Use of Rapid Scan datasets when Understanding CI and Other Processes

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Outline

1. Motivations for using 1–min Super Rapid Scan for GOES–R (SRSOR) data

2. Direct analysis of SRSOR-observed updrafts

3. “Single channel sounding” concept

4. SRSOR-generated mesoscale Atmospheric Motion Vectors for convective storm analysis (J. Apke)

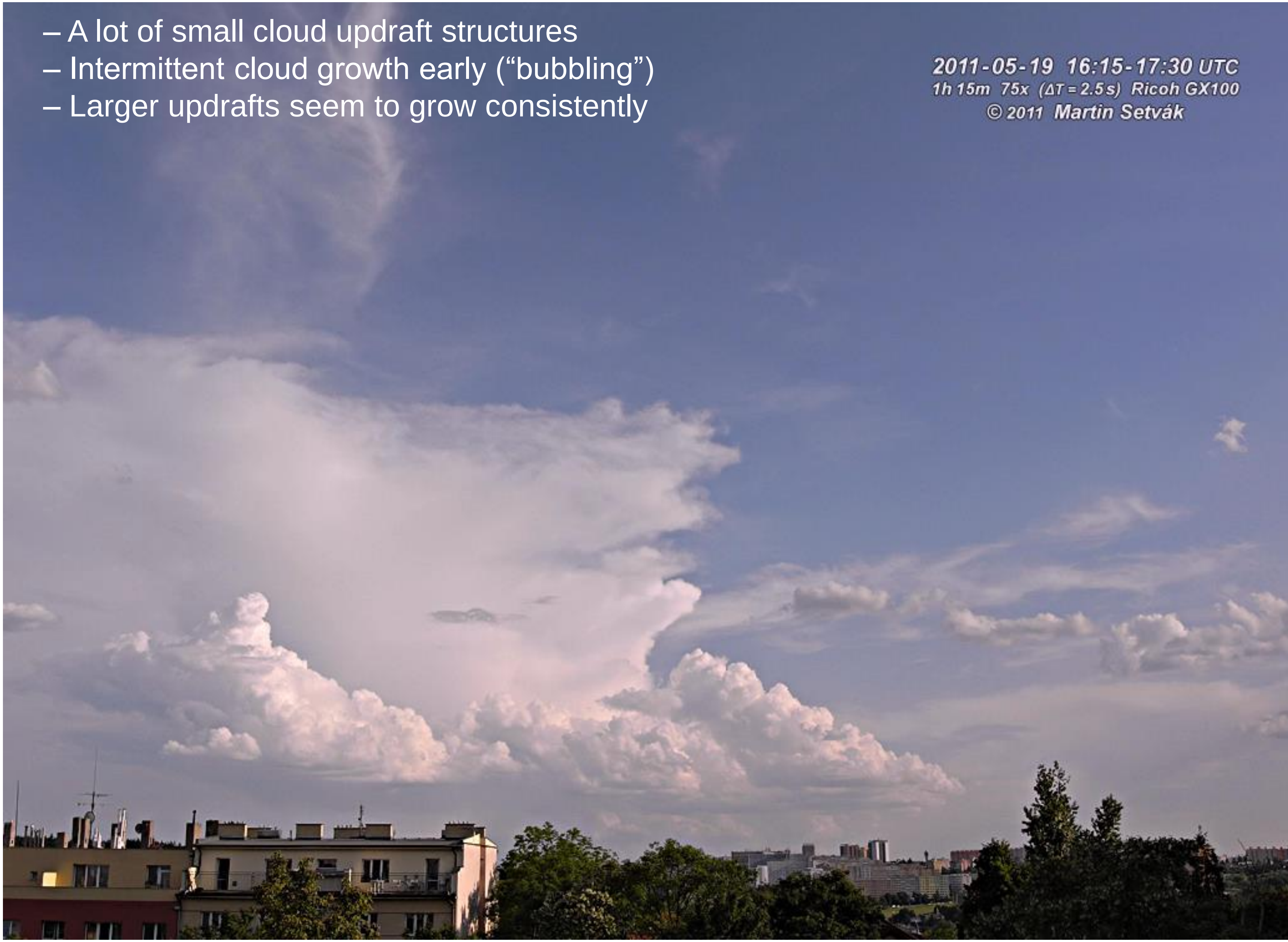
5. Conclusions and potential new applications

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...

Courtesy of UCAR

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



c/o Martin Setvak

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.

• Initial indications showed 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**.

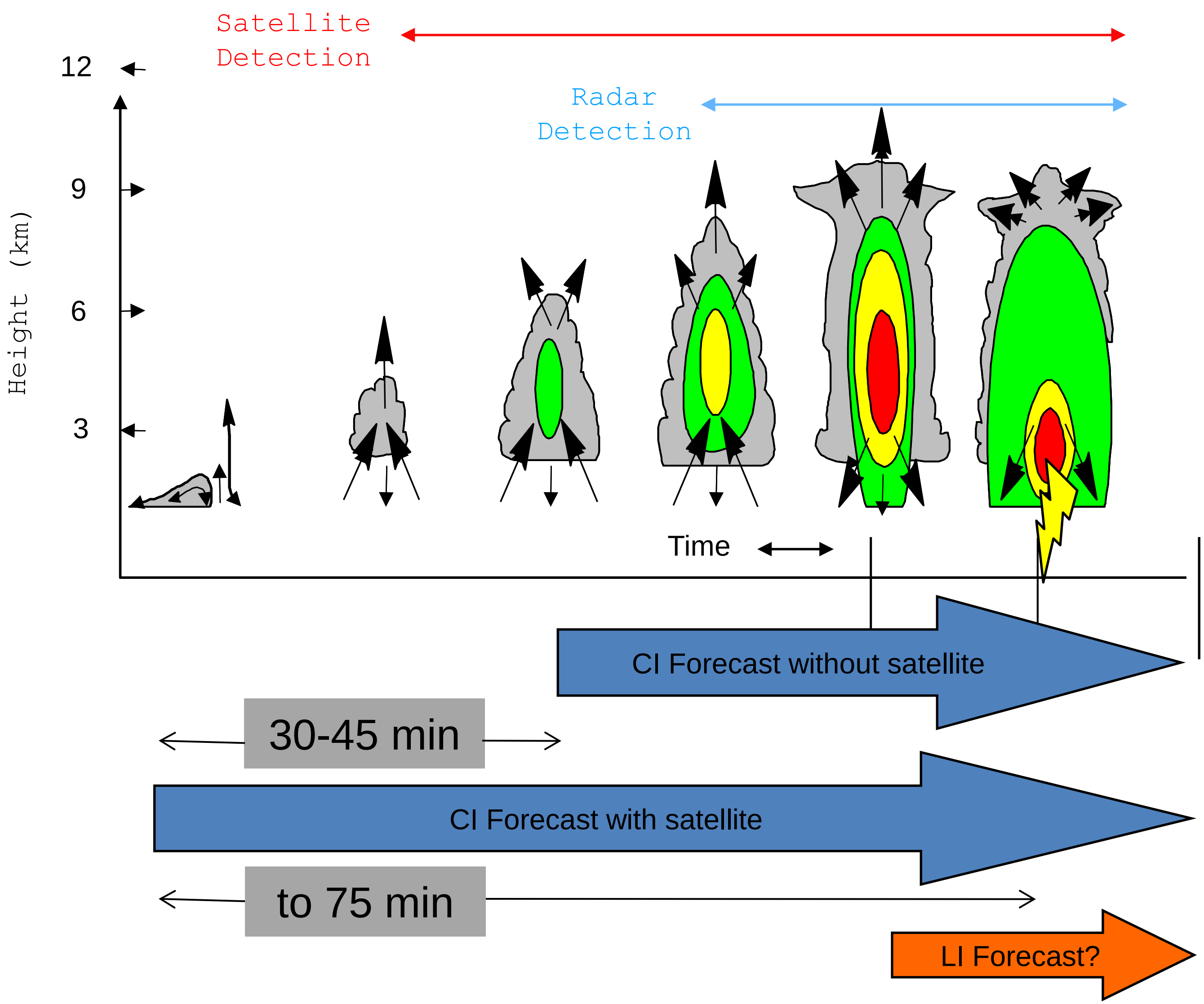
• Evaluation of 1 min updraft acceleration data provides a key link in the **use of cloud-top fields to diagnose *in-cloud* processes**, in a similar manner how the T–r_e concepts relate to updraft strengths (e.g., relatively small r_e values correlated with more intense updrafts).

• Prior studies find that the 1–min resolution cloud-top cooling rates are 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!**

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?

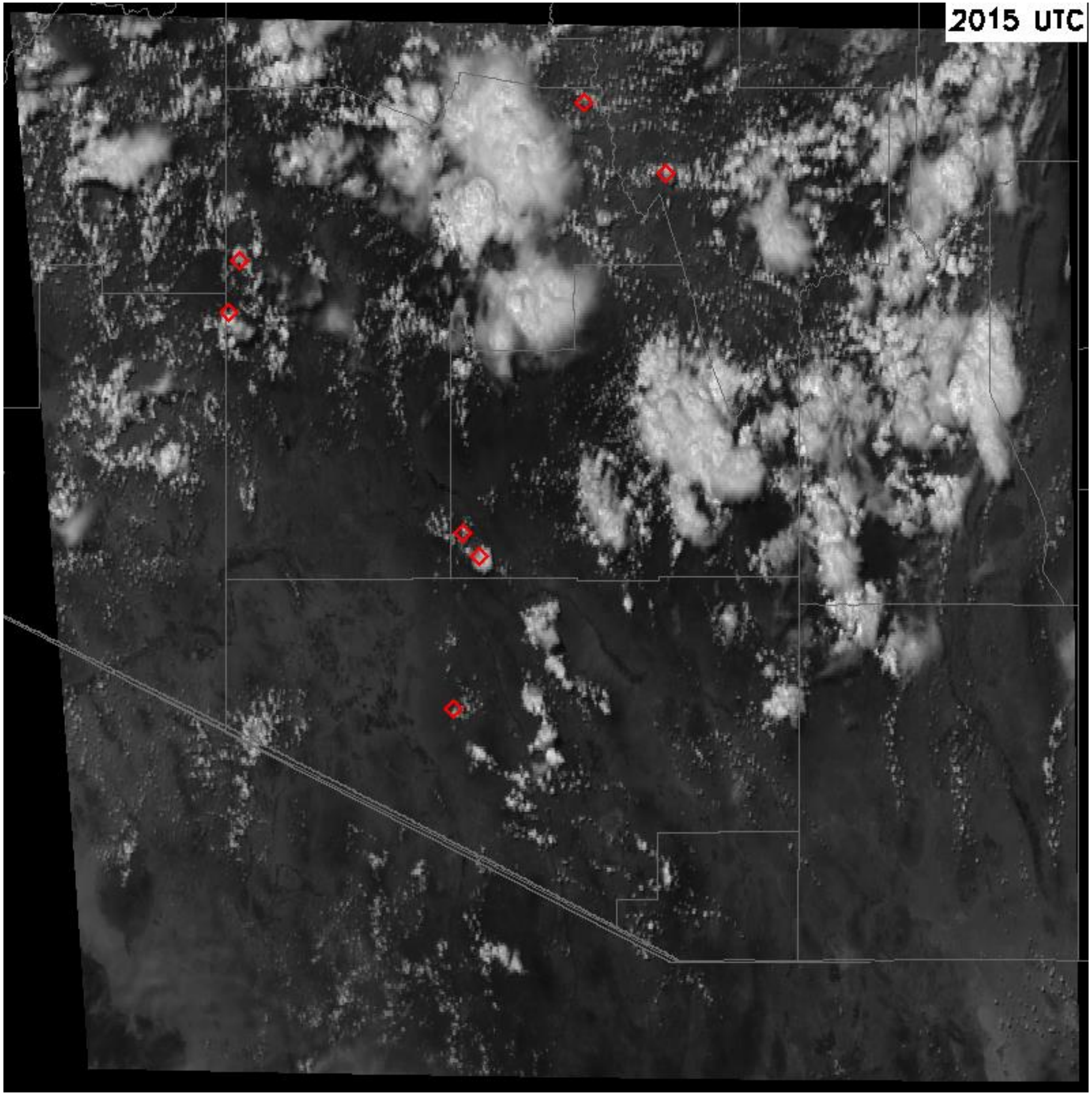
Collection of Updraft Information

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.

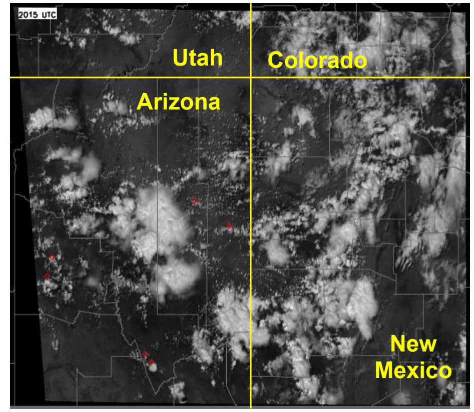
Catalog 10.7 µm T_B, and compute vertical motions, assuming GOES 10.7 µm T_B is equivalent to cloud-top temperature for optically thick clouds. Also, consider method by Adler and Fenn (1981).



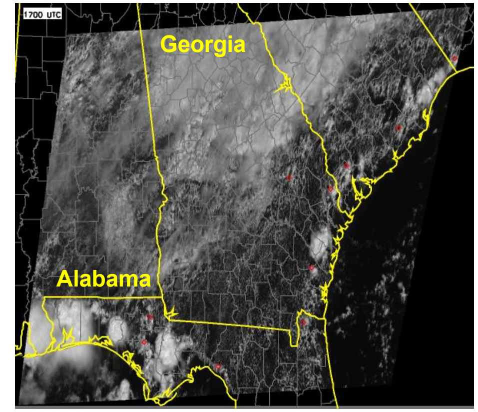
Regions of SRSOR updraft collection for this study.

Additional SRSOR data were collected in 2015

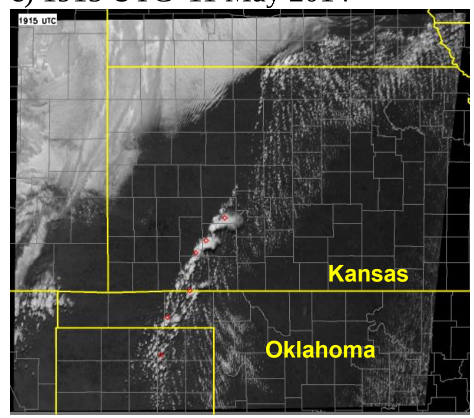
a) 2015 UTC 20 August 2012



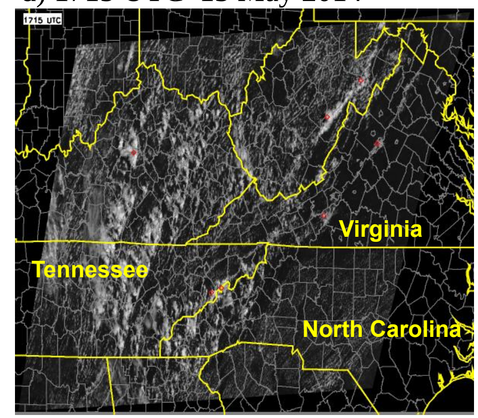
b) 1700 UTC 20 August 2013



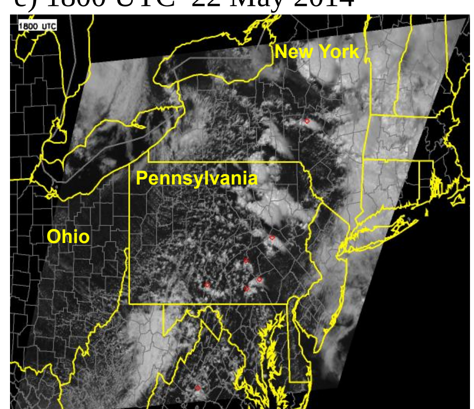
c) 1915 UTC 11 May 2014



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 ∑δCAPE.

- Assess correlations between δw and ∑δCAPE, across all updrafts, as well as for individual updrafts.

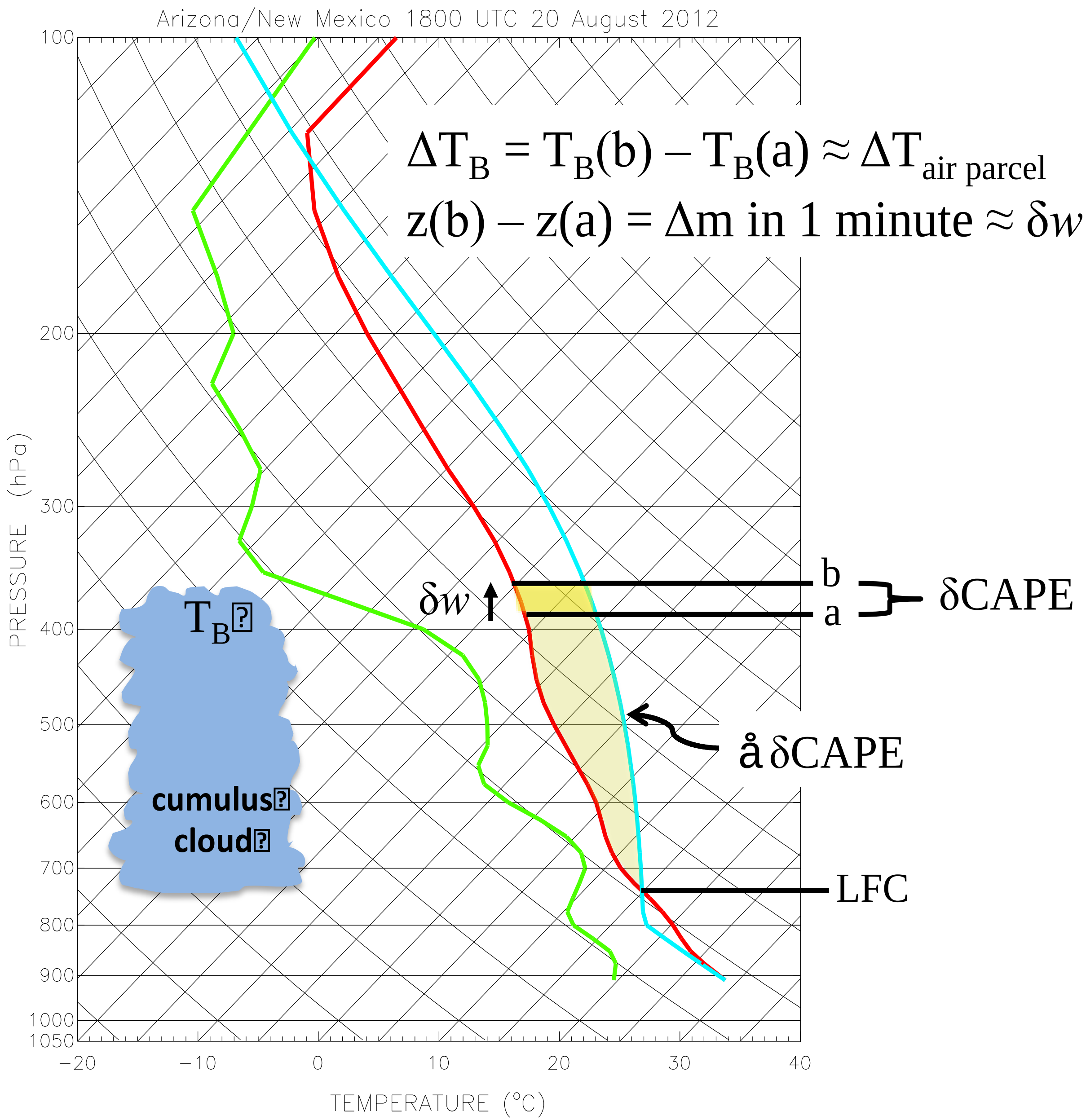
- Evaluate when correlations are highest, and in turn, where they were the lowest.

