Using hyperspectral infrared soundings to enhance time component of environmental factors driving severe convective storms

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Trajectory-Enhanced AIRS Observations of Environmental Factors Driving Severe Convective Storms

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ABSTRACT

We investigate environmental factors of severe convective weather using temperature and moisture retrievals from the Atmospheric Infrared Sounder (AIRS) that lie along parcel trajectories traced from tornado, large hail, and severe wind producing events in the central United States. We create AIRS proximity soundings representative of the storm environment by calculating back trajectories from storm times and locations at levels throughout the troposphere, using the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model forced with the 32-km North American Regional Reanalysis (NARR) and 12-km North American Mesoscale Forecast System (NAM12). The proximity soundings are calculated for severe weather events including tornadoes, hail ≥2 in. diameter, and wind gusts >65 mph (29 m s^{-1}) specified in the NCEI Storm Events database. Box-and-whisker diagrams exhibit more realistic values of enhanced convective available potential energy (CAPE) and suppressed convective inhibition (CIN) relative to conventional ‘‘nearest neighbor’’ (NN) soundings; however, differences in lifting condensation level (LCL), level of free convection (LFC), and significant tornado parameter (STP) from the HYSPLIT-adjusted back traced soundings are more similar to NN soundings. This methodology should be extended to larger swaths of soundings, and to other operational infrared sounders, to characterize the large-scale environment in severe convective events.

Long history of ‘proximity sondes’ to assess environmental differences among convective mode, intensity, severe weather events (tornadoes, winds, hail), etc.

Brooks et al., 1994; Rasmussen and Blanchard, 1998; Doswell and Evans, 2003; Thompson et al, 2003; 2012; etc.

Previous studies show higher CAPE, higher boundary layer RH, lower CIN, lower LCL, and lower LFC for tornadic supercells

Also notable differentiation among hail size, within tornado EF-scale, wind gust speed, etc.

Kalmus et al., 2019, in press

Efforts to use surface- or satellite-based hyper-spectral IR remote sensing as 'proximity sondes' a mixed success

CAPE from Atmospheric Infrared Sounder (AIRS) underestimated, but CIN closer to radiosondes (Botes et al., 2012, JGR)

CAPE from AIRS unbiased compared to radiosondes if retrieved surface temperature replaced with surface observation (Gartzke et al., 2017, JAMC)

Rapid pre-convective evolution of CAPE & CIN with Atmospheric Emitted Radiance Interferometer (AERI) (Feltz and Mecikalski, 2002, WF)

Differentiation between tornadic and non-tornadic supercells using AERI (Wagner et al., 2008, WF)

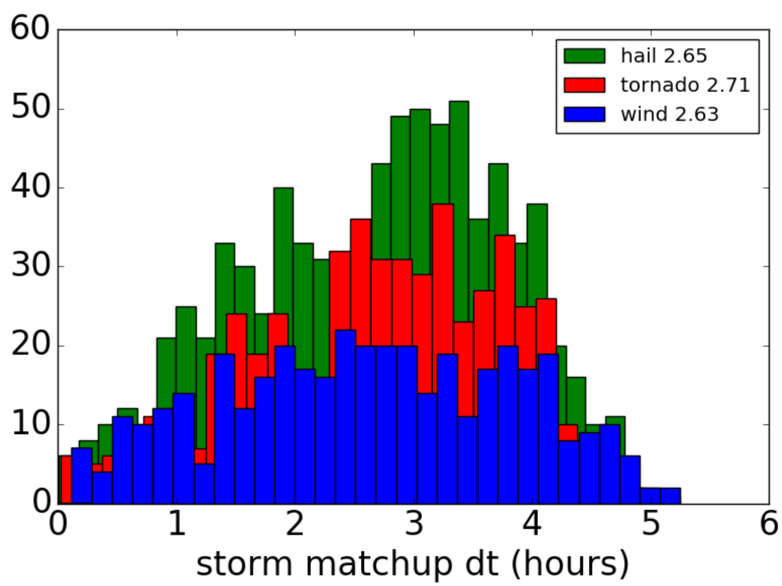
Kalmus et al., 2019, in press

Satellite-based hyper-spectral observations from AIRS, CrIS, and IASI have untapped potential

<u>Our hypothesis is that time component very substantial and could be accounted for using trajectory modeling</u>

Our approach is to use AIRS Level-2 soundings with the HYSPLIT model fed by operational (NAM 12-km) and reanalysis (NARR) forcings

Match Storm Prediction Center (SPC) storm reports to AIRS swath observations (tornado EF scale, hail ≥ 2”, wind gusts ≥ 65 kts)



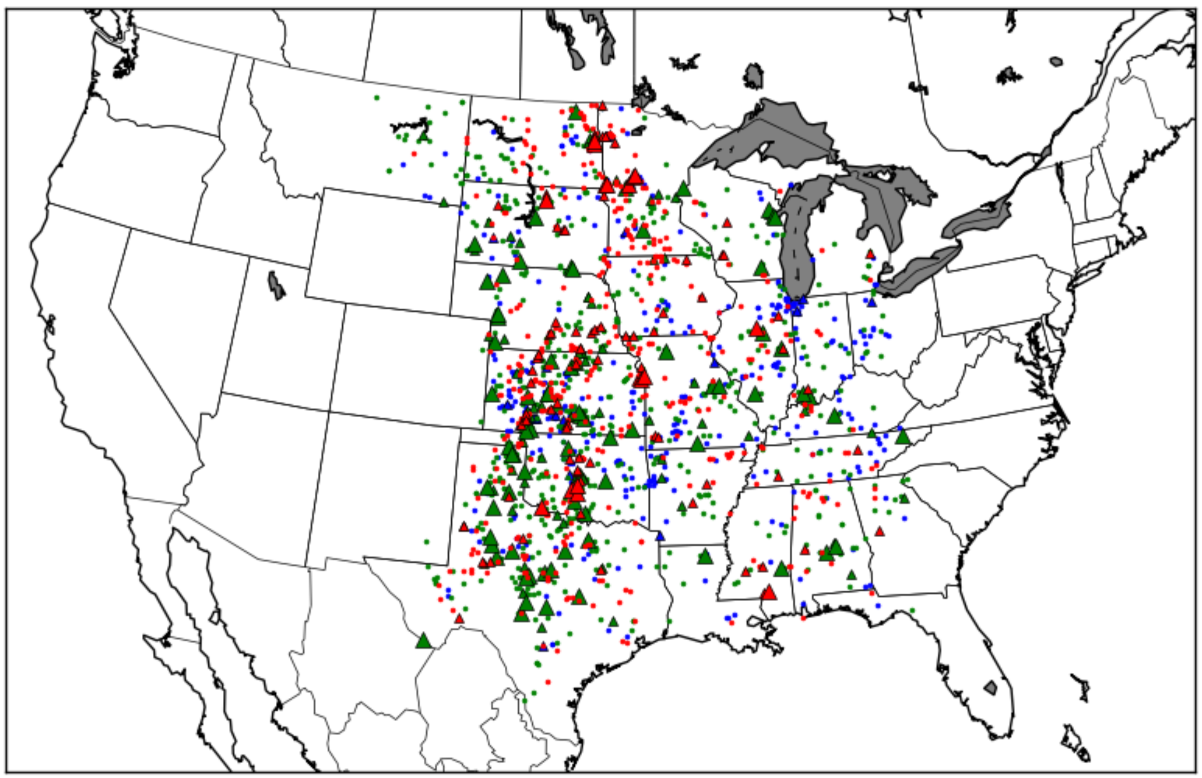
Kalmus et al., 2019, in press

storm sample

Match NCEI Storm Events database reports to AIRS swath observations
tornado EF scale, hail ≥ 2”, wind gusts ≥ 65 kts

25,820 such reports between 83°W and 110°W, 2003-2016

cut reports: before 13:00 local time, no NN matchup, HYSPLIT lost level (topology), level with no matchup, level with AIRS DQ2. 1750 events left in NARR analysis, 1079 in NAM12

