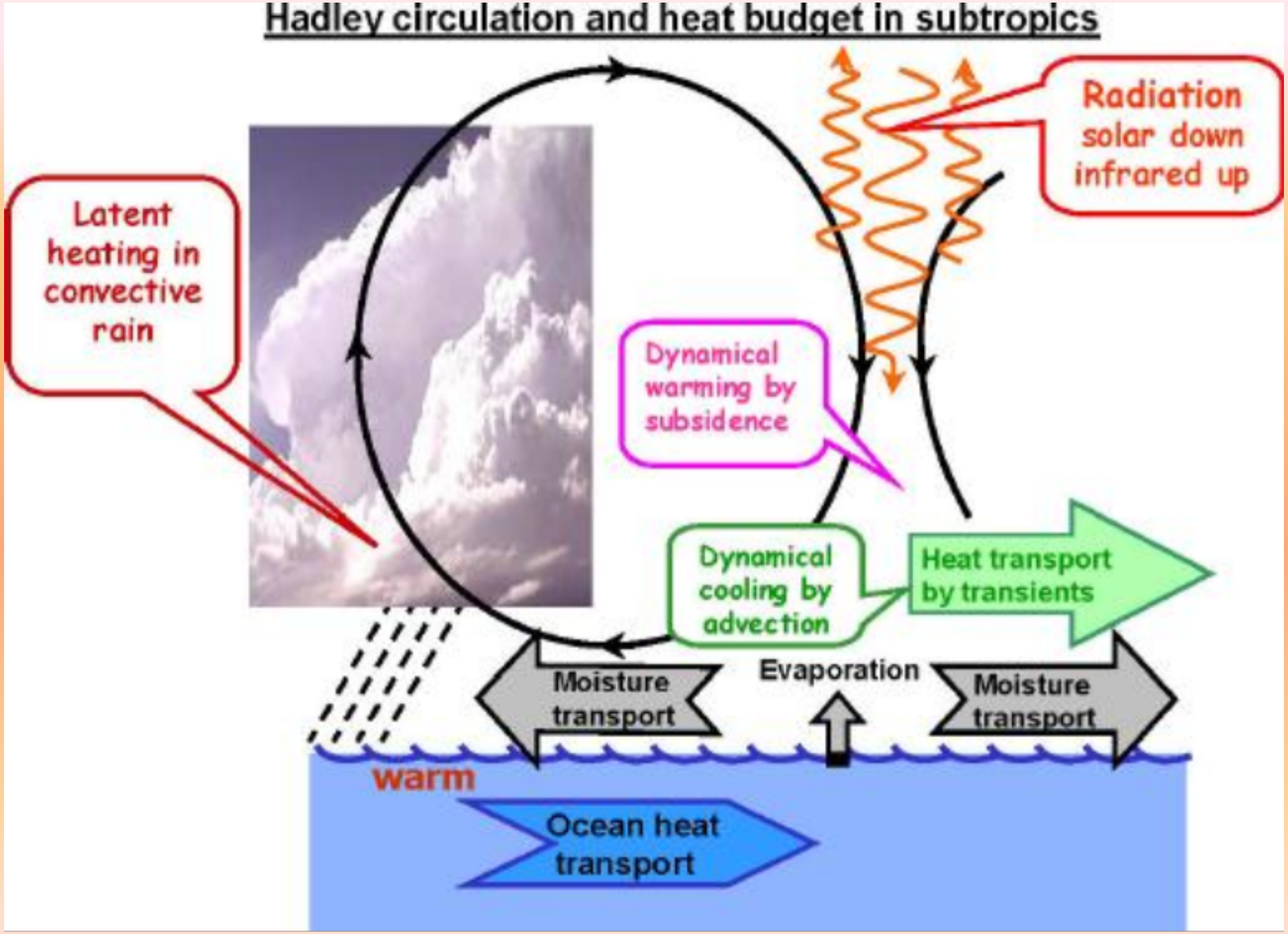


http://www.ugamp.nerc.ac.uk/research/review/slingos1.htm

Importance of Tropical Convection Ia: General Circulation

- Key Role in Tropical Heat Budget
  - *Thus Global Heat/Moisture Budget!*
  - Hadley Circulation: Poleward transport of moisture and energy
    - Midlatitude Rossby waves
    - 'Seamless transport'; Trenberth and Stepaniak 2003
    - Poleward transport of heat, subsidence in subtropics
  - Mid to lower troposphere moisture
    - Precursor for moist convection with nonlinear dependence (e.g. Tompkins 2001)
    - Drives ascending branch of Hadley Circulation

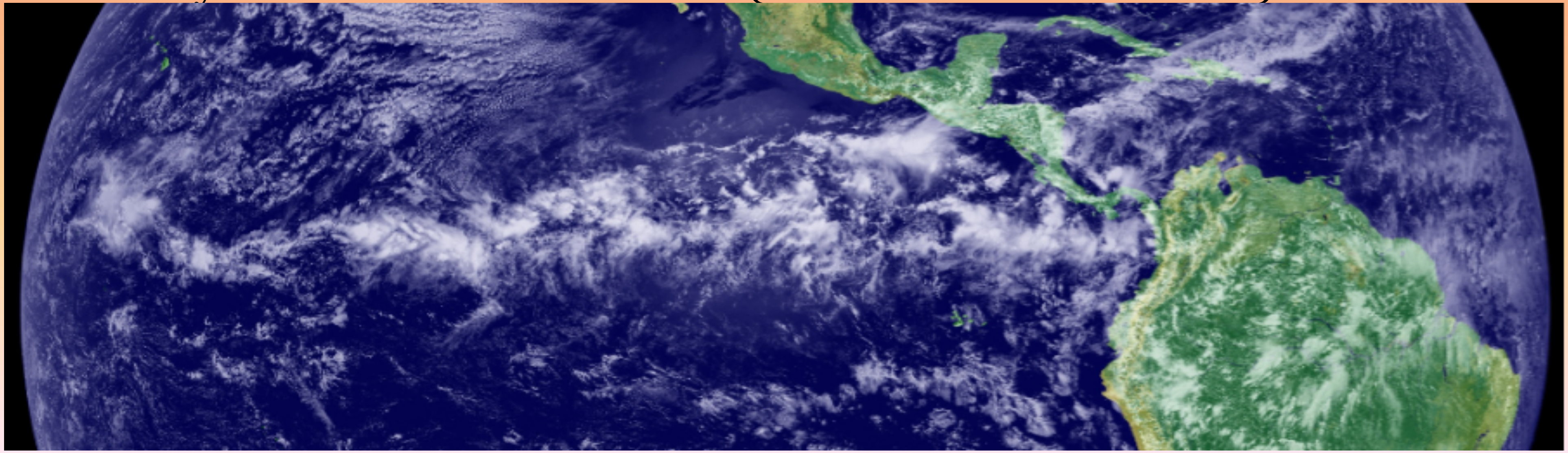
Example:



From Trenberth and Stepaniak 2003.

Importance of Tropical Convection Ib: Role of Water Vapor

- Distribution of water vapor plays significant role in geophysical processes (+ geopolitical processes)
- Water vapor instrumental in governing flow of energy in climate system
  - Dominant greenhouse gas
  - Regulates formation/dissipation clouds
  - Latent heat source/sink
  - Many feedbacks into climate (Held and Soden 2000)