- 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 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),

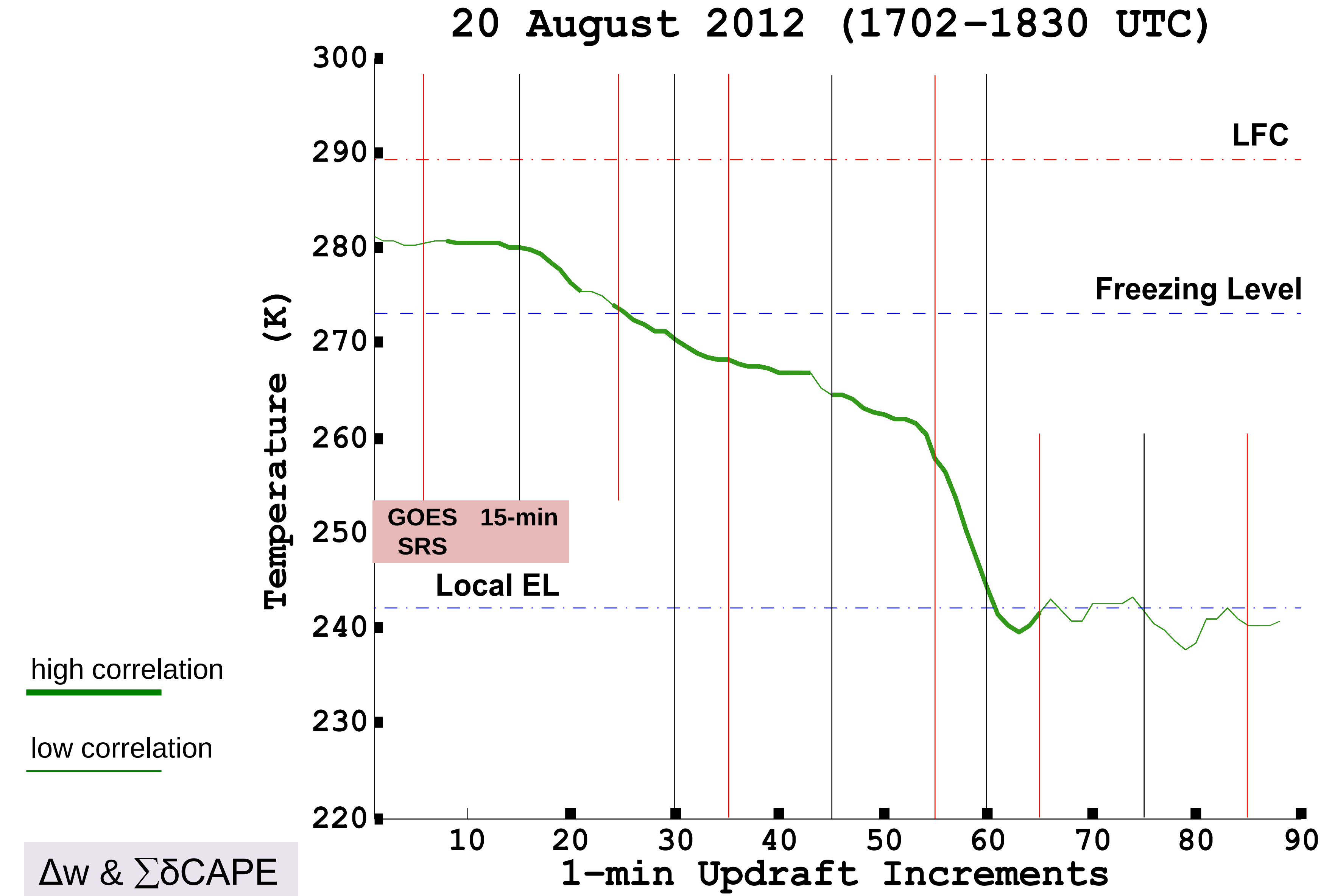
$$\frac{dw}{dt} = -g\,\frac{(T_v' - \overline{T}_v)}{\overline{T}_v} = B$$

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?

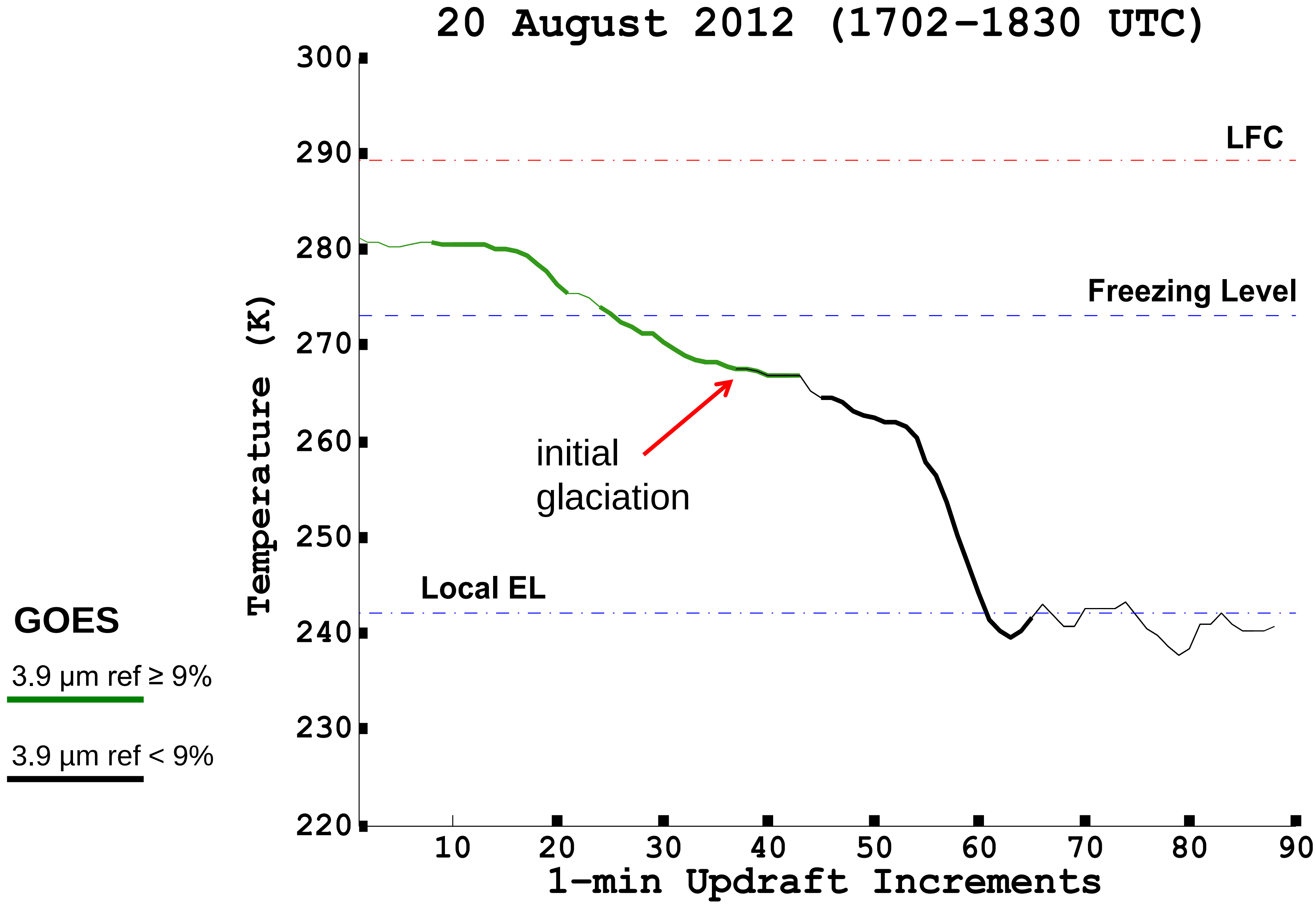
Single Updraft Analysis



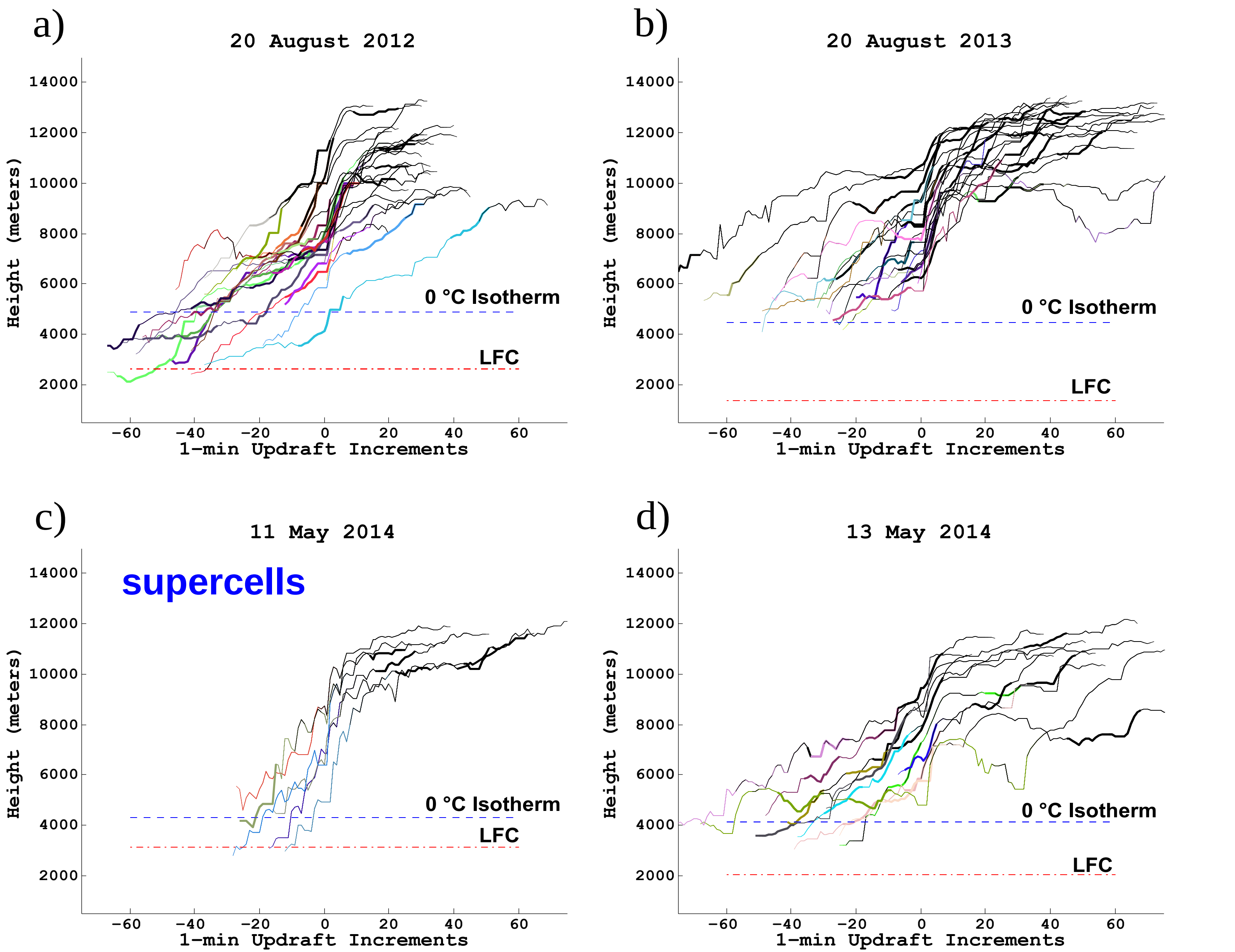
Δw & ∑δCAPE

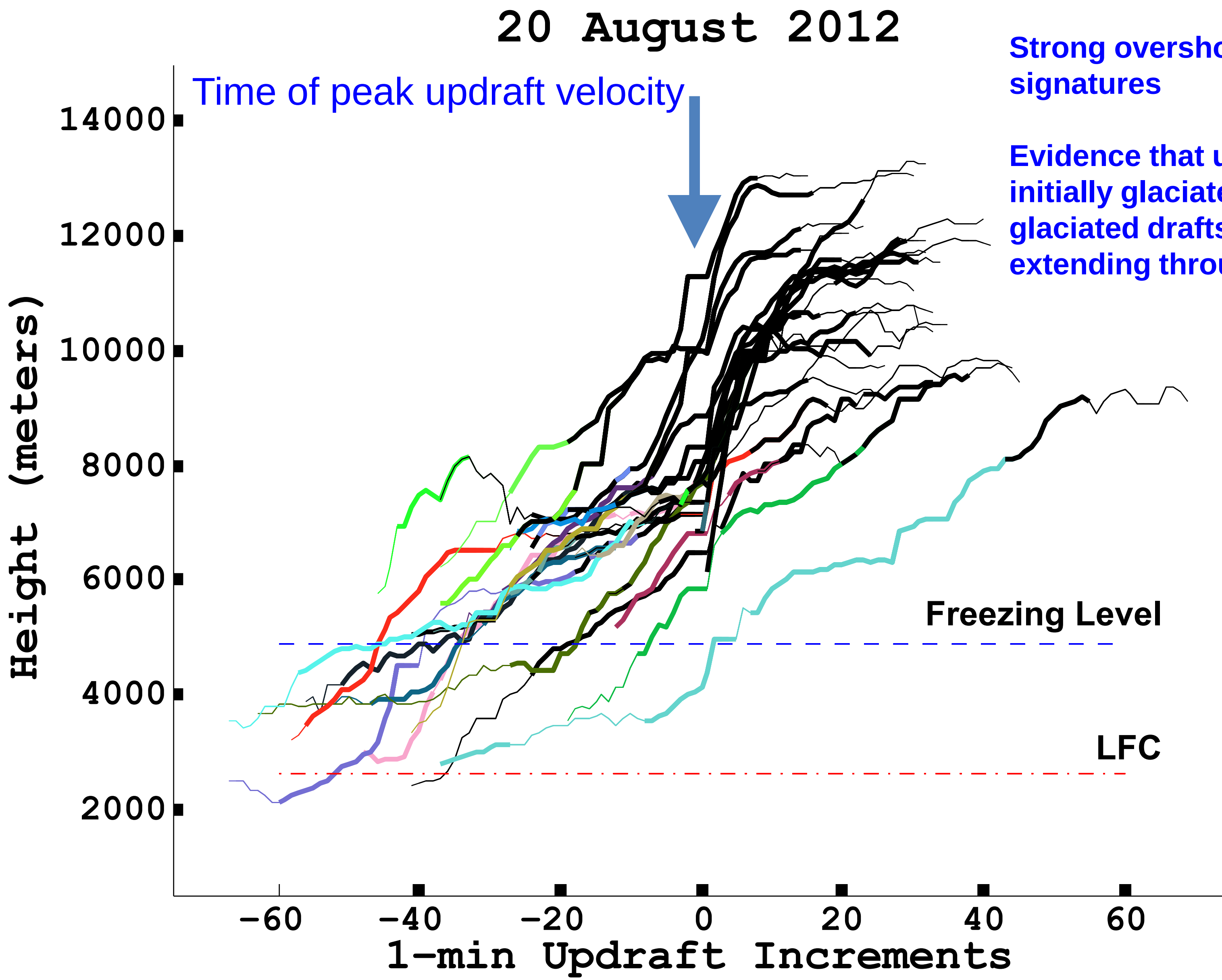
87 minutes

Single Updraft Analysis



Many Updrafts





Strong overshooting top signatures

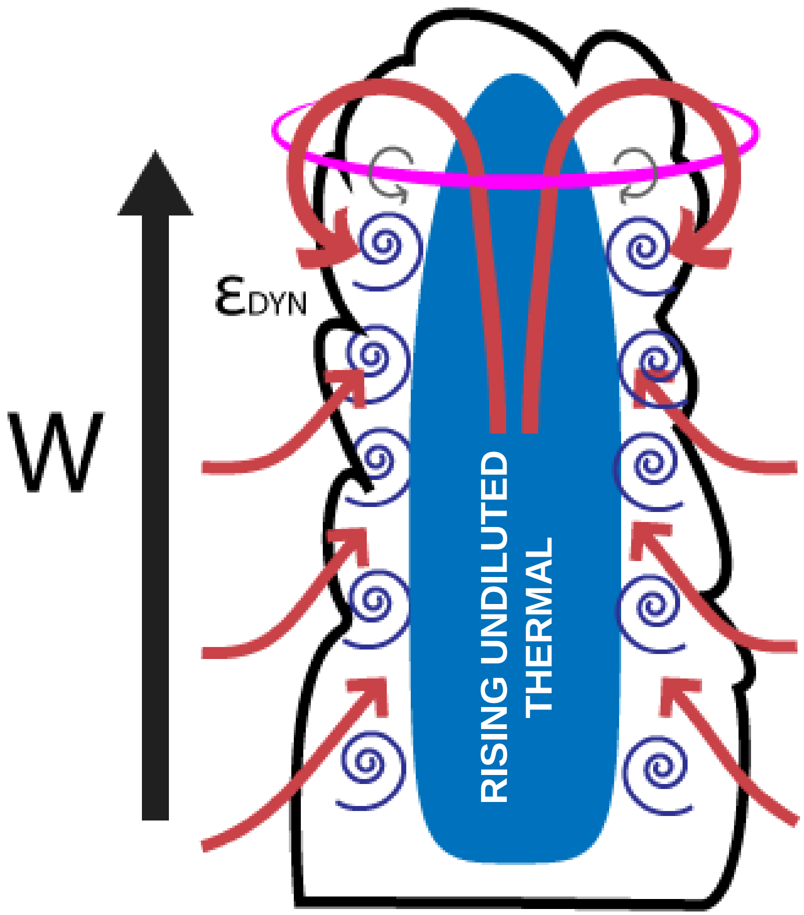
Evidence that updrafts may initially glaciate, with un-glaciated drafts later extending through an anvil

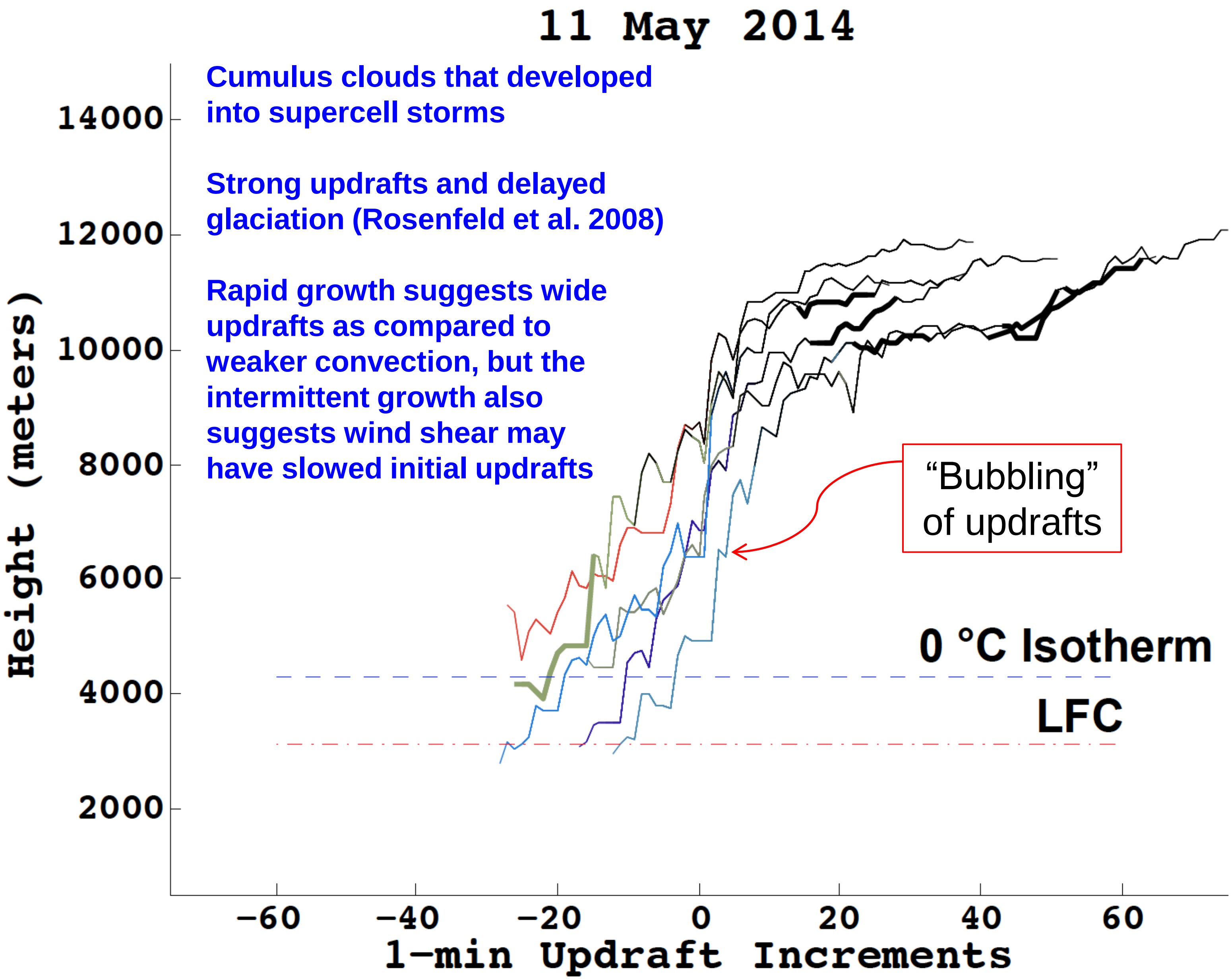
Interpretation

- 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.