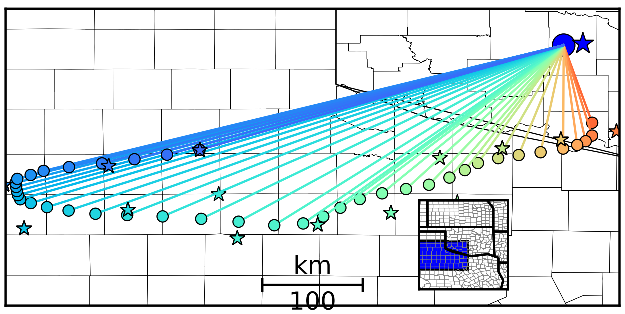


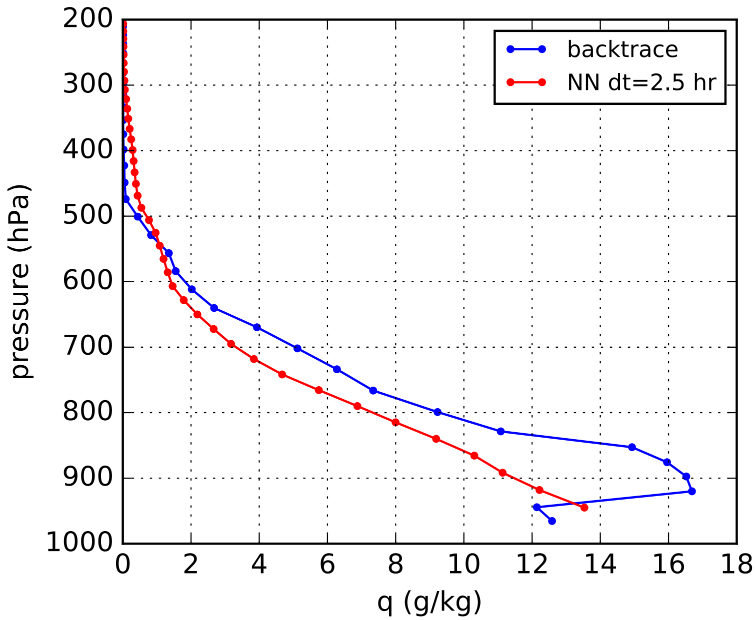
Meteorology drives HYSPLIT: NARR v. NAM12

Differences in meteorology do matter

32 km 3 hourly NARR

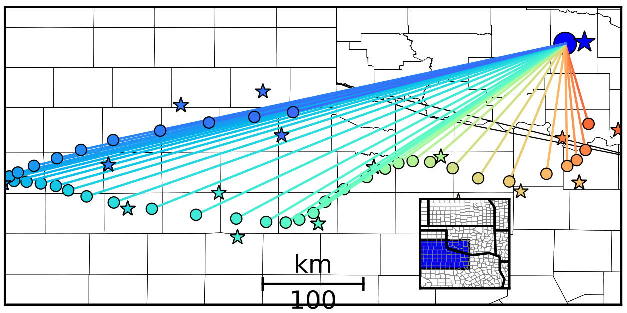
North American Regional Reanalysis

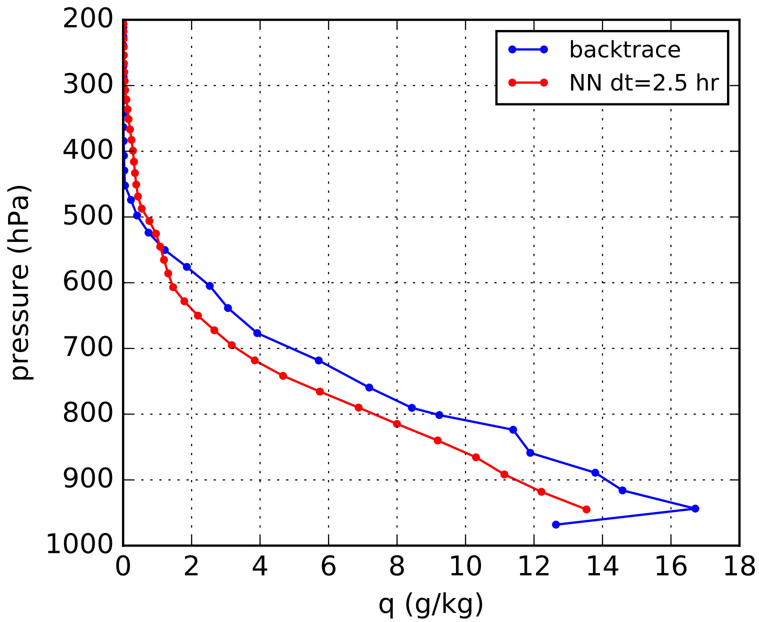




12 km hourly NAM12

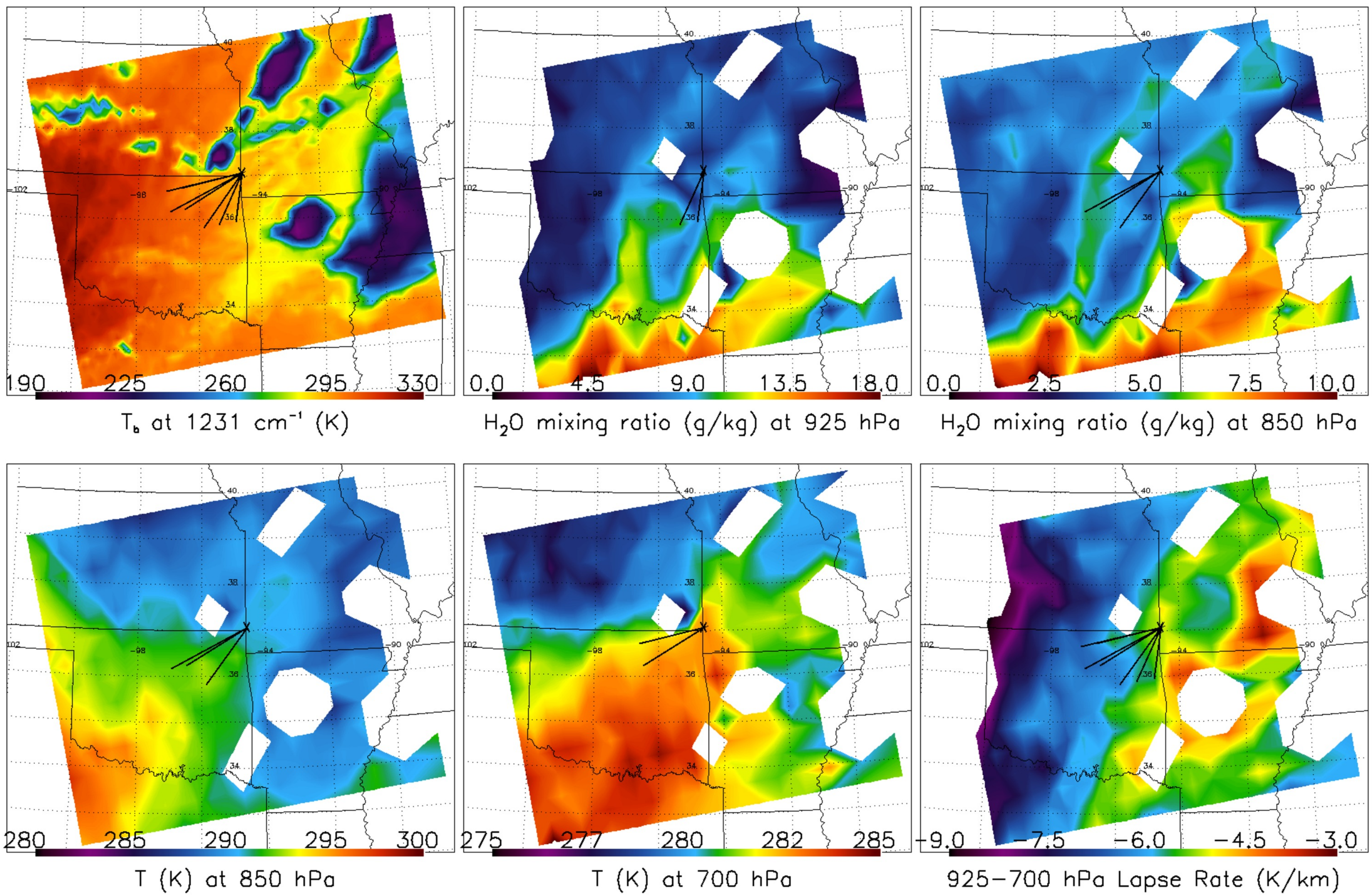
North American Mesoscale Forecast System
available from 2008





1:30 pm overpass before Joplin EF5 tornado (5/22/11)

