Assimilating GOES-R Latent Heating in FV3 using Machine Learning

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+ Best wishes for your PhD Defense!

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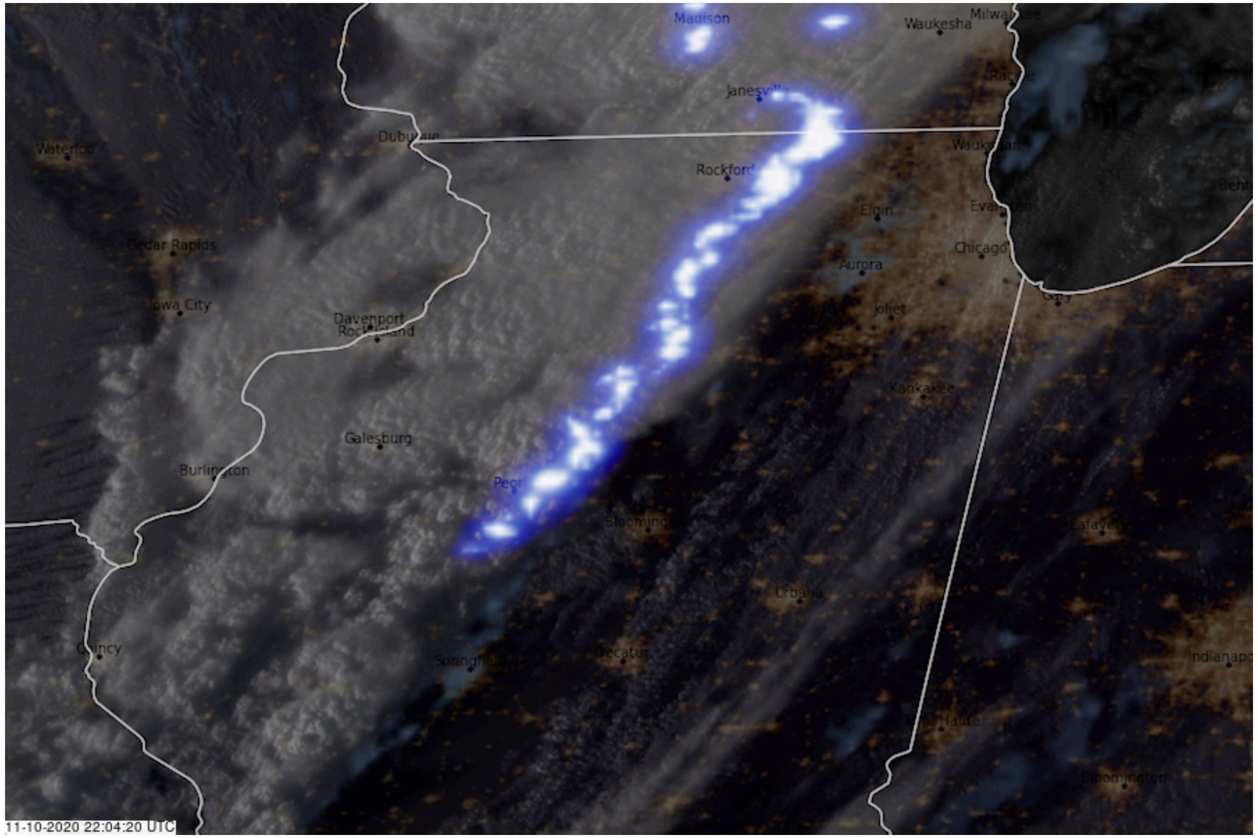
Importance and Motivation

