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# Forecasting Dynamic Line Rating with Spatial Variation Considerations

## 2021 Grid of the Future

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Idaho National Laboratory

# Outline

- Motivation
- Background
  - Dynamic Line Rating (DLR)
  - Computation Fluid Dynamics (CFD)
  - High-Resolution Rapid Refresh (HRRR) forecast model
  - General Line Ampacity State Solver (GLASS)
- Case Study Methodology
  - Study region
  - CFD mesh
  - GLASS with different spatial resolution
- Results

# Motivation

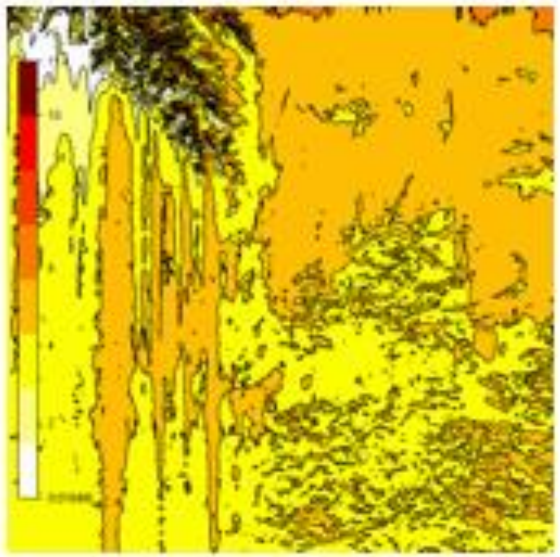
- Large interest by transmission operators to increase the ampacity of lines
  - Economic reasons, congestion
  - Dynamic Line Ratings (DLR)
    - Often provides additional ampacity
- DLR can vary along path of line
  - Dense DLR devices needed to identify limiting section
  - Direct monitoring solutions often require outages to install
  - Can be very costly
- Coupling DLR with CFD simulations
  - CFD provides wind field results at fine resolution
  - Outages are not required
  - Weather station needed to ‘validate’ DLR forecast

# Dynamic Line Rating

- Ampacity is the maximum allowable current of a conductor
- DLR allows ampacity calculation with real-time or forecasted weather conditions
- Static line ratings use conservative weather assumptions
- DLR is more accurate and can increase the ampacity of conductor
- CIGRE & IEEE Standards
  - Convective & radiative cooling and solar & joule heating
- Wind speed and direction are primary cooling factors
  - Can have large spatial variations
    - Identifying limiting span challenging
  - Researchers have been investigating CFD

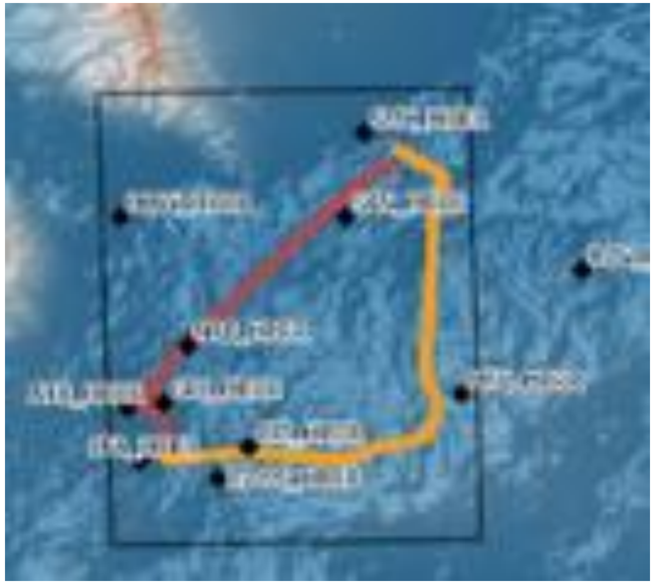
# Computational Fluid Dynamics

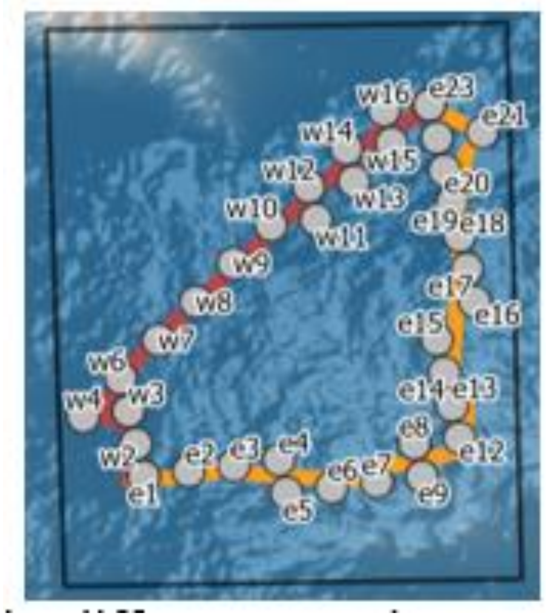
- Simulations to calculate the flow filed (speed and direction) of wind
- Computational mesh or points where flow field is calculated
- WindSim 9.0 Software
  - Steady-state Reynolds-averaged Navier-Stokes (RANS) turbulence model
  - Near ground effects are not resolved
    - Log-law model
    - Terrain data from national land cover database