Illustrates rich horizontal & vertical structure in T and q

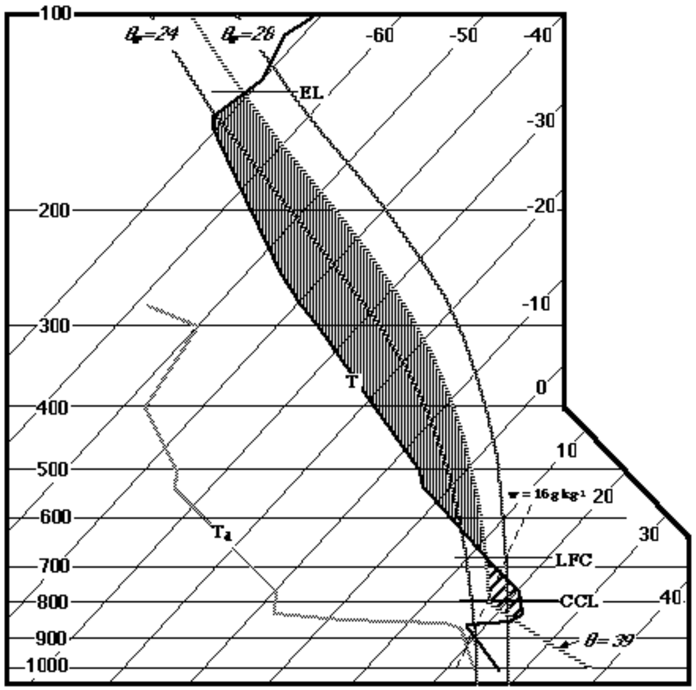


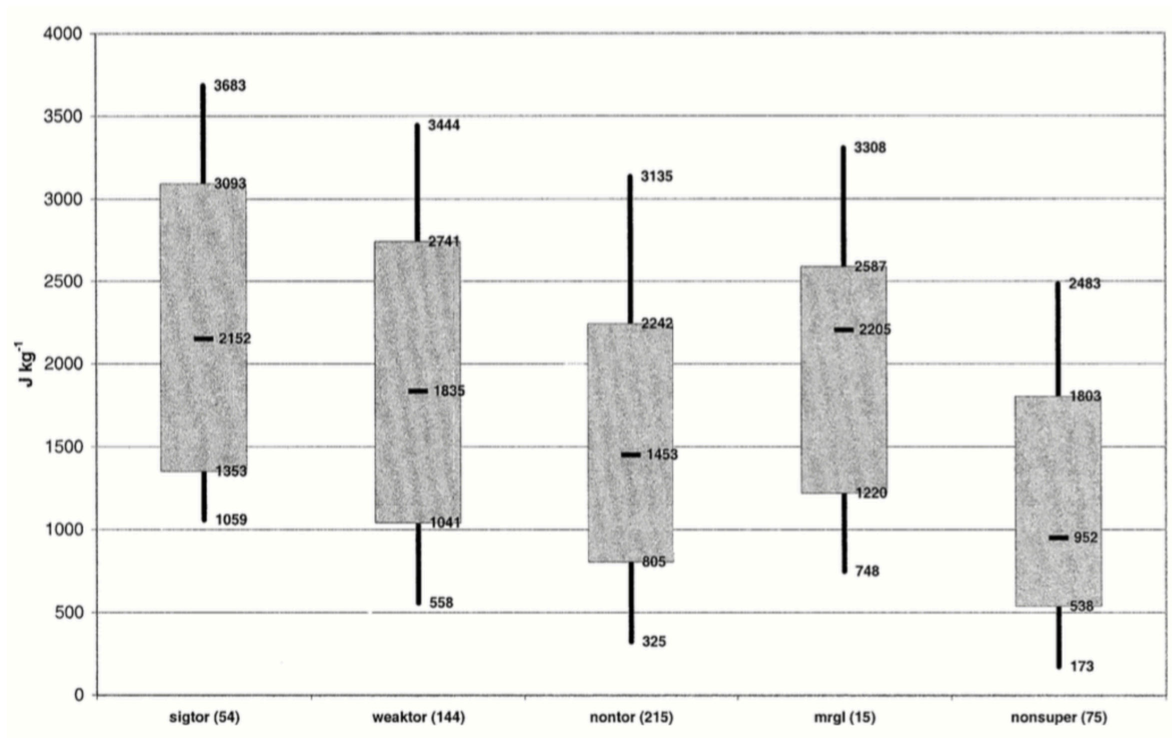
ted

CAPE enhancement in backtrace method compared to NN for tornadoes and strong winds

