Investigating Tropical Cyclone Intensity Change using WRF simulations, In-Situ Field Data and Satellite and Aircraft Remote Sensing Observations

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Acknowledgments

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J. Molinari

R. Rogers

R. Kakar

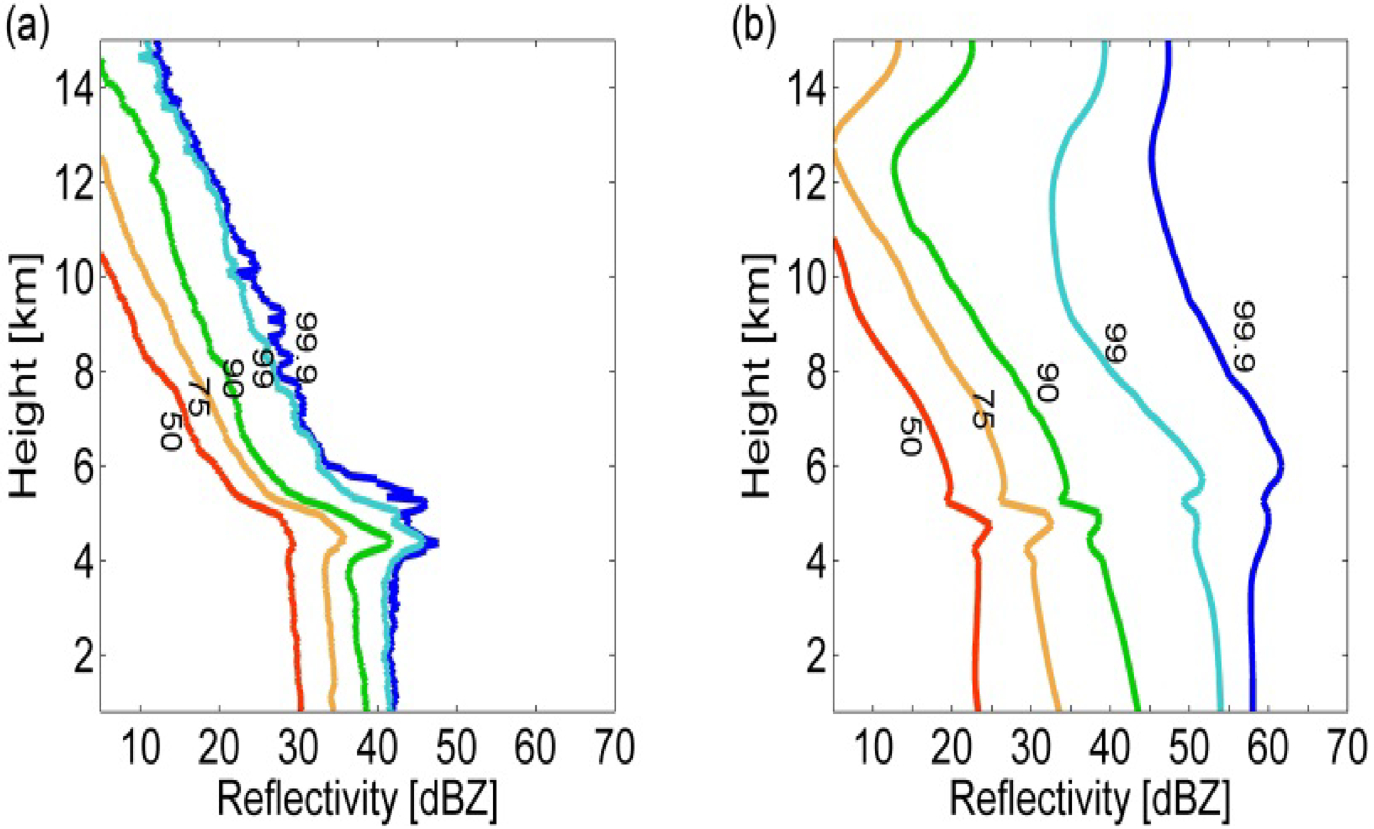
Research Topics

1. Examine mechanisms driving intensity change of Dennis (2005), Earl (2010) and Ike (2008) using WRF simulations & observations.

2. Assess how dust in SAL acting as CCN impacts TC intensity using ensemble of simulations.

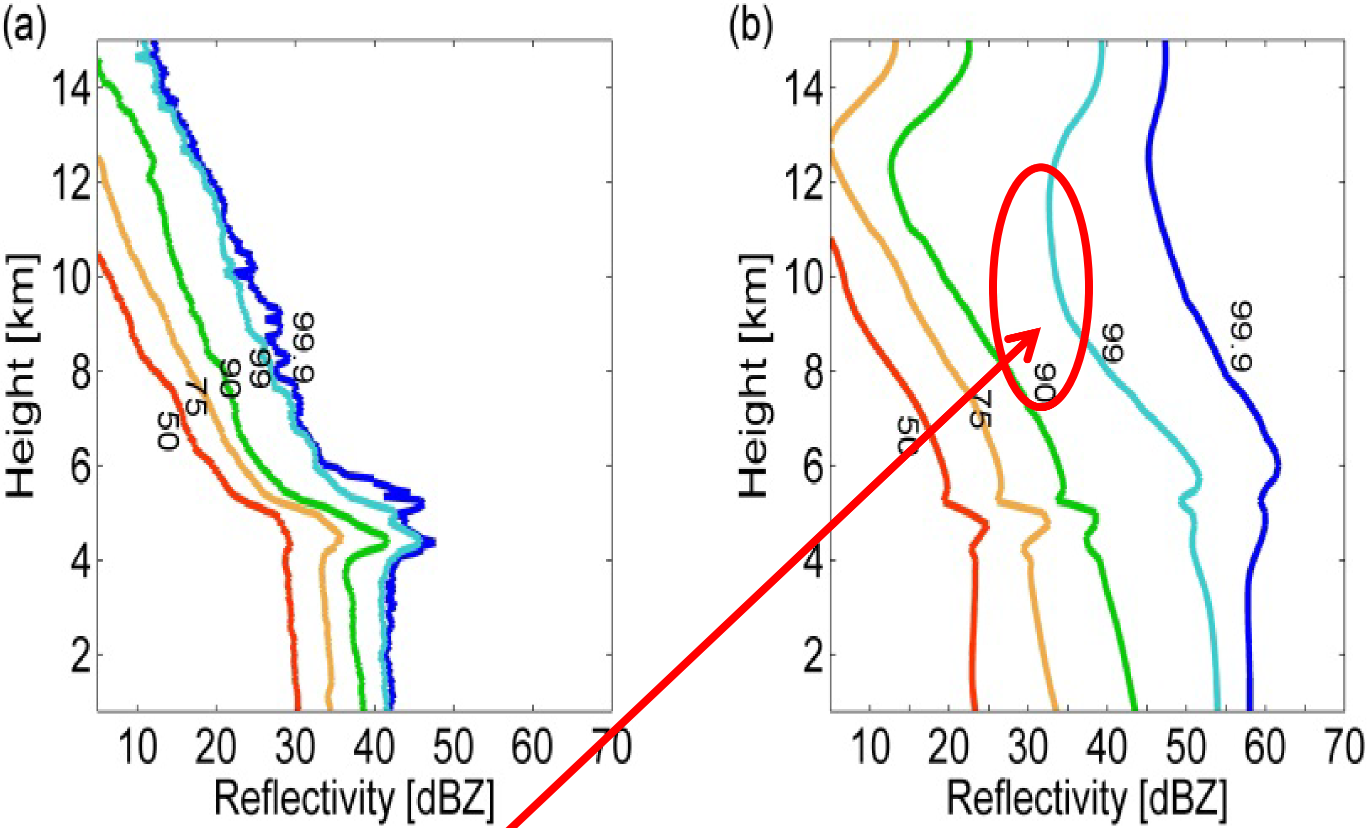
3. Using in-situ data to improve model representations of hydrometeor SDs as gamma functions

