Numerical Simulation of Lightning and Electric Charge Structures during LEE

Yonggang Wang, Thomas White, Scott Steiger
Department of Atmospheric and Geological Sciences
SUNY Oswego

Presentation for LEE Science Meeting at SUNY Oswego

July 24th, 2023

Outline

- Motivation & Objective
- Background: lightning parameterization
- Model configuration
- Preliminary results
- Future works

Motivation & Objective

- Uncertainties to accurately model storm electrification
  - Model needs to capture environment and storm
  - Simulated electrification is further sensitive to microphysical and electrical parameterizations

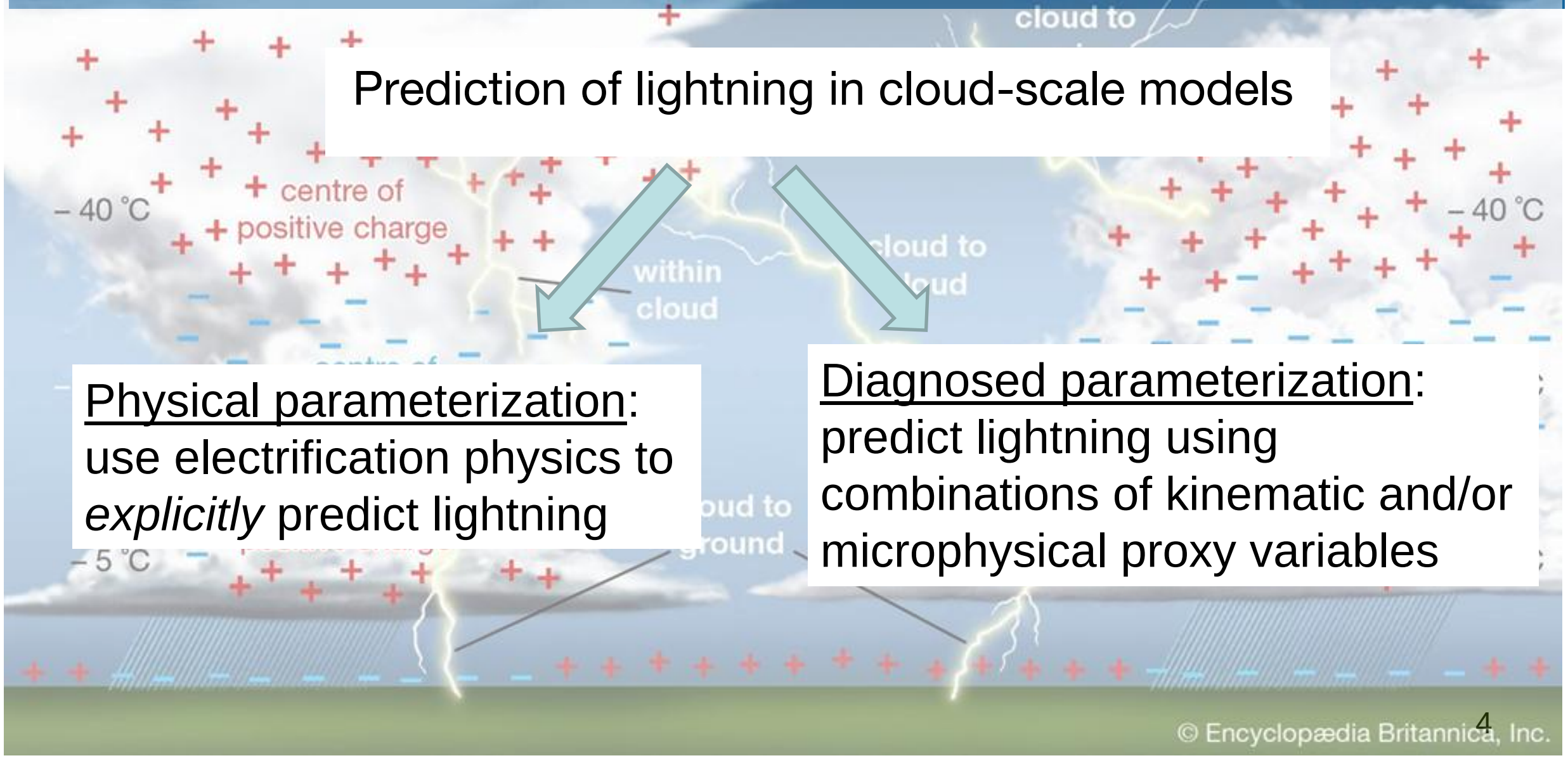
- Observation sets during LEE will help to describe where uncertainties lie

<u>LEE modeling objective</u>

To assess how well electrification numerical modeling performs in lake-effect thunderstorms

Lightning Forecast in NWP

Prediction of lightning in cloud-scale models



<u>Physical parameterization</u>: use electrification physics to *explicitly* predict lightning