Much less of an effect for large hail

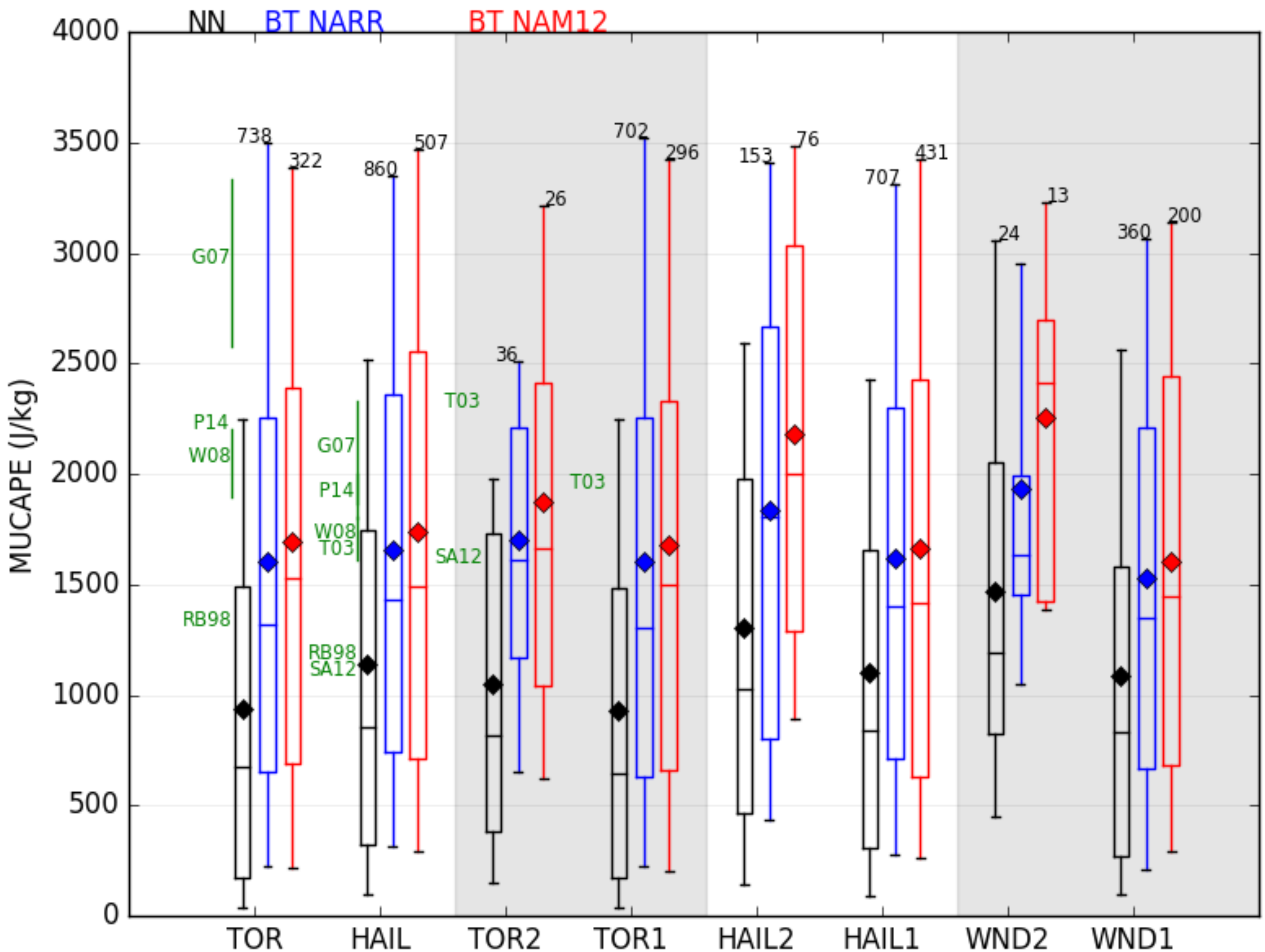
NAM12 shows additional enhancement





Thompson et al. 2003

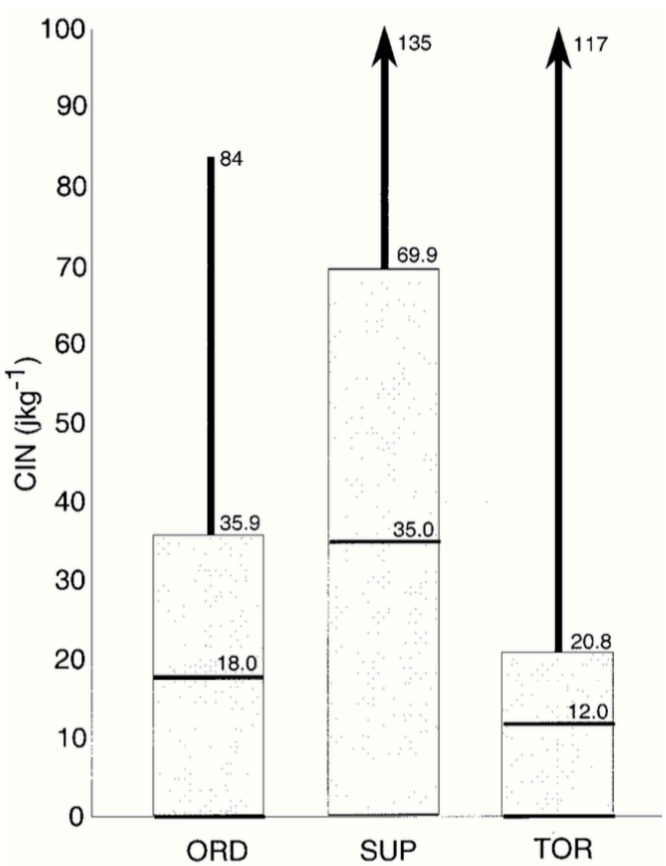
AIRS CAPE



Kalmus et al., 2019, in press

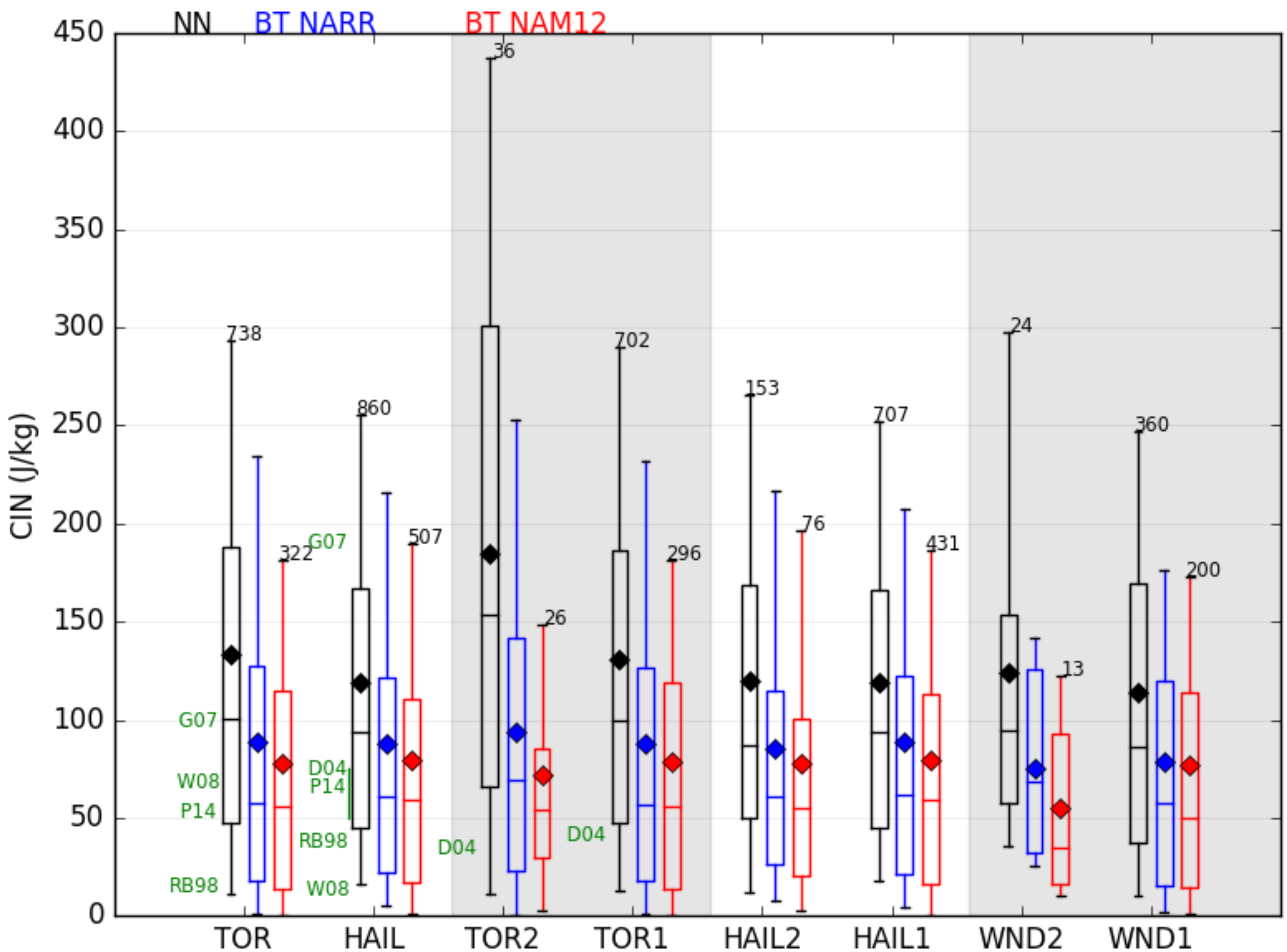
CIN reduced in backtrace method compared to NN

CIN using NAM12 and NARR similar



Rasmussen and Blanchard, 1998

AIRS CIN



Kalmus et al., 2018, in revision

EF4-5 small sample size but big differences in indices

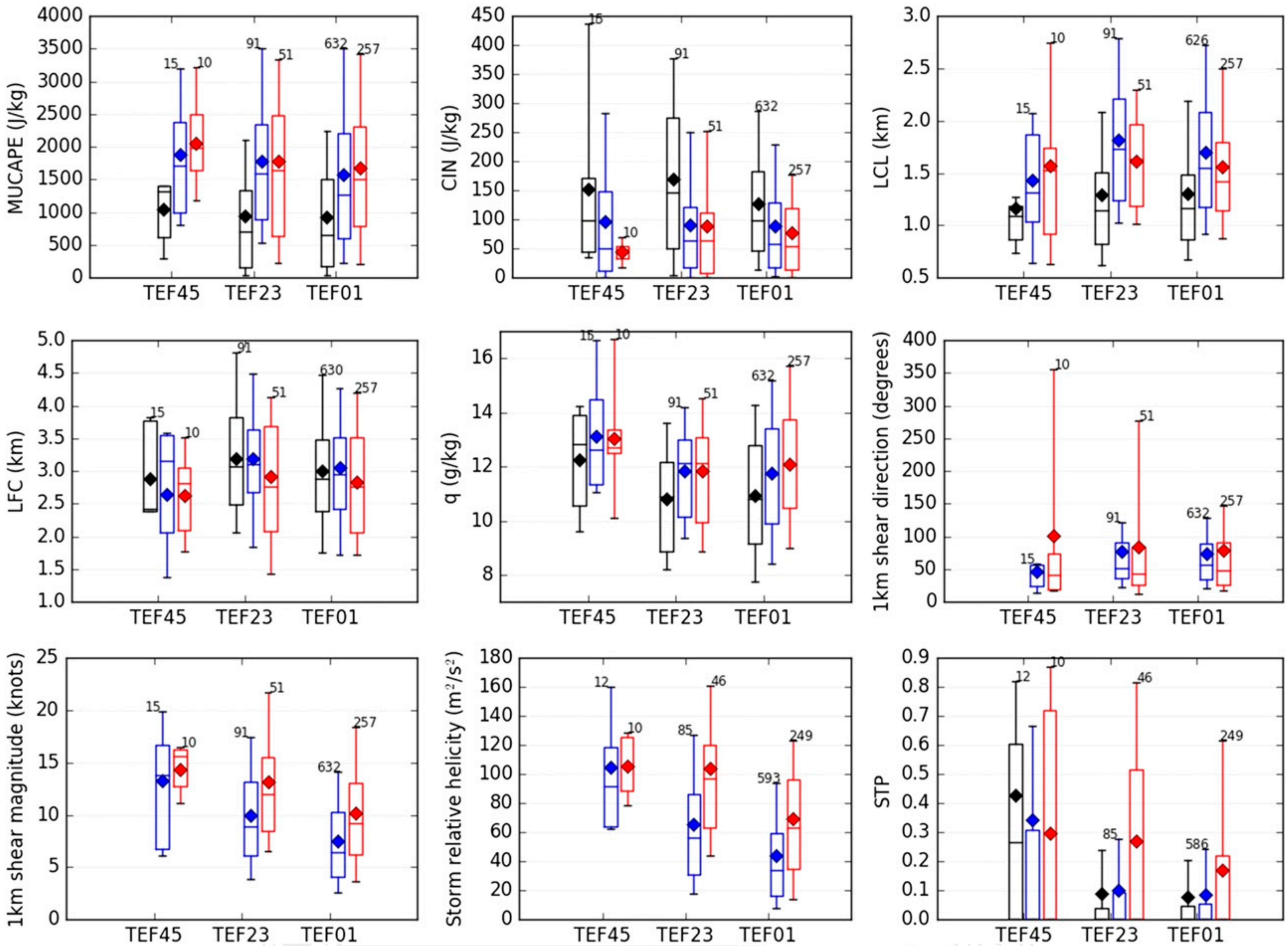


FIG. A1. Convective indices depicted in Figs. 5–13 for EF0–1, EF2–3, and EF4–5 categorizations. Black indicates NN analysis, blue indicates backtrace analysis with NARR, and red indicates backtrace analysis with NAM.

