Using 1-min GOES Observations to Diagnose Earlier Signs of Convective Initiation, Determine Cumulus Cloud Updraft Characteristics, and Infer In-Cloud Processes

John R. Mecikalski[1], Chris P. Jewett[2], and Jason Apke[1]

[1]Atmospheric Science Department
University of Alabama in Huntsville
Huntsville, Alabama, USA

[2]Earth Science Systems Center
University of Alabama in Huntsville
Huntsville, Alabama, USA

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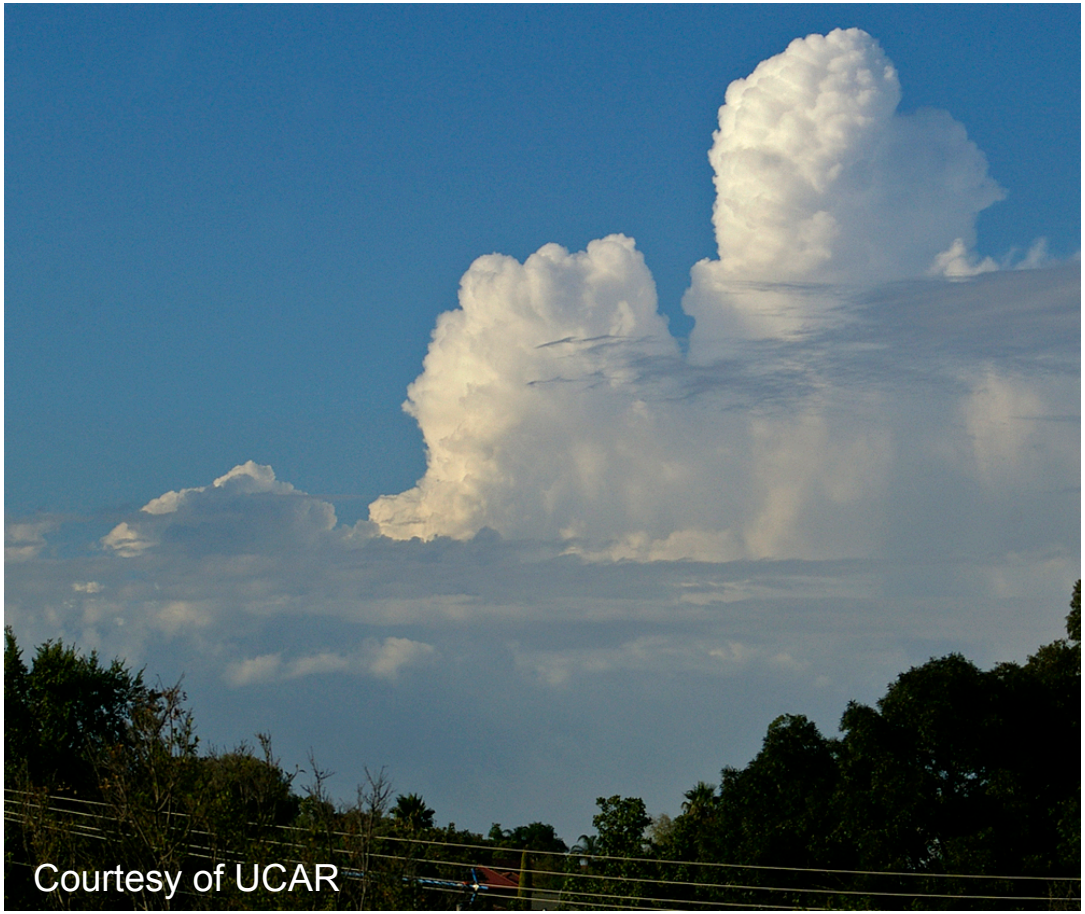
What Does SRSOR Data Offer?

– There remains a gap in our ability to observe in-cloud processes, below cloud top downward to where radar echoes may only be weakly developed. Yet, visual appearances of cumulus clouds can at least subjectively imply general features.
– High frequency observations are becoming more common, from satellite, radar, etc.
– New nowcasting capabilities...



– A lot of small cloud updraft structures
– Intermittent cloud growth early (“bubbling”)
– Larger updrafts seem to grow consistently

15 second data

c/o Martin Setvak

Motivation & Hypotheses for Study

(1) There is need to **understand how to use** geostationary satellite imagery datasets that will become available at 30-sec to 1-min time resolutions from the GOES–R Advanced Baseline Imagery (ABI); Also, Himawari–8 AHI as presently available.

- **New understanding**
- **New applications**

(2) Evaluation of 1 min updraft acceleration data provides a key link in the **use of cloud-top fields to diagnose *in-cloud* processes**, in a similar manner how the T–r_e concepts relate to updraft strengths (e.g., relatively small r_e values correlated with more intense updrafts).

(3) For the first time, **GOES data will arrive at frequencies greater than WSR-88D radar and other commonly observed weather data!**

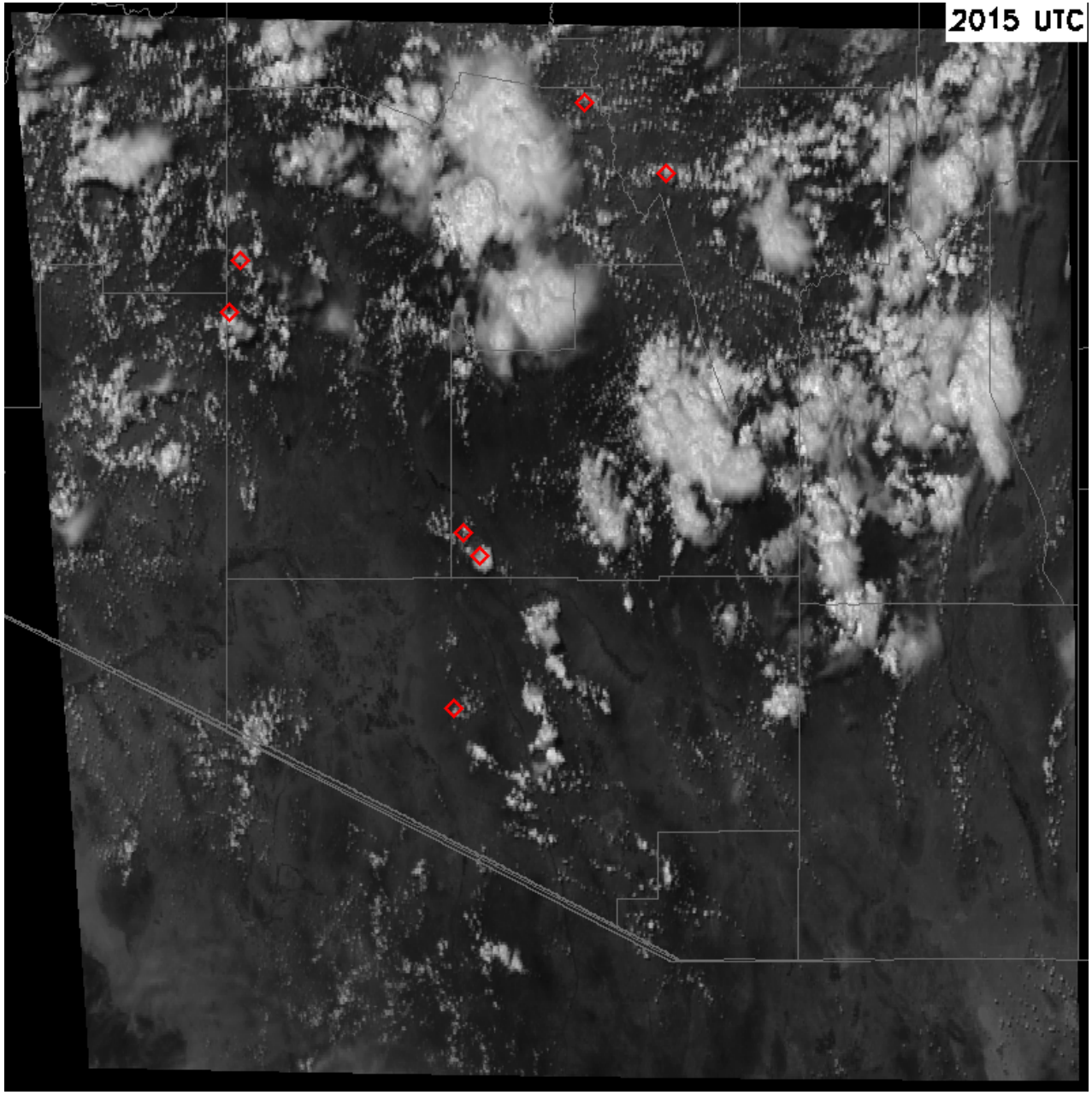
Collection of Updraft Information

20 August 2012
20 August 2013
11, 13 & 22 May 2014

Growing cumulus clouds between 1600 and 2200 UTC. Followed methodology of Lensky and Rosenfeld (2006)

Red circles are located of sampled updrafts.

