A cloud-scale lightning data assimilation technique and the explicit forecast of lightning with full charging/discharge physics within the WRF-ARW model.

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Scientific goals:

•Total lightning is correlated to basic storm quantities often diagnosed or predicted in NWP models: graupel/ice mixing ratio/volume, w, cwc.

•Therefore, *Can total lightning data (IC+CG) be used as a tool within NWP models to provide better initial conditions for convection at cloud resolving scales (dx ≤ 3km)?*

•Improved Initial Conditions will provide a better physical background at analysis time towards improving short term high impact weather forecasts (~3h). Lightning data can also used used to limit the presence of spurious convection (and cold pools). Key in radar data sparse area.

•Total lightning data from the ENTLN were assimilated into the WRF-ARW model at cloud-resolving scales using a computationally inexpensive smooth analytical function and tested in real time in the WRF-NSSL operational testbed (CONUS at dx=4 km).

•To alleviate the need to use proxies for lightning in the model (e.g. lightning threats), full charging/discharge physics are currently being implemented into WRF-ARW within the NSSL 2 moment microphysics.

24 May 2011case

Model setup and WRF lightning nudging:

•Triple nested grid with D01/D02/D03=9/3/1-km and 35 vertical levels. I.e., from GEOS-R (CPS scale) to 'convection-resolving' scales. Focus on the 3-km output (current operational NWP model resolution).

•No feedbacks between grids allowing independent comparisons of the model output on the 3 grids.

•12Z NAM 40-km re-analysis data used as input for IC/BC.

•D01,D02,D03 started at 12, 14, 16Z, respectively.

•Lightning nudged via a smooth continuous function for Q_v within the mixed-phase region (0° to -20° C) as a function of N_{flash} and simulated Q_g (and $Q_{satwater}$). This increases θ_v buoyancy and generates updrafts.

•Lightning nudging conducted within WSM6 microphysics.

•Assimilation of pseudo-GLM 9-km N_{flash} simultaneously on all grids between 1930-2130Z in 10-min bins.

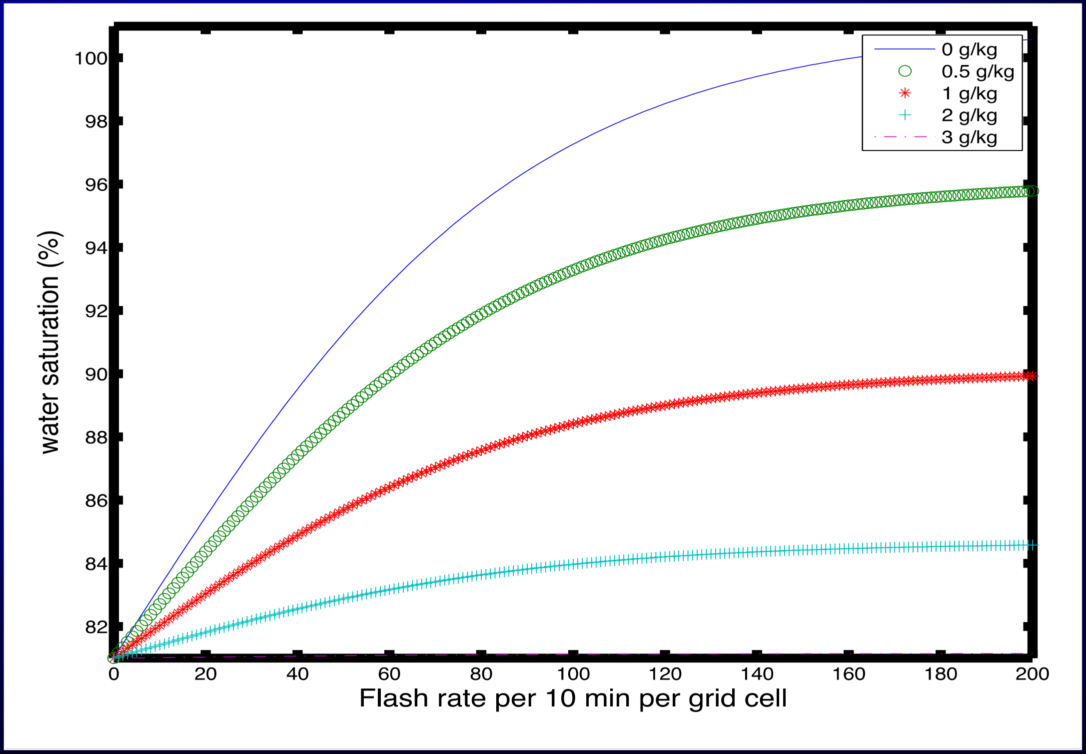
Lightning nudging function

Q_v within the 0° C to -20° C layer was increased as a function of 9-km N_{flash} (X) and simulated Q_g and $Q_{satwater}$. Increasing Q_v at constant T increases θ_v buoyancy and ultimately generate an updraft.

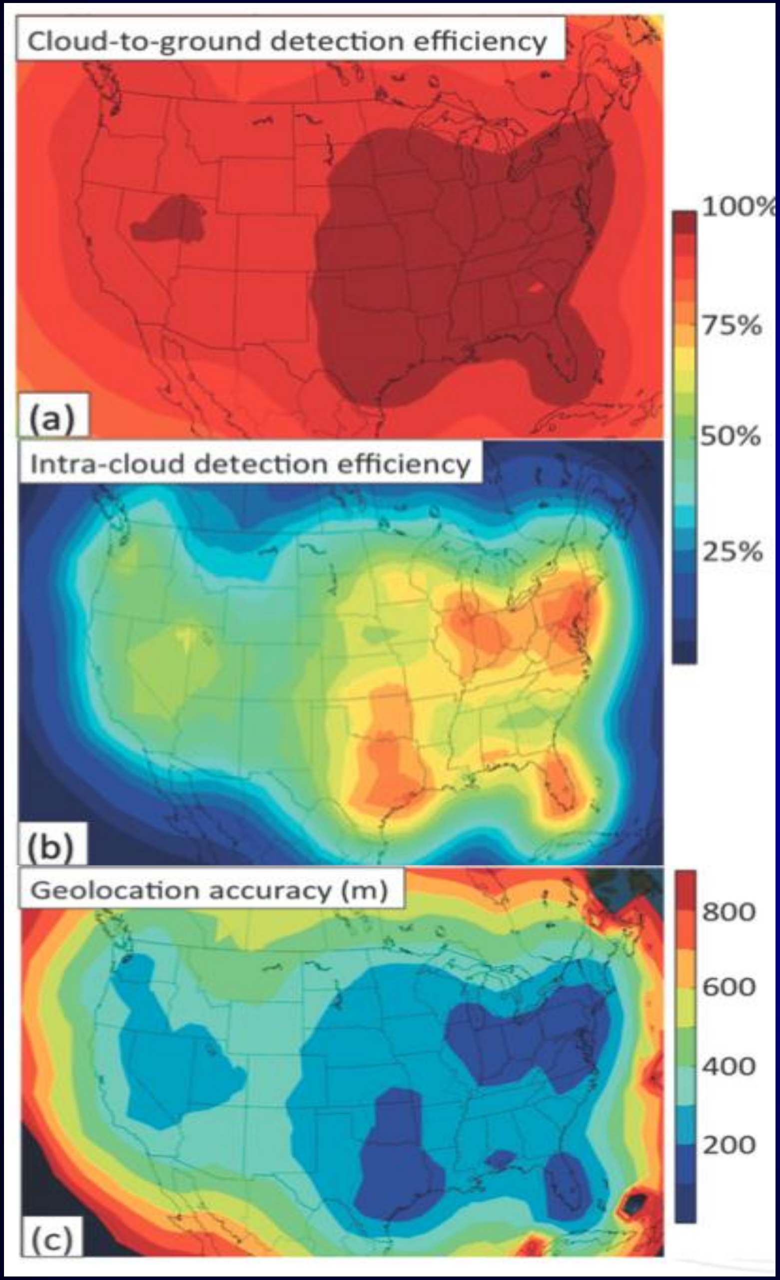
$$Q_v = AQ_{\mathrm{sat}} + BQ_{\mathrm{sat}} \tanh(CX)\,[1 - \tanh(DQ_g^{\alpha})]$$

-Only applied whenever simulated RH ≤ A*Qsat and simulated Qg < 3 g/kg.

-A controls minimum RH threshold (here 81%). B and C the slope (how fast to saturate) and D how much Qv is added at a given Qg value.



ENTLN network



http://earthnetworks.com/OurNetworks/LightningNetwork.aspx

- •Measure broadband electric field, from 1 Hz to 12 MHz.
- •Effective proxy for GOES-R total lightning measurements.
- •Remarkable detection efficiency for CG return strokes over CONUS (98%) and IC with efficiencies > 70% over OK.
- •High network density results in overall small geo-location error generally (< 300 m over OK).