To summarize

We account for time gap in AIRS soundings with HYSPLIT

This produces more realistic convective indices

The backtrace convective indices show more separation between wind, hail and tornadoes than the nearest neighbor

This work does not account for convective storm mode, would expect even more separation if accounted for

This work also does not account for surface T/Td (e.g., Gartzke et al. 2017) which would potentially improve results

“TRAJECTORY MODEL-ENHANCED NUCAPS SOUNDINGS FOR TRANSITION INTO AWIPS-II AND CONVECTIVE INITIATION FORECAST SKILL ASSESSMENT”

to

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)
JPL Task Plan No. 82-105302

January 18, 2018

Solicitation: “Joint Polar Satellite System Proving Ground and Risk Reduction Program 2018-2020 Call for Proposals”

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Current work with NOAA/MSFC

Use NOAA-Unique Combined Atmospheric Processing System (NUCAPS) soundings with forward trajectories in time

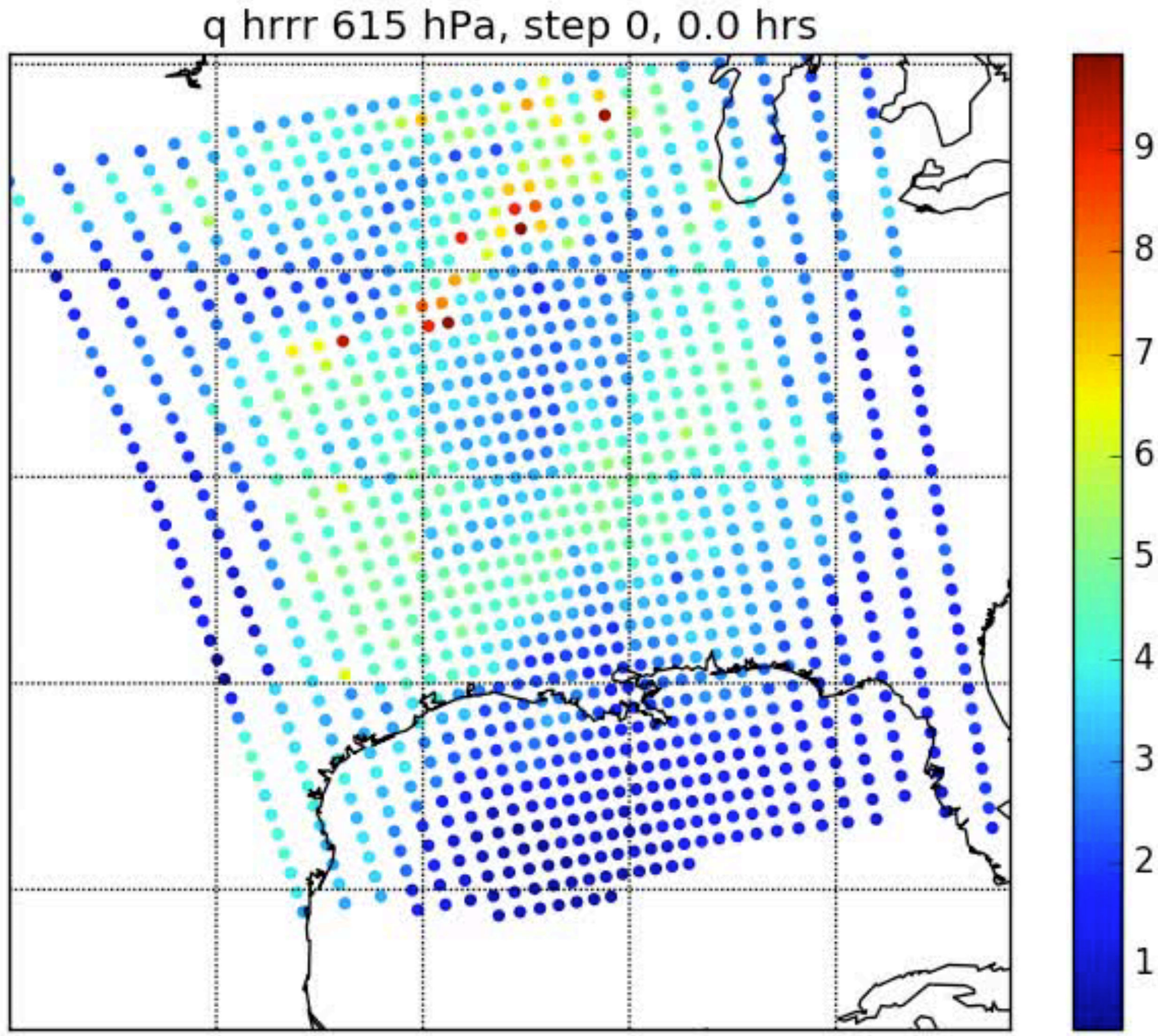
HYSPLIT driven by 3-km High Resolution Rapid Refresh (HRRR) model: called “NUCAPS-FCST”

Apply to full granules of NUCAPS sounding data over the U.S.

Produce forecasts 4-6 hours into future in 30 min increments assuming simple adiabatic parcel theory

Prototype tool created and now MSFC transitioning into the Advanced Weather Interactive Processing System (AWIPS)

Forecasters will use these data in the Hazardous Weather Testbed (HWT) coming up later in April until early June in Norman, OK


q hrrr 615 hPa, step 0, 0.0 hrs
9
8
7
6
5
4
3
2
1

Some notes on methodology

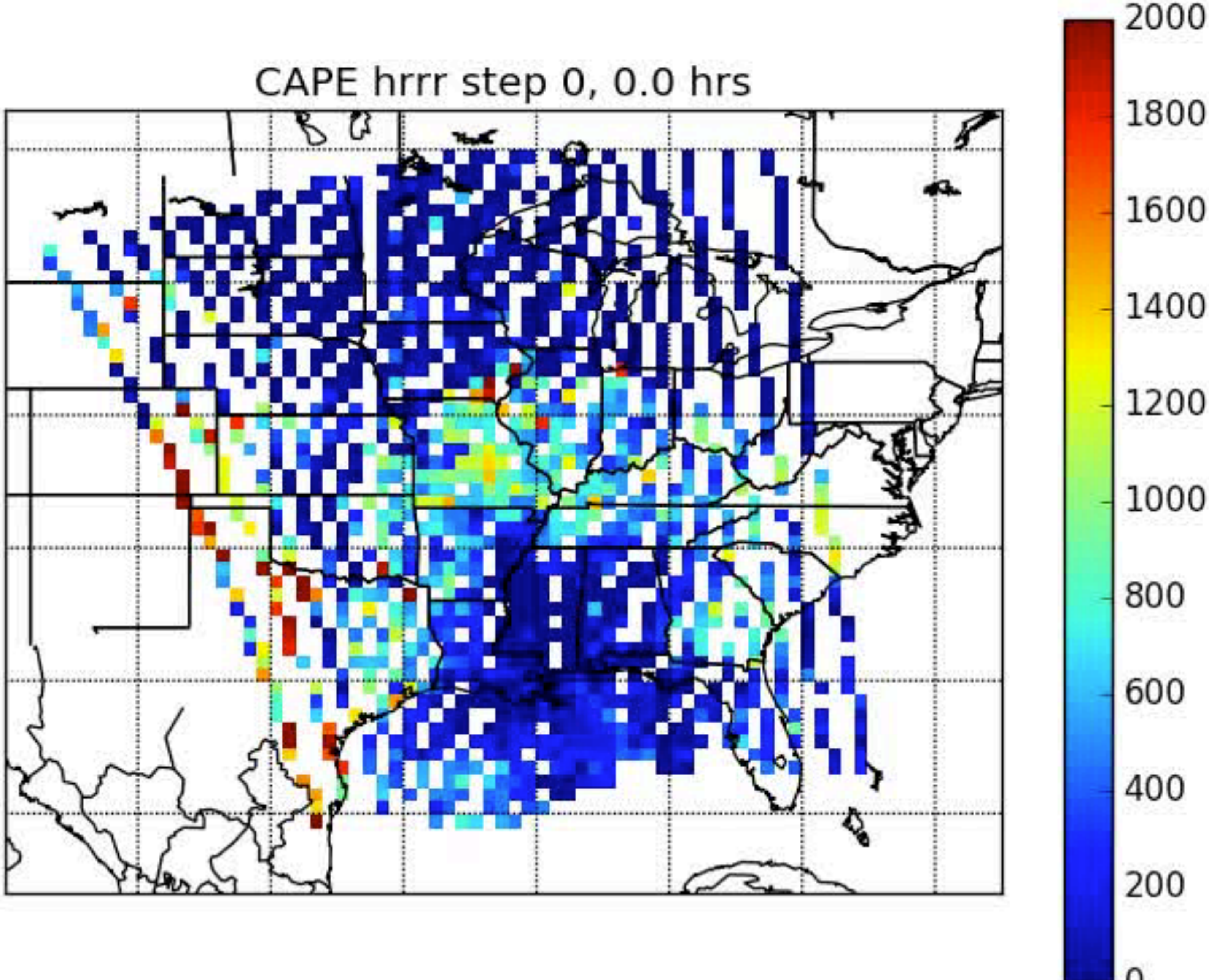
As the parcels are advected around in space and time, they are recombined into vertical profiles each 30 min segment and a new "sounding" is made

