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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Abstract

To improve forecast of convection, two new assimilation techniques of total lightning data at cloud-resolving scales have been developed. The first is a direct forcing technique (implemented the WRF-ARW) for initiating and maintaining convection. The second uses the Ensemble Kalman Filter (EnKF) method, which can modulate convection and help suppress spurious convection. The first method was used in the case of the 24 May 2011 Oklahoma tornado outbreak. This case was selected because of the availability of high fidelity data collected by the dense network of the Oklahoma Mesonet. Lightning data assimilation forced deep, moist precipitating convection to occur in the model at roughly the locations and intensities of the observed storms depicted in the NSSL NMQ radar reflectivity mosaic product. The nudging function for the total lightning data locally increases the water vapor mixing ratio (virtual potential temperature) via a computationally inexpensive smooth continuous function using gridded pseudo-GOES-R resolution (9 km) flash rate and simulated graupel mixing ratio as input variables.

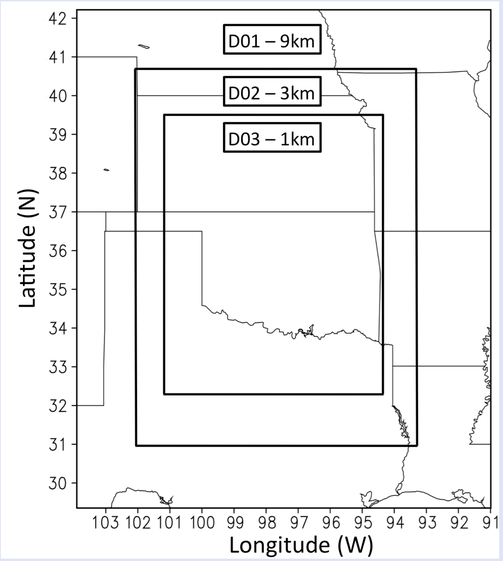
To demonstrate its utility, the second part of this talk will present preliminary results of the recent implementation of the lightning assimilation scheme within the operational WRF-NSSL daily 4 km forecast runs.

The EnKF method uses relationships between lightning flash rate and graupel mass or storm volume as an observation operator for total flash rate. Tests have been carried out using Observation System Simulation Experiments (OSSEs) and real-data (pseudo-GLM derived from LMA), particularly the 8 May 2003 Moore, OK, supercell storm.

Lightning threats are currently diagnosed from model variables known to be well correlated with the occurrence of lightning (e.g., graupel mixing ratio, ice water content). To alleviate this need and provide a more physically sound approach to this problem, a full charging/discharge model is currently being implemented into the NSSL two-moment microphysics scheme within the WRF-ARW model.

a) Model setup in a flash

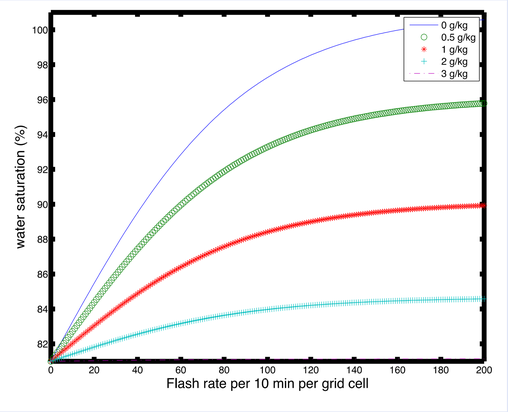
- Triple nested grid with D01/D02/D03=9/3/1-km and 35 vertical levels. I.e., from GEOS-R (CPS scale) to 'convection-resolving' scales. Focus on the 3-km output (current operational NWP model resolution).
- WSM 6 microphysics
- No feedbacks between grids allowing independent comparisons of the model output on the 3 grids.
- 12Z NAM 40-km data used as input for IC/BC.
- D01, D02, D03 started at 12, 14, 16Z, respectively.
- Lightning assimilation carried out using a smooth continuous function for water vapor. Total lightning data obtained from the Earth Networks® Total Lightning Network (ENTLN).
- Assimilation of 9-km gridded lightning simultaneously on all grids between 1930-2130Z in 10-min bins.



b) Assimilation function

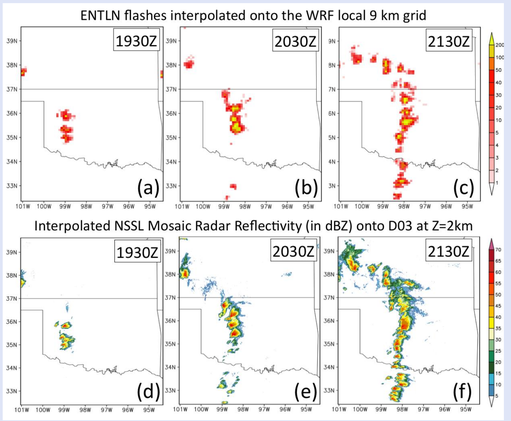
- Because lightning flashes are generally associated with the presence of updrafts, whenever flashes are present at a given I,J location, the water vapor mixing ratio (Qv) within the 0°C to -20°C layer was increased as a function of 10-min gridded flash count (X) and simulated graupel mixing ratio (Qg) and water saturation mixing ratio (Qsat).
- Only applied whenever modeled 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.