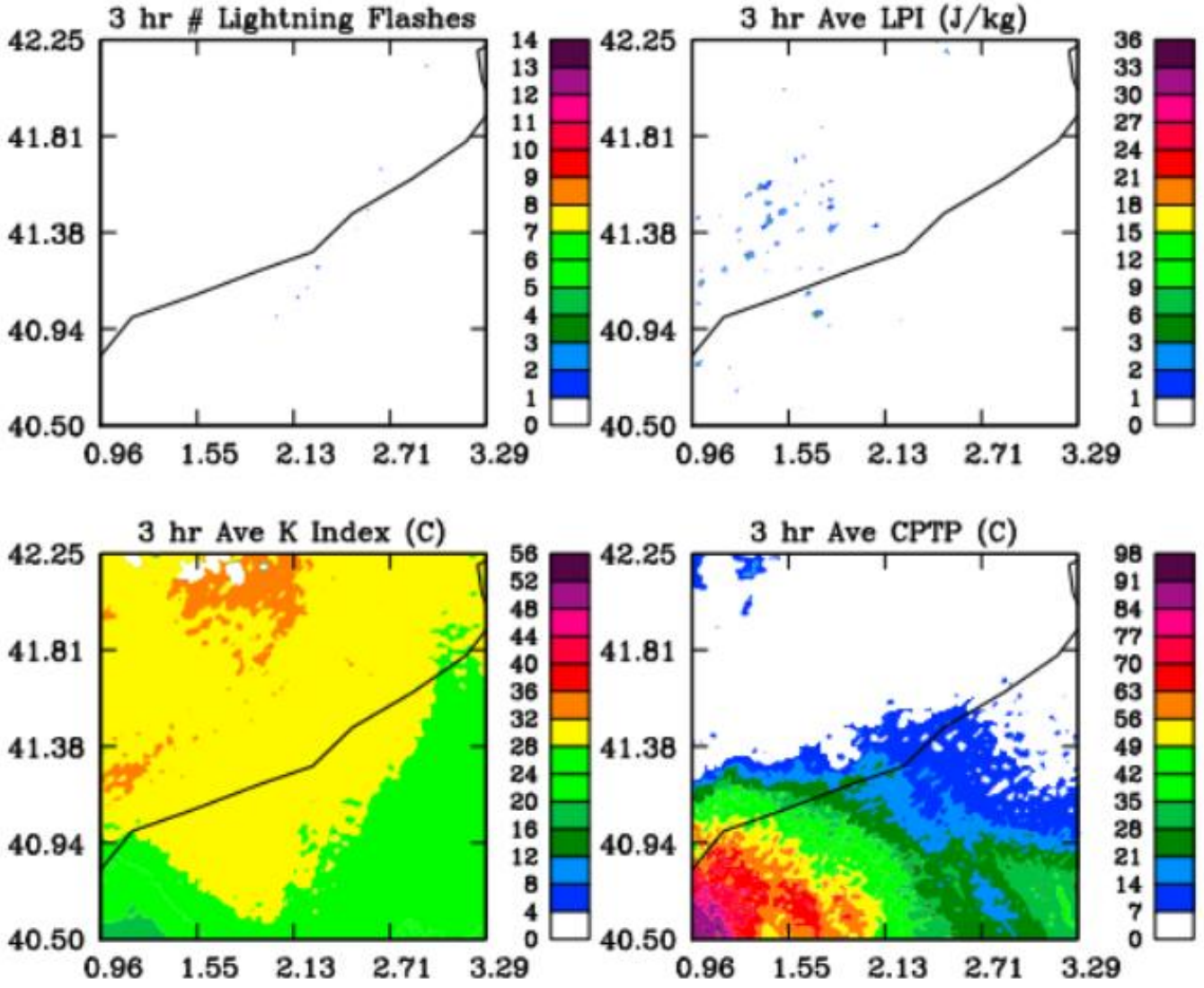
<u>Diagnosed parameterization</u>: predict lightning using combinations of kinematic and/or microphysical proxy variables

Diagnosed Parameterization of Lightning

- K index determines probability of thunderstorms
  - $KI = (T_{850} - T_{500}) + Td_{850} - (T_{700} - Td_{700})$
- Cloud Physics Thunder Parameter provides a “plain view” of where thermodynamics support thunderstorms
  - $CPTP = (-19^{o}C - T_{EL})(CAPE_{-20oC} - K)/K$
- Lightning potential index measures potential for charge generation and separations that leads to lightning flashes
  - $LPI = f(w, Q_{liquid}, Q_{ice}, Q_{snow}, Q_{graupel})$
  - charging zone 0C to -20C?