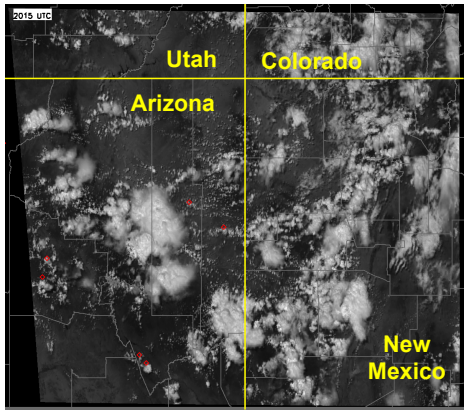
Catalog 10.7 μm T_B, and compute vertical motions, assuming GOES 10.7 μm T_B is equivalent to cloud-top temperature for optically thick clouds. Also, consider method by Adler and Fenn (1981).



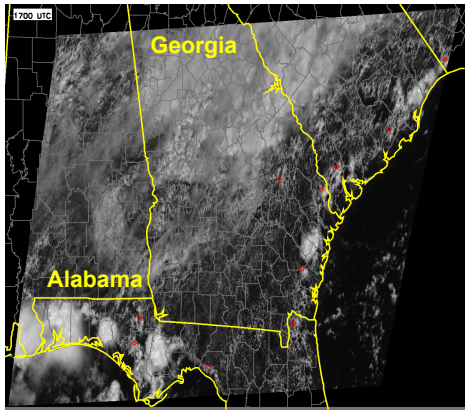
Regions of SRSOR updraft collection for this study.

Additional SRSOR data were collected in 2015

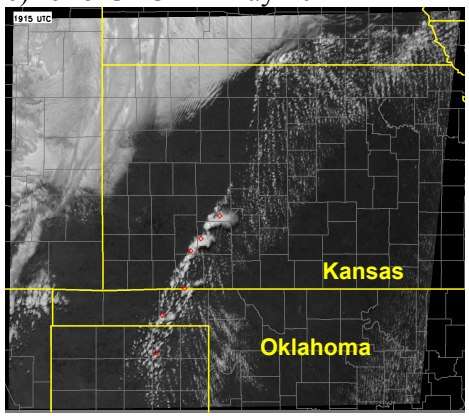
a) 2015 UTC 20 August 2012



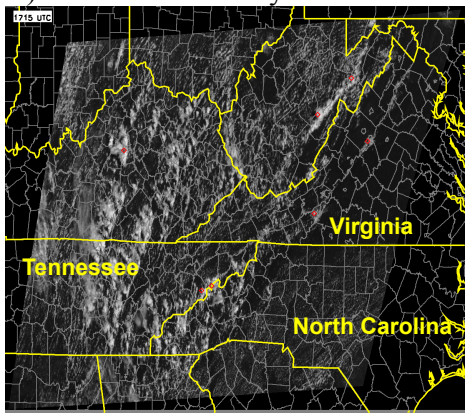
b) 1700 UTC 20 August 2013



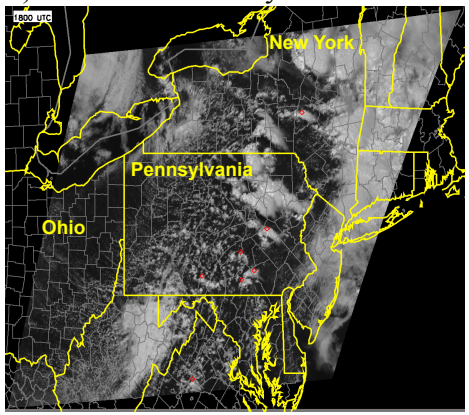
c) 1915 UTC 11 May 2014



d) 1715 UTC 13 May 2014



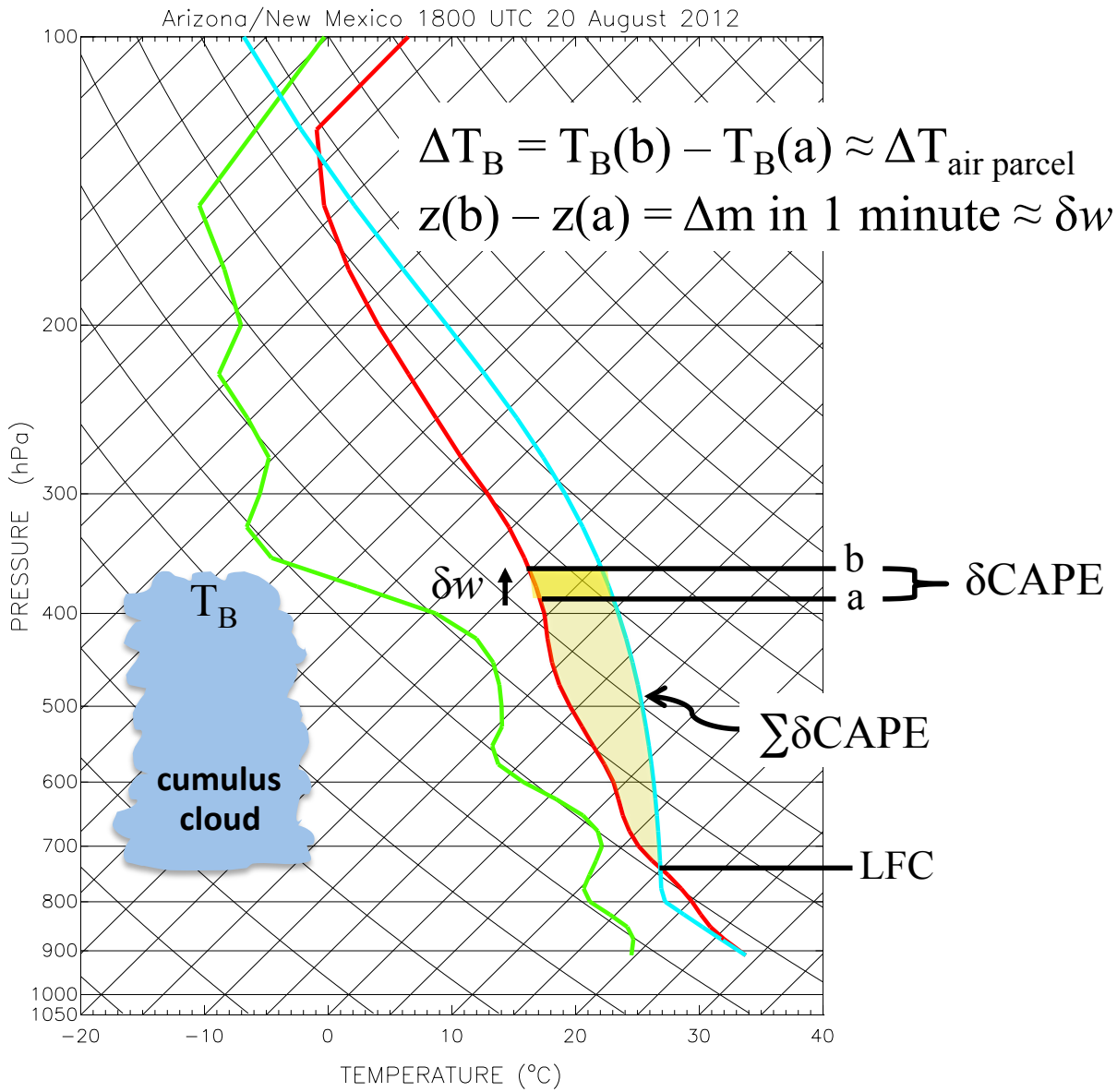
e) 1800 UTC 22 May 2014



Methodology

- Updraft collection:
  - Evaluated 71 updrafts, which span from 33 to 152 min in a Lagrandian framework
  - Derived *w* and the change in w (δw; ms^{-1}) in 1 minute increments
  - Develop summed incremental amount of CAPE an updraft penetrated through for each 1–min of cloud growth ($\sum\delta$CAPE; Jkg^{-1}) for comparison to *w*
- Collect proximity (~2 model grid points) soundings from Rapid Update Cycle (RUC) and Rapid Update (RAP) models as a means of assessing the thermodynamic environment in which the cumulus clouds were developing.
- Once the vertical motions were computed, determine the change in CAPE (δCAPE) over the vertical distance the updraft moved over the previous 1 minute, using RUC/ RAP model soundings. Sum δCAPE to the new level and form an updated $\sum\delta$CAPE.
- Assess correlations between δw and $\sum\delta$CAPE, across all updrafts, as well as for individual updrafts.
- Evaluate when correlations are highest, and in turn, where they were the lowest.
- Determine what properties of in-cloud processes GOES SRSOR data help measure.
- Also compute SRSOR 3.9 μm reflectance, as a proxy to cloud-top glaciation (when 3.9 μm reflectance falls below 9%; Lindsey et al. 2006).
- Assess relationships between δw and 3.9 μm reflectance.