4. Construct comprehensive set of space borne microwave & radar data to examine role of varying TC morphology on RI.

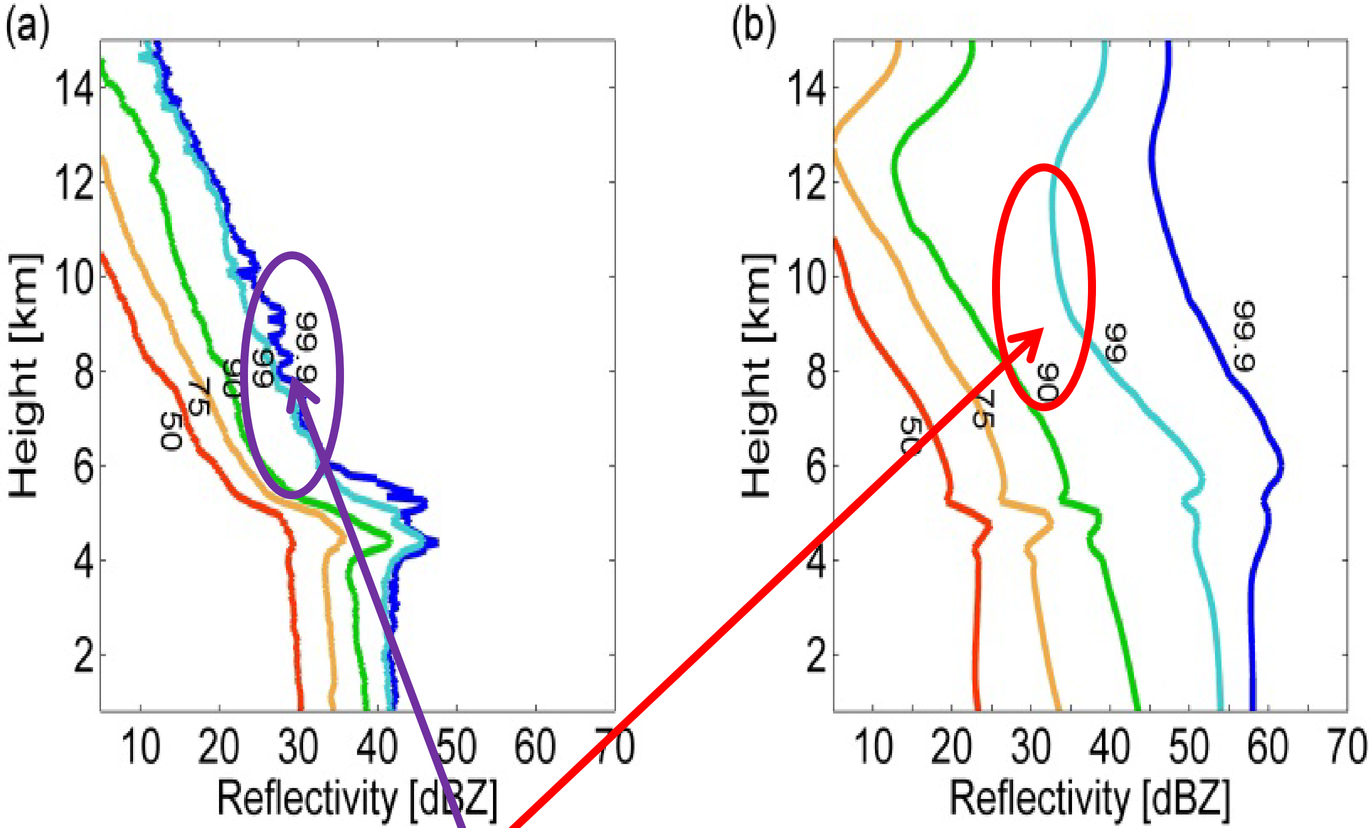


WRF simulation

- 1-km grid spacing, 55 levels
- 1-km data saved @ 2 minutes

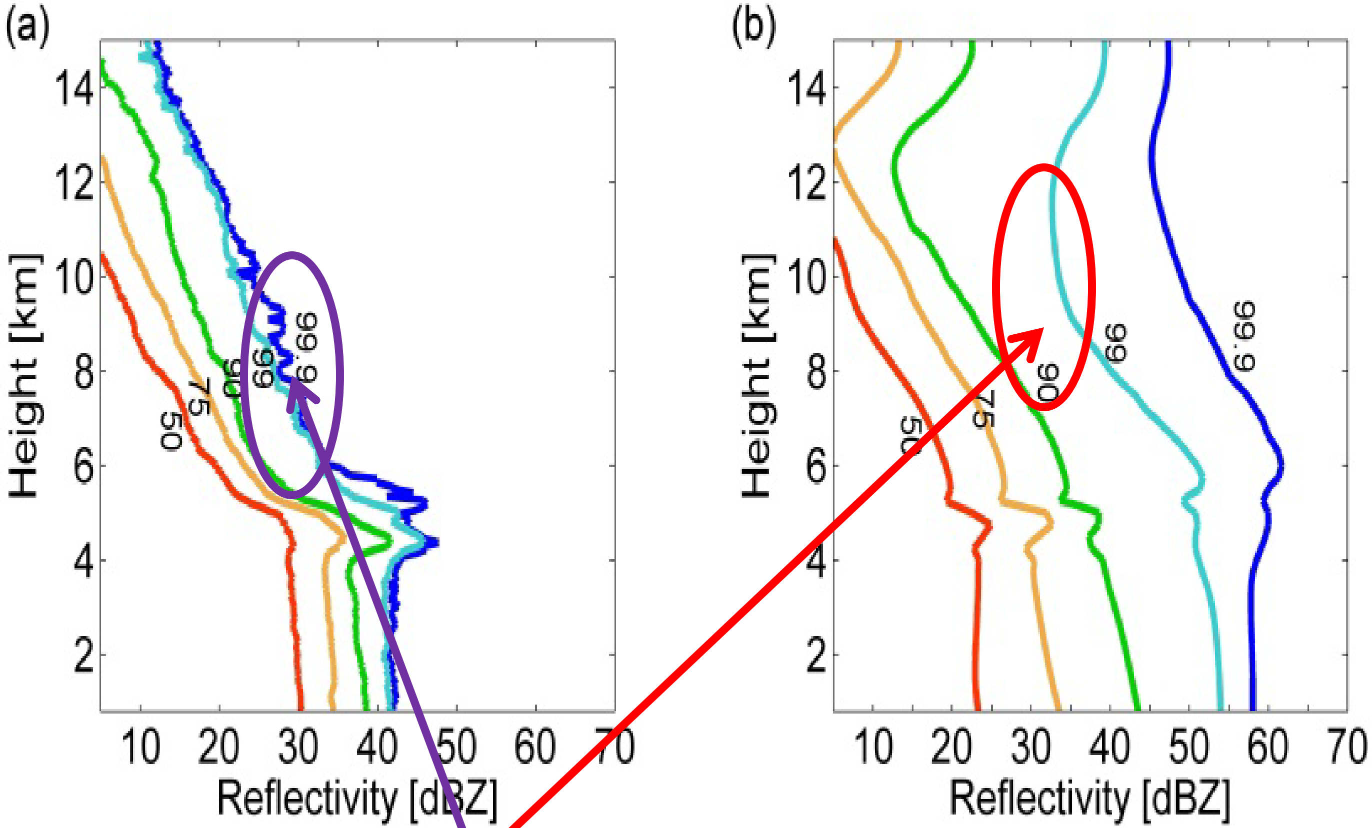


3.0% of *Z* exceed 25 dBZ at 10 km in simulation



3.0% of *Z* exceed 25 dBZ at 10 km in simulation

< 0.1 % of Z > 25 dBZ in EDOP data

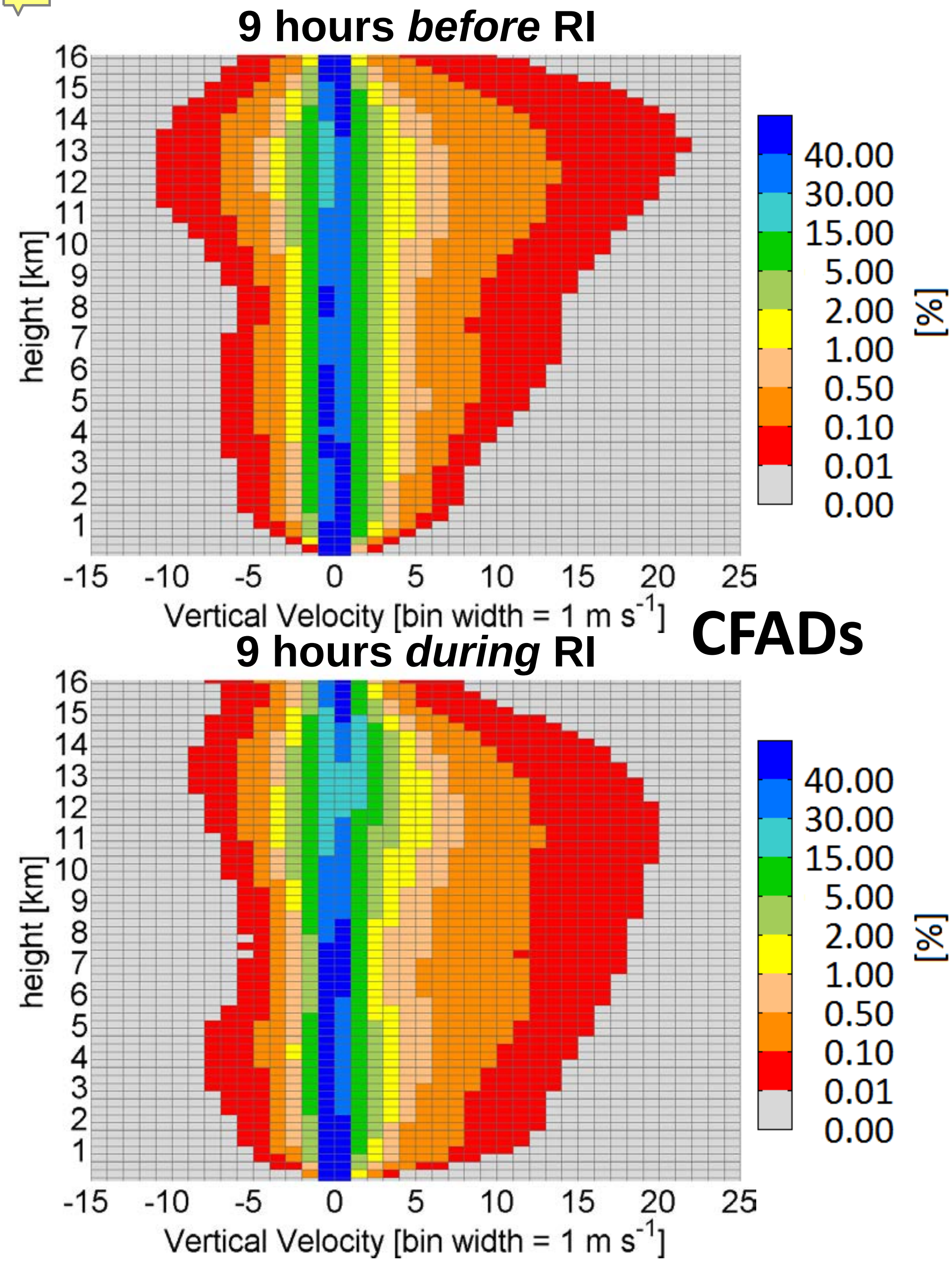


3.0% of *Z* exceed 25 dBZ at 10 km in simulation

< 0.1 % of Z > 25 dBZ in EDOP data

Frequency of largest *Z* above melting layer over-predicted

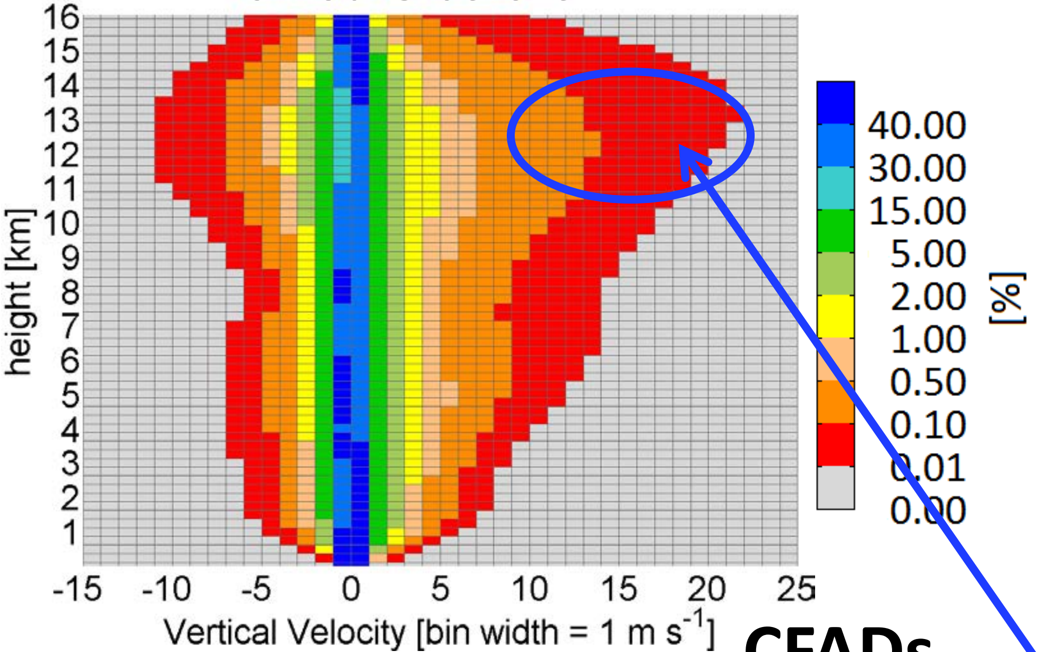
WRF Simulations of Hurricane Dennis



Cumulative CFADs within 75 km before & during RI

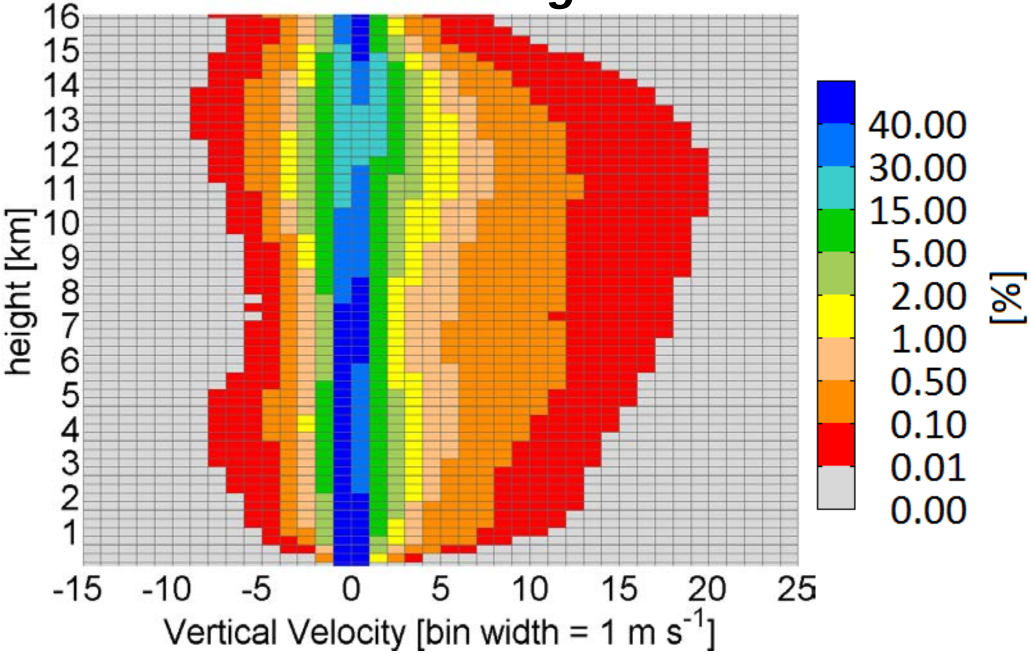
WRF Simulations of Hurricane Dennis

9 hours *before* RI



CFADs

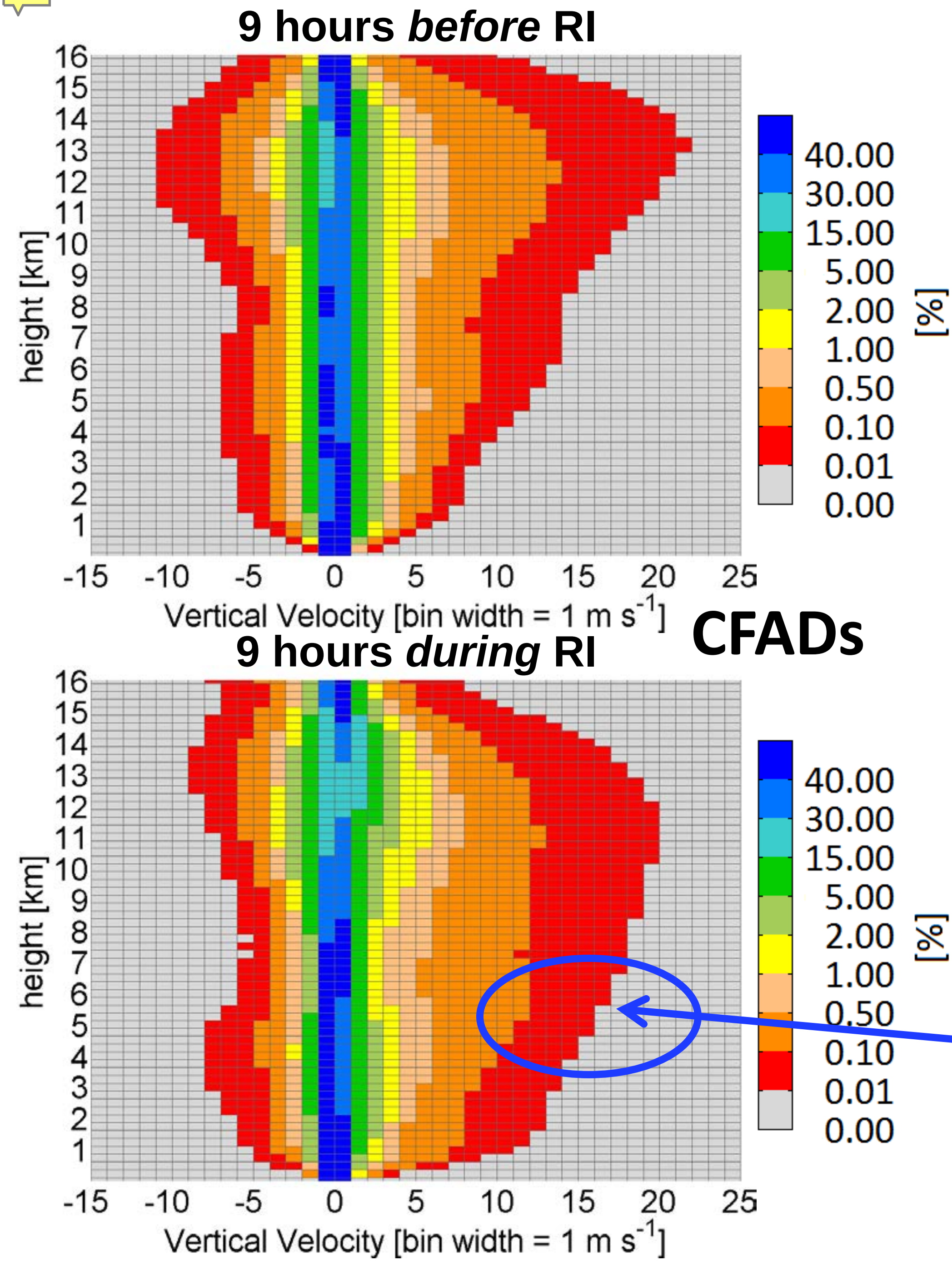
9 hours *during* RI



Cumulative CFADs within 75 km before & during RI

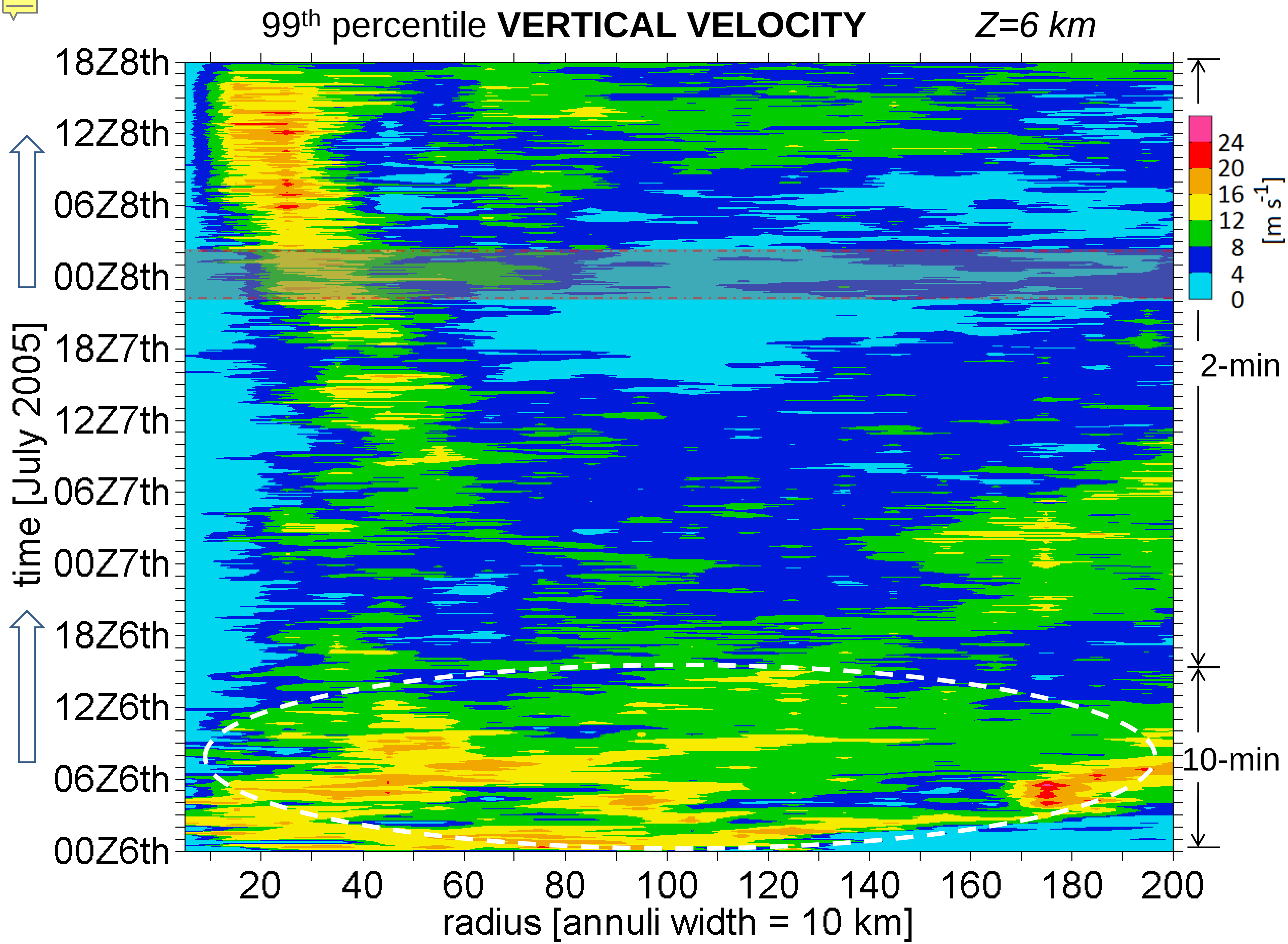
Distribution broader before RI for z > 11 km,

WRF Simulations of Hurricane Dennis

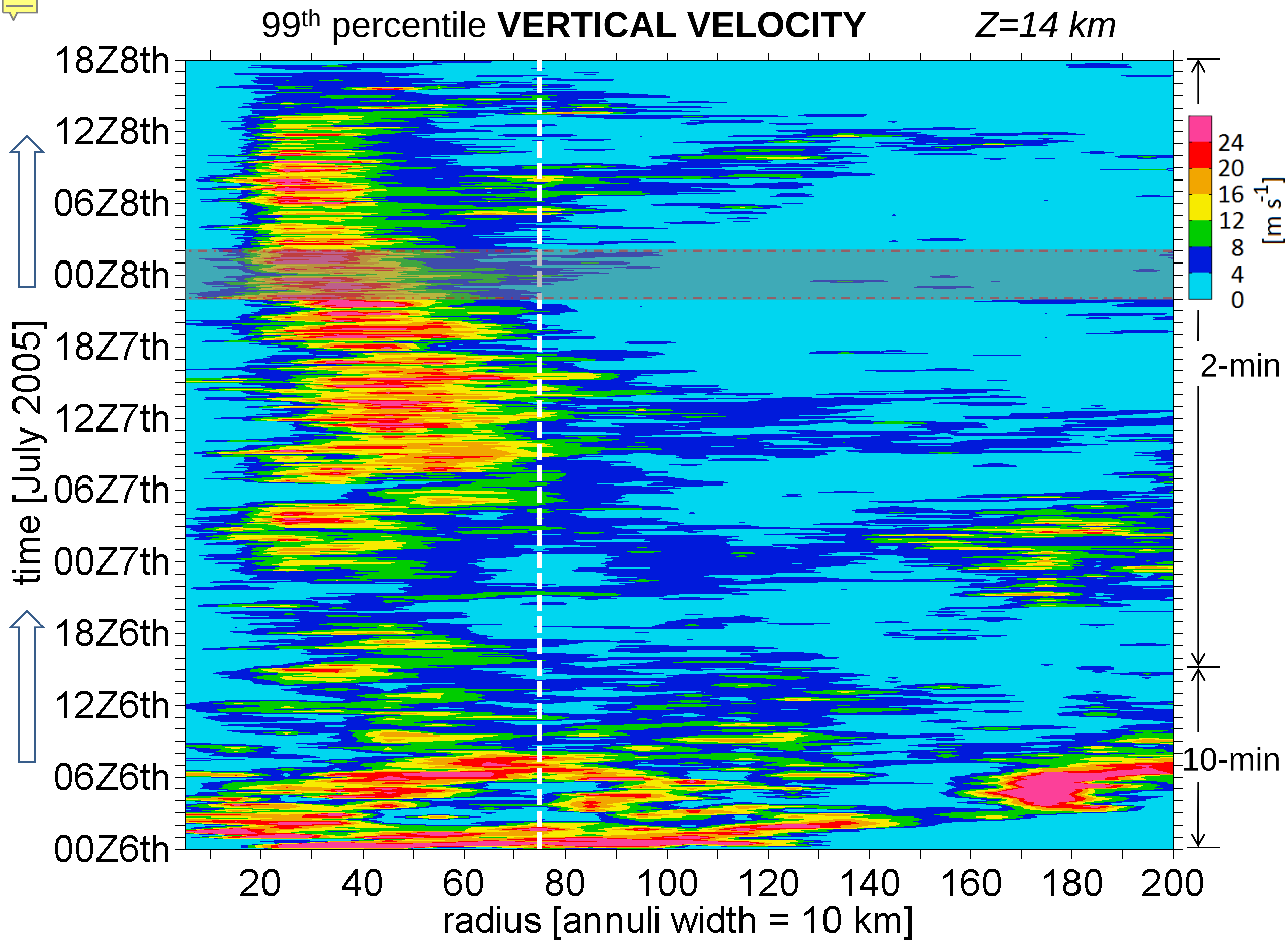


Cumulative CFADs within 75 km before & during RI

Distribution broader before RI for z > 11 km, but broader after RI for z < 6 km

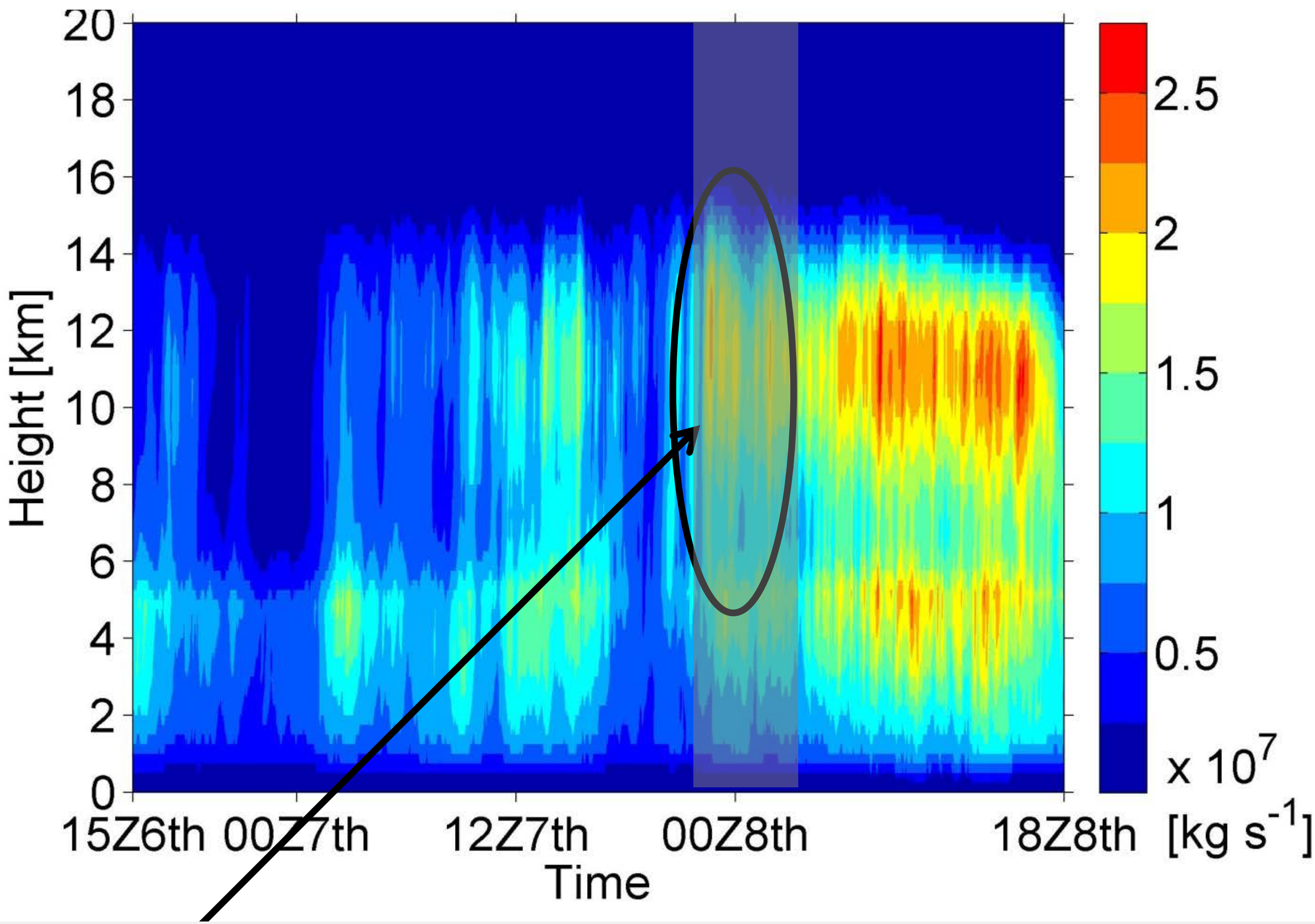


99th percentile VERTICAL VELOCITY
Z=6 km
18Z8th
12Z8th
06Z8th
00Z8th
18Z7th
12Z7th
06Z7th
00Z7th
18Z6th
12Z6th
06Z6th
00Z6th
time [July 2005]
20
40
60
80
100
120
140
160
180
200
radius [annuli width = 10 km]
24
20
16
12
8
4
0
[m s-1]
2-min
10-min