Yair et al. (2010)

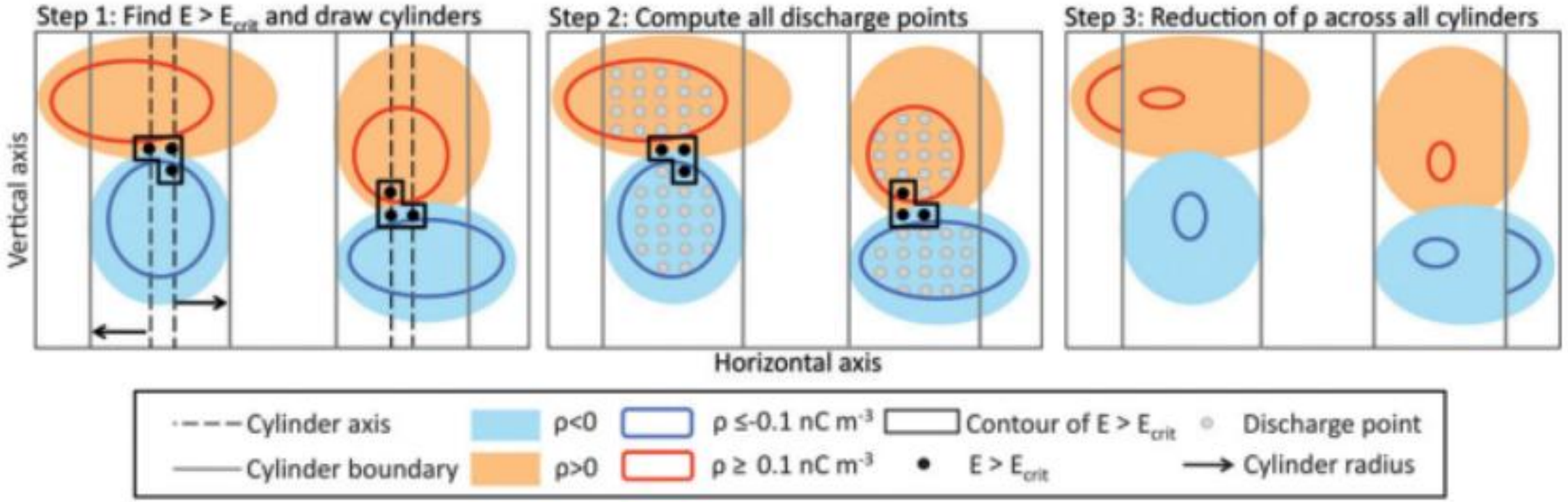
Diagnosed Parameterization of Lightning (cont.)



- LPI showed the most accuracy and precision predicting characteristics of observed lightning

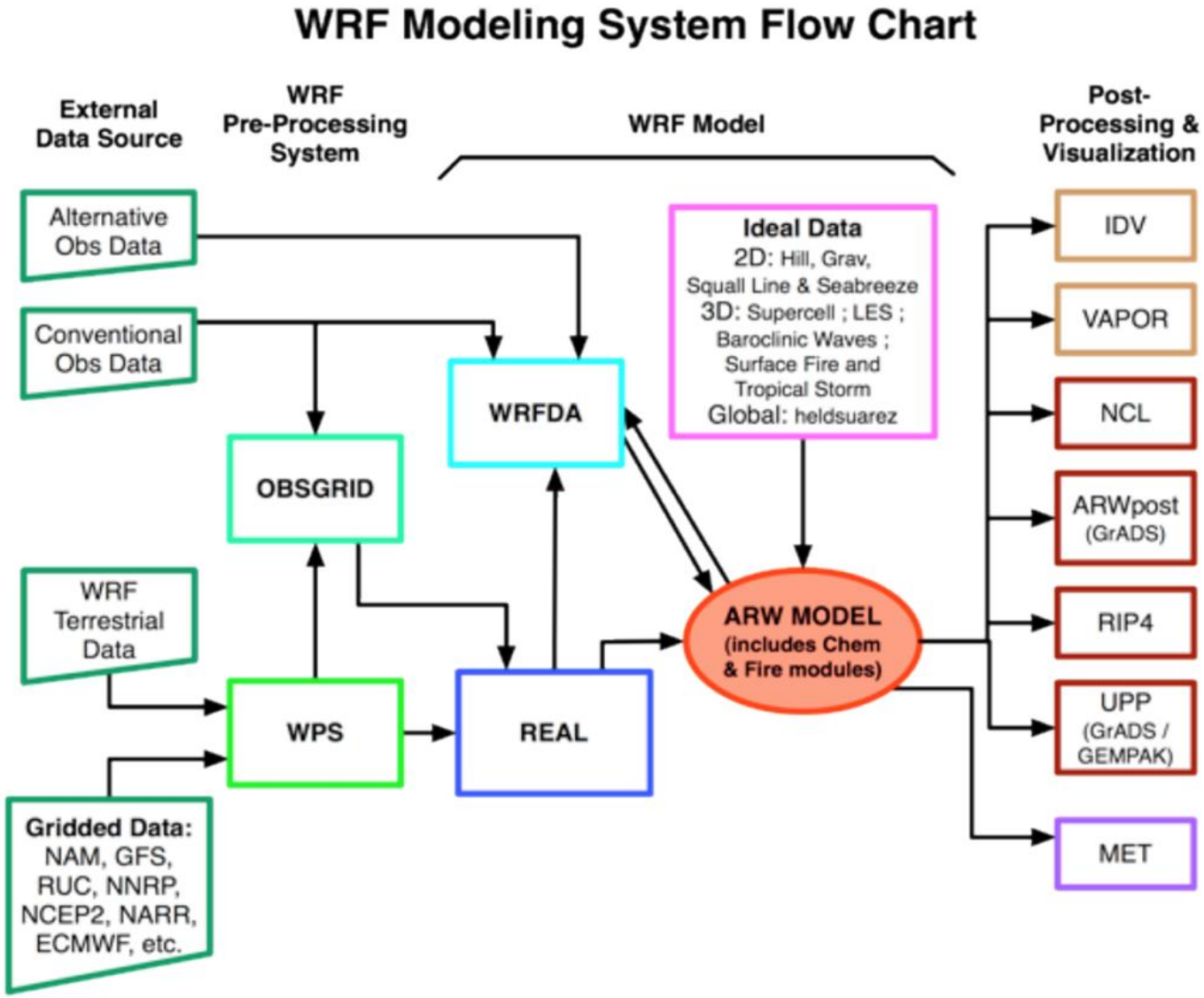
Yair et al. (2010)

