Diagnosing Cumulus Cloud Updraft Characteristics and Inferring In-Cloud Processes 1-min GOES Observations

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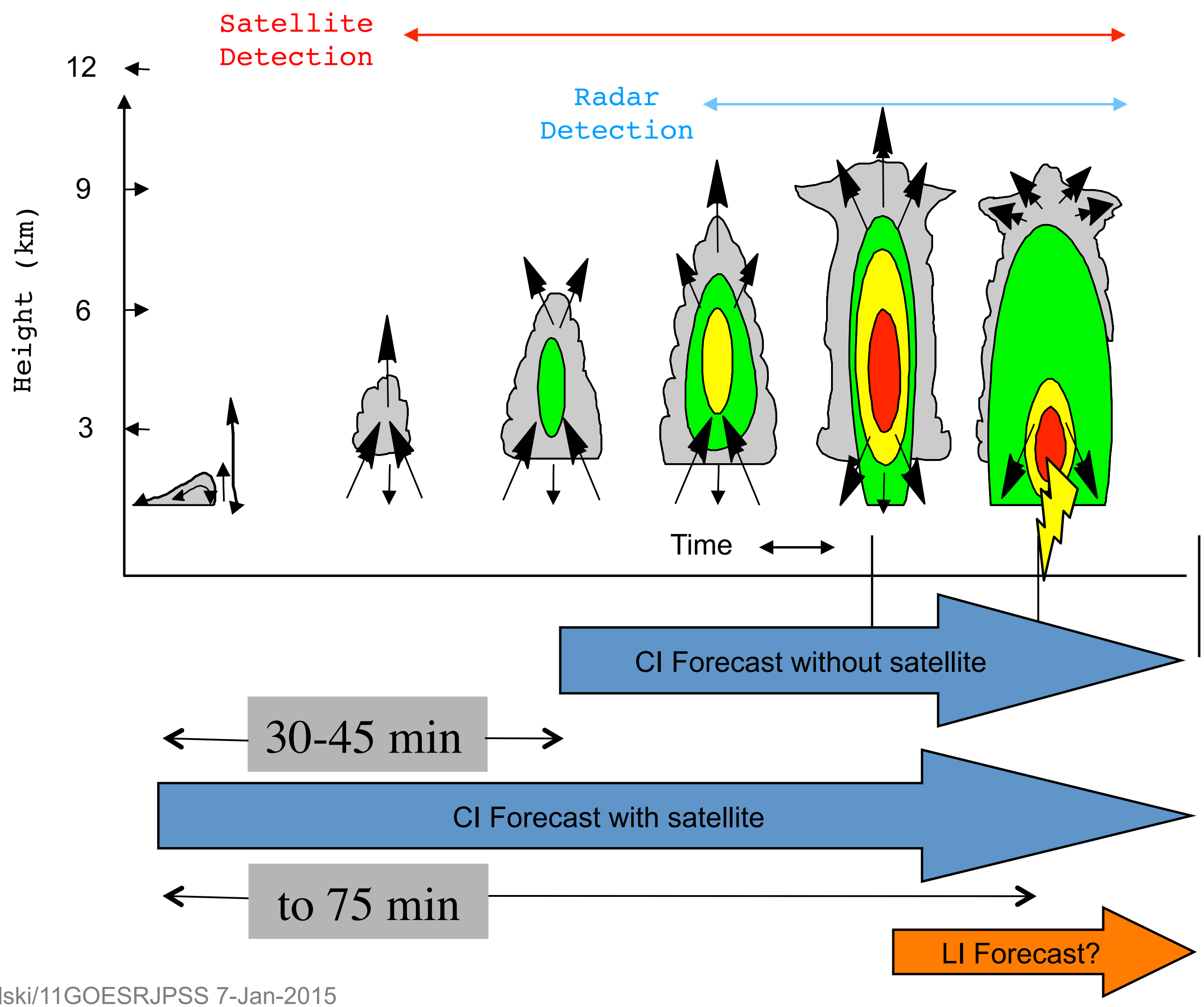
Convective & Lightning Initiation: Conceptual Idea

Current forecast lead times from satellite...



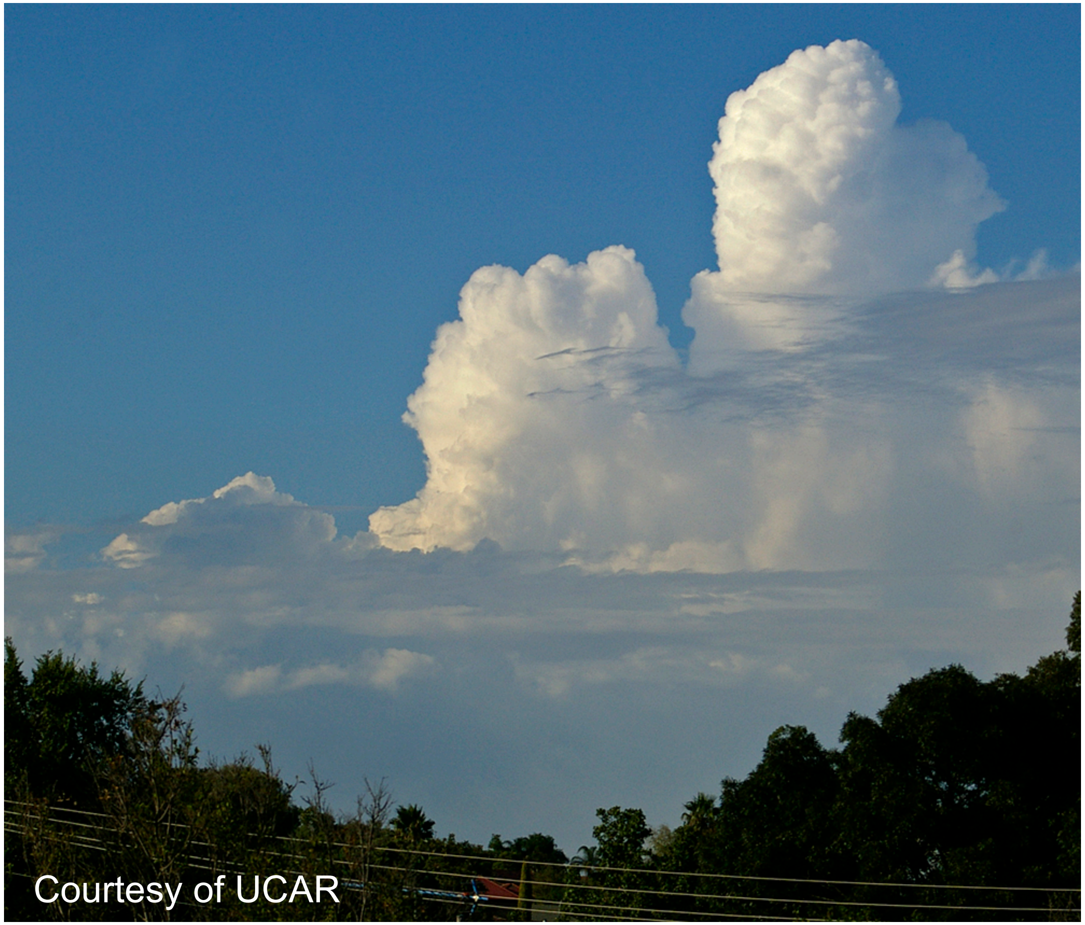
Lead time increases with slower growing cumulus clouds (i.e. low CAPE environments)

What can we do for early CI detection?

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.