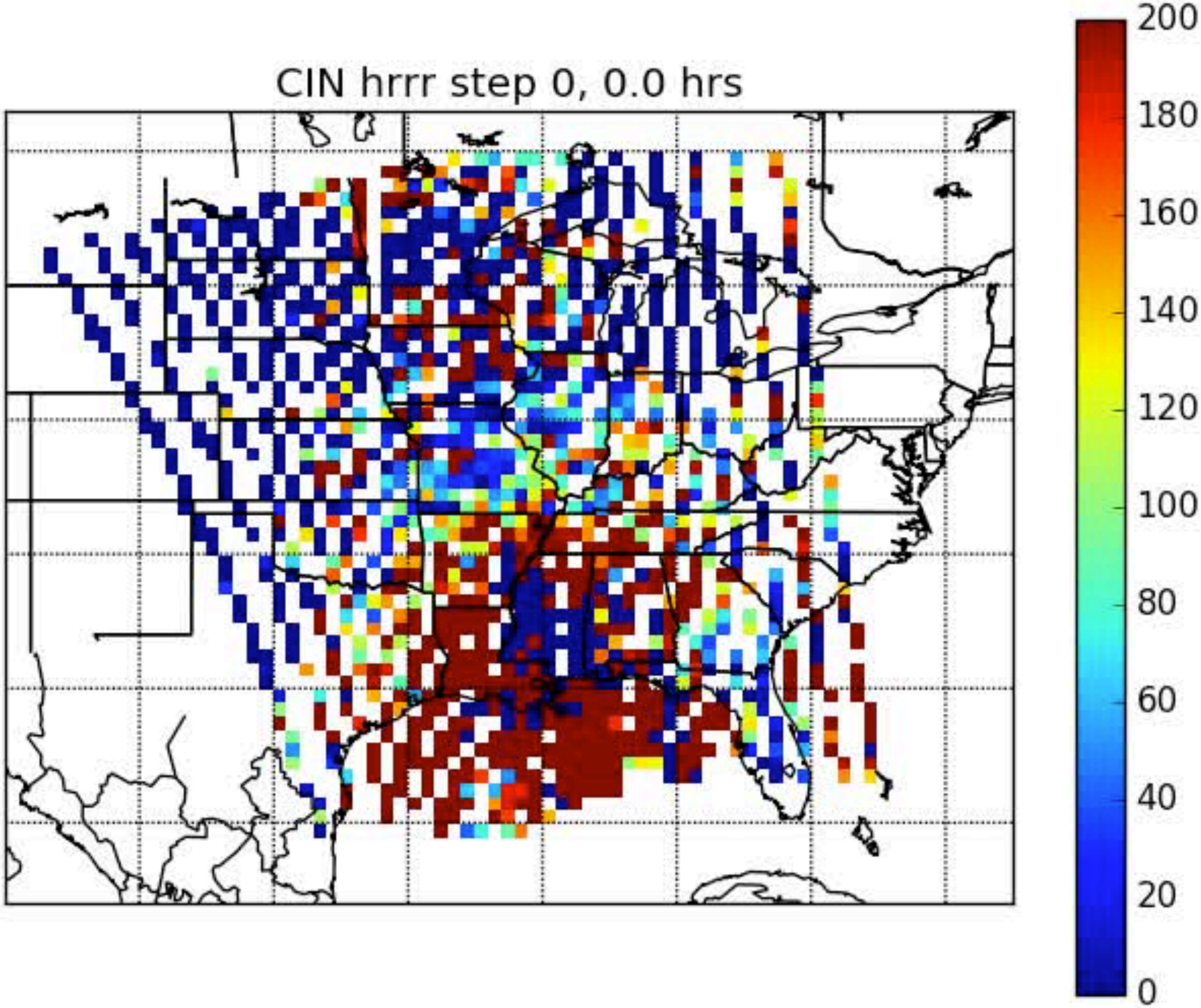
These are made on 0.5x0.5 degree grids

Soundings may have more or less levels than previous time steps and they are not constrained to a fixed pressure grid (parcels move vertically)

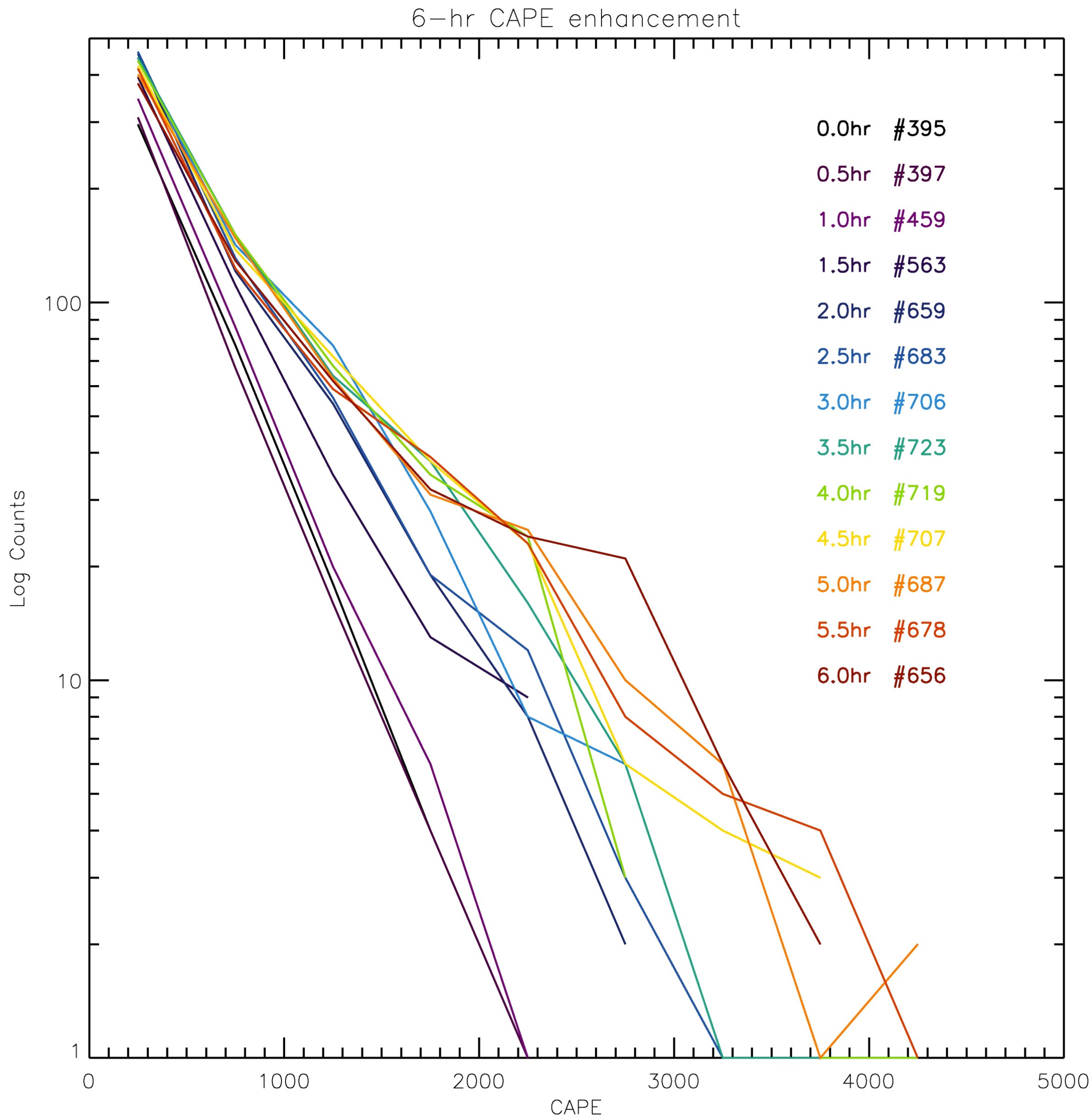
One can calculate convective indices for these new gridded soundings