Physical Parameterization of Lightning



Fierro et al. (2013) Implemented an explicit charging and discharge lightning scheme within the WRF-ARW Model.

Weather Research & Forecasting (WRF) Model



- Numerical weather prediction system
- Designed for both operational forecasting and atmospheric research

Lightning Parameterization in WRF-ARW

=1 : PR92 based on maximum w; redistributes flashes within dBZ > 20 (for convection resolved simulations)

=2 : PR92 based on 20 dBZ top; redistributes flashes within dBZ > 20 (for convection resolved simulations)

=3 : predicts potential for lightning activity; based on Yair et al., 2010

=11 : PR92 based on level of neutral buoyancy from convective parameterization (for a scale where cumulus parameterization schemes is used; intended for use at 10<dx<50km)

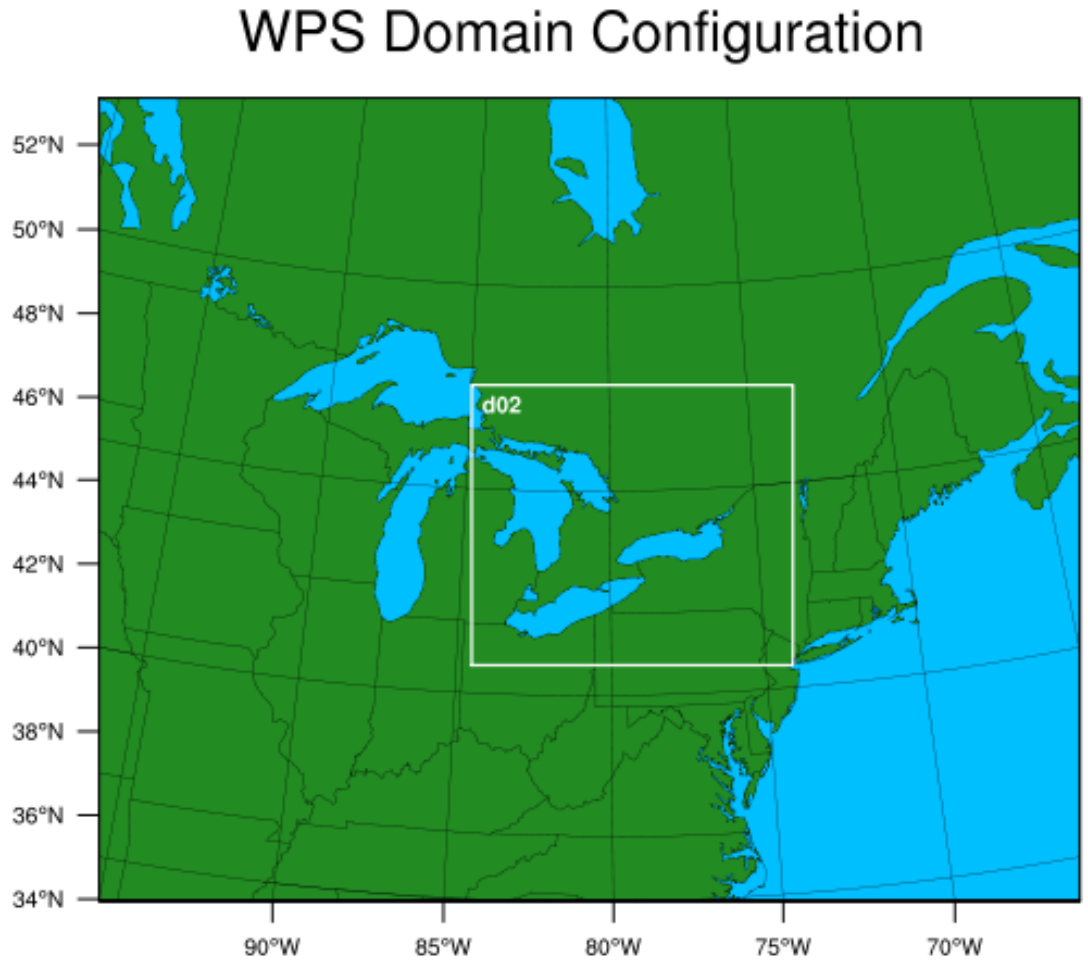
Model Domain

Domain 1:

- 288 grid boxes east to west
- 236 grid boxes north to south
- 9 km spatial resolution

Domain 2:

- 283 grid boxes east to west
- 247 grid boxes north to south
- 3 km spatial resolution



Initialization Data

- Sensitivity study by Gharaylou et al. (2020)
  - WRF-Elec simulations used ERA-interim data, National Centers for Environmental Prediction Final Analysis (NCEP-FNL) data and the NCEP operation GFS data
  - ERA data shows most success in overall lightning activity prediction (specific flash location)
  - GFS data shows most success in number of lighting flash density (flashes per grid box)

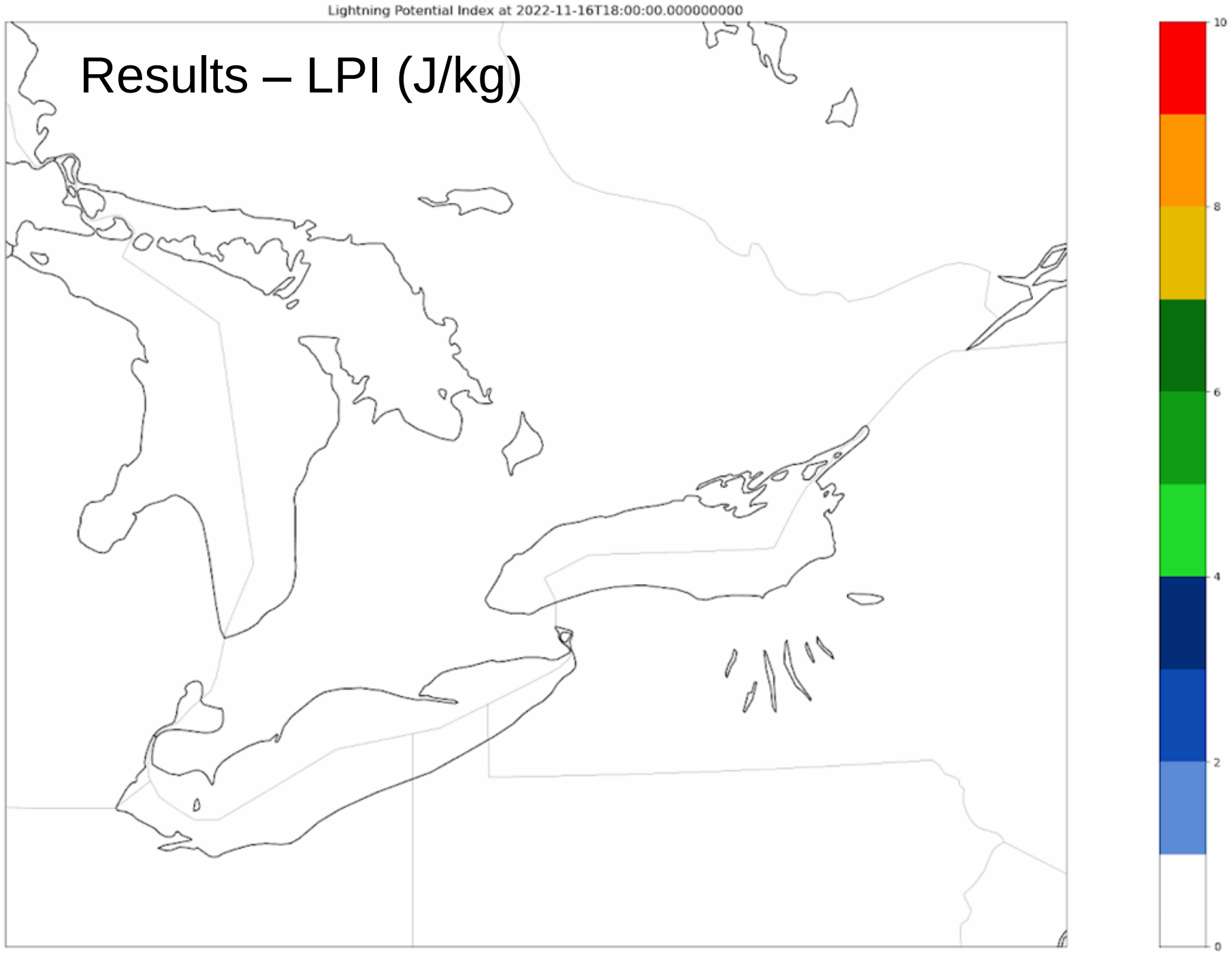
Grid Cell Size & Microphysics

- Sensitivity study by Sokol and Minářová (2020)
  - Used the COSMO NWP model to study summer thunderstorm
  - Performed sensitivity tests of horizontal resolution: 1.2 km vs. 2.2 km
  - Performed sensitivity tests of cloud microphysics scheme: 1-moment vs. 2-moment
  - Prediction (LPI) was more successful for models having higher resolution and for simulations using 2-moment cloud microphysics