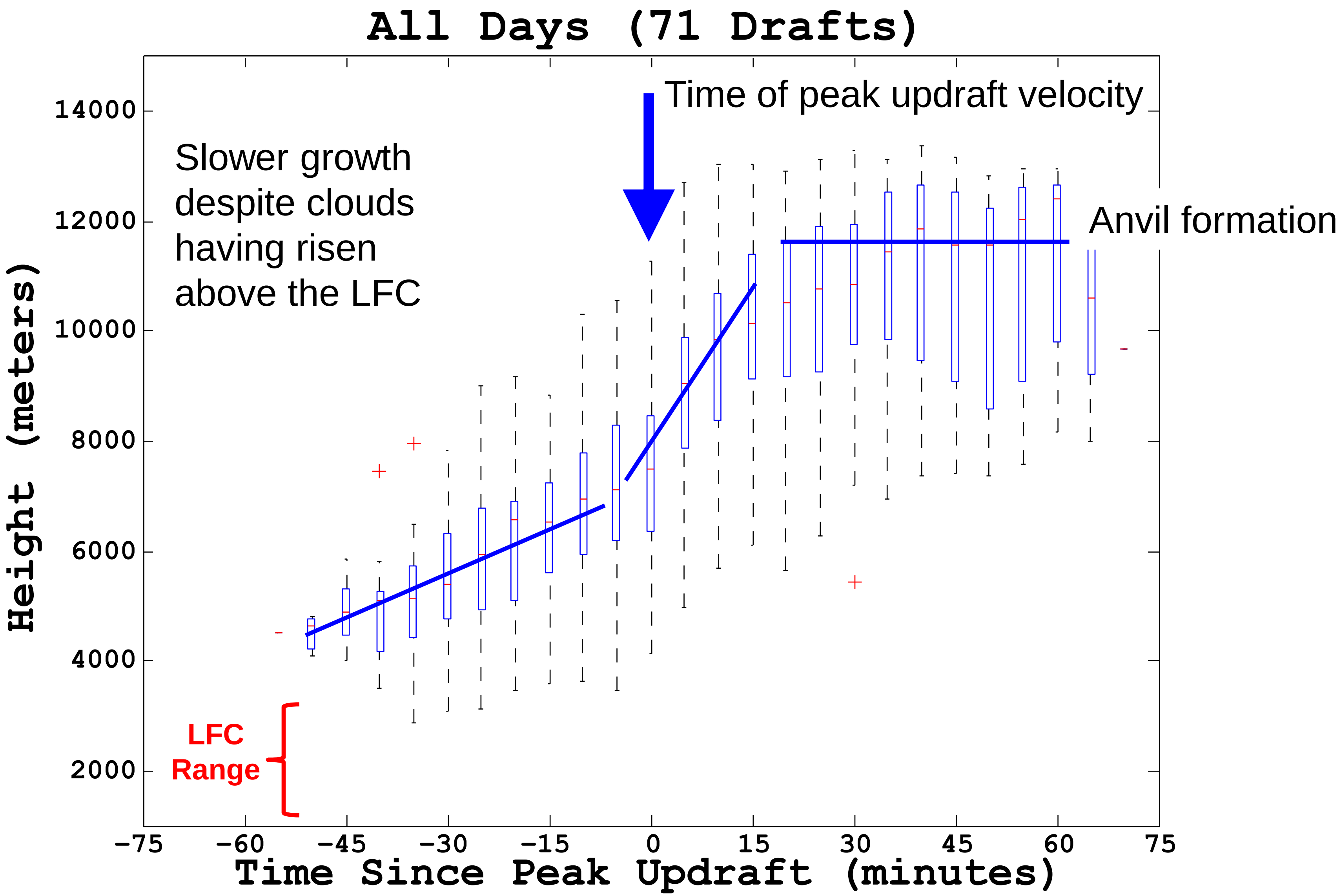
- Where the correlations between δw and ∑δCAPE are low, influences of dynamic entrainment ($\boldsymbol{\varepsilon}_{DYN}$) are likely leading to more diluted thermals with environmental air.

- 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

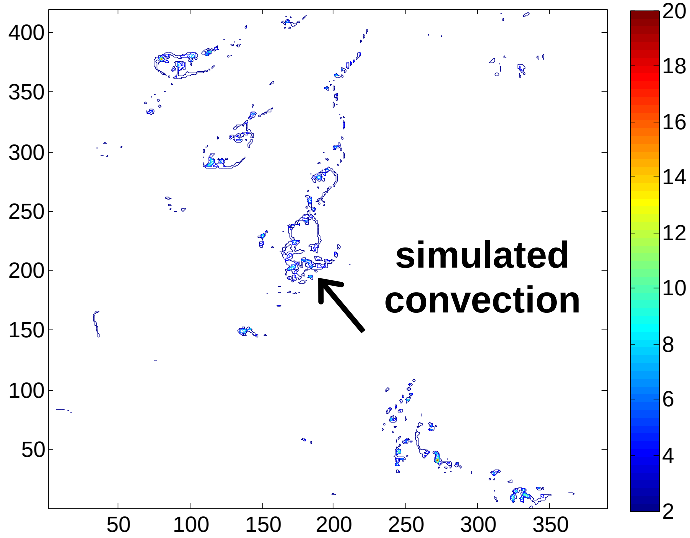
Day		draft	Time (UTC)	Peak w (ms^{-1})	MDA (m)	ΔT ZLVL-MDA (°K)	T_B(ref39<9%)
20 August 2012		1	1602-1705	6.6	3575	-9.6	264
CAPE	2228	2	2017-2146	15.2	9985	24.6	243
LFC	2600	3	2017-2157	16.5	4486	-5.5	237
0 °C Isotherm Level	4900	4	2017-2155	12.8	8300	18.2	255
EL	14300	5	1702-1849	14.7	4980	-2.2	254
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**

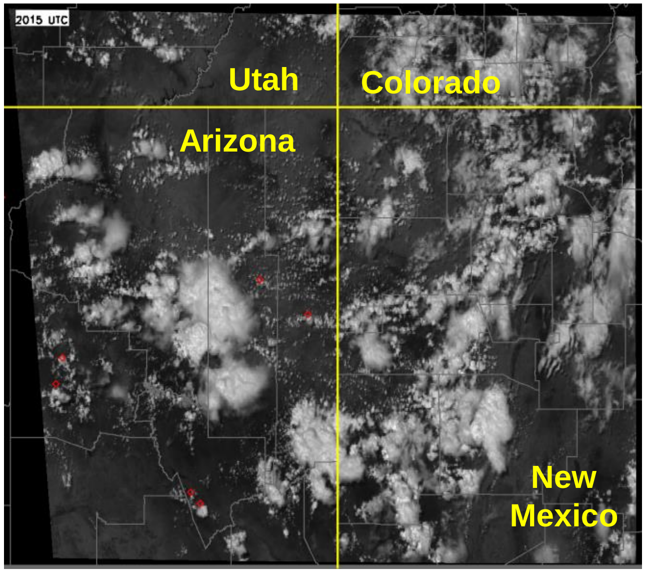
On average, updrafts attained their peak ~3200 m above the 'freezing level' (or 0°C isotherm altitude) near 8100 m, of magnitudes 4.5 to near 21 ms^{-1}.

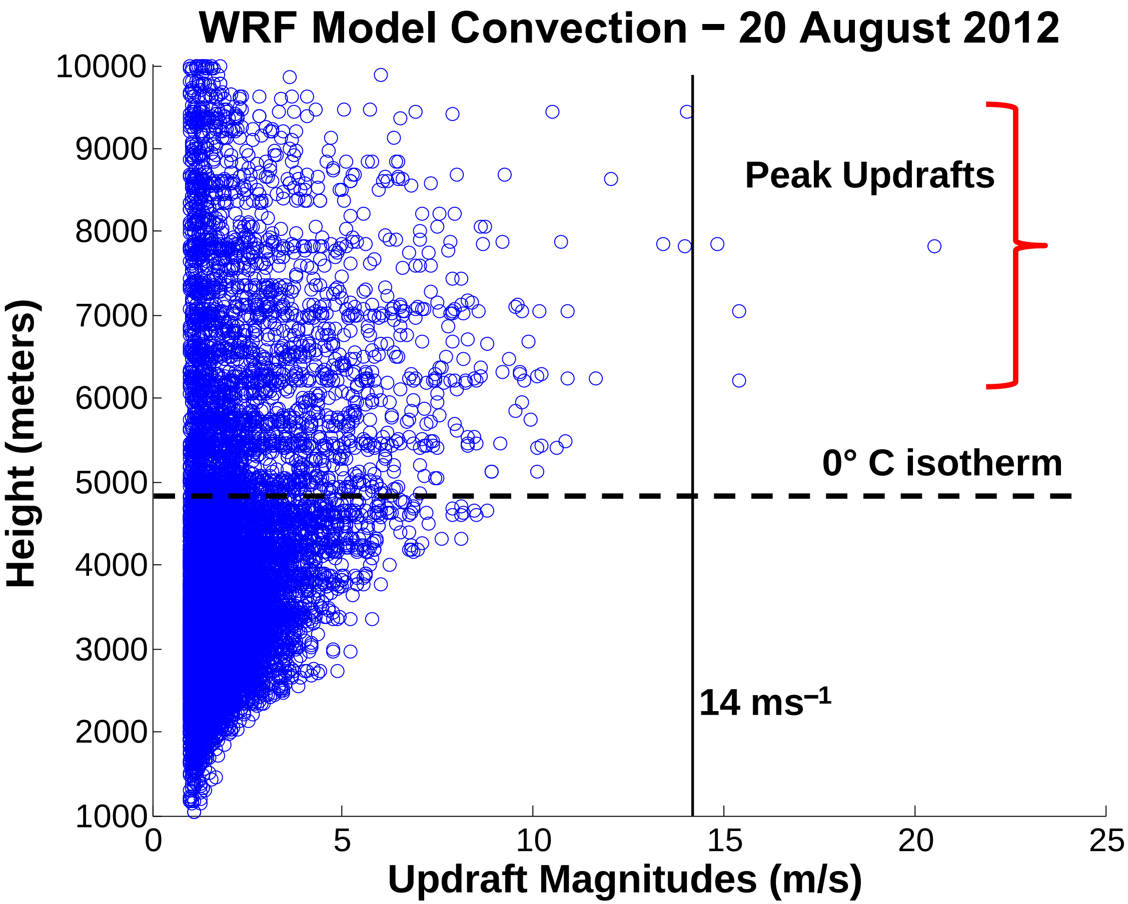
Most updrafts were less than 14 ms^{-1}.

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

Comparison to WRF 1 km Resolution Simulations

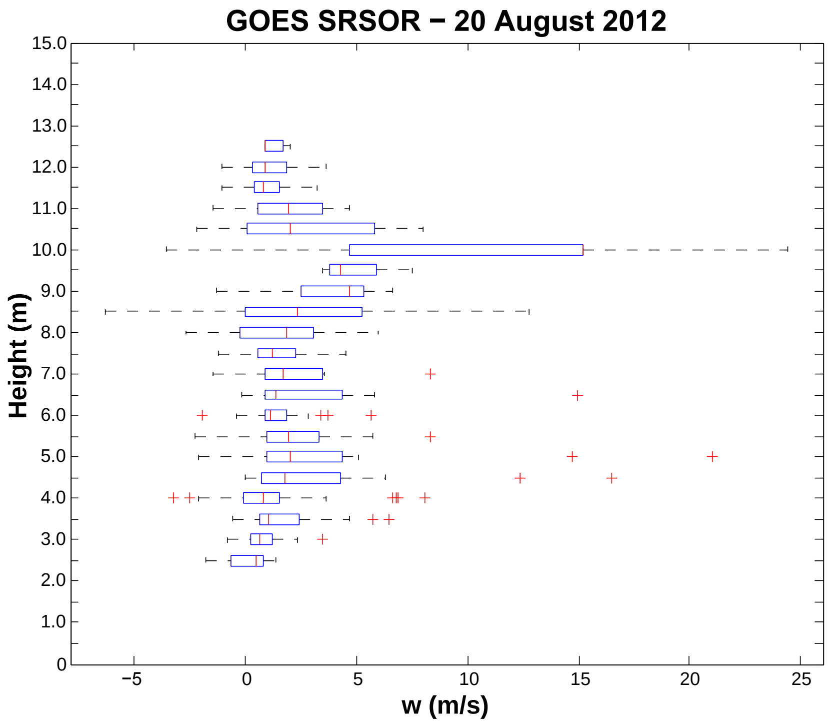


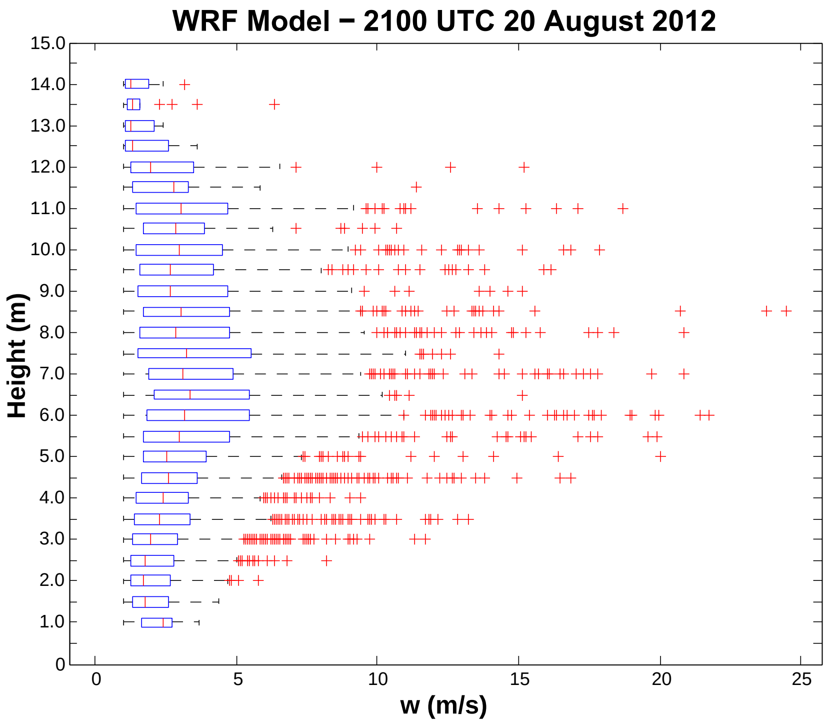




The agreement between SRSOR-estimated *w*'s and updrafts in WRF model simulations is very good.

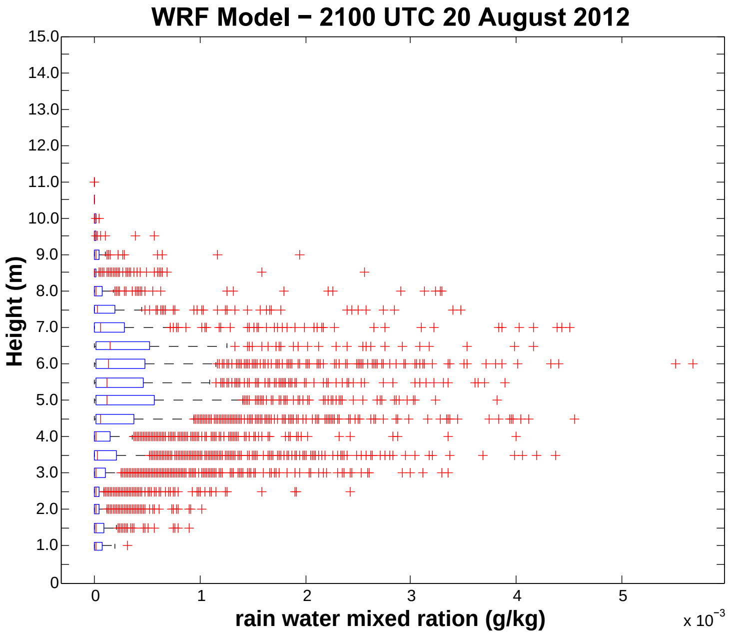
Likely both are underestimated given low resolution of data/model. In-cloud *w's* should be ~2 times larger than cloud-top rising rates (Romps and Charn 2015).

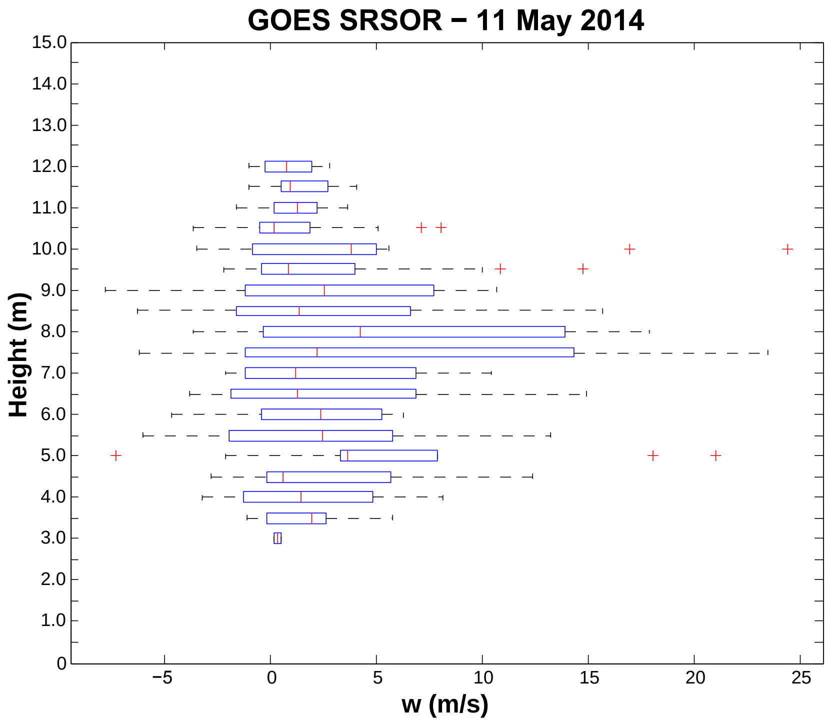


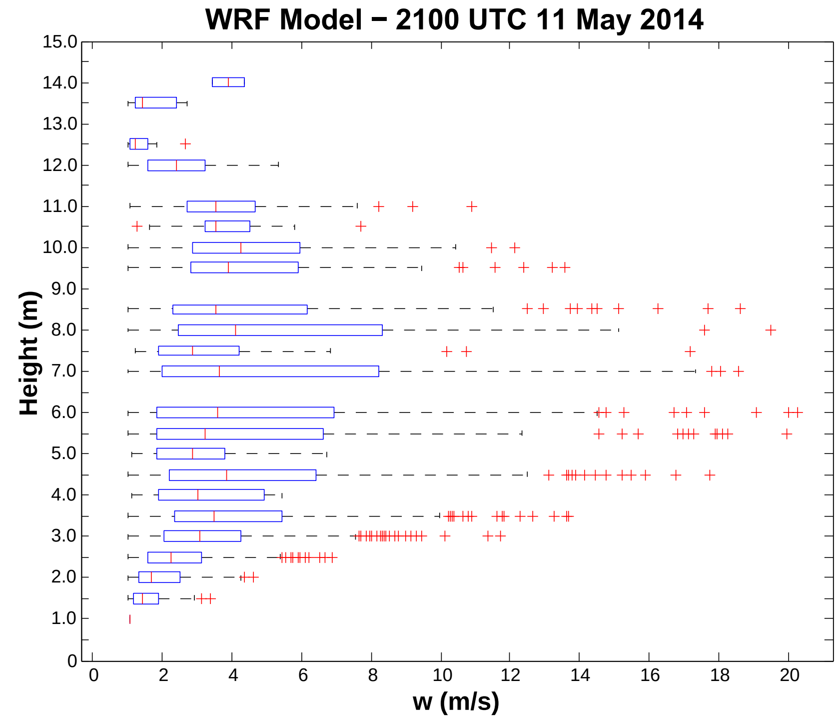


Comparison–SRSOR versus 1 km WRF

- Maximum updrafts nearly coincident at similar levels
- Updraft magnitudes tend to be higher in WRF (yet as expected as in-cloud updrafts are ~2x cloud-top rising rates
- Mixing ratio values suggest water loading will peak at/below ~7-8 km AGL

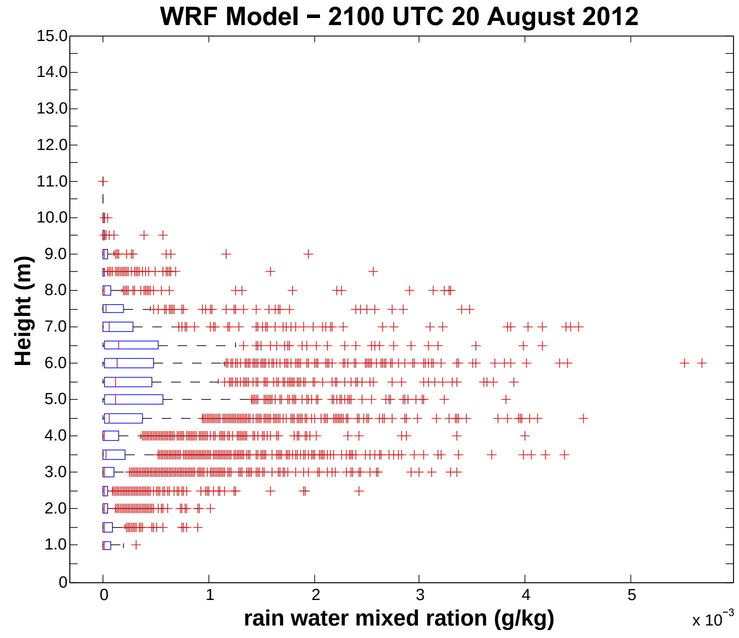






Comparison–SRSOR versus 1 km WRF

- Maximum updrafts nearly coincident at similar levels; better agreement...
- Peak updrafts both peak near ~8 km AGL
- Mixing ratio values suggest water loading will peak between 5-7 km AGL



Single Channel Sounding – Recovery of Profiles

Hypotheses:

(1) GOES SRSOR data provide us a sense for what amount of CAPE is actually realized by a growing cumulus cloud. By analyzing the rate of updraft growth, given knowledge of total CAPE from a proximity of clear-sky model sounding, <u>the amount of CAPE</u> in the cloud layer can be computed.