Methodology



Theory – Factors influencing parcel vertical accelerations

In the absence of dynamic perturbation pressure effects (Emanuel 1994, p. 7–8), the vertical acceleration of a parcel can be described as

$$\frac{dw}{dt} = -\frac{\rho'}{\rho} g \approx -\frac{T_v'}{\overline{T}_v}$$

Where g is gravity, ρ is density relative to a hydrostatic basic state, ρ' is the perturbation from the basic state, T_v is the basic state virtual temperature, while T_v' is the perturbation virtual temperature. Substituting $T_v'=T_v-T_v$ in Eq. (1), we arrive at an expression for parcel buoyancy (B),

$$\frac{dw}{dt} = -g\frac{(T_v' - \overline{T}_v)}{\overline{T}_v} = B$$

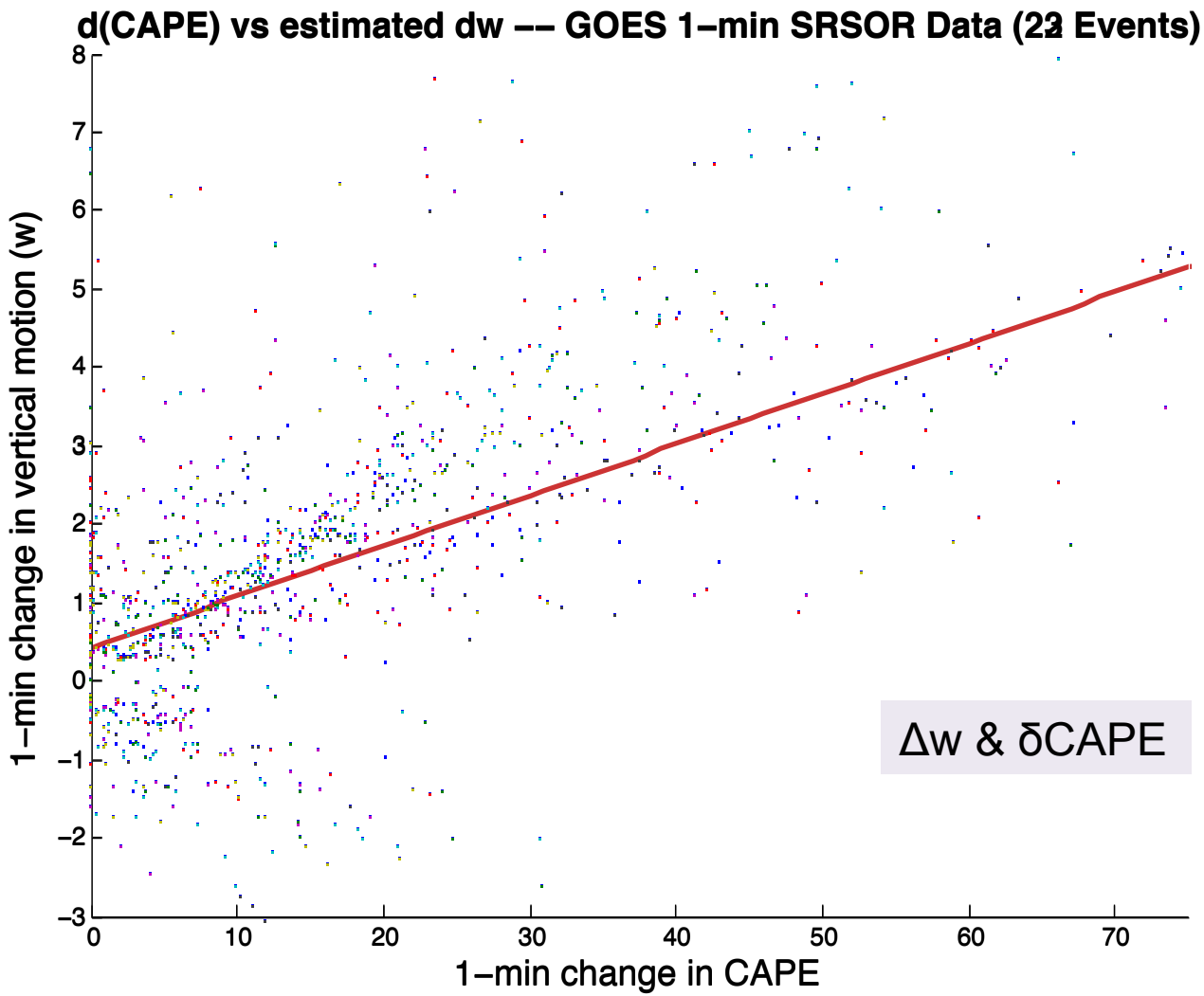
Equations (1) and (2) can be further expanded using the equation of state $p=\rho R_d T_v$ and $T_v \approx T(1+0.61q_v)$, where q_v is the mixing ratio of water vapor in air (Houze 1993, pp. 26 and 36), leading to

$$B = g\left(\frac{T'}{\overline{T}} - \frac{p'}{\overline{p}} + 0.61q_v - q_H\right)$$

What aspects of *B* can 1–min GOES data measure?
CAPE profile? Latent Heat Release? Entrainment? Hydrometeor Loading?