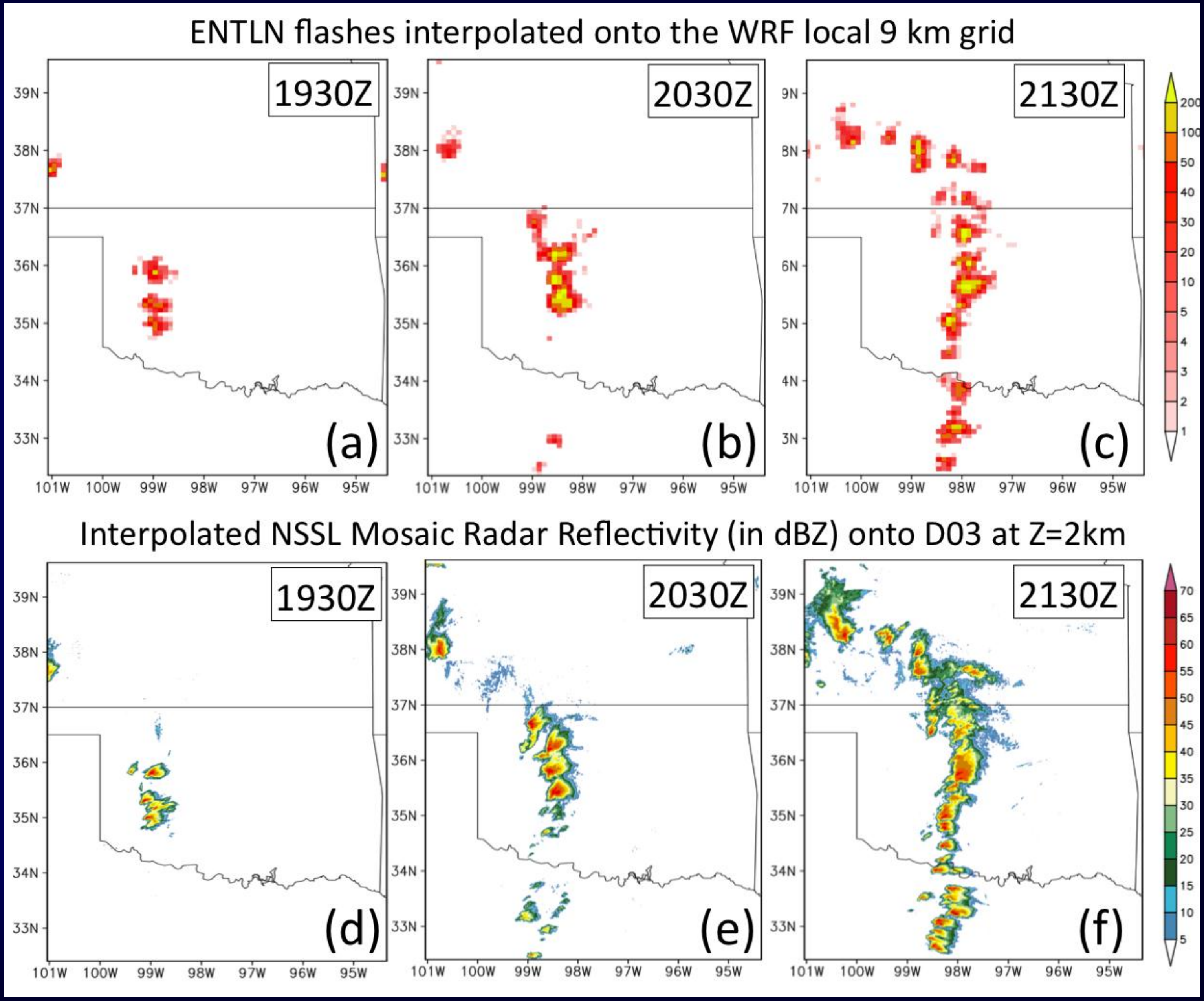
Graphics courtesy of Jim Anderson, Stan Heckman and Steve Prinzivalli from EarthNetworks®-Used with Permission.

