Lightning Forecast Algorithm (LFA) Overview

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Tutorial

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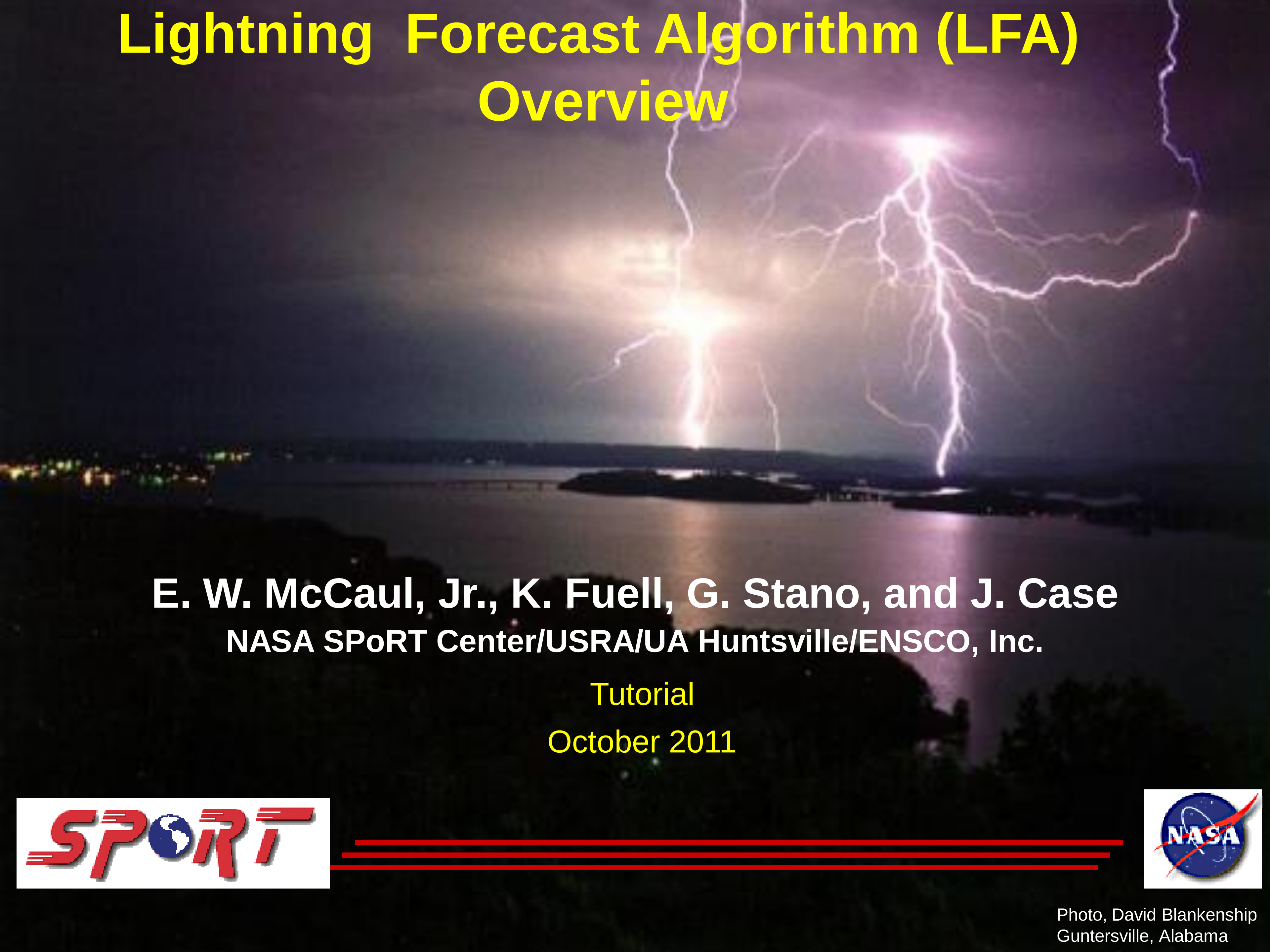


Photo, David Blankenship
Guntersville, Alabama

Pre-module Question 1

1. What is meant by “total lightning?”

Answer to Pre-module Question 1

Question:
1. What is meant by “total lightning?”

Answer:

Total lightning refers to the sum of cloud-to ground and intracloud lightning activity. Total lightning is much better correlated with storm dynamics than is mere cloud-to-ground lightning.

Pre-module Question 2

2. What is the difference between storm lightning flash rate and lightning flash origin density?

Answer to Pre-module Question 2

Question:

2. What is the difference between storm lightning flash rate and lightning flash origin density?

Answer:

Flash origin density describes how many total flash origins occur *per unit area* per unit time, whereas storm total flash rate is the total flash origin rate of an *entire storm*; the total flash rate at any given time can be obtained by integrating the flash origin density over a storm's footprint.

Pre-module Question 3

3. How can numerical simulations of clouds and their microphysics be used to make forecasts of lightning flash origin density?

Answer to Pre-module Question 3

Question:

3. How can numerical simulations of clouds and their microphysics be used to make forecasts of lightning flash origin density?

Answer:

Lightning occurs when graupel and ice crystal regions within a storm acquire enough charge to trigger air breakdown; since many models now prognose these ice hydrometeors, it is possible to estimate gridded flash origin densities based on gridded hydrometeor fields.

Learning Goals and Objectives

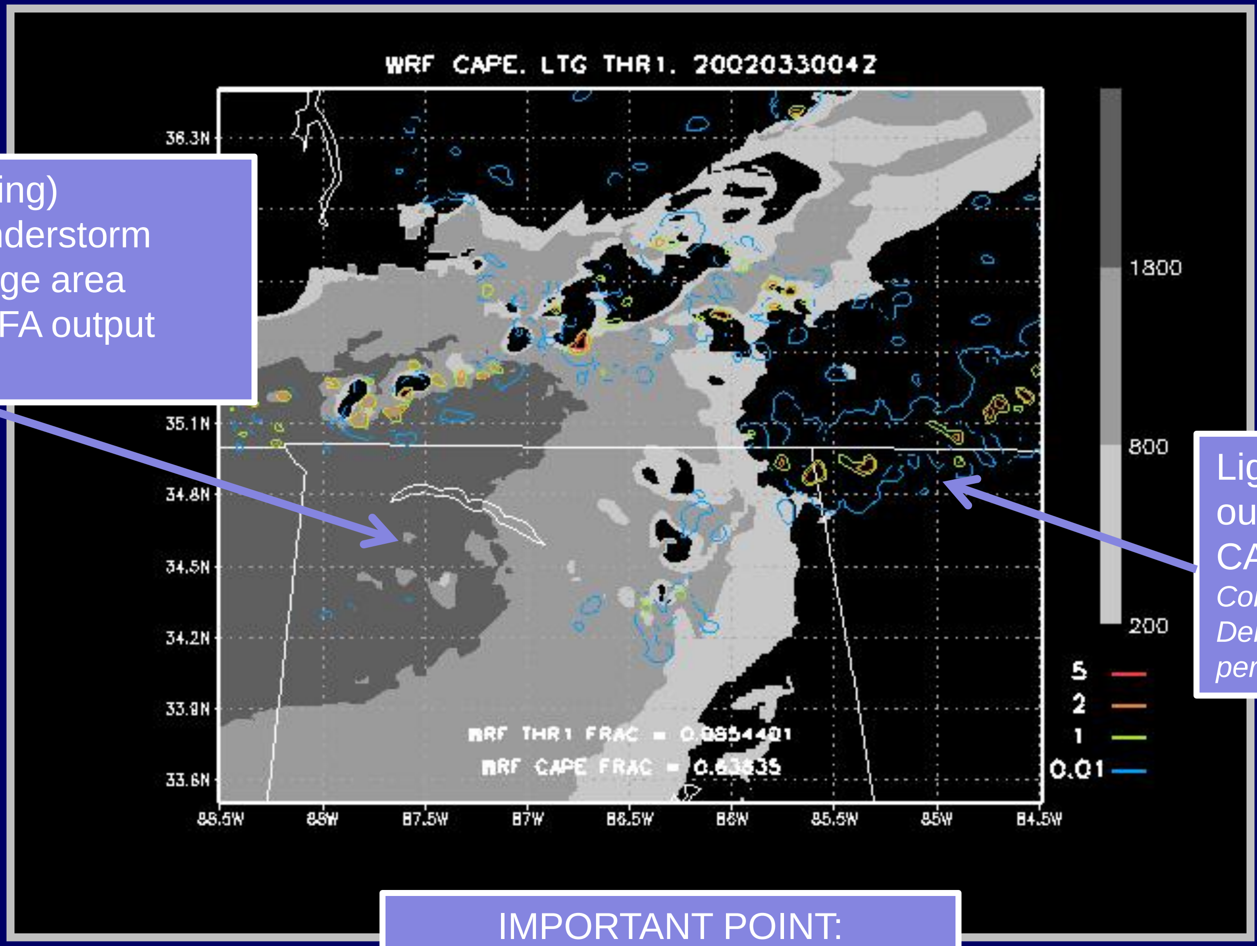
Goal: Understand how output fields from a cloud model can be used to create a lightning threat product

- Be able to list the model fields used to create lightning product
- Understand the benefits of the model fields chosen related to observed lightning characteristics from a ground-based lightning detection network
- Understand how model fields are used to create the lightning forecast algorithm
- Understand the limitations of using gridded model fields for a lightning product

Goal: Be able to apply lightning forecast products to aid in characterizing the lightning threat

- Be able to describe what the lightning product represents
- Understand how to interpret product in order to determine the lightning threat for the event
- Be able to use knowledge of product benefits and limitations in conjunction with other forecast parameters to improve the forecast of severe weather threat for a given area

Purpose / Why Lightning Forecast Algorithm (LFA) is Needed



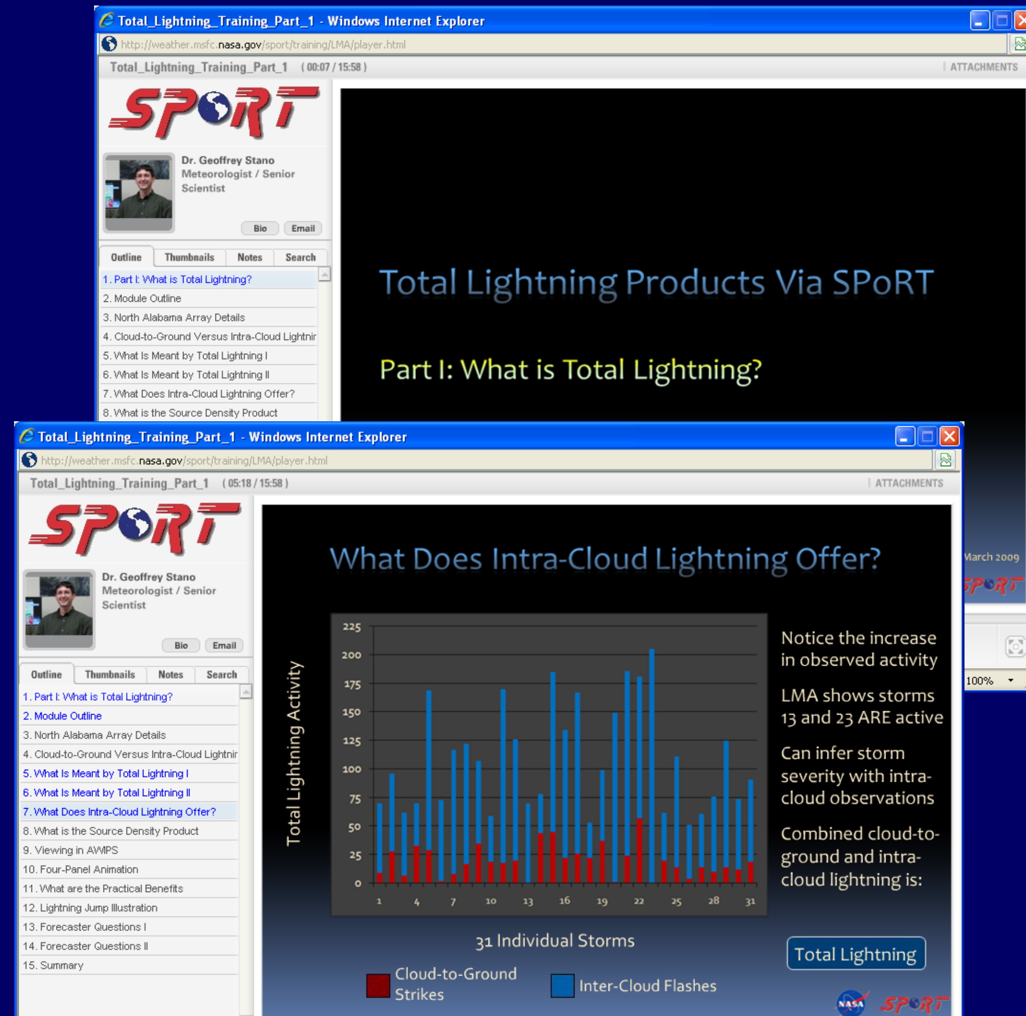
CAPE (gray shading) overforecasts thunderstorm threat: note the large area compared to the LFA output (colored contours)

Lighting can occur outside significant CAPE zones.
Contours are Flash Rate Density per km^2 per 5 minutes

IMPORTANT POINT:
LFA gets coverage correct; hence, it would be useful for data assimilation testing

Total Lightning Primer

- This LFA module assumes the user is familiar the with total lightning concepts presented in “Total Lightning Products via SPoRT” training module (see link at bottom right).
- Lightning Mapping Array (LMA)
  - Observes individual stepped leaders of entire flash (referred to as sources)
  - Observes flashes not detected by the NLDN
  - Observes intra-cloud lightning which is related to storm strength
- Total lightning: Combination of the CG and IC lightning (see graphic in lower image)
  - Red = Cloud to ground (CG) lightning from NLDN
  - Blue = Intra-cloud flashes (IC)
  - Note the IC lightning makes up a very large percentage of the total lightning (i.e. total lightning is much more than the NLDN)



Training module on total lightning can be found at:
http://weather.msfc.nasa.gov/sport/training/

Design of LFA

How LFA was trained

- Cases that the LFA was developed from

LFA model proxy fields

- What the LFA uses to forecast lightning

Calibration of proxy fields

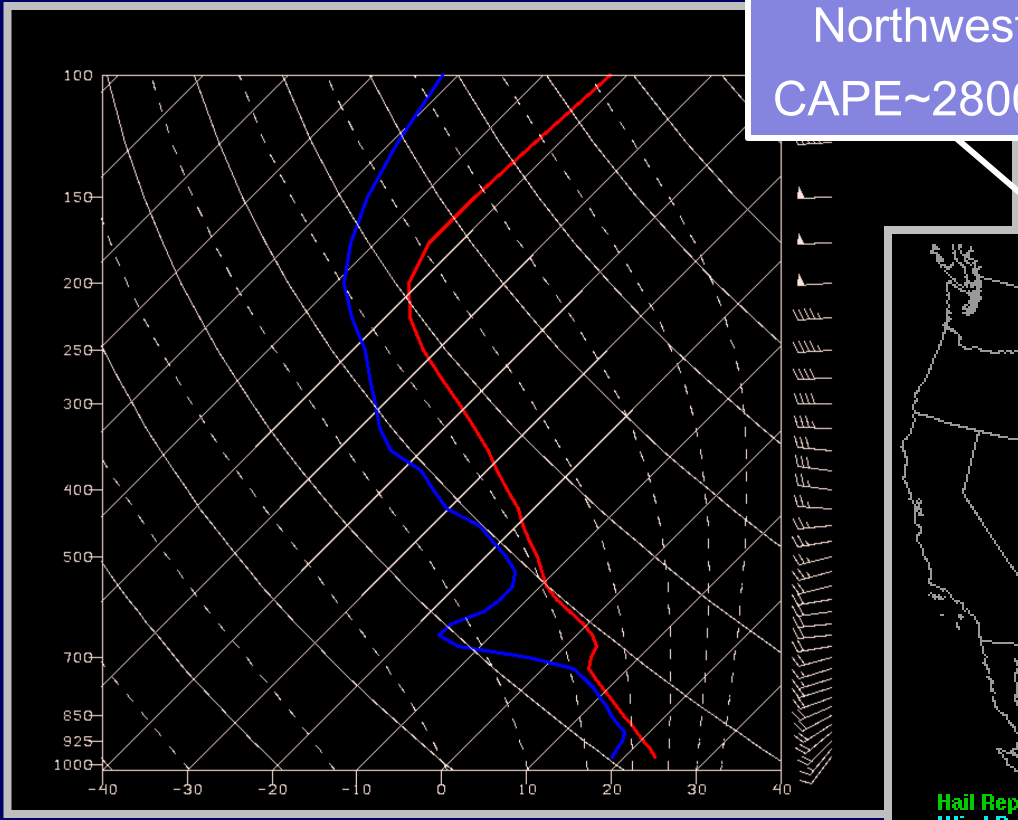
Creation of final, blended threat product

- Combining the best calibration results into one, unified output

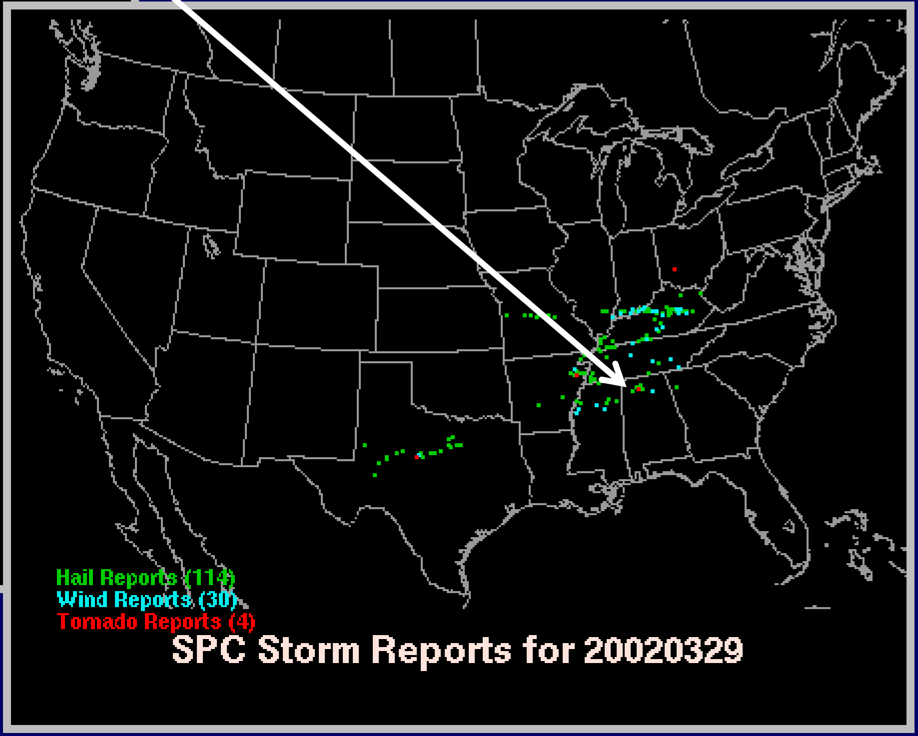
Design – How LFA was Trained

- The LFA was trained using a small but diverse set of storm events that were observed well by the North Alabama Lightning Mapping Array (NALMA)
- Flash rate densities for the cases ranged from 2-3 flashes per sq. km per 5 min (fl/km^2/5min), up to about 14 fl/km^2/5min
- Storm type included wintertime post-frontal storms, springtime supercells, and summer pulse storms
- For each storm case, a 2-km WRF regional simulation was made and the strongest storms in both the observations and simulations were compared
- Next slides will demonstrate a training case from 30 March 2002

WRF Sounding, 0300 UTC 30 March 2002



Northwest AL
CAPE~2800 J/kg

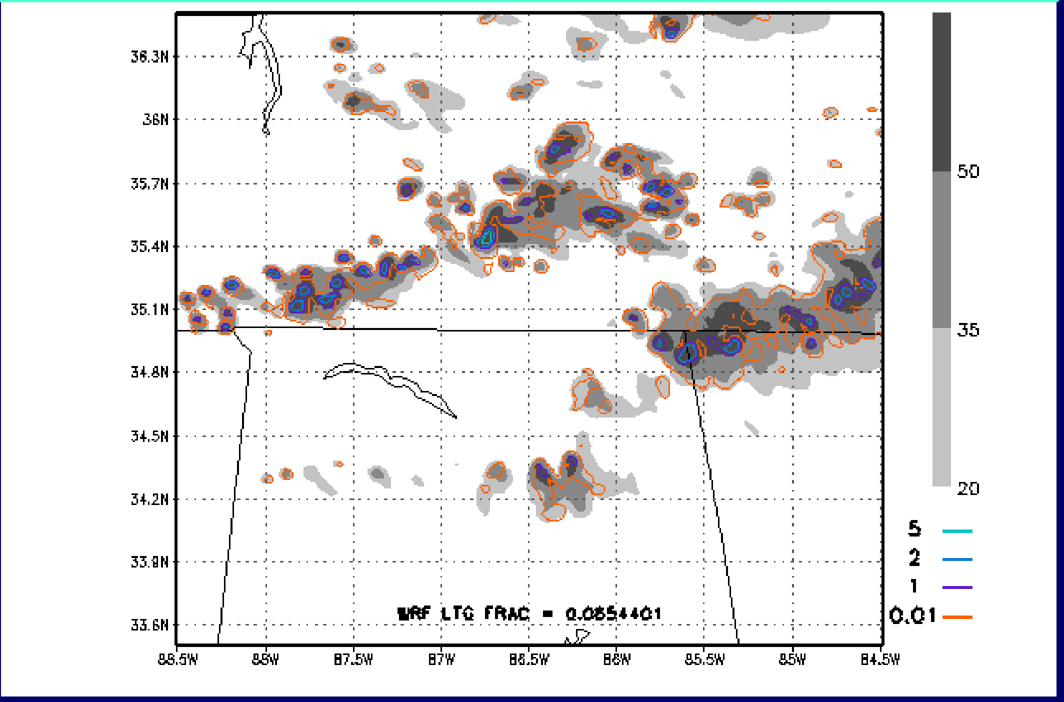


Event Description:
Squall line with isolated tornadic supercell over Northern Alabama

Design – LFA Model Proxy Fields

Based on previous global observational studies, two main proxy fields were studied. One is graupel flux at the -15°C level (GFX). This is assessed by finding the product of graupel mixing ratio and updraft speed at the -15°C level. GFX is sensitive to updraft variations, but cannot always give accurate threat coverage in storm anvils.

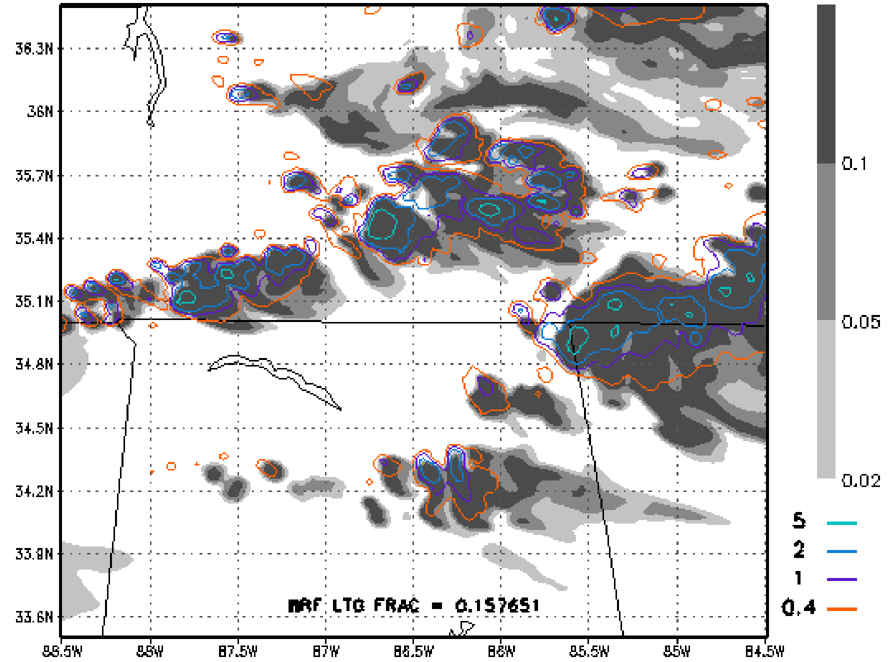
Flash density (colored contours, flashes/km^2/5min) based on model graupel flux, overlaid on WRF reflectivity (gray shading, dBZ) for 0400 UTC on 30 March 2002



Design – LFA Model Proxy Fields

The second proxy is the vertical ice integral (VII), obtained by integrating all the cloud ice, snow and graupel in each grid column. VII gives good coverage of threat in storm anvils, but does not vary much with time. Both proxies (GFX, VII) are saved as horizontal gridded fields, and their peak values for each full simulation are recorded.

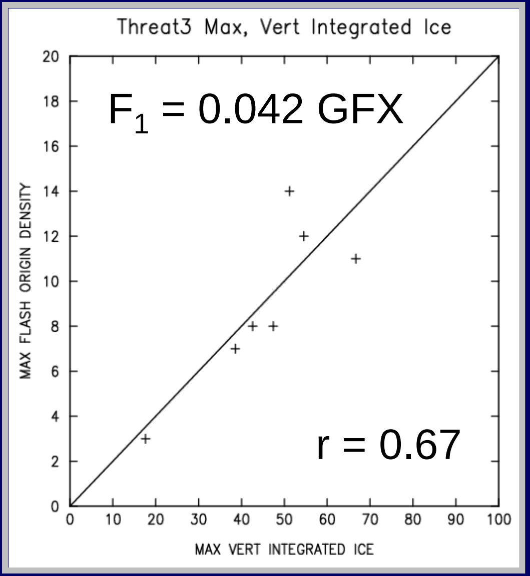
Flash density (colored contours, flashes/km2/5min) based on model vertically integrated ice, overlaid on WRF ice concentration (gray shading) for 0400 UTC on 30 March 2002

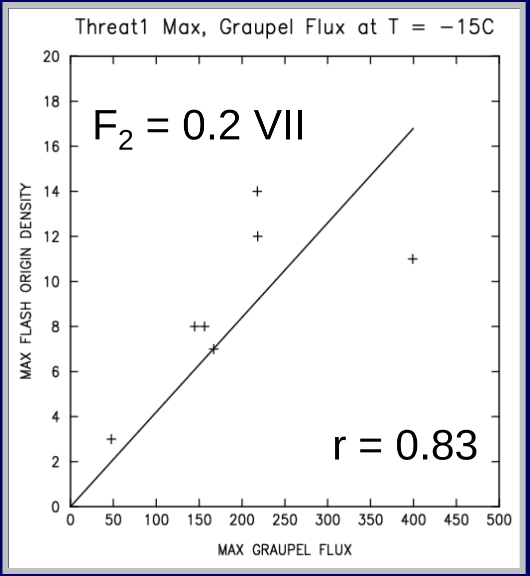


Design – Calibration of Proxy Fields

NALMA observations of total lightning were then analyzed for each storm outbreak. NALMA sources were clustered into flashes, and gridded flash origin density maps were created. Analogous with the simulation proxies, the peak values of flash origin density were noted for each storm outbreak.

Scatterplots were then constructed to show the relation between peak observed flash origin densities and peak model-simulated proxy field values. Linear regressions were significant, and the regression slopes could be used to transform proxy values to observed values. Both proxies were calibrated to yield the same peak flash rates.



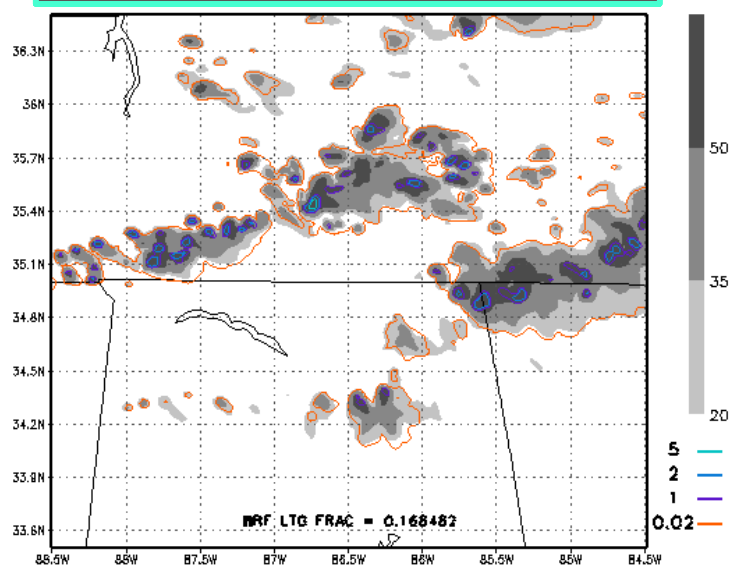


Design – Final Blended Threat

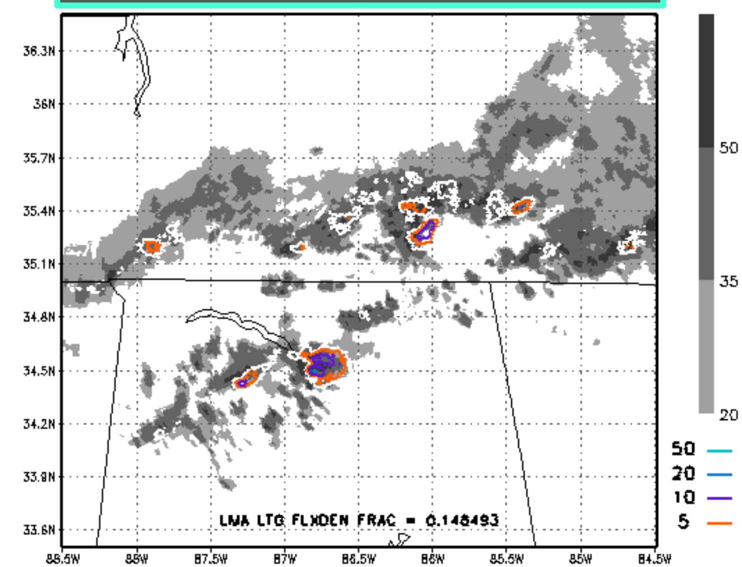
GFX provides good temporal variability but lacks the areal coverage of the lightning threat. However, the VII has the opposite characteristics. Therefore, a blend of the two threats was needed in order to obtain a single threat that retained the best of both GFX and VII, while minimizing their limitations.

Both GFX and VII are highly correlated, with only their footprints differing. Thus it is safe to blend them by doing a simple weighted average. It was found that only a small contribution from VII was adequate to provide good areal coverage, so after testing it was decided to assign a weight of 0.95 to GFX, and a weight of 0.05 to VII.

Flash origin density from model proxies



Flash extent density from LMA network



30 March 2002, 0400 UTC

WRF LFA Methodology: Disadvantages

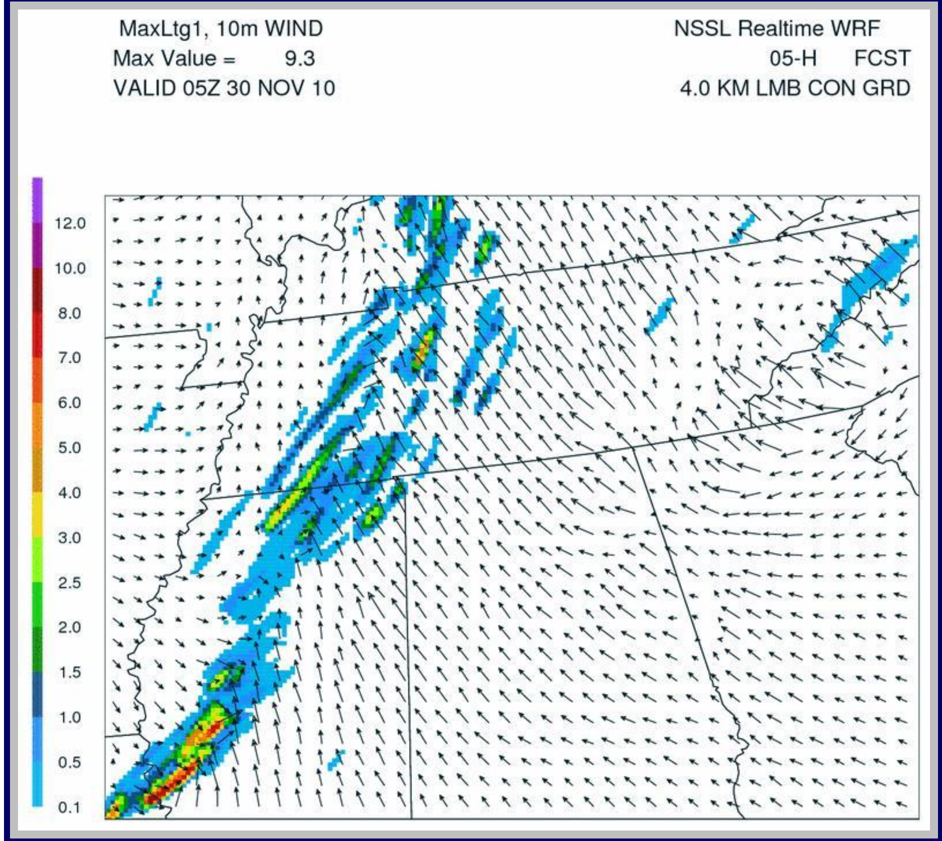
- Method is only as good as the model output; models usually do not make storms in the right place at the right time
- Small number of cases; lack of extreme LTG events in training set means uncertainty in calibrations
- Calibrations should be redone whenever model configuration is changed, or grid mesh resized
- 4-km WRF data has a tendency to under-represent updrafts relative to 2-km training runs; therefore, we rescale GFX to have a peak that matches VII before making Lightning Threat Product; this procedure may change in future

WRF LFA Methodology: Advantages

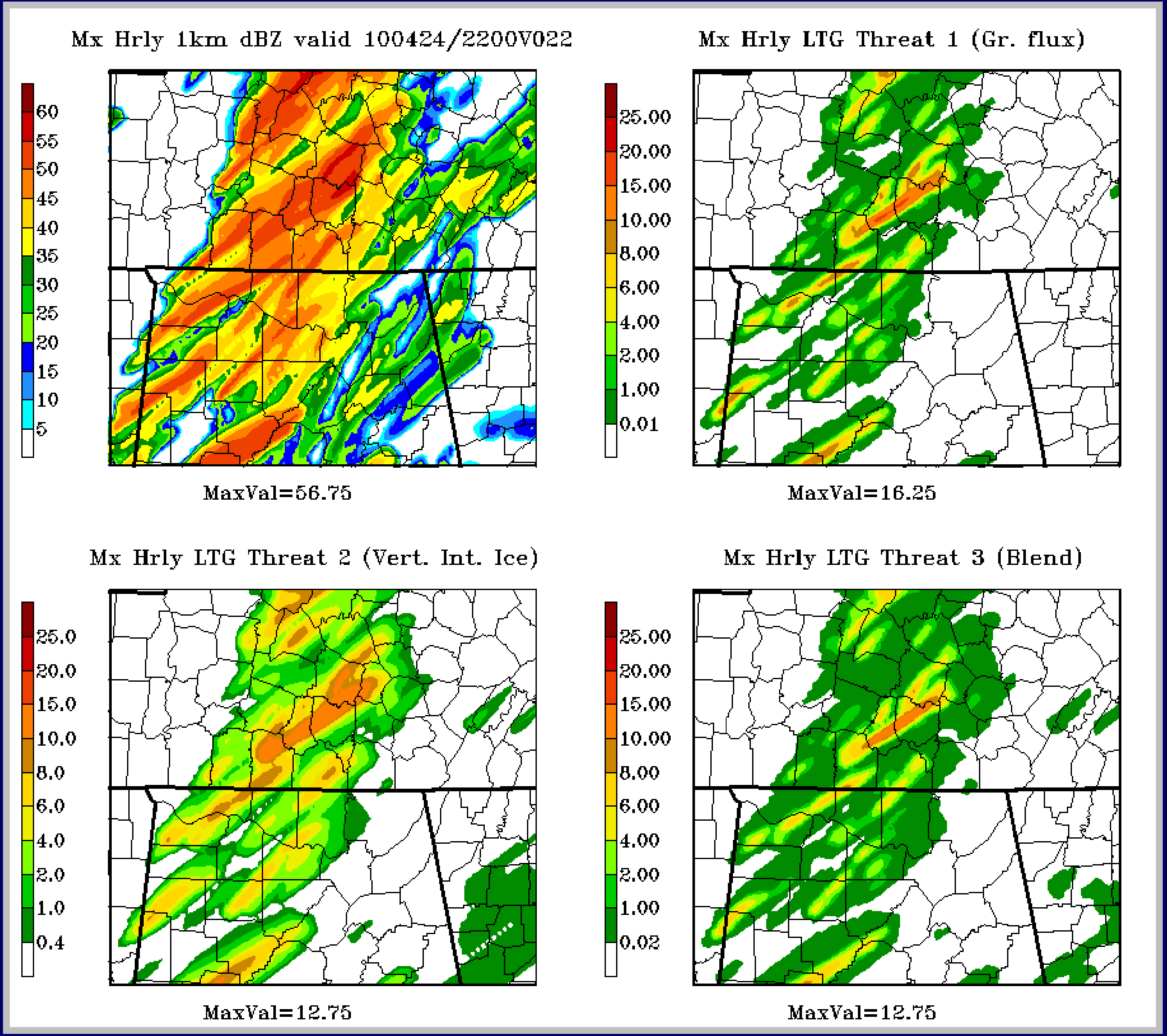
- LFA is based on observations of lightning physics; should be robust and regime-independent
- Can provide quantitative estimates of flash rate fields; use of thresholds allows for accurate depiction of lightning threat areal coverage
- LFA is a fast and simple diagnostic tool; based on fundamental model output fields; no need for complex, costly electrification modules
- LFA is designed to use gridded proxy fields; there is no need to deploy cell ID algorithms

LFA in NSSL WRF daily CONUS runs

1. LFA now used routinely in NSSL WRF 36-h 4-km runs
2. See www.nssl.noaa.gov/wrf and look for LTG Threat plots
3. Results are depicted in terms of gridded *hourly maxima* (not snapshots) of the 2 threats, *before* rescaling threat 1; units are flashes per sq. km per 5 min
4. To make the blended threat, we first rescale GFX threat to account for coarser NSSL WRF mesh.
5. Potential issues:
    a. In snow events, can have spurious VII threat
    b. In extreme storms, VII threat fails to keep up with GFX
6. NSSL collaborators, led by Jack Kain, tested LFA reliability against existing LTG forecast tools, with favorable findings

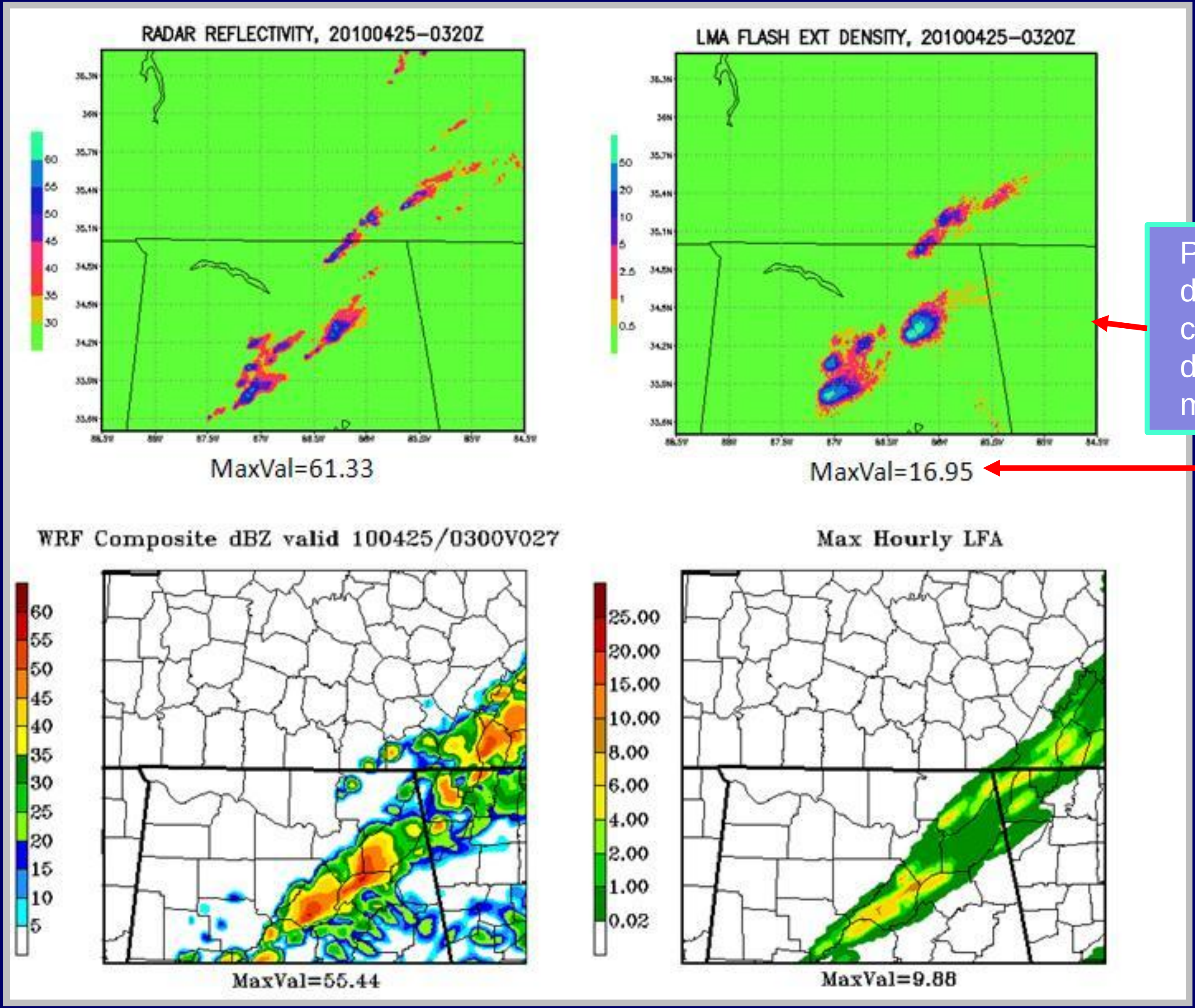


Sample NSSL WRF LFA output: 24 April 2010



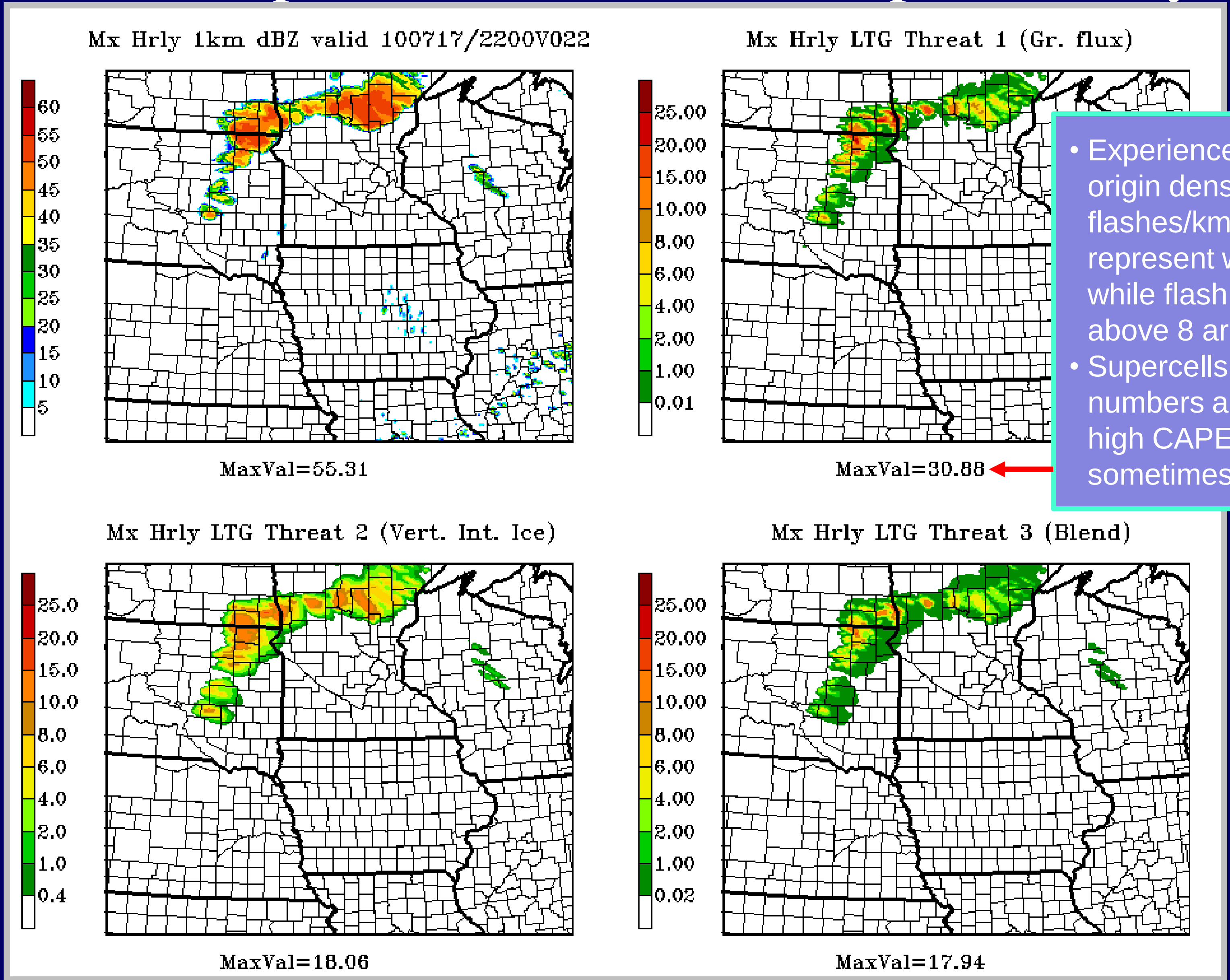
- LFA cannot diagnose lightning threat outside of a storm's hydrometeor envelope
- Thus, forecasters must exercise their own judgment in handling *bolt from the blue* lightning threats

Obs + Sample NSSL WRF LFA: 25 April 2010



Plot shows flash *extent* density, while the LFA is calibrated off flash *origin* density (not shown, but max value noted below)

Sample NSSL WRF LFA output: 17 July 2010



- Experience shows that flash origin densities of less than 3 flashes/km²/(5 min) represent weak convection, while flash origin densities above 8 are often severe
- Supercells usually achieve numbers above 8, with a few high CAPE storms sometimes as high as 30+

WRF LFA Tips for Users

- LFA seeks to match *simulated peak* flash origin density with *observed peak* flash origin density; because of differences in probability density functions of simulated vs. observed LTG features, cell flash counts derived from LFA may be wrong
- Small number of cases, lack of extreme LTG events in training set means uncertainty in calibrations; work is ongoing to find and add high flash-rate cases to calibration database
- Original LFA study used WRF WSM6 microphysics; use of other microphysics or grid meshes lends uncertainty to results; work is ongoing with CAPS ensembles to quantify this uncertainty
- Currently, when using 4 km WRF data, with its tendency to under-represent updrafts relative to 2 km mesh, we force GFX to have a peak that matches VII before making Lightning Threat Product; this procedure may change in future
- In winter regimes, VII can exist in absence of GFX; work is ongoing to see if VII alone accurately predicts lightning

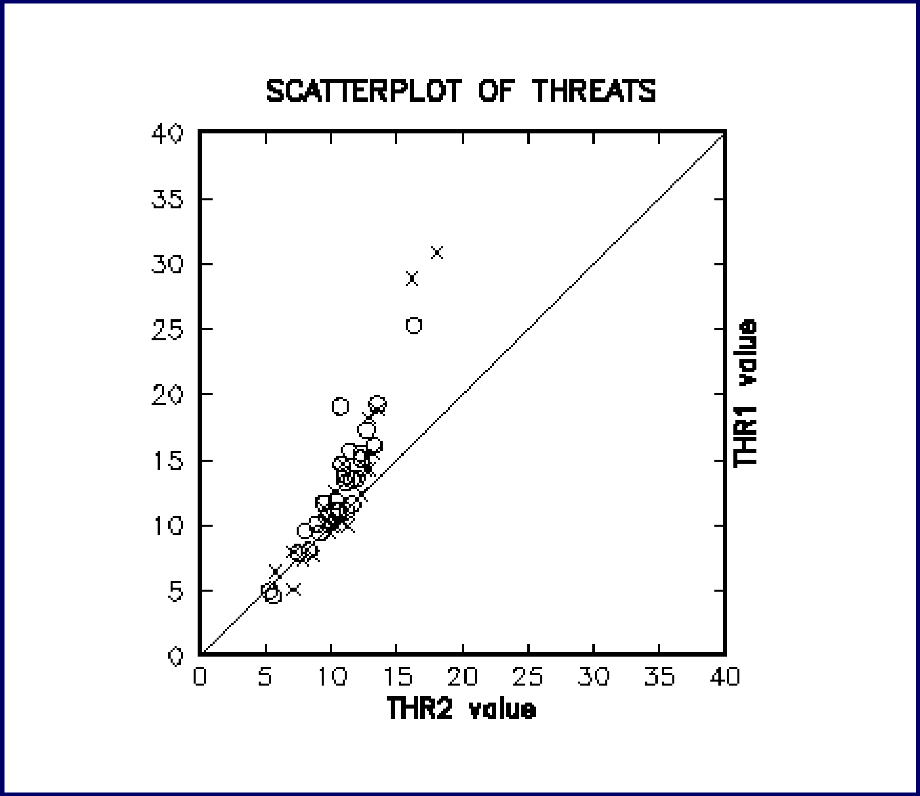
LFA in CAPS 2011 WRF ensemble runs

- LFA was used in CAPS WRF 36-h ensemble runs
- See http://www.caps.ou.edu/~fkong/sub_atm/spring11.html and look for blended LTG-3 probability plots (last 2 items on each daily link)
- Results are expressed in terms of hourly gridded maxima for the two threats, before rescaling of threat 1
- To make the blended threat, we use fields of hourly maxima of the GFX and VII threats, after appropriate rescaling of the GFX threat; this is similar to NSSL WRF procedure
- Issues: it is not feasible to redesign the LFA to handle explicitly every imaginable combination of microphysics and IC choices; basic LFA is applied to each ensemble member, and variations in output will be examined to assess sensitivity; where hail is allowed with graupel, GFX will include hail, too

Current/Future Work: Optimize LFA for High Flash Rate Lightning Events

Scatterplot of selected NSSL WRF output for GFX (THR1) and VII threats (THR2)

The threats should cluster along diagonal; deviation at high flash rates indicates need for recalibration



Acknowledgments

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McCaul, E. W., Jr., S. J. Goodman, K. LaCasse and D. Cecil, 2009: Forecasting lightning threat using cloud-resolving model simulations. *Wea. Forecasting*, **24,** 709-729.