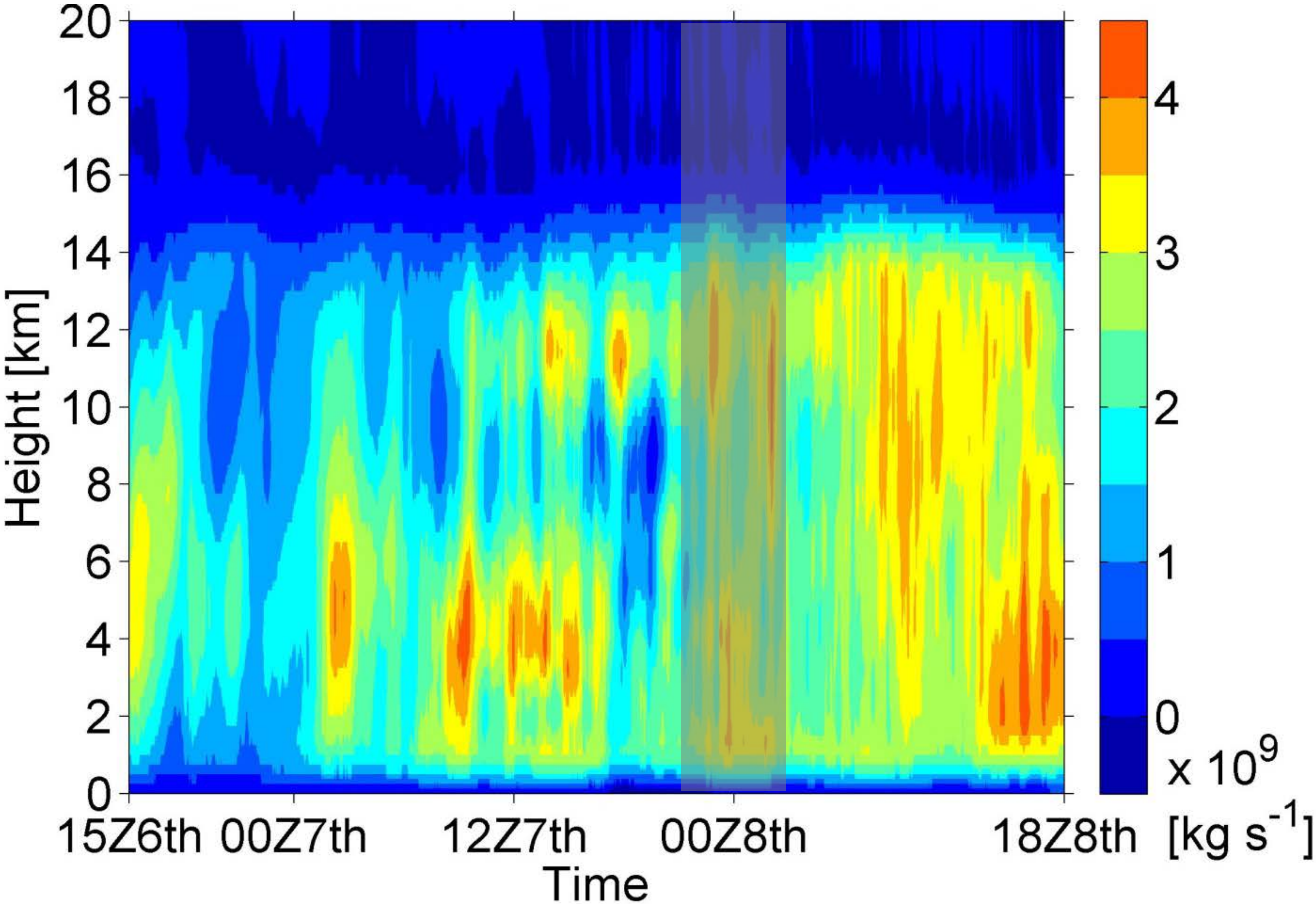
99th percentile VERTICAL VELOCITY
Z=14 km
18Z8th
12Z8th
06Z8th
00Z8th
18Z7th
12Z7th
06Z7th
00Z7th
18Z6th
12Z6th
06Z6th
00Z6th
time [July 2005]
20
40
60
80
100
120
140
160
180
200
radius [annuli width = 10 km]
24
20
16
12
8
4
0
[m s-1]
2-min
10-min

Convective **Updraft hydrometeor mass flux** *r < 75 km*



Increase in upward hydrometeor mass flux at upper levels before RI

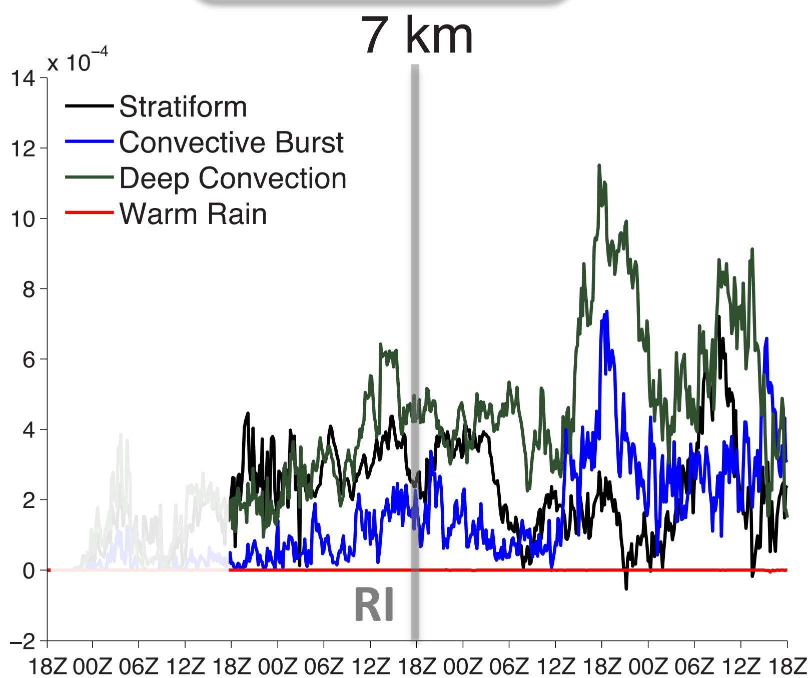
Net air **mass flux** r < *75 km*



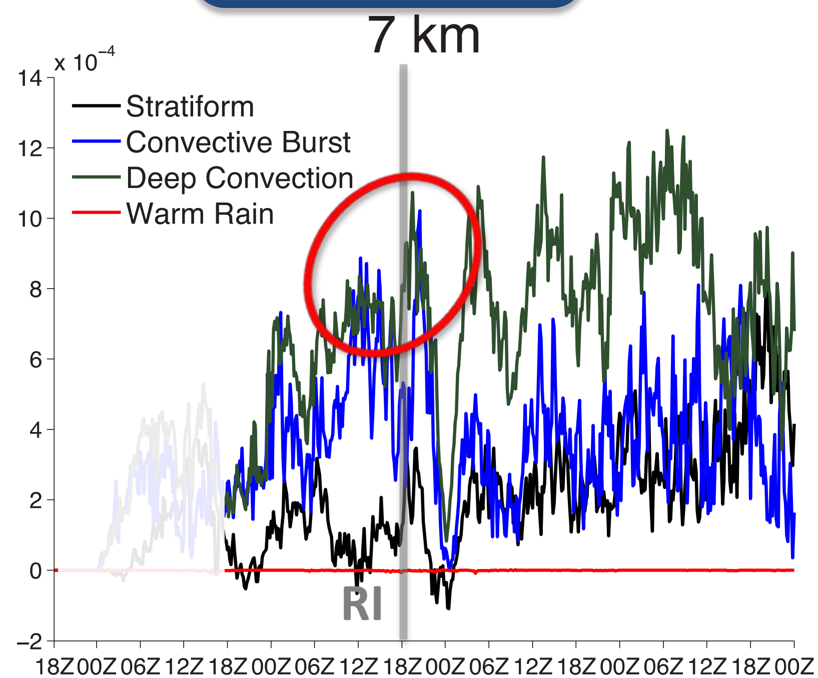
Increase in air mass flux before RI, but also occurred well before RI and at lower levels

WRF: Innermost 1° Diabatic Heating

Ike
(Low Shear)



Earl
(High Shear)

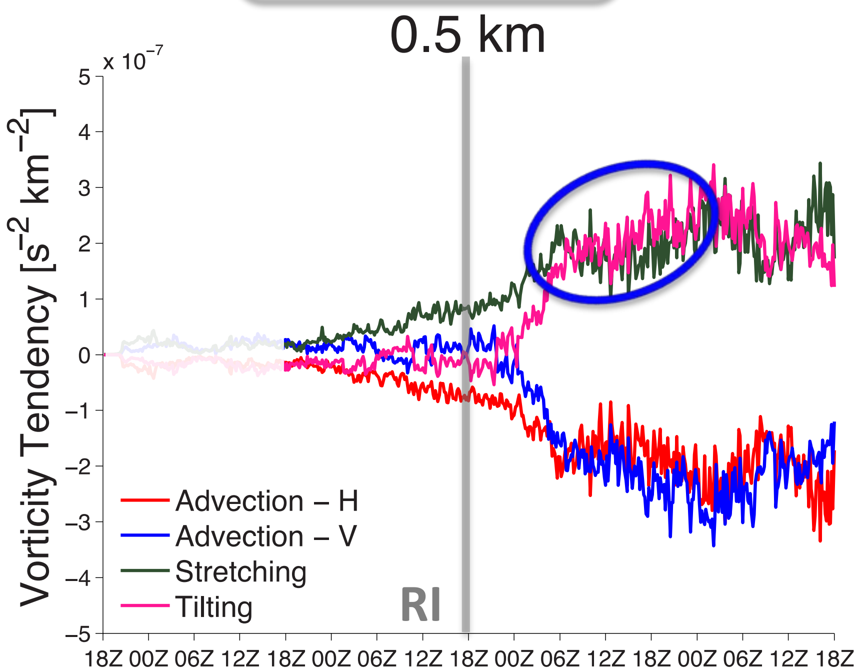


In high shear, convective bursts cover an ***order of magnitude less area*** than deep convection, yet provide ***more net diabatic heating*** leading up to RI.

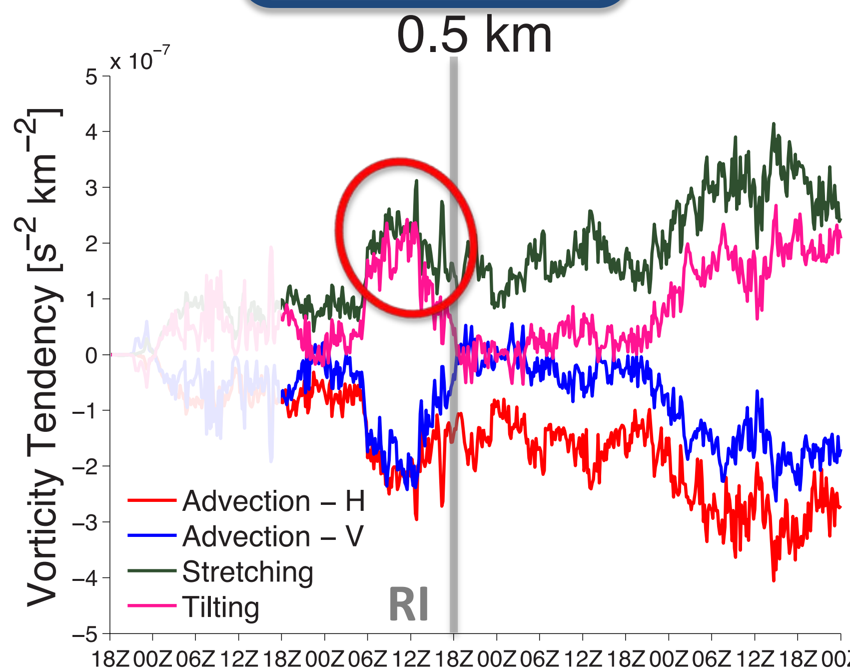
Burst: $W_{mean} \geq 5$ m s^{-1} from 700 - 300 hPa; *Rogers (2010)*
Precipitation Type: *Steiner et al. (1995)*

WRF: Innermost 1° Vorticity Tendency

Ike
(Low Shear)



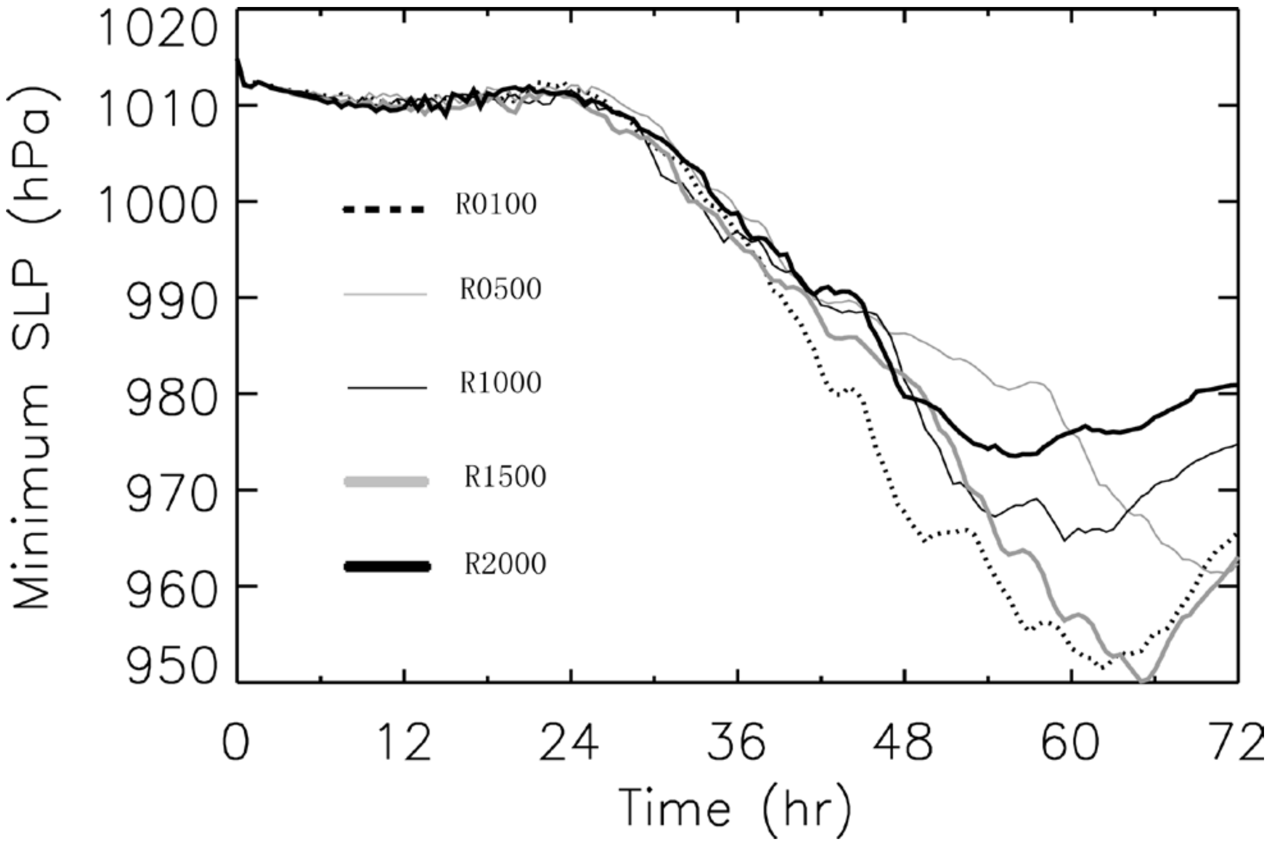
Earl
(High Shear)



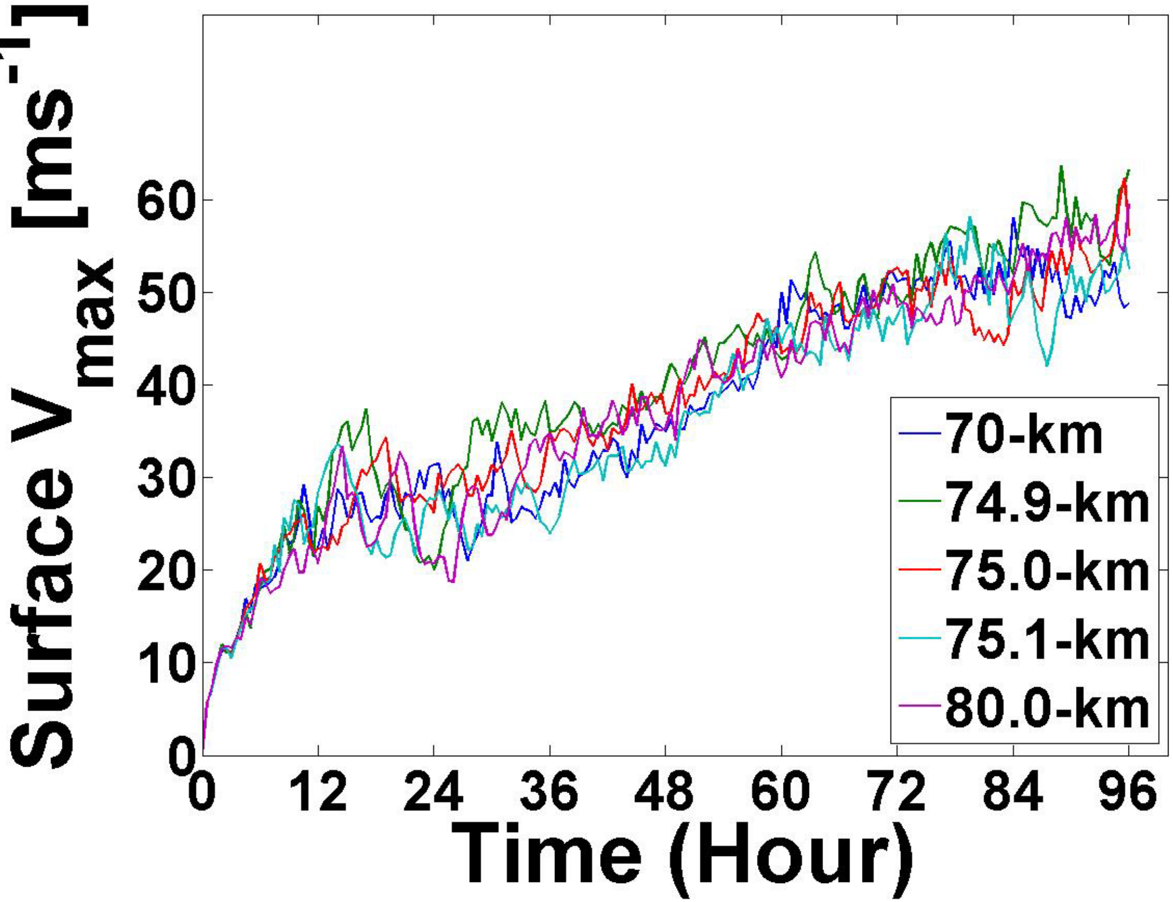
In low shear at low-levels, ***stretching*** is the primary contributor ***leading up to RI***, with ***tilting also contributing later*** in the RI cycle.