Observations 1930-2130Z

2130Z=analysis time
2230Z=1h forecast

- 9-km interpolated ENTLN flash count
- Same on all 3 grids

OBS-NSSL Mosaic NMQ interpolated onto WRF 1 km grid **D02**



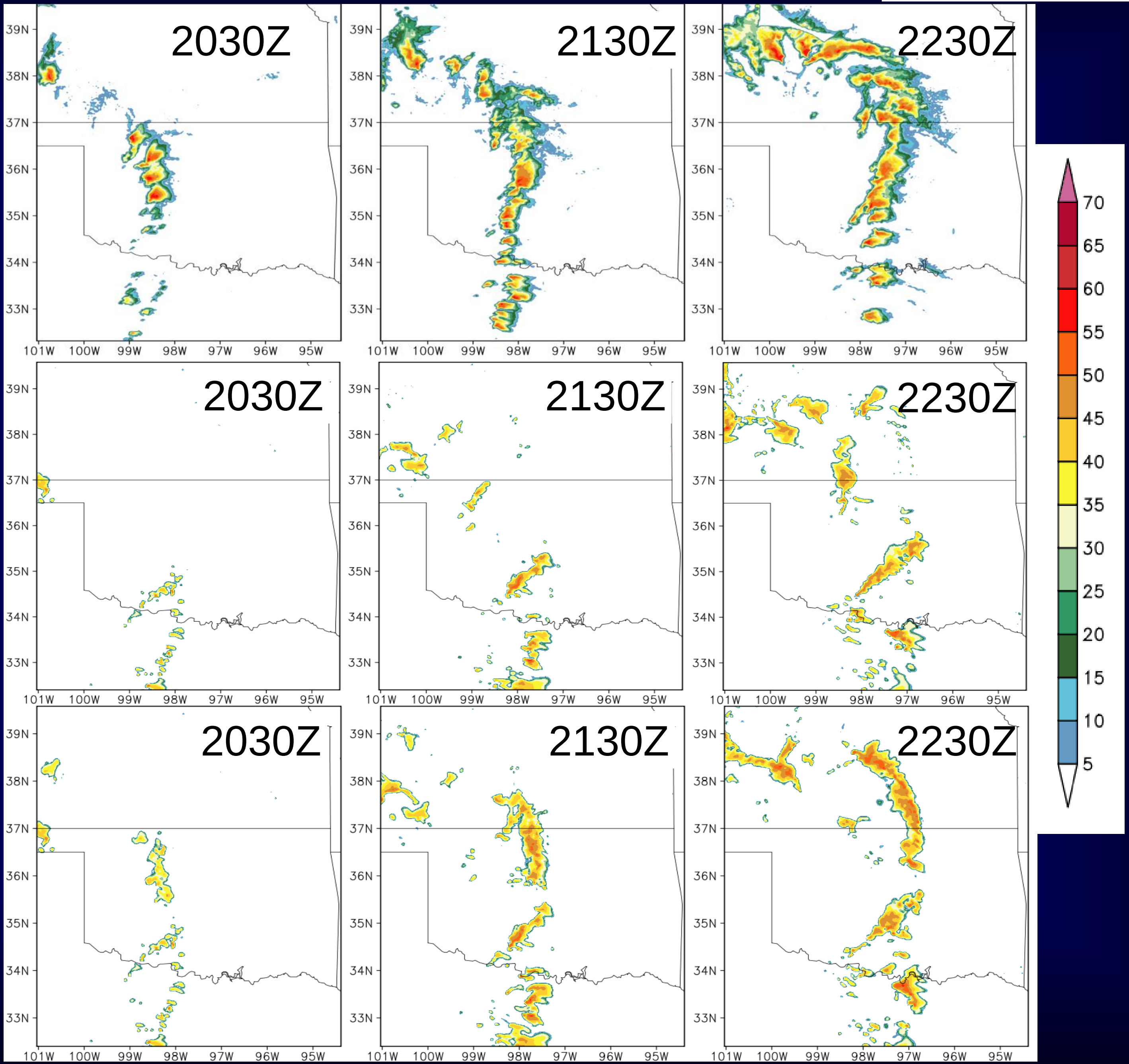
Results (Z=2km) D02

2130Z=analysis time
2230Z=1h forecast

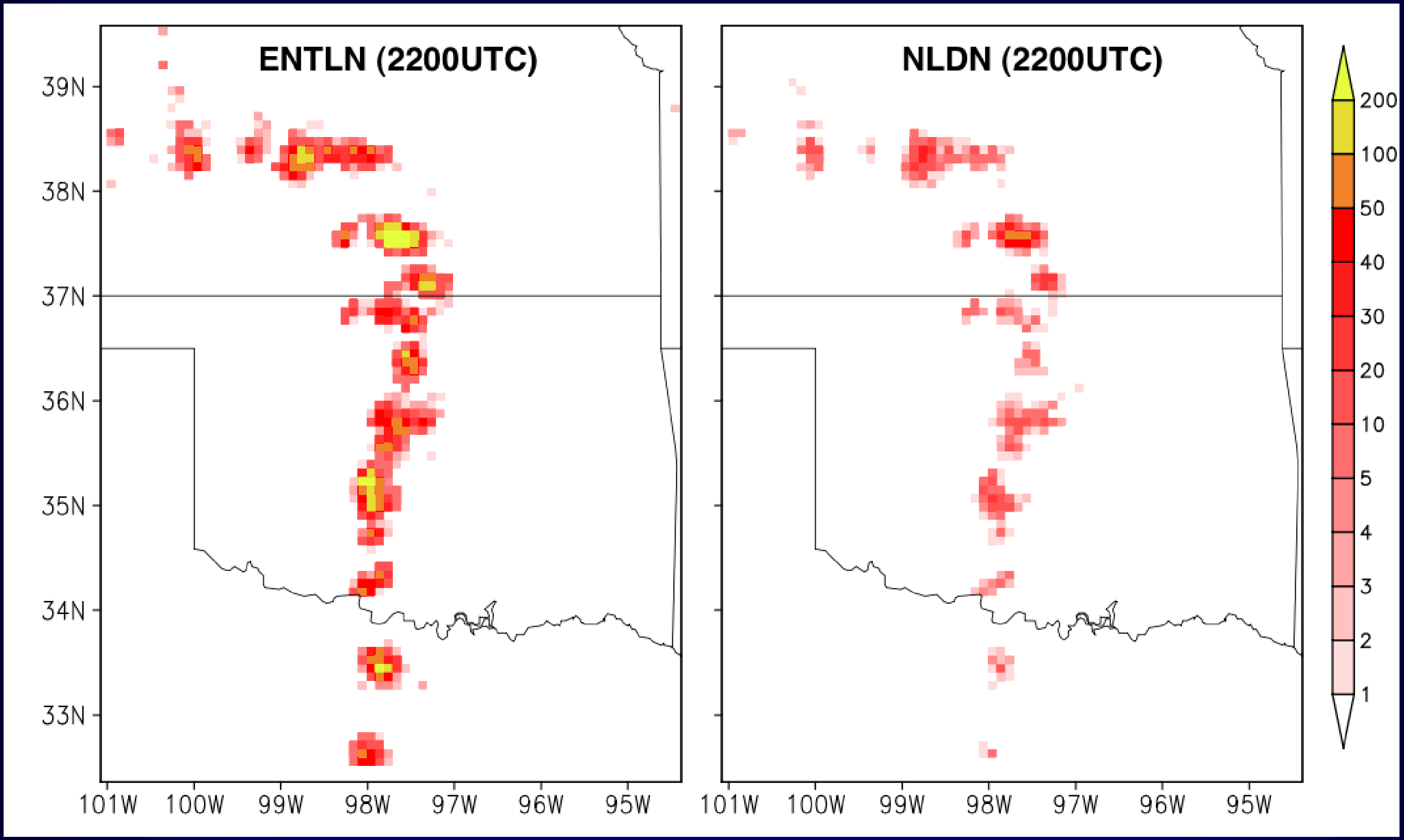
OBS-NSSL MOSAIC Interpolated onto WRF 3-km grid **D02**

CTRL

LIGHT

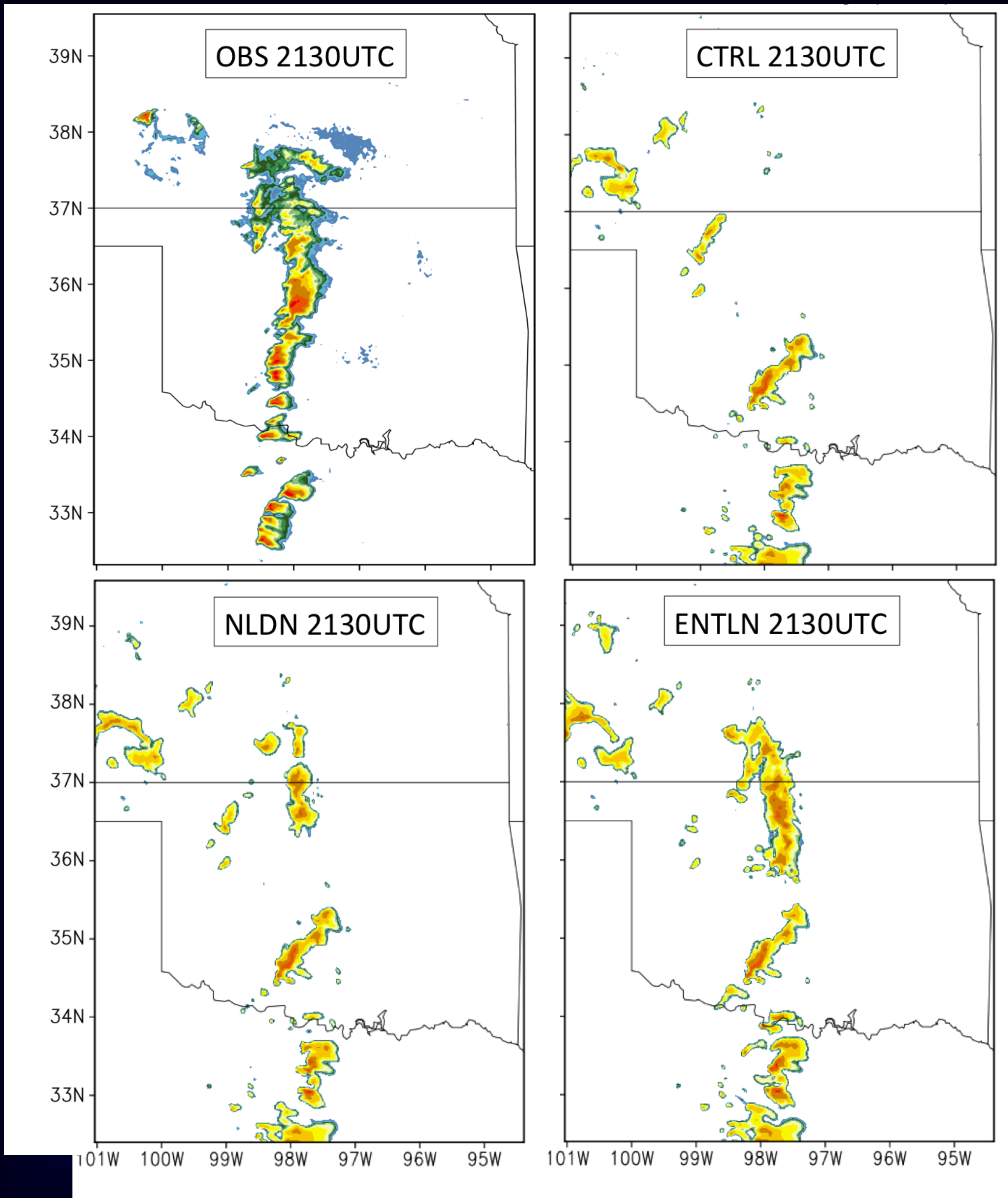


ENTLN (CG+IC) versus NLDN (CG-only)



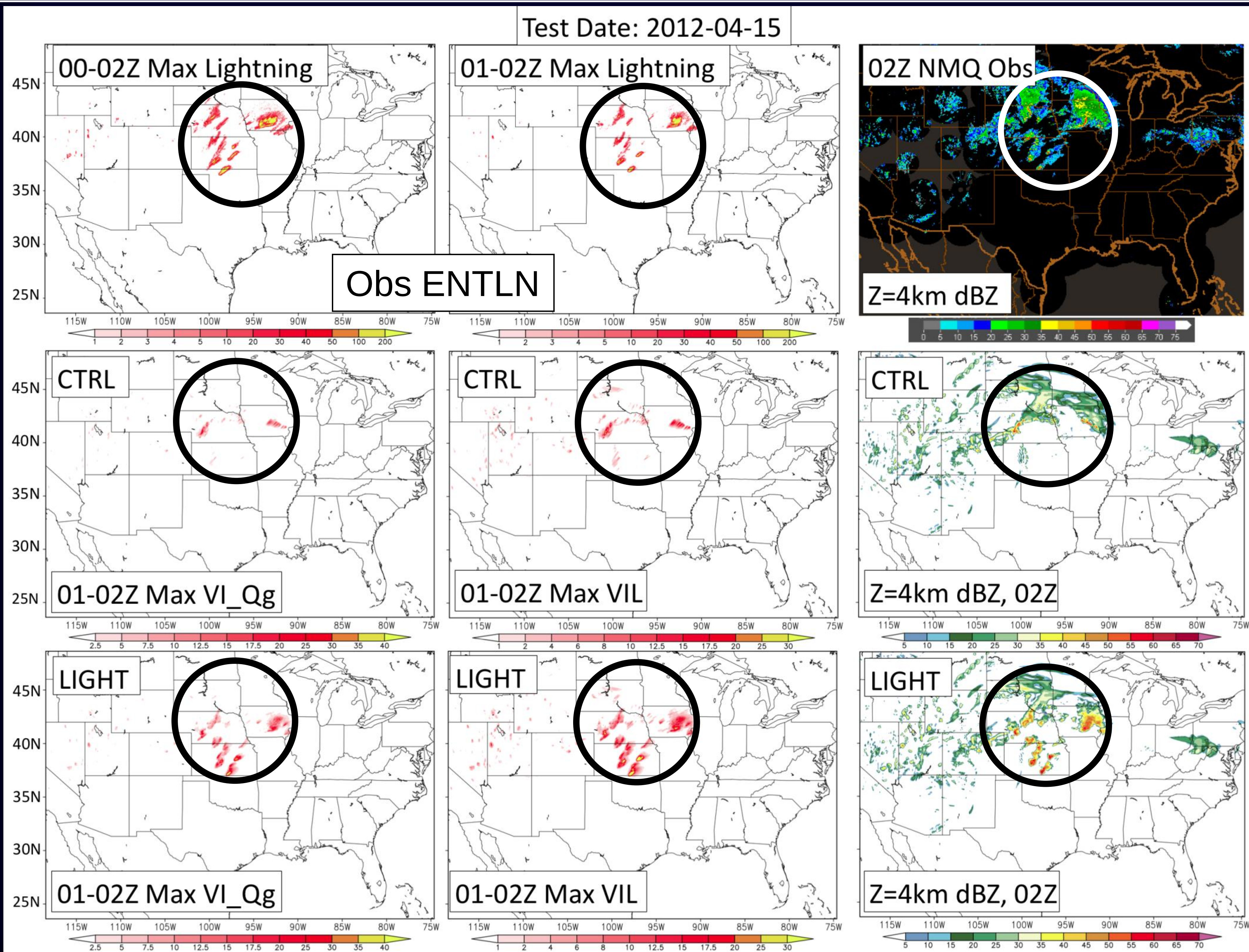
ENTLN/NLDN ≈ (IC+CG)/CG Ratio of 9x9-km 10-min gridded flash counts ranges from 2 to 10. IC+CG also spans a larger area. IC also better correlated with W and hence, timing of the convection.