(2) With GOES SRSOR, it is theoretically possible to use 1-min observations of growing deep convective clouds to retrieve <u>an environmental temperature</u> profile using only the cloud-top 10.7-μm channel data.

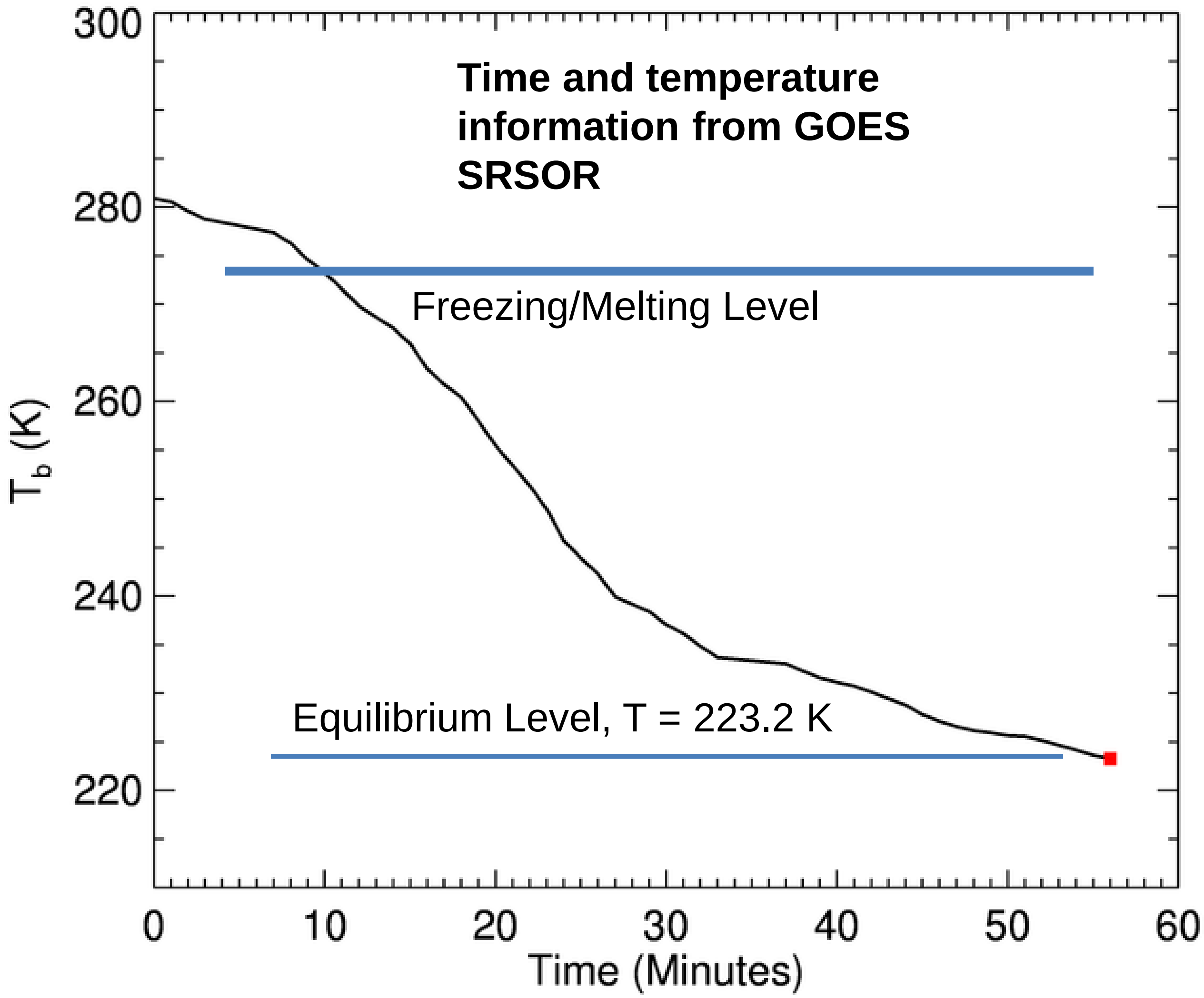
Single Channel Sounding – Recovery of Profiles

A Few Key Questions:

1. *Does the satellite brightness temperature (T_B) measured by GOES data at the convective cloud top height follow a convective parcel path, or an environmental temperature path because of mixing (i.e., What is the satellite showing us)?*
   → Adler and Fenn (1981) approximated that T_B is somewhere in between the parcel path and environmental temperature, rather than one or the other (re: the use of a 2.5 K km^{-1} lapse rate).

2. *How does the cloud top vertical velocity as estimated from SRSOR observations (and subsequently, cloud top cooling) relate to the effective buoyancy in the layer?*
   → Mecikalski et al. (2016) suggests that the T_B cooling in a layer responds to the amount of instability in that layer. See also Romps and Charn (2015), as well as considerations of the factors influencing buoyancy (water loading, entrainment).

Single Channel Sounding – Methodology

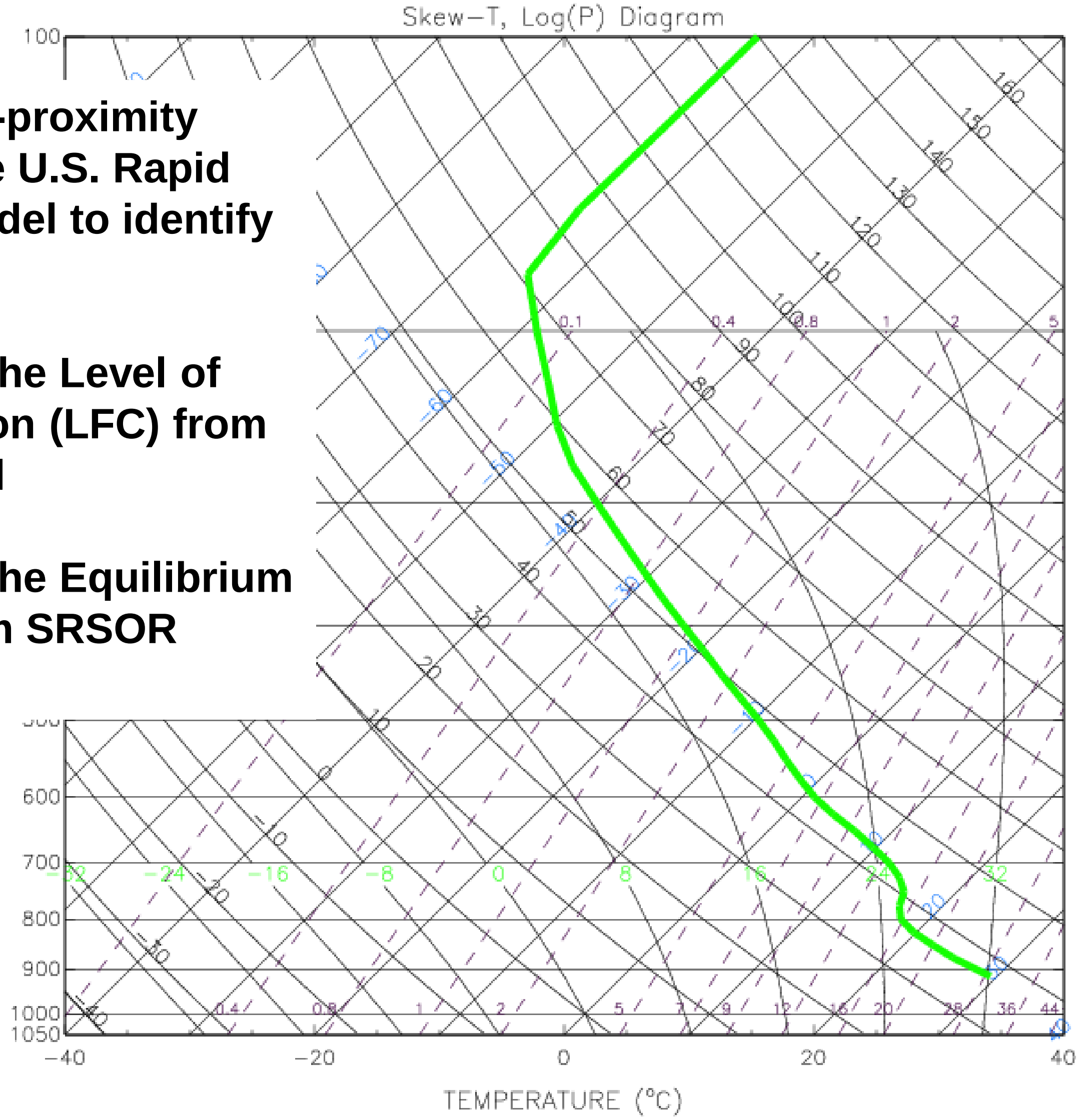


Time series of GOES SRSOR T_B (K) of a storm on 11 May 2014 with levels of neutral buoyancy (no change in temperature) highlighted in red.

Start with a storm-proximity sounding from the U.S. Rapid Refresh (RAP) model to identify two key points:

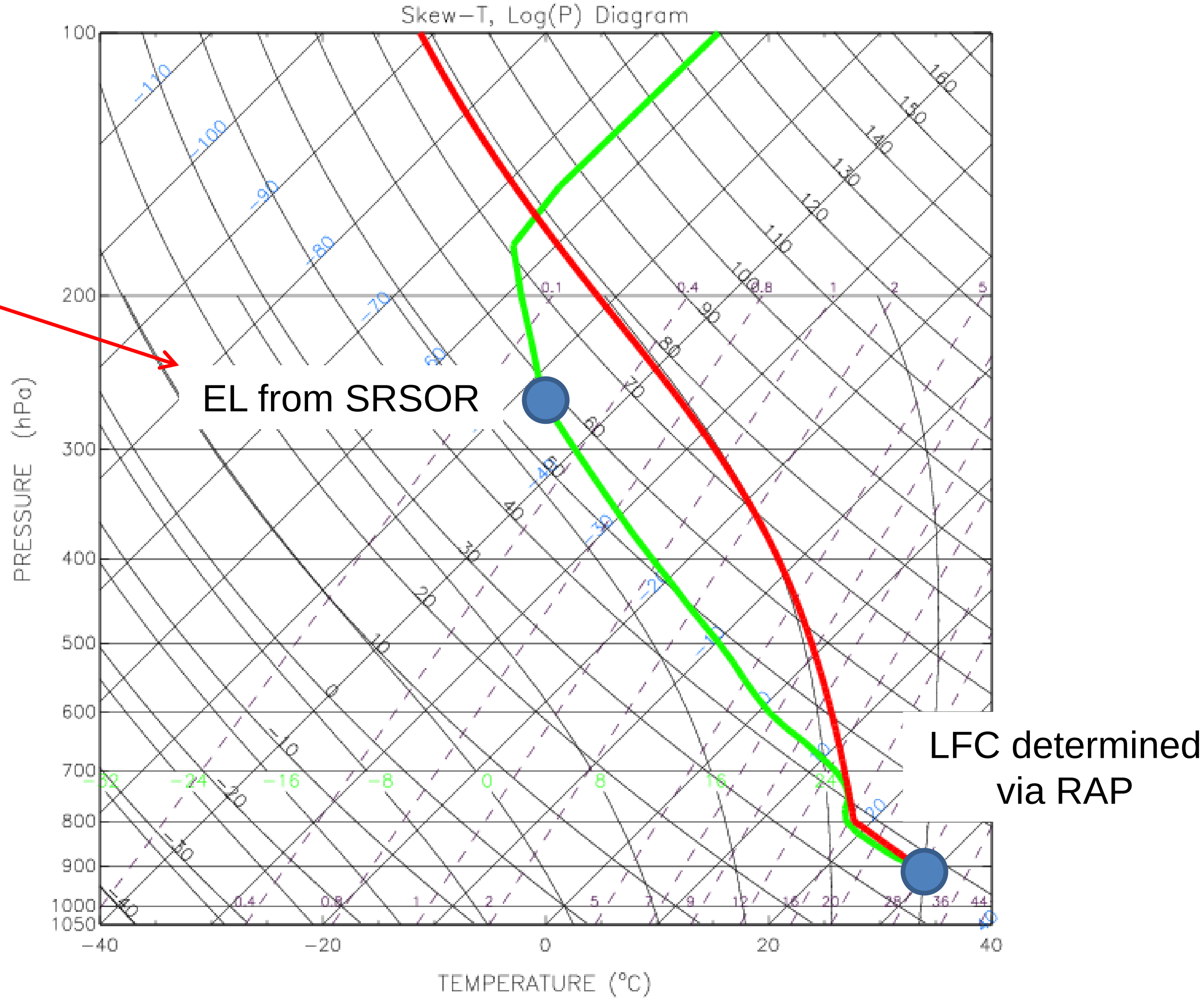
(1) The height of the Level of Free Convection (LFC) from the RAP model

(2) The height of the Equilibrium Level (EL) from SRSOR observations



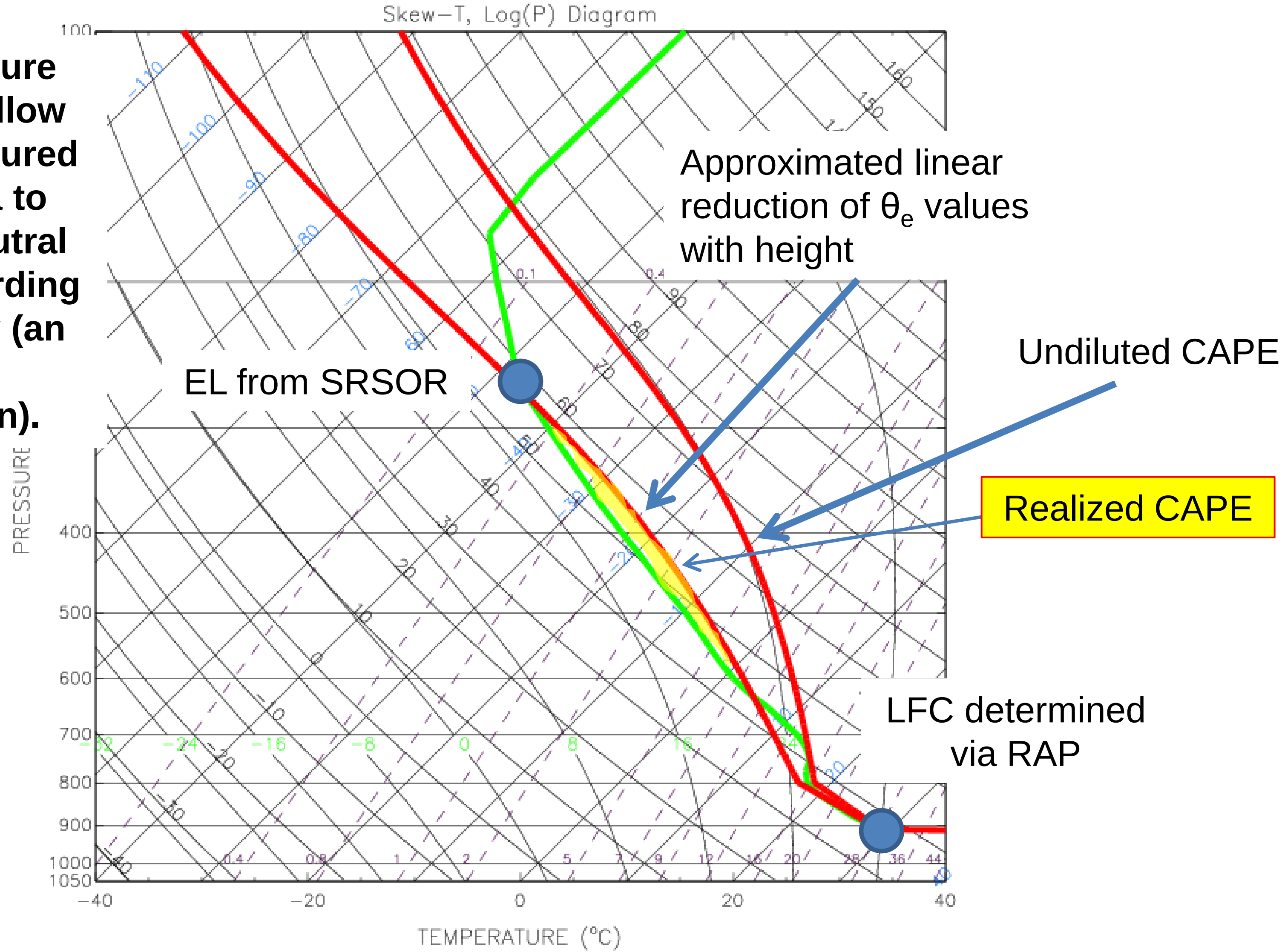
Single Channel Sounding example from 11 May 2014

1-min data provide us a better ability to assess where the EL will form for a convective cloud.



Single Channel Sounding example from 11 May 2014

Parcel temperature is modified to allow for the EL measured via SRSOR data to be a level of neutral buoyancy according to parcel theory (an entrainment parameterization).