In high shear at low-levels, ***stretching and tilting*** contribute nearly the same amount ***preceding RI***, with ***stretching eventually dominating***.

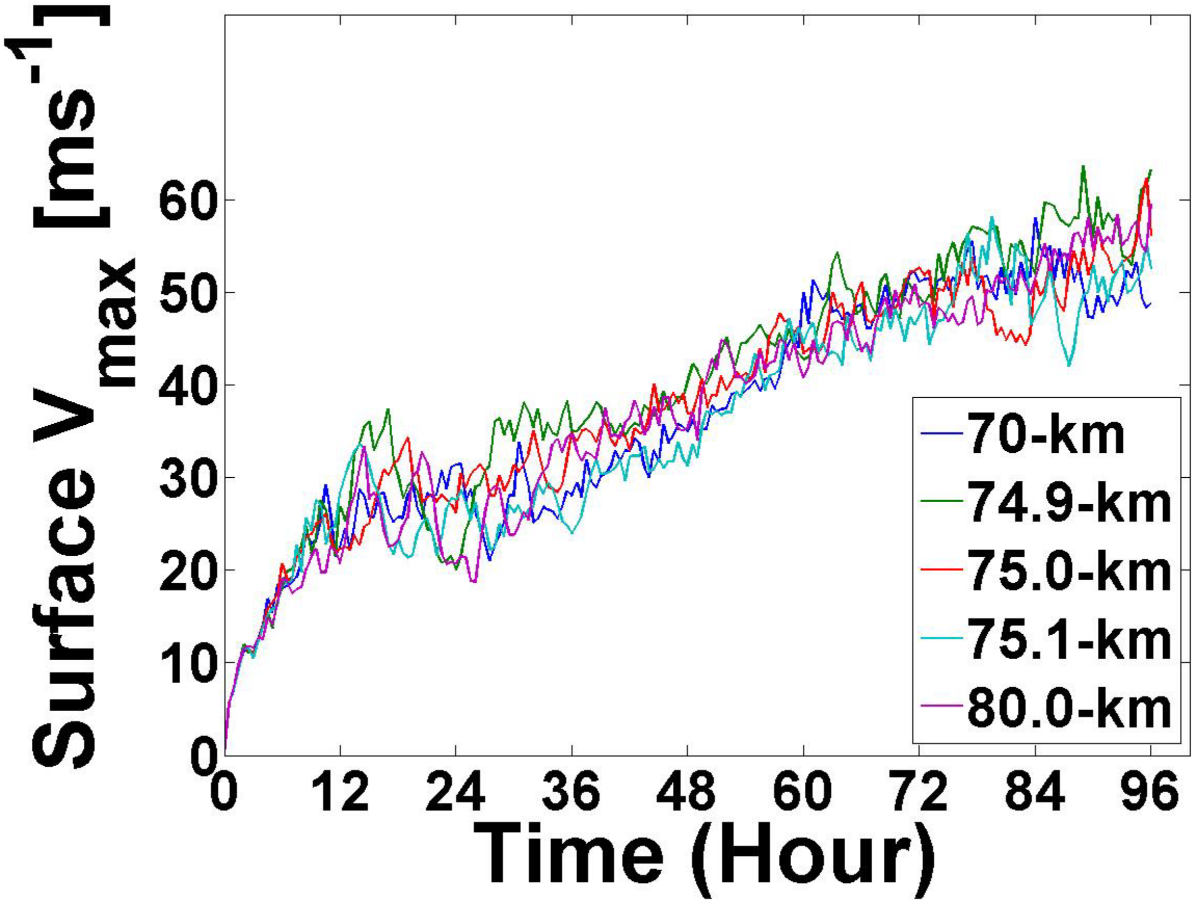
SAL Aerosol Influence on TCs



- **Zhang et al. (2007, 2009) suggested TCs sensitive to variations in CCN number**
  - **TC intensity exhibited non-monotonic response to increases in CCN concentration**

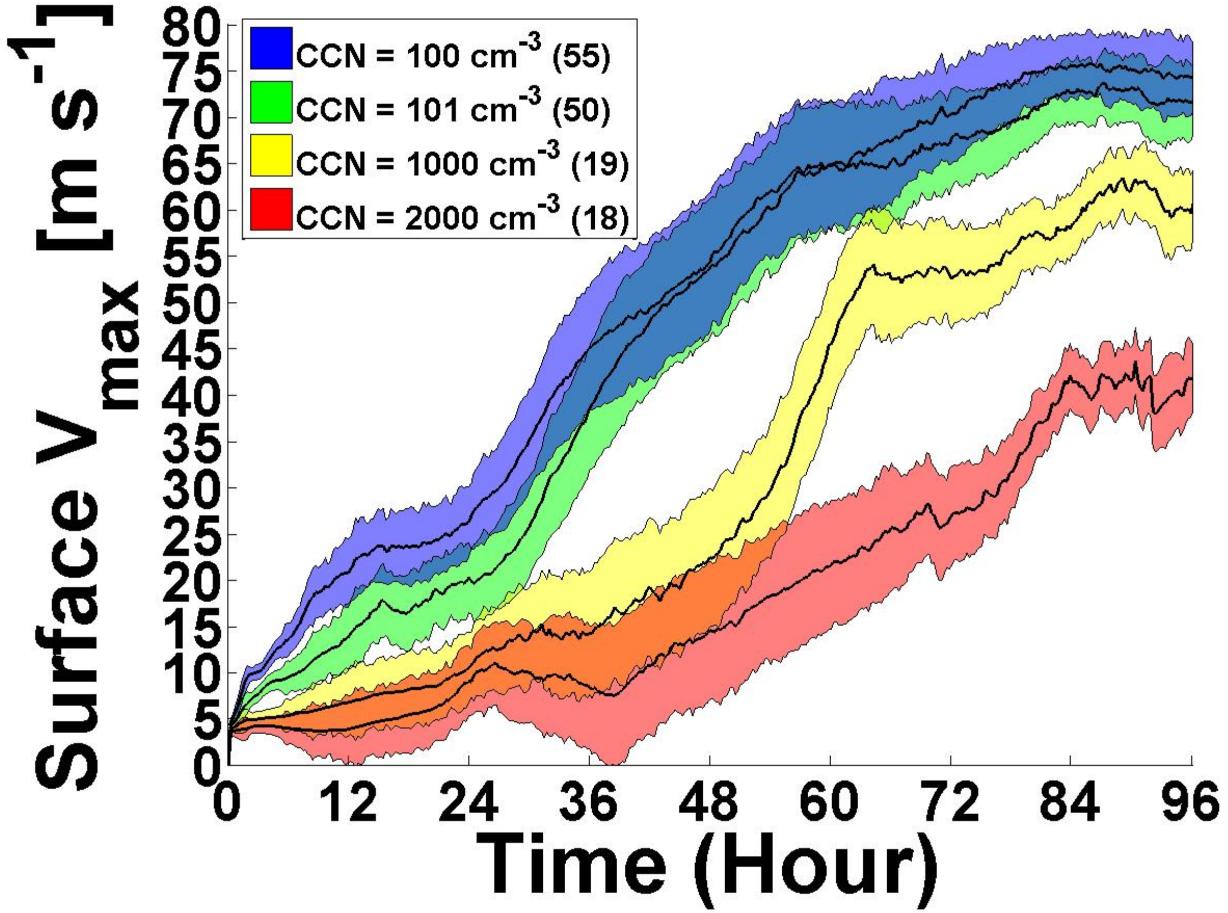


TCs exhibit sensitivity to other ICs, such as RMW of initial vortex

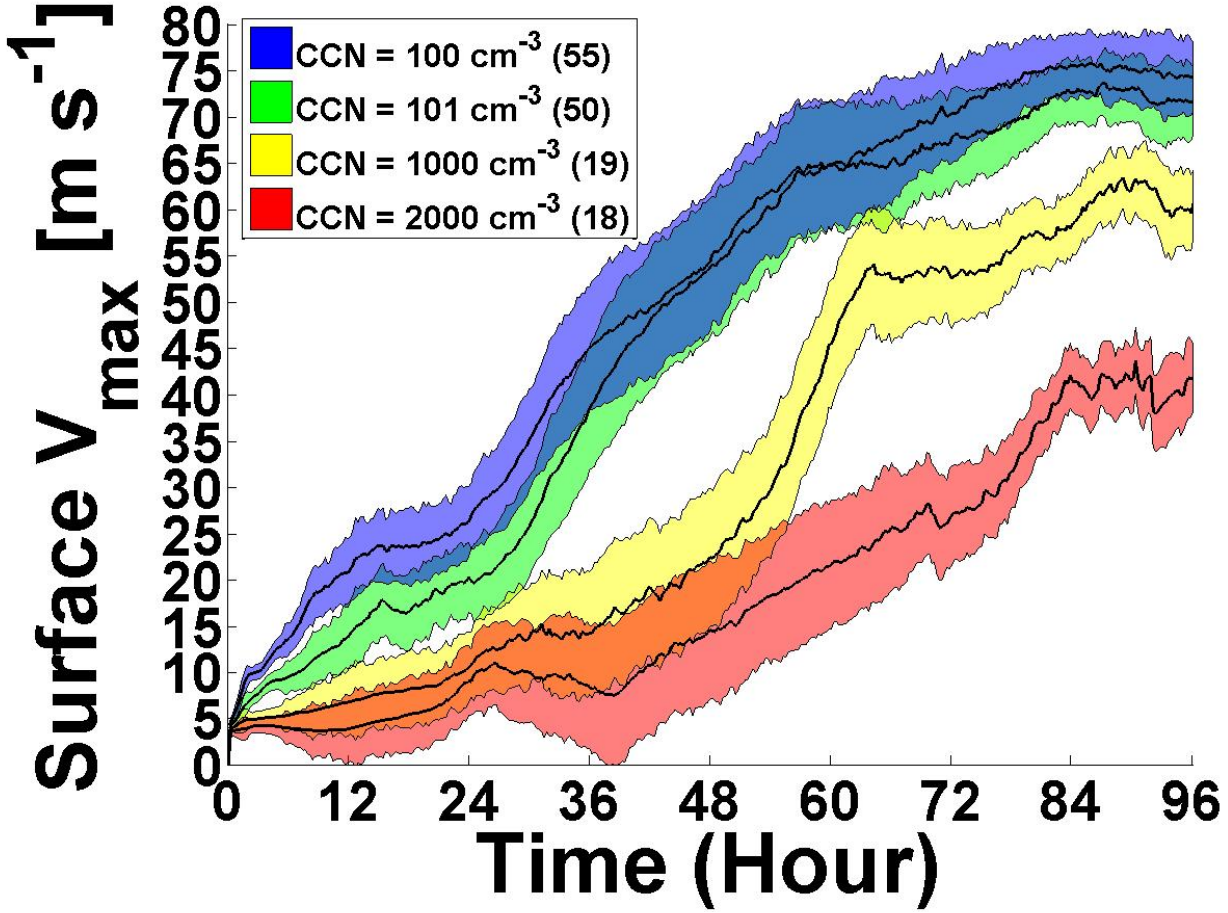


TCs exhibit sensitivity to other ICs, such as RMW of initial vortex

Is non-monotonic response of TCs to CCN caused by *non-linear amplification of noise* associated with perturbations in ICs?



Ensemble where CCN concentration varied for different initial T, q, RMW, vortex height, bubble temperature



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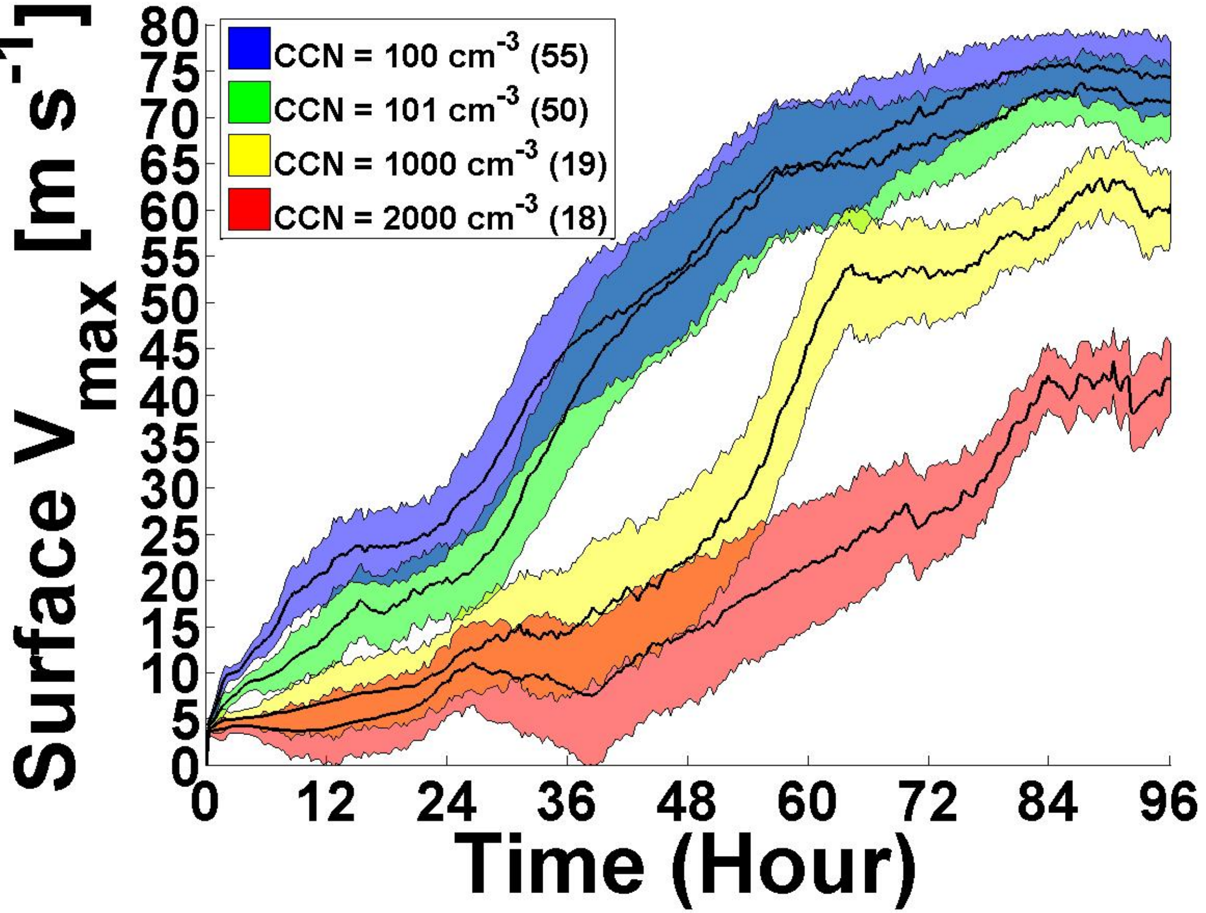
Distinct monotonic response to varying CCN

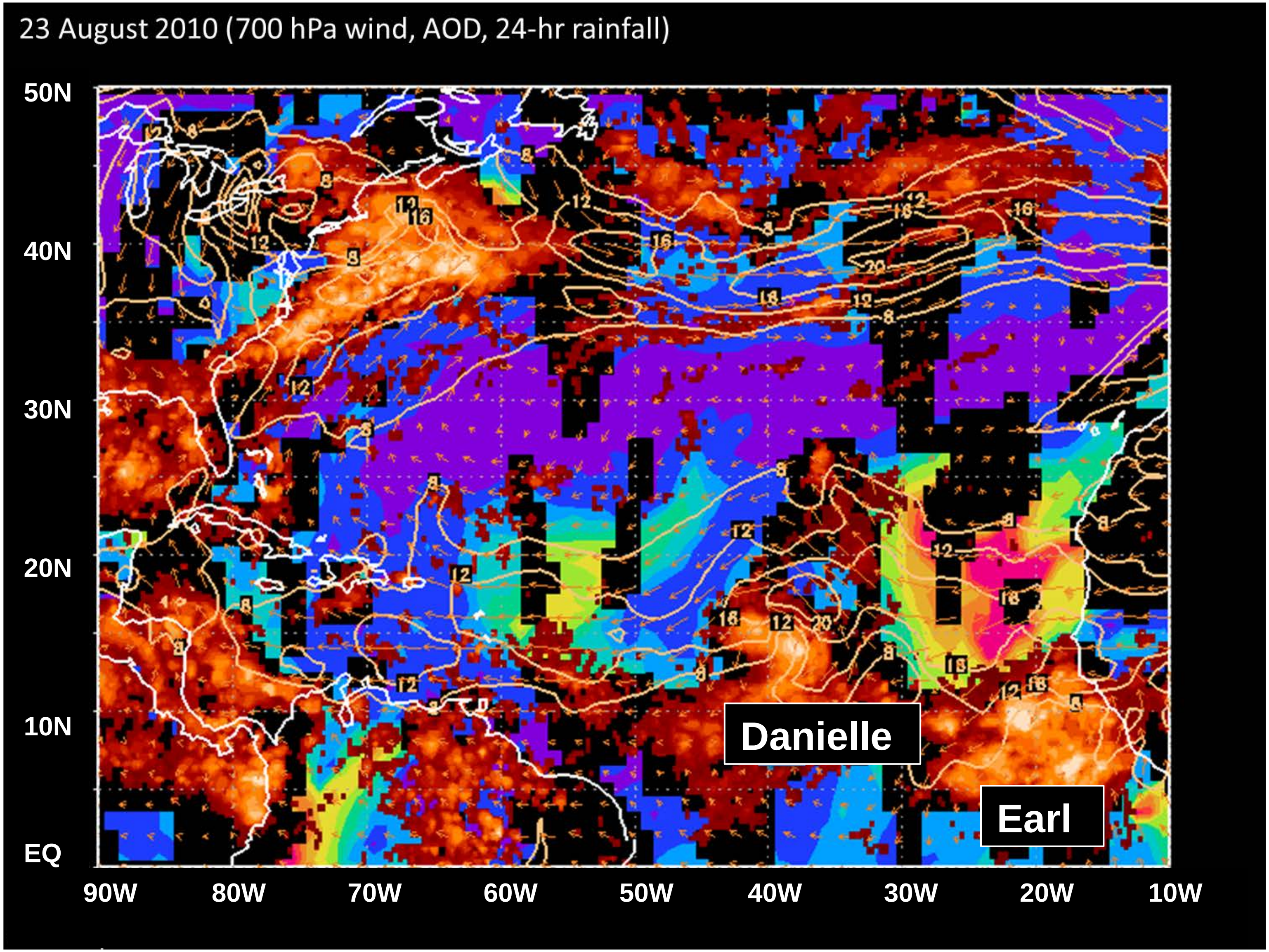


Ensemble where CCN concentration varied for different initial T, q, RMW, vortex height, bubble temperature