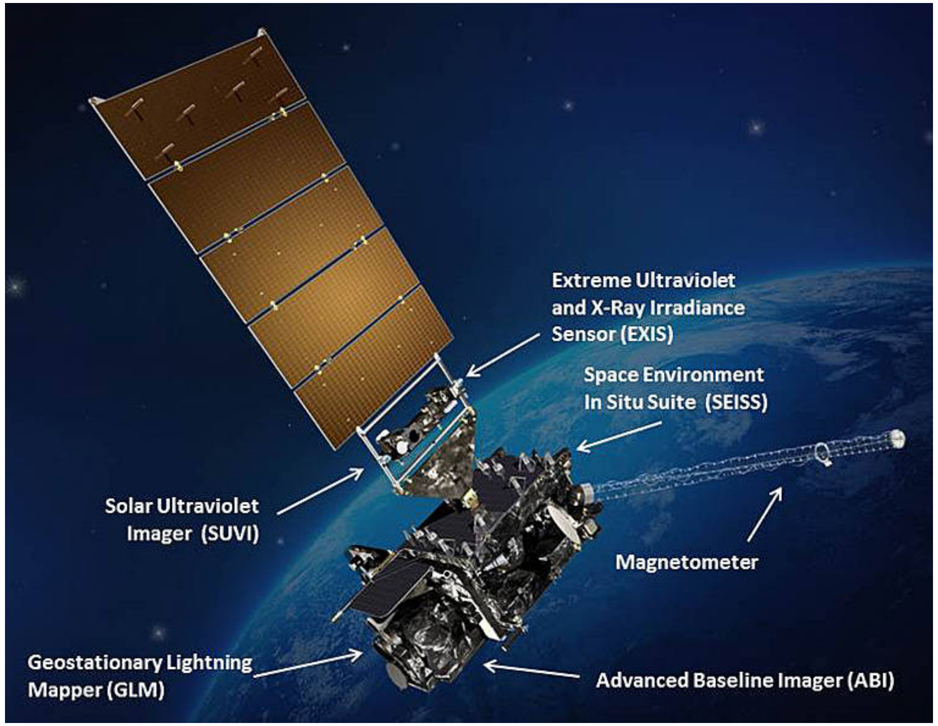
- Severe weather has tremendous impacts on human life and the economy:
  - https://www.ncdc.noaa.gov/billions/
- Convective-scale numerical weather prediction is an important tool for Preparedness and Response to severe weather hazards
- Good forecasts require data to initialize storms in the models
- Motivation: to bring the benefits of GOES-R Series observations to convective-scale data assimilation



Severe storms sweeping across the Midwest
Image credit: Dakota Smith (CIRA)
http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/

Introduction

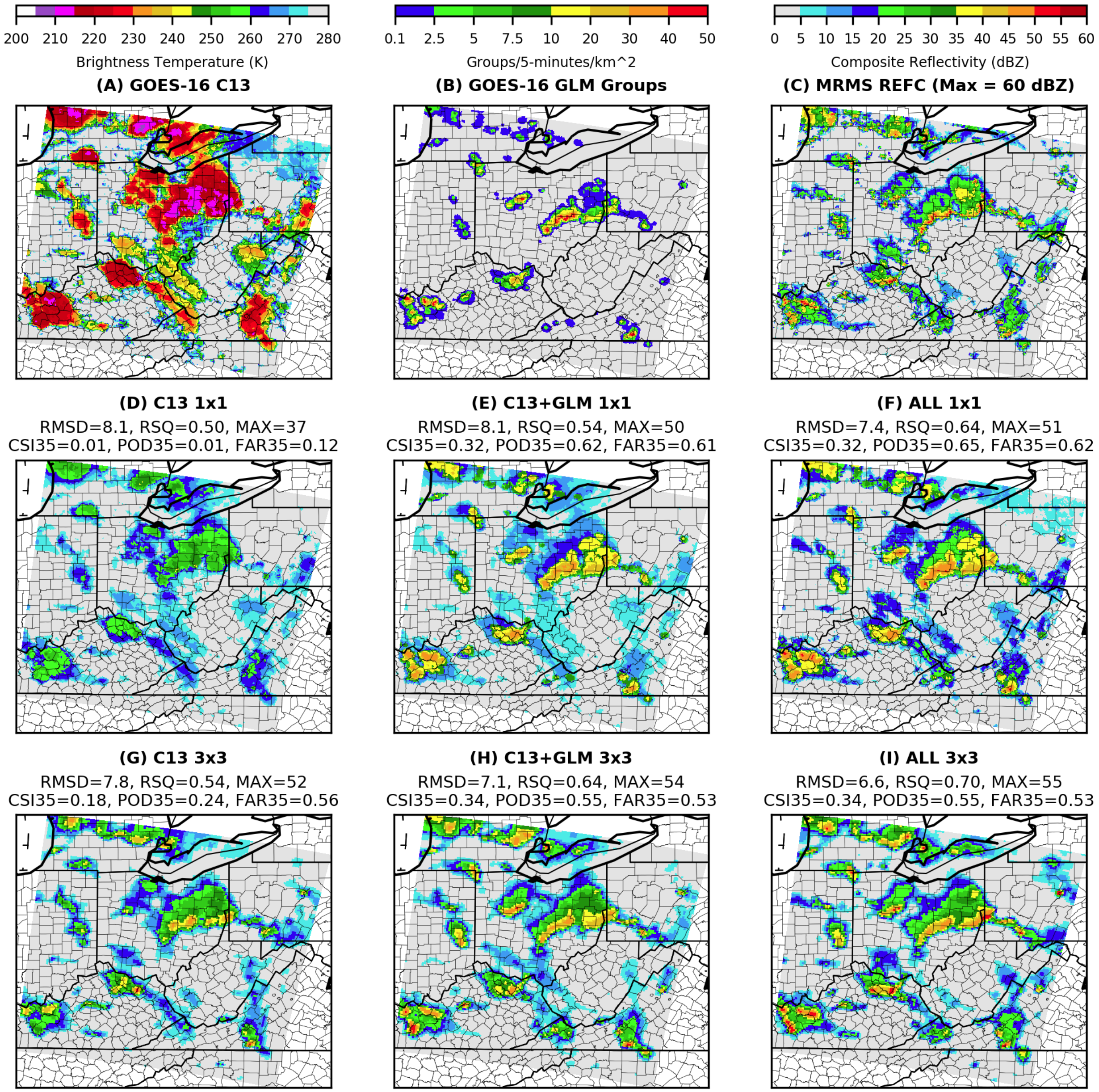
- Statement of the problem
  - GOES data have long been used by human forecasters for situational awareness
  - Limited usage in numerical weather prediction, especially in cloudy or precipitating pixels
- Statement of the opportunity
  - 3x greater spectral resolution
  - 4x greater spatial resolution
  - 5x greater temporal resolution
  - Lightning mapping