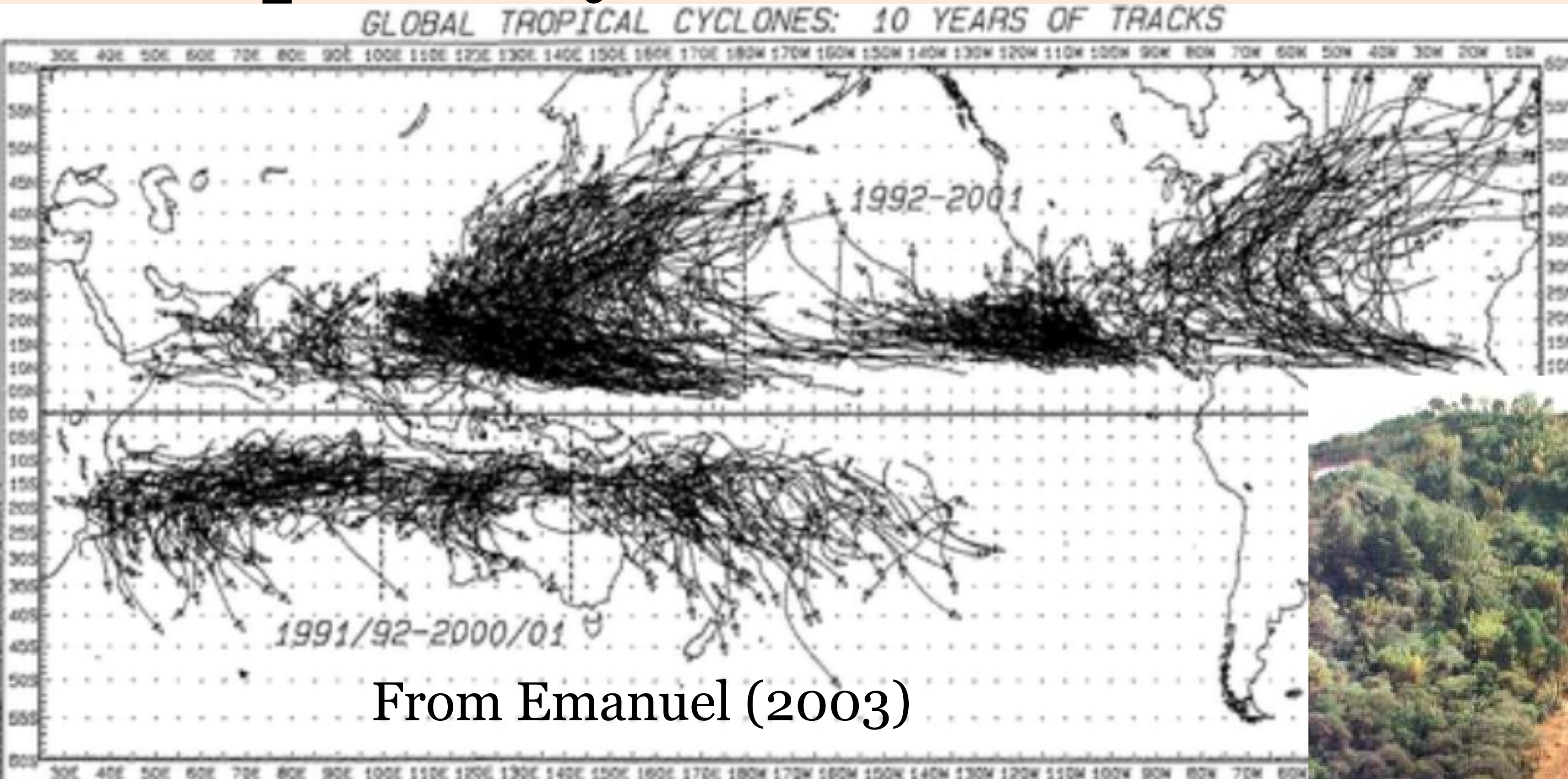


Importance of Tropical Convection II: Tropical Cyclones

- Basics
  - Non-frontal, synoptic scale, warm core low pressure systems
  - Originate in tropical/sub-tropical oceans
  - Deep, moist convection
  - Similar scales to MCS
- Differences from (Extratropical Cyclones)
  - Barotropic (vs. baroclinic potential energy)
  - Strongest winds near surface (tropopause)
  - Symmetric, circular (comma shape)
  - Vertical orientation (tilting)

Tropical storm Aere: Philippines, May 8, 2011
http://thewatchers.adorraeli.com/2011/05/08/tropical-storm-aere/

Tropical Cyclone Tracks and Impacts



From Emanuel (2003)

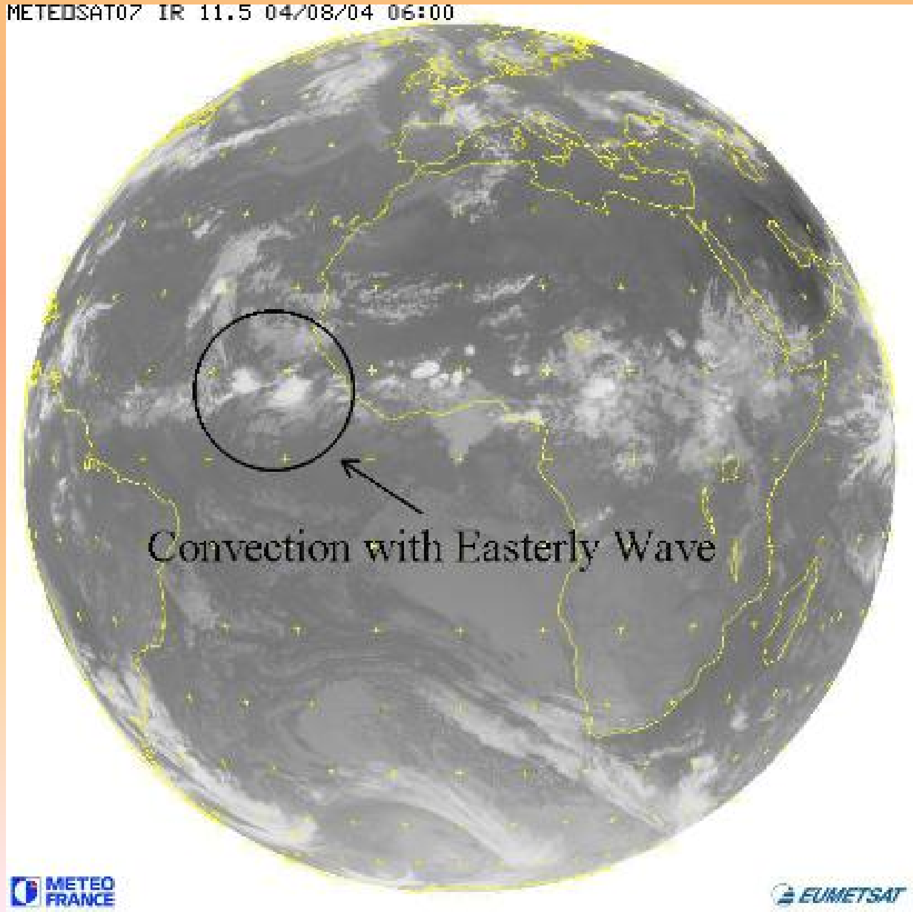
Impacts upon Human and Ecosystems, Ge omorphology

http://resources1.news.com.au/images/2011/05/09/1226052/216649-philippines-storm.jpg

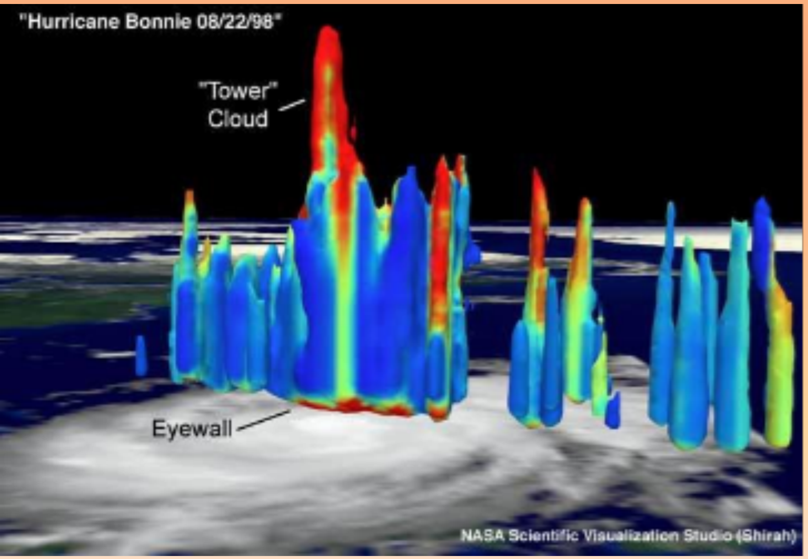
http://www.indiatalkies.com/2011/01/cyclone-wilma-lashes-zealand-brings-floods-landslides.html

Importance of Tropical Convection III: Tropical Cyclogenesis

- Preceded by disturbances
  - Easterly waves, tropical upper-tropospheric troughs, frontal boundaries
  - Sustained convection
    - Organize/evolve into TD
    - Diabatic forcing
    - Cyclonic vorticity
    - Weak wind shear
    - Divergence aloft



General Formation Mechanisms



1. MCS forms and embedded within easterly wave
2. Interaction with other systems (e.g. MJO, ITCZ) under sufficient SST, wind shear, planetary vorticity
3. MCS cumuli develop into hot towers
4. Hot towers merge with other vortices to form isolate vortex
5. Develops further via self-induced moist enthalpy fluxes from sea surface (Carnot heat engine)

http://earthobservatory.nasa.gov/Features/Simpson/Images/convective_tower.jpg

Purpose of Study

- **Big Question:** How does disturbance with concentrated mid-level cyclonic ζ evolve into low level circulation system? (Raymond and Sessions 2007, hereafter RS07)
    - Low level winds produce heat flux necessary for tropical Carnot engine (Emmanuel 1986)
- **Heavy rain regions tend to have more moist, stable profiles (RS07)**
- *Present study aims to gain spatial understanding of how convection influenced by environment*

The Weak Temperature Gradient (WTG) Approximation

- Horizontal ρ and T gradients small in tropics (G-waves)
  - Temperature equation balance achieved by diabatic heating and vertical advection of θ
  - Convection governed by Tsfc and RH (CAPE and CIN) as well as free troposphere RH (suppression via entrainment)
  - RH influences diabatic heating => vertical velocity=> horizontal divergence
    - Presence of Abs. Vort. creates rotation
- Foundation of balanced dynamical models in tropics (Sobel and Bretherton 2000)
  - Explicit inclusion of diabatic processes
- *Parameterization of convective environment*