# High-Resolution Rapid Refresh (HRRR) Model

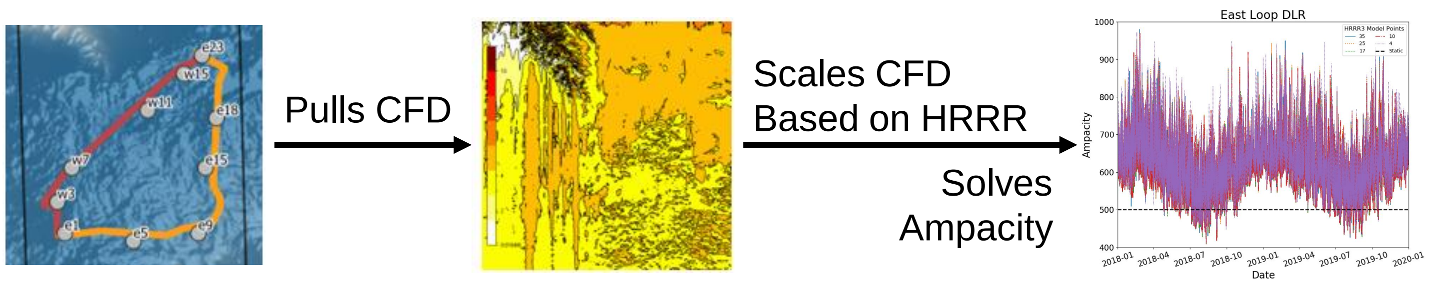
- HRRR forecast model developed by NOAA (National Oceanic and Atmospheric Administration)
- Convection-allowing forecast model that outputs meteorological variables
  - Wind speed and direction
- 3km grid resolution
  - Resolution needed for study





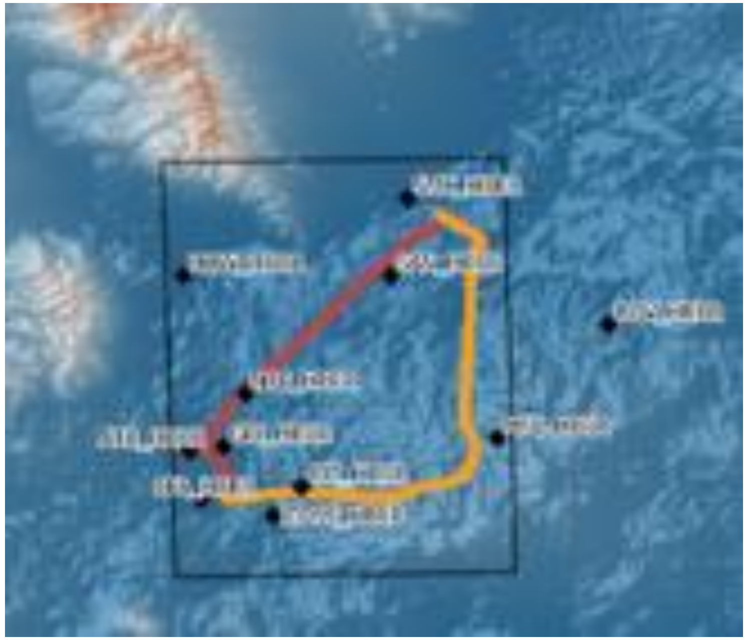
# General Line Ampacity State Solver

- Inputs to glass (constants)
  - Multiple CFD simulation results
  - Transmission line structure locations
  - Conductor type
- HRRR forecast data
  - GLASS pulls most relevant CFD flow field
  - Scales the results accordingly (velocity and directions)
  - IEEE Std. 738 ampacity calculation at mid-points
  - Returns limiting ampacity (DLR) and location



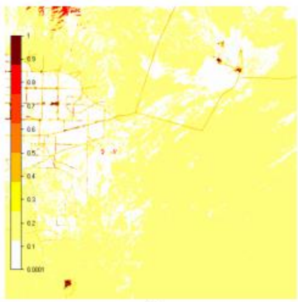
# Case Study Region