GOES-R Satellite
Image credit: NASA
https://www.nasa.gov/content/goes-r/index.html

Why Machine Learning?

- Convolutional approaches use spatial information and spatial context
  - No spatial information: Panel D
  - With spatial information: Panel G
  - Truth: Panel C
- Critical for cloudy and precipitating scenes where radiances saturate
- Machine learning (ML) provides convenient framework for fusing radiances and lightning
  - Panel H, Panel I



Hilburn, K. A., I. Ebert-Uphoff, and S. D. Miller, 2020: Development and interpretation of a neural network-based synthetic radar reflectivity estimator using GOES-R satellite observations. *J. Appl. Meteor. Climatol.*, https://doi.org/10.1175/JAMC-D-20-0084.1.

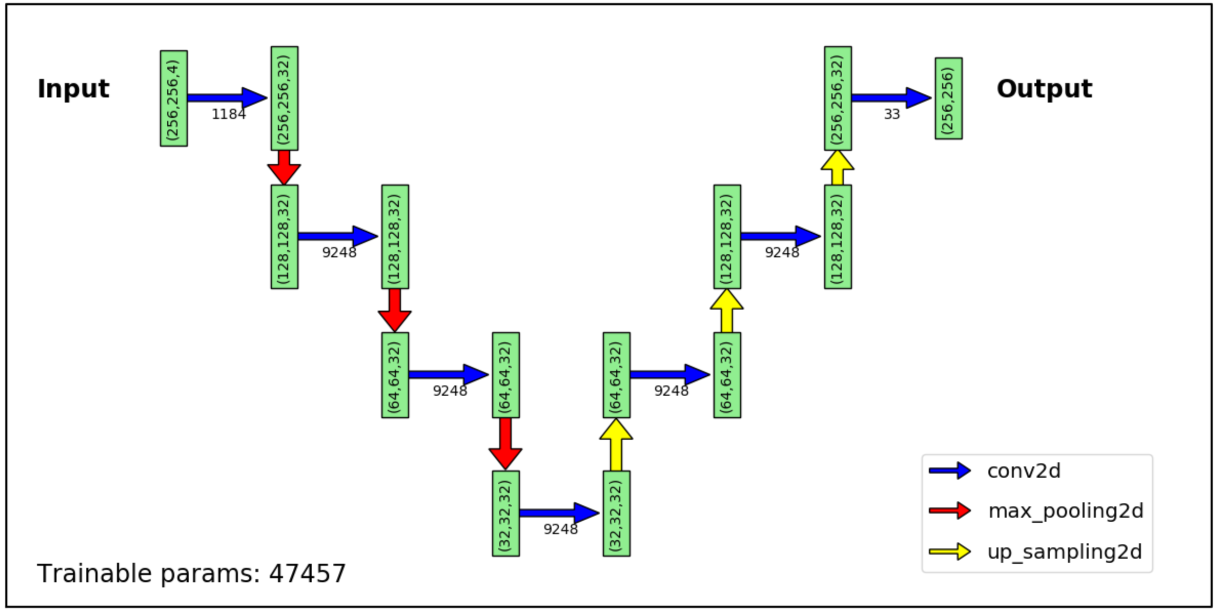
Datasets

- These datasets combine GOES and MRMS data on the HRRR grid (3x3 km)
- The smallest dataset (CONUS1) gave good results when data augmentation was used
- The medium dataset (CONUS2) gave a good depiction of warm season convective-scale phenomena
- Effective number of samples is based on 50x50 pixel (150x150 km) receptive field for GREMLIN model
- The largest dataset (CONUS3) has been prepared and experiments are underway