The Weak Temperature Gradient (WTG) Approximation

Horizontal Operator

$$\frac{\partial T}{\partial t} + \mathbf{u}_h \cdot \nabla T + \omega S = Q_T$$

Temperature Time Rate Of Change

U-Wind component

Vertical Velocity

Static Stability (T/θ) (dθ/dp)

Temperature

Gravity waves redistribute buoyancy anomalies

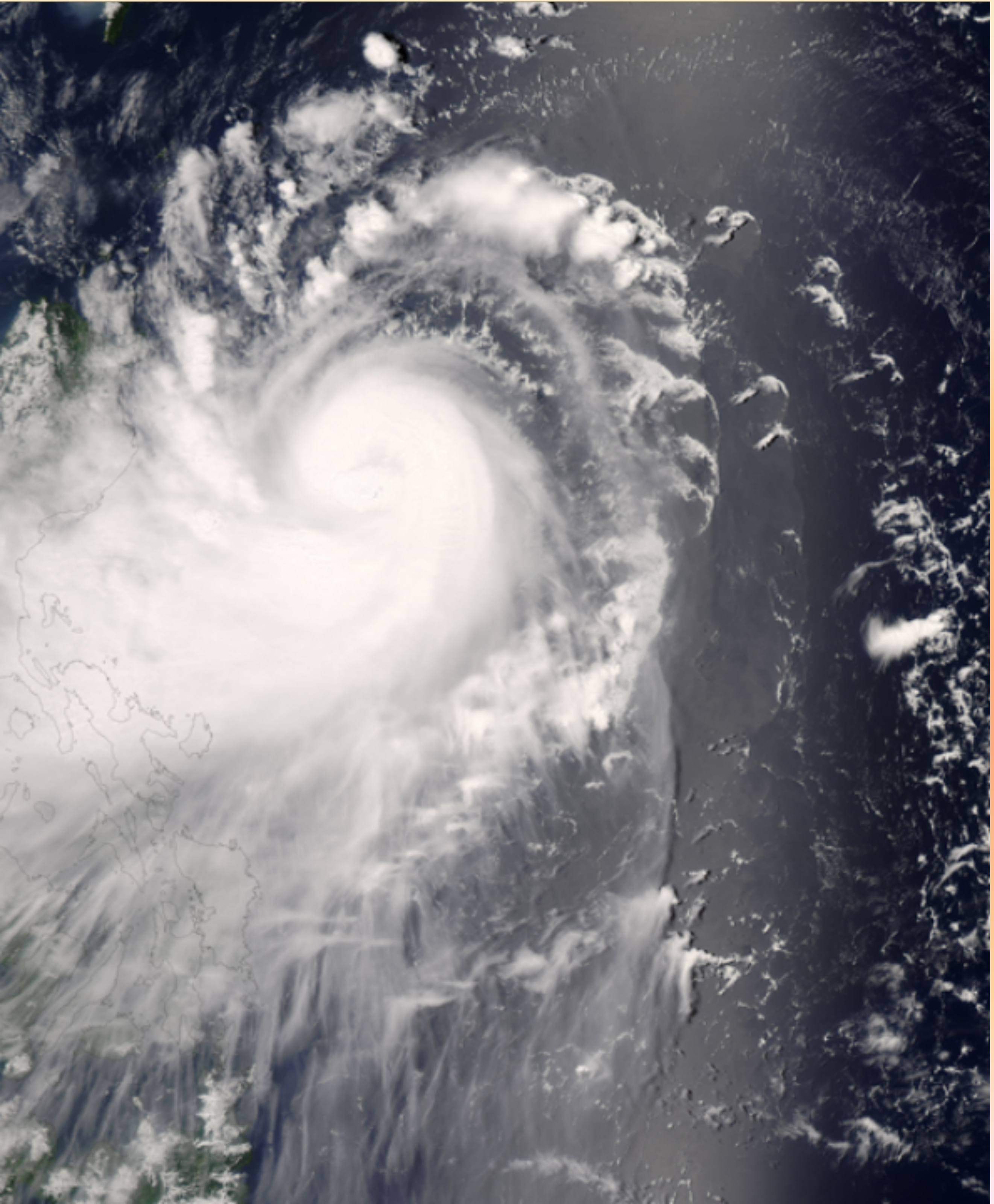
$$\frac{\partial T}{\partial t} + \mathbf{u}_h \cdot \nabla T \quad \boxed{\omega S = Q_T}$$

Was prognostic eqn for T, now for ω!

The WTG!

Model Description

- Cloud Resolving Cumulus Ensemble Model in WTG
  - Periodic BC
  - Effects of non-periodic BC simulated by sink terms in governing eqns of spec. moist. ent and mix. ratio
  - Drives mean vertical profile of Tv to ref profile
    - Result of mean vert. vel. profile
  - Cooling by vertical adv. Θ counters latent/diabatic heating
  - Vertically advects moisture, moist entropy
- Run for 240 time steps
- $100km^2$ domain (dx,dy=1km)



Typhoon Nuri

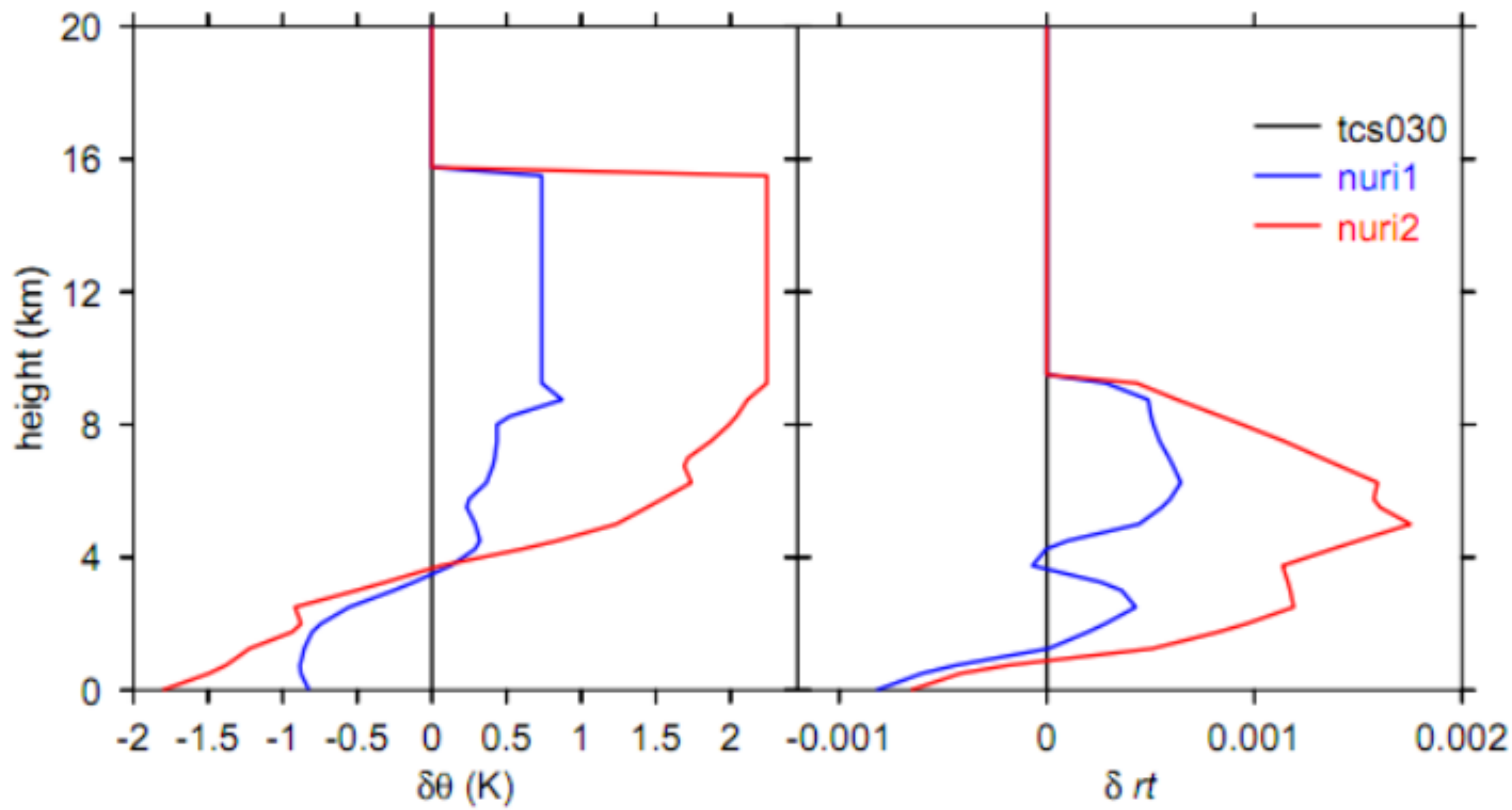
- August 18, 2008
- Impacted Phillipenes, Hong Kong
- 18 killed, many injuries
- Significant damages to infrastructure (300mil KN)