Note that the filled grid elements will move around with time as parcels move in or out of a given grid


CAPE hrrr step 0, 0.0 hrs
2000
1800
1600
1400
1200
1000
800
600
400
200
0

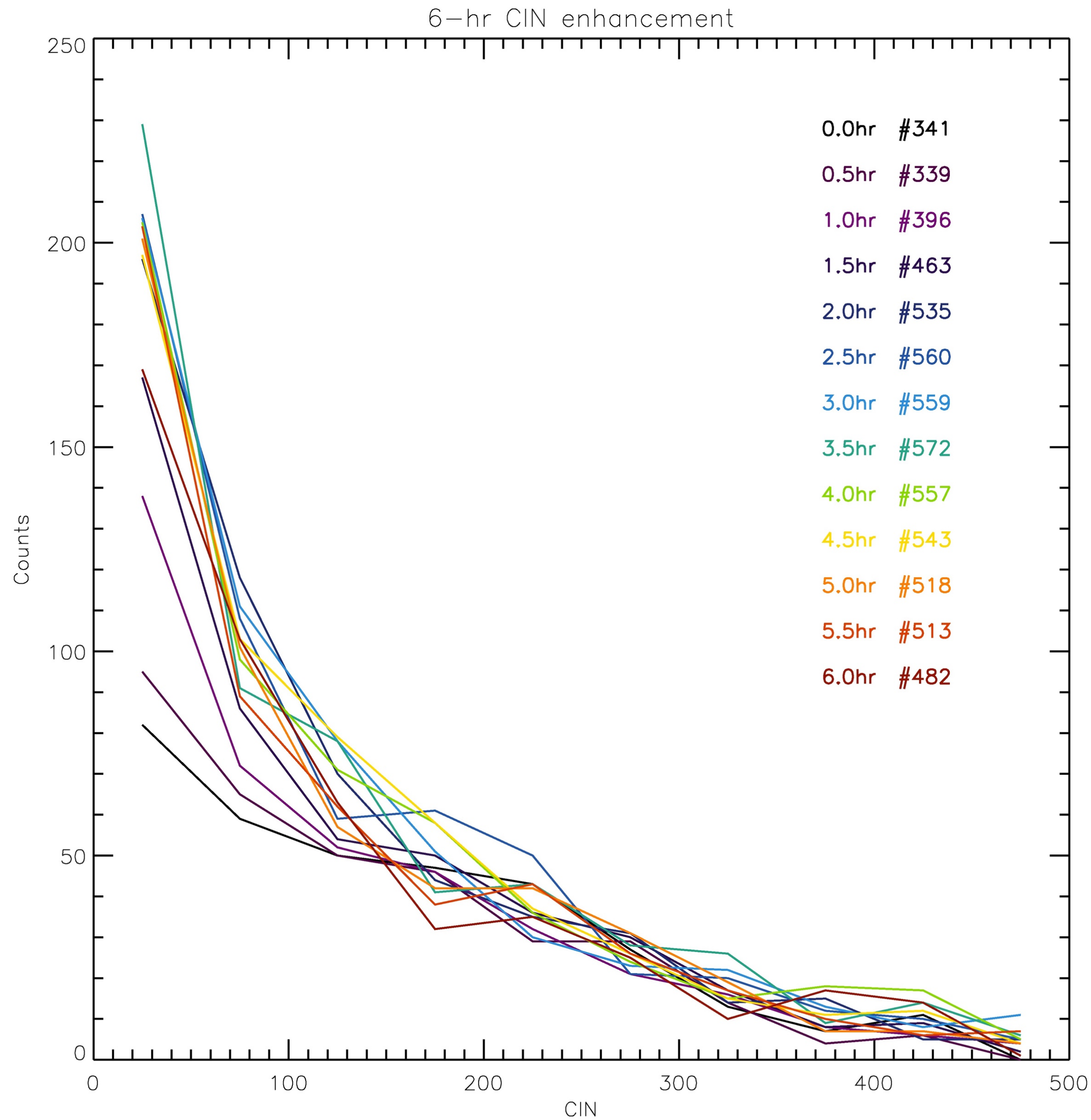

CIN hrrr step 0, 0.0 hrs
200
180
160
140
120
100
80
60
40
20
0

High values of CAPE are enhanced with time
(Log scale in counts to better see enhancement)