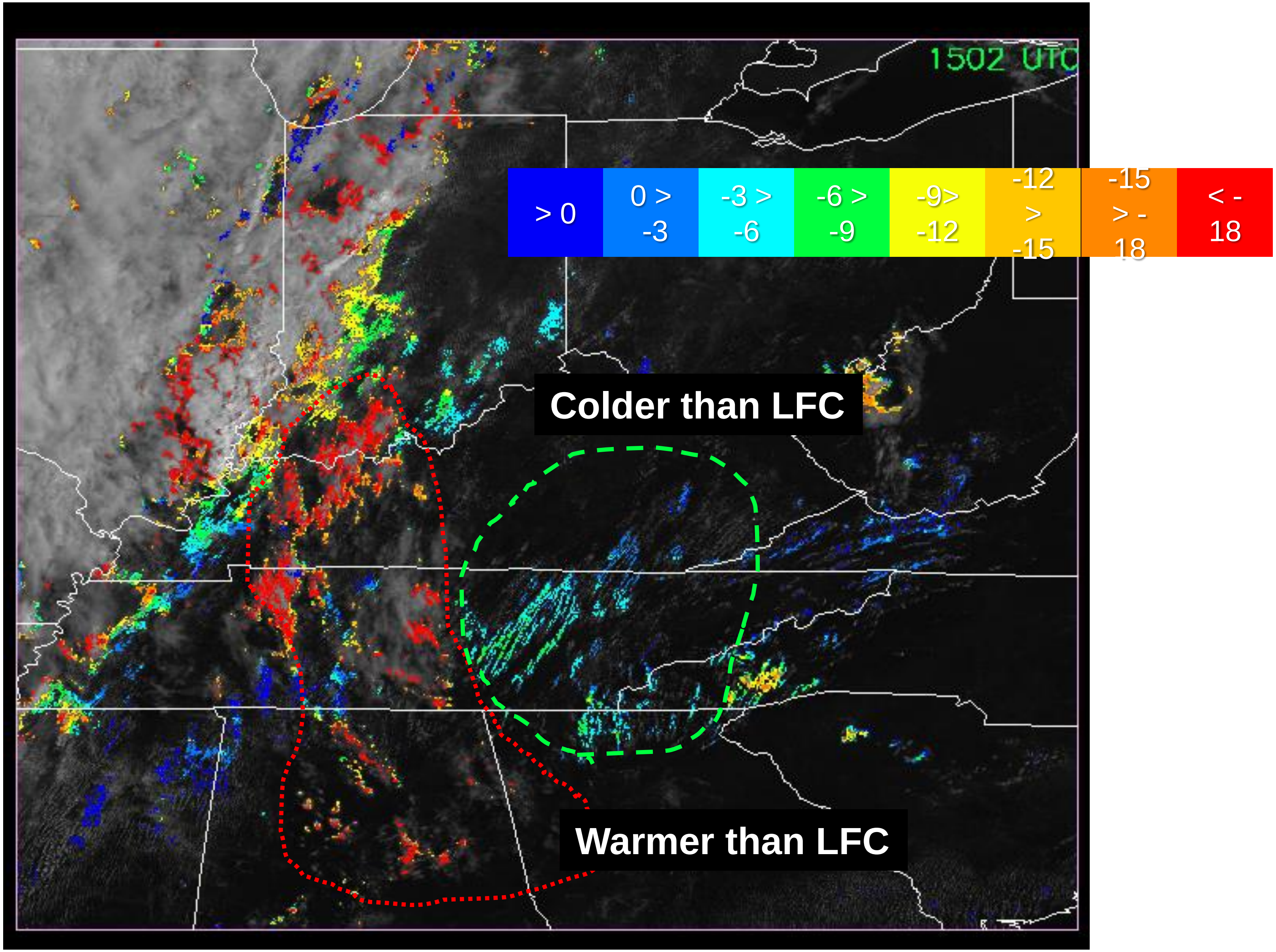


Single Channel Sounding example from 11 May 2014

Overall Results & Future Directions

1) Highest correlation between δw and $\sum\delta$CAPE 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 (δw–$\sum\delta$CAPE) 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



On the Development of Real-Time GOES Super Rapid Scan Derived Flow Products of Deep Convective Cloud Tops

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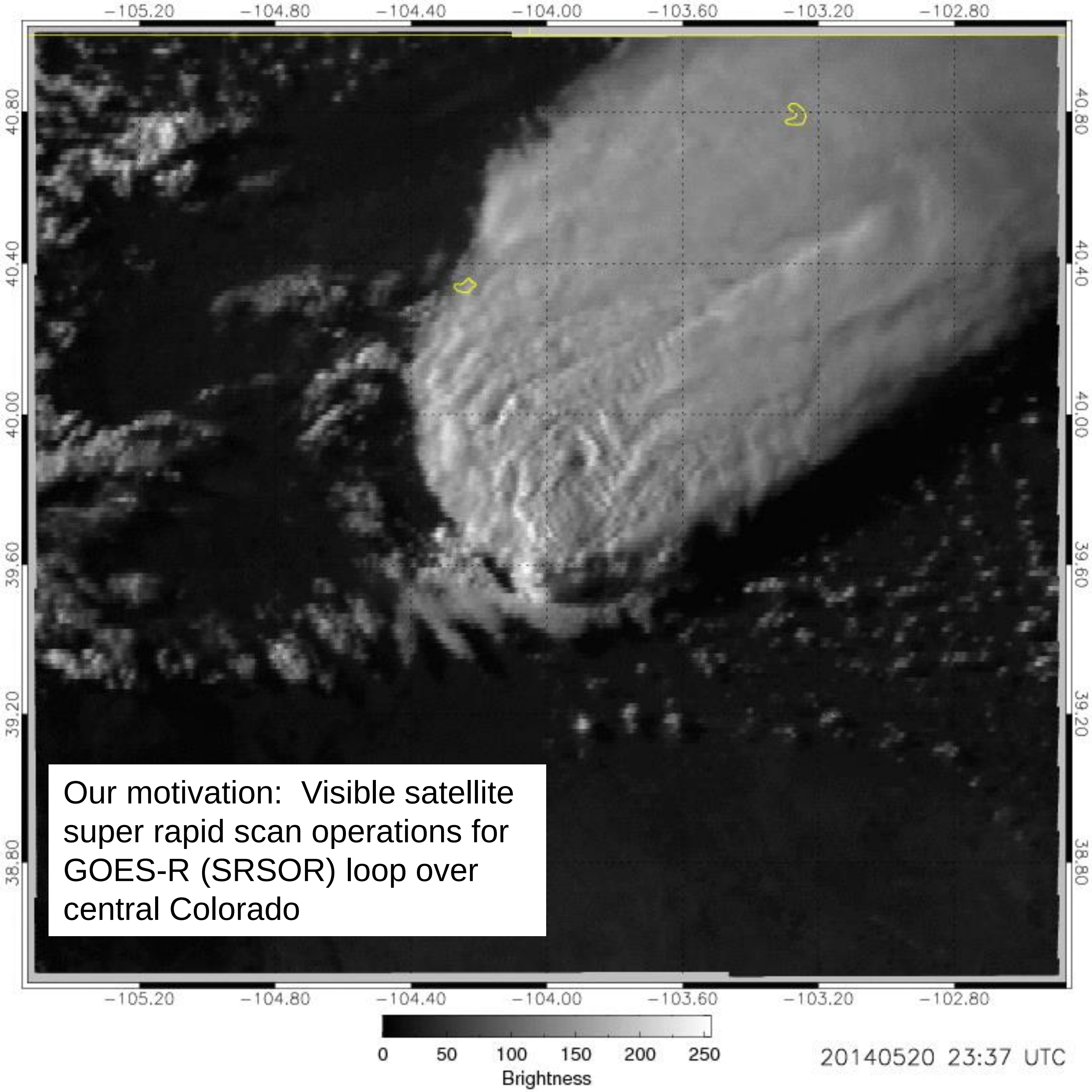
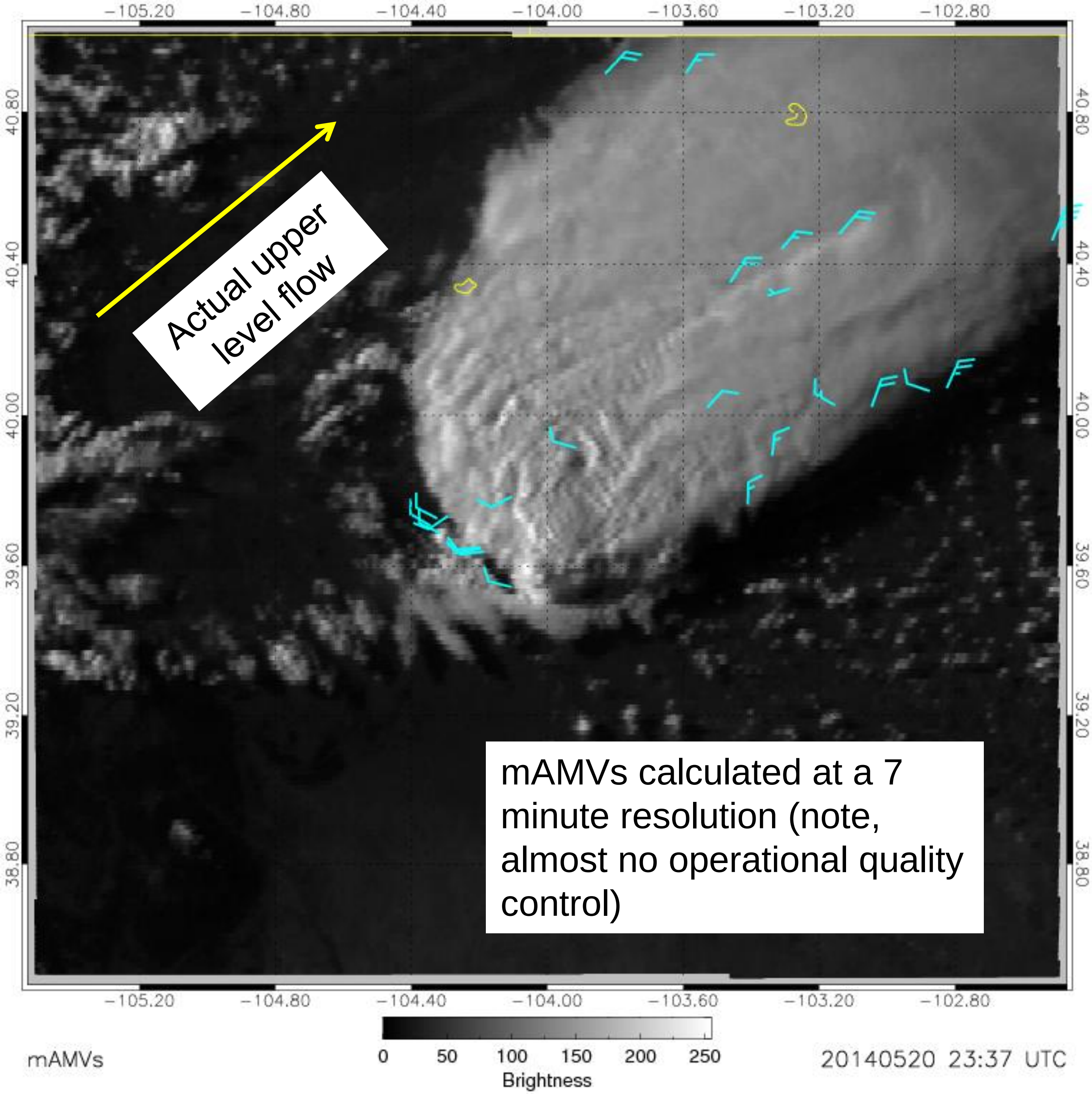


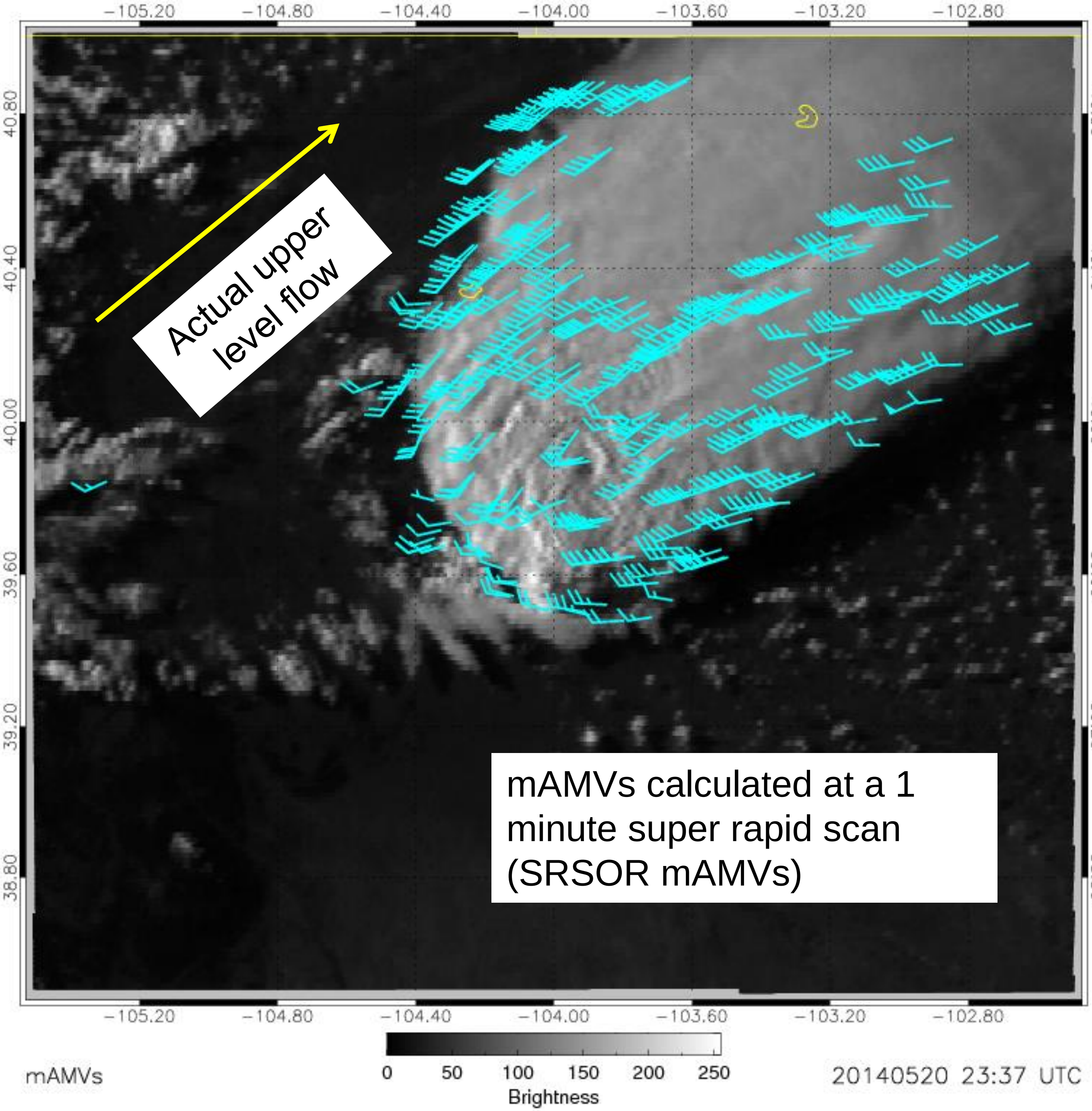
−105.20
−104.80
−104.40
−104.00
−103.60
−103.20
−102.80
40.80
40.40
40.00
39.60
39.20
38.80
Our motivation: Visible satellite super rapid scan operations for GOES-R (SRSOR) loop over central Colorado
0
50
100
150
200
250
Brightness
20140520 23:37 UTC

Background

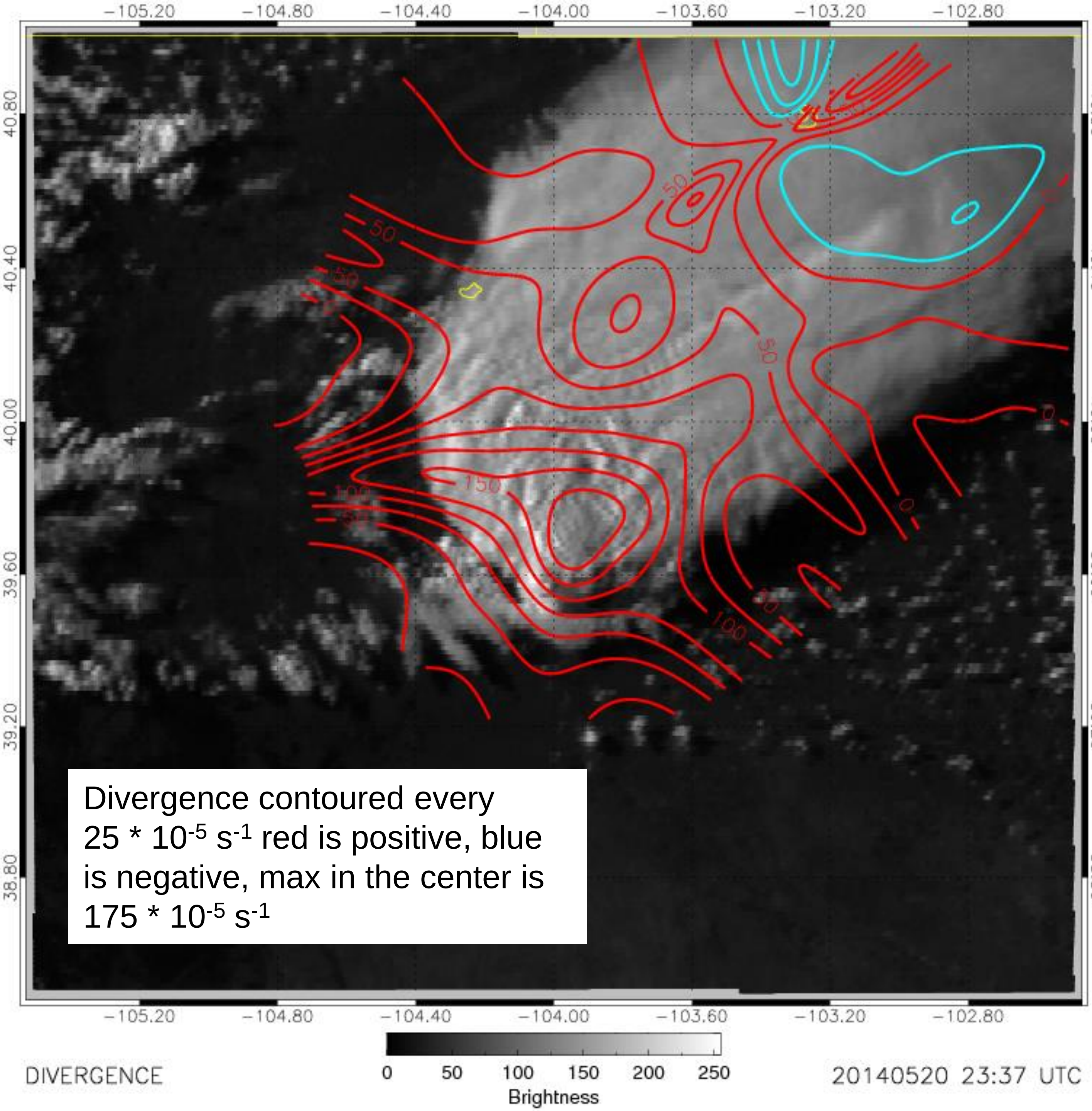
- The mesoscale atmospheric motion vector (mAMV) program (Velden et al. 1997, 1998; Bedka and Mecikalski, 2005) is already used for experimental algorithms such as GOES-R CI (Mecikalski and Bedka, 2006; Walker et al. 2012; Mecikalski et al. 2015)
  - Generates wind estimates by tracking targets of interest, such as boundaries, minima and maxima in Visible/IR using cross-correlation techniques
- Now we are repurposing it to resolve winds at higher levels (above 500 mb) with higher temporal resolution
- Several cases are analyzed with this presentation, five instances of supercells, one ordinary convective events
- A single pass Barnes analysis is used to interpret flow characteristics such as divergence and vorticity at cloud top (Apke et al. 2016, JAMC, *In review*)



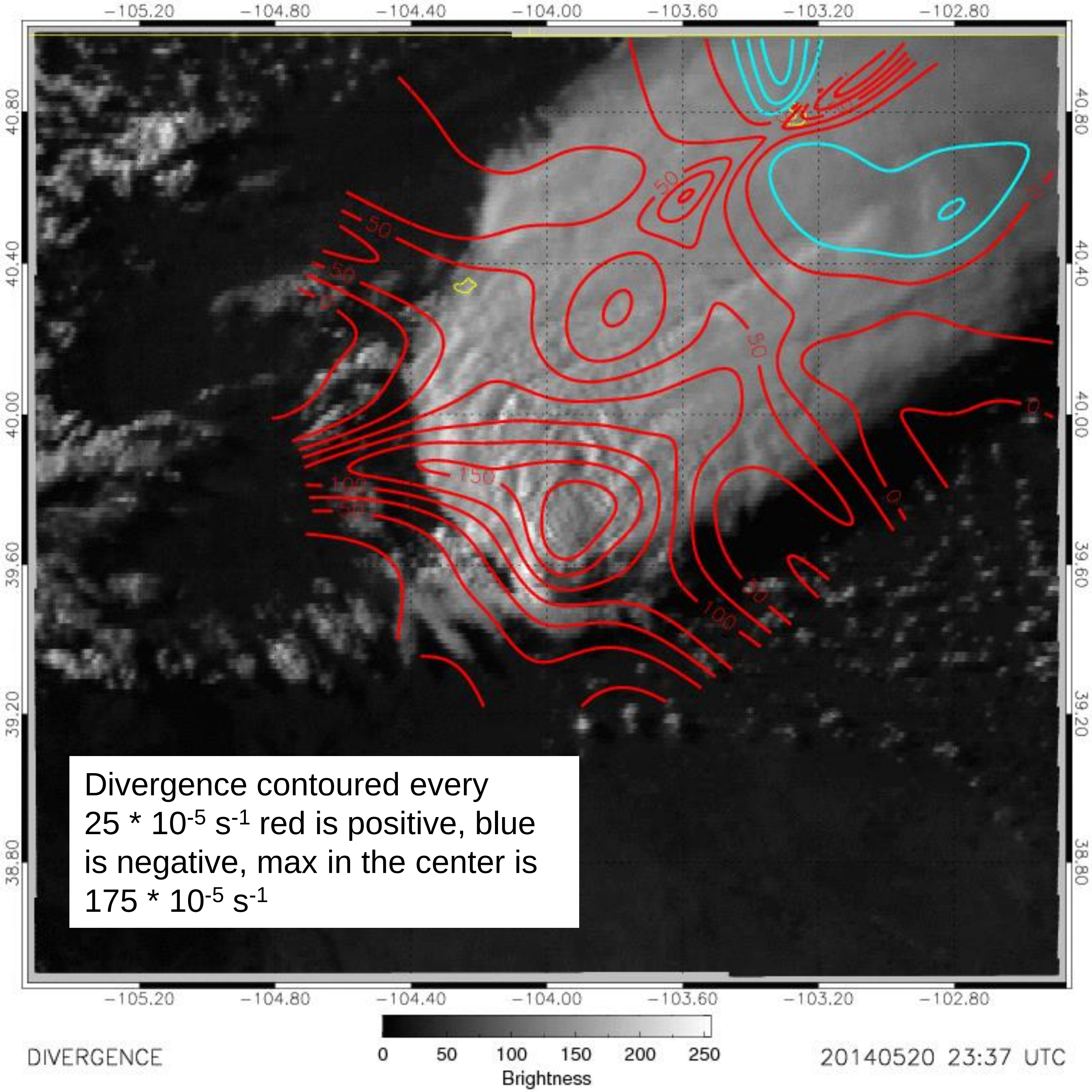
Actual upper level flow
mAMVs calculated at a 7 minute resolution (note, almost no operational quality control)
−105.20
−104.80
−104.40
−104.00
−103.60
−103.20
−102.80
40.80
40.40
40.00
39.60
39.20
38.80
0
50
100
150
200
250
Brightness
mAMVs
20140520 23:37 UTC



