Evolution of a Modeled Severe Convective Storm with and without Lightning Data Assimilation – Derecho, June 2012

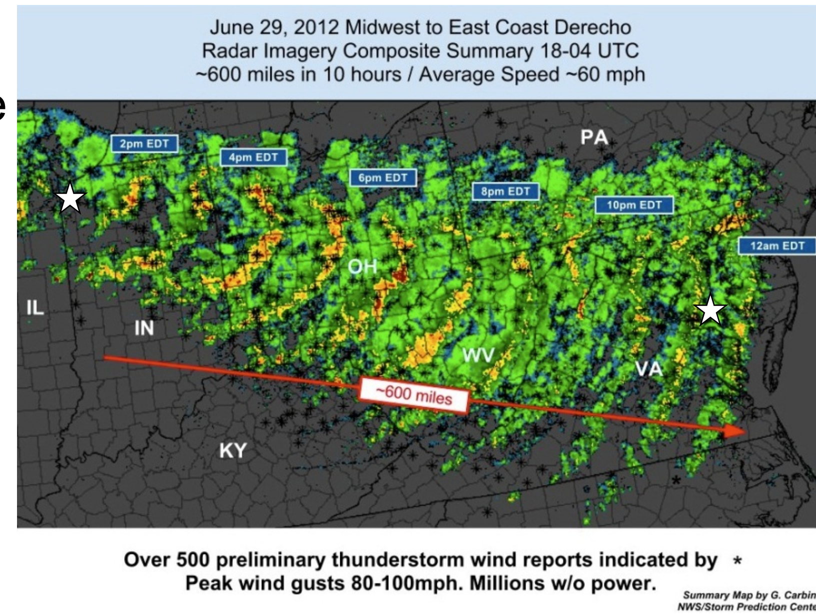
Dr. Antti Pessi
Research Scientist
Vaisala - Boulder, Colorado

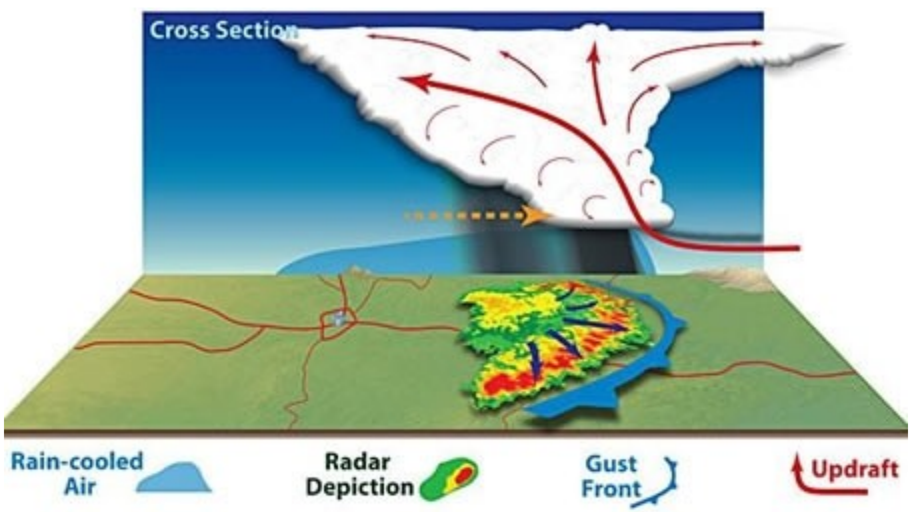
Image courtesy of Brittney Misialek

VAISALA

North-American Derecho, 29 June 2012

- Derecho is a straight-line wind storm as opposed to rotating tornadic storm.
    - Fast-moving band of severe thunderstorms that produce strong winds
- Occurred 29-30 June 2012 between Chicago and Washington D.C.
- Wind gusts up to 45 m/s
- In the midst of 2012 North-American heat wave
- 22 fatalities
- Over 4 million people lost power
- Cost hundreds of millions