Assimilation results at analysis time.



As expected from the above preface, the use of total lightning data leads to improved representation of the convection at analysis time than with CG-only.

Real -time implementation into WRF-NSSL 4-km CONUS runs



New WRF explicit charging/discharge model

- Currently Implemented:

NSSL 2 moment microphysics (qw, qc, qh, qg, qi and qs).

5 non-inductive collisional charging schemes + separation of charge during mass exchange (or phase change)

Space charge on each hydrometeor species as scalars (sedimentation, diffusion and advection of charge).

- Future/current work:

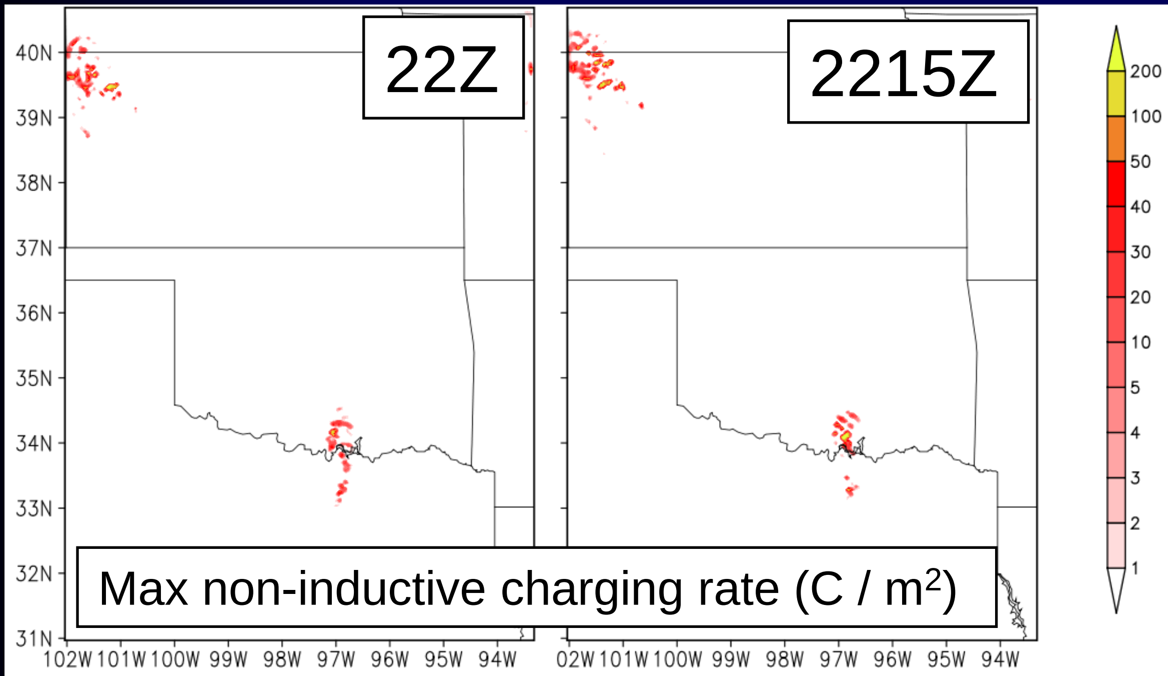
Solve for the local E (potential) field in 3-D (mpi Poisson solver).

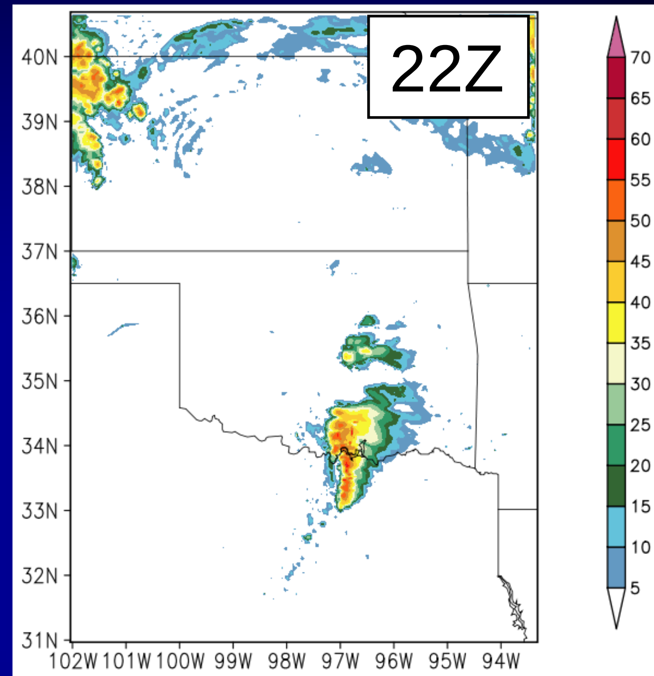
Implement polarization/inductive charging.

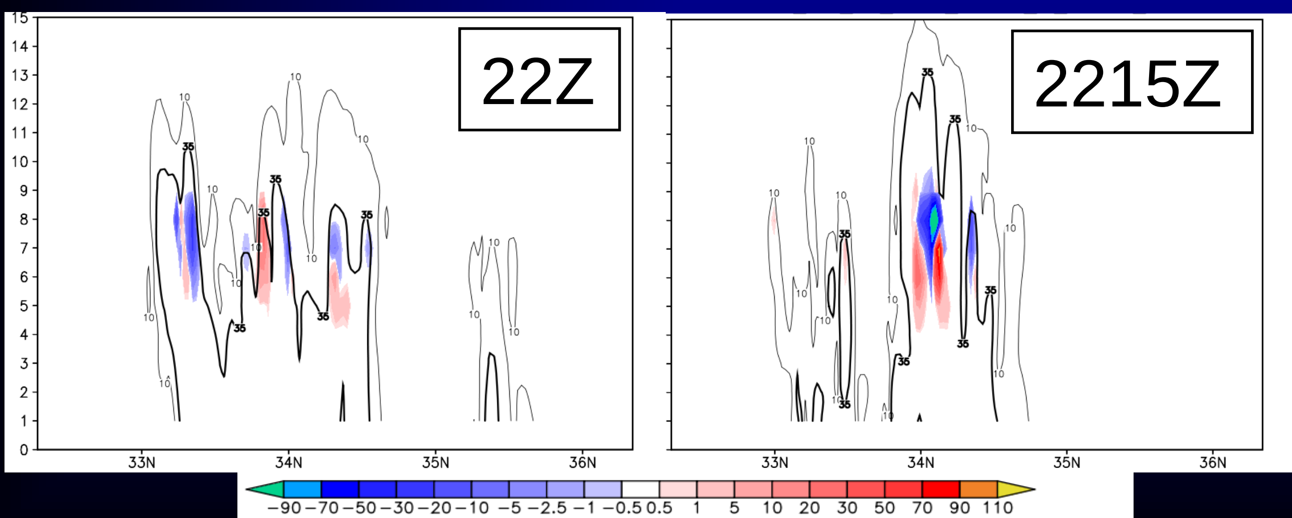
Column 1-D lightning discharge based on breakeven Ecrit threshold (following an implementation similar to Fierro and Reisner, 2011)

Preliminary tests with Los Alamos HIGRAD Model revealed that this lightning scheme is overall computationally cheap.