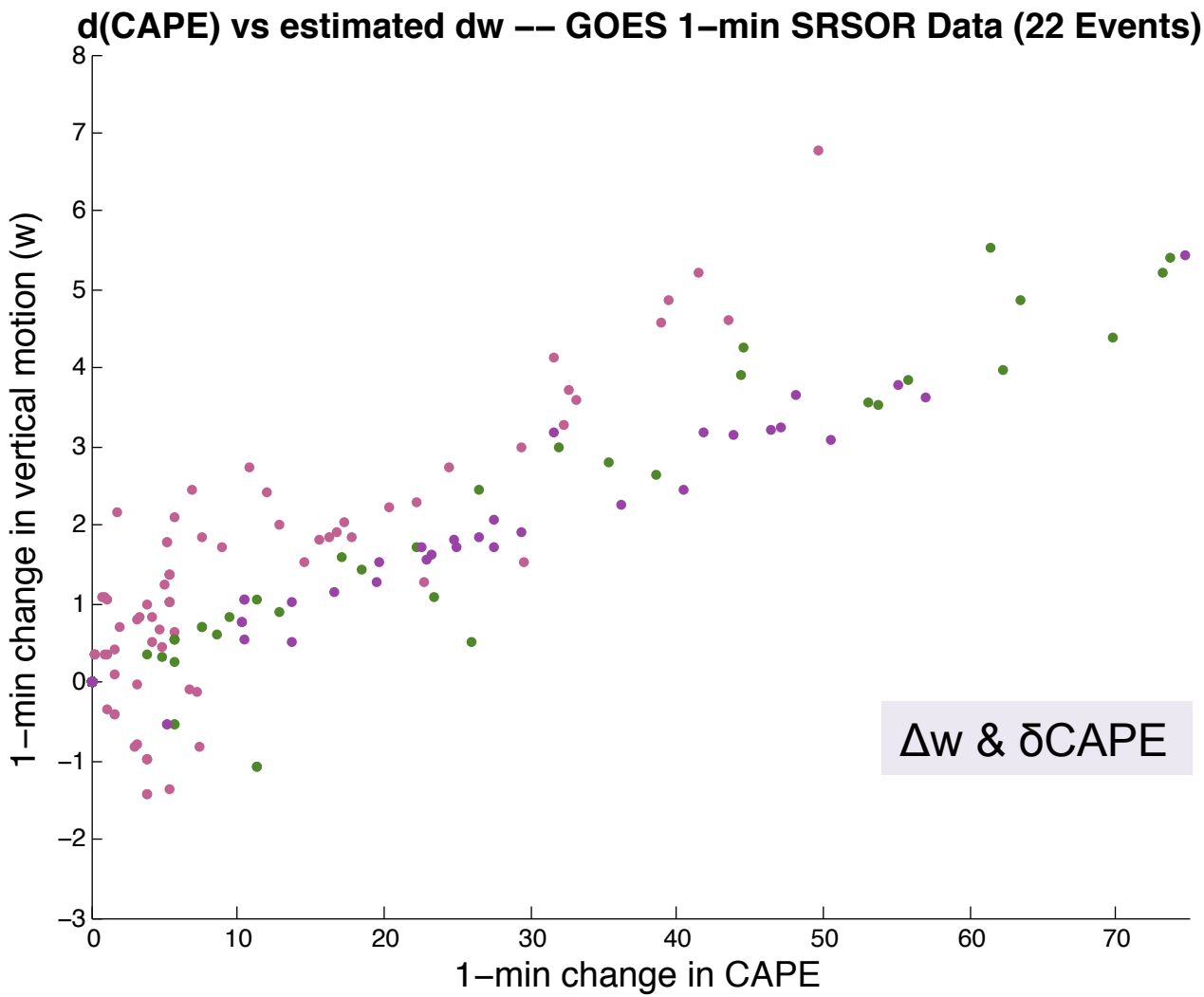
Initial Results

R > 0.711 overall

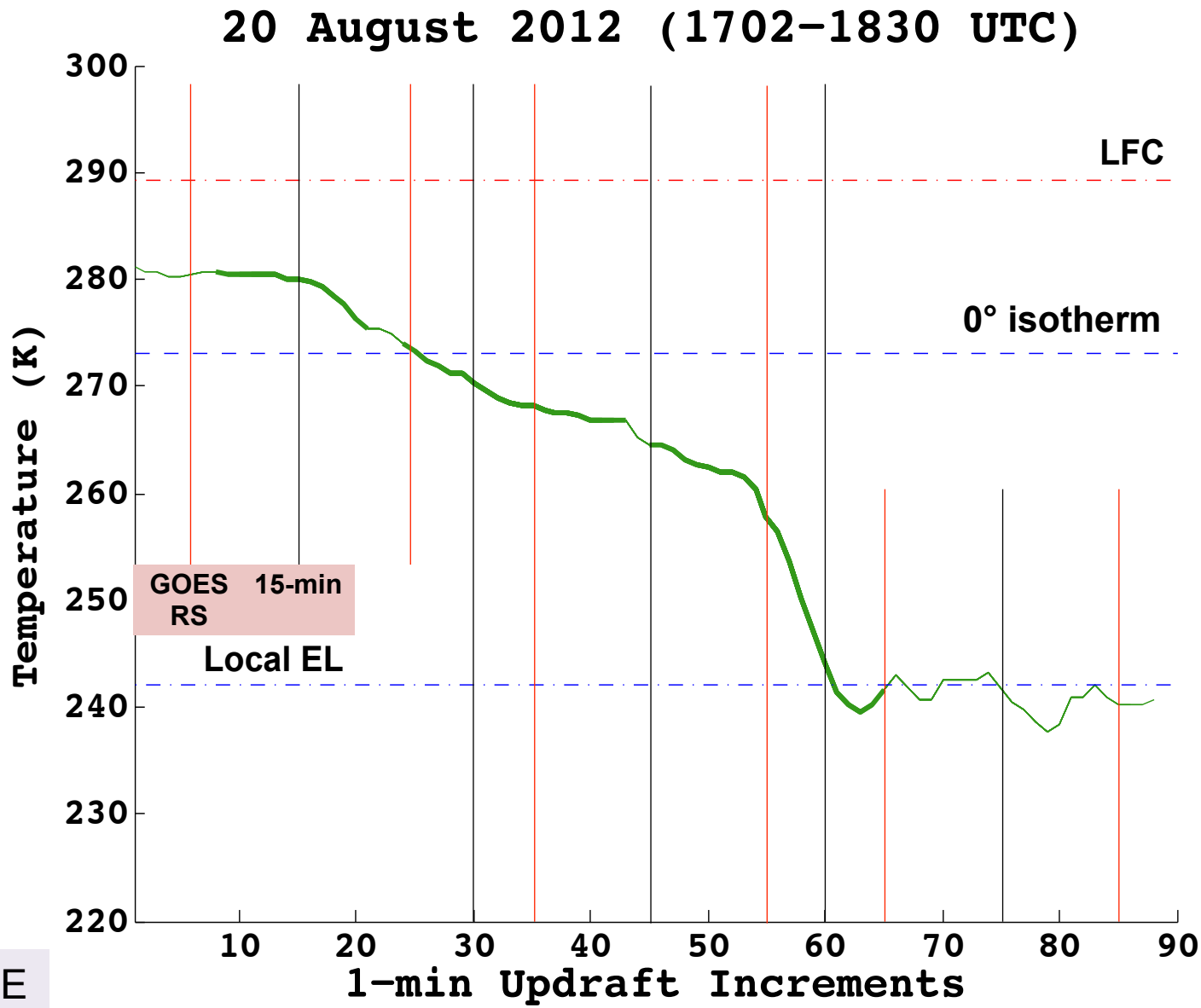


Initial Results

R > 0.92



Single Updraft Analysis



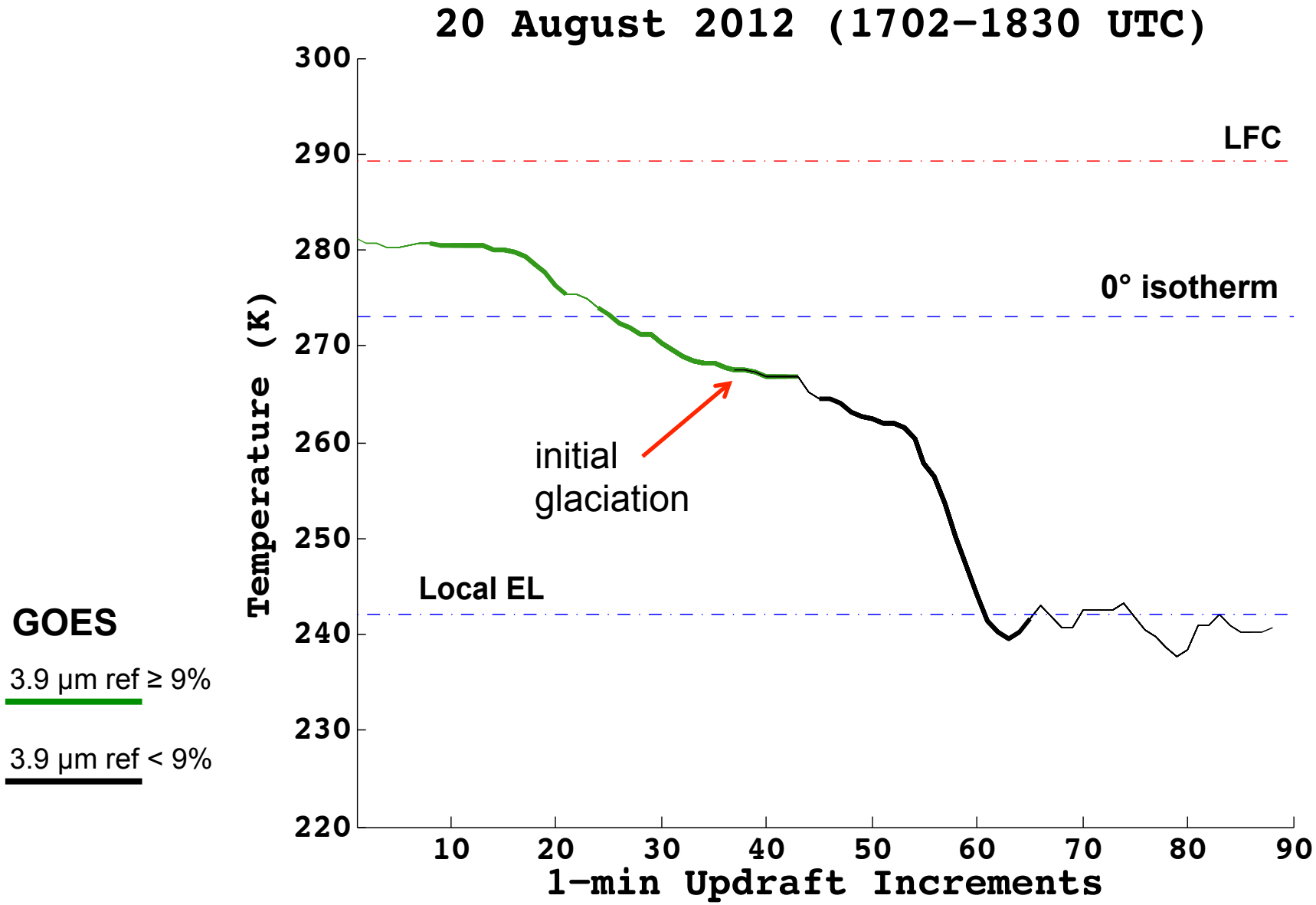
high correlation

low correlation

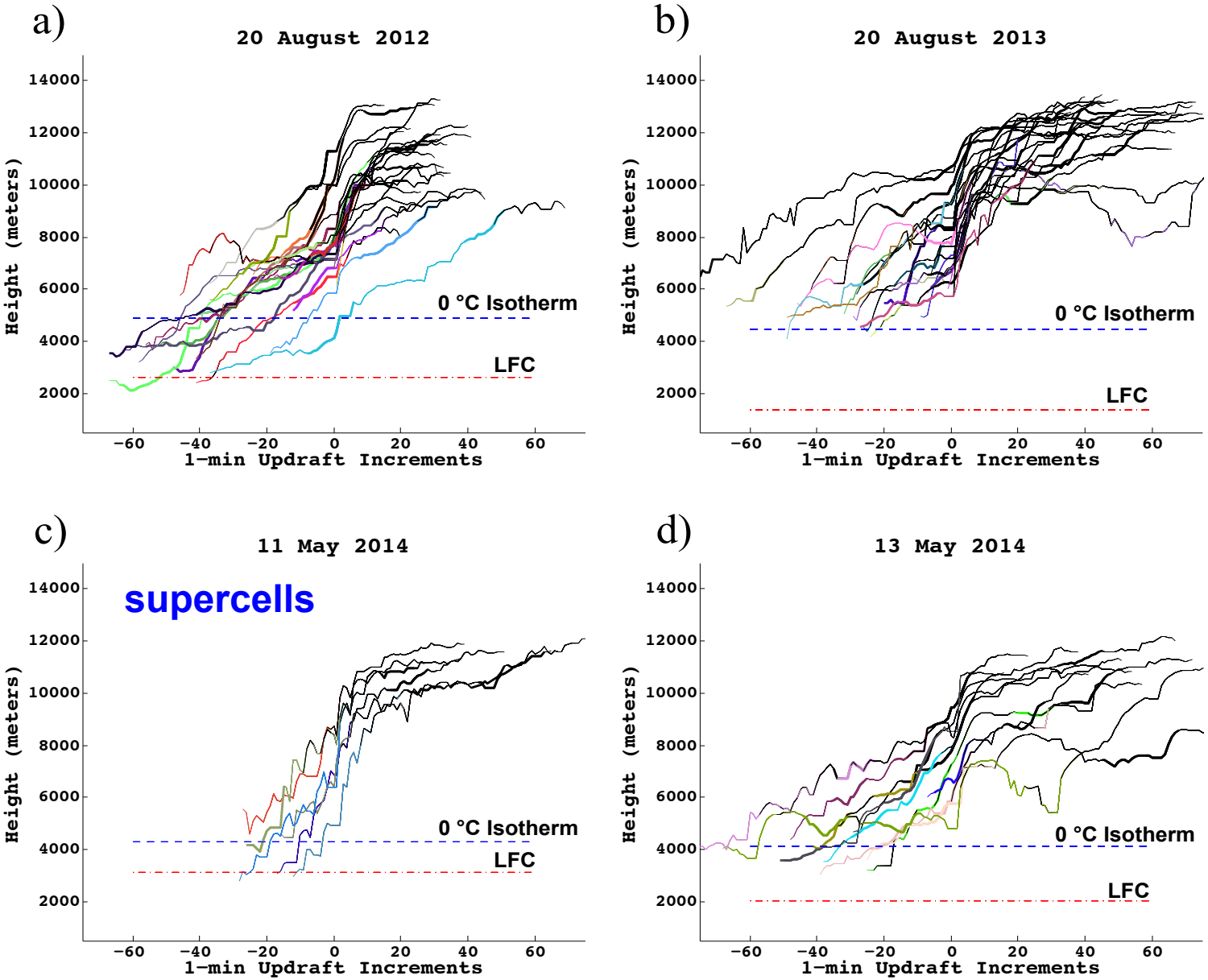