SRSOR data should have a lot to offer toward bridging this observational gap.



Courtesy of UCAR

Motivation & Hypotheses for Study

• 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/–9 AHI as presently available.

• There exists a **close relationship between the acceleration of an updraft as observed in 1 min resolution 10.7 µm brightness temperature fields and the shape of the instability** (i.e. convective available potential energy–CAPE) profile.

• 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).

• The 1–min resolution cloud–top cooling rate is related to actual in–cloud vertical motion through some bias offset (cloud top growth rates are known to be less than in-cloud updraft speeds).

• **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

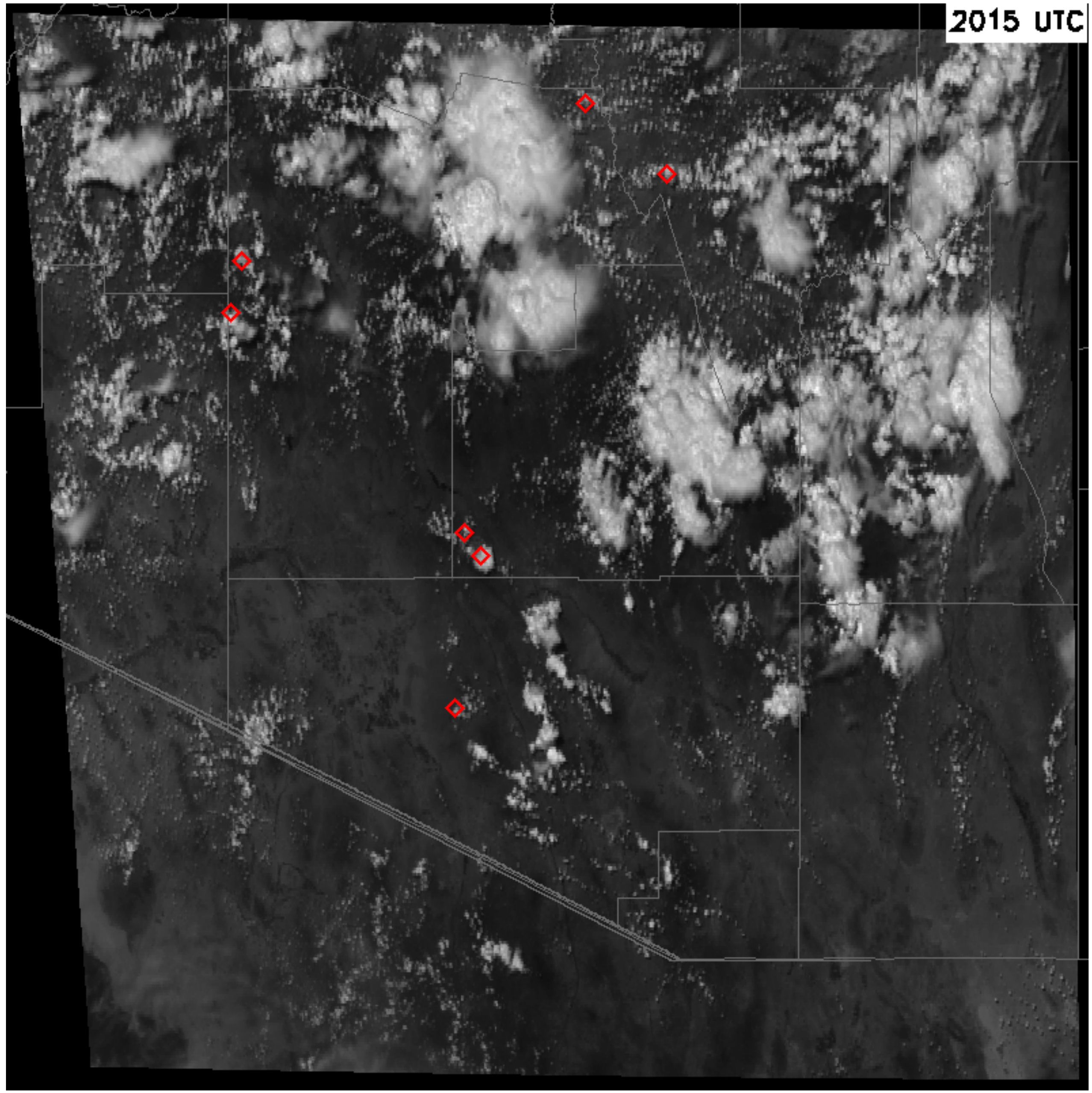
20 August 2012
20 August 2013
11, 13 & 22 May 2014

Growing cumulus clouds between 1600 and 2200 UTC.

Red circles are located of sampled updrafts.

Catalog 10.7 μm T_B, and compute vertical motions, assuming GOES 10.7 μm TB is equivalent to cloud-top temperature for optically thick clouds.

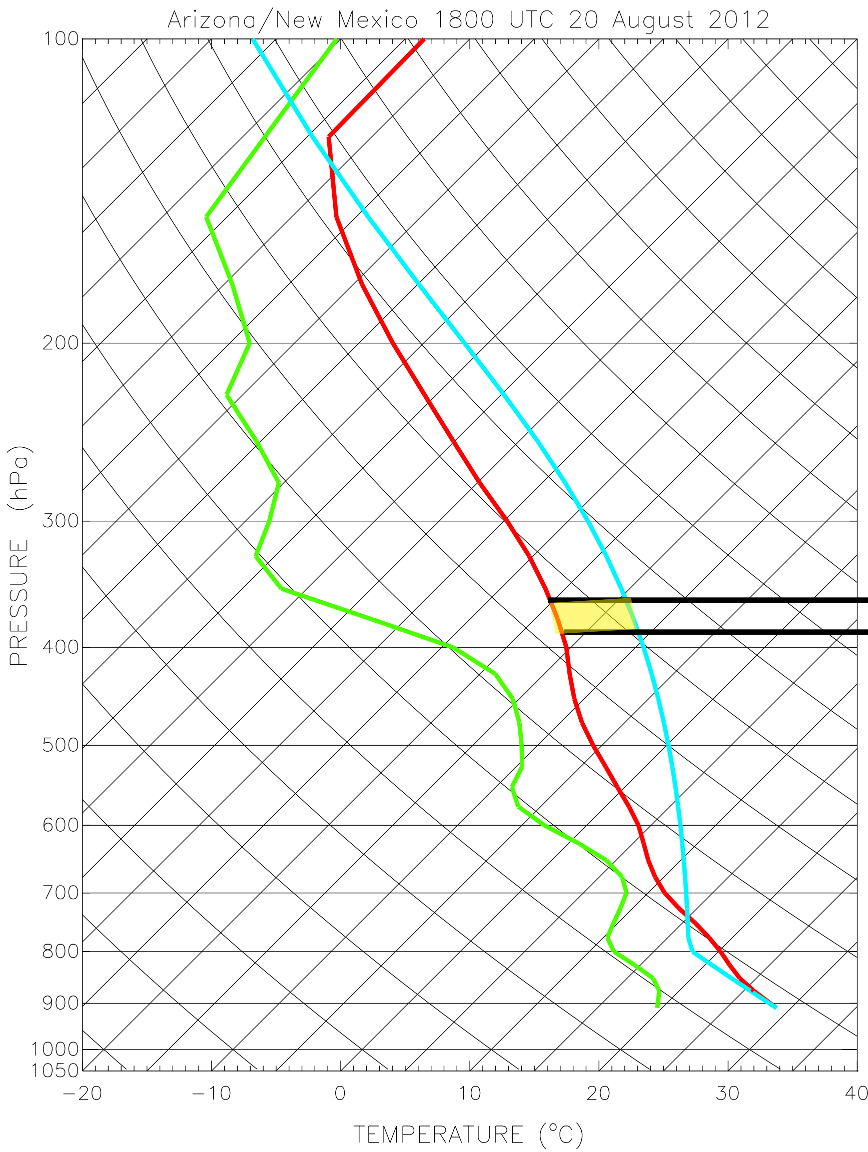
Also, consider method by Adler and Fenn (1981).