Distinct monotonic response to varying CCN

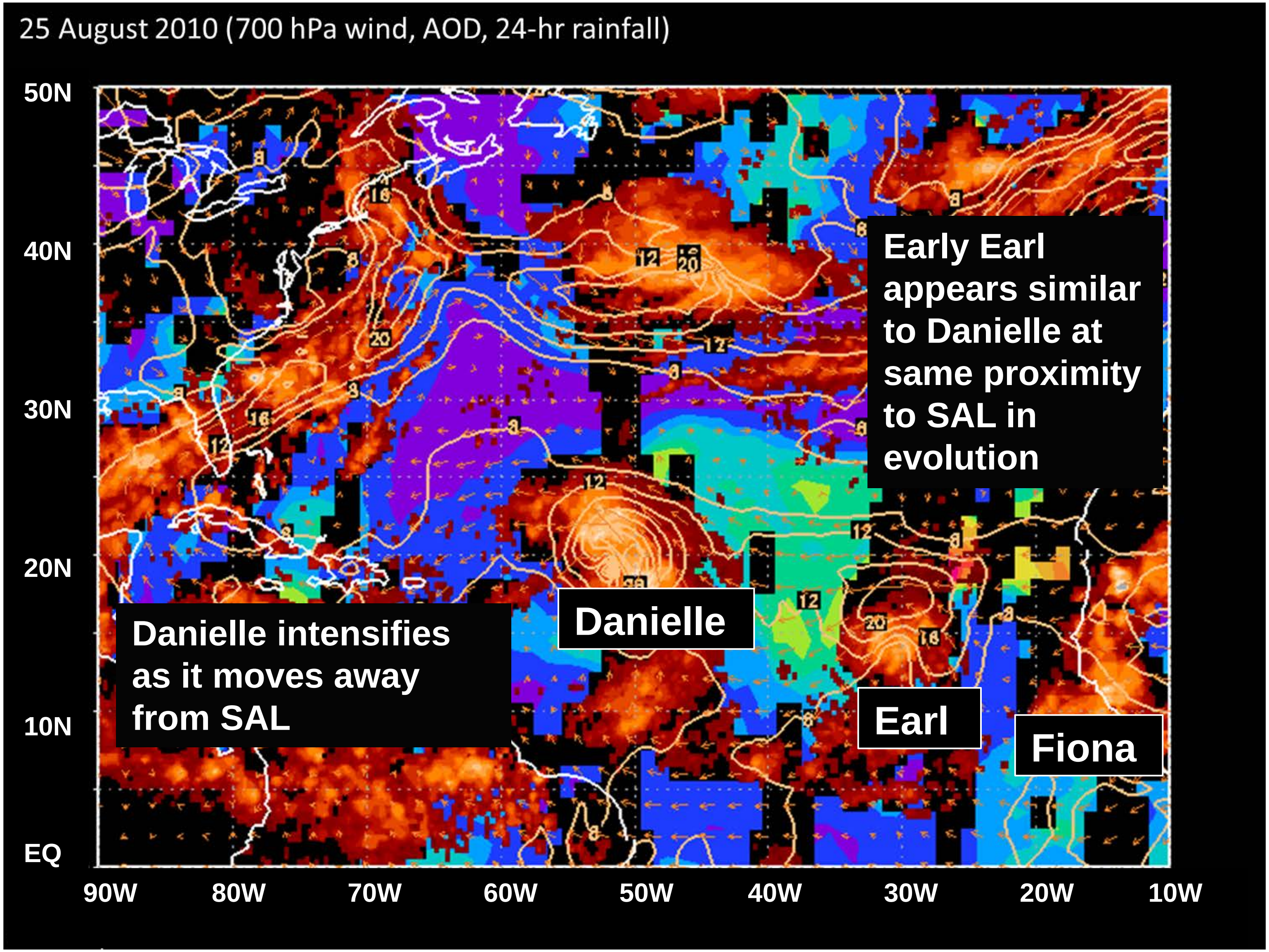
Future: dependence on time of CCN input, response to IN

Evolution of Danielle, Earl, and Fiona (2010)



- Orange coloring denotes 24 hour TRMM rainfall
- Color-filled contours represent AOD
- Contoured is 700 hPa wind

Evolution of Danielle, Earl, and Fiona (2010)



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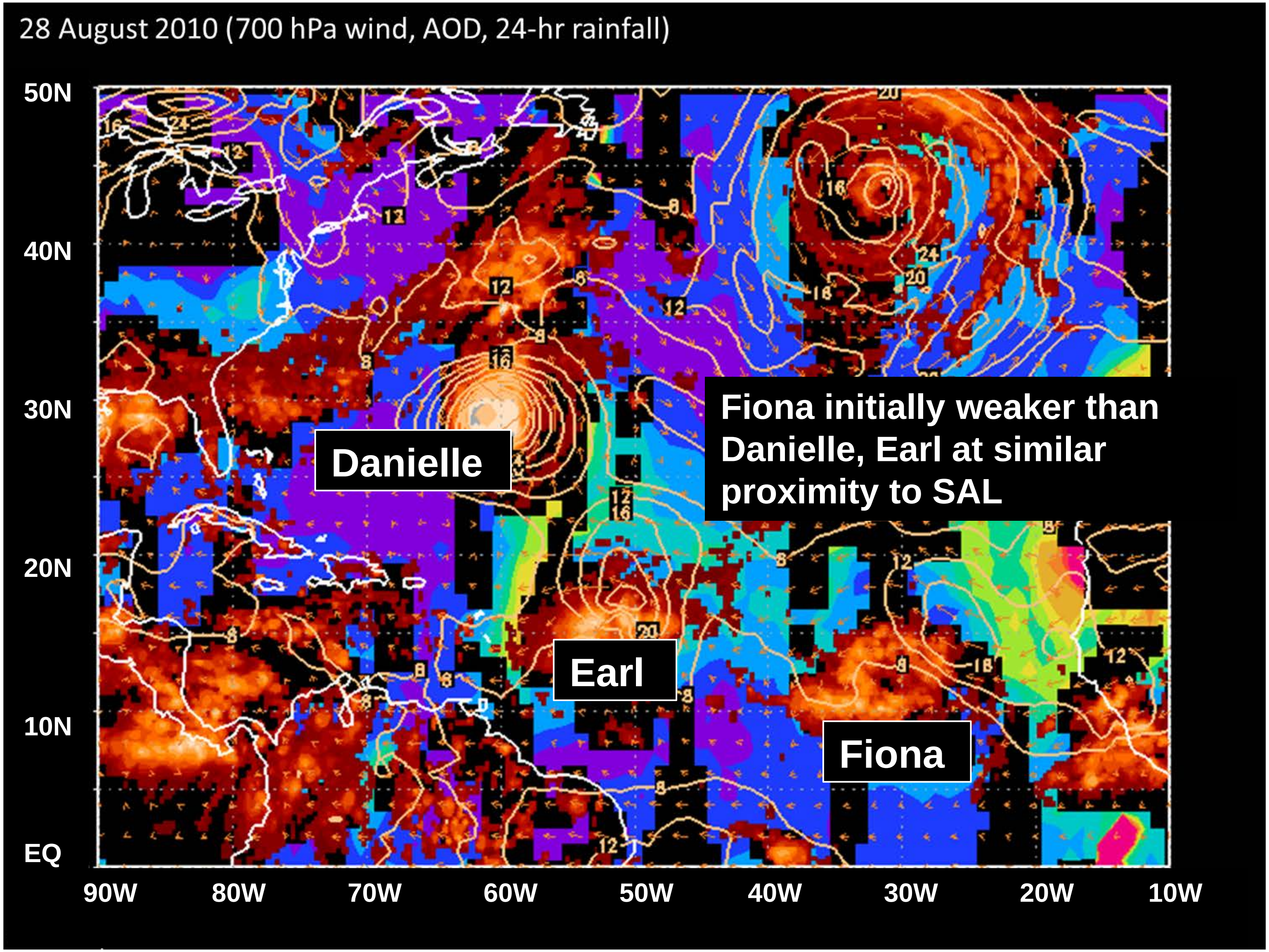

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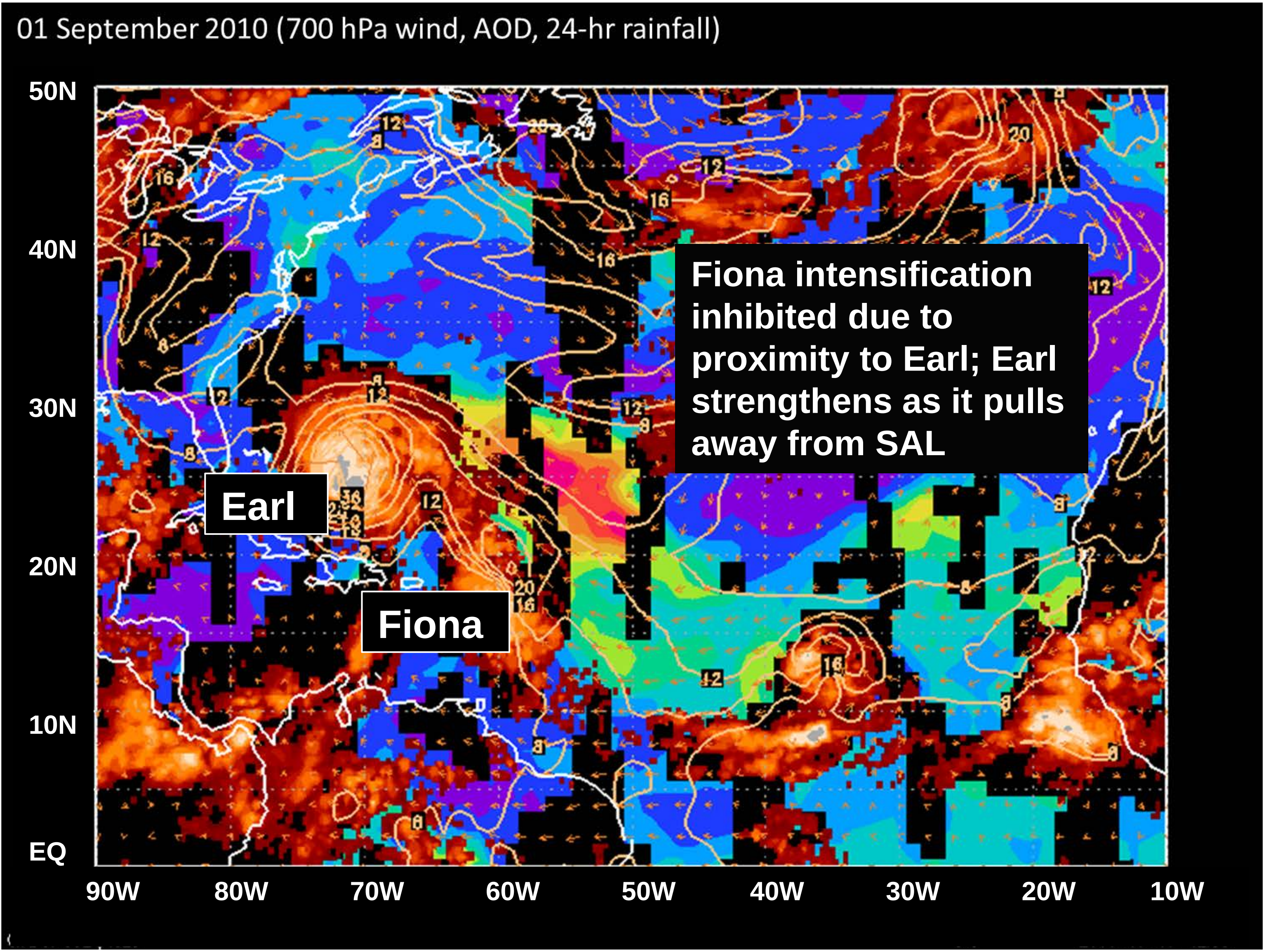

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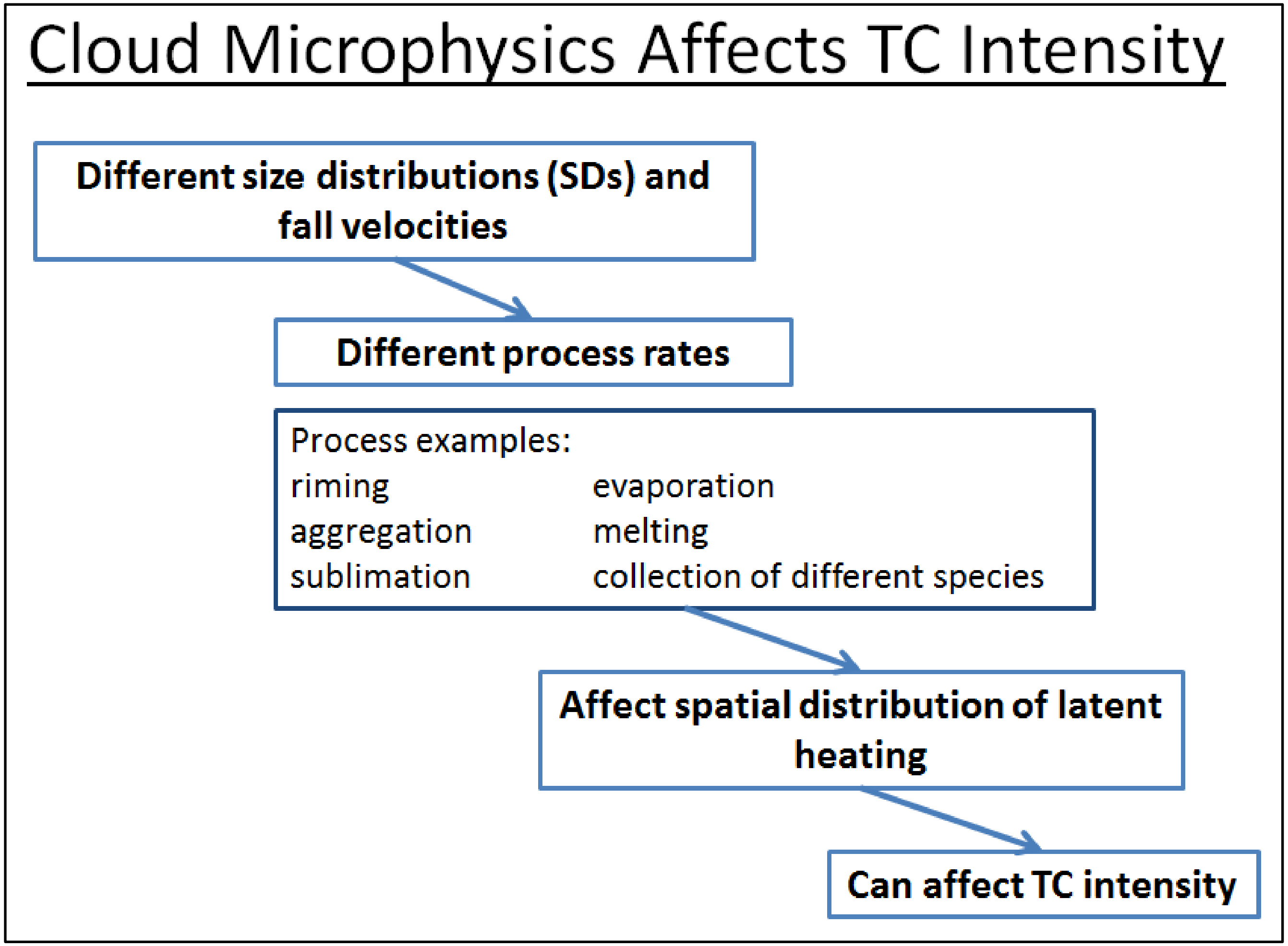
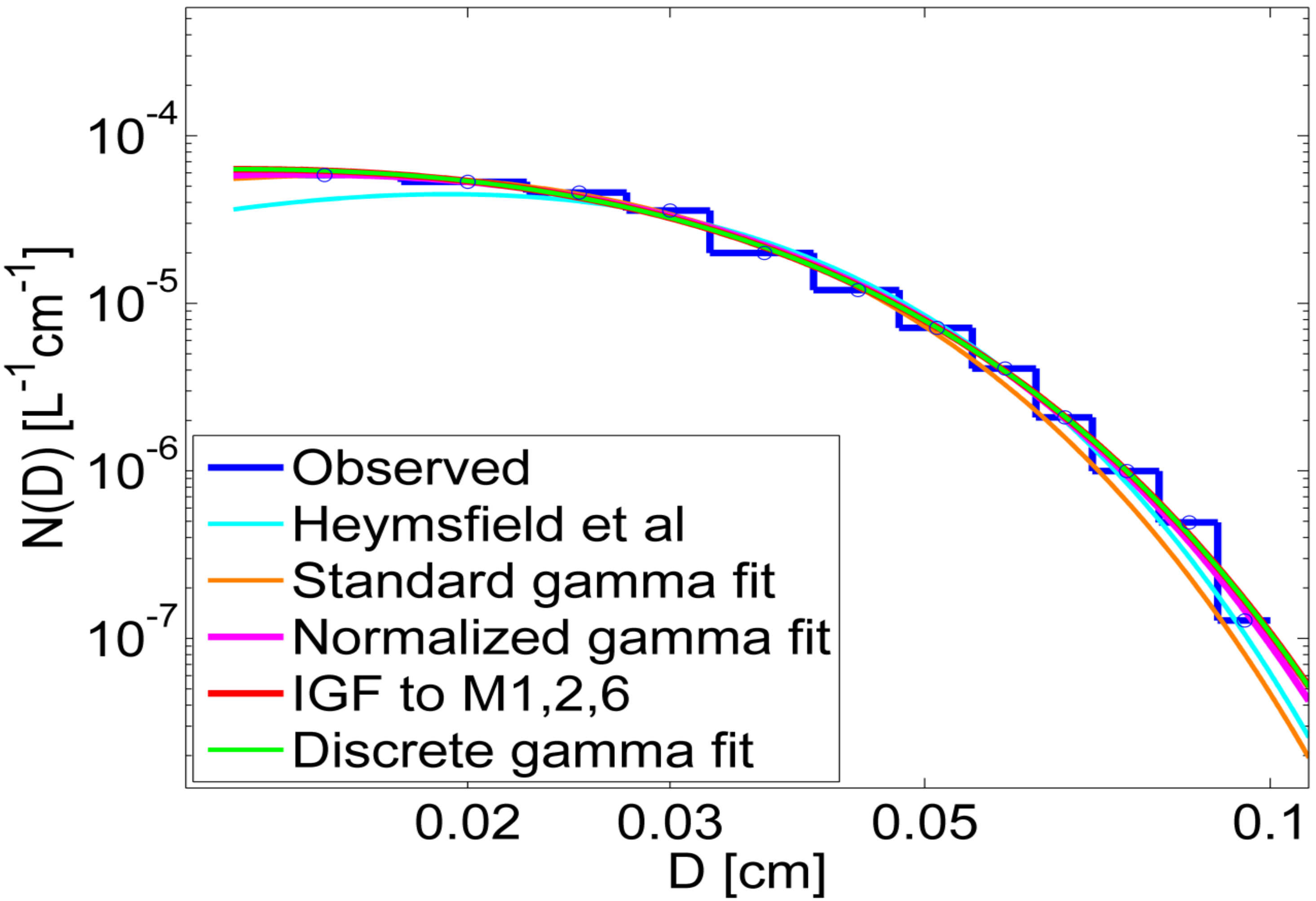
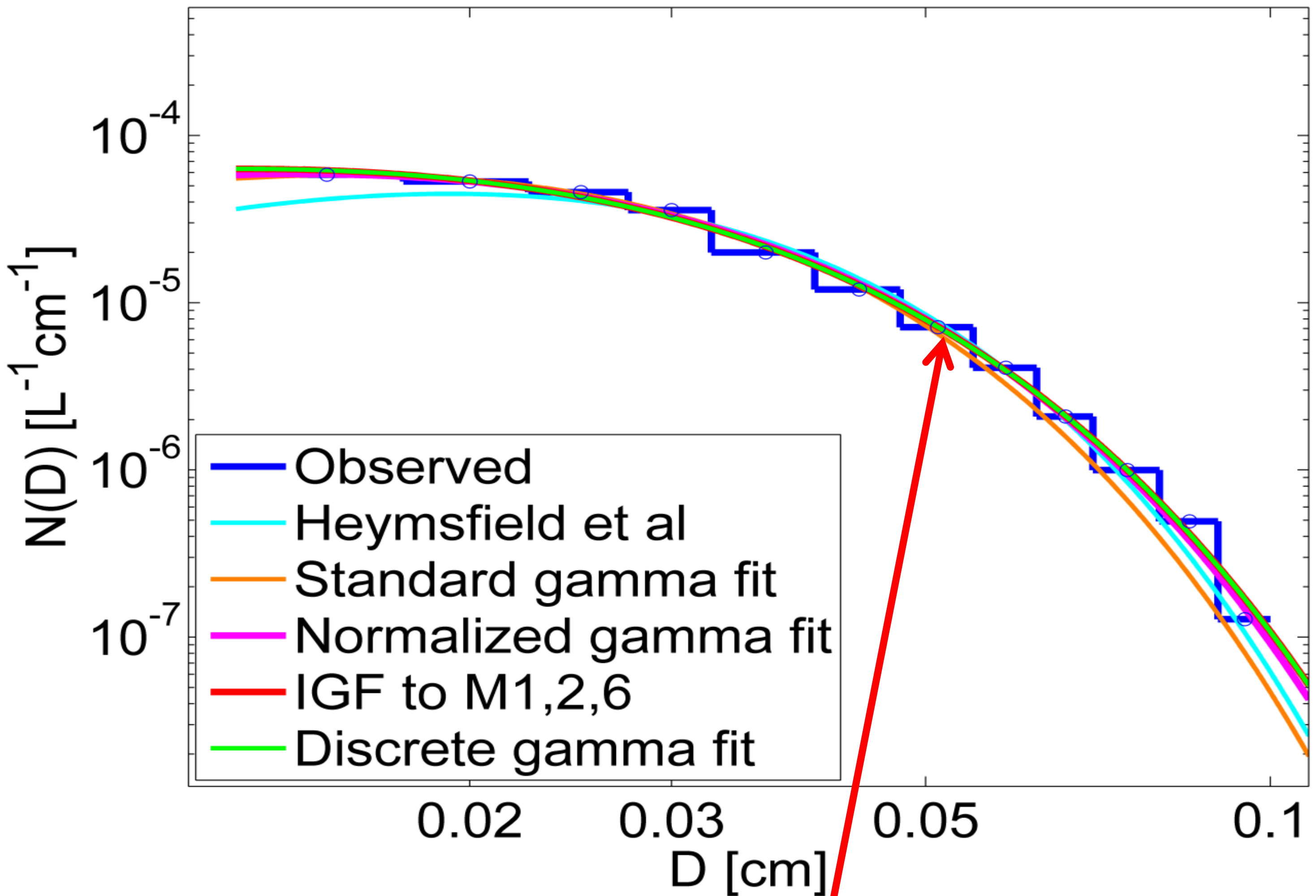