Dataset	Number of Images	Image Size	Effective Number Samples	Reference
CONUS1	225	256 x 256	5,850	Hilburn et al. (2019) Joint Satellite Conference
CONUS2	1,800	256 x 256	46,800	Hilburn et al. (2020) J. Appl. Meteor. Climatol.
CONUS3	63,850	1799 x 1059	48,653,700	This presentation

ML Models

- GREMLIN: GOES Radar Estimation via Machine Learning to Inform NWP
- The theoretical receptive field for this model is 50x50 pixels, which is the neighborhood over which inputs are combined to produce one output pixel
- The new larger dataset will allow experiments with deeper models that have larger receptive fields



Loss Functions and Metrics

- The GREMLIN model was trained using a weighted loss function to put more emphasis on the relatively infrequent higher reflectivity values
- A performance diagram was used to ensure that GREMLIN provides good estimates across all reflectivity values
- Recent work using neighborhood loss functions, such as Fraction Skill Score, show promise to improve results by avoiding the double-penalty problem with misplaced convective-scale features

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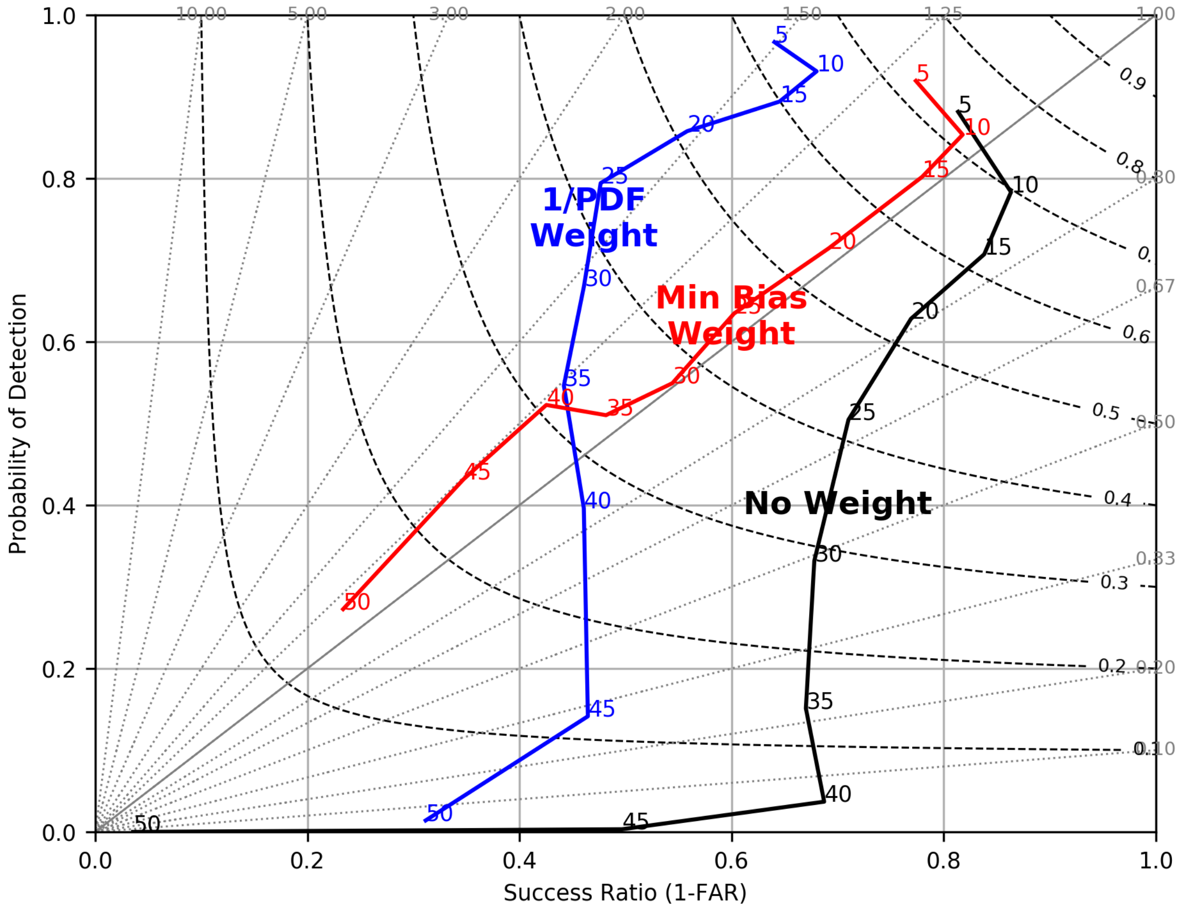
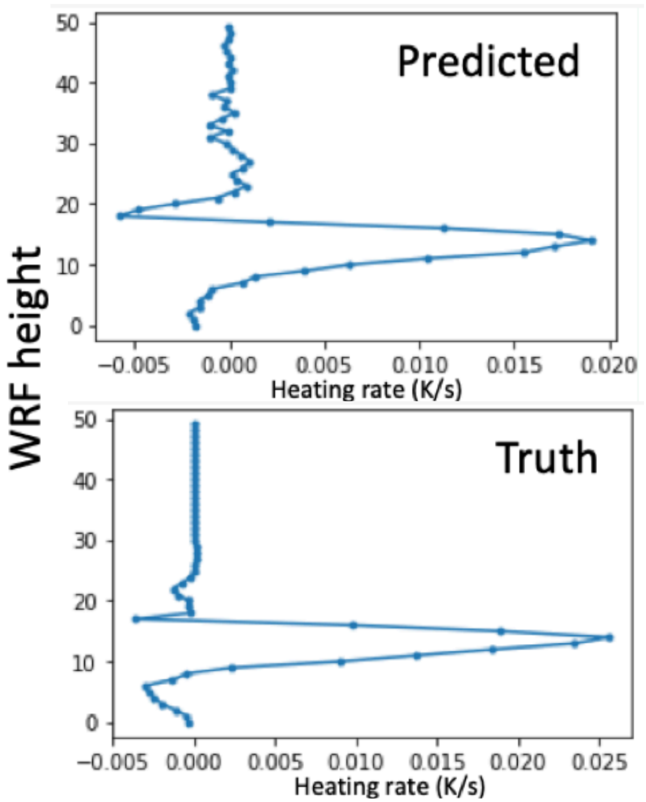
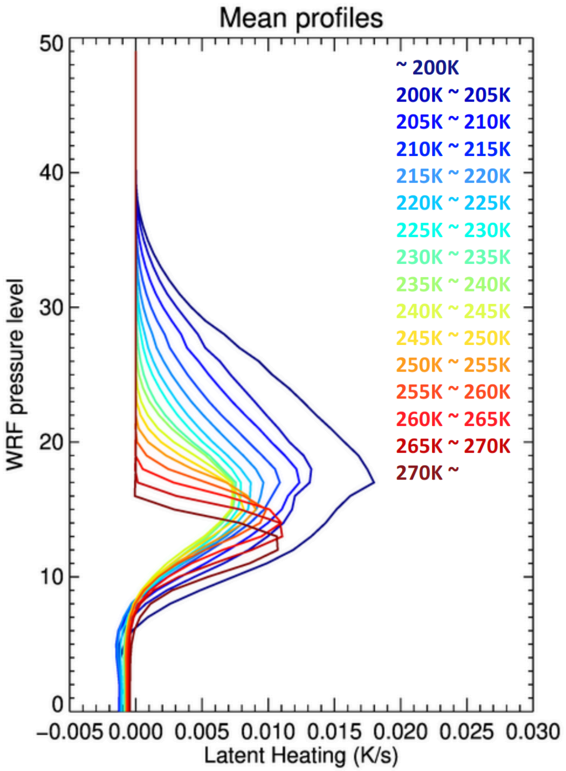


Ongoing and Future Work

- Extending GREMLIN to all conditions using:
    - Larger dataset
    - Deeper model
    - Solar reflective bands
- Vertical profile model
    - Using a fully-connected (dense) NN shows promise based on WRF OSSEs (left panels)
    - Latent heating profiles show expected physical relationship with cloud top temperature (right panel)
- Uncertainty estimator
    - Estimating observation errors for DA
- DA experiments, OSSEs





Yoonjin Lee, PhD Dissertation: Using GOES-16 ABI Data to Detect Convection, Estimate Latent Heating, and Initiate Convection in a High-Resolution Model.