Methodology

- Updraft collection:
  - Evaluated 71 updrafts, which span from 33 to 152 min in a Lagrandian framework
  - Derived *w* and the change in w (δ*w*) in 1 minute increments
  - Develop incremental convective available potential energy (δCAPE) 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.
- Assess correlations between δ*w* and δCAPE, 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 δ*w* and 3.9 μm reflectance.

Methodology



$\Delta TB \approx \Delta T_c$

Δm in 1 minute $\approx \delta w$

δCAPE

Theory – Factors influencing parcel vertical accelerations

In the absence of dynamic perturbation pressure effects (Emanuel 1994, p. 7–8; Doswell and Markowski 2004), the vertical acceleration of a parcel can be described as

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

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),

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

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

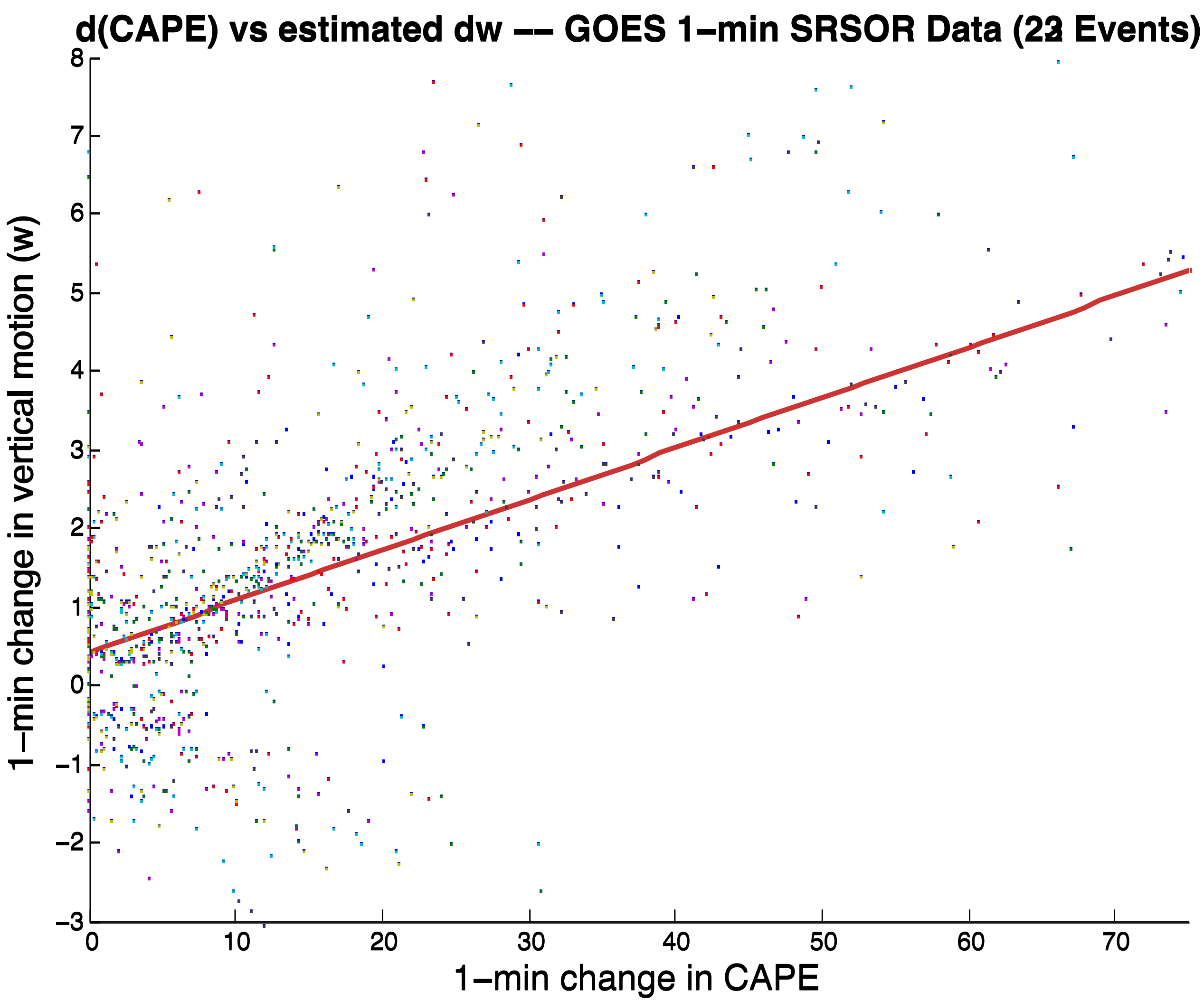
$$B = g\left(\frac{T'}{\bar{T}} - \frac{p'}{\bar{p}} + 0.61q_v - q_H\right)$$

What aspects of *B* can 1–min GOES data measure?

CAPE profile? Entrainment? Hydrometeor Loading?