3 Convective Environments

- Radiative Convective Equilibrium from TCS-030
  - Control profile
  - Quiescent or 'far from cyclone'
  - 5m/s V wind
- Reference Profiles from TCS-08 Field Program
  - Dropsondes used to study 2008 typhoon Nuri
  - Perturbation Runs (thermodynamically more stable)
    - Cool (warm) temperature anomaly at low (upper) level
    - 'Bottom heavy' profiles
- Nuri-1 Perturbation Run
  - Represent environment inside cyclone
- Nuri-2 Perturbation Run
  - Represent later stages in development

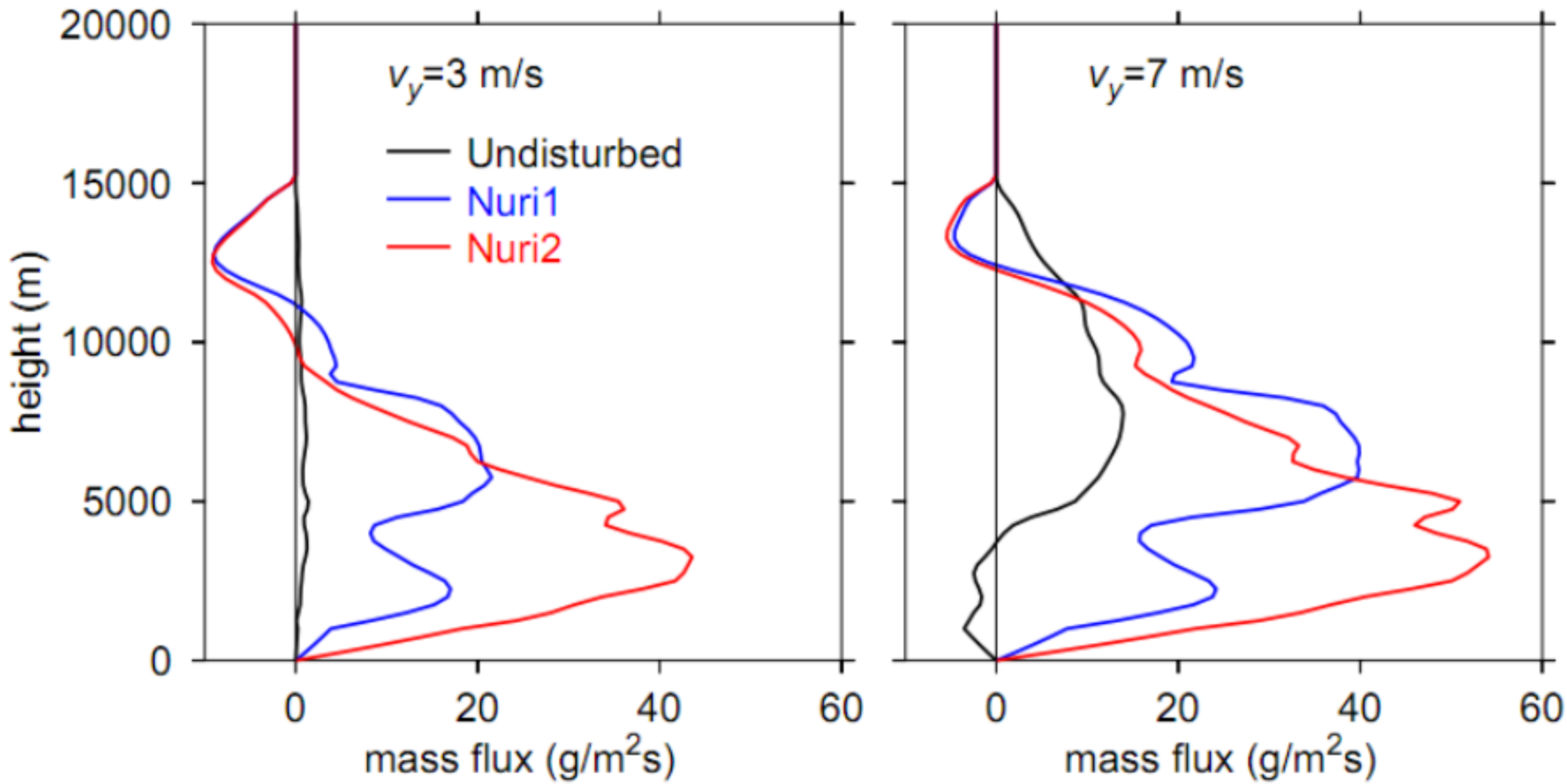
Reference Profiles I: Stability

$$\delta\theta = \begin{cases} \theta_{NURI} - \theta_{TCS030} & 0 < z < 9.25km \\ constant & 9.25km < z < 15km \\ 0 & z > 15km \end{cases}$$



RCE with SST=303 K, $v_y = 3$ m/s

Reference Profiles II: Mass Flux



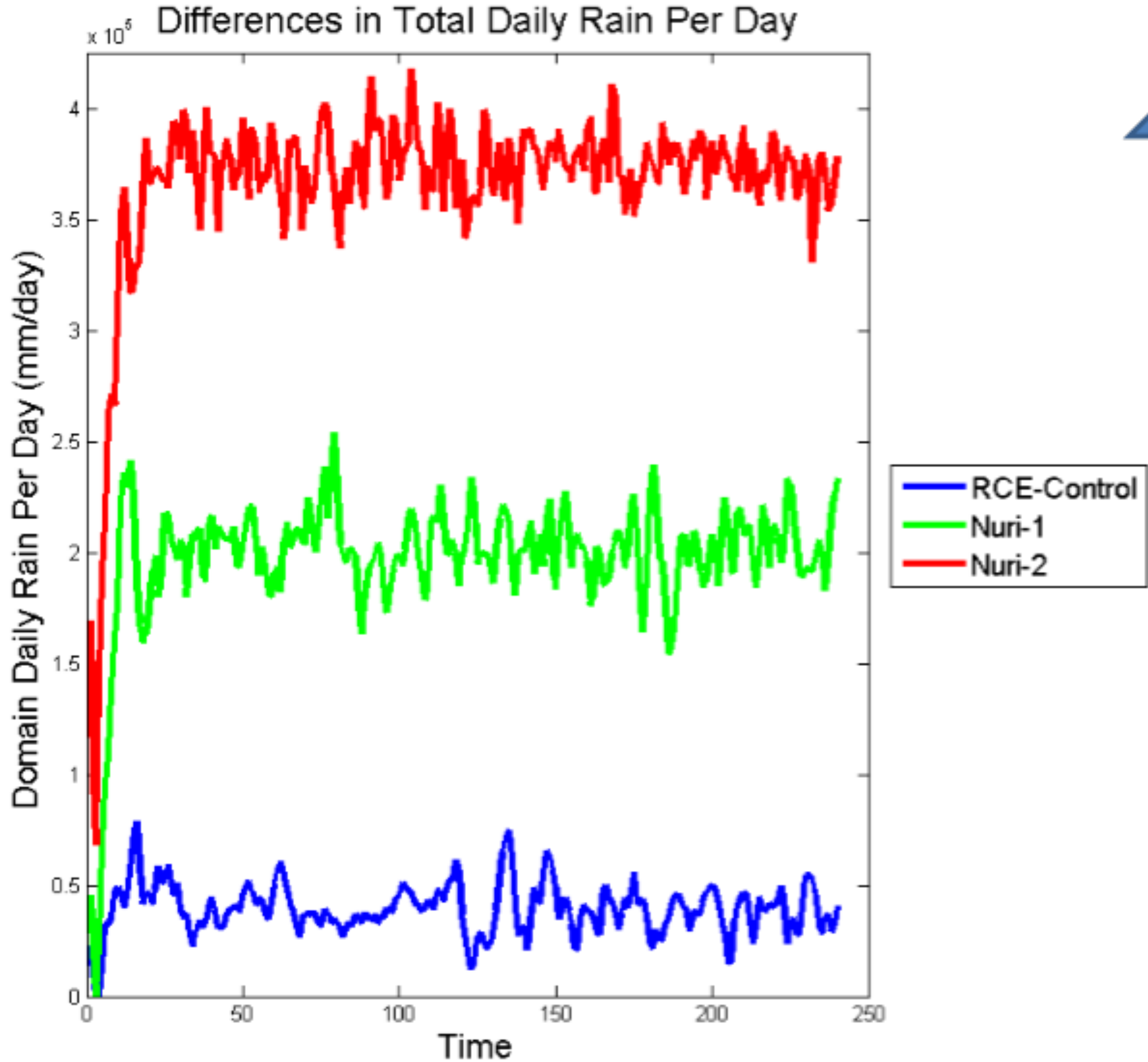
Analysis Methods

- Goal to develop spatial visualization of convective strength through time for each environment
- Focus on Rain Per Day quantity
  - Proxy for strength of convection
- Animations
- Characterize size/strength of convection for each environment (Zero-th order examination)
  - Shape of convection for given percentiles