Δw & ∑δCAPE

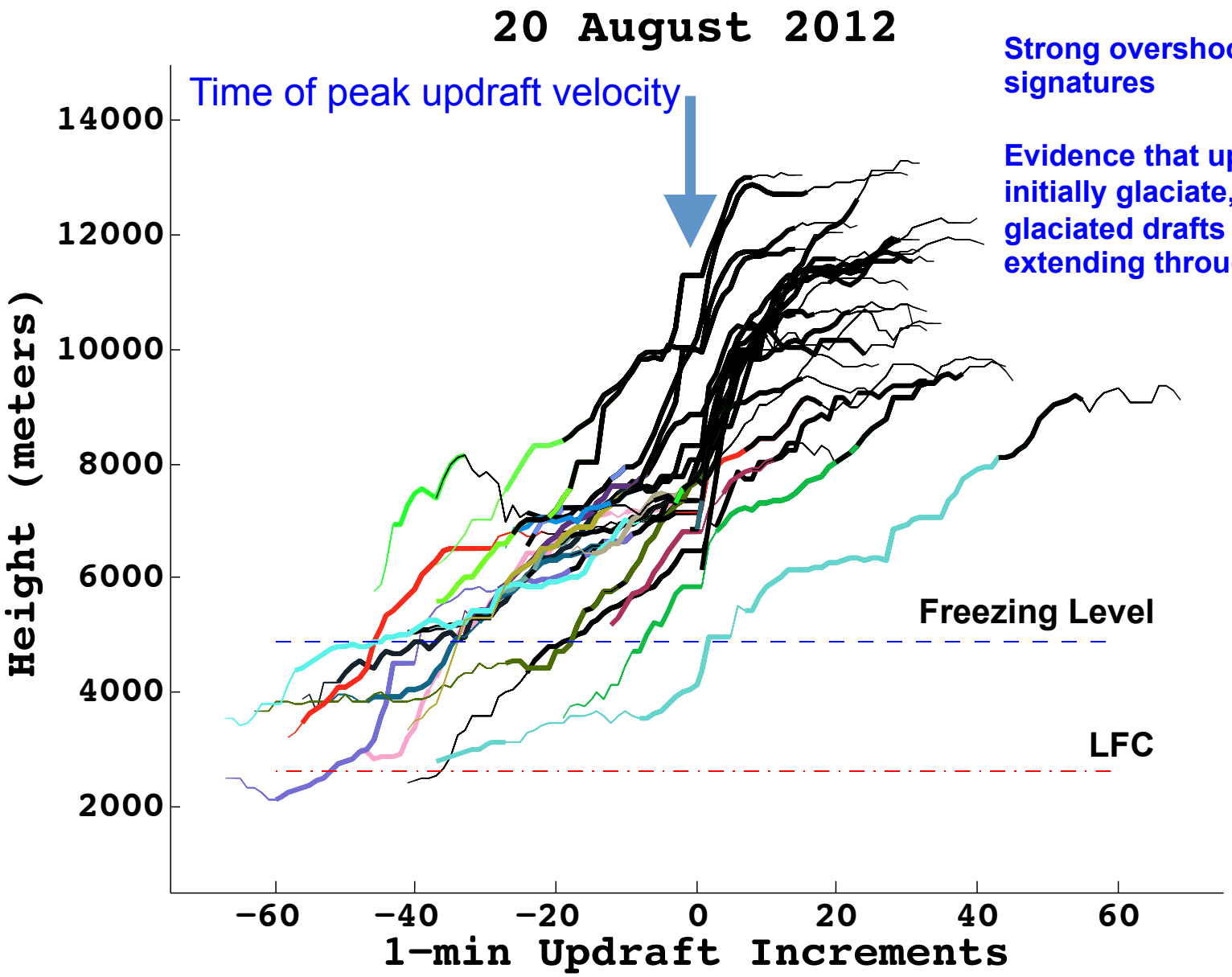
87 minutes

Single Updraft Analysis



Many Updrafts





Strong overshooting top signatures

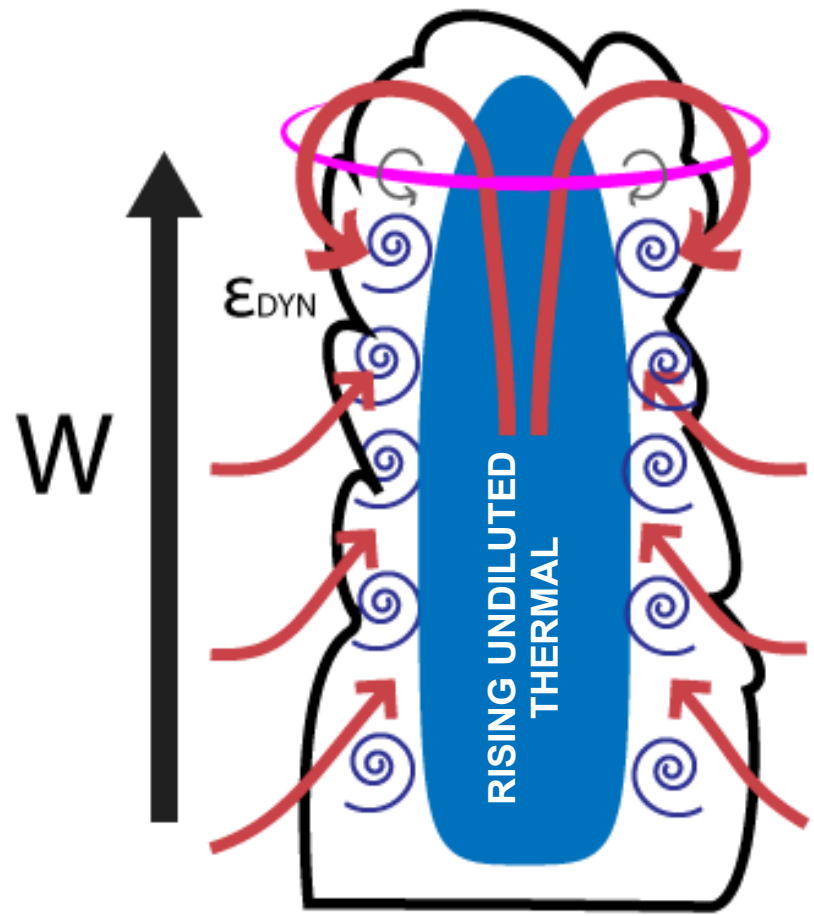
Evidence that updrafts may initially glaciate, with un-glaciated drafts later extending through an anvil