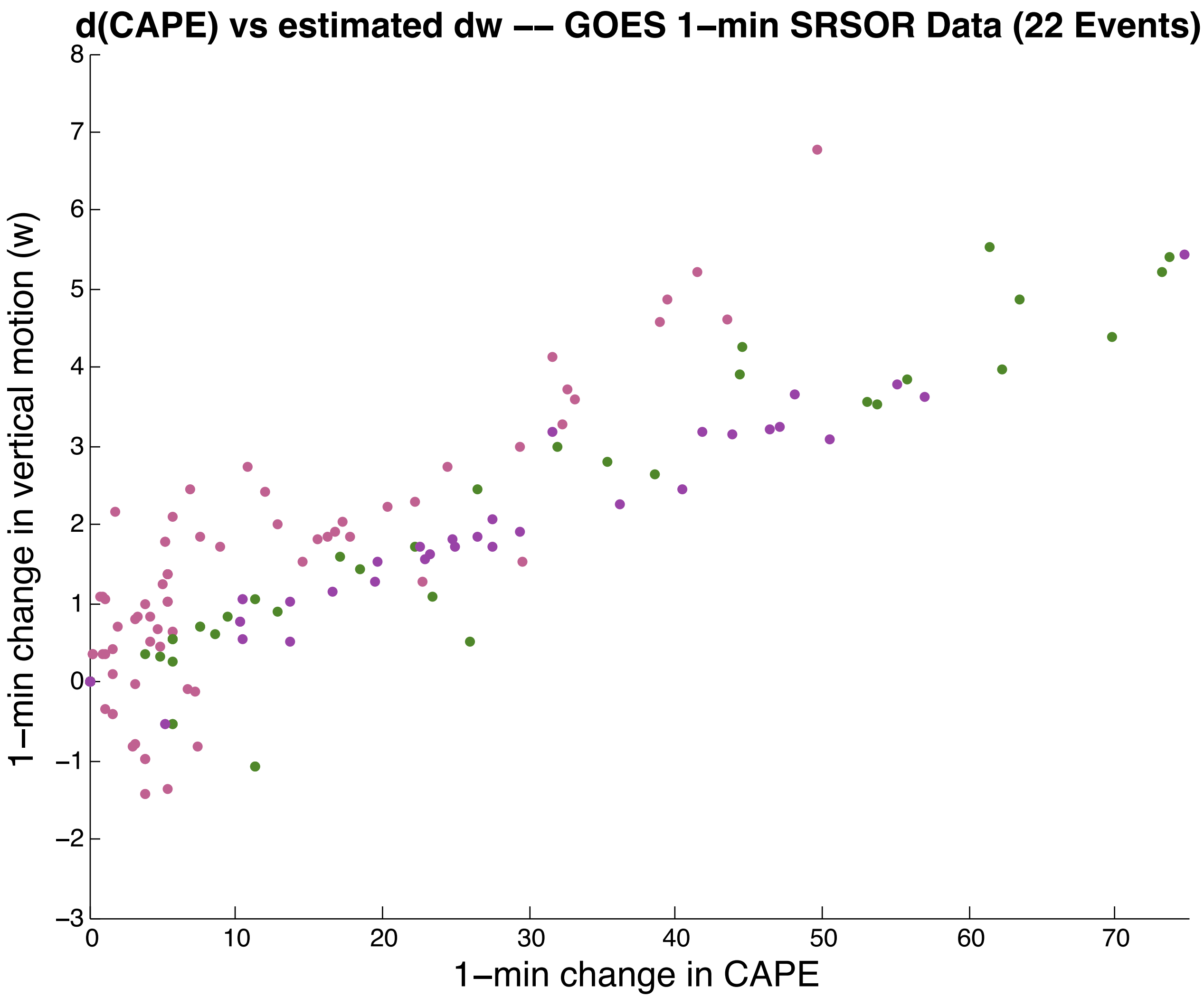
Initial Results

R > 0.711 overall

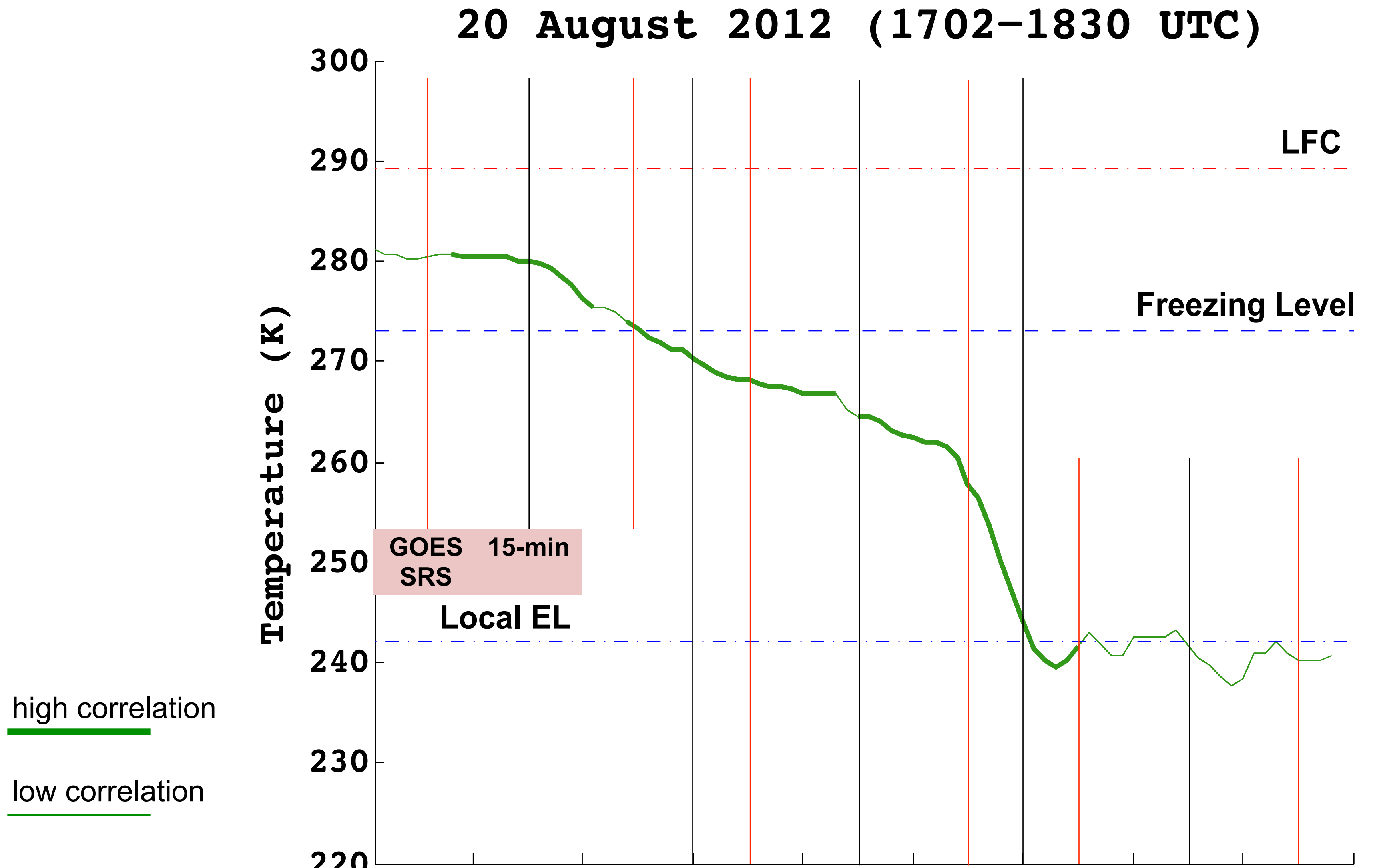


Initial Results

R > 0.92



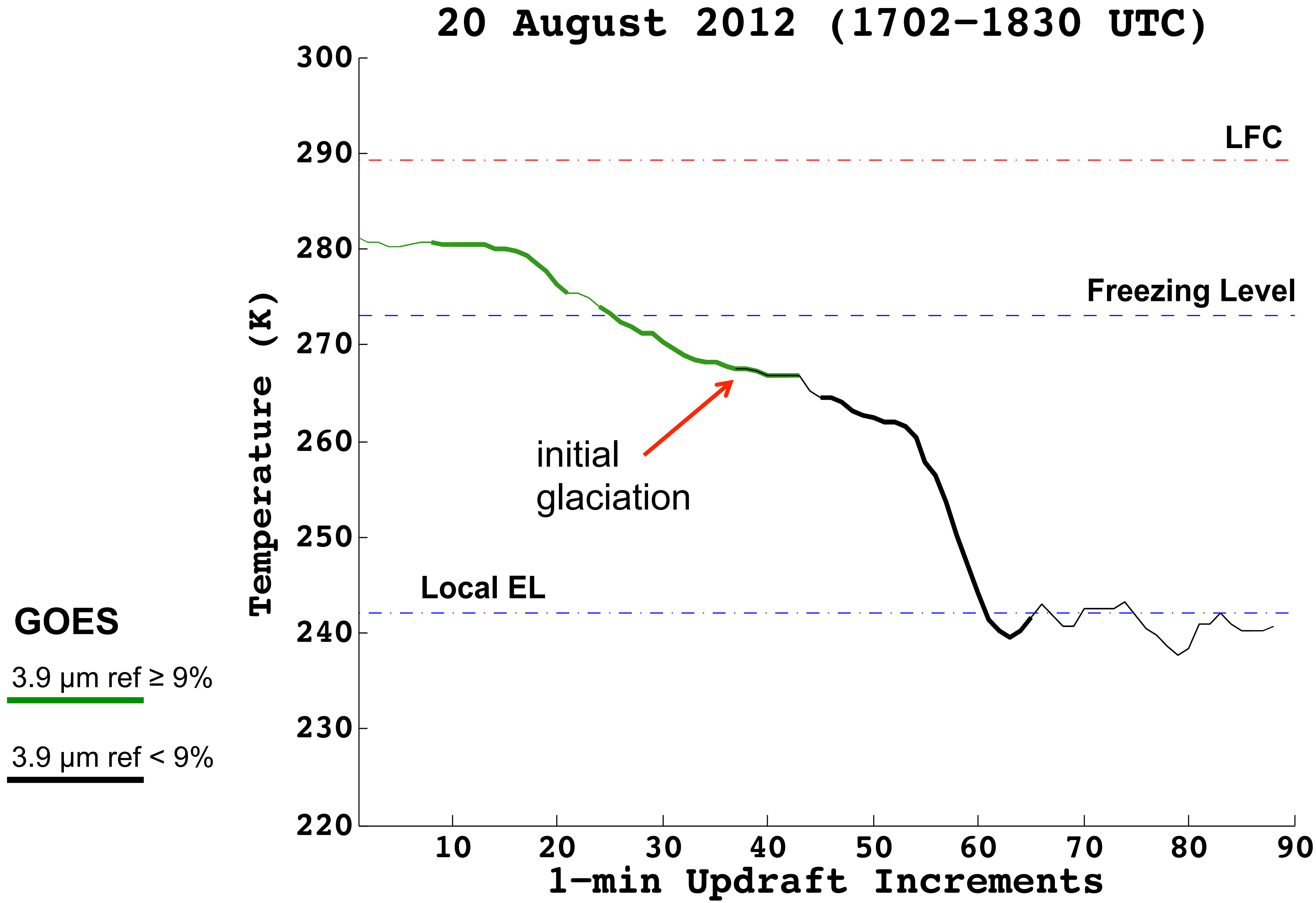
Single Updraft Analysis



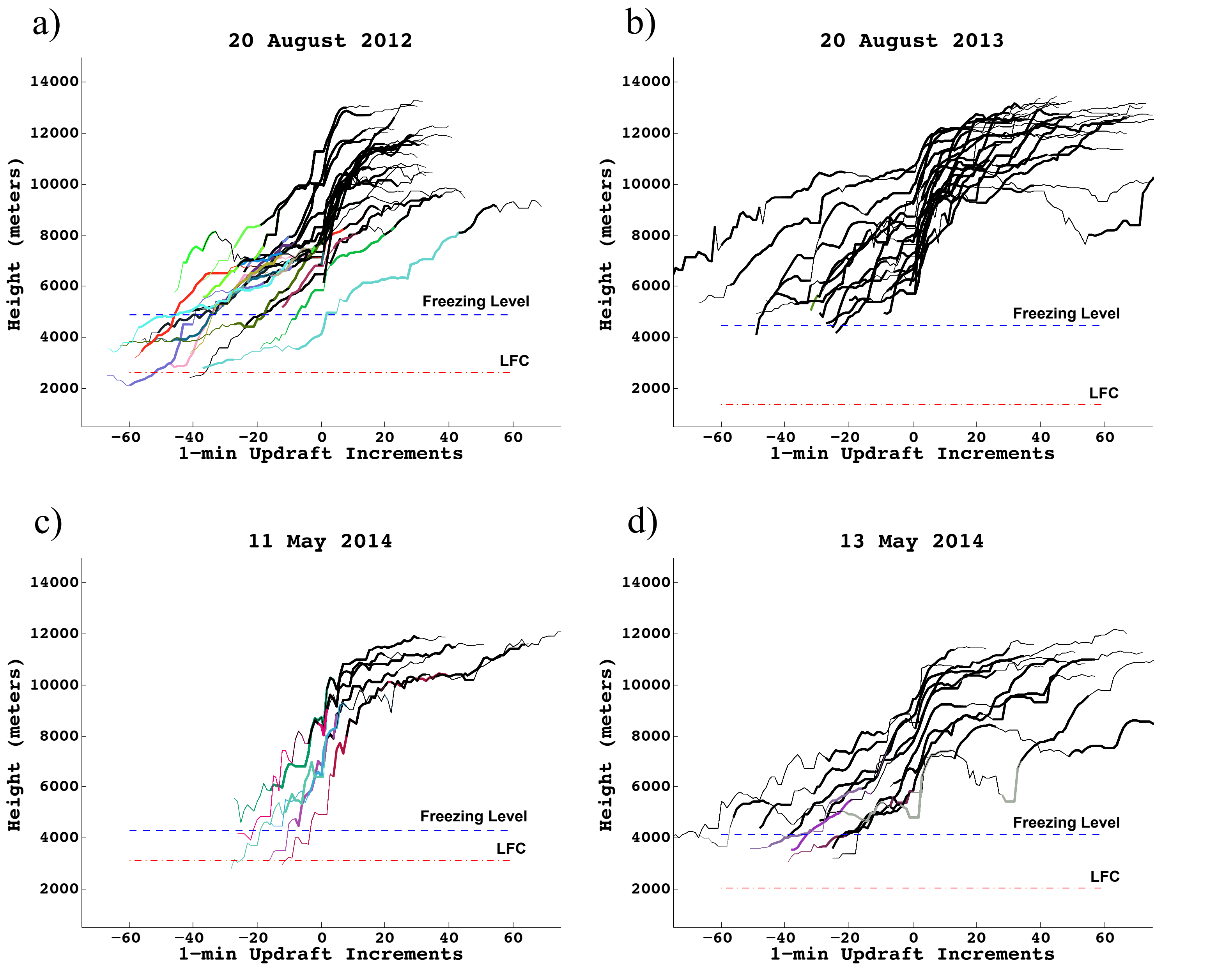
δw – δCAPE