Results: Start with Animations of Rain Per Day

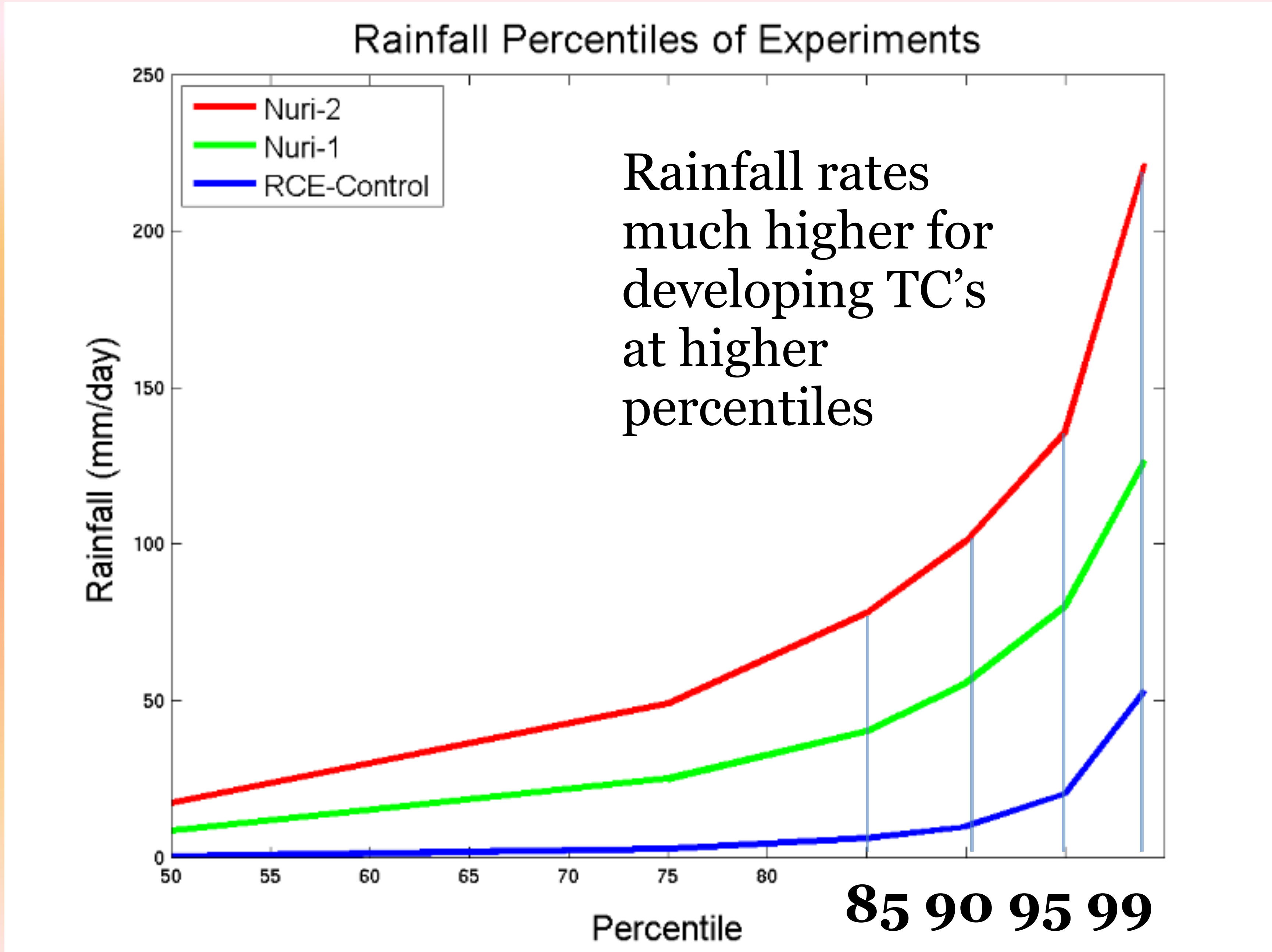
- RCE Control
- Nuri-1
- Nuri-2

Results: Rain Per Day Differences

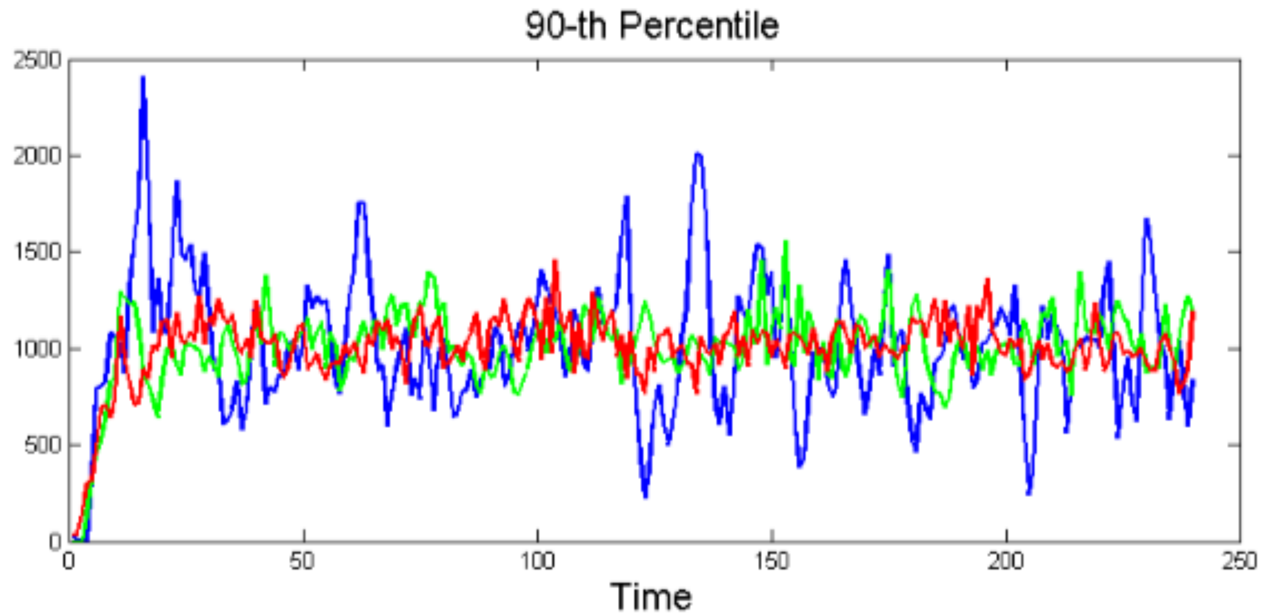


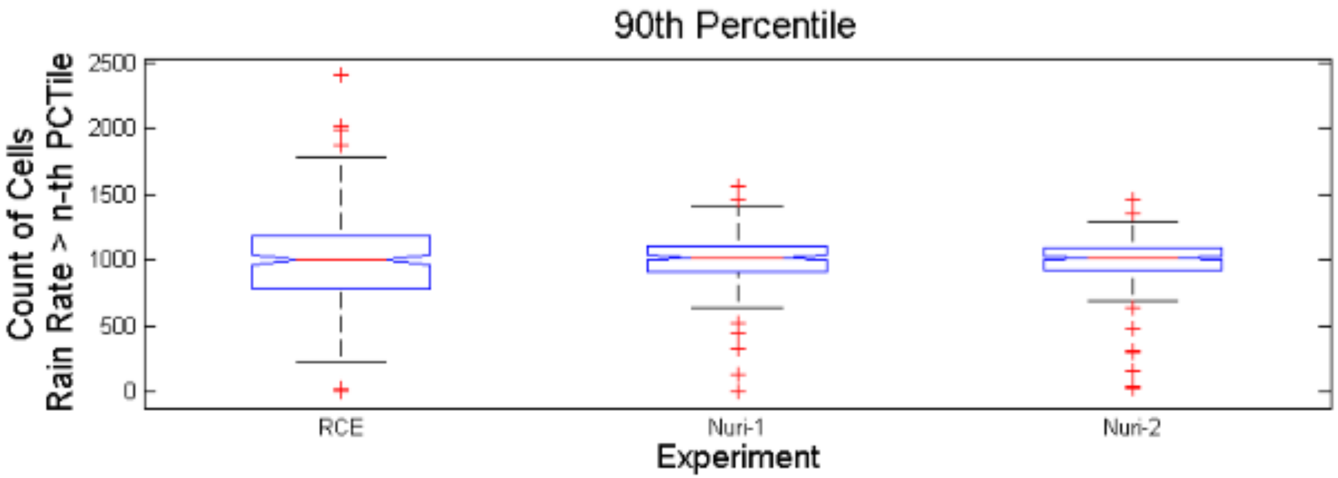
- Convection strengthens as TC develops.
- Variances different between experiment
  - (F-test , 99% CI)