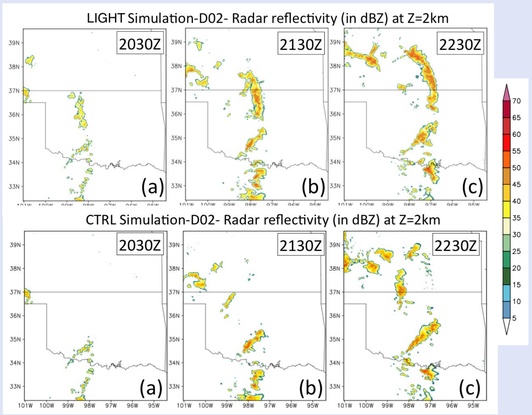
$$Q_v = AQ_{\text{sat}} + BQ_{\text{sat}}\tanh(CX)\,[1-\tanh(DQ_g^{\alpha})]$$



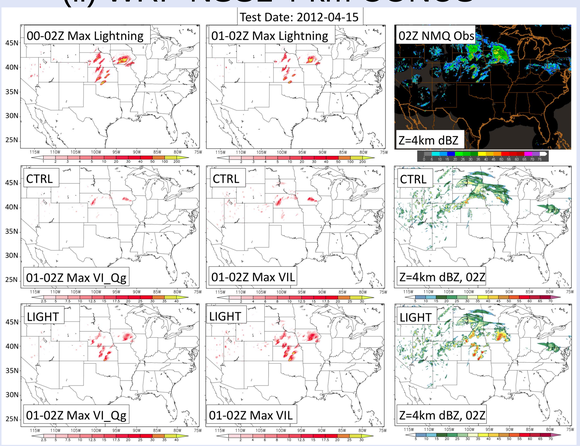
c) Results

(i) 24 May case

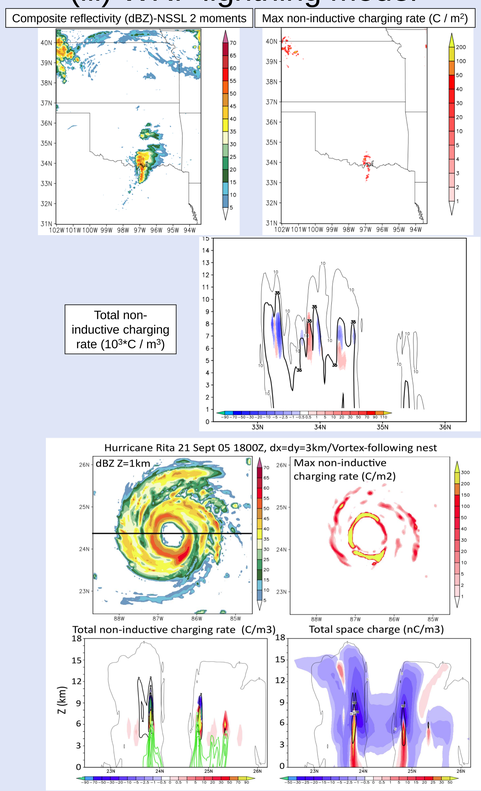




(ii) WRF-NSSL 4-km CONUS

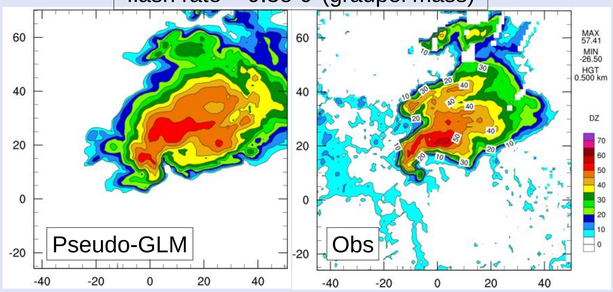


(iii) WRF lightning model



(iv) COMMAS EnKF

flash rate = 9.3e-9*(graupel mass)



d) Summary/Future work

- The assimilation of the total lightning data for only a few hours prior to the analysis time significantly improved the representation of the convection at analysis time and at the 1-hour forecast within the convective permitting/resolving grids (i.e., 3/1 km). Computationally inexpensive and impose minimum constraints on model physics.
- Real time implementation into the WRF-NSSL CONUS 4-km testbed also showed promising results.
- A physically sound non-inductive charging scheme was implemented into WRF within NSSL 2 moment microphysics. Space charges on all hydrometeor are also tracked. Ongoing work: implementing a 1D discharge model with polarization charging.
- EnKF assimilation of pseudo-GLM data can effectively reproduce the basic supercellular reflectivity structure of the storm and maximum updraft speeds. Since the GLM will produce observations over a much larger area than radar observations are available, these results show promise that EnKF assimilation of GLM data can be an effective substitute for assimilation of radar data in data-sparse areas.
- Future work will examine ways to further improve the pseudo-GLM based analyses by exploring additional observation operators. Also, the effects of assimilating both radial velocity data and pseudo-GLM data will be tested.