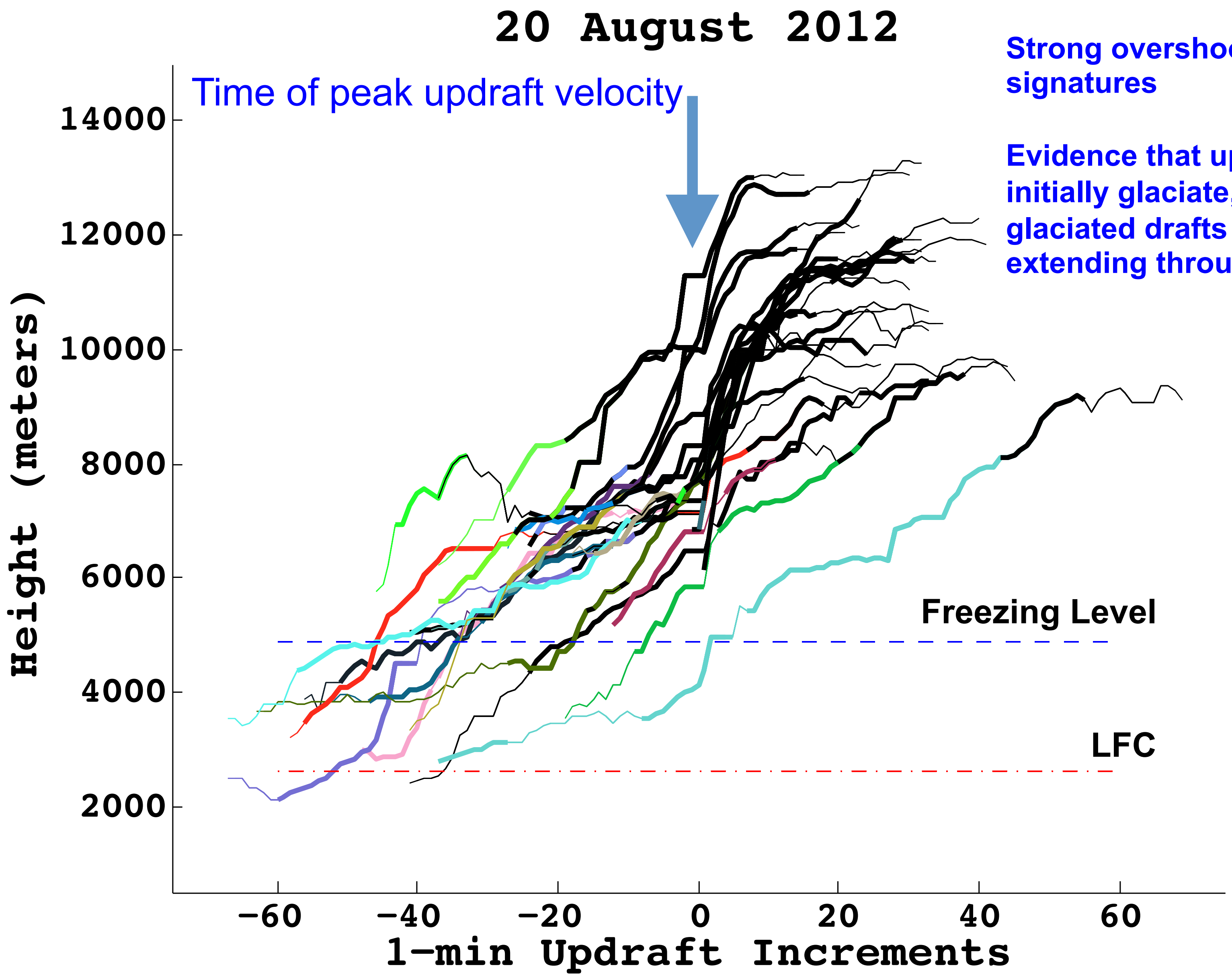
87 minutes

Single Updraft Analysis



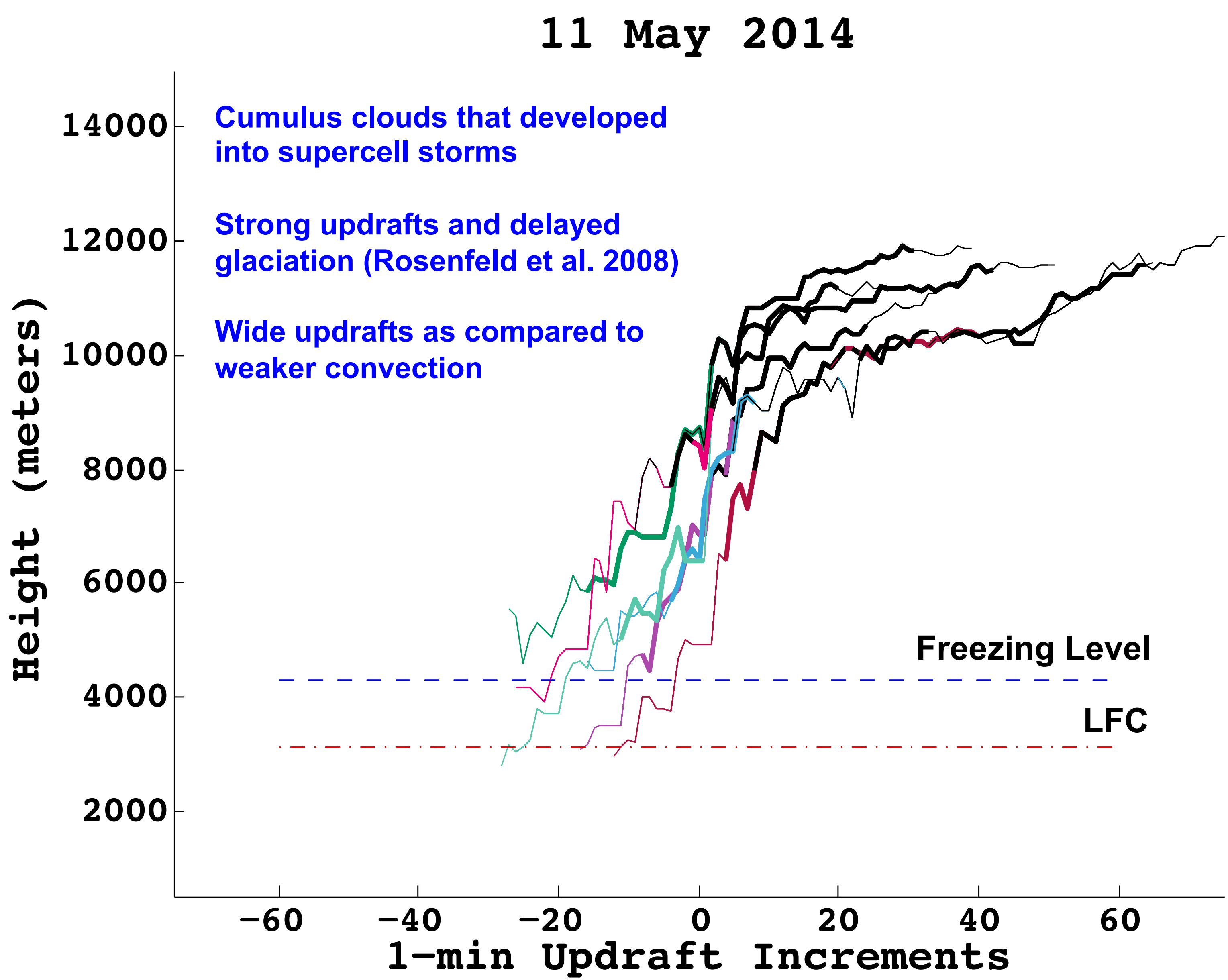
Many Updrafts



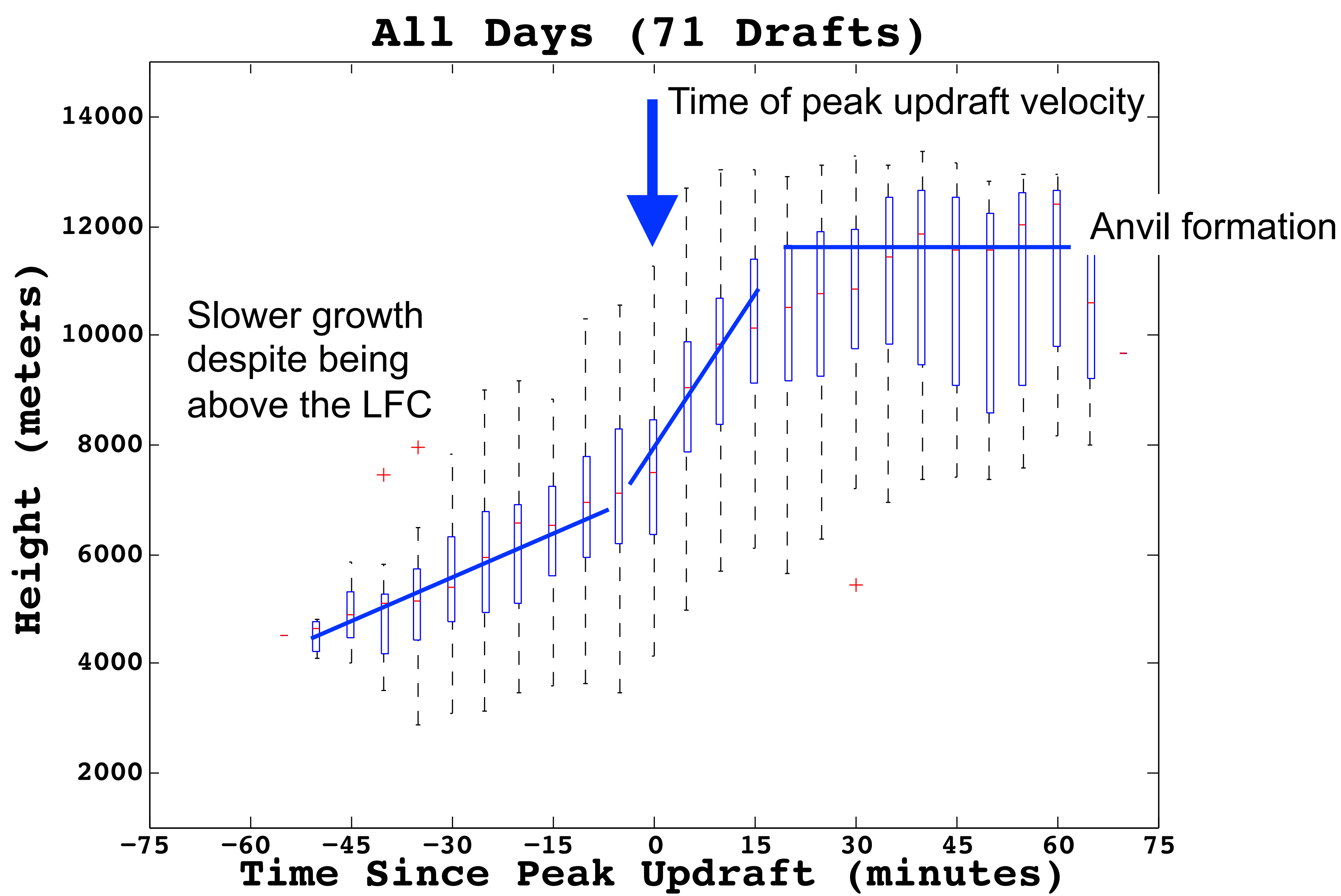


Strong overshooting top signatures

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


11 May 2014