Images courtesy of NOAA/NWS

VAISALA

Vaisala's Global Lightning Dataset GLD360 lightning strokes

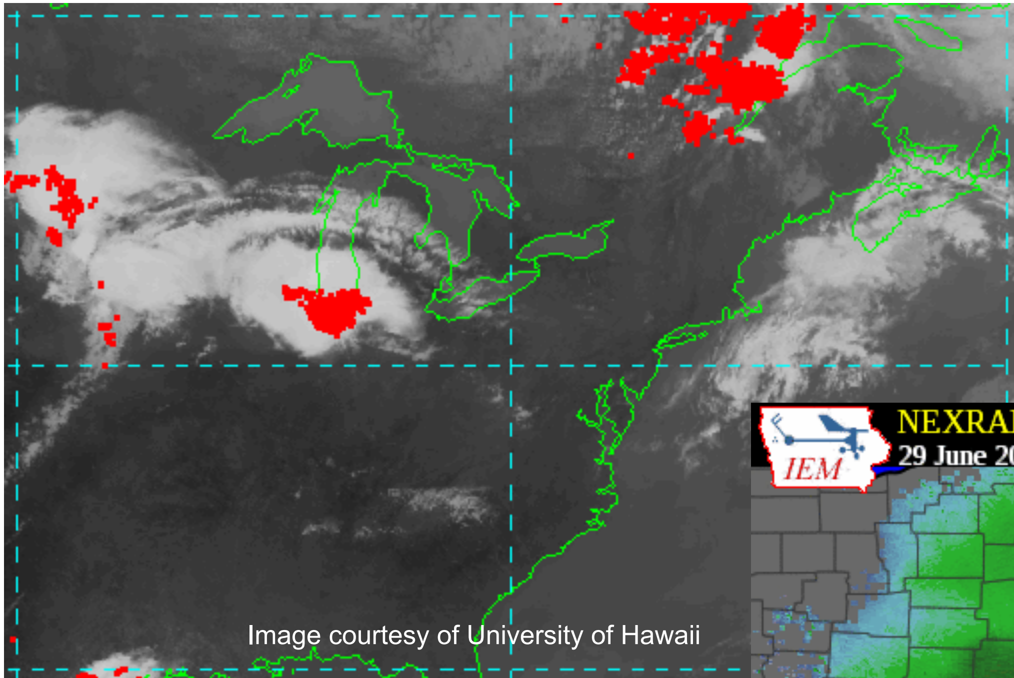


Image courtesy of University of Hawaii

NEXRAD radar reflectivity

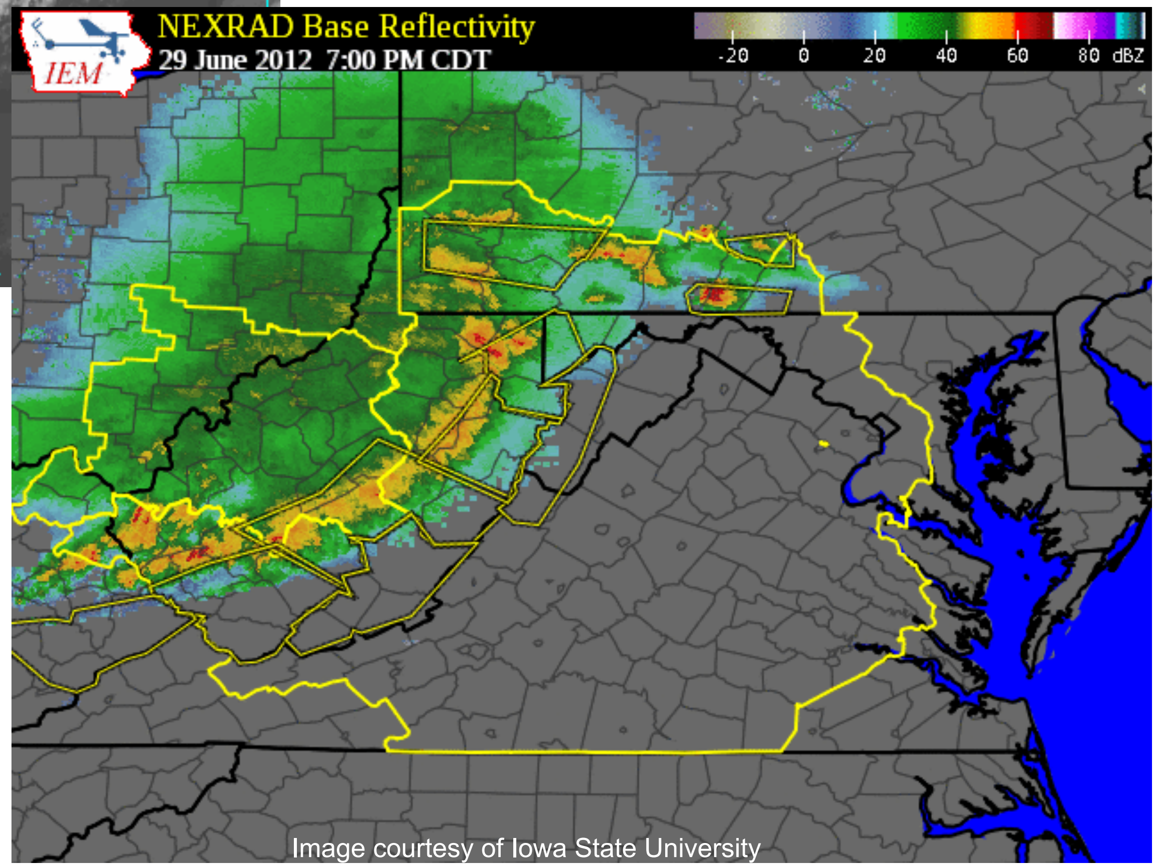


Image courtesy of Iowa State University

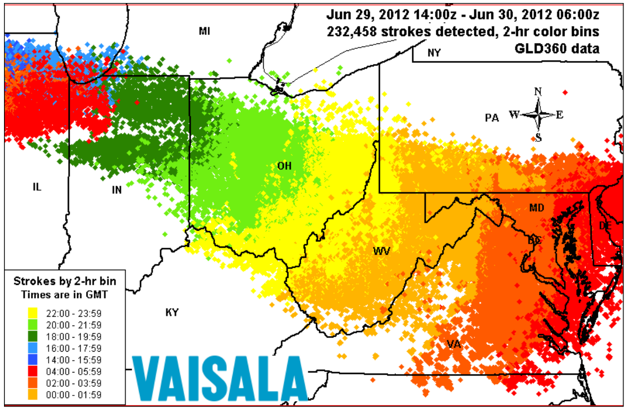
VAISALA

How can we utilize lightning observations to make better forecasts?

Lightning Data Assimilation (LDA) method – basic idea

- Data assimilation system used is the Local Analysis and Prediction System (LAPS)
- Lightning rates are converted to 3-D radar reflectivity fields.
- Reflectivity field is used by LAPS cloud analysis where it modifies primarily the cloud hydrometeor fields.
- WRF model is initialized with LAPS analysis.

First step: Need to find the lightning–reflectivity relationships, i.e. vertical reflectivity profiles corresponding to different lightning rates.

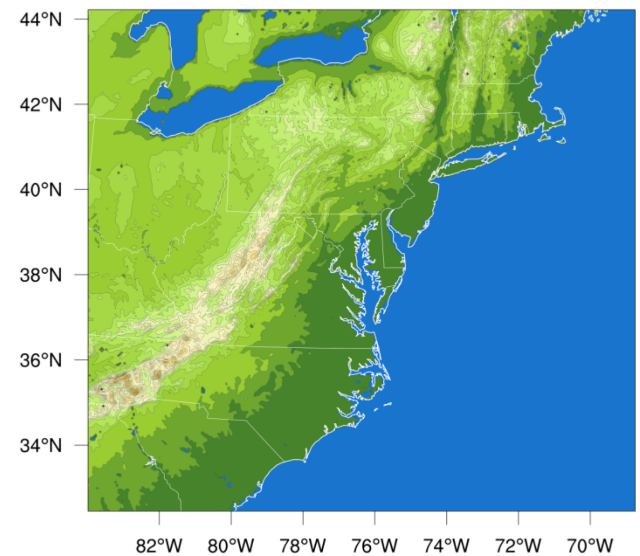


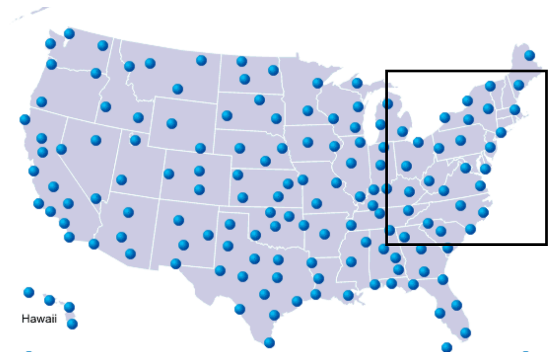
232,000 lightning strokes detected during the derecho

How to determine lightning-reflectivity relationships

- Lightning and radar data were analyzed over the northeast United States.
- Analyzed 5-month period with 226,000 lightning strokes.
- Derecho event was **not** included in the lightning-reflectivity analysis.
- Lightning data from Vaisala's GLD360.
- Radar data from NEXRAD network.
- LAPS was used to create complete 3-D analyses of **real** radar reflectivity on a 4 km grid (41 vertical levels).
- Lightning strokes were counted ± 10 minutes around the analysis time over each grid cell.

(Pessi, 2013: Characteristics of Lightning and Radar Reflectivity in Continental and Oceanic Thunderstorms. *AMS annual meeting*.)