Results: Percentile Perspective

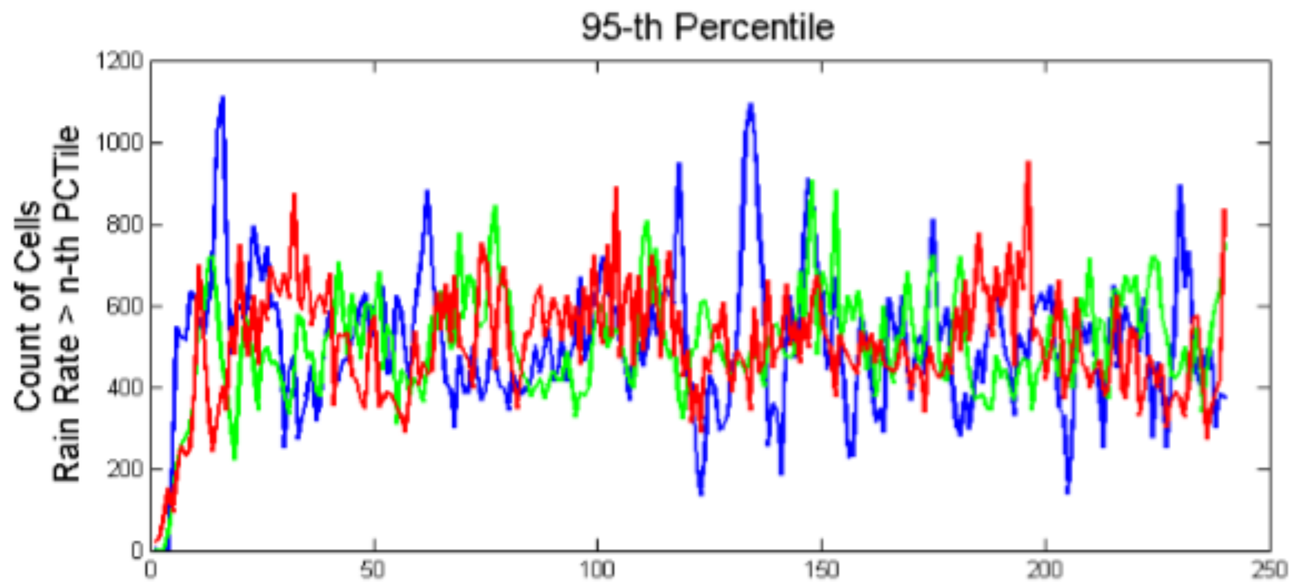


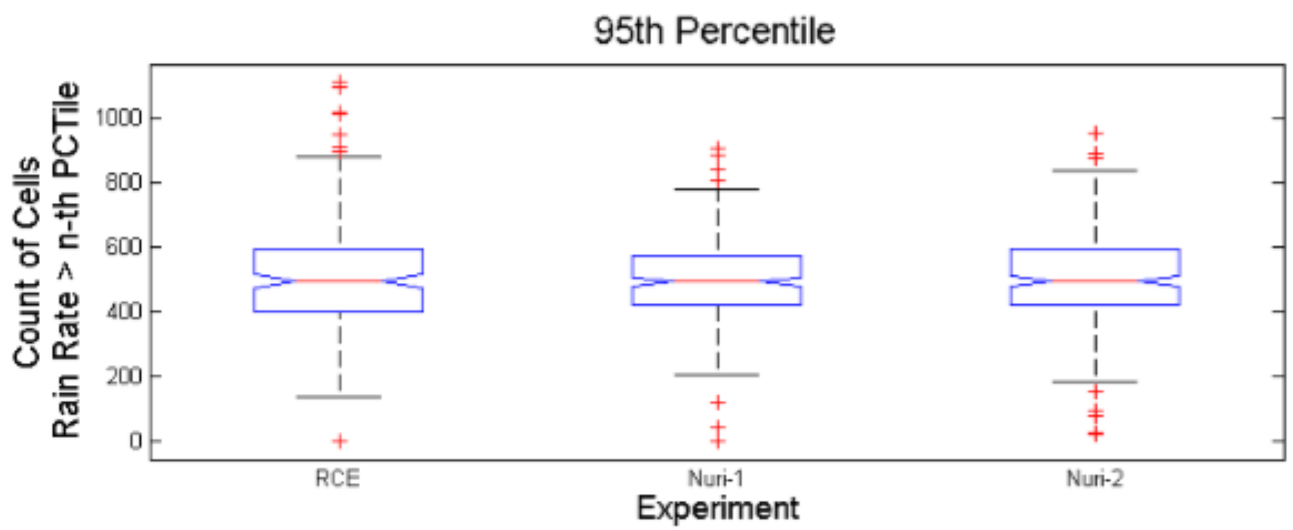
Results: 90th Percentile



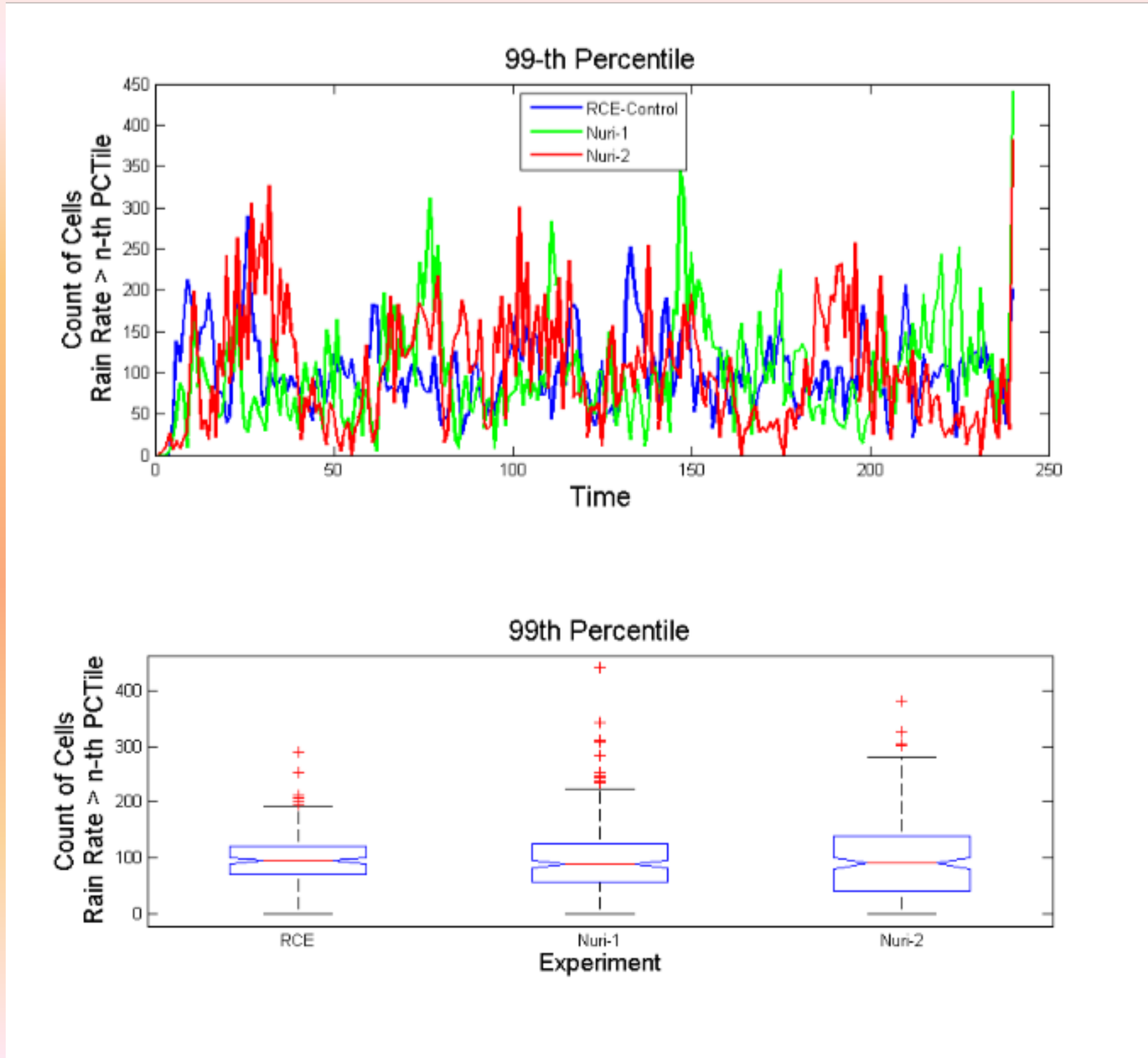


Results: 95th Percentile

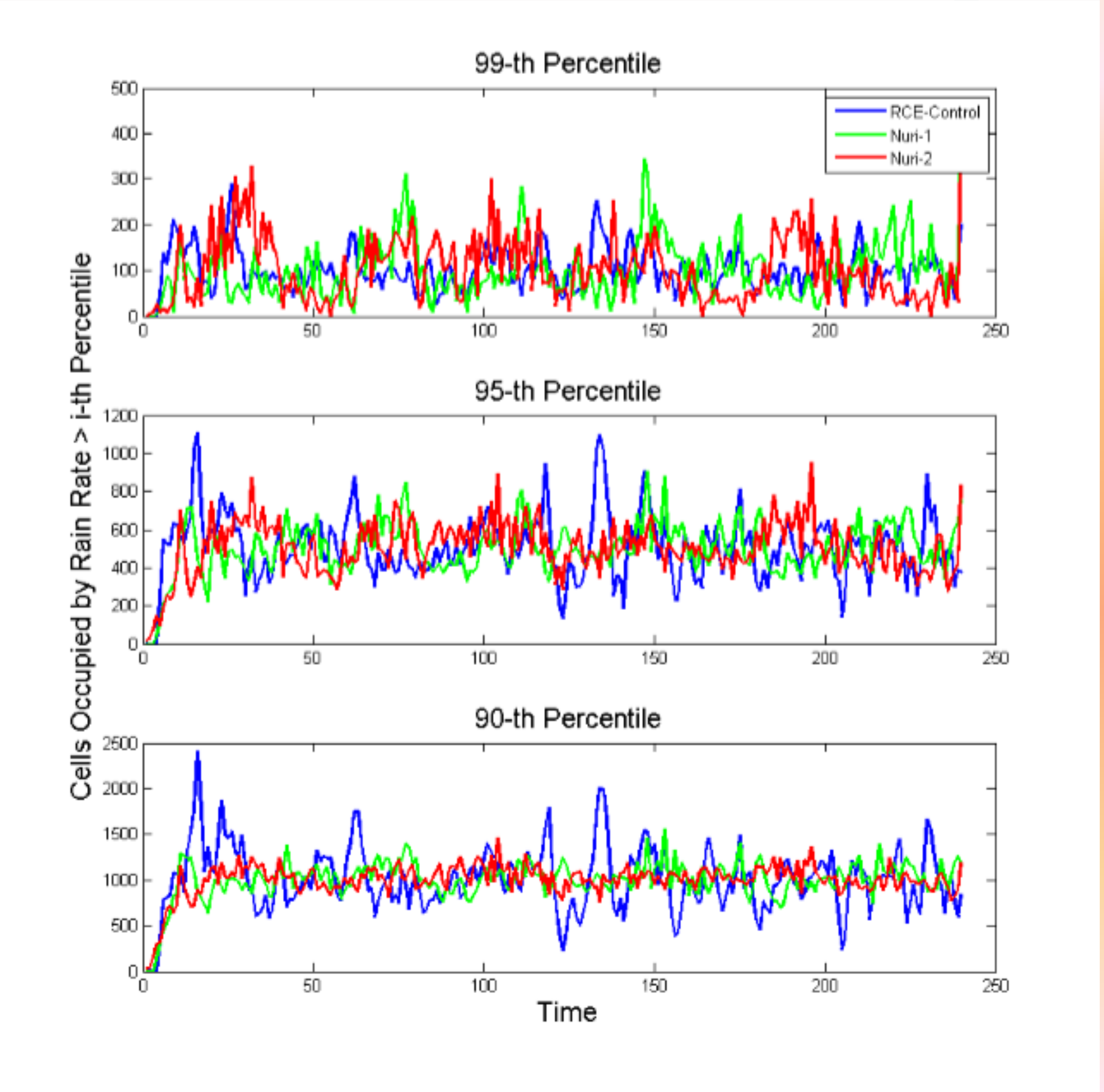




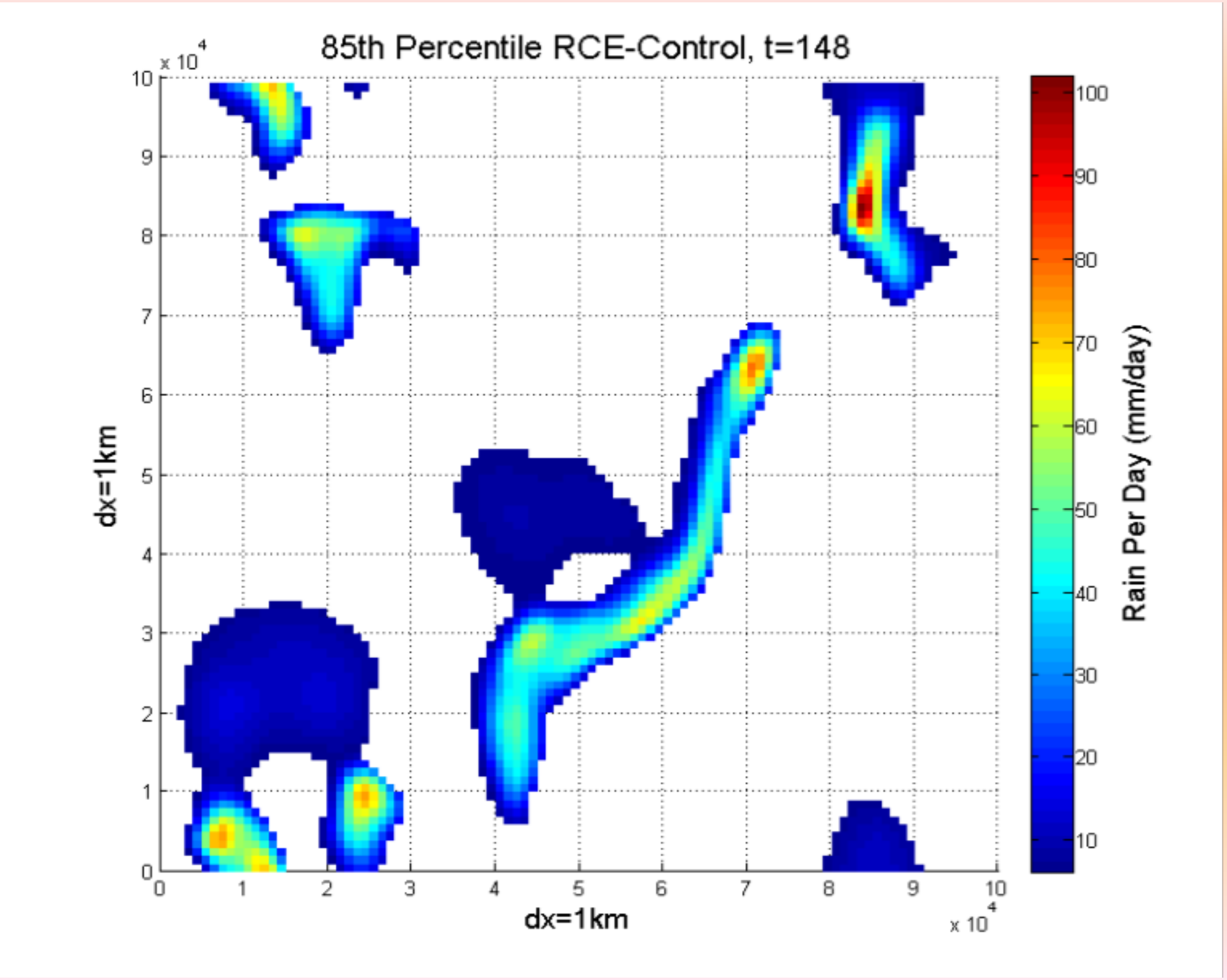
Results: 99th Percentile



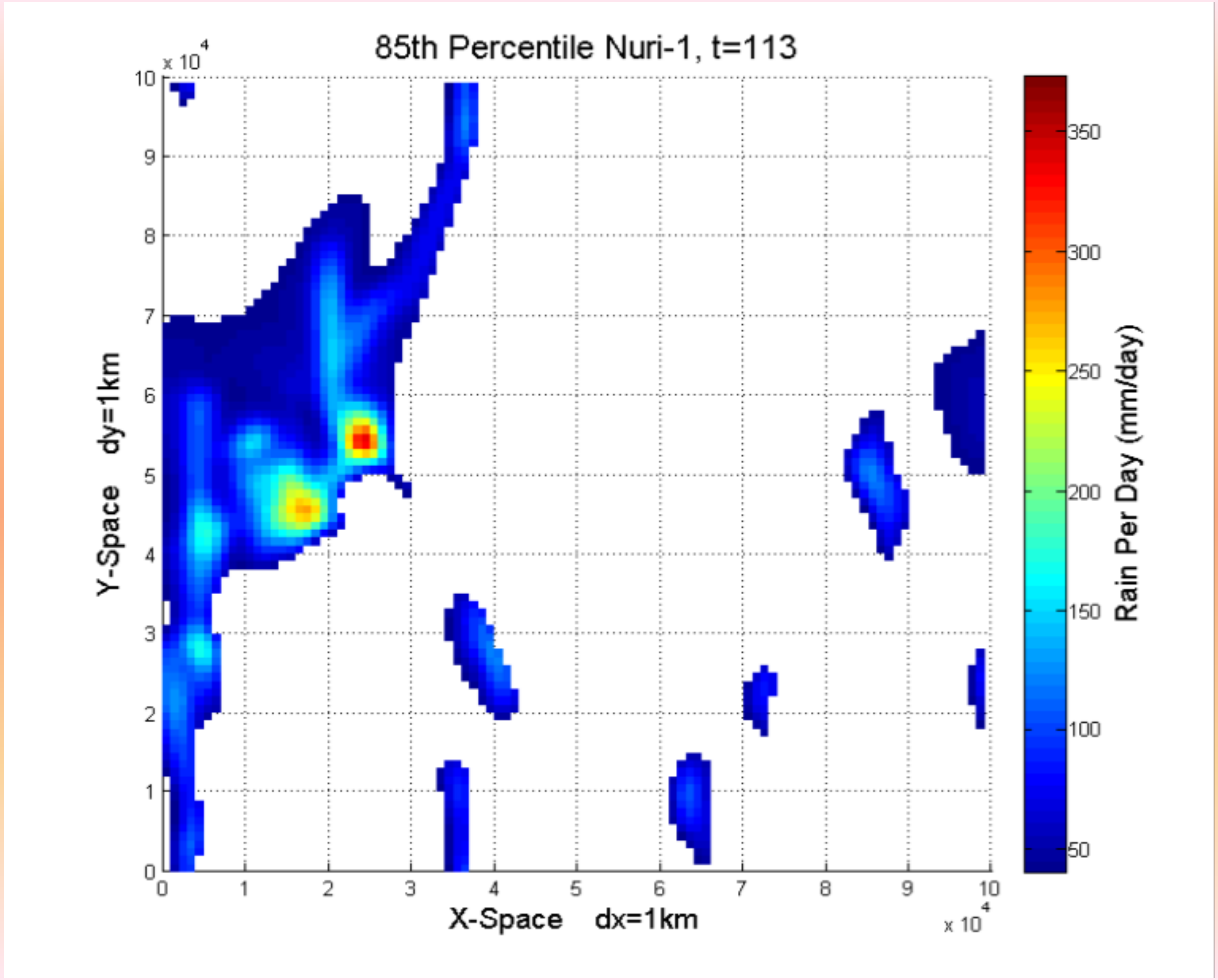
Results: Percentiles Together



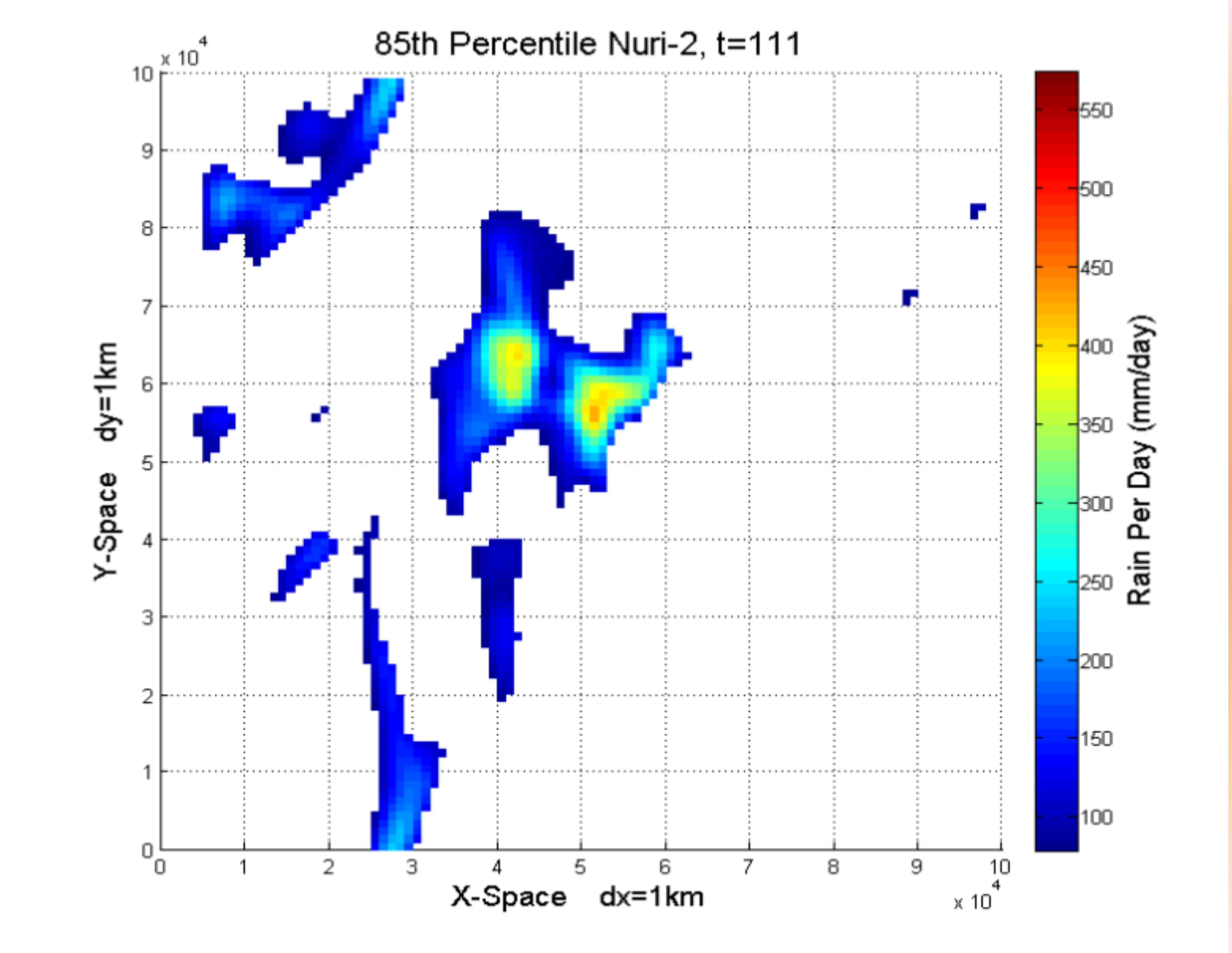
Results: Examples of Horizontal Scales



Results: Examples of Horizontal Scales



Results: Examples of Horizontal Scales