Cumulus clouds that developed into supercell storms
Strong updrafts and delayed glaciation (Rosenfeld et al. 2008)
Wide updrafts as compared to weaker convection
Freezing Level
LFC
Height (meters)
14000
12000
10000
8000
6000
4000
2000
−60
−40
−20
0
20
40
60
1−min Updraft Increments

General Updraft Statistics



General Updraft Statistics

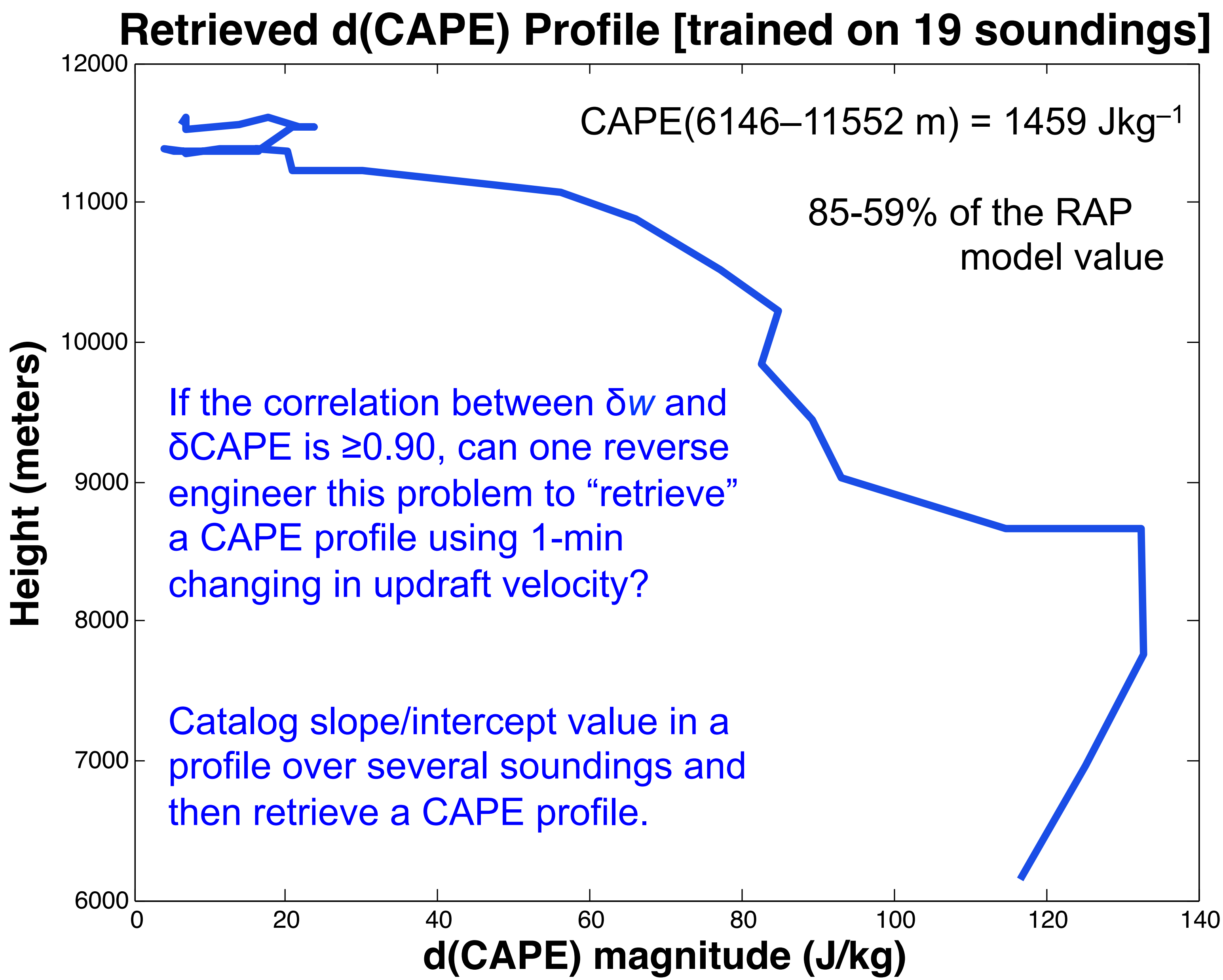
Peak *w*
MDA = maximum updraft altitude
ΔT ZLV-MDA = cloud-top temperature difference between freezing level and MDA

In general, updrafts attain their peak updraft ~3200 m above the freezing level.