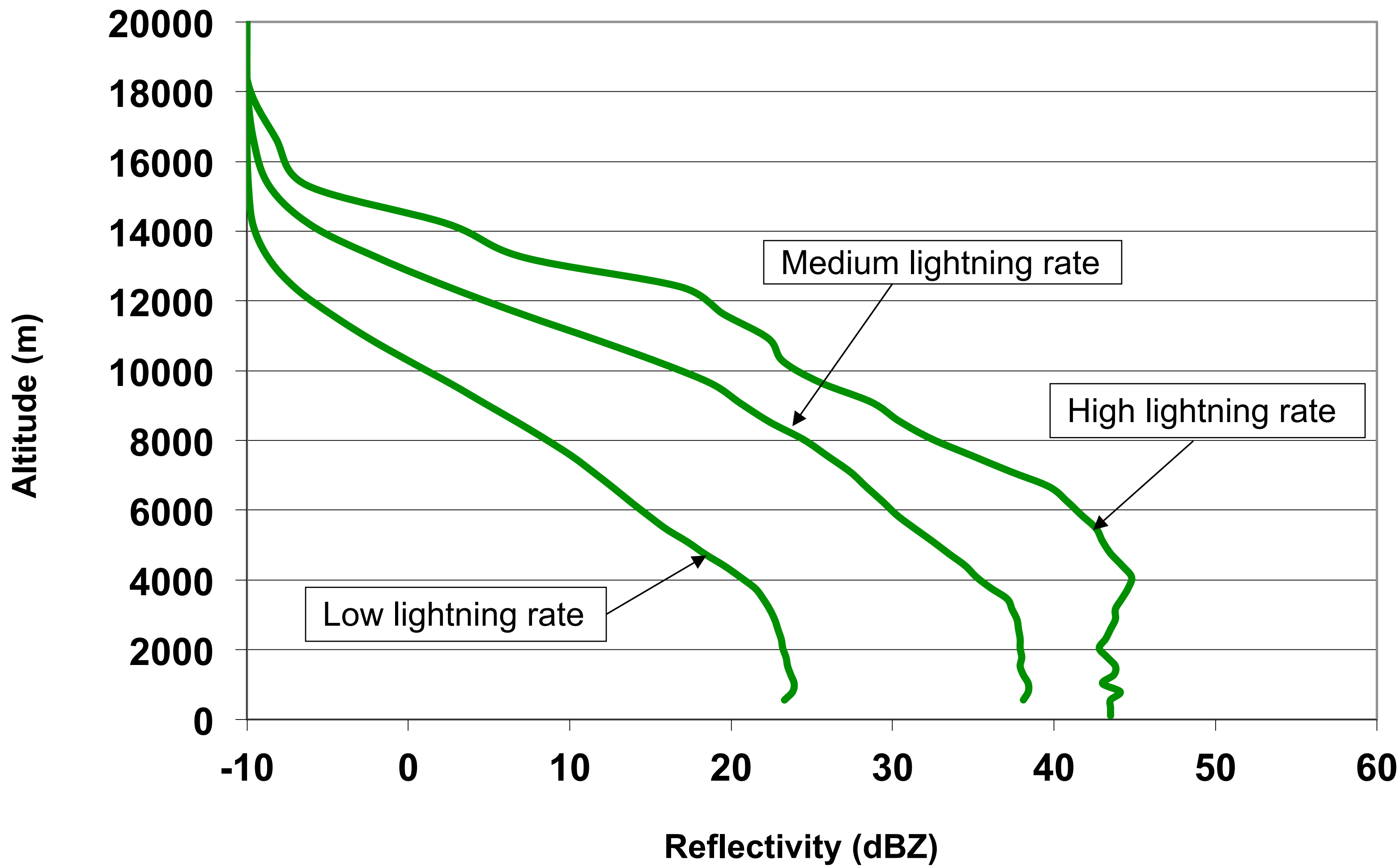


United States WSR-88D sites

(Images courtesy of NOAA)

VAISALA

Lightning vs. vertical reflectivity profiles



Experiment design

Data assimilation system:

- LAPS analyses used NAM background, surface obs, soundings, profilers and GOES-13 satellite data.
  - LDA experiment used lightning data in addition.
- Read lightning data file (± 10 min time window) and add stroke counters to each grid cell (4 km grid length).
- Read 3-D temperature and geopotential height fields from current LAPS analysis.
- Find tropopause. Tropopause is defined as a layer where temperature lapse rate is < 2°C/km and altitude is over 10 km.
- Convert lightning counts to radar reflectivity profiles.
- Set reflectivity values to -10 dBZ above tropopause.

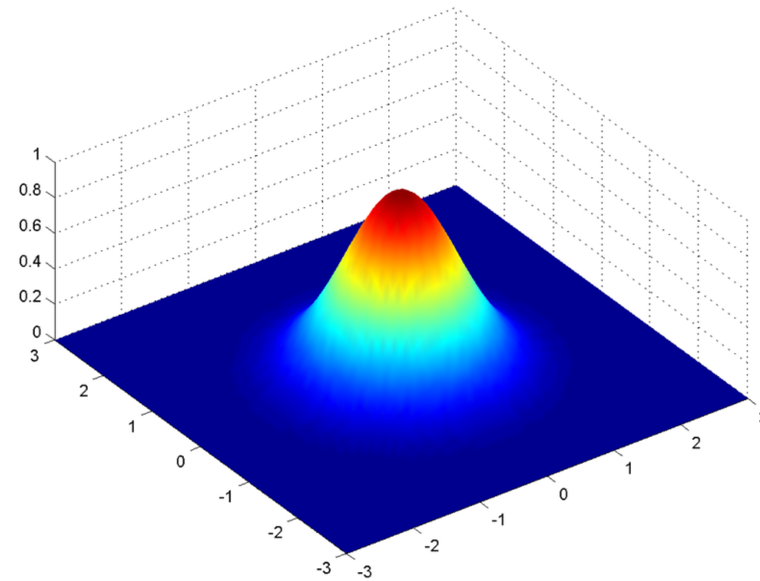
VAISALA

Experiment design

- Smooth reflectivity field horizontally
  - Expand the impact of lightning to surrounding grid cells using Gaussian distribution function.

$$R(x) = R_0 \times e^{-\frac{1}{\alpha}x^2}$$

Adjusts horizontal radius of influence

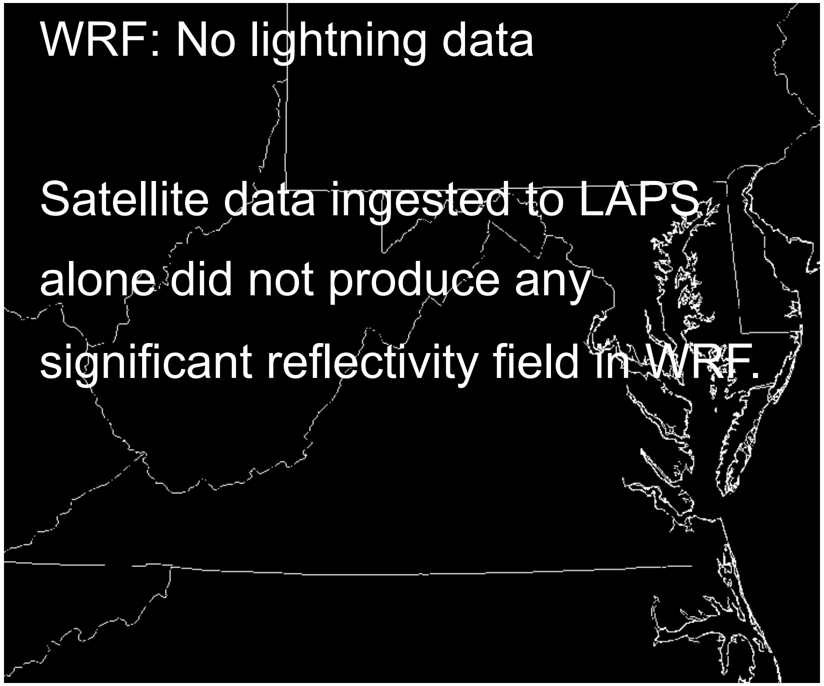


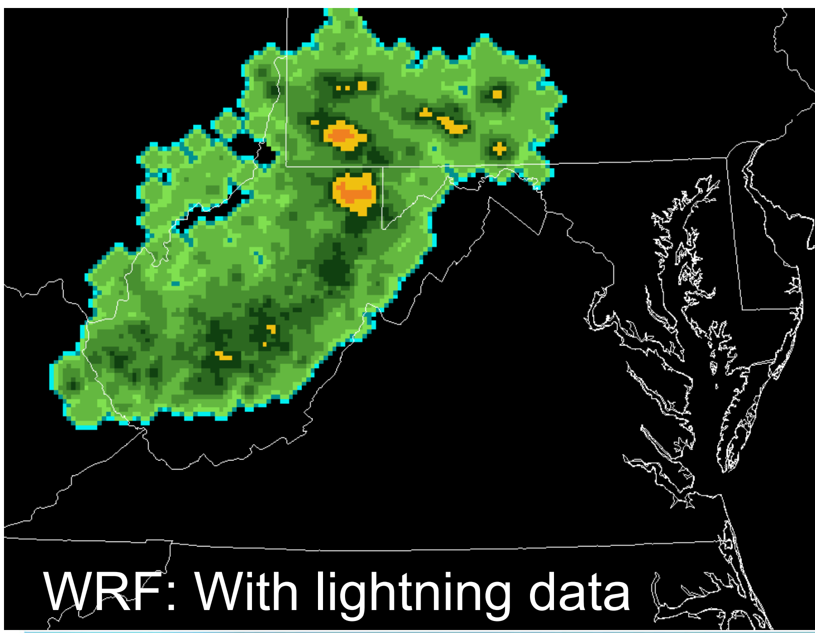
Numerical model:

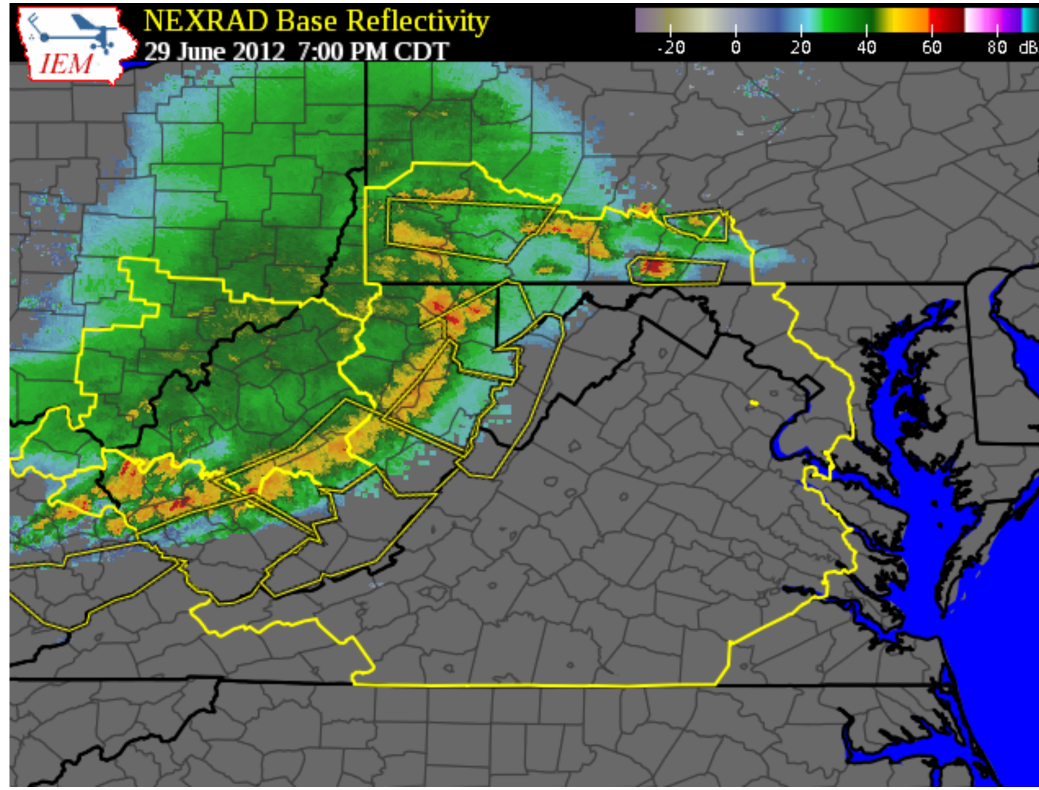
- WRF 3.4.1
- Single domain with 4-km grid length, 39 vertical levels
- WRF model was initialized with LAPS and run for 6 hours with 5-minute output