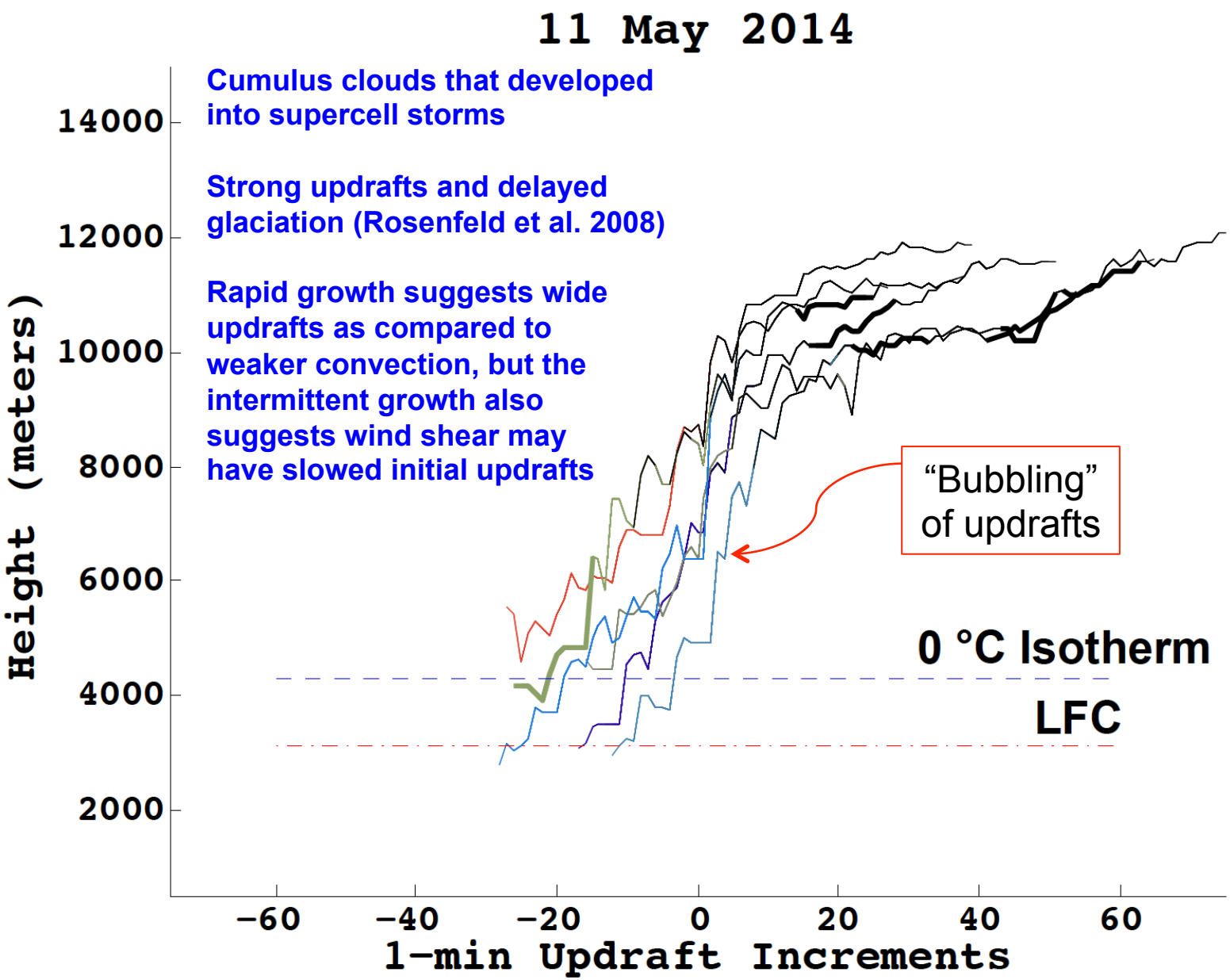
Interpretation

- Segments of the updraft where δw and ∑δCAPE are highly correlated suggest that the observed updraft is responding more directly to the local instability, or an in-cloud updraft is penetrating to cloud top.

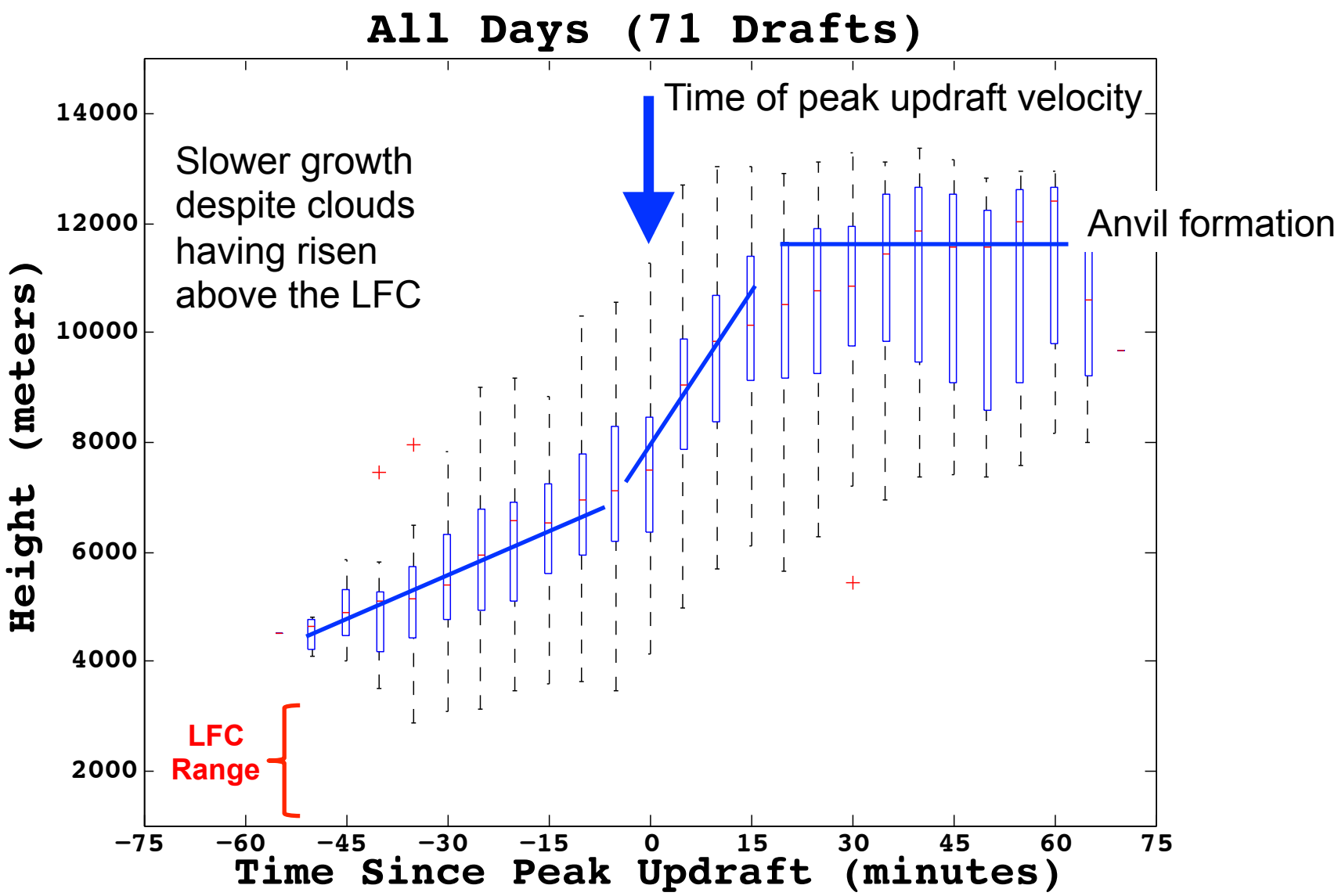
- Where the correlations between δw and ∑δCAPE are low, influences of dynamic entrainment ($\boldsymbol{\varepsilon}_{DYN}$) are likely leading to more diluted thermals with environmental air.