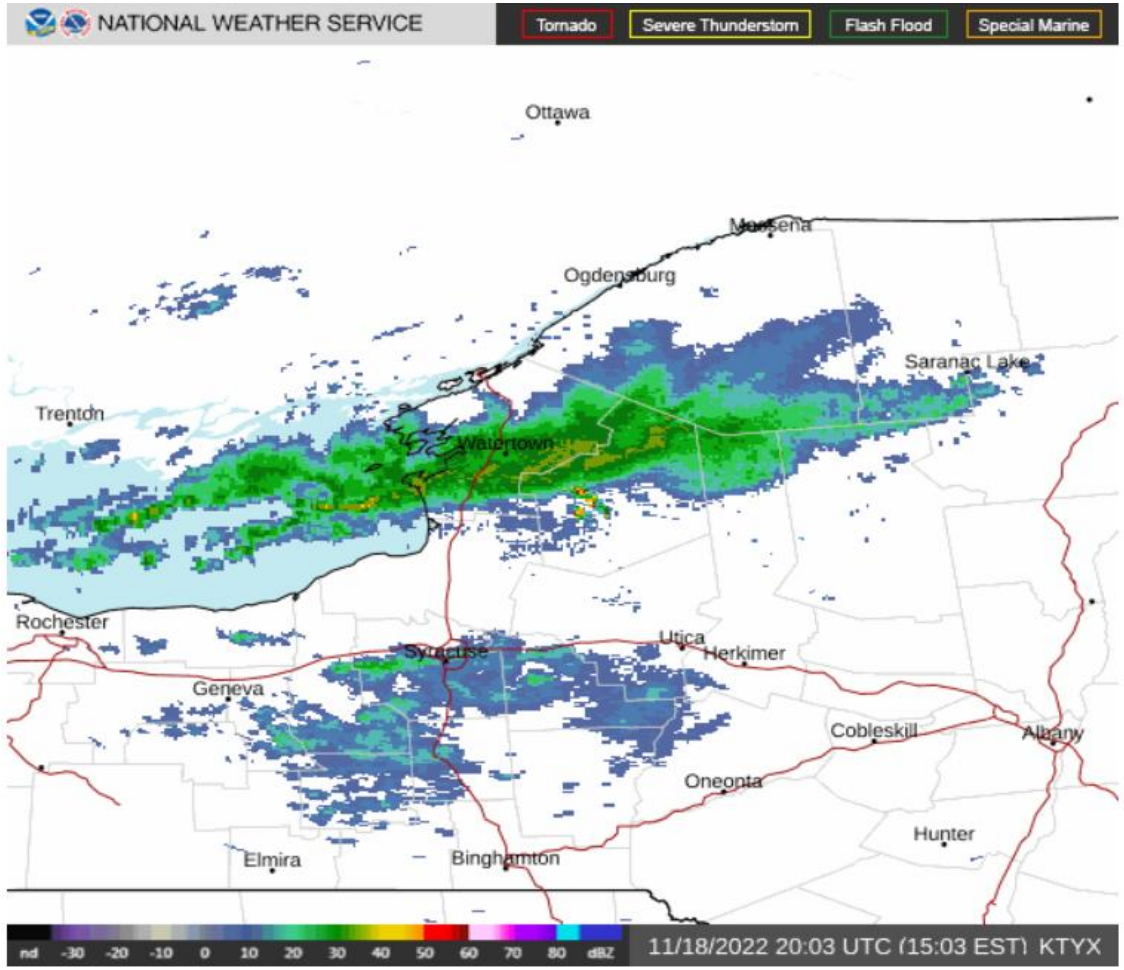
Model Configuration

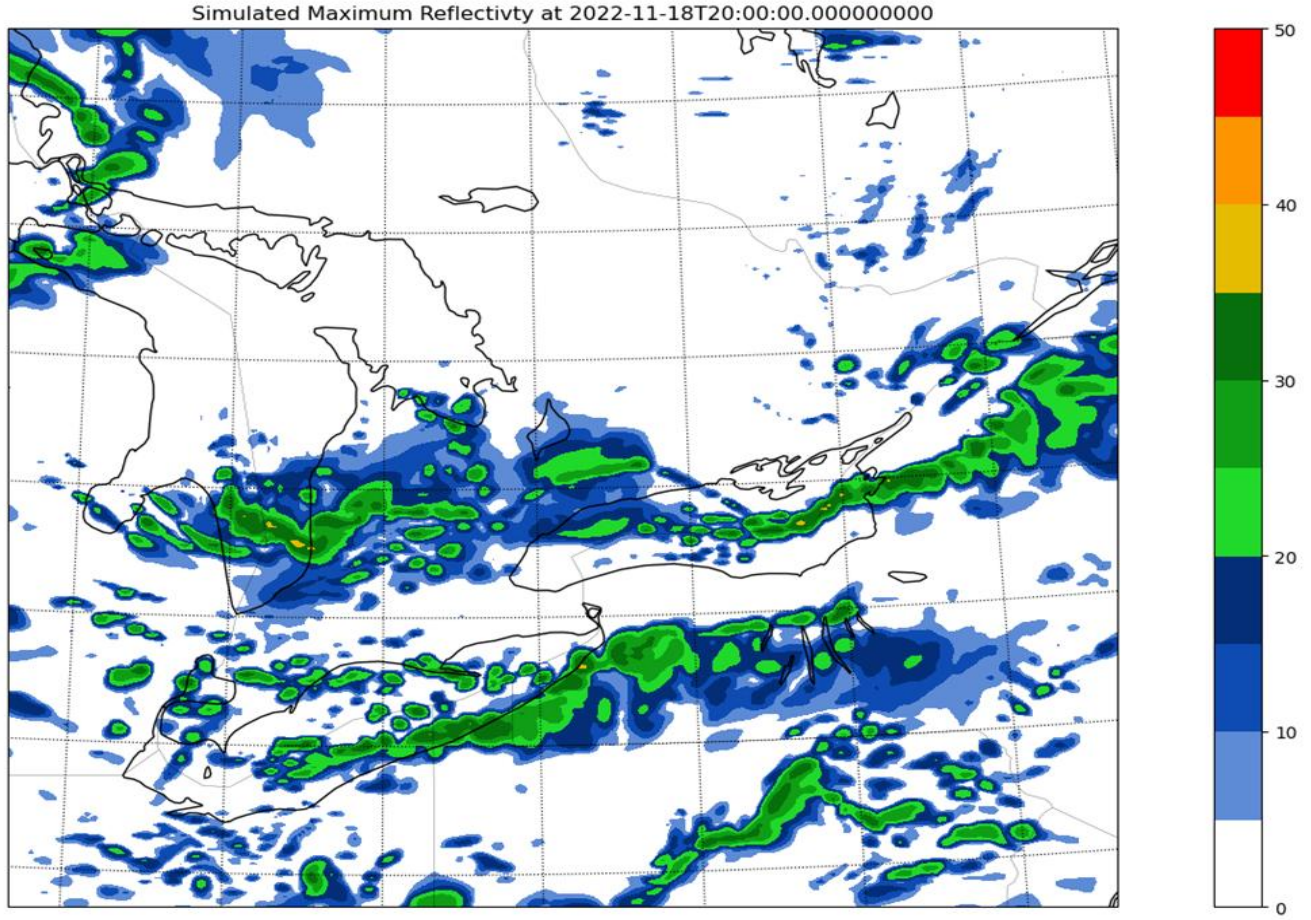
- Driven by ECMWF Reanalysis v5 (ERA5)
- Time period: 11/16/2022 18Z – 11/19/2022 00Z (LEE IOP2)
- Microphysics: NSSL 2-moment & Morrison 2-moment schemes
- Cumulus: Grell-Freitas for outer domain only
- LW & SW radiation: RRTMG
- PBL: YSU
- Feedback = 1 (two-way nested grid)
- Lightning option: 3, Predicts Lightning Potential based on *Yair et al. (2010)*

Results – LPI (J/kg)