Results

Simulated vs observed radar reflectivity - analysis

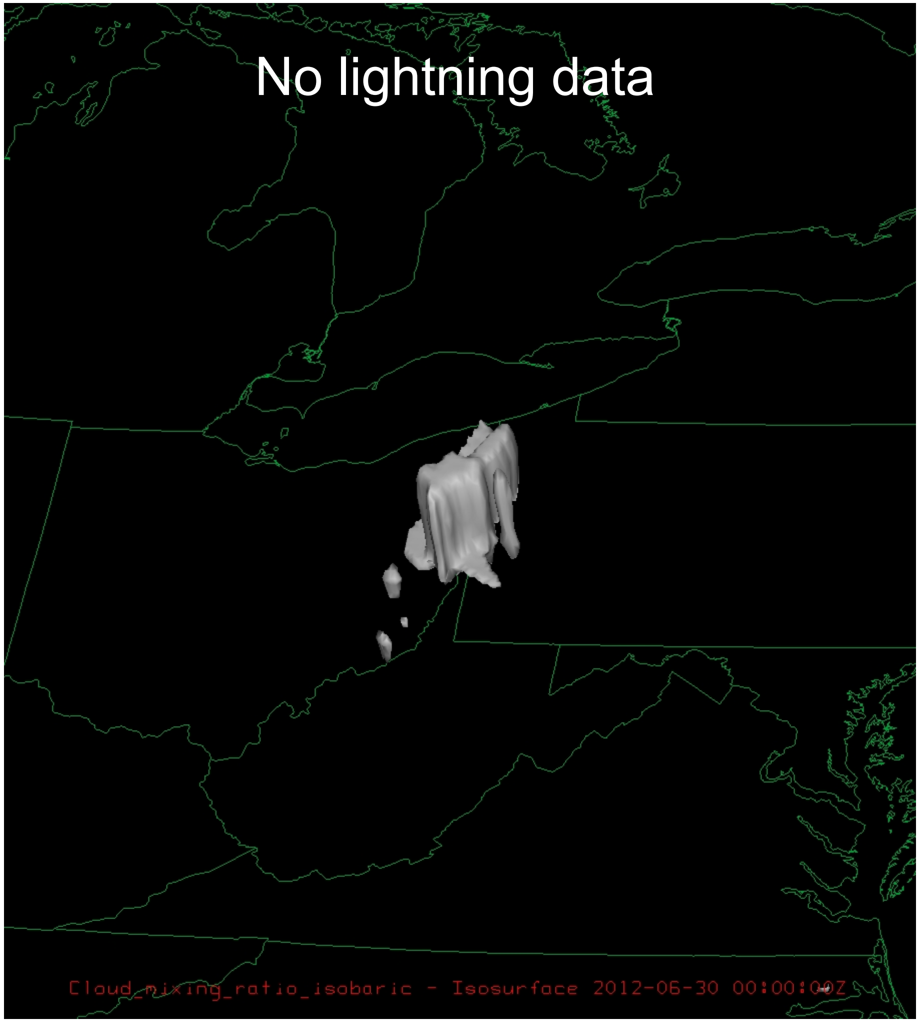


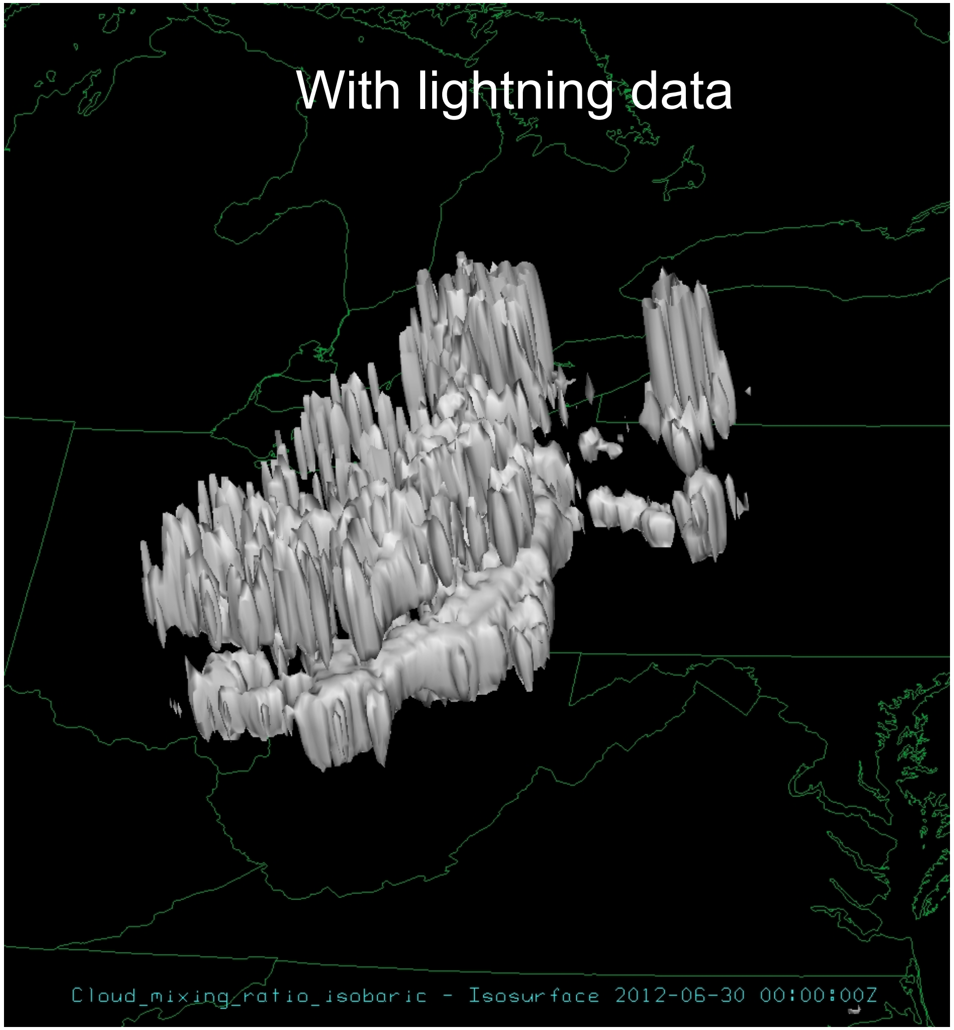




Observed radar reflectivity

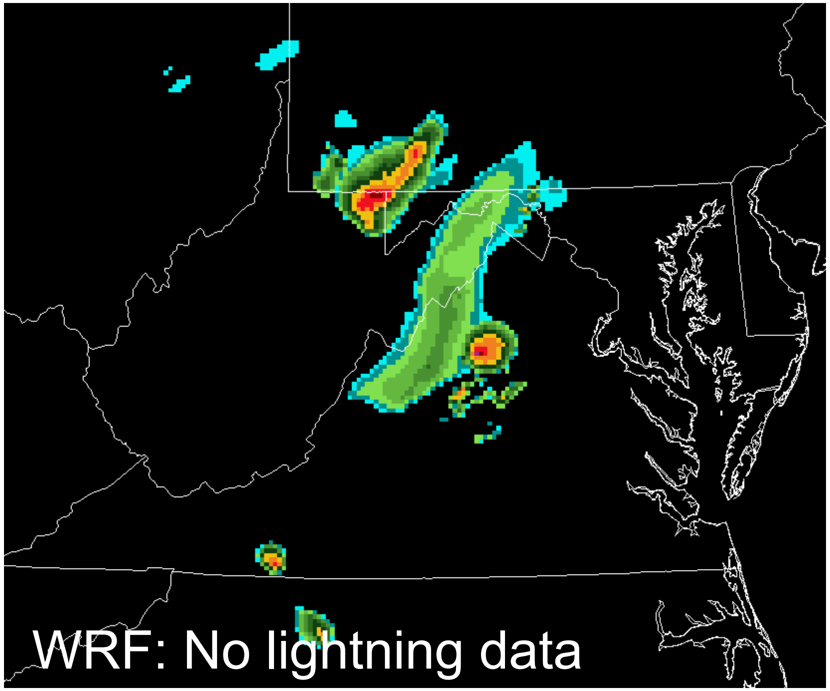
Cloud water mixing ratio analysis -
showing values over 10^{-4} kg/kg