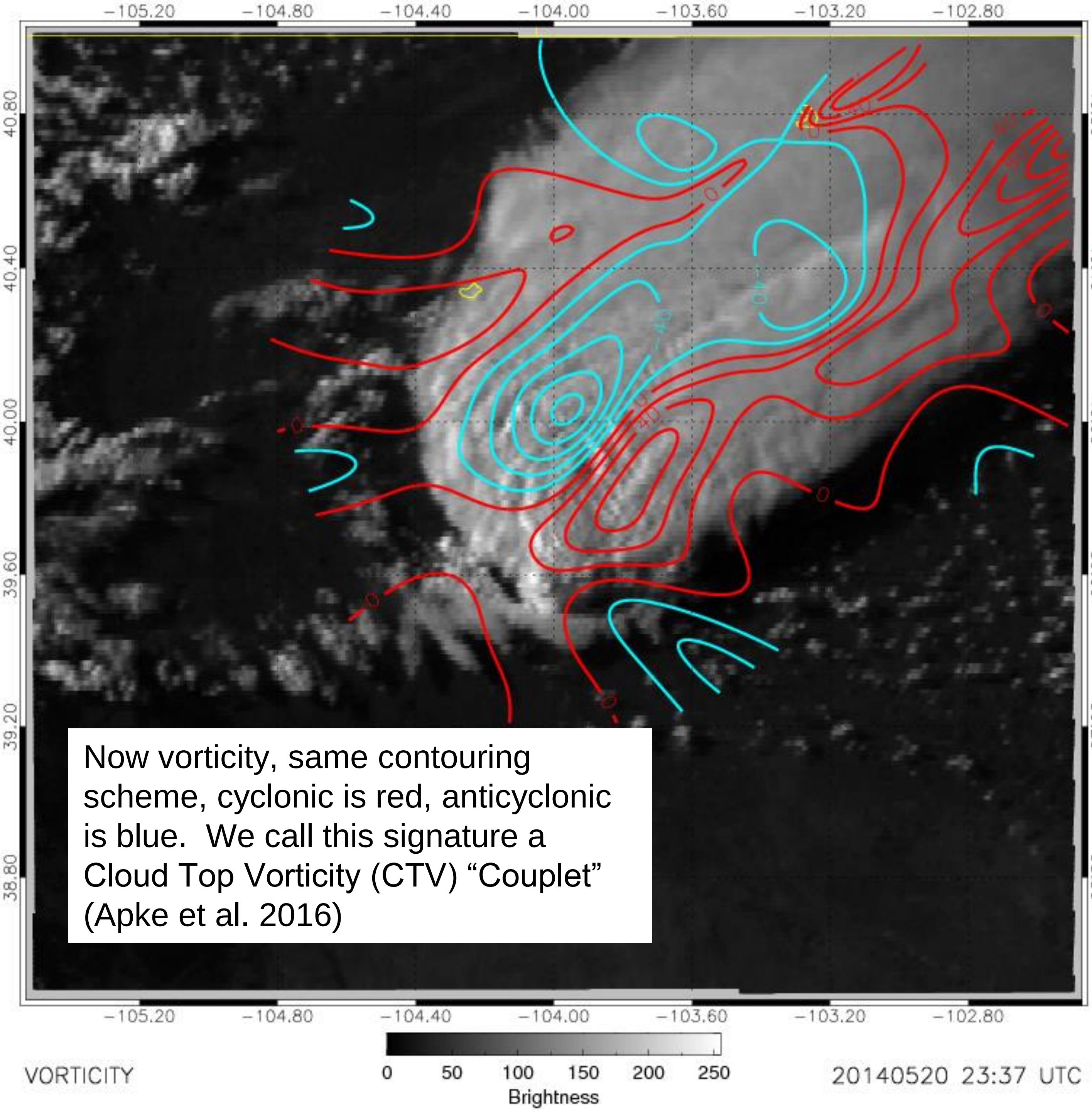
Actual upper level flow
mAMVs calculated at a 1 minute super rapid scan (SRSOR mAMVs)
−105.20
−104.80
−104.40
−104.00
−103.60
−103.20
−102.80
40.80
40.40
40.00
39.60
39.20
38.80
0
50
100
150
200
250
Brightness
mAMVs
20140520 23:37 UTC



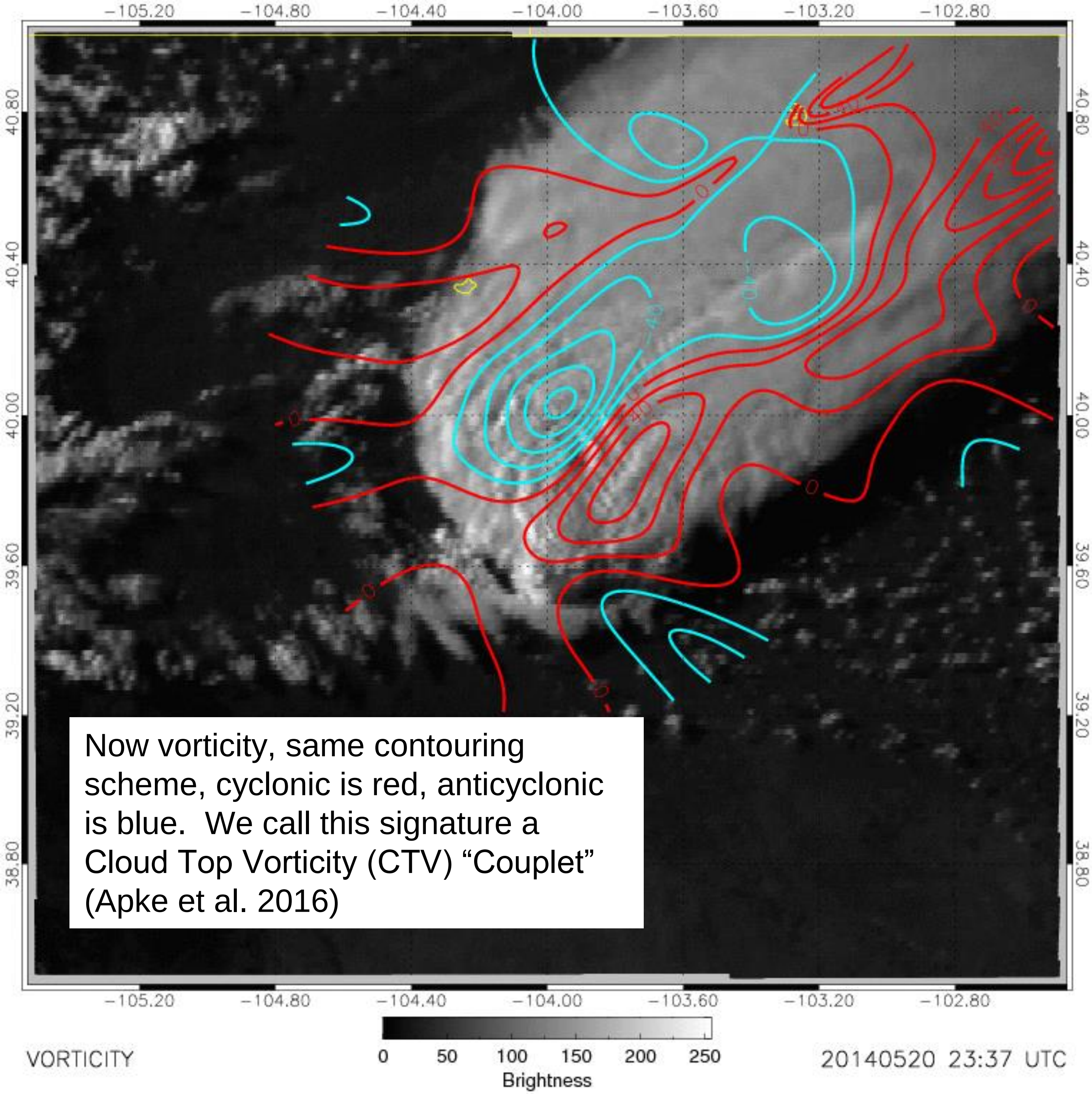
Divergence contoured every $25 * 10^{-5}\ s^{-1}$ red is positive, blue is negative, max in the center is $175 * 10^{-5}\ s^{-1}$



−105.20
−104.80
−104.40
−104.00
−103.60
−103.20
−102.80
40.80
40.40
40.00
39.60
39.20
38.80
50
100
150
0
Divergence contoured every 25 * 10-5 s-1 red is positive, blue is negative, max in the center is 175 * 10-5 s-1
0
50
100
150
200
250
Brightness
DIVERGENCE
20140520 23:37 UTC



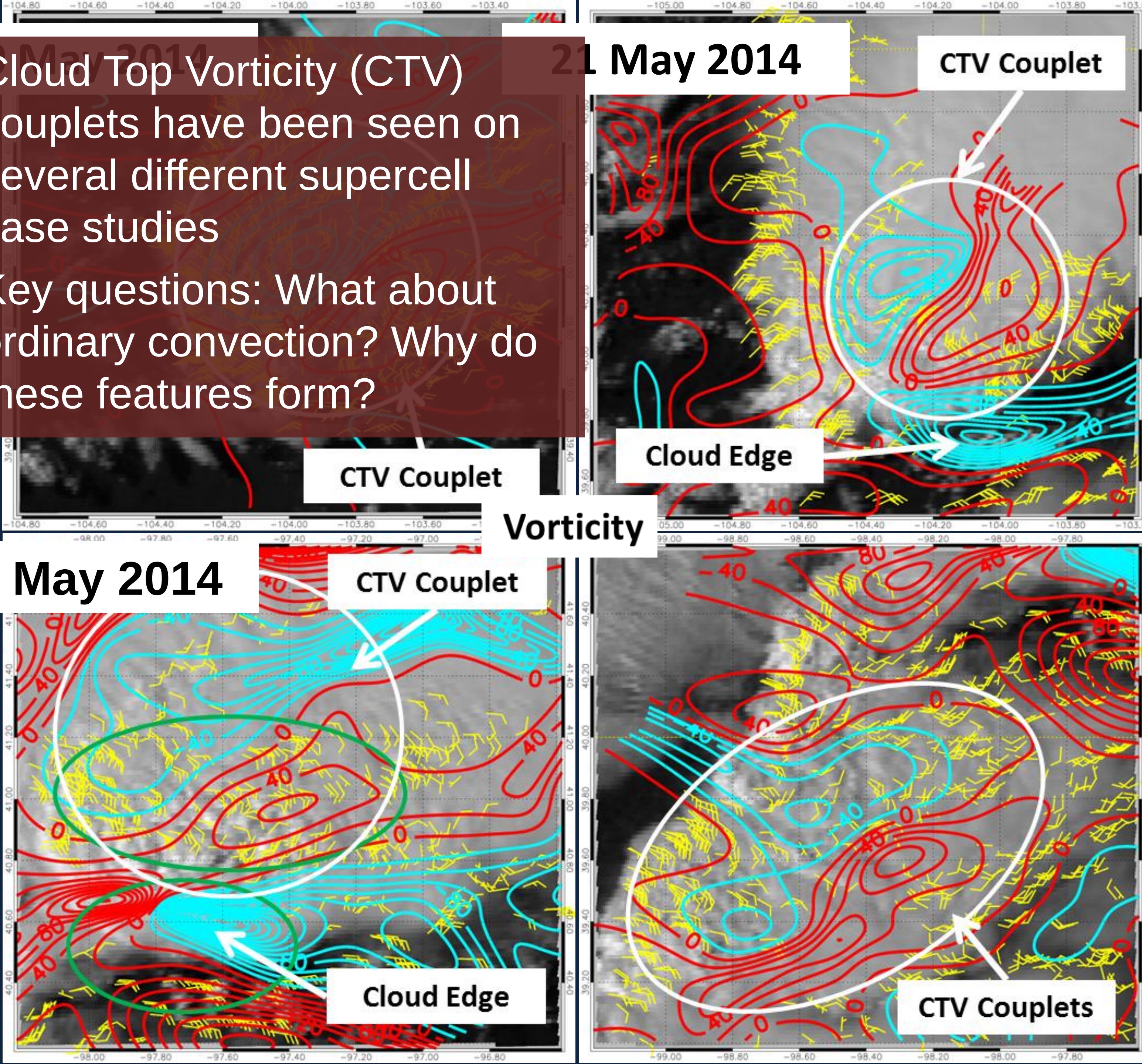
Now vorticity, same contouring scheme, cyclonic is red, anticyclonic is blue. We call this signature a Cloud Top Vorticity (CTV) “Couplet” (Apke et al. 2016)



Now vorticity, same contouring scheme, cyclonic is red, anticyclonic is blue. We call this signature a Cloud Top Vorticity (CTV) "Couplet" (Apke et al. 2016)

Figure 1. 20 May 2014 supercell photographed near Burlington, Colorado.
(*Photo provided courtesy of Roger Hill*)

- Cloud Top Vorticity (CTV) couplets have been seen on several different supercell case studies
- Key questions: What about ordinary convection? Why do these features form?