Composite Reflectivity – Radar vs. WRF



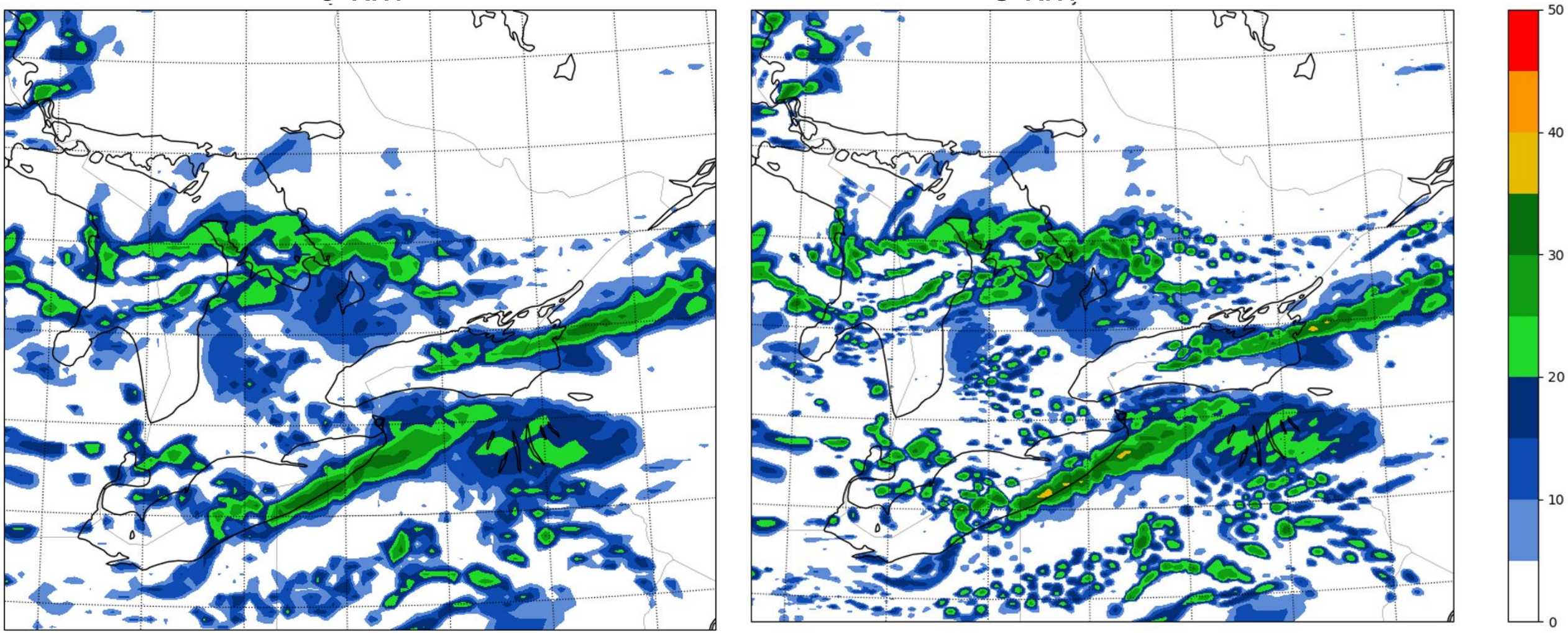


11/18/2022 20Z

Sensitivity to Grid Cell Size

9 km

3 km

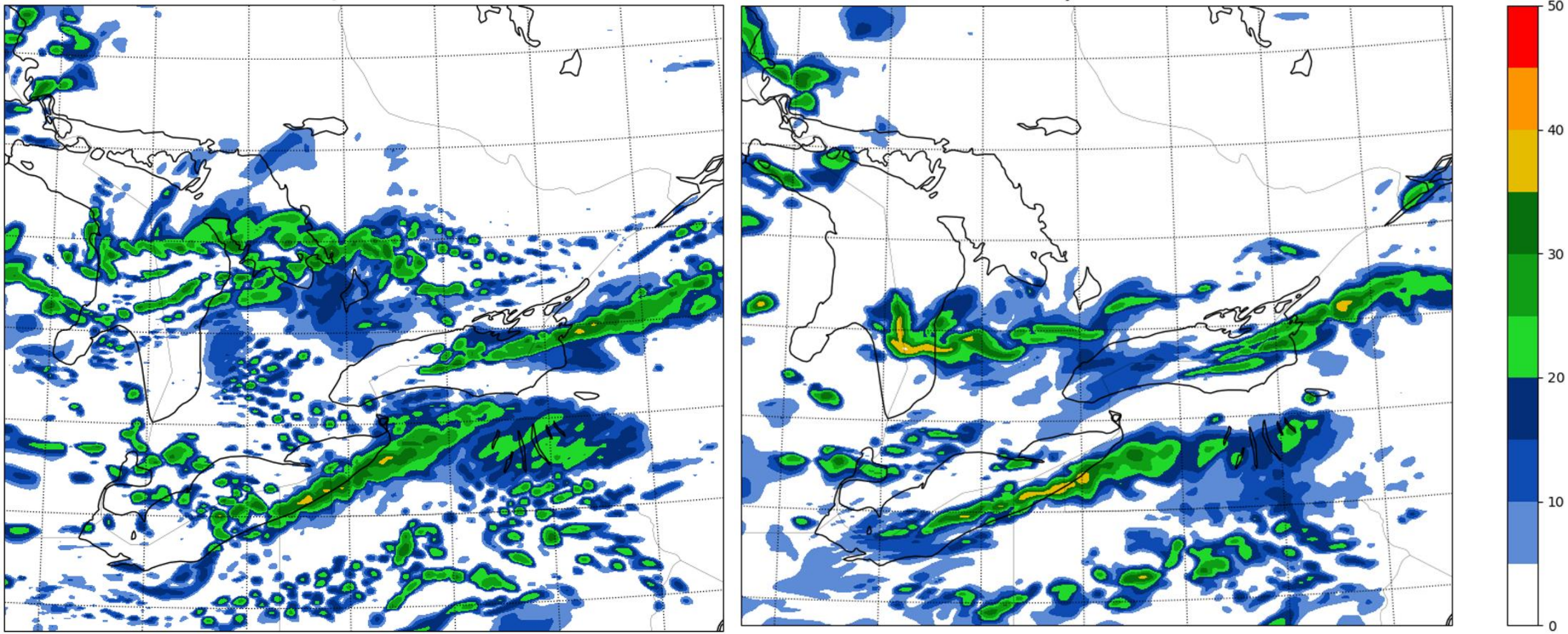


11/18/2022 20Z: composite reflectivity

Sensitivity to Microphysics Scheme

NSSL 2-moment

Morrison 2-moment



11/18/2022 20Z: composite reflectivity (3 km)

Future Works

- Further model evaluation
- Simulation of IOP2 using WRF-Elec (many thanks to Ted Mansell and John Trostel!)

- Questions for discussion
  - Finer horizontal resolution?
  - Recommendation for the next IOP to simulate?
  - Idealized simulation?

Thank You!