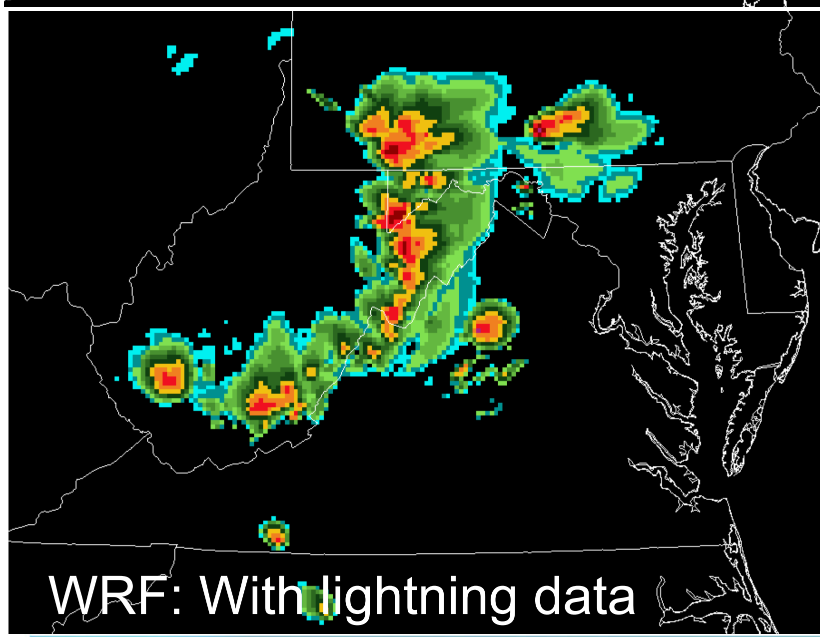


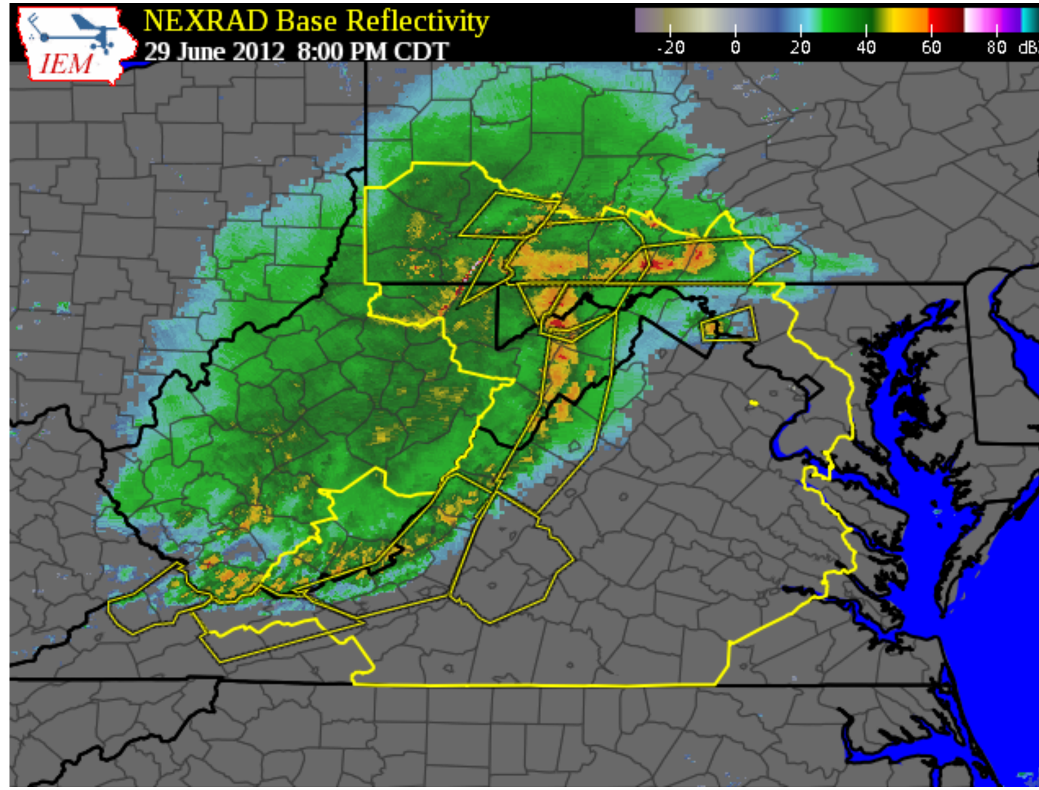


VAISALA

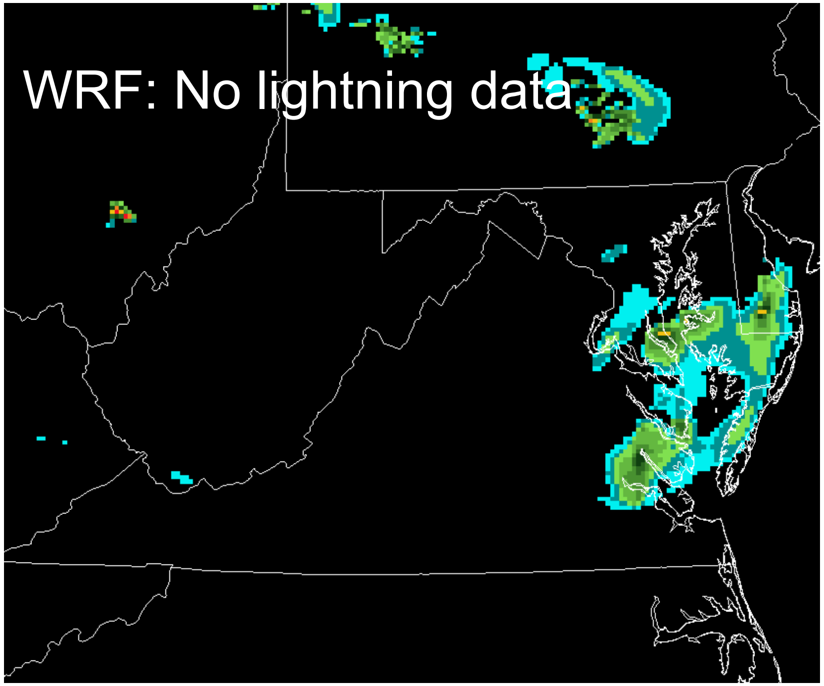
Simulated vs observed radar reflectivity - 1-hour forecast