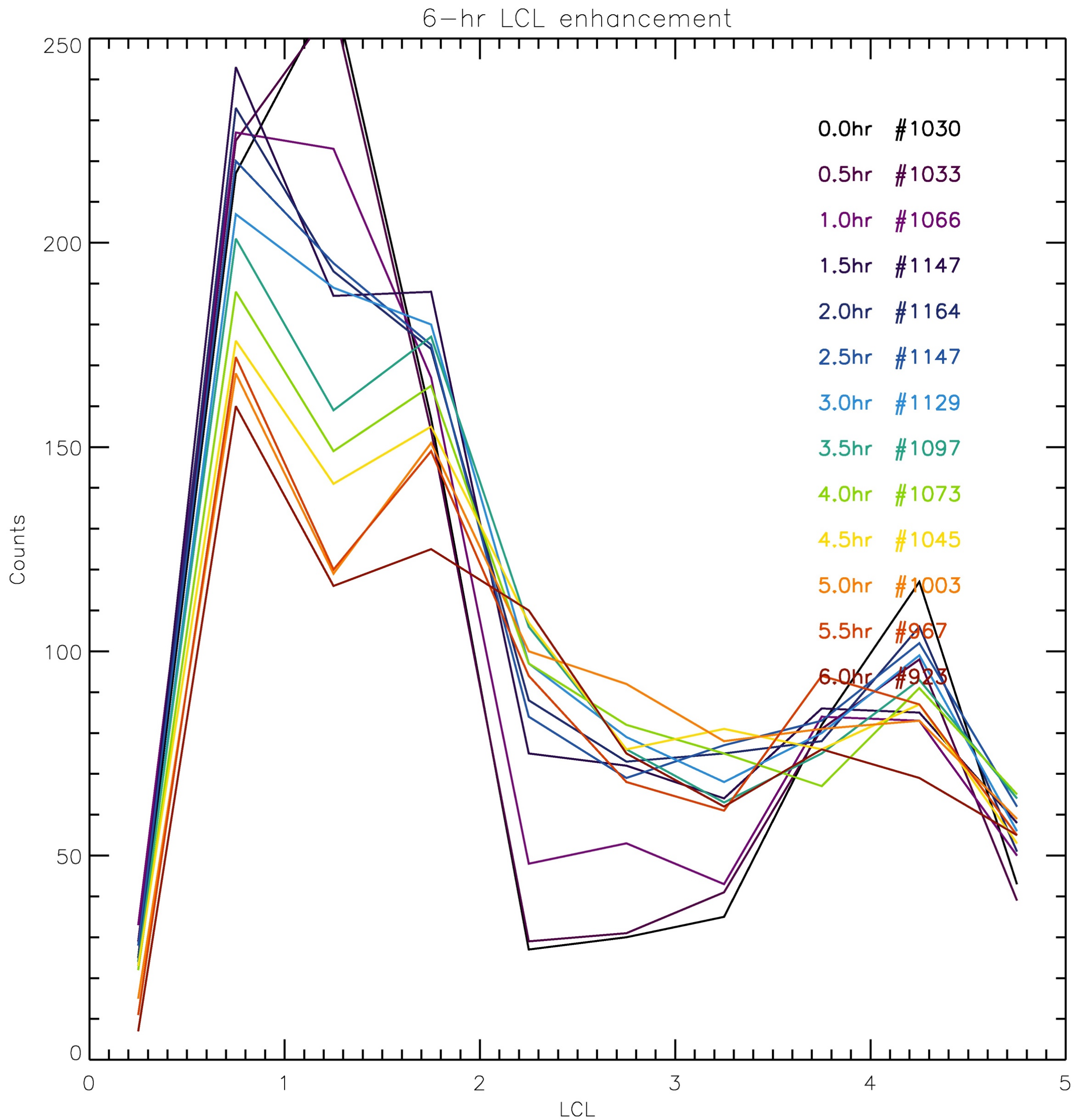


Increased frequency of low CIN values

More complex behavior for high CIN but counts small

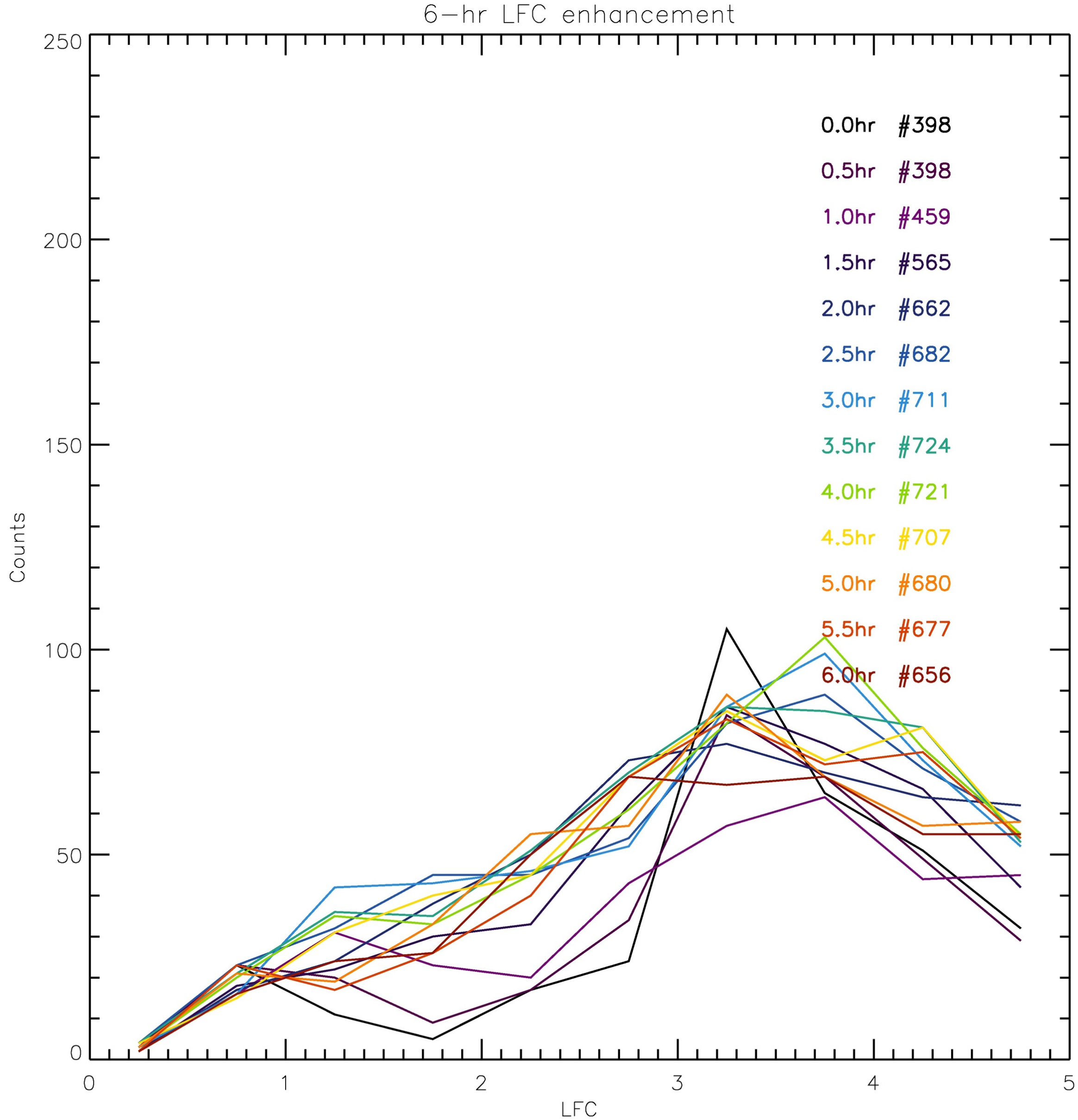


LCL shifts from strong bimodal to more unimodal
LCL problems susceptible to not handling surface T/Td

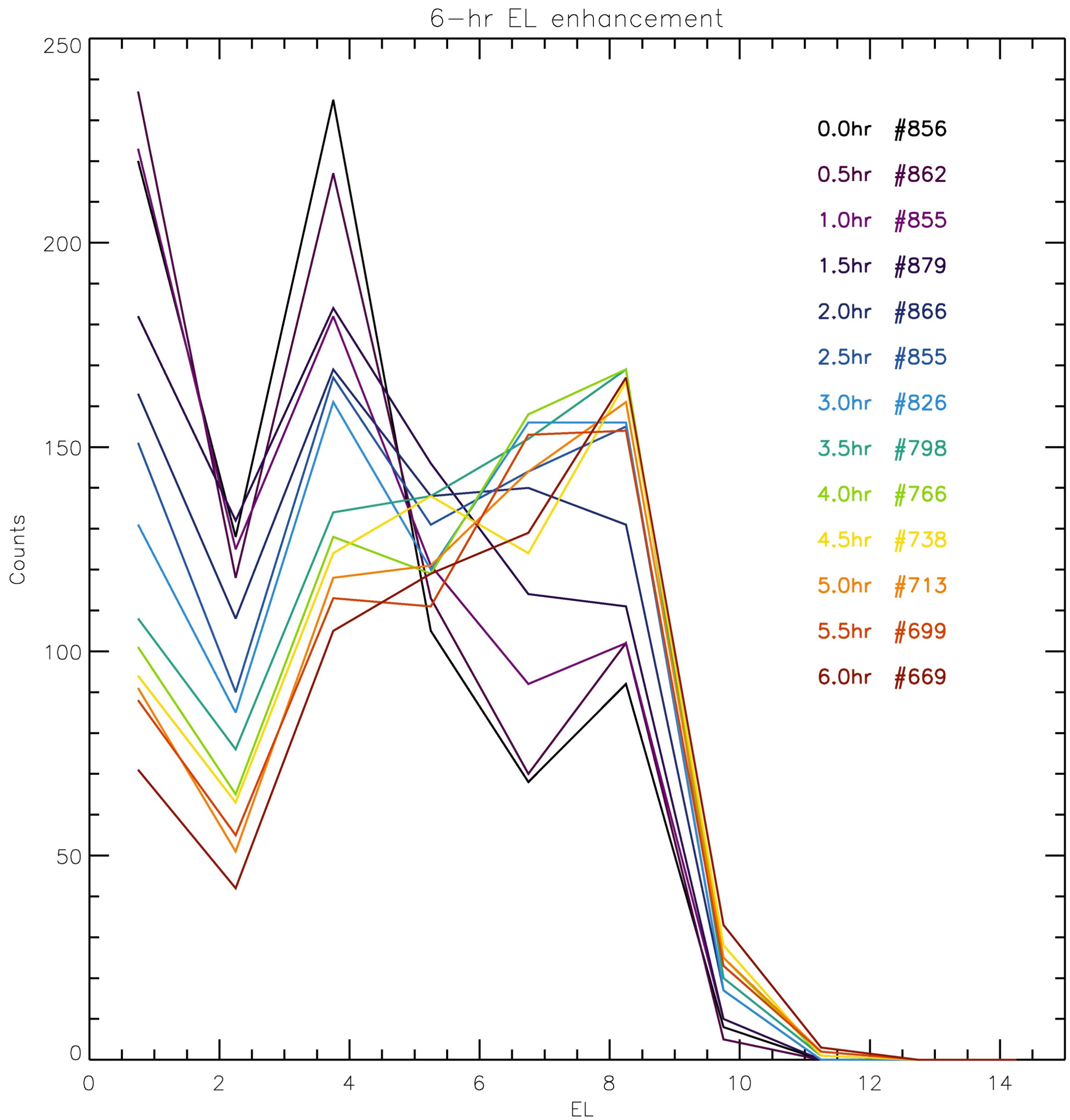


More low end values of LFC with time

Although more overall values of LFC with time



Dramatic increase in EL with time shows convective potential



Conclusions

Spanning the temporal gap between AIRS overpass and severe weather events increases the value of the AIRS data

We are applying our AIRS/HYSPLIT methodology to the severe weather forecasting problem

Operational testing will begin on April 22

In the future we will further improve the value of this approach by bringing in other data sets (e.g. surface moisture)