- **Gamma functions $N(D) = N_0 D^{\mu} e^{-\lambda D}$ are used to represent SDs**

How do N_0, μ and λ vary with environmental/cloud conditions, and how accurately can they be determined?

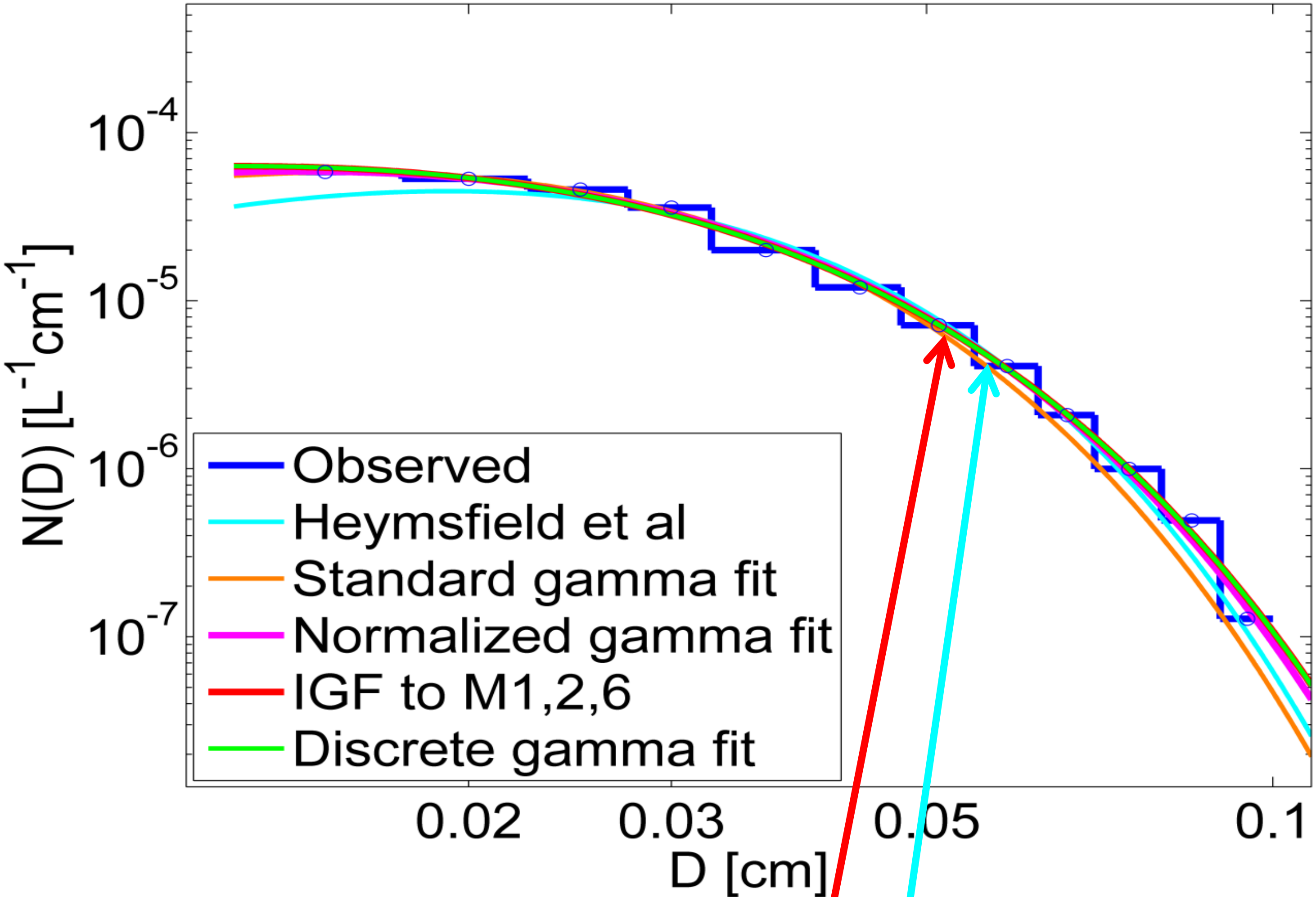


Even though fits all look quite good, there can be huge range in N_0, λ and μ



Even though fits all look quite good, there can be huge range in N_0, λ and μ

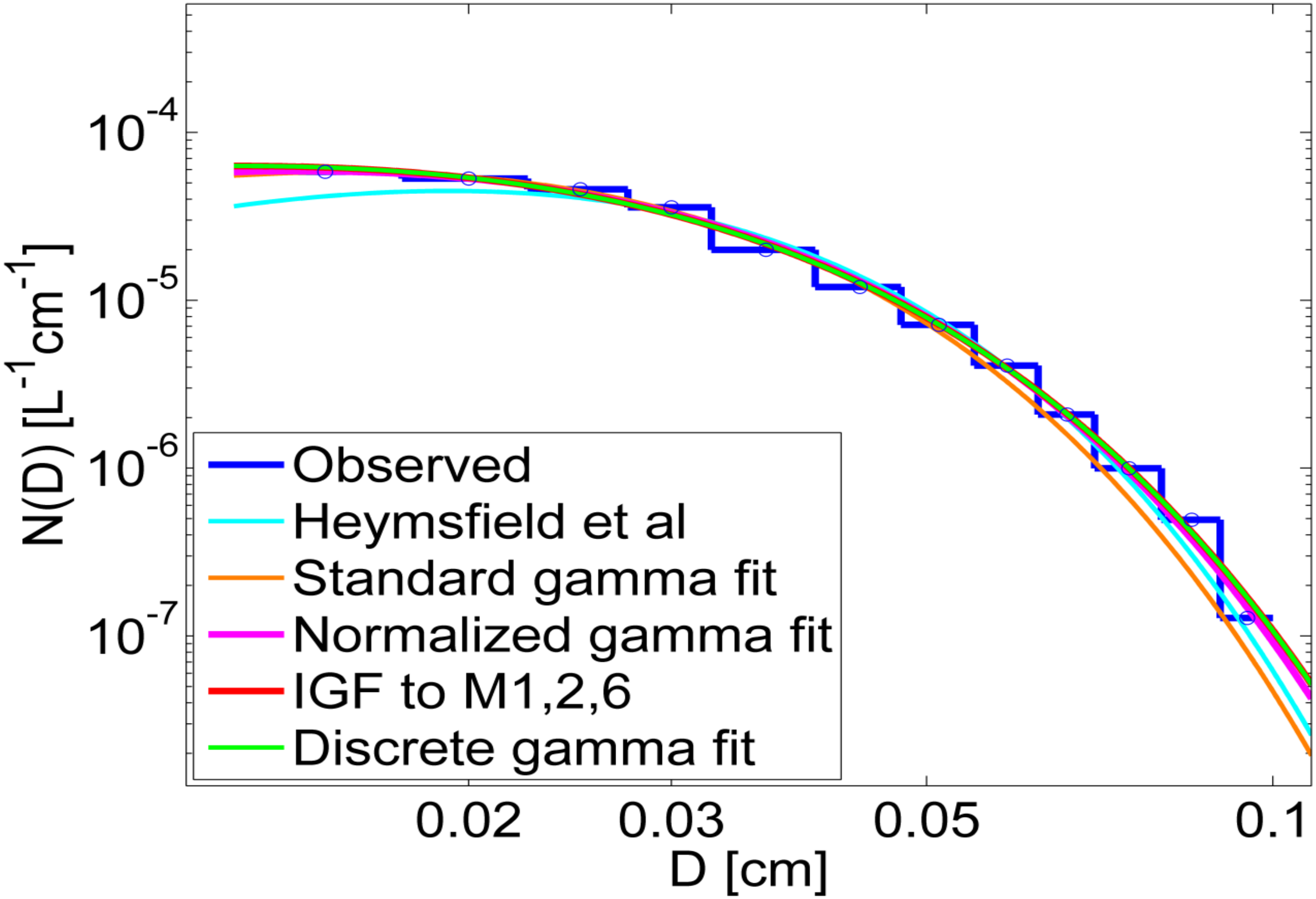
IGF: N_0 6.3×10^{-1} μ=1.86; λ =1.1×10^{2}



Even though fits all look quite good, there can be huge range in N_0, λ and μ

IGF: N_0 6.3×10^{-1} $\mu=1.86$; $\lambda=1.1\times10^{2}$

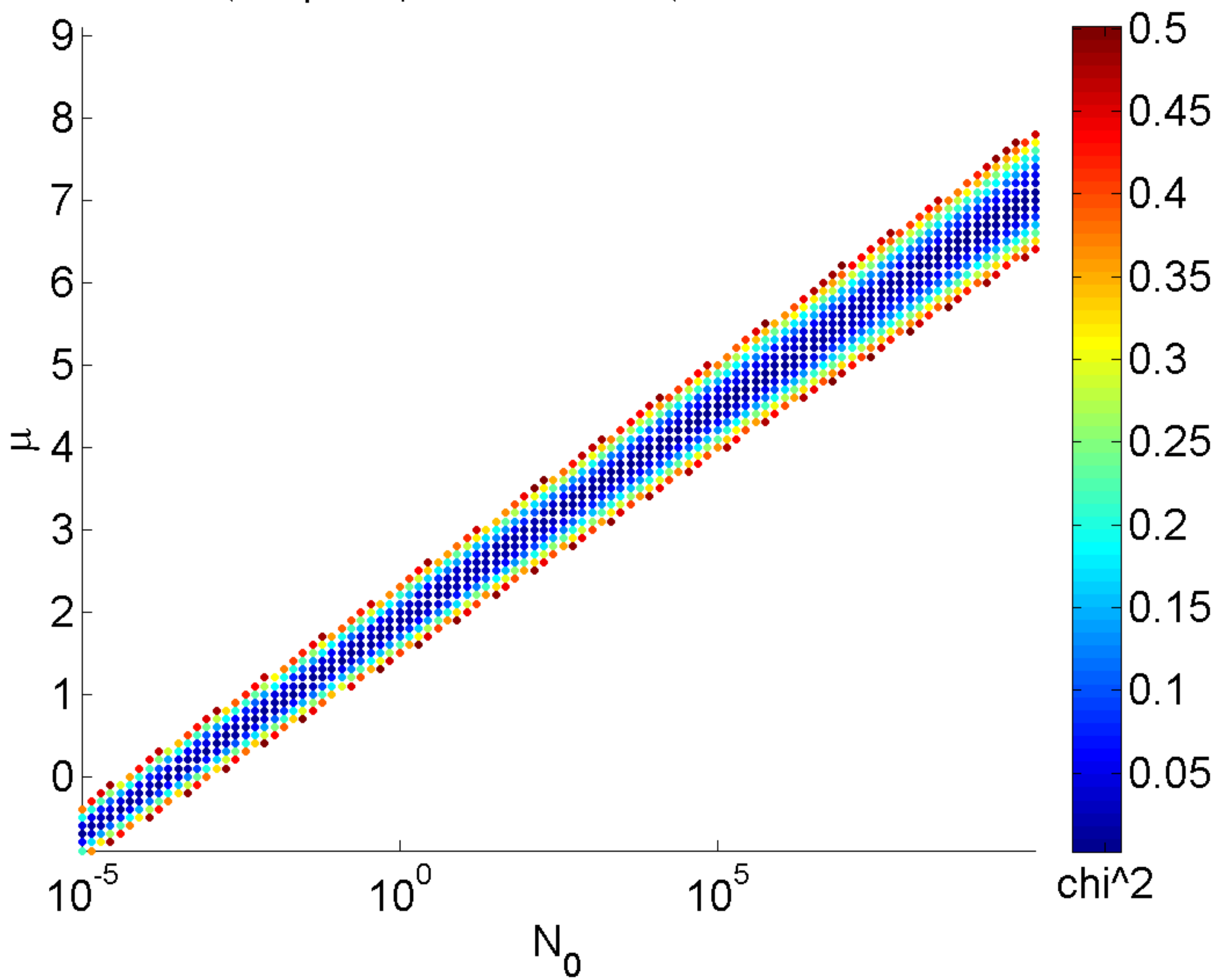
Hey: N_0 7.3×10^{1} $\mu=2.97$; $\lambda=1.4\times10^{2}$



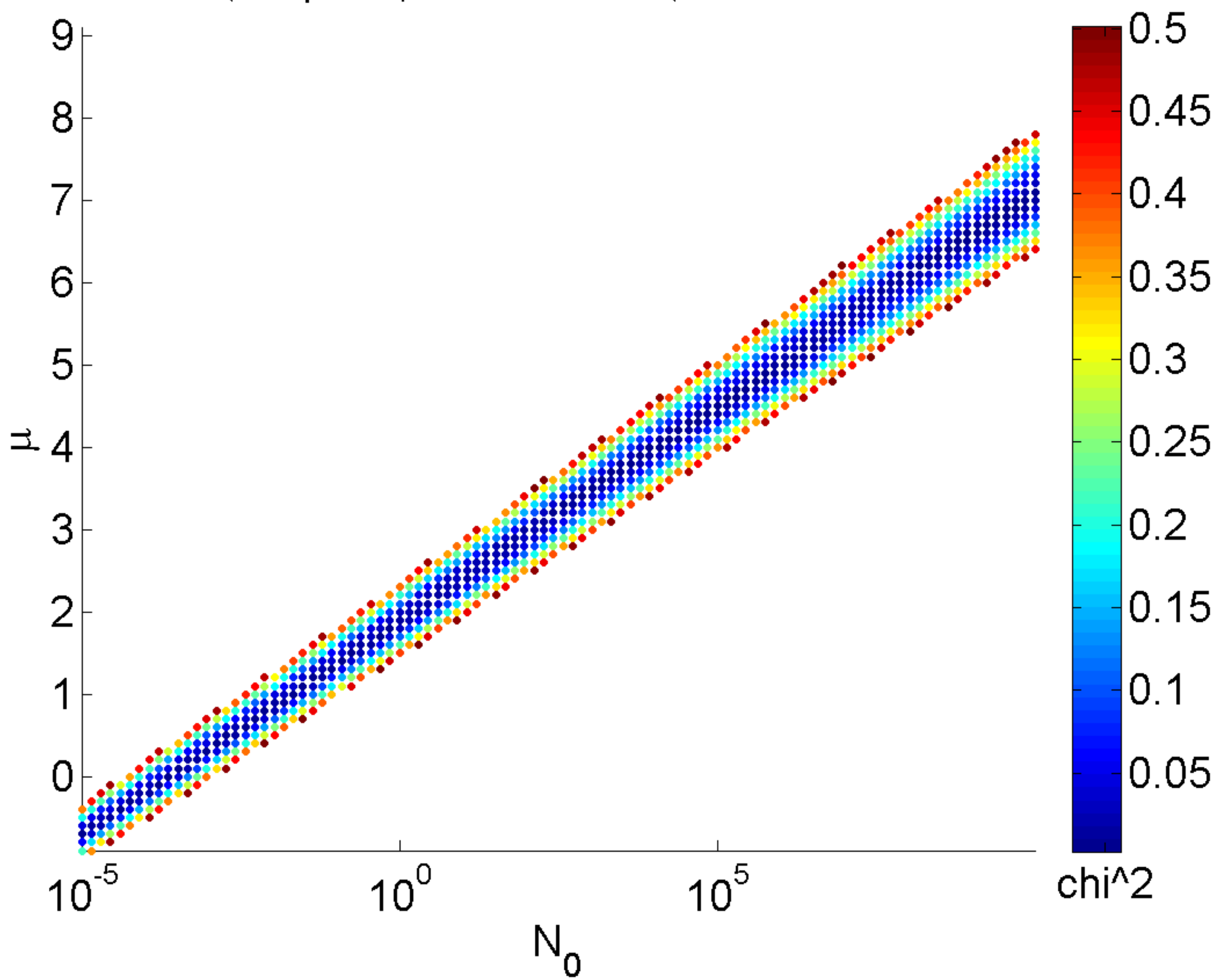
There is broad range of $N_0/\mu/\lambda$ that fit SD well

$N_0/\mu/\lambda$ determined depend on tolerance allowed

→ Can't represent by single $N_0/\mu/\lambda$ value



Surface of equally realizable solutions with $\Delta\chi^2 = 0.5$ of χ_{min}^2

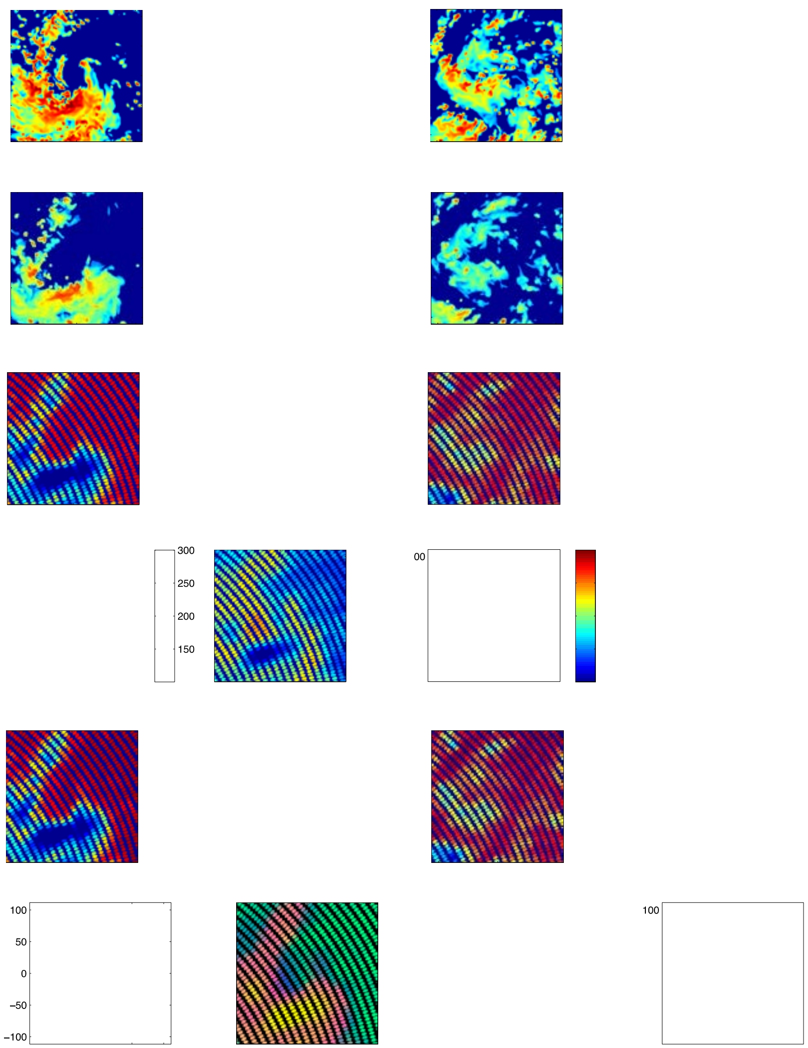


Show how surfaces vary with T, w, TC stage of development in Mascio et al. (2012)

How can operational passive microwave imagery help in observing, understanding and predicting RI processes and pathways?