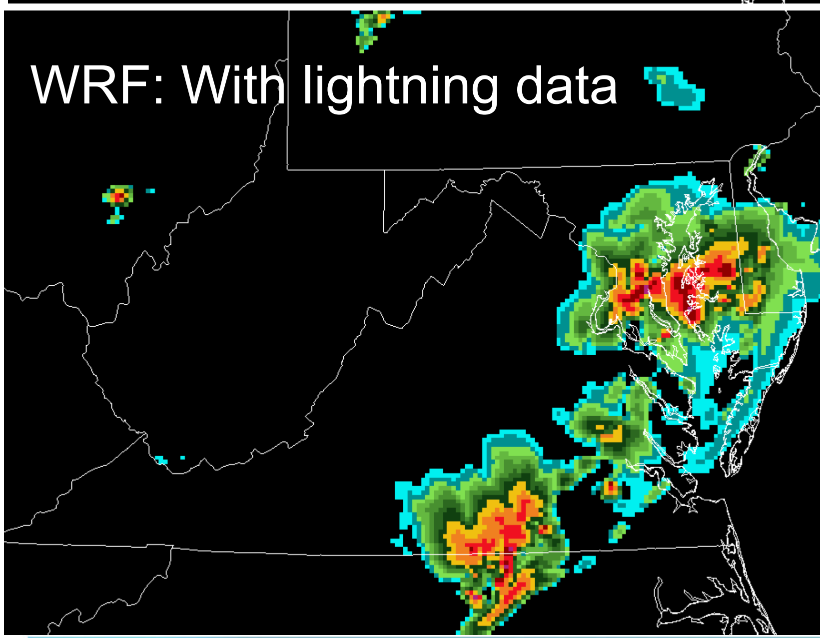


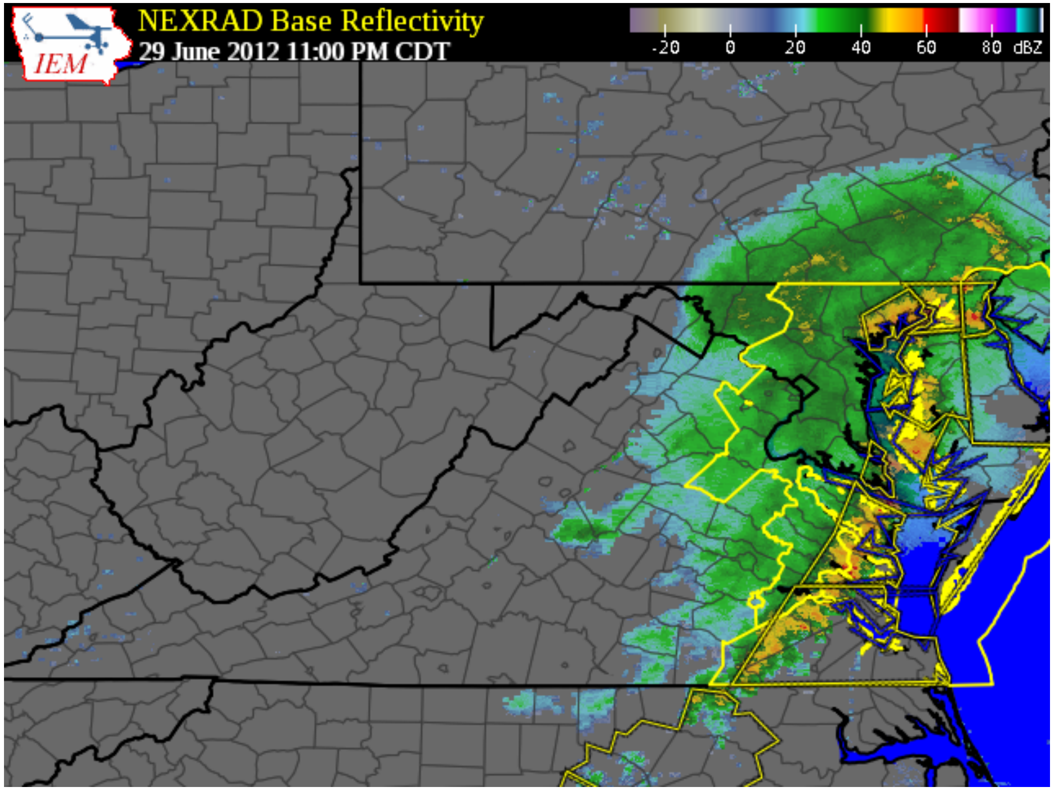


Observed radar reflectivity



Simulated vs observed radar reflectivity - 4-hour forecast

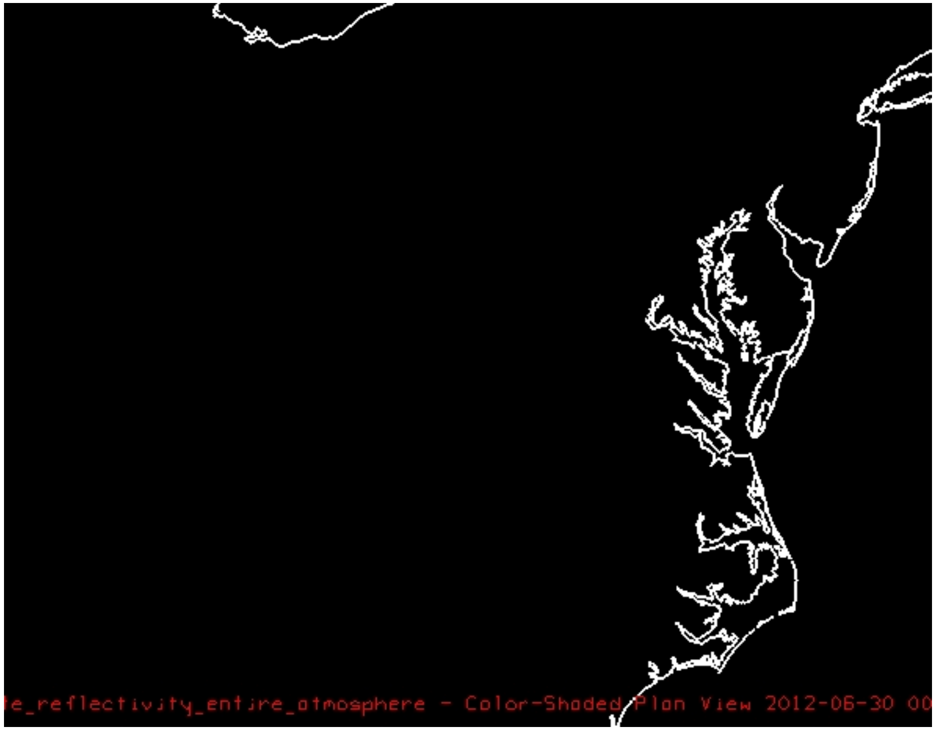




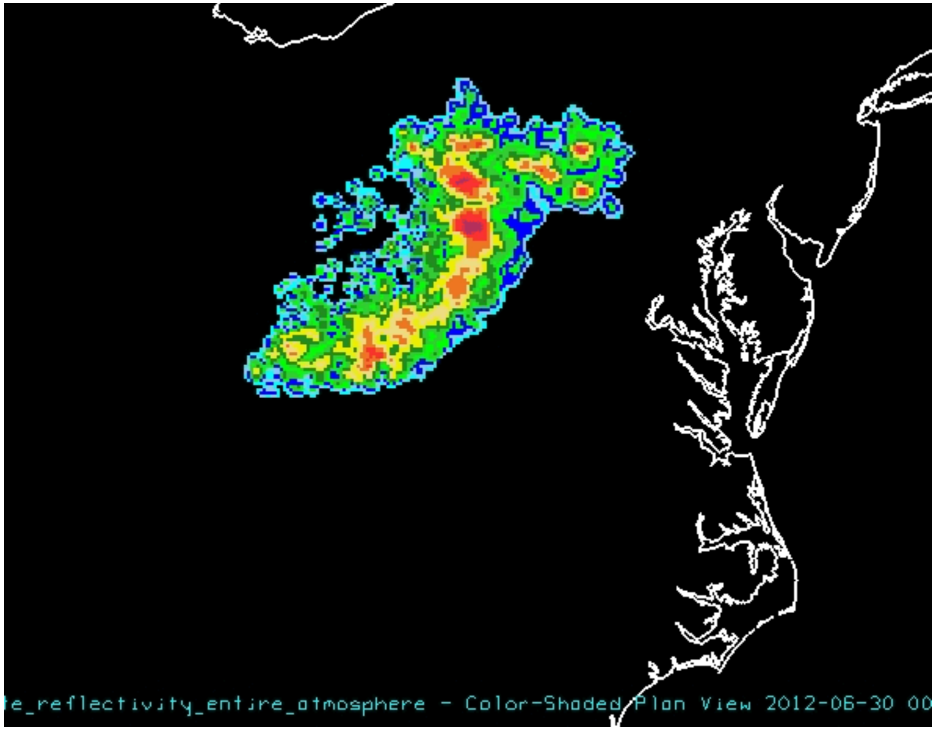
Observed radar reflectivity

VAISALA

WRF reflectivity

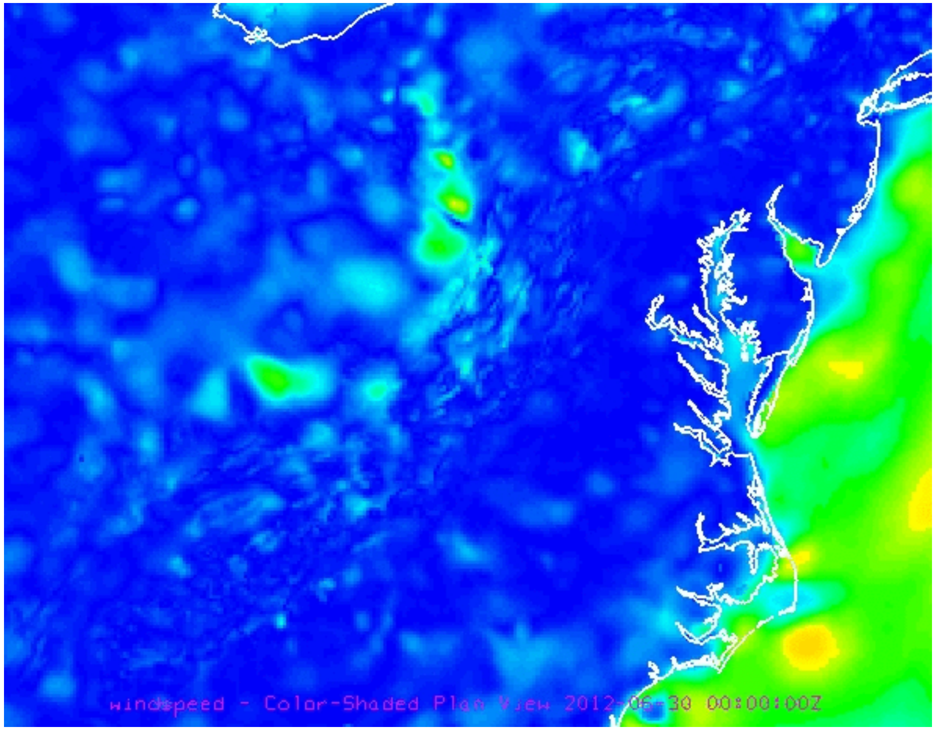


No lightning data

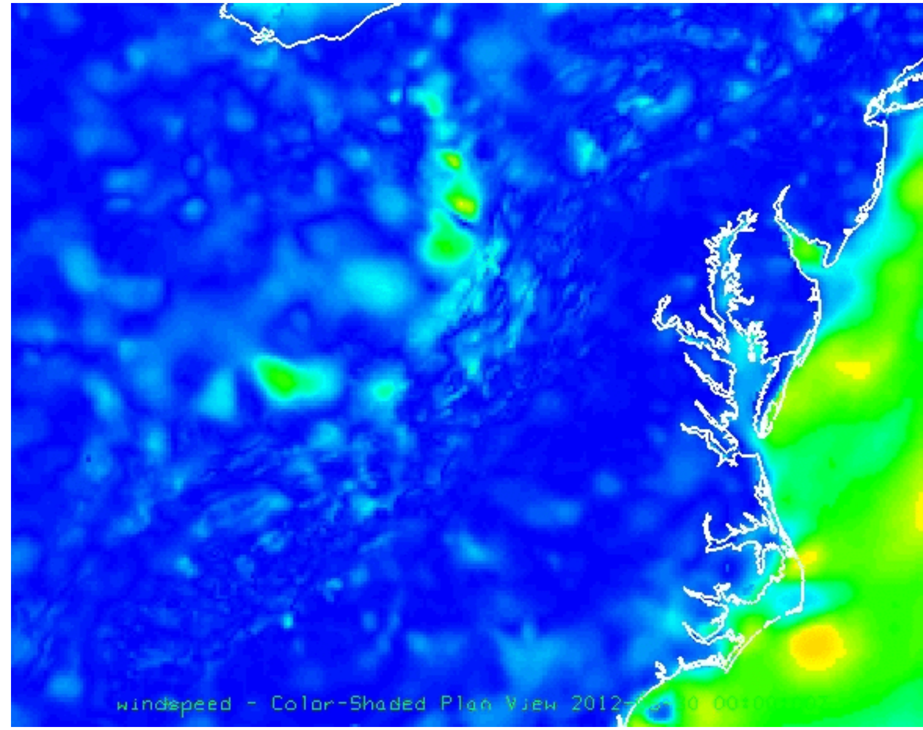


With lightning data

WRF wind speed



No lightning data



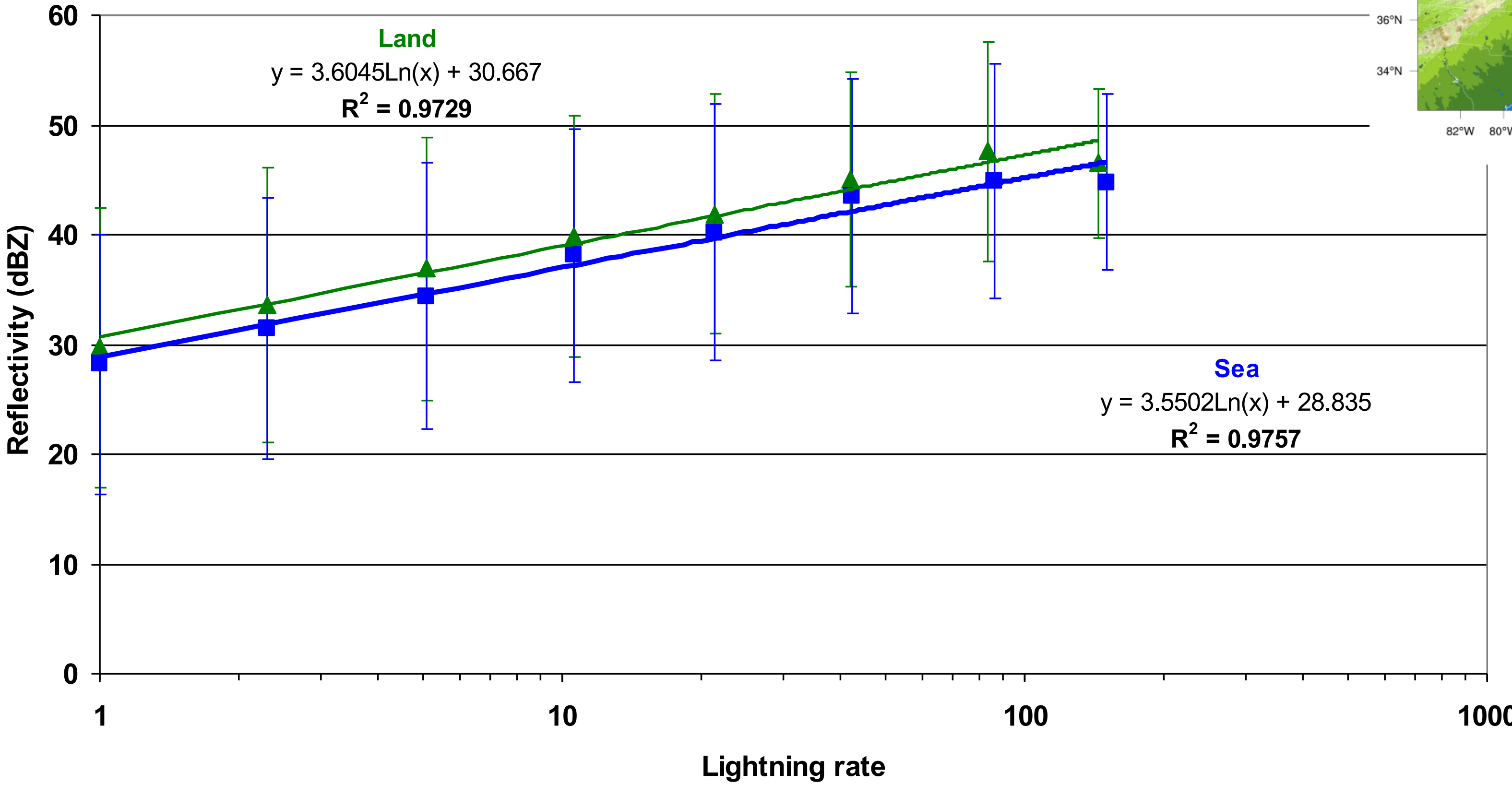
With lightning data

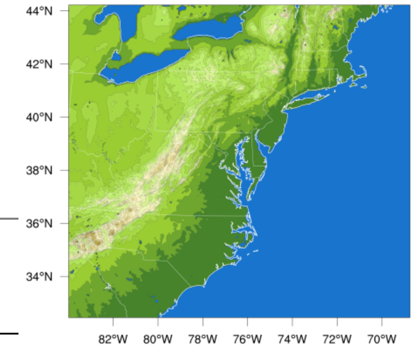
Summary

- LAPS Lightning Data Assimilation (LDA) method creates a 3-D reflectivity field based on empirical lightning-reflectivity relationships.
- Goal of the study was to create best possible initial conditions for the model – not to fine tune WRF.
- Derecho structure was simulated more realistically with the LDA method.
- The LDA system collects continuously statistics of the lightning-reflectivity relationship *if there is any radar coverage* over the domain. That information can be used to refine the relationships or to dynamically adjust the relationships, i.e. to create a self-calibrating algorithm.
- Lightning data assimilation method available soon in the regular LAPS distribution package at laps.noaa.gov!

Extra slides

Lightning vs. composite reflectivity





VAISALA