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

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Image courtesy of Brittney Misialek
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’s Global Lightning Dataset
GLD360 lightning strokes

NEXRAD radar reflectivity

Image courtesy of University of Hawaii

Image courtesy of Iowa State University
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.
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.)
Lightning vs. vertical reflectivity profiles

- Low lightning rate
- Medium lightning rate
- High lightning rate

Altitude (m)

Reflectivity (dBZ)
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.
Experiment design

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

\[ R(x) = R_0 \times e^{\alpha x^2} \]

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
Simulated vs observed radar reflectivity - analysis

WRF: No lightning data

Satellite data ingested to LAPS alone did not produce any significant reflectivity field in WRF.

WRF: With lightning data

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

No lightning data

With lightning data
Simulated vs observed radar reflectivity - 1-hour forecast

WRF: With lightning data

WRF: No lightning data

Observed radar reflectivity

Image courtesy of Iowa State University
Simulated vs observed radar reflectivity - 4-hour forecast

WRF: No lightning data

WRF: With lightning data

Observed radar reflectivity

Image courtesy of Iowa State University
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!

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**NOTE:** The information provided is from a presentation slide and is subject to change. For the most up-to-date information, please visit the official LAPS and WRF websites.

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Extra slides
Lightning vs. composite reflectivity

**Land**

\[ y = 3.6045 \ln(x) + 30.667 \]

\[ R^2 = 0.9729 \]

**Sea**

\[ y = 3.5502 \ln(x) + 28.835 \]

\[ R^2 = 0.9757 \]