Variational Assimilation of Total Lightning at Cloud Resolving Scales

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Photo: J. LaDue
$Q_v$ within a layer above cloud base is adjusted (increased) as a function of flash rate ($X$) and simulated $Q_g$ and $Q_{satwater}$. Increasing $Q_v$ at constant $T$ boosts thermal buoyancy (via $\theta_v$) and ultimately generates an updraft.

$$Q_v = AQ_{sat} + BQ_{sat} \tanh(CX) \left[ 1 - \tanh(DQ_g^a) \right]$$

- Only applied whenever simulated RH and $Q_g <$ fixed thresholds: i.e., if the model already is in the right direction don’t adjust $Q_v$.

Fierro et al. (2012, 1014, 2016, 2018)
## GSI Experiments

- Logical follow-on: apply this philosophy to GSI in quasi-realtime

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Description</th>
<th>Data assimilated</th>
<th>Model variables impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL</td>
<td>Control run</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>LDA (H=6km)</strong></td>
<td>Lightning DA run. horizontal length scale of 6 km.</td>
<td>ENTLN flash extent density rates.</td>
<td>$q_v$ (LCL-15 km)</td>
</tr>
<tr>
<td><strong>PREBUFR</strong></td>
<td>PREPBUFR DA run</td>
<td>NCEP PREPBUFR data bundle</td>
<td>*</td>
</tr>
<tr>
<td><strong>PEBUFR+LDA (H_default)</strong></td>
<td>Lightning+PREPBUFR DA run. GSI default horizontal length scale ~100km.</td>
<td>NCEP PREPBUFR data bundle ENTLN flash extent density rates.</td>
<td>$q_v$ (LCL-15 km) + *</td>
</tr>
<tr>
<td><strong>PEBUFR+LDA_BKG (H_default)</strong></td>
<td>Lightning+PREPBUFR DA run. GSI default horizontal length scale ~100km.</td>
<td>NCEP PREPBUFR data bundle ENTLN flash extent density rates.</td>
<td>$q_v$ (LCL-15 km) + *</td>
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*NCEP ADP Global Upper Air and Surface Weather Observations (PREPBUFR format) are composed of a global set of surface and upper air reports: land surface, marine surface, radiosonde, pibal and aircraft reports from the Global Telecommunications System (GTS), profiler and US radar derived winds, SSM/I oceanic winds and TCW retrievals, and satellite wind data from the National Environmental Satellite Data and Information Service (NESDIS). The reports can include pressure, geopotential height, temperature, dewpoint temperature, wind direction and speed. Report time intervals range from hourly to 12 hourly. Source: https://gcmd.nasa.gov*
GSI: representative case

- Strongly forced case -> good performance for CTRL. LDA still improves short term forecast when $H \leq 10$ km.
- GSI, however does not allow for multiscale VAR passes and assumes a large default $H$ (~100 km) for all variables!
  → Not mature enough for assimilating convective scale information together with mesoscale data.
- use of NSSL 3DVAR. (cf Fierro et al. 2018 JCSDA Quarterly Newsletter for details).
NEWS3DVAR Experiments

- Use a similar approach than for GSI but combine LDA with level II radar data instead of PREPBUFR (follow Fierro et al. 2016).

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<td>Vr and dBZ</td>
<td>q_r, q_g, q_i, q_s, q_h, u, v, w, θ</td>
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<td>Lightning+radar assimilation run</td>
<td>GLM flash density rates, Vr and dBZ</td>
<td>q_v (LCL-15 km), q_r, q_g, q_i, q_s, q_h, u, v, w, θ</td>
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NB: level II data from ~70 radars were assimilated
Forecasts use NSSL 2-mom microphysics.
NEWS3DVAR: Quasi-realtime tests with GLM data

GLM densities and Qv fields

7 June 2018, 0000Z forecast (t=0h)

GLM Flash Densities (h⁻¹ 9 km⁻²)

Z=3-7km, layer-averaged Qv (g kg⁻¹)

Lightning VAR DA params:
- RH=95%, z=LCL-15km.
- 0 density pts=missing obs

Radar VAR DA params:
- Vr (missing obs <= 25 dBZ)
- Hydrometeors (R=4km)

- H=24, 12 km: multi-scale:
  - 24km, 12km: Vr
  - 12km: lightning
- V=2 grid points for all vars
- One cycle (0000Z)
NB: Bias already present in CTRL, is exacerbated in DA runs due to increase in storm coverage. Not caused by DA but inherent to microphysics. Other schemes tested had similar or higher bias.
7 June 2018, 0000Z forecast (t=6h)

APCP (mm)

0600Z MRMS
0600Z CTRL
0600Z GLM
0600Z RAD
0600Z RAD+GLM

LAT (deg N)
LON (deg W)

PRECIP: 6-h forecast
07 June 2018, 0000Z forecast: FSS for APCP

1 mm threshold

CTRL
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

GLM
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

RAD
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

RAD+GLM
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

5 mm threshold

CTRL
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

GLM
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

RAD
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

RAD+GLM
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

10 mm threshold

CTRL
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

GLM
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

RAD
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km

RAD+GLM
- 30 km
- 24 km
- 18 km
- 12 km
- 6 km
- 3 km
Ongoing and future work

• Experiments only employ one cycle (at 00Z): test influence of additional 3DVAR cycles with different frequencies.

• Run additional cases spanning different convective regimes.

• Increase/decrease the assimilation time window.

• Establish the significance at the 5% level of the difference between score metrics: ETS(GLM)-ETS(CTRL) etc ... using random sampling (bootstrapping).

• Develop/Implement dynamic weighting between radar and lightning during the DA.

• Continue to work on producing real-time evaluation graphics, which could be used during real time experiments (e.g., HWT).

• Start thinking about hybrid ensemble-3DVAR implementation for lightning.
7 June 2018, 0000Z forecast (t=12h)

APCP (mm)

PRECIP: 12-h forecast
dBZ: 5-h forecast
07 June 2018, 0000Z forecast: ETS for APCP

1 mm threshold

CTRL
GLM
RAD
RAD+GLM

5 mm threshold

CTRL
GLM
RAD
RAD+GLM

10 mm threshold

CTRL
GLM
RAD
RAD+GLM
Real-time implementation into WRF-NSSL 4-km CONUS runs

Model CI Prob (%) within R=25 miles

LIGHT-01Z  LIGHT-02Z

CTRL-01Z  CTRL-02Z

SPC reports

OBS-02Z

cf Fierro et al. (2014, MWR)
Real-time implementation into WRF-NSSL 4-km CONUS runs

Test Date: 2012-04-15

00-02Z Max Lightning

01-02Z Max Lightning

02Z NMQ Obs

Obs ENTLN

Z=4km dBZ

01-02Z Max VI_Qg

01-02Z Max VII

CTRL

01-02Z Max VI_Qg

01-02Z Max VII

CTRL

CTRL

Z=4km dBZ, 02Z

LIGHT

Z=4km dBZ, 02Z

LIGHT

LIGHT

Obs ENTLN
ENTLN network

• 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.

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