Example: Modified Saunders and Peck (1998)

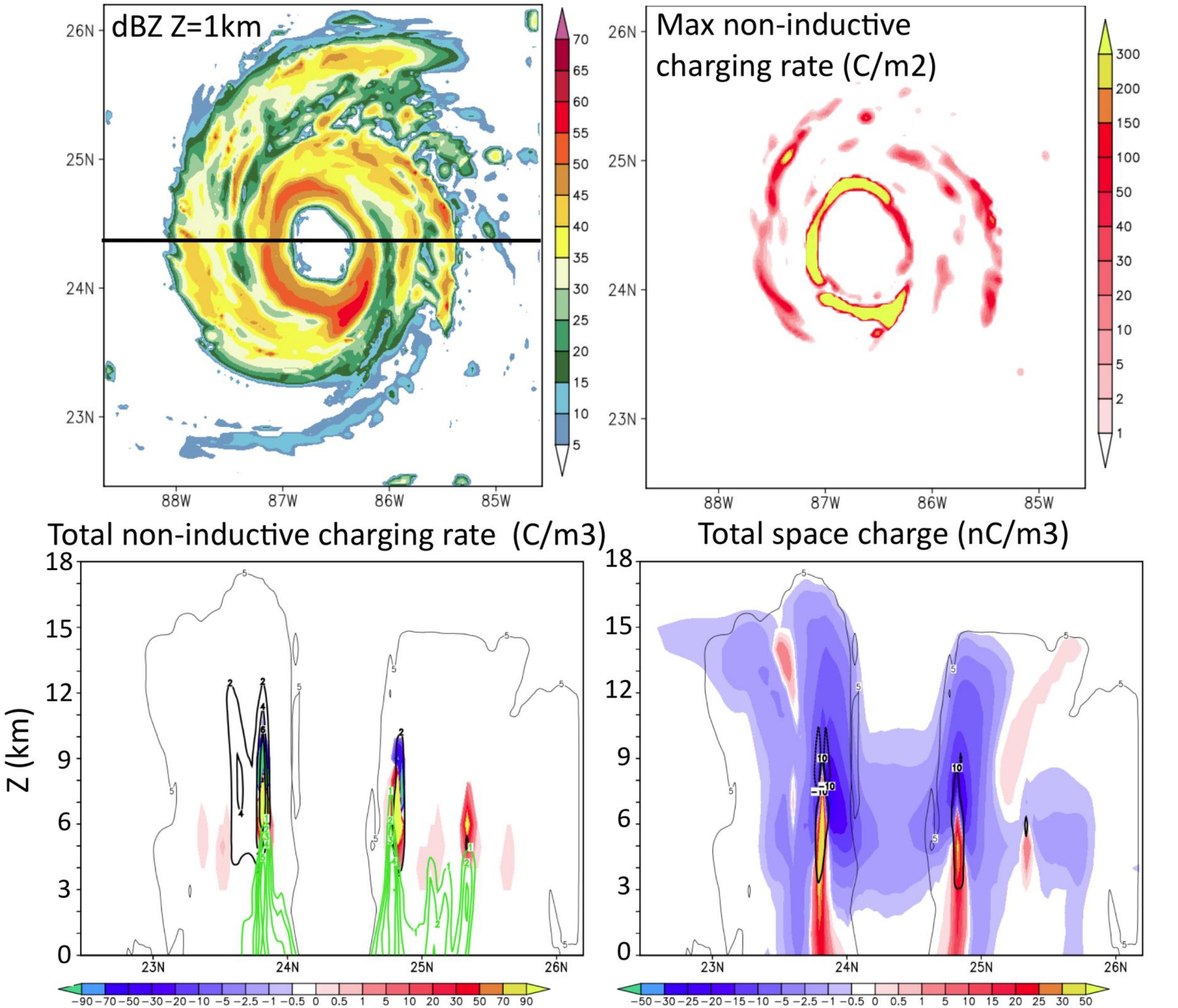




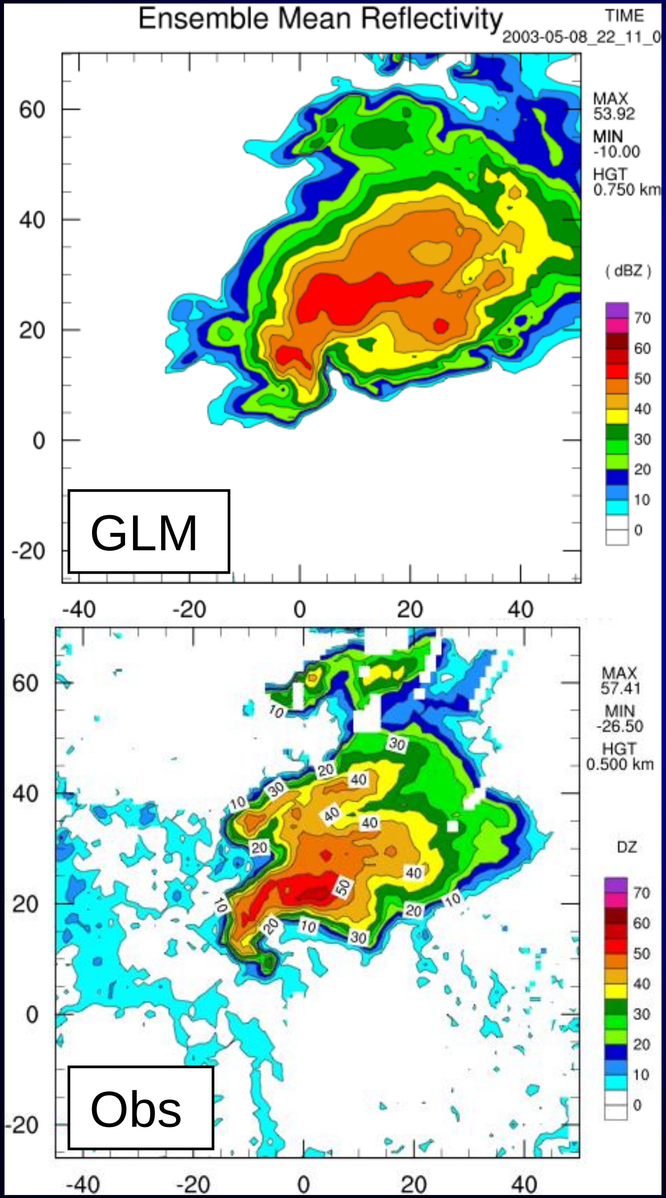


Total non-inductive charging rate (10^3*C / m^3)

Hurricane Rita 21 Sept 05 1800Z, dx=dy=3km/Vortex-following nest



EnKF Assimilation of Pseudo-GLM flash rates (8 May 2003 Supercell)



<u>Methodology:</u>

The pseudo-GLM flash rates (derived from OK-LMA on a ~8x6 km grid) were binned in one minute intervals and assimilated using an observation operator that consists of a linear relationship between total flash rate and graupel mass.

<u>Conclusions:</u>

1) EnKF assimilation of pseudo-GLM data *<u>alone</u>* can effectively reproduce the basic supercellular reflectivity structure of the storm.