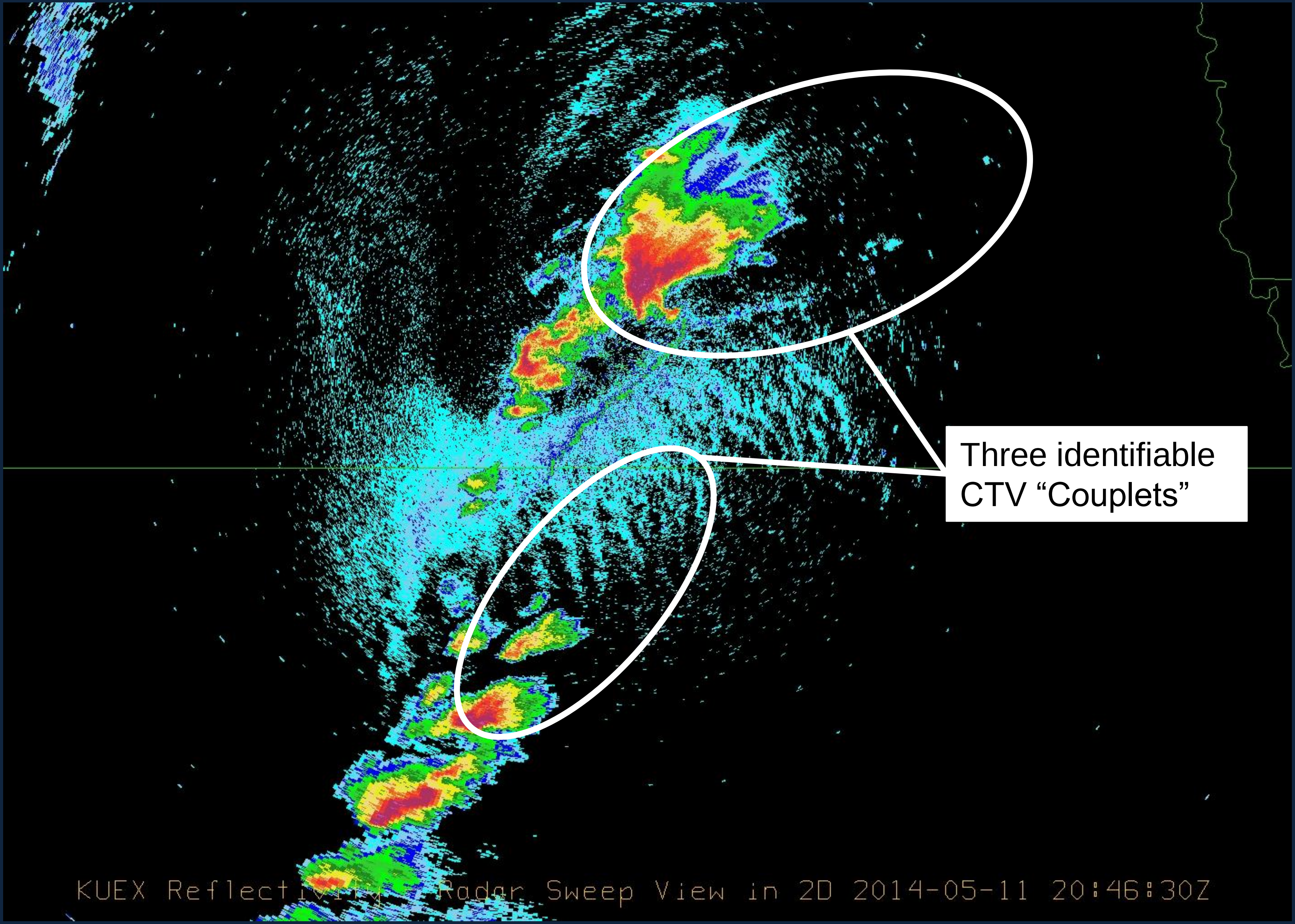
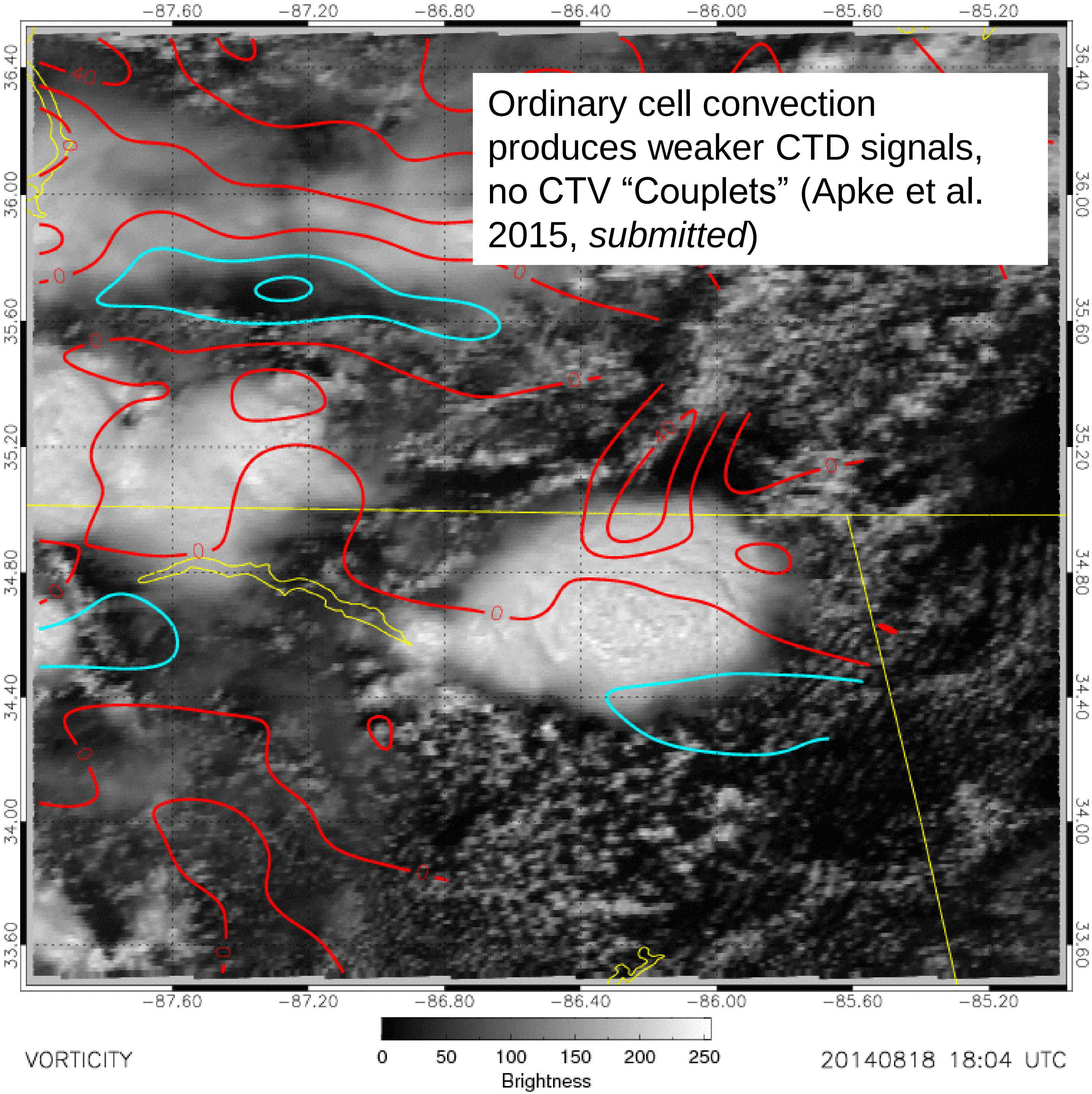
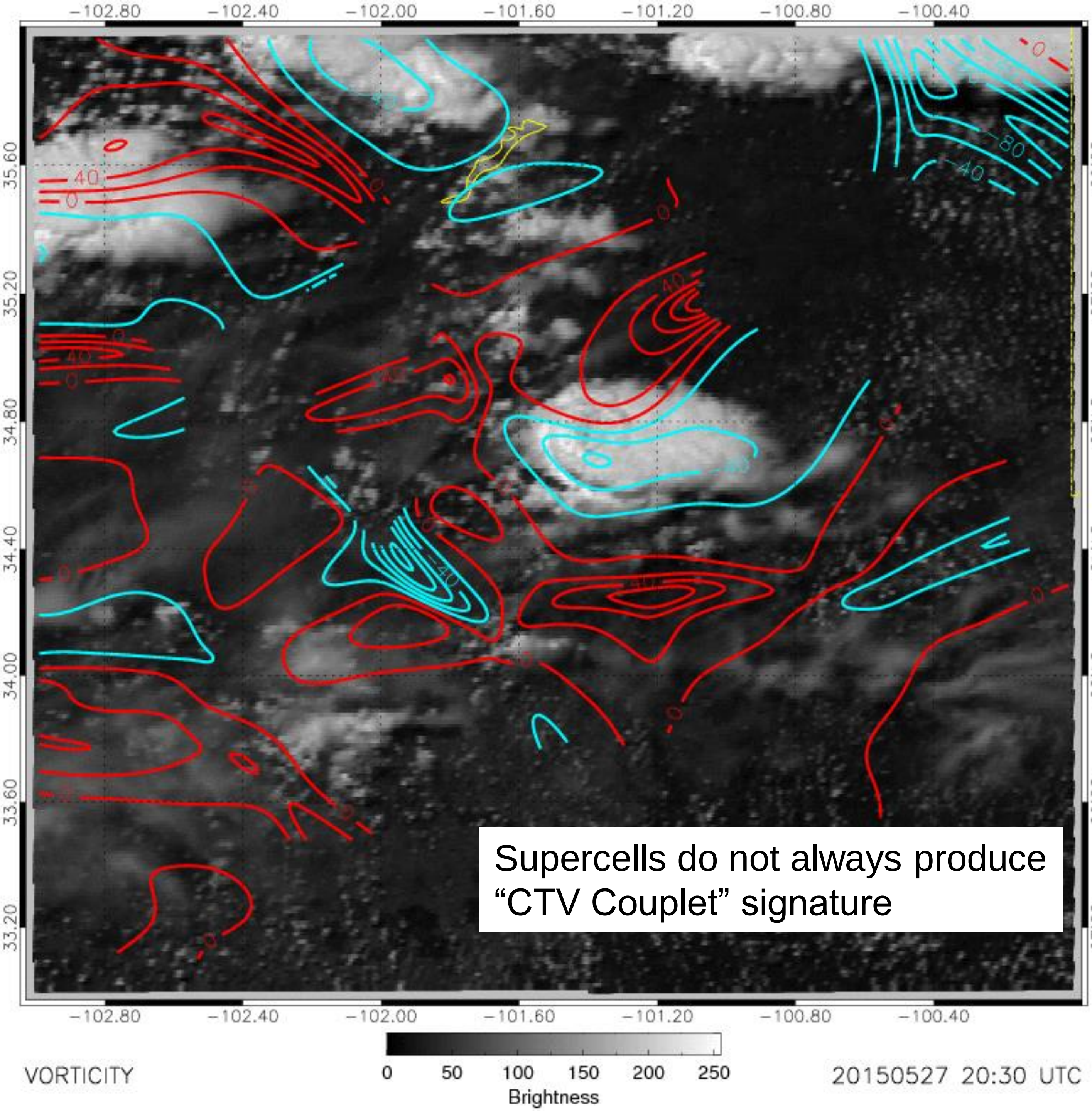
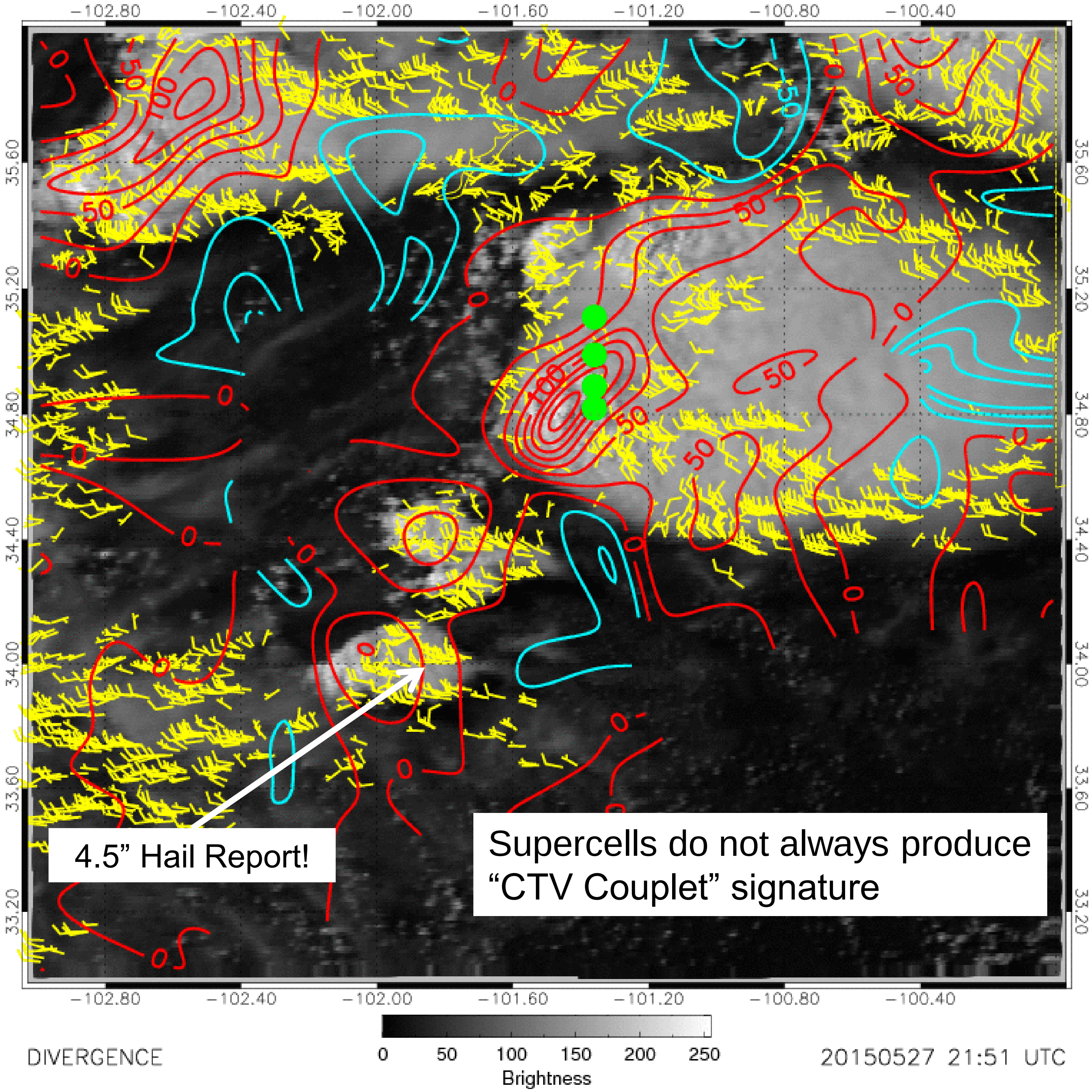


Figure 2. 11 May 2014 KUEX radar reflectivity at 0.5˚ tilt

Ordinary cell convection produces weaker CTD signals, no CTV "Couplets" (Apke et al. 2015, *submitted*)

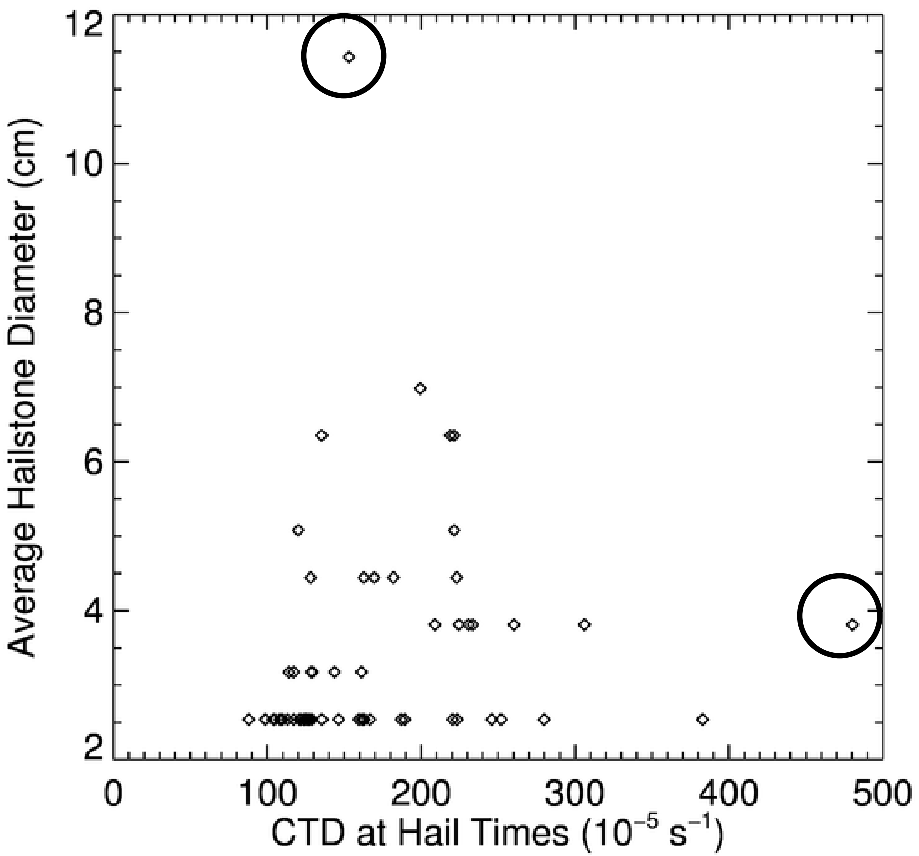



−102.80
−102.40
−102.00
−101.60
−101.20
−100.80
−100.40
35.60
35.20
34.80
34.40
34.00
33.60
33.20
Supercells do not always produce
“CTV Couplet” signature
0
50
100
150
200
250
Brightness
VORTICITY
20150527 20:30 UTC



−102.80 −102.40 −102.00 −101.60 −101.20 −100.80 −100.40
35.60
35.20
34.80
34.40
34.00
33.60
33.20
4.5” Hail Report!
Supercells do not always produce “CTV Couplet” signature
DIVERGENCE
0 50 100 150 200 250
Brightness
20150527 21:51 UTC

Weak Positive Trend observed in comparison of Hail size to CTD



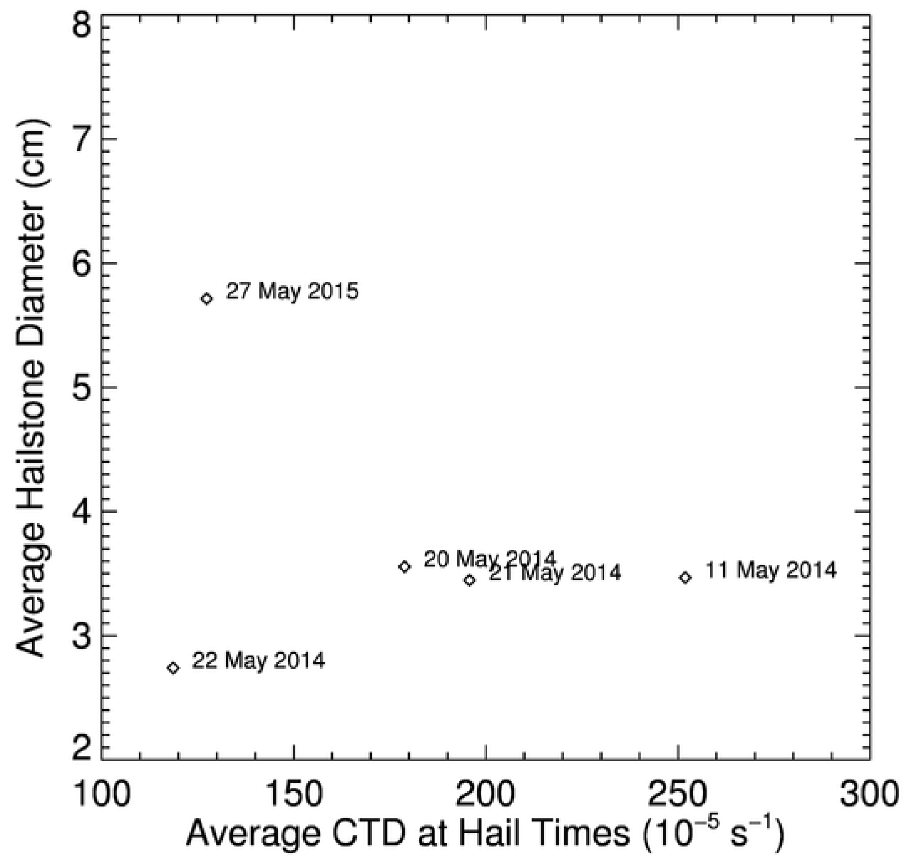


Figure 6. a) Hail diameter (cm) for five supercell storms compared to average CTD value in a 10 minute period prior to the storm report and b) total average hail size compared to total average CTD in a 10 minute period prior to each report for each case study.

Development for Real Time Use

- Idealized simulations were performed using the Weather Research and Forecasting (WRF) Advanced Research WRF dynamics core (Weisman and Klemp 1982)
  - Two pre-convective environments similar to Weisman and Klemp (1982)
- Explored potential problems with mAMV objective analysis methods
- Explored the utility of 1-minute flow fields derived from satellite as related to severe weather forecasting on the ground
  - Comparing hail size to observed cloud top divergence (Witt and Nelson 1991)
  - Analyze the use of cloud top flow fields in forecasting tornado development when combined with ground based datasets (Bedka et al. 2015; Not shown here)

Supercell Convection

Time 1

Time 2

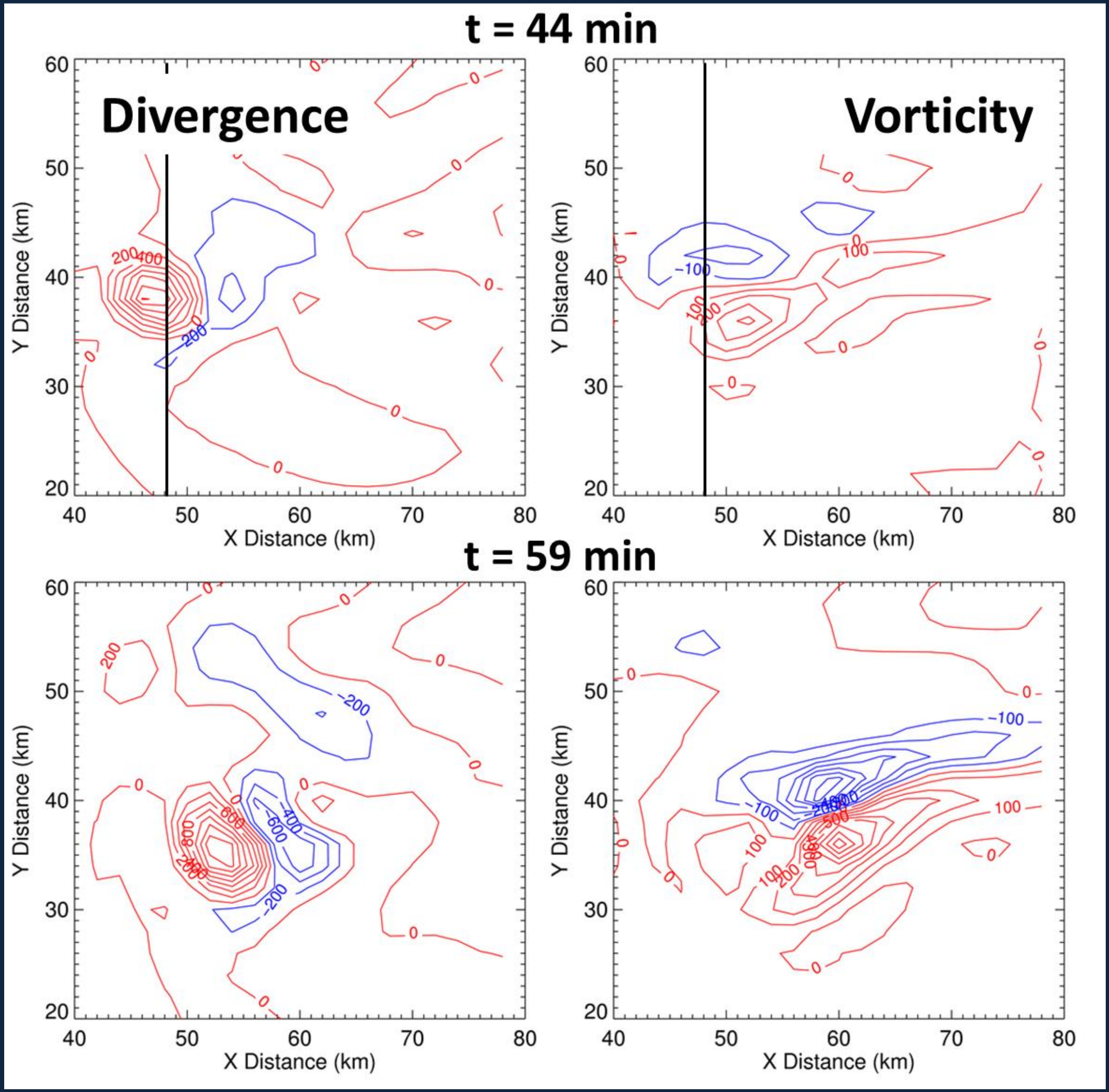


Figure 4. WRF-ARW hodograph A output (quarter circle shear) plan view at a height z = 13 km with divergence, now contoured every 200 * 10^{-5} s^{-1} for cleanliness (left column) and vertical vorticity contoured every 100 * 10^{-5} s $^{-1}$ and d) divergence contoured every 100 * 10^{-5} s^{-1}. (Adapted from Apke et al. 2016, *In review*)