Key Results

- The ability of Convolutional Neural Networks to utilize spatial context is essential for this application and offers breakthrough improvement in skill compared to traditional pixel-by-pixel based approaches.

- The usage of Machine Learning in Data Assimilation applications provides new information content from satellite data that is currently going unused, especially for cloudy and precipitating scenes.

Significance and Broader Impact

- Addresses NOAA goals and NESDIS Strategic Plan
  - Utilization of GOES-R sensors
  - ABI+GLM data fusion
- Supports NWS Commitment to building Weather-Ready Nation
  - Extending the value of satellite imagery and products
  - Improving weather forecast services and numerical predictions
- In addition to data assimilation applications, this work is also relevant to aviation and nowcasting applications
- Contact:
  - Kyle Hilburn (Kyle.Hilburn@colostate.edu)
  - Yoonjin Lee (Yoonjin.Lee@colostate.edu)

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Overview Slides

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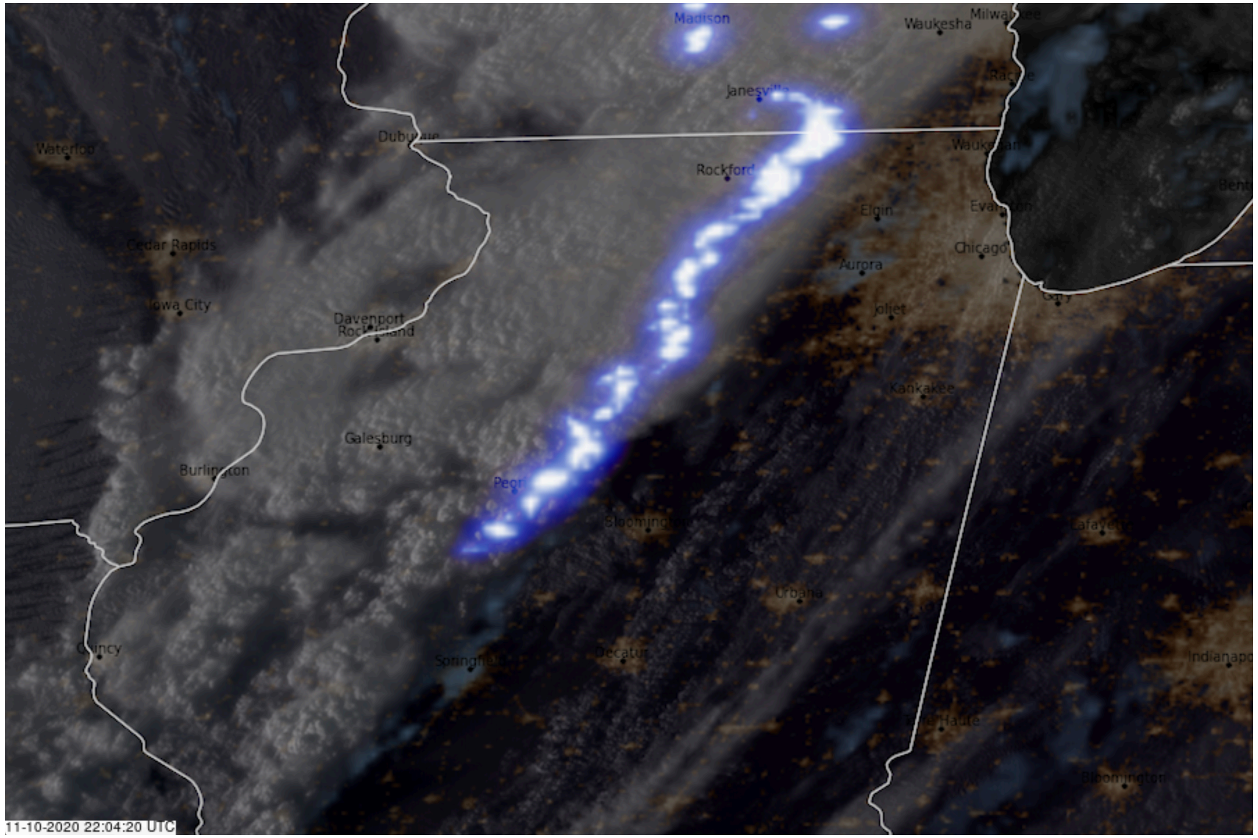

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