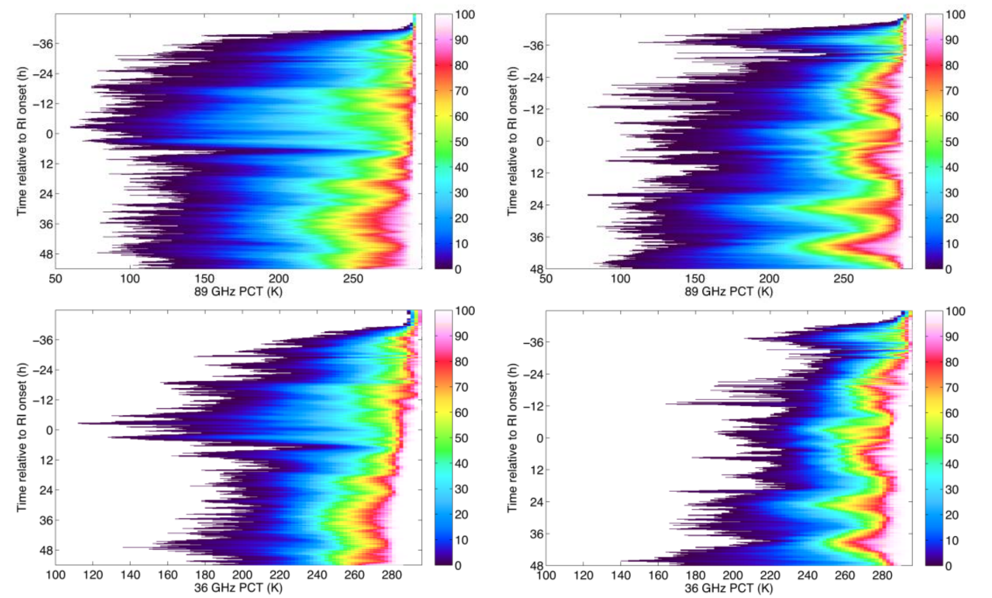
<u>Tool:</u> WRF + Nagoya/Goddard Satellite Data Simulator Unit

Earl *6 h prior to RI* Ike



Use simulations as prototypes for development of RI prediction algorithms, understand processes during RI going on in the model, and compare against FC, satellite observations

Earl *T_b CDFs* Ike

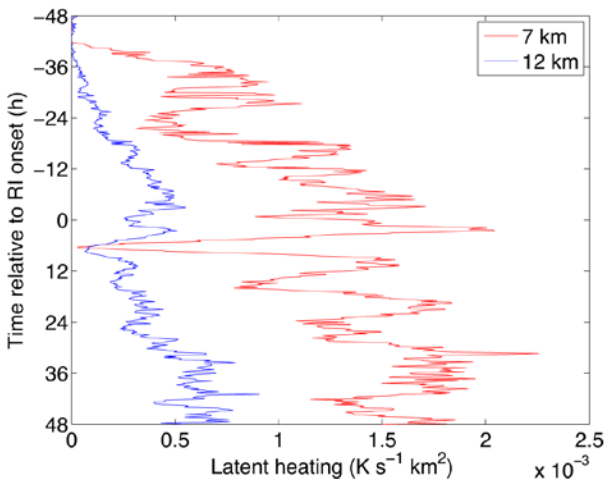


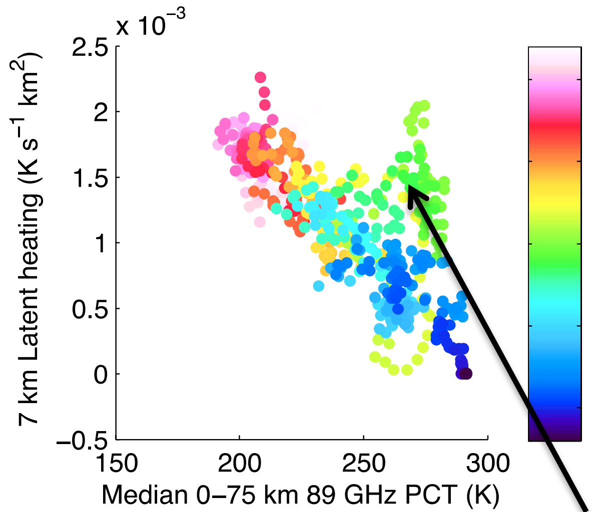
Earl – Gradual deepening, Ike – Rapid deepening +18-24 h

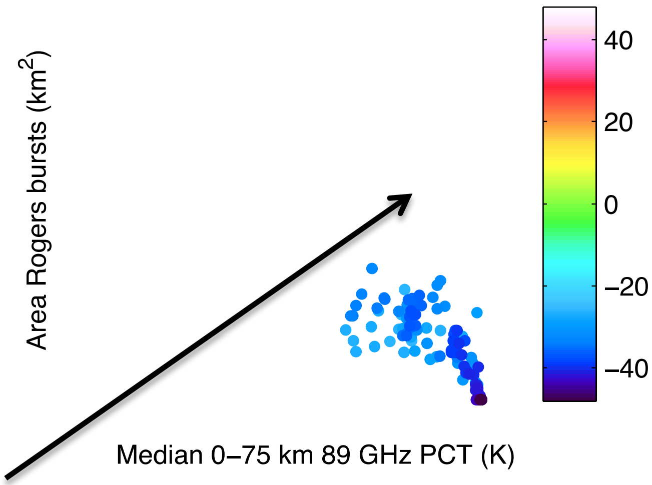
Earl WRF+SDSU output

Simulated latent heating and convective burst activity relative to RI onset

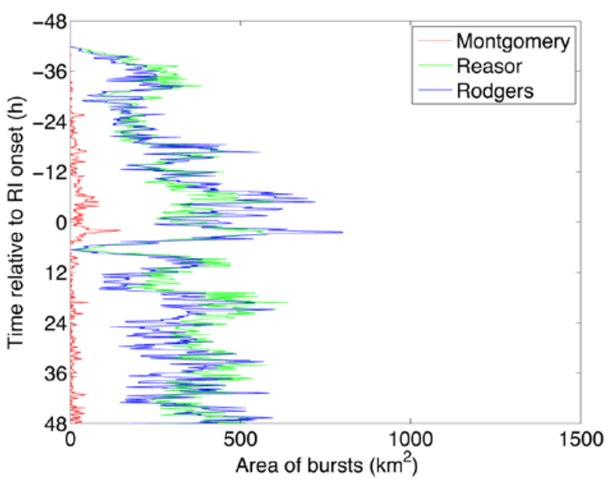
89 GHz Tb statistics (0-75 km median [top] and std dev [bottom]) as a function of time relative to RI onset (colors)

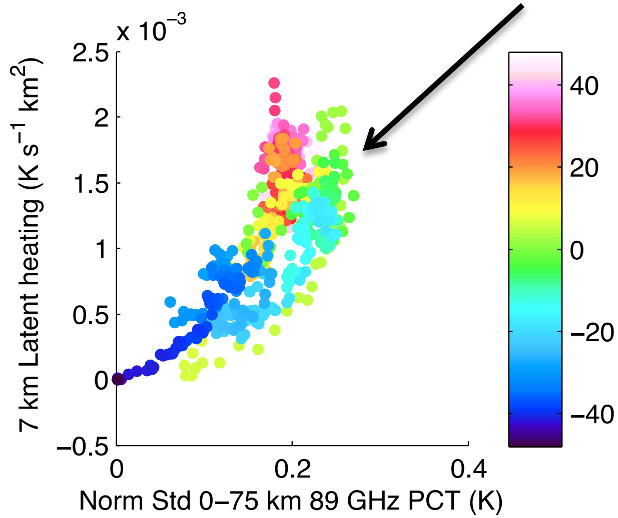


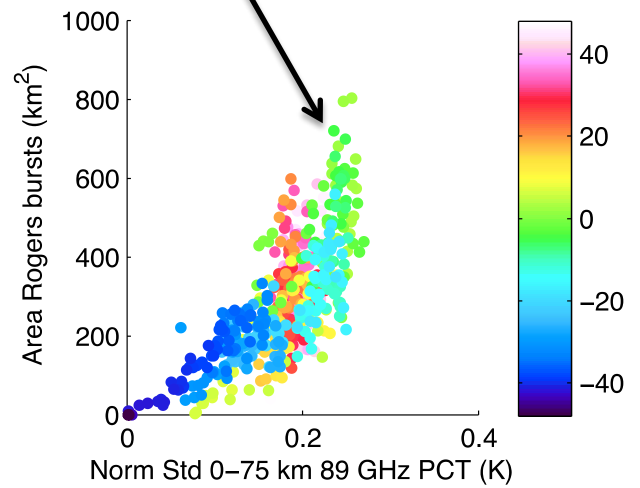




Asymmetric, “bursty” convection (modest median, large std dev) 18-0 h prior to RI







Ike WRF+SDSU output

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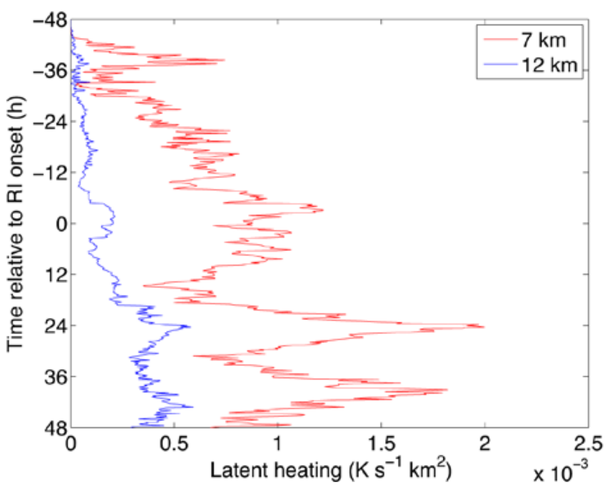
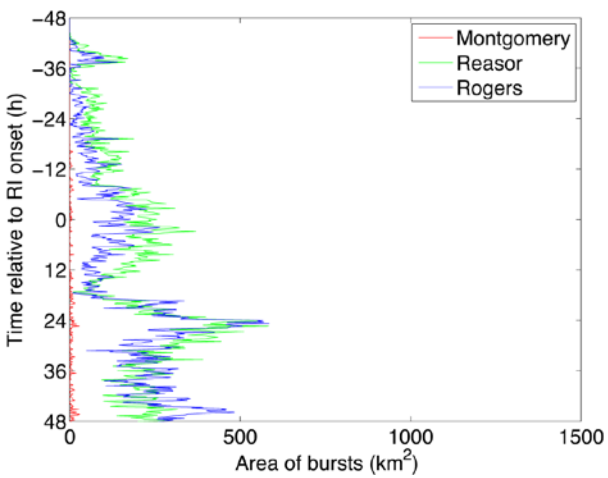
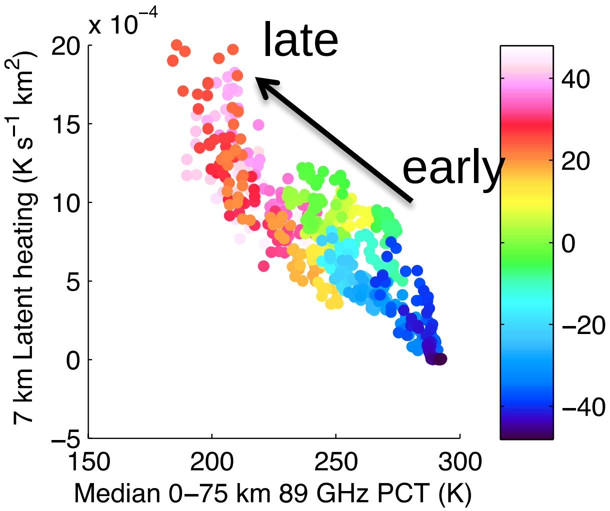
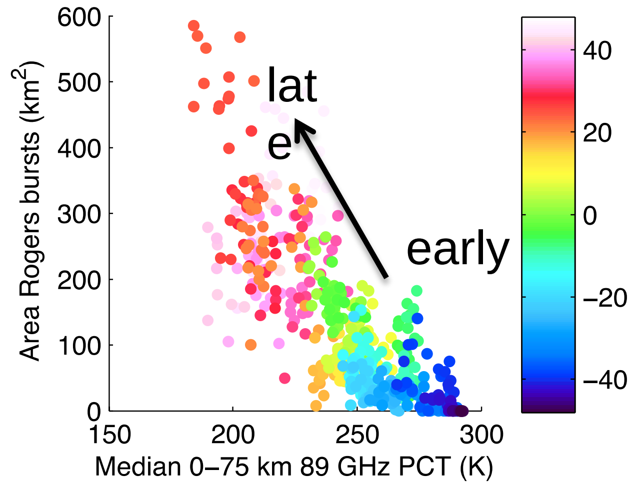


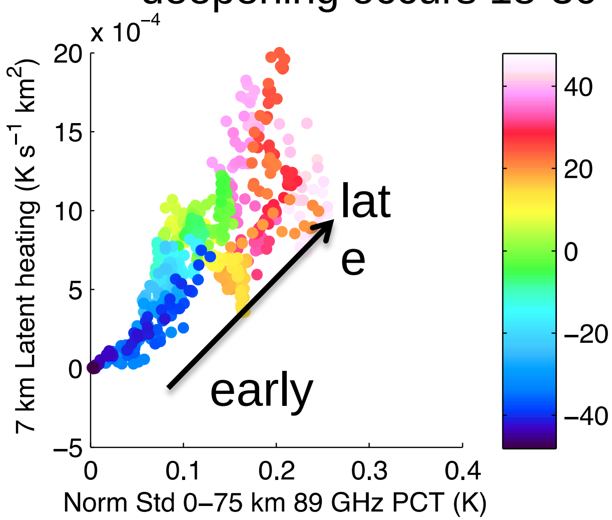


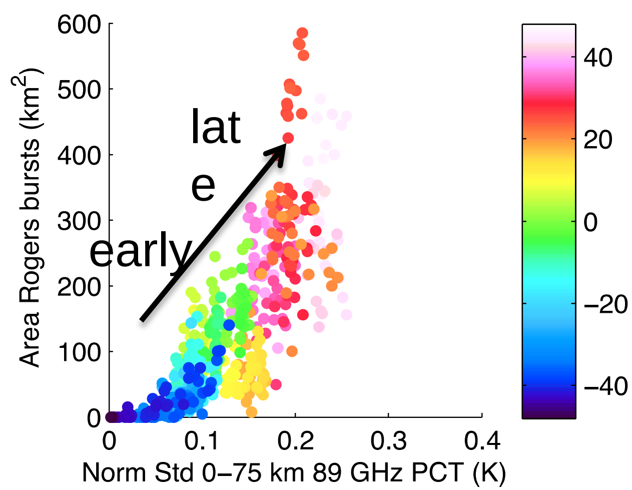
89 GHz Tb statistics (0-75 km median [top] and std dev [bottom]) as a function of time relative to RI onset (colors)





RI phase begins with symmetric modest convection, rapid deepening occurs 18-30 h after RI onset bursts ensue





See more at Poster Session II

Summary

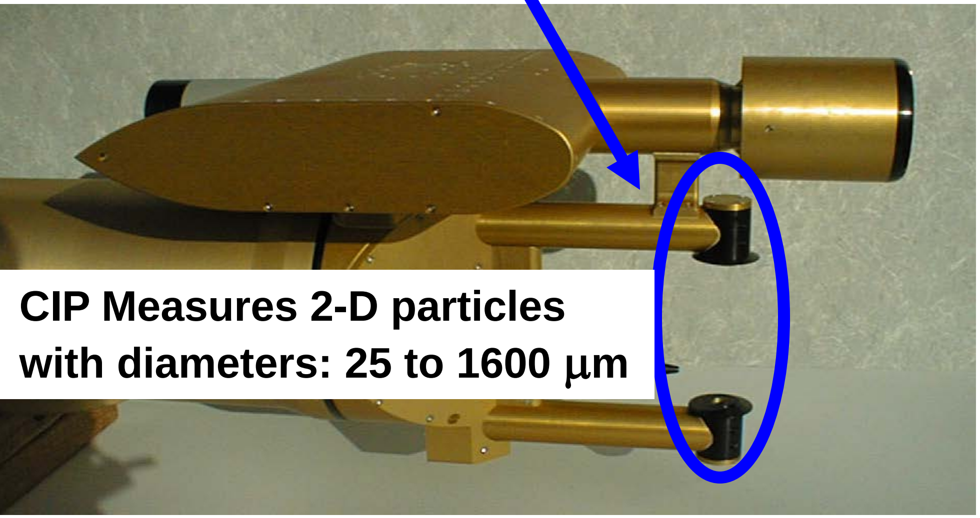
- WRF simulations of Dennis, Earl and Ike showing mid-level increases in vertical velocity outliers and hydrometeor upward fluxes are precursors to RI
  - Next step is to compare against GRIP+HS3 observations
- Techniques for understanding uncertainties in gamma parameters derived from in-situ data available
  - Next step is to apply to GRIP in-situ data
- Increases in CCN appear to weaken TC from idealized simulation
  - Next case is to simulate Earl and evaluate against observations
- Necessary to examine causes of RI as function of shear
  - Look for consistencies between model & 2010/2012-14 observations

How?