Results: Animations of 90th Percentiles

- RCE
- Nuri-1
- Nuri-2

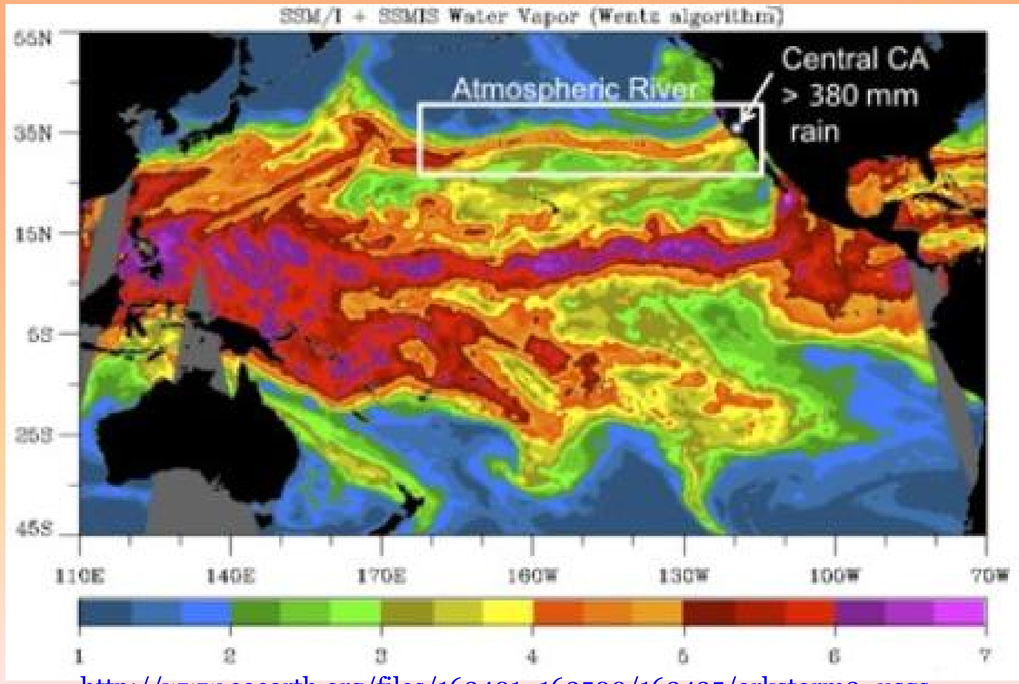
Conclusions

- Random? RCE more so while organization increases as TC develops. Not definitive…
- Horizontal scales: Large variance!
    - Nuri-1: >20km^2
    - Nuri-2 : 20km^2
    - RCE : >20km^2
- Convective plumes increased in strength not necessarily size as development progressed.
- Agreement with RS07, moistening, enhanced stability of lower troposphere enhances mass flux and UVM
    - Enhanced precipitation

Future Work
(Or How I Can Return to Split…)

- Further higher order analysis necessary to assess:
  - Randomness/autocorrelation of convection
  - Spatial extent (with significance)
  - Power Spectrum Analysis
  - Fourier Transforms
  - Scaling Laws?
  - More research into techniques used by experts in field will help!

Even us in far midlatitudes care about tropical activity!



http://www.eoearth.org/files/162401_162500/162425/arkstorm2_usgs.jpg

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- Darko Koracin, M.S. advisor, UNR/DRI (funding support, encouraged me to participate)
- Sharon Sessions, Split mentor, NMT (assigned/helped with project)