2) These results show promise that EnKF assimilation of GLM data can be an effective substitute for assimilation of radar data in data-sparse areas.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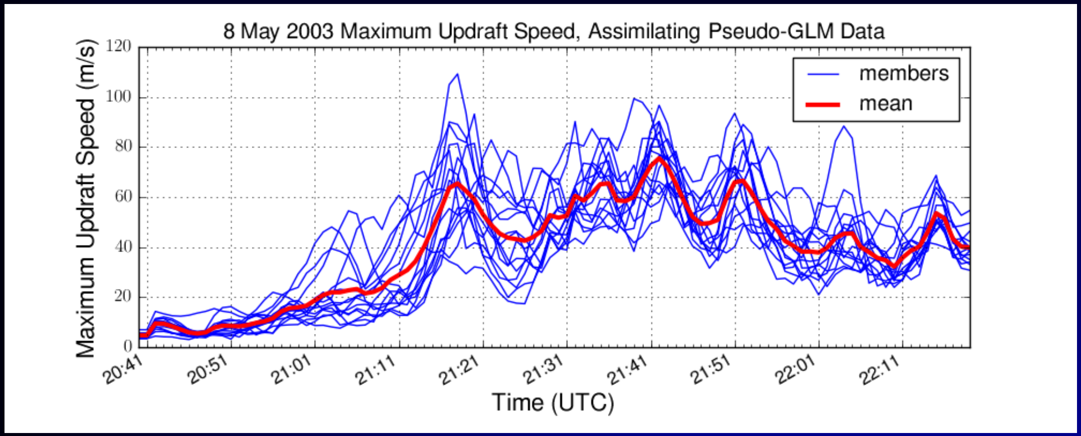
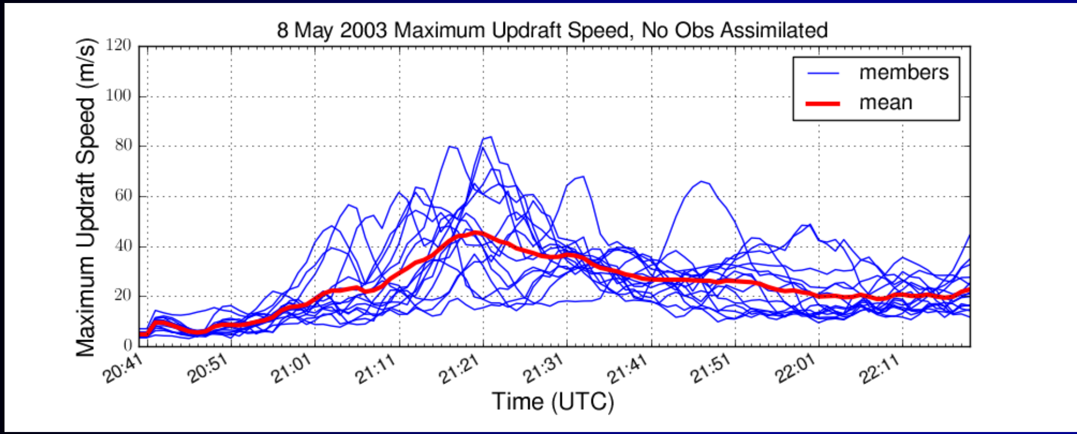
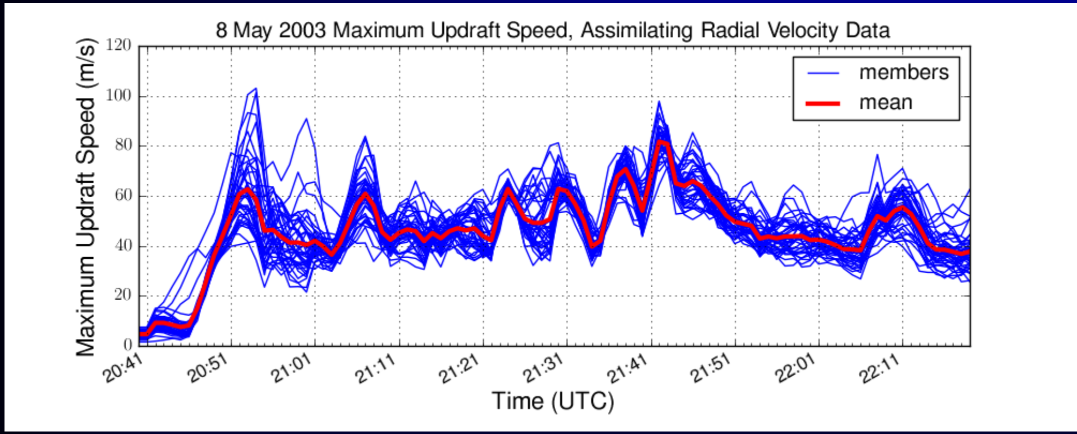
Questions?



Maximum updraft speed when assimilating pseudo-GLM Obs.

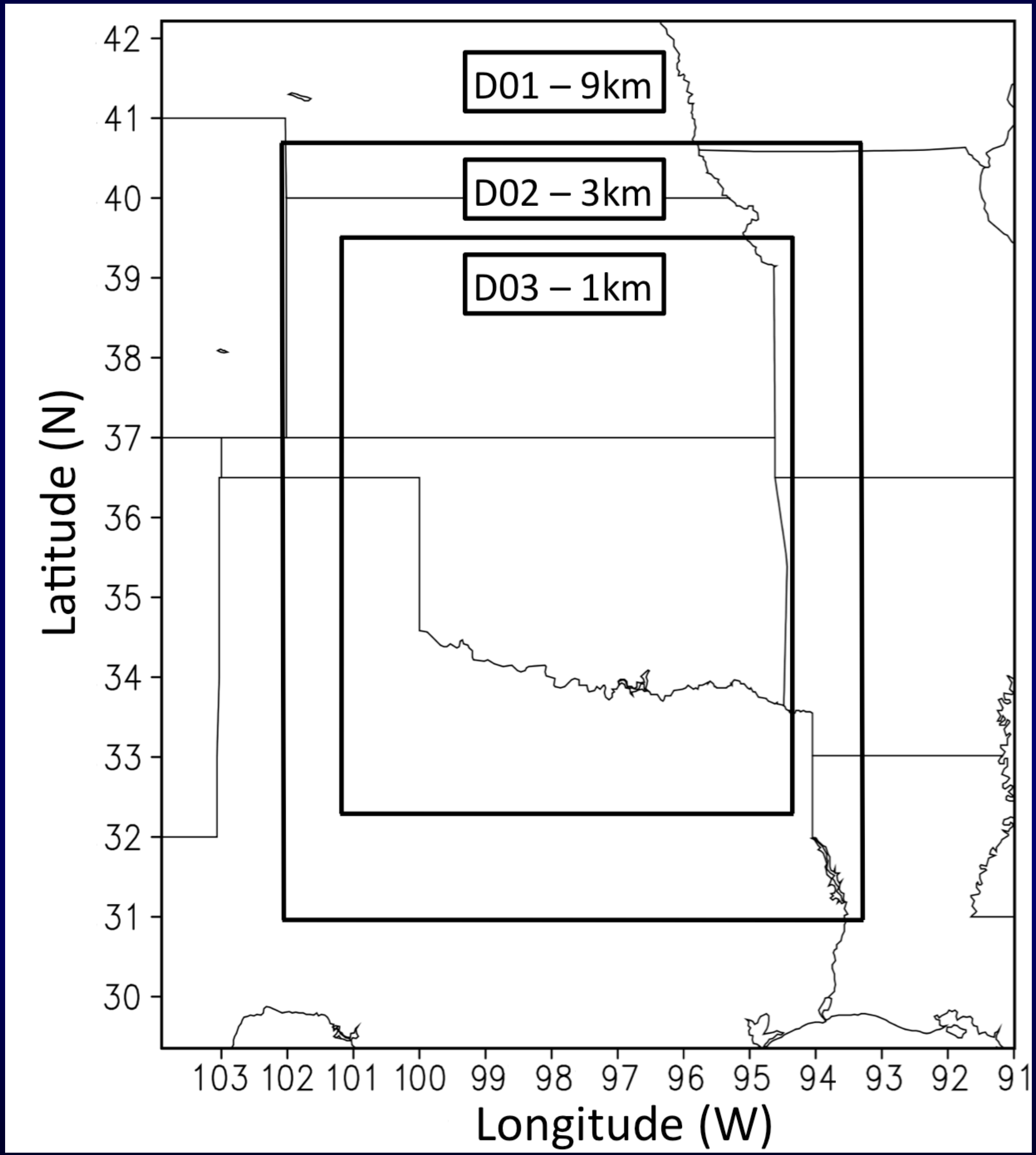


Maximum updraft speed when no obs of any kind were assimilated. As with the reflectivity, the updraft speed is non-zero here due to noise and thermal bubbles used to initiate convection and create/maintain ensemble spread. (control run)



Domain-wide max updraft speed when assimilating radial velocity obs. (Should approximate the true updraft speed)