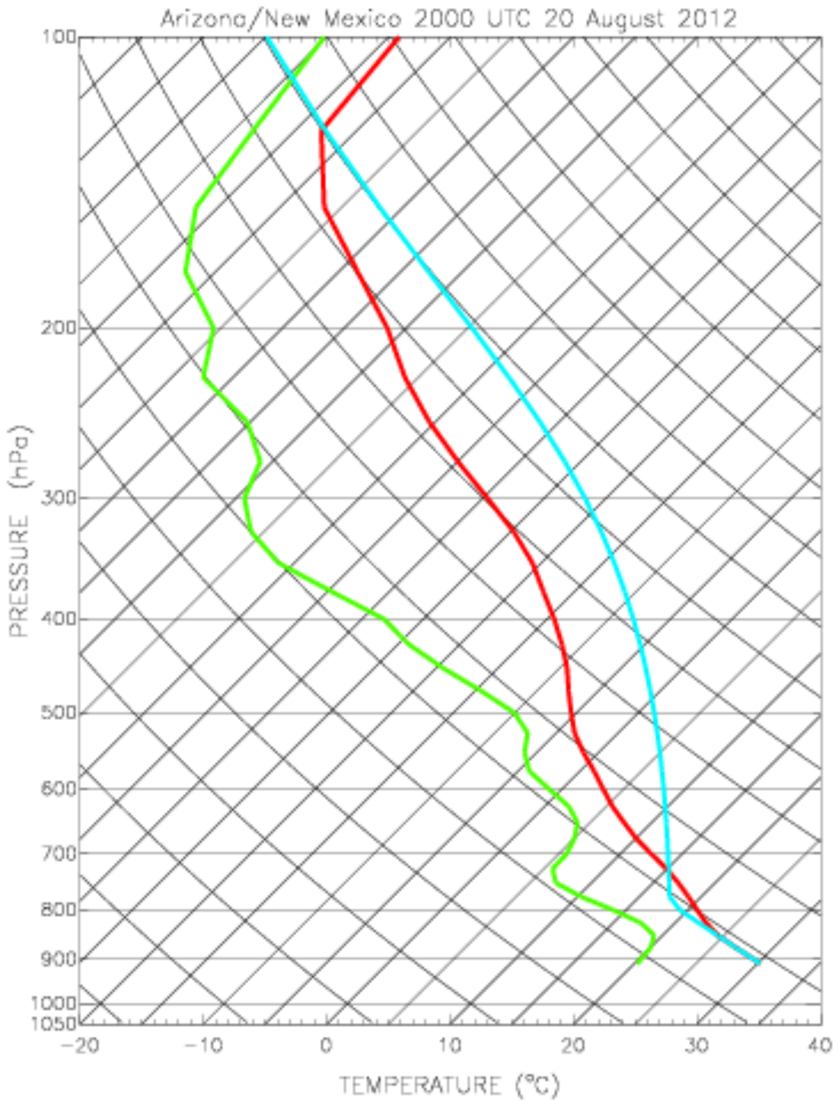
Peak updraft velocities are not that far off those that may be occurring based on parcel theory.

Day		draft	Time (UTC)	Peak w (ms^{-1})	MDA (m)	ΔT ZLVL-MDA (°K)
20 August 2012		1	1602-1705	6.6	3575	-9.6
CAPE	2228	2	2017-2146	15.2	9985	24.6
LFC	2600	3	2017-2157	16.5	4486	-5.5
Freezing Level	4900	4	2017-2155	12.8	8300	18.2
EL	14300	5	1702-1849	14.7	4980	-2.2
ave(MDA)–ZLVL	3233	6	1702-1830	8.3	9094	23.1
		7	1702-1810	4.7	6417	6.1
		8	1702-1839	11.6	9834	28.7
		9	1715-1850	7.7	4881	-2.1
		10	1749-1859	7.6	5412	1.0
		11	1706-1840	7.6	8800	20.8
		12	1754-1859	8.8	9149	24.5
		13	2106-2201	12.2	11274	35.8
		14	2036-2129	20.3	11283	36.4
		15	2017-2108	16.5	9897	27.9
		16	2032-2137	21.3	9977	29.2
		17	2017-2134	8.1	9989	30.0
		18	2119-2219	8.1	8789	17.3
		19	2031-2028	7.1	8652	21.0
		20	2051-2150	13.3	8039	12.9
		21	2017-2051	13.5	6956	4.7
		22	2017-2050	9.6	9152	19.5
				11.46	**8133**	**11.5**

Single Channel Sounding – Recovery of CAPE



Comparison to Parcel Model – PRELIMINARY



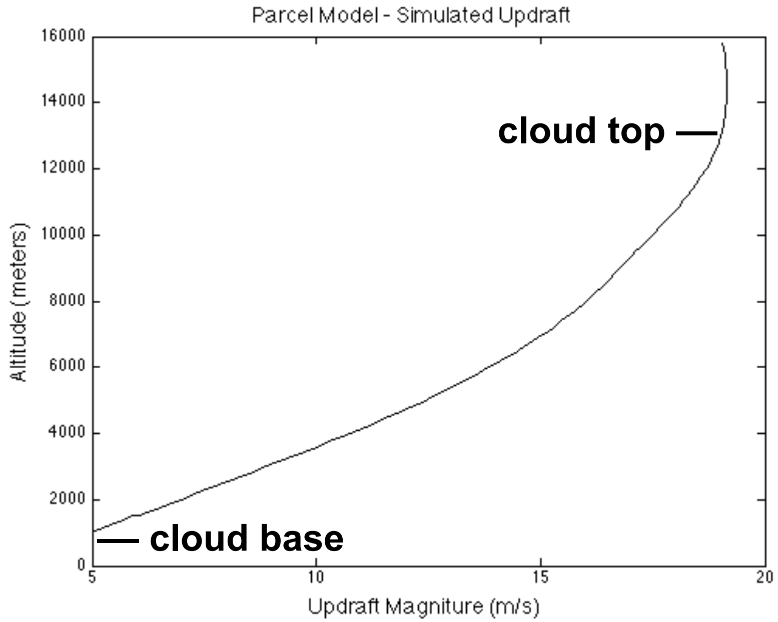
RAP Model Sounding
2000 UTC 20 August 2012

Adler and Mach (1986) parcel model

$$\frac{dw}{dt} = \frac{\alpha g(T - T_e)}{T_e} - g q_l - \mu_w |w| w$$

$$\frac{dT}{dt} = -w\frac{g}{c_p} - |w| w (T - T_e)$$

Solved model using 4th order Runge-Kutta



Results

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 signature (as noted in literature)

2) Warmer updrafts in early stages of growth are less coupled to environmental stability, perhaps because of the restriction of a capping inversion, and/or there being a lot of up- and downdrafts within a single pixel (as the cumulus "bubble"), or due to entrainment, hydrometeor loading, or simple 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, as a means of knowing when an updraft will accelerate the quickest assuming an available CAPE profile (Carey et al.).

4) If the environment surrounding existing convection is relatively "constant" in terms of the CAPE profile, the δw profile from one cloud may help predict the character of nearby/future convection.

5) The notion of a "single channel" (10.7 μm) sounding can be considered, so to retrieve a proximity profile of instability/CAPE.

Results

6) The rapid acceleration in the middle troposphere suggests that the “CI process” is coupled to mesoscale boundary layer flows that take time to form, and subsequently support convection extending to the tropopause.

Potential Applications

- A product that estimates location where the local capping inversion has broken, within <5 minutes of occurrence. Product can be used alone, or within a convective initiation algorithm, i.e. GOES–R CI.
- Retrieval of a “Single Channel” (10.7 μm) soundings – a proximity profile of instability/CAPE. Perhaps valuable when studying pyroCb events in terms of the energy released from a fire, or in a volcanic erruption.
- New, basic research on cloud updraft behavior with respect to near-term cloud microphysical formation, and lightning charging/occurrence in advance of first-flash lightning initiation.
- Quantifying aspects of hydrometeor loading and entrainment.

The –3 to 0 hour Convective Forecasting Timeline

Gravelle et al. (2015)