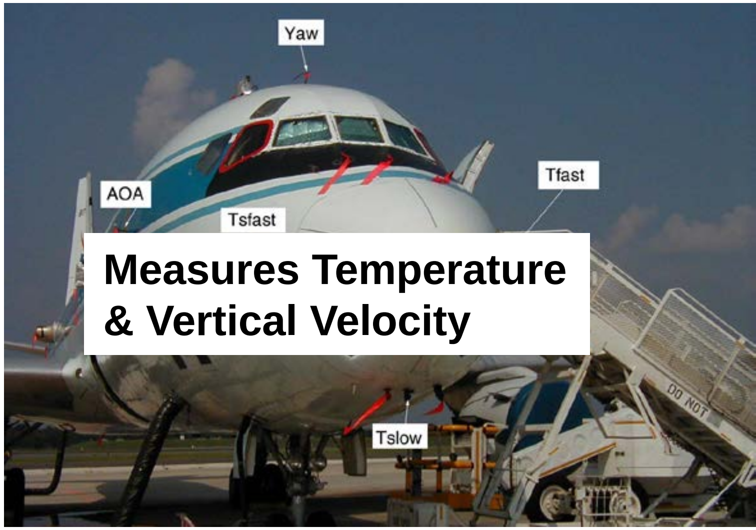
Probes

Cloud, Aerosol, and Precipitation Spectrometer (CAPS)

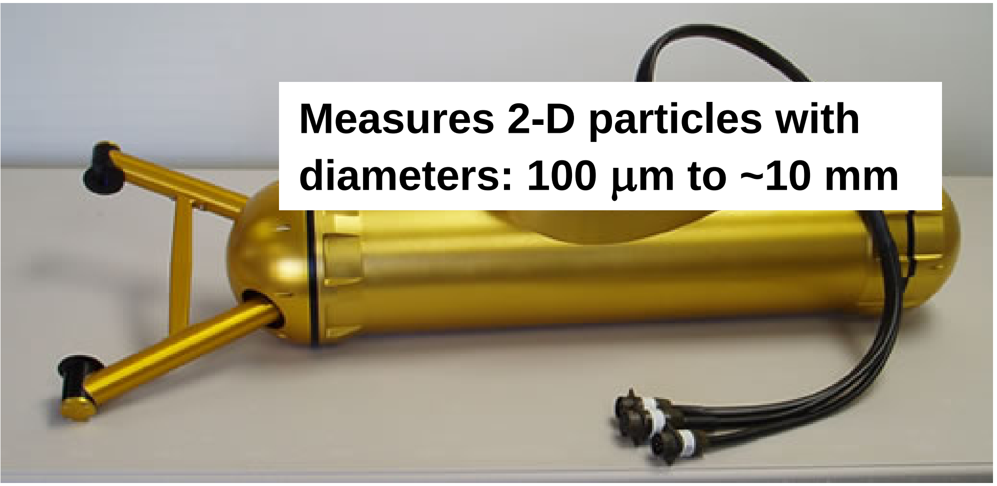
- *Cloud and Aerosol Spectrometer (CAS)*
- *Cloud Imaging Probe (CIP)*



Meteorological Measurement System (MMS)



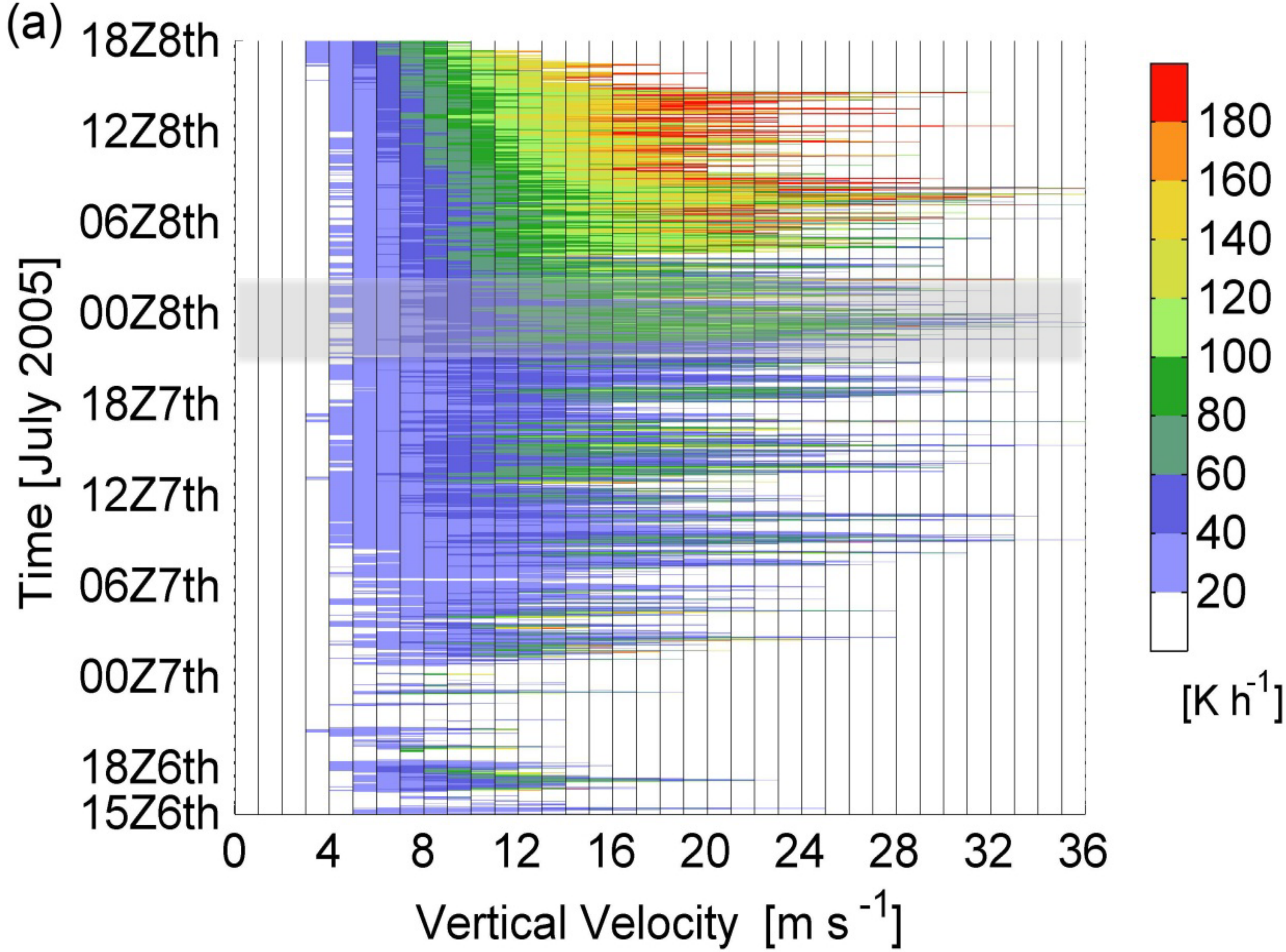
Precipitation Imaging Probe (PIP)



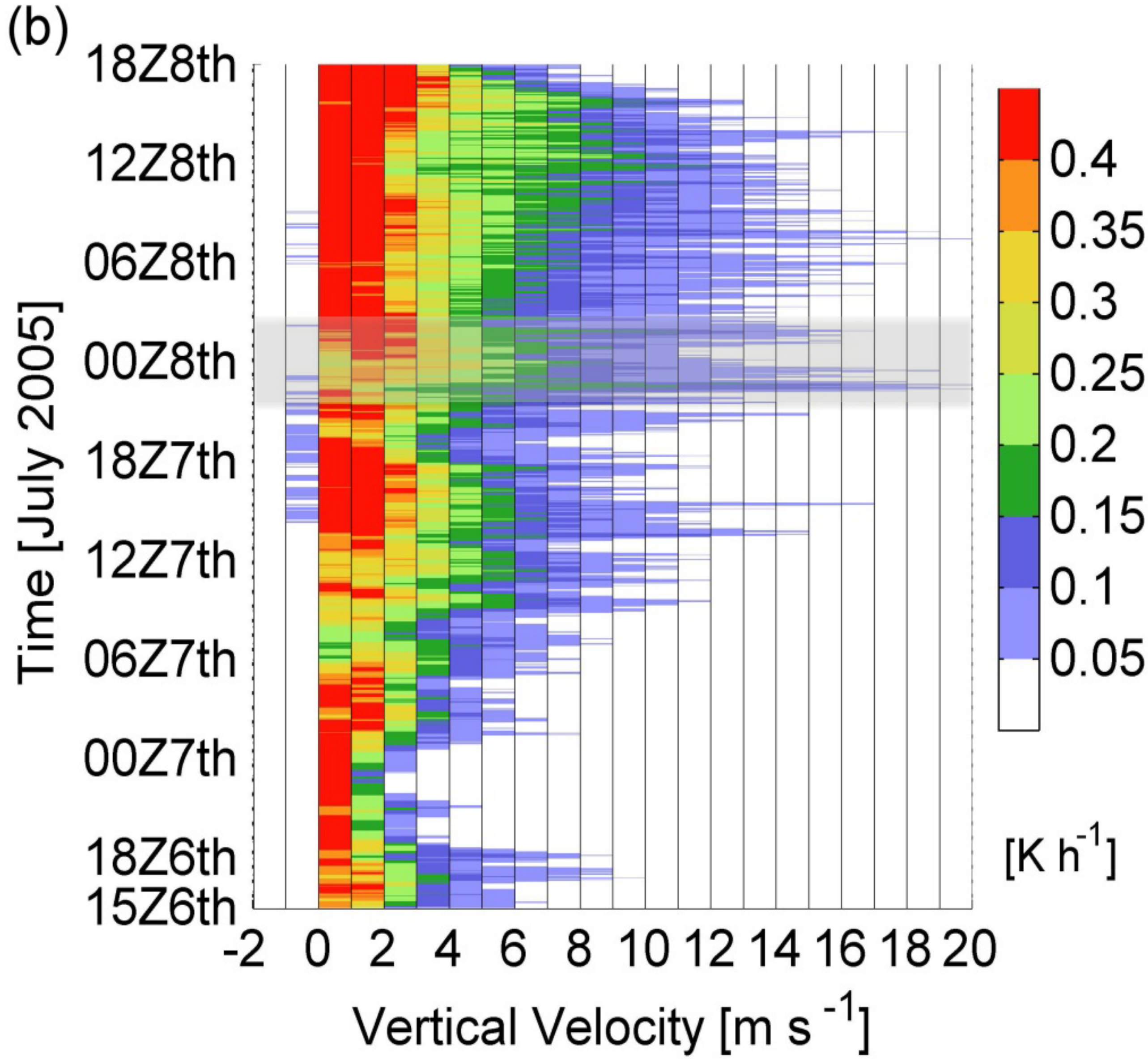
Composite Size Distribution:

CIP: $125 < D < 1000$ μm

PIP: $D > 1000$ μm



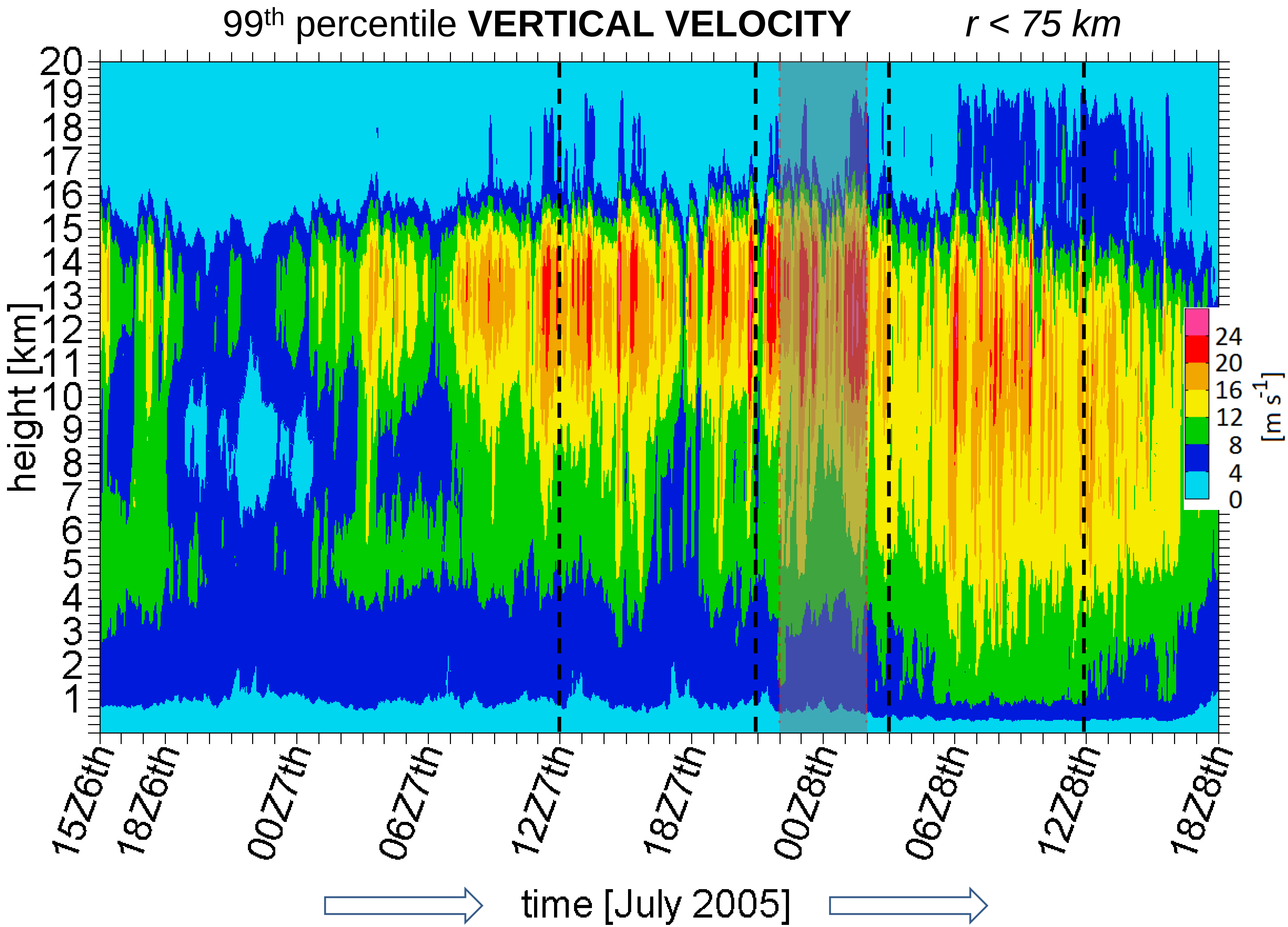
Average latent heating in volume elements with large vertical velocity is large, and increases after RI

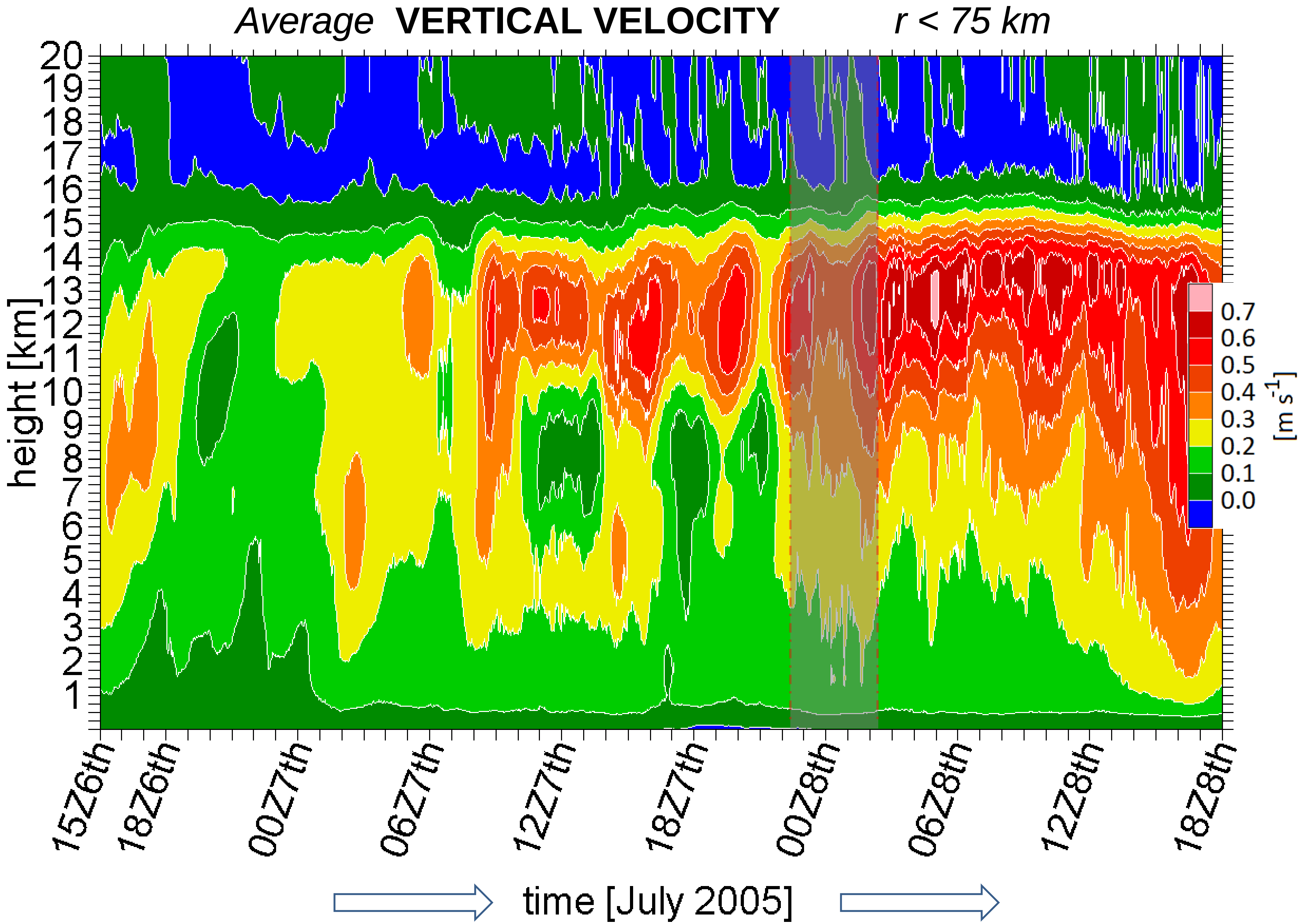


BUT, lower velocity bins dominate aggregate latent heating both before and after RI

Conclusions from WRF simulations

- **Outliers of w better indicator of RI than averages**
  - **Precursor to RI *at upper levels* (e.g., 14 km)**
  - **Continual broadening and convergence toward TC center**
- **Outlier (e.g., 99.9th percentile) w *at lower levels* (e.g., 6 km) increase only *after* onset of and *during* RI**
- **Immediately prior to RI, increase in upward hydrometeor mass flux for $10 < z < 15$ km**
  - **Levels with $z < 1.5$ km make big contributions to air mass updraft flux, but this does not seem to be precursor to RI**
- **Vertical velocities in 90-99.99th percentile have minimal effect on aggregate latent heating**
  - **Latent heating dominated by $w < 2$ m s^{-1}**
- **Necessary to examine causes of RI as function of shear**


99th percentile VERTICAL VELOCITY
r < 75 km
height [km]
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
24
20
16
12
8
4
0
[m s-1]
15Z6th
18Z6th
00Z7th
06Z7th
12Z7th
18Z7th
00Z8th
06Z8th
12Z8th
18Z8th
time [July 2005]


Average VERTICAL VELOCITY r < 75 km
height [km]
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
[m s-1]
15Z6th
18Z6th
00Z7th
06Z7th
12Z7th
18Z7th
00Z8th
06Z8th
12Z8th
18Z8th
time [July 2005]