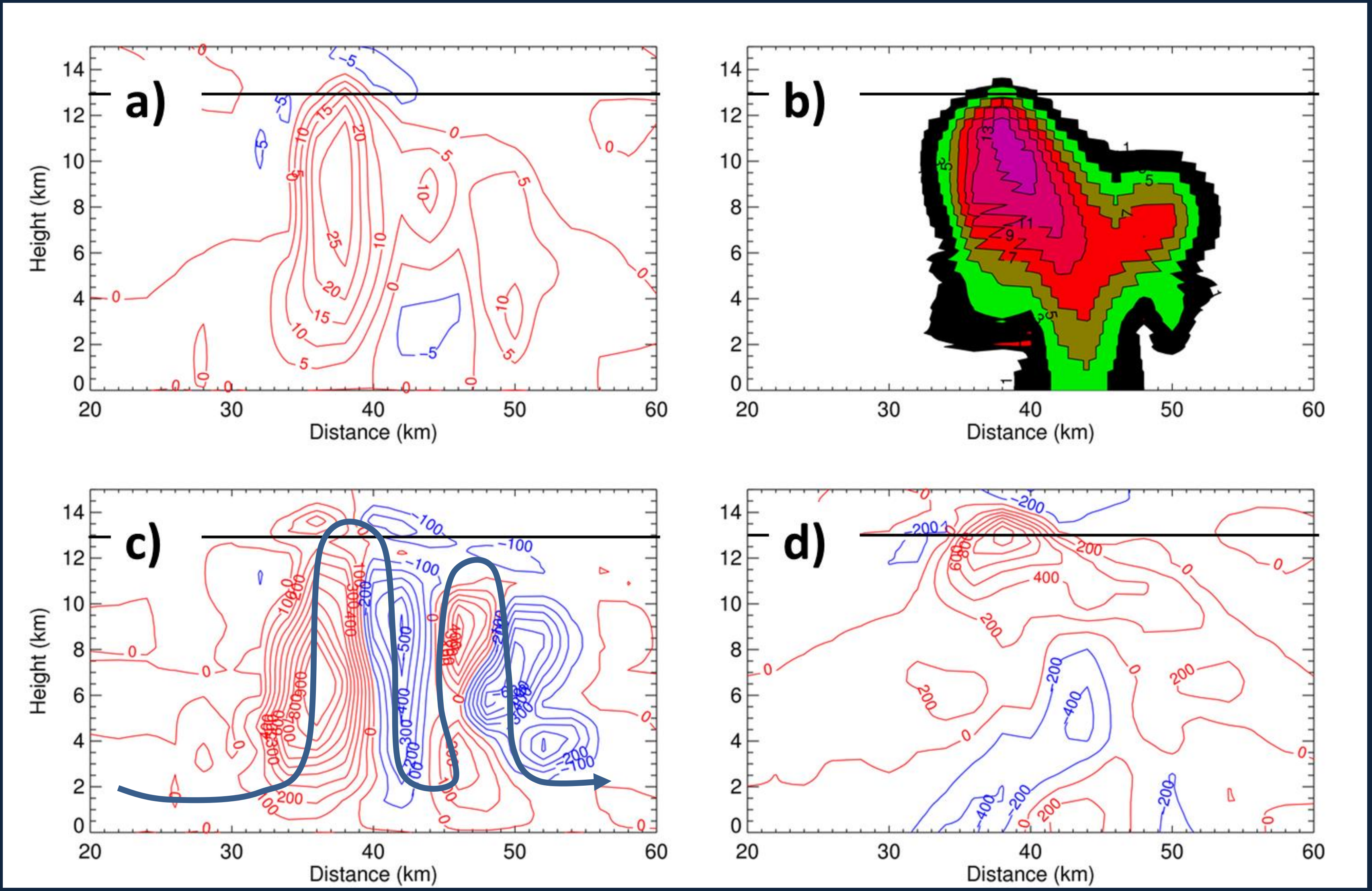
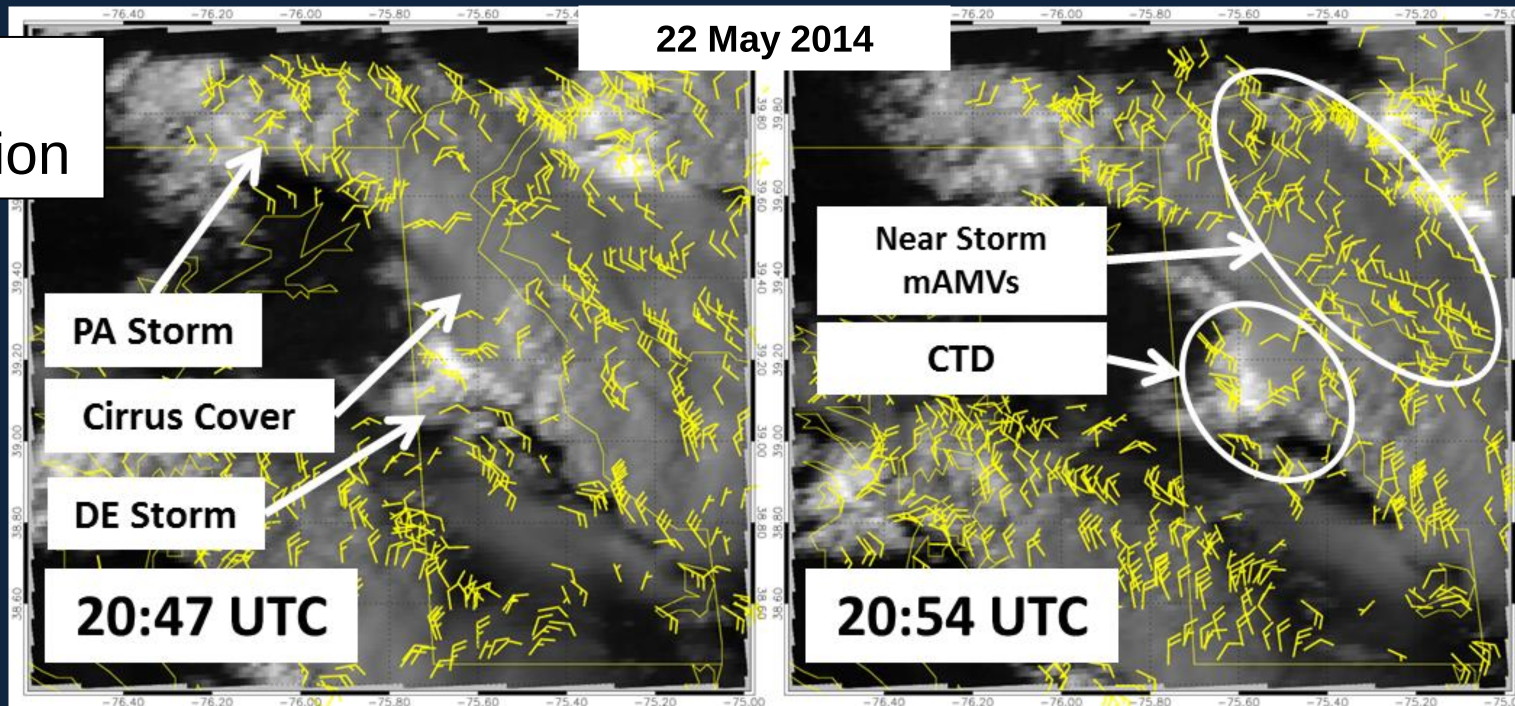
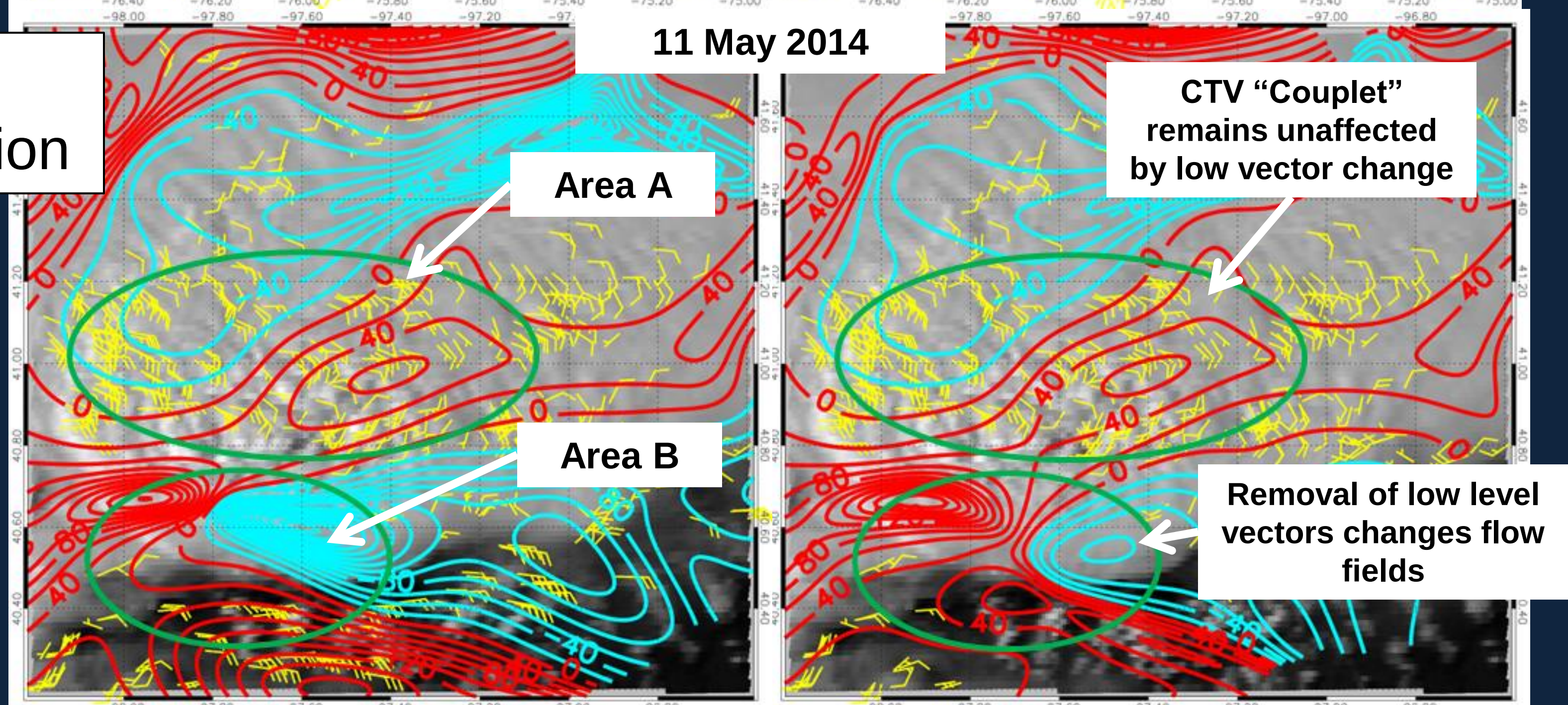


Figure 5. 44 minute WRF-ARW hodograph A output (quarter circle shear) south to north cross section at x = 46 km with a) w (m s^{-1}), b) total liquid water content (cloud water and rain water, g m^{-3}), c) vertical vorticity contoured every 100 * 10^{-5} s $^{-1}$ and d) divergence contoured every 100 * 10^{-5} s^{-1}. (Adapted from Apke et al. 2016, *In review*)

Cirrus Contamination

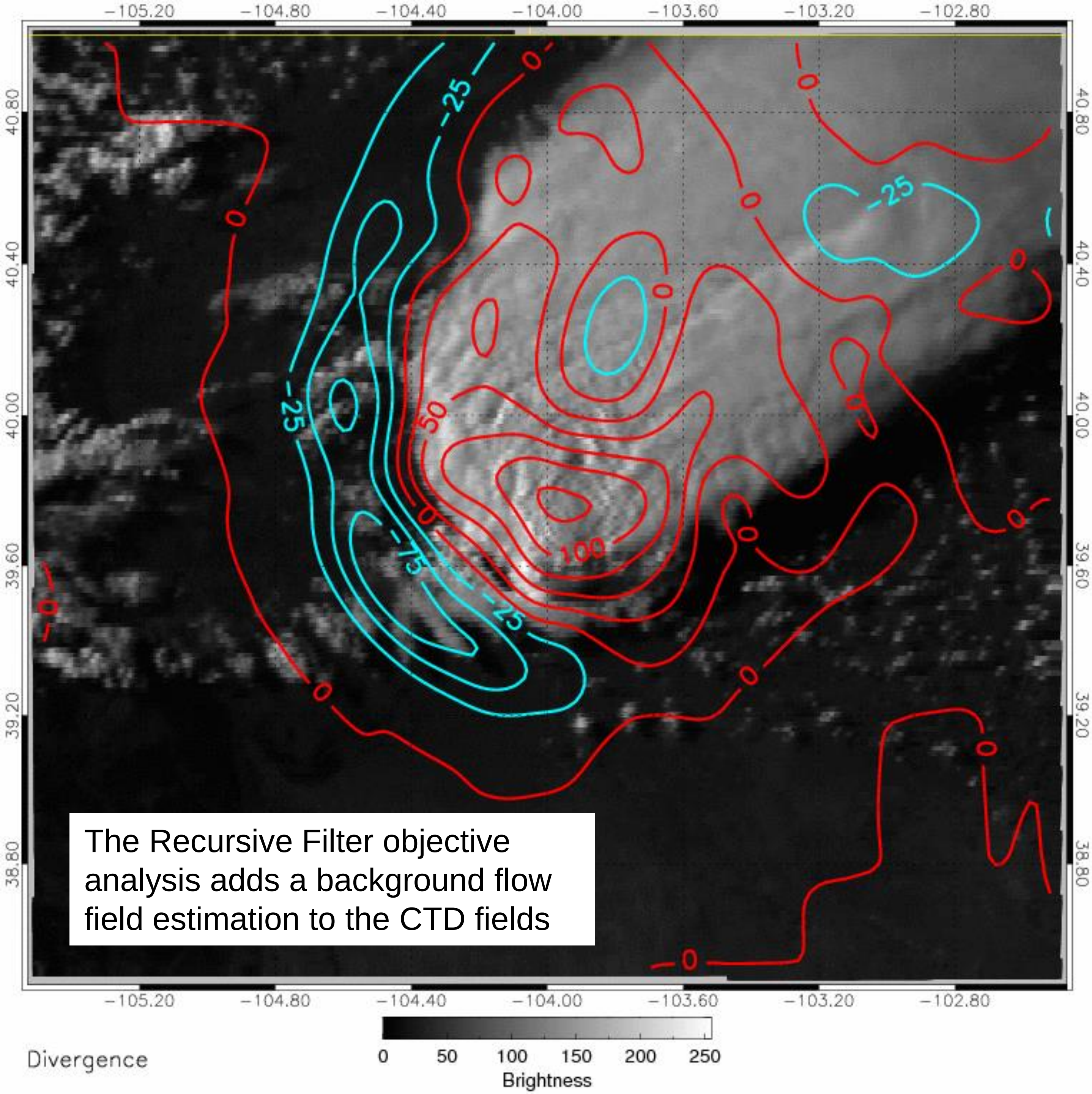


Cloud Edge Contamination

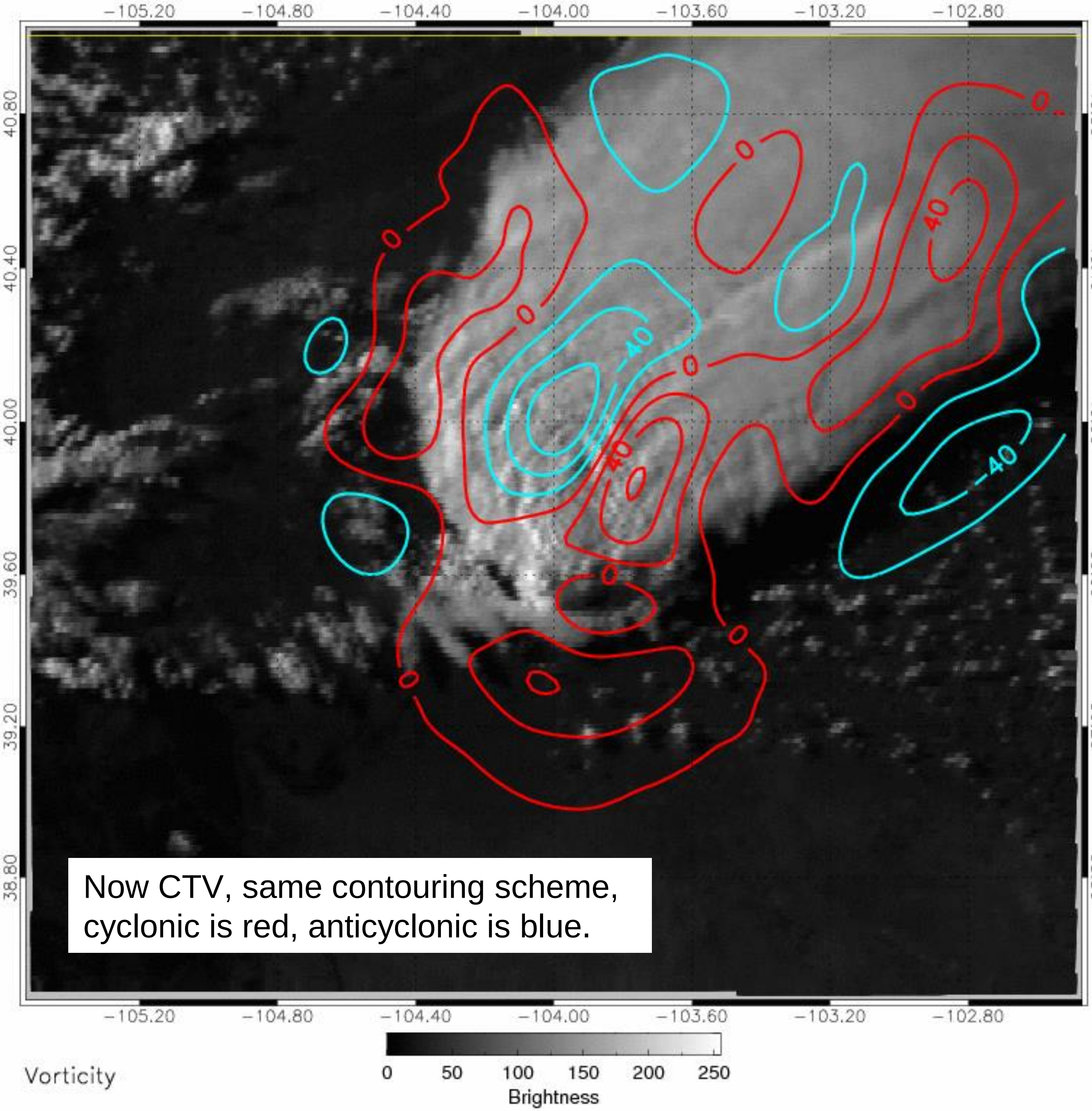


Recursive Filter Approach

- The RF approach in one dimension (Hayden and Purser 1995):
- Applies forwards and backwards to a grid of values, where the smoothing parameter controls the spatial scale of the filter
- The analysis is determined by the quality of observations near a grid point
  - The quality is determined by the obs. deviation from a background dataset at the grid point and obs. density
- With multiple forward and backwards passes, the RF approach can be shown to be equivalent to a single pass of a Gaussian (Barnes) filter



The Recursive Filter objective analysis adds a background flow field estimation to the CTD fields



Now CTV, same contouring scheme, cyclonic is red, anticyclonic is blue.

Conclusions

- The addition of several new mAMVs in highly “transient” target regions on top of deep convection have allowed us to begin resolving vorticity and divergence patterns that *cannot be seen with lower temporal resolutions*
- Divergence <u>and </u>CTV couplets seen successfully in roughly 60% of supercell cases, strong (relative to measurements over non-supercell convective events)
- Strong, non-transient (in the storm relative sense) cloud top divergence was seen in all examined supercell cases

Conclusions

- With the use of GOES SRSOR and cloud top mAMVs we can now resolve rotation and divergence at cloud tops, yielding the possibility of *discriminating between ordinary and supercellular convection using satellite/model data only*
- WRF-ARW ordinary convective case did not produce the vortex “couplet” phenomena at cloud top, however the supercell did!
- Cloud top flow utility in real time is still being explored, likely will be used with other ground based datasets for severe weather forecasting
- Vorticity was successfully seen in several cases
  - Problems with this method are generally caused by cirrus contamination and low vector/cloud edge contamination, which may have affected hail and CTD comparisons
  - Future work will use additional datasets to attempt to identify why cells don’t produce the couplet phenomena at the cloud top

RSS Channel Selection

John Mecikalski
Jochen Grandell–EUMETSAT

FCI Channel Sections

Instrument information

▶ Details

CHANNEL	CENTRE WAVELENGTH	SPECTRAL WIDTH	SPATIAL SAMPLING DISTANCE (SSD)
VIS 0.4	0.444 µm	0.060 µm	1.0 km
VIS 0.5	0.510 µm	0.040 µm	1.0 km
VIS 0.6	0.640 µm	0.050 µm	1.0 km; 0.5 km*
VIS 0.8	0.865 µm	0.050 µm	1.0 km
VIS 0.9	0.914 µm	0.020 µm	1.0 km
NIR 1.3	1.380 µm	0.030 µm	1.0 km
NIR 1.6	1.610 µm	0.050 µm	1.0 km
NIR 2.2	2.250 µm	0.050 µm	1.0 km; 0.5 km*
IR 3.8 (TIR)	3.800 µm	0.400 µm	2.0 km; 1.0 km*
WV 6.3	6.300 µm	1.000 µm	2.0 km
WV 7.3	7.350 µm	0.500 µm	2.0 km
IR 8.7 (TIR)	8.700 µm	0.400 µm	2.0 km
IR 9.7 (O_3)	9.660 µm	0.300 µm	2.0 km
IR 10.5 (TIR)	10.500 µm	0.700 µm	2.0 km; 1.0 km*
IR 12.3 (TIR)	12.300 µm	0.500 µm	2.0 km
IR 13.3 (CO_2)	13.300 µm	0.600 µm	2.0 km

Note: *The channels VIS 0.6, NIR 2.2, IR 3.8 and IR 10.5 are delivered in both FDS and RRS sampling configurations, the latter is indicated by * in the table.*

<u>Question</u>:

Are these 4 channels during RSS (over 1/4th the Full Disk region) optimal?

- Other 4-channel combinations?
- Other applications?
- Seasonal consideration?

Will seek feedback from the CWG on what is the optimal and/or other possible configurations for the RSS mode of data collection.

This feedback will be needed by the end of 2016.

Questions?

Thank you!