WRF Domain: 24 May

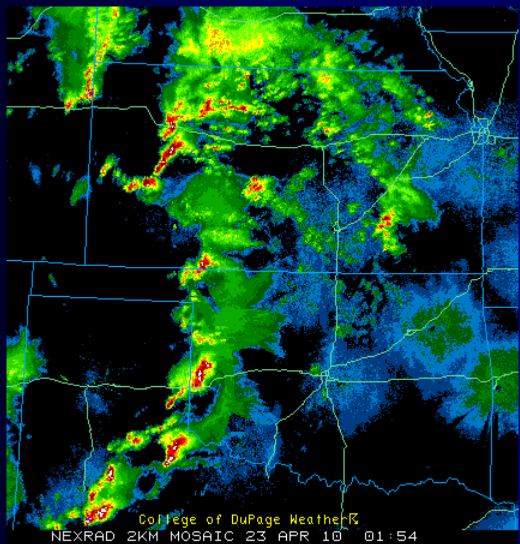


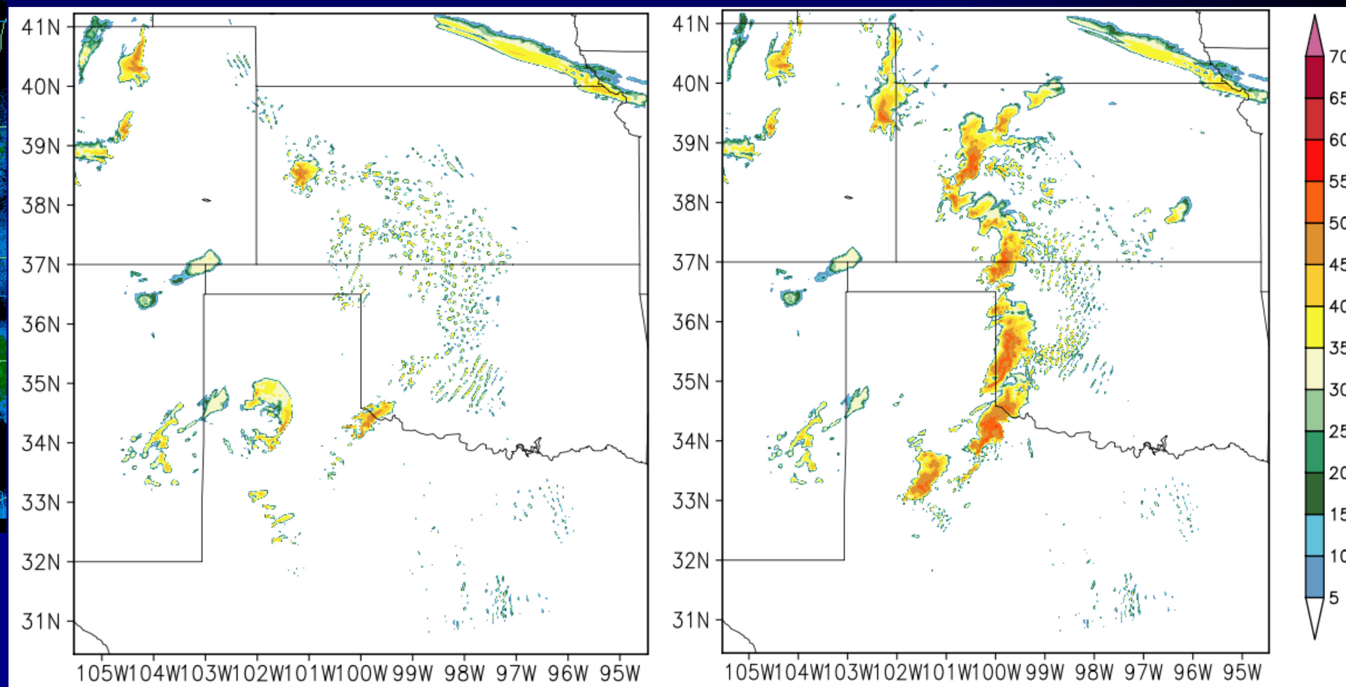
Other case studies: 23 April (1-km): 2 h assimilation

Obs

CTRL

With ENTLN data

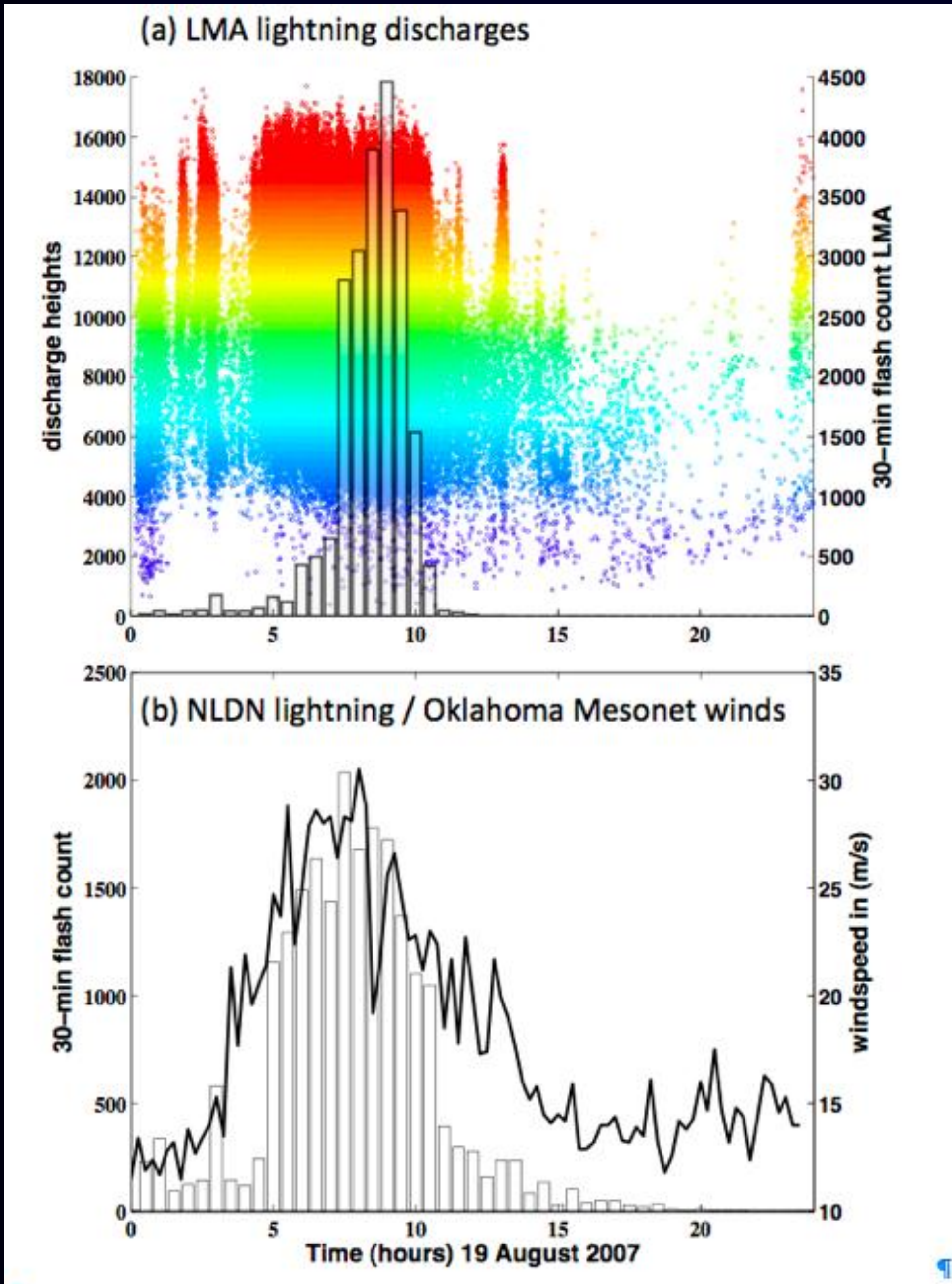




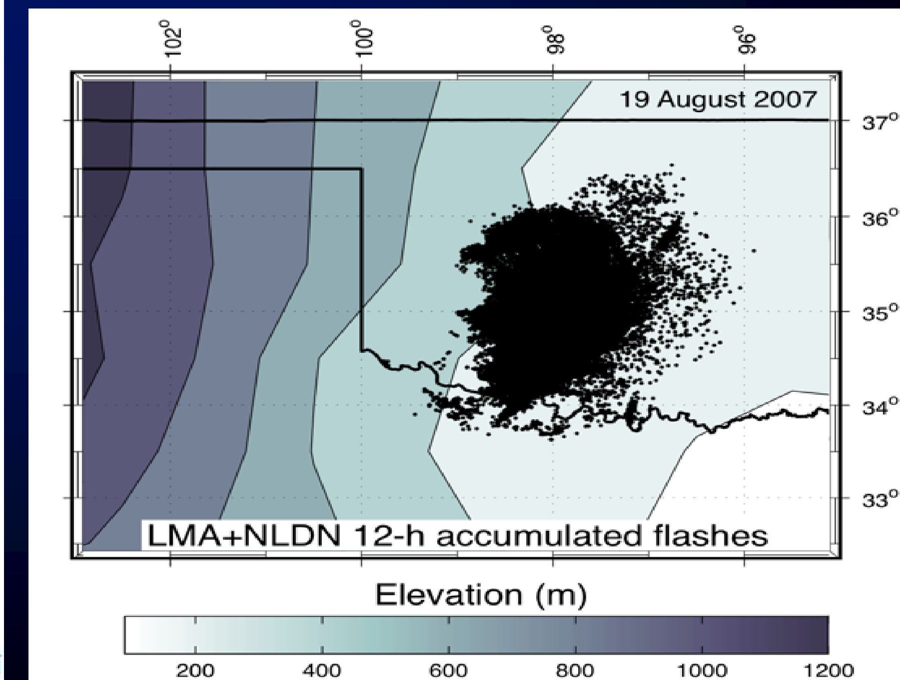
0200Z

As expected, early supercellular activity *at analysis time* is better resolved using lightning (in this case lightning points were supersaturated wrt water in the 0° C to -20° C layer independently of flash rate).