- Low correlations between δw and ∑δCAPE could also imply a period of updraft weakening, or a bubbling within a main updraft region.




11 May 2014
Cumulus clouds that developed into supercell storms
Strong updrafts and delayed glaciation (Rosenfeld et al. 2008)
Rapid growth suggests wide updrafts as compared to weaker convection, but the intermittent growth also suggests wind shear may have slowed initial updrafts
"Bubbling" of updrafts
0 °C Isotherm
LFC
Height (meters)
14000
12000
10000
8000
6000
4000
2000
-60
-40
-20
0
20
40
60
1-min Updraft Increments

General Updraft Statistics



Updraft Statistics – SRSOR Estimated

Peak *w* (peak updraft) MDA = maximum updraft altitude

ΔT ZLVL–MDA = cloud-top temperature difference between freezing level and MDA

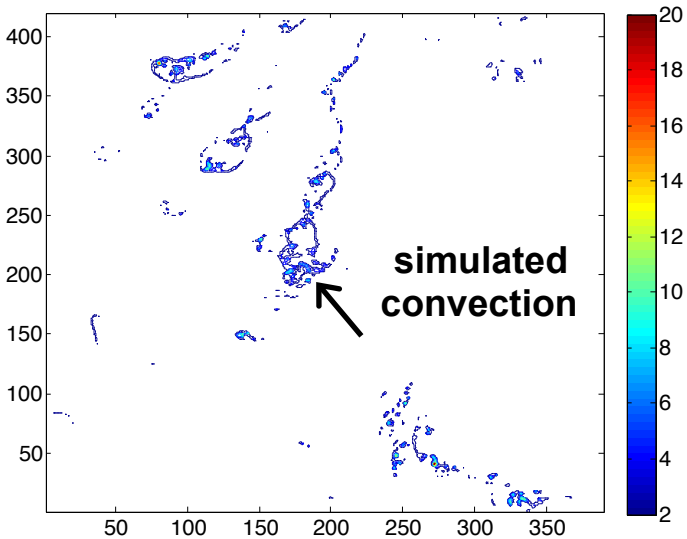
Day		draft	Time (UTC)	Peak w (ms^{-1})	MDA (m)	ΔT ZLVL-MDA (°K)	T_B(ref39<9%)
20 August 2012		1	1602-1705	6.6	3575	-9.6	264
CAPE	2228	2	2017-2146	15.2	9985	24.6	243
LFC	2600	3	2017-2157	16.5	4486	-5.5	237
0 °C Isotherm Level	4900	4	2017-2155	12.8	8300	18.2	255
EL	14300	5	1702-1849	14.7	4980	-2.2	254
ave(MDA)–ZLVL	3233	6	1702-1830	8.3	9094	23.1	260
		7	1702-1810	4.7	6417	6.1	264
		8	1702-1839	11.6	9834	28.7	252
		9	1715-1850	7.7	4881	-2.1	264
		10	1749-1859	7.6	5412	1.0	255
		11	1706-1840	7.6	8800	20.8	262
		12	1754-1859	8.8	9149	24.5	253
		13	2106-2201	12.2	11274	35.8	260
		14	2036-2129	20.3	11283	36.4	258
		15	2017-2108	16.5	9897	27.9	260
		16	2032-2137	21.3	9977	29.2	260
		17	2017-2134	8.1	9989	30.0	262
		18	2119-2219	8.1	8789	17.3	262
		19	2031-2028	7.1	8652	21.0	255
		20	2051-2150	13.3	8039	12.9	266
		21	2017-2051	13.5	6956	4.7	264
		22	2017-2050	9.6	9152	19.5	265
				11.46	**8133**	**16.5**	**258.0**

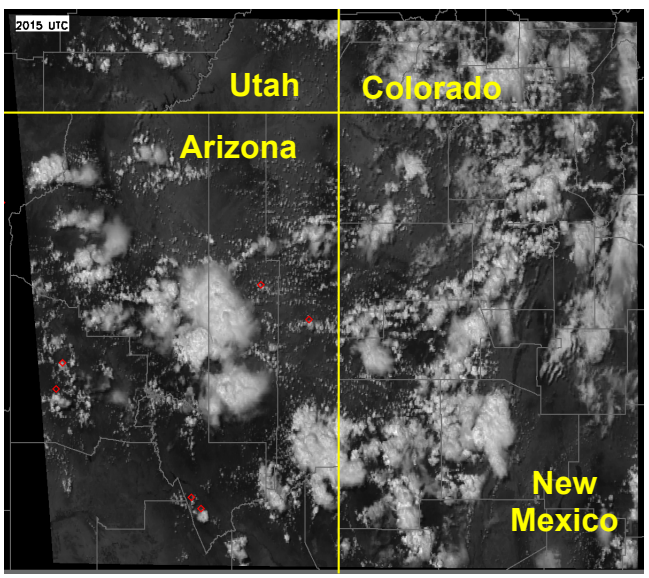
On average, updrafts attained their peak ~3200 m above the 'freezing level' (or 0°C isotherm altitude) near 8100 m, of magnitudes 4.5 to near 21 ms^{-1}.

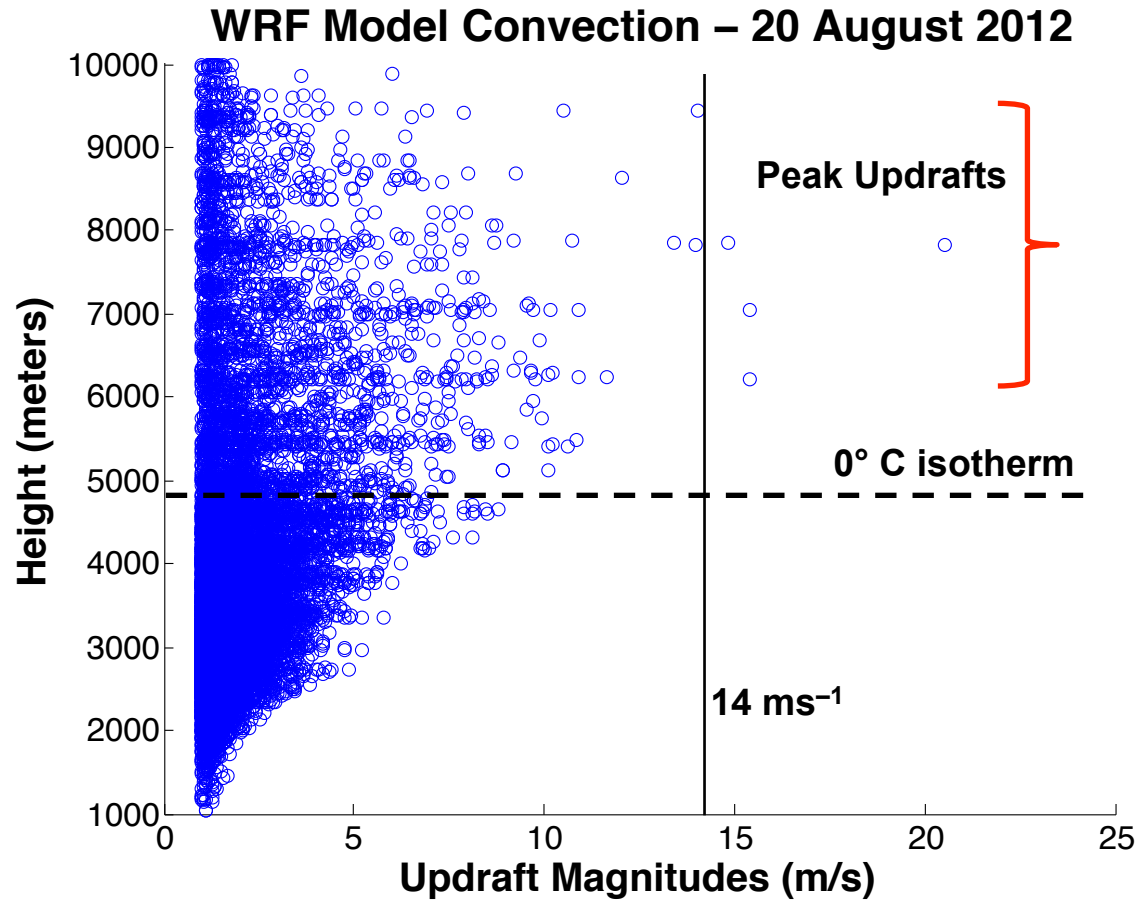
Most updrafts were less than 14 ms^{-1}.

Question: How comparable are these peak updraft velocities to reality?

Comparison to WRF 1 km Resolution Simulations







The agreement between SRSOR-estimated *w*'s and updrafts in WRF model simulations is very good.

Likely both are underestimated given low resolution of data/model. In-cloud *w's* should be ~2 times larger than cloud-top rising rates (Romps and Charn 2015).

Overall Results & Future Directions

1) Highest correlation between δ*w* and ∑δCAPE appears to occur when cloud–top T_B's are below ~260 K, and the updraft is growing rapidly. Strong latent heat-updraft acceleration/updraft invigoration signature.

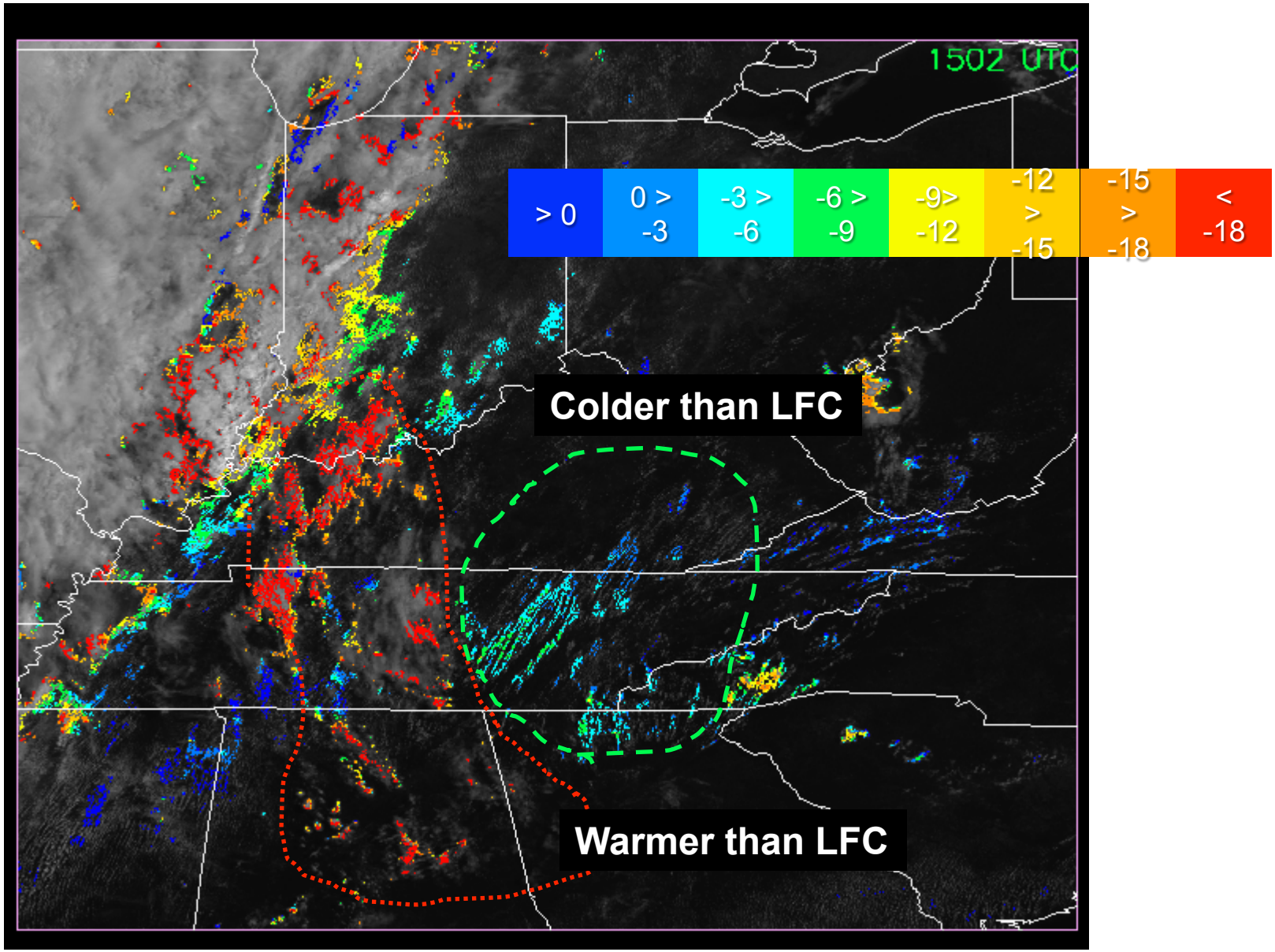
2) Warmer updrafts in early stages of growth are less coupled to environmental stability, related to a capping inversion, and/or there being many up- and downdrafts within a single pixel (as the cumulus "bubble"), or to entrainment, hydrometeor loading, or pixel filling.

3) High correlations (δ*w*–∑δCAPE) suggest that SRSOR updraft information can be coupled to other models that assess lightning initiation/in-cloud charging (Carey et al. 2007).

4) The rapid updraft acceleration in the middle troposphere suggests the "CI process" is coupled to 3D mesoscale boundary layer flows that takes time to form, and then to support deep convective growth.

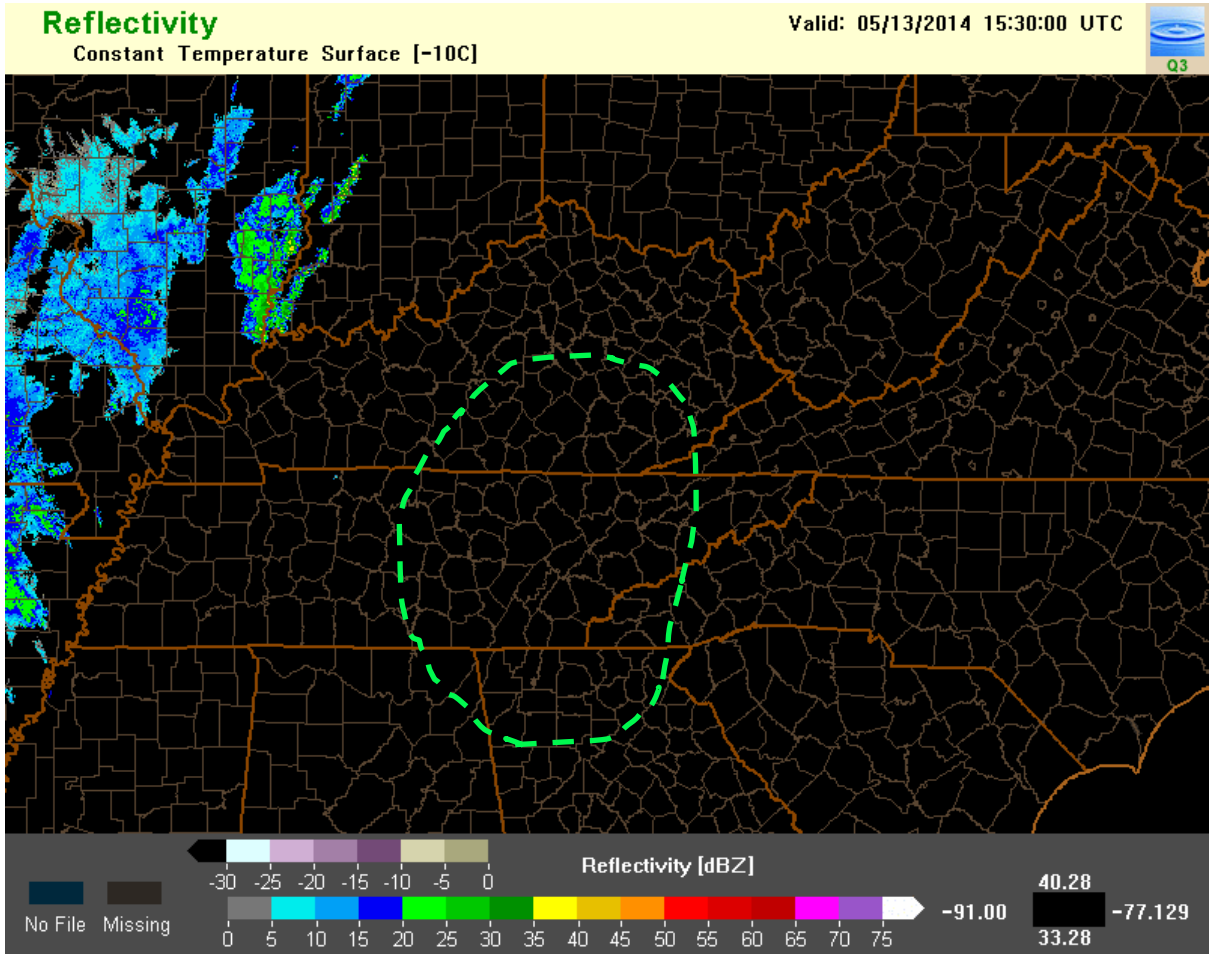
5) Use dual-Doppler analysis to help compare SRSOR-observed growth rates with in-cloud updrafts, following on other similar studies that use lidar and cloud radar.

“Early Convective Initiation” Product based on SRSOR Data



“Early Convective Initiation” Product – Validation

Radar validation



Questions?

Thank you!