

The WRF Lightning Forecast Algorithm: Refinement and Incorporation into Convective Ensemble Forecasts

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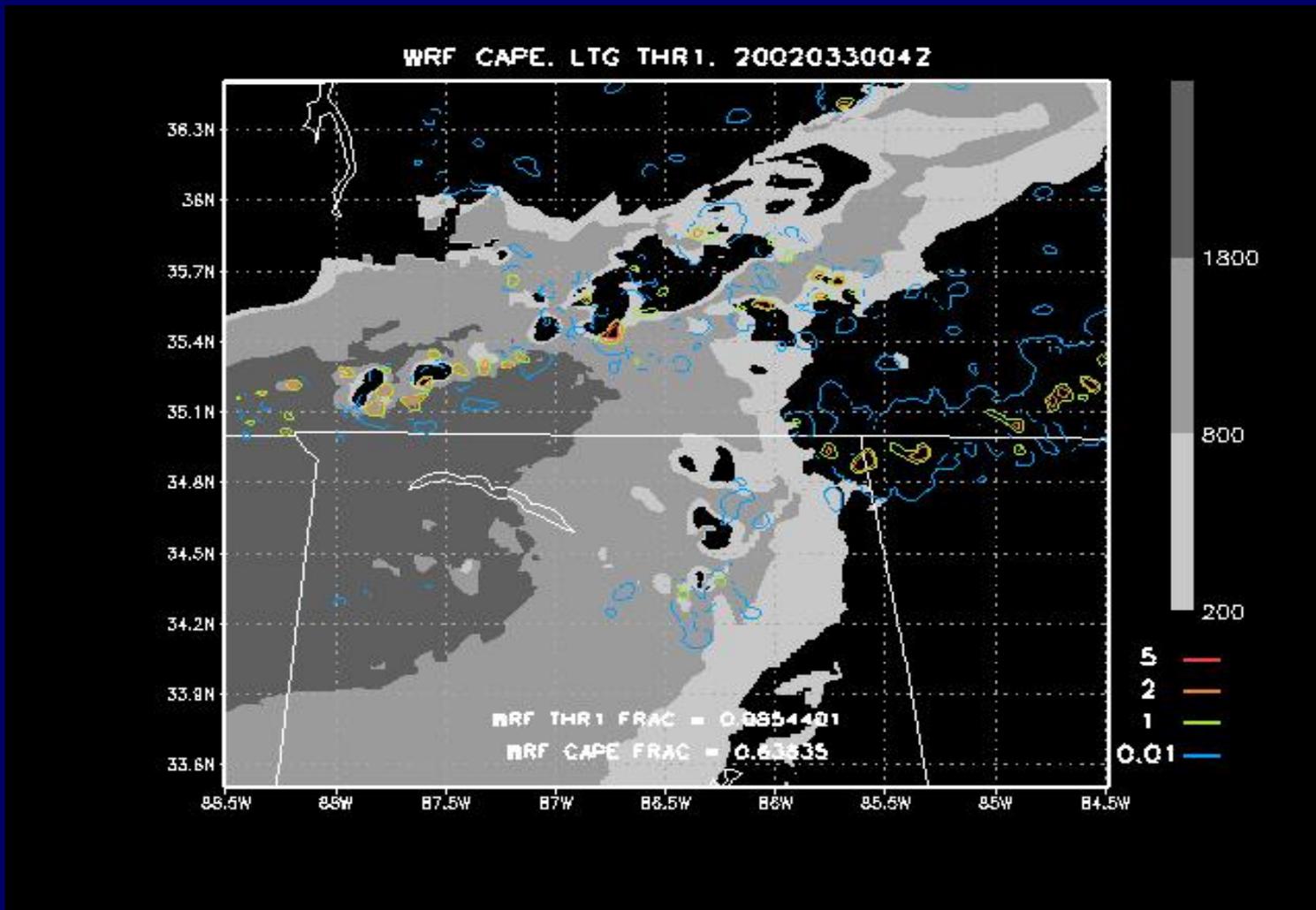
1. USRA Huntsville; 2. ENSCO NASA SPoRT; 3. Univ. of Oklahoma;
4. NOAA/NESDIS; 5. NOAA/SPC

Science Week

May 1, 2012

Photo, David Blankenship
Guntersville, Alabama

Motivation: Compare coverage CAPE vs LFA LTG1





LFA Objectives

Given LTG link to large ice, and a cloud-scale model like WRF, which prognoses hydrometeors, LFA seeks to:

1. Create WRF forecasts of LTG threat (1-36 h), based on simple proxy fields from explicitly simulated convection
2. Construct an empirically calibrated threat that yields accurate quantitative peak flash rate densities for the strongest storms, based on LMA total LTG observations
3. Provide robust algorithm for use in making gridded proxy LTG data, and for potential uses with DA



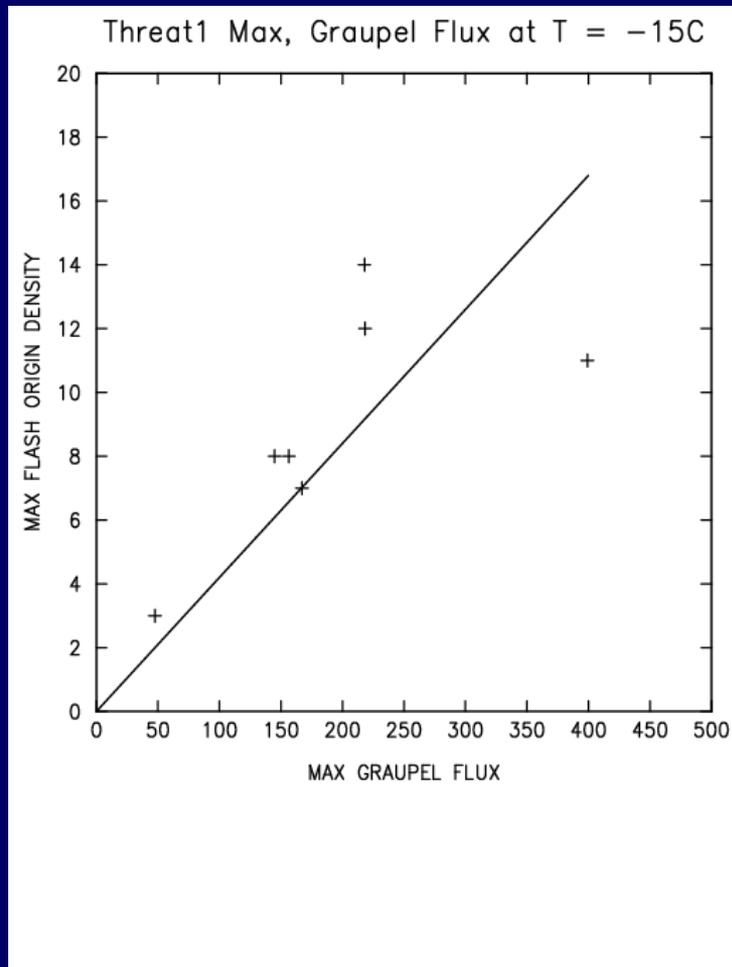
Calibration Curve

LTG1 (GFX)

$$F_1 = 0.042 \text{ GFX}$$

$$F_1 > 1.50$$

$$r = 0.67$$



Units of F_1 are
fl/km²/5 min



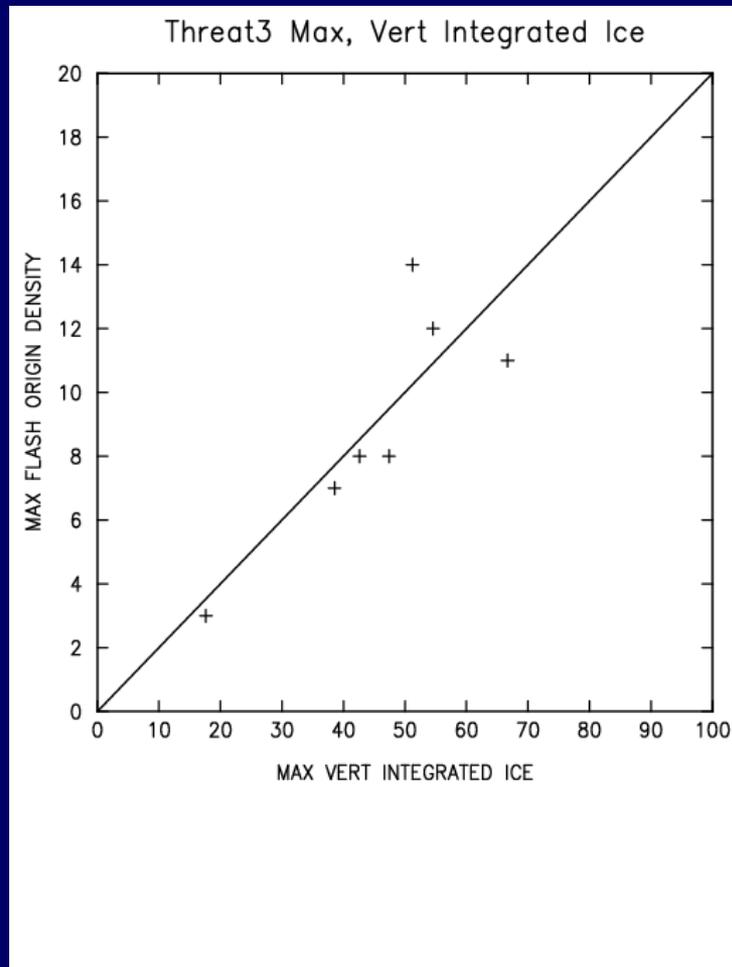
Calibration Curve

LTG2 (VII)

$$F_2 = 0.2 \text{ VII}$$

$$F_2 > 0.4$$

$$r = 0.83$$



Units of F_2 are
fl/km²/5 min



Construction of blended threat:

1. LTG1 and LTG2 are both calibrated to yield correct peak flash densities
2. The peaks of LTG1 and LTG2 also tend to be coincident in all simulated storms, but LTG2 covers more area
3. Thus, weighted linear combinations of the 2 threats will also yield the correct peak flash densities
4. To preserve most of time variability in LTG1, use large weight w_1
5. To preserve areal coverage from LTG2, avoid very small weight w_2
6. Tests using 0.95 for w_1 , 0.05 for w_2 , yield satisfactory results
7. Thus, set $LTG3 = 0.95*LTG1 + 0.05*LTG2$



LFA Threat Methodology: Advantages

- Methods based on LTG physics; should be robust and regime-independent
- Can provide quantitative estimates of flash rate fields; use of thresholds allows for accurate threat areal coverage
- Methods are fast, simple, and empirical; based on fundamental model output fields; no need for complex electrification modules



LFA Threat Methodology: Disadvantages

- Methods are only as good as the numerical model output; models usually do not make storms in the right place at the right time; models sometimes do bad forecasts; saves at >5 min can miss LTG jumps
- Small number of cases, scarcity of extreme LTG events means uncertainty in calibrations at high end
- Calibrations should be redone whenever model is changed, or error bars acknowledged regarding sensitivities to grid mesh, model microphysics (see data from CAPS ensembles below)



WRF Configuration (LFA study)

Prototypical Original Case

- 2-km horizontal grid mesh
- 51 vertical sigma levels
- Dynamics and physics:
 - Eulerian mass core
 - Dudhia SW radiation
 - RRTM LW radiation
 - YSU PBL scheme
 - Noah LSM
 - WSM 6-class microphysics scheme (graupel; no hail)
- 8h forecast initialized at 00 UTC with AWIP212 NCEP EDAS analysis;
- Also used METAR, ACARS, and WSR-88D radial vel at 00 UTC;
- Eta 3-h forecasts used for LBCs



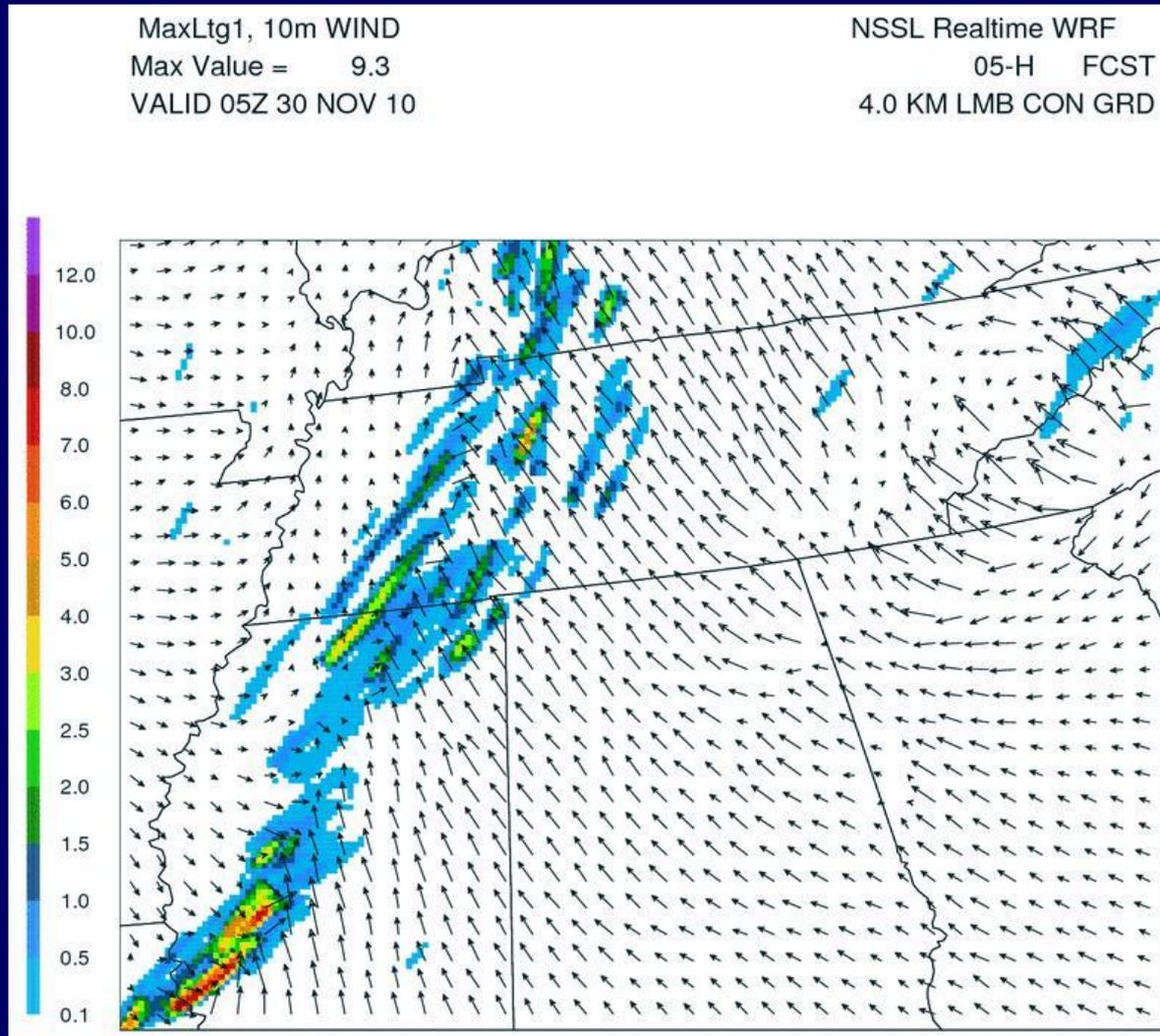
WRF Configuration (NSSL)

Typical Operational Case

- 4-km horizontal grid mesh
- 35 vertical sigma levels
- Dynamics and physics:
 - Eulerian mass core
 - Dudhia SW radiation
 - RRTM LW radiation
 - MYJ PBL scheme
 - Noah LSM
 - WSM 6-class microphysics scheme (graupel; no hail)
- 36h forecast initialized at 00 UTC with AWIP212 NCEP EDAS analysis on 40 km grid;
- 0-36-h NAM forecasts used for LBCs



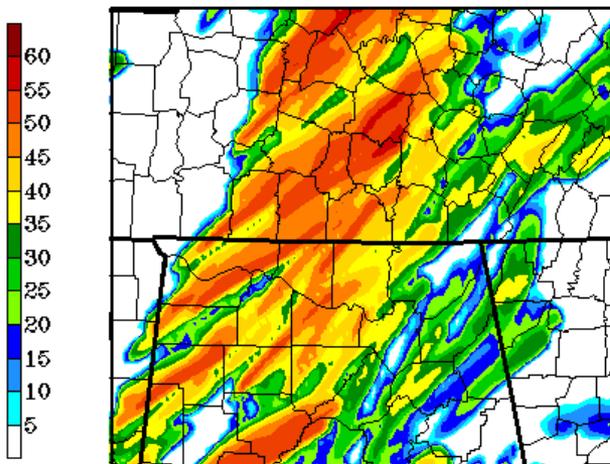
Sample of NSSL LFA output, 20101130 (see www.nssl.noaa.gov/wrf)





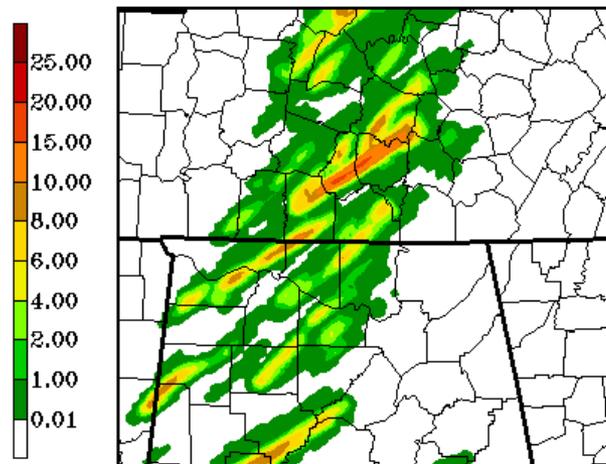
NSSL WRF data: 24 April 2010

Mx Hrly 1km dBZ valid 100424/2200V022



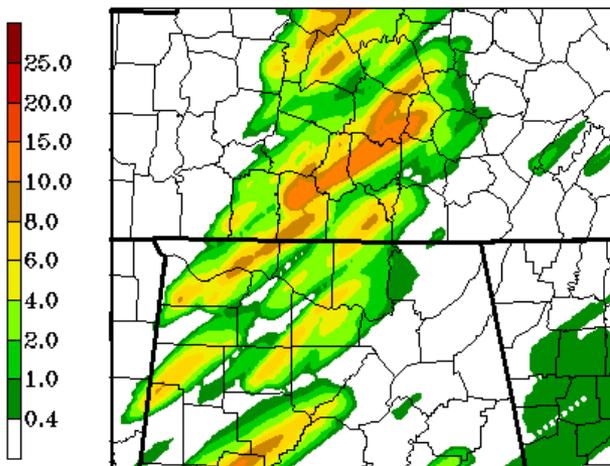
MaxVal=56.75

Mx Hrly LTG Threat 1 (Gr. flux)



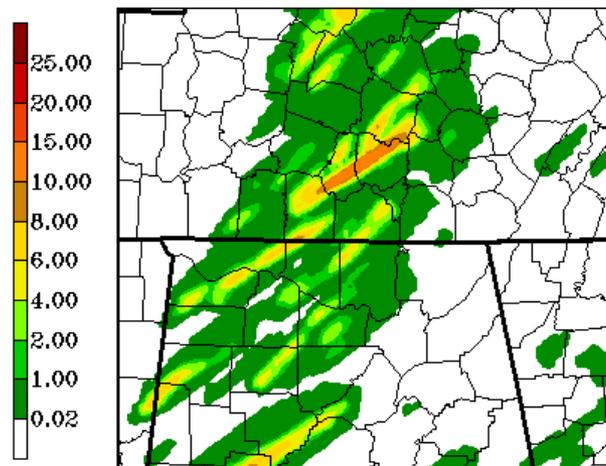
MaxVal=16.25

Mx Hrly LTG Threat 2 (Vert. Int. Ice)



MaxVal=12.75

Mx Hrly LTG Threat 3 (Blend)

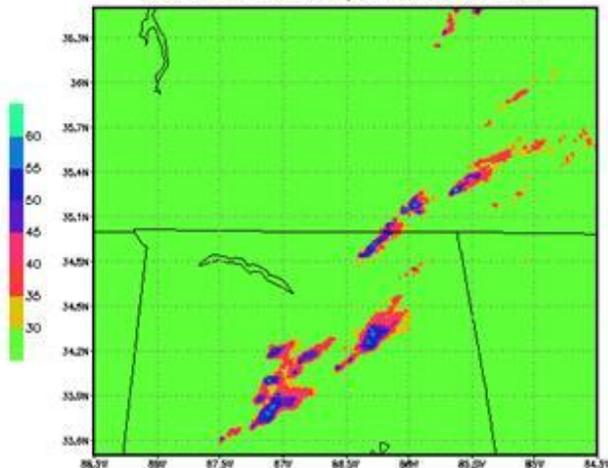


MaxVal=12.75



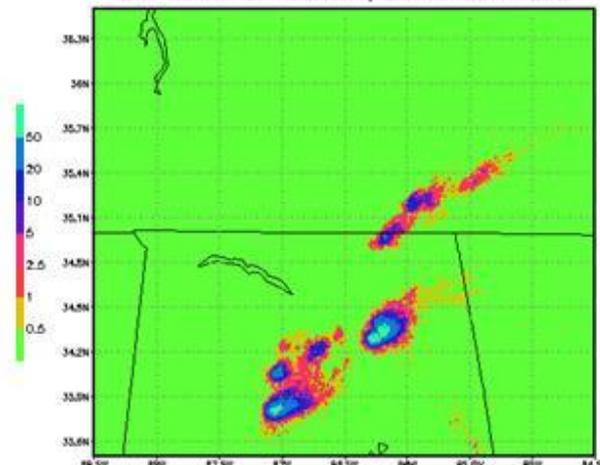
Obs, NSSL WRF data: 25 April 2010

RADAR REFLECTIVITY, 20100425-0320Z



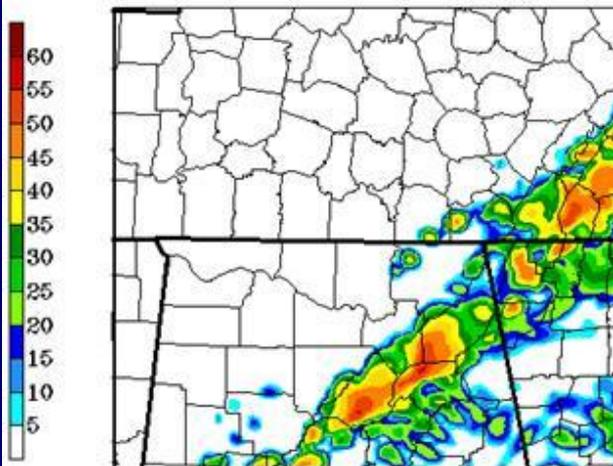
MaxVal=61.33

LMA FLASH EXT DENSITY, 20100425-0320Z



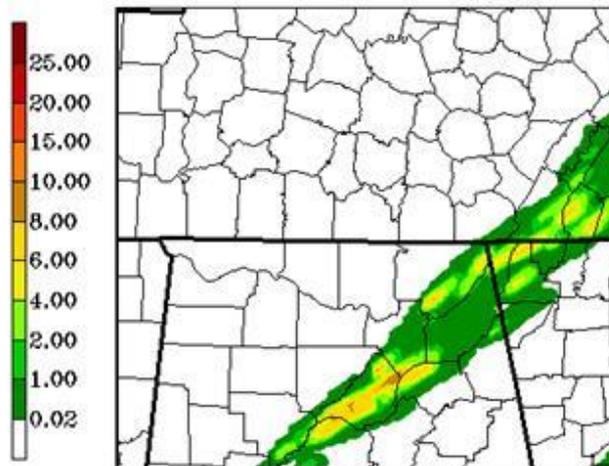
MaxVal=16.95

WRF Composite dBZ valid 100425/0300V027



MaxVal=55.44

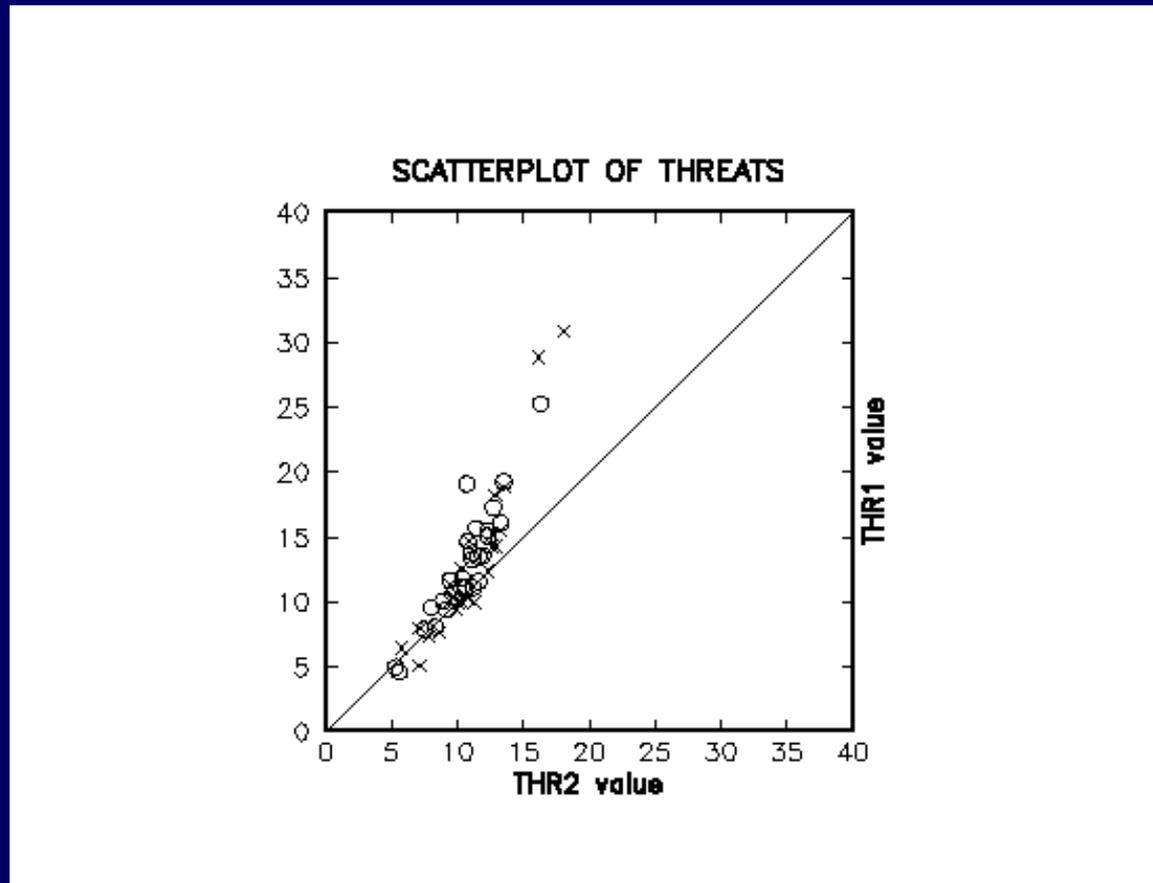
Max Hourly LFA



MaxVal=9.88



Scatterplot of selected NSSL WRF output for LTG1, LTG2 (internal consistency check)



Threats 1, 2 should cluster along diagonal; deviation at high flash rates indicates need to check calibration



Year-1 LFA studies, NSSL WRF, 2010-2011: *(examined to test robustness in larger sample of model runs)*

1. Obtained NSSL WRF daily output for full 2010-2011 for three regions: HUN, OUN, USA
2. HUN region examined (preliminary)
3. OUN, USA regions to be examined soon
4. Metric used in statistics scoring: did LTG occur in WRF LFA and/or in LMA obs, within the regions, in 4-24 h periods?
5. Preliminary inspection of results shows:
 - frequent spurious activation of LFA in wintertime stratiform
 - occasional divergent LTG1, LTG2 values in high FRD cases, with LTG1 always $>$ LTG2 (should be equal)
6. Thus: need to reevaluate LFA for *very low, very high FRDs*



Year-1 LFA studies, NSSL WRF, 2010-2011: *(examined to test robustness in larger sample of model runs)* Preliminary findings for **winter weather, JFMD2010, JFM2011**

1. HUN region examined only (others to be examined later)
2. First findings, for **winter weather (very low FRDs)**:
 - LFA produces 77 d of false alarms from LTG2
 - LFA gives only 40 d of false alarms from LTG1
 - no TSSN hits in HUN 2010; one in Jan 2011 (LTG1, LTG2)
 - if require $LTG1 > 0.01$, could reduce winter FA days by ~50%
 - if require $LTG1 > 1.5$, reduce FA days from 40 to 6 (85%)
 - use of LTG1 threshold too large might adversely affect deep convection; 3 of 6 FA events are for sleet, and these kinds of FA are impractical to eradicate



Year-1 LFA studies, NSSL WRF, 2010-2011:

Contingency table findings for HUN **winter stratiform weather**
format: $n(\text{JFMD2010}) + n(\text{JFM2011}) = \text{total}$
uses **LTG1 threshold = $0.01 \text{ fl km}^{-2}/(5 \text{ min})$**

hit days

$$0 + 1 = 1$$

false alarm days

$$23 + 17 = 40$$

miss days

$$0 + 0 = 0$$

true null days

$$75 + 43 = 118$$



Year-1 LFA studies, NSSL WRF, 2010-2011:

Contingency table findings for HUN **winter stratiform weather**
format: $n(\text{JFMD2010}) + n(\text{JFM2011}) = \text{total}$
uses **LTG1 threshold = $1.50 \text{ fl km}^{-2}/(5 \text{ min})$**

hit days

$$0 + 1 = 1$$

false alarm days

$$3 + 3 = 6$$

miss days

$$0 + 0 = 0$$

true null days

$$95 + 57 = 152$$



Year-1 LFA studies, NSSL WRF, 2010-2011: Contingency table findings for HUN **winter stratiform weather** (HUN area: $32.3 < \text{lat} < 36.7$; $-91.6 < \text{lon} < -82.1$)

- winter stratiform regimes are dominated by large WRF bias; many low-grade false alarms, but few “hits,” and no “misses”
- using forecast day-scale performance as the metric, we find:

LTG1 > 0.01:

POD = 1.00

FAR = 0.98

CSI = 0.02

BIAS = 41.0

TSS = 0.75

HSS = 0.04

LTG1 > 1.50:

POD = 1.00

FAR = 0.86

CSI = 0.14

BIAS = 7.0

TSS = 0.96

HSS = 0.24

Increasing the LTG1 threshold helps, but rarity of hits a problem



Year-1 LFA studies, NSSL WRF, 2010-2011: *(examined to test robustness in larger sample of model runs)* Preliminary findings for **convective weather, JJA 2010-2011**

1. HUN region examined only (others to be examined later)
2. First findings, for **convective weather** in HUN region, regarding **general statistical behavior** of LFA:
 - WRF has spinup problems in hours 0-4; exclude them
 - To eliminate double-counting, exclude WRF data after 24h
 - WRF output missing on 3 of 184 days in JJA 2010-11
 - WRF predicts LTG in HUN for all 181 days in JJA 2010-11
 - LMA observes LTG in HUN for 169 days in JJA 2010-11
 - LFA produces only 11 d of false alarms (FAR=0.07)
 - LFA produces zero false null (miss) days (POD=1.00)
 - LFA has more false alarm days in transitional months



Year-1 LFA studies, NSSL WRF, 2010-2011:

Contingency table findings for HUN **convective weather**

format: $n(\text{JJA}2010) + n(\text{JJA}2011) = \text{total}$

uses **LTG1 threshold = $0.01 \text{ fl km}^{-2}/(5 \text{ min})$**

hit days

$$86 + 83 = 169$$

false alarm days

$$3 + 8 = 11$$

miss days

$$0 + 0 = 0$$

true null days

$$0 + 1 = 1$$



Year-1 LFA studies, NSSL WRF, 2010-2011:

Contingency table findings for HUN **convective weather**

format: $n(\text{JJA}2010) + n(\text{JJA}2011) = \text{total}$

uses **LTG1 threshold = $1.50 \text{ fl km}^{-2}/(5 \text{ min})$**

hit days

$$86 + 83 = 169$$

false alarm days

$$3 + 6 = 9$$

miss days

$$0 + 0 = 0$$

true null days

$$0 + 3 = 3$$



Year-1 LFA studies, NSSL WRF, 2010-2011:

Contingency table findings for HUN **convective weather**

(HUN area: $32.3 < \text{lat} < 36.7$; $-91.6 < \text{lon} < -82.1$)

- convective regimes are dominated by large WRF hit rate; few false alarms, but some are big; again no “misses”
- using forecast day-scale performance as the metric, we find:

LTG1 > 0.01:

POD = 1.00

FAR = 0.07

CSI = 0.94

BIAS = 1.07

TSS = 0.08

HSS = 0.15

LTG1 > 1.50:

POD = 1.00

FAR = 0.05

CSI = 0.95

BIAS = 1.05

TSS = 0.25

HSS = 0.38

Increasing the *LTG1* threshold helps, but rarity of nulls a problem



Year-1 LFA studies, NSSL WRF, 2010-2011:

Contingency table findings for HUN **Springtime weather**

(HUN area: $32.3 < \text{lat} < 36.7$; $-91.6 < \text{lon} < -82.1$)

- Spring (AM) convective regimes feature large WRF hit rate; some nulls and false alarms; again no “misses”
- using forecast day-scale performance as the metric, we find:

LTG1 > 0.01:

POD = 1.00

FAR = 0.28

CSI = 0.72

BIAS = 1.39

TSS = 0.42

HSS = 0.46

LTG1 > 1.50:

POD = 1.00

FAR = 0.21

CSI = 0.79

BIAS = 1.27

TSS = 0.60

HSS = 0.65

Increasing the *LTG1* threshold helps, but scores already good

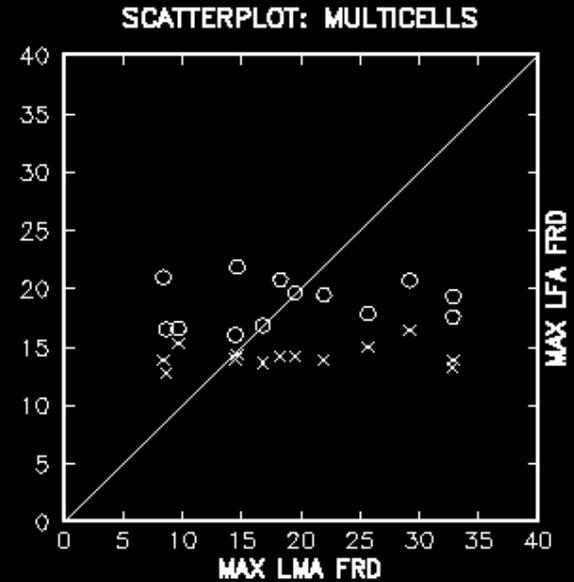
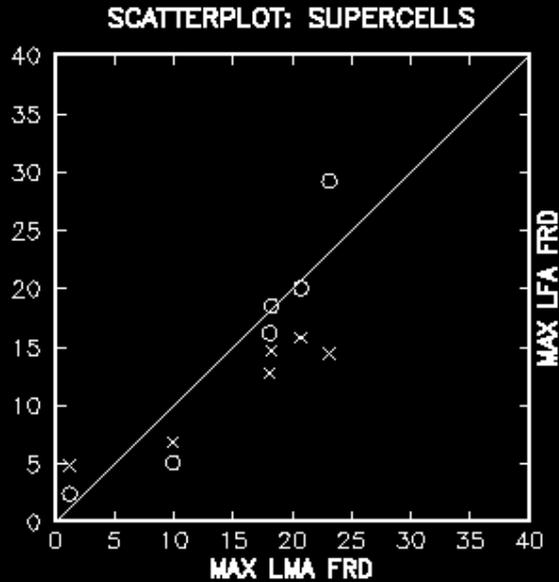


Convective regimes - predictability:

1. Supercell cases well handled quantitatively by LFA;
2. Multicell cases are predicted by LFA, but handled less well quantitatively;
3. LFA seems to provide best results for convective regimes that are most predictable;
4. LFA relies heavily on accurate forecasts of midlevel w ; WRF seems to have difficulty in unsheared, multicell regimes, where it may not always represent midlevel updraft speeds accurately;
5. LTG rates are to some extent proxies for midlevel updraft; thus real-time comparison of LFA FRD with LMA FRD says something about realism of WRF forecasts of storm w .



NALMA, LFA Scatterplots by regime:

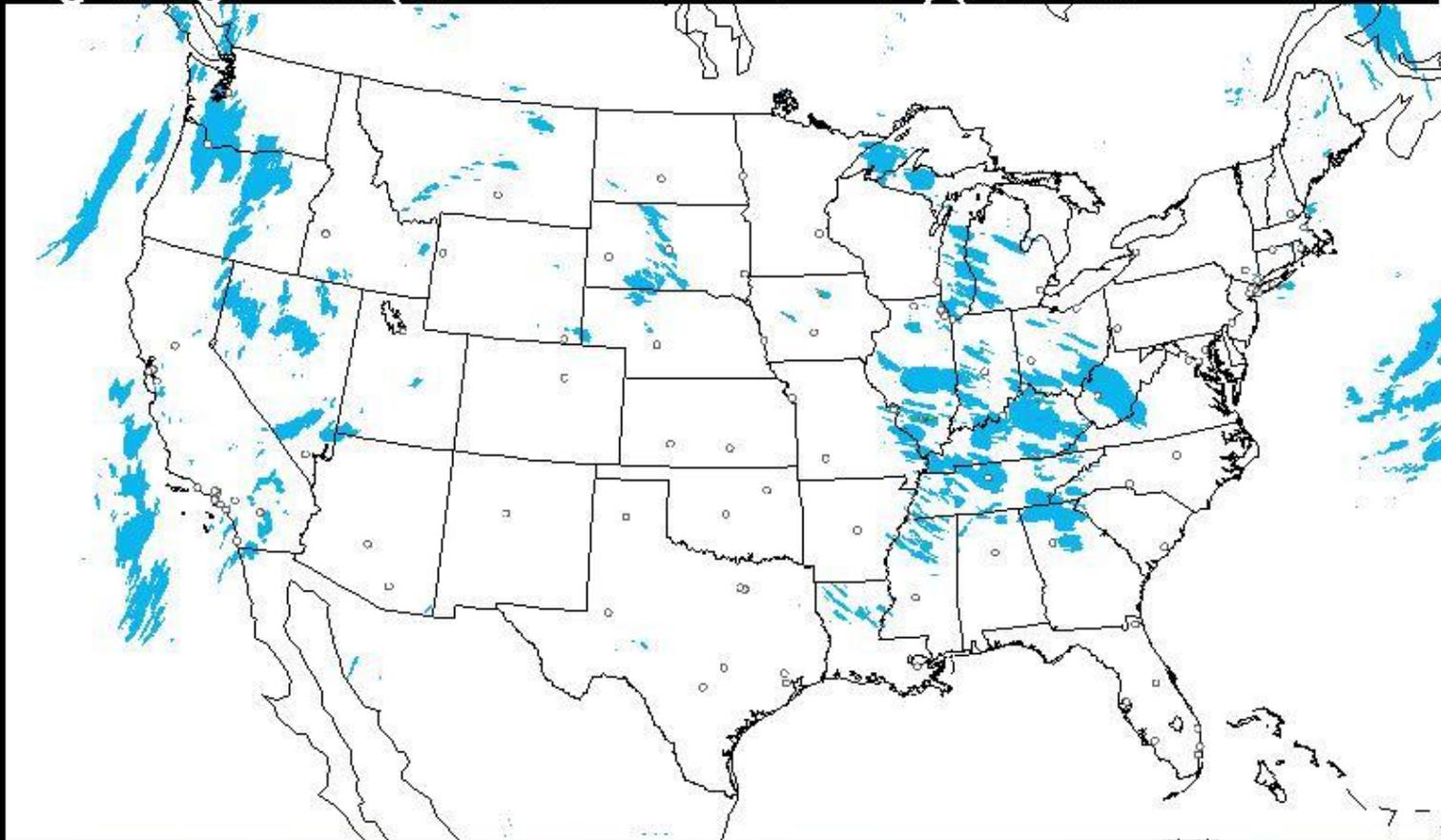




HRRR 04/25/2012 (16:00) 8h fcst - Experimental

Valid 04/26/2012 00:00 UTC

Lightning Threat (comb of LTG1 and LTG2) (flashes / km² / 5 min)



.02 .5 1 1.5 2 2.5 3 4 5 6 7 8 10 12



Future Work:

1. Continue collaborations with NSSL, CAPS, HRRR, AWC to implement, test revised LFA
2. Complete study of LMA cases from 2010, 2011 NSSL and 2011 CAPS WRF runs; examine 2012 data when available
3. Evaluate revised LFA for 2012 low-FRD, high-FRD cases; use NALMA, OKLMA as needed; check accuracy of LFA areal coverage
4. Study performance of revised LFA in CAPS ensembles under varying model configurations:
 - other physics schemes;
 - other combinations of hydrometeor species;
5. Assess LFA for dry summer LTG storms in w USA;
6. Examine HWRF runs (by others) to assess LFA in TCs;
7. Assist efforts to use LFA output in LTG DA for GOES-R



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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.