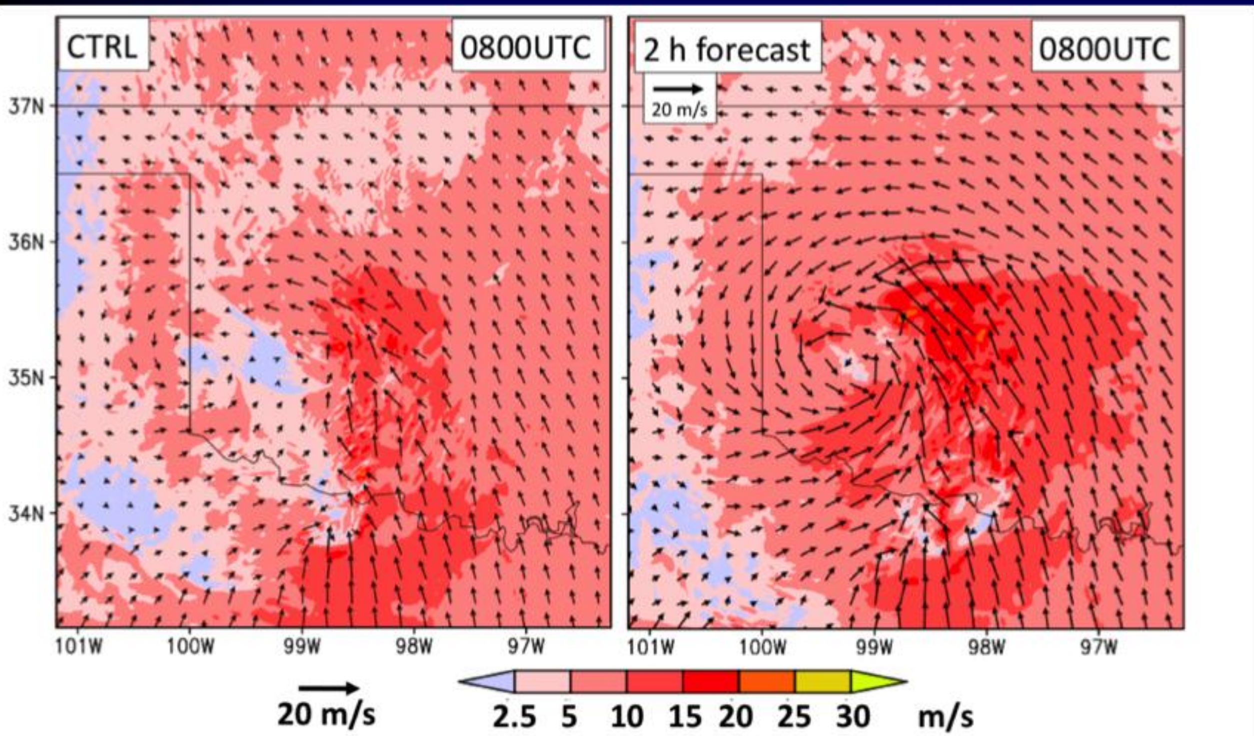
TC Erin: 1) Observations



- Similar to Rita; TS Erin ‘eyewall’ was lit up with lightning flashes during its intensification period.
- LMA detected 8 times as many flashes as NLDN-
- Topology of accumulated 12-h LMA+NLDN flashes starting at 00Z 19 Aug used to ‘control’ microphysics in WRF runs



Tropical Storm Erin



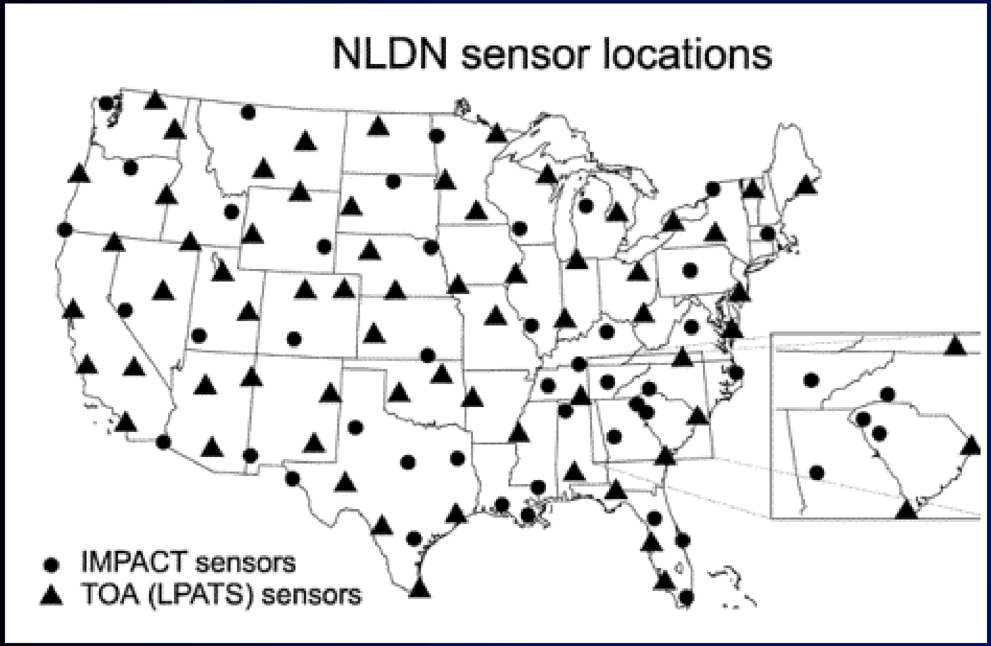
- Assimilating LMA+NLDN lightning data for the first 6 h resulted in a better 2 h (=0800Z) forecast compared to CTRL.
- Note that for this case, the WRF convection had to be severely reduced outside the lightning area for the assimilation to have a notable effect on the vortex intensification

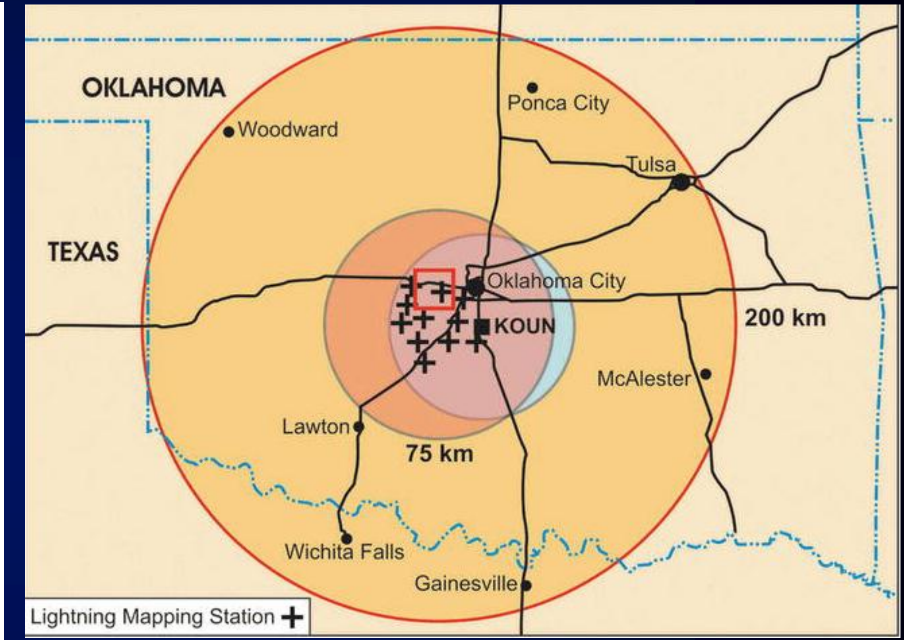
$$if\,(q_x \geq \beta / \rho_{air})\ then\ q_x = \max(\alpha^* q_x, \beta / \rho_{air})$$

where b is the mixing ratio threshold (0 for run QX0), α=0.2, q_x is the mixing ratio of hydrometeor class x

LMA and NLDN networks in a nutshell

•The OK LMA consists of a group of stations located near the TLX radar, while NLDN covers CONUS evenly:





Map of NLDN sensor locations and type (IMPACT - Improved Performance from Combined Technology; TOA - Time Of Arrival) for CONUS.

Blue circle indicates a 60-km radius from KOUN and the peach-shaded circle indicates a 75-km radius from the center of the LMA network. (Bruning et al. 07)

23 April 2010 case

Setup in a 'flash':

- Domain covers portion of S. Plains (500x600 grid zones)
- Dx=dy=2 km with 35 vertical levels
- WSM 6 microphysics
- NAM 40 km data used as initial conditions.
- Run started at 00Z
- WTLN total lightning data interpolated onto WRF grid in 10 min intervals in the following set of 4 experiments

(i)By directly interpolating the lat/lon WTLN data onto the 2 km domain grid (G2)

(ii)By first interpolating the WTLN data onto the domain using an hypothetical GEOS-R resolution of 10 km and then extrapolate that 10 km data onto the 2 km domain (G10).

(iii)Then, in separate experiments, for G2 and G10, the lightning data was nudged in during during the first 2 h of simulation after 00Z.

Conclusions:

- This new, simple cloud-scale lightning assimilation scheme showed promising results in producing a better representation of the observed convection at analysis time in the WRF-ARW model at horizontal grid spacings of 3 and 1-km.

- Those improved initial conditions could significantly improve forecasts of high impact weather events. Especially valuable for cases were model fails in reproducing observed mesoscale environment (and thus forcing).

- The developed lightning assimilation scheme use a smooth analytical function, easy to implement (as demonstrated in the real time WRF-NSSL 4-km CONUS framework) and computationally inexpensive.

- Total lightning data shows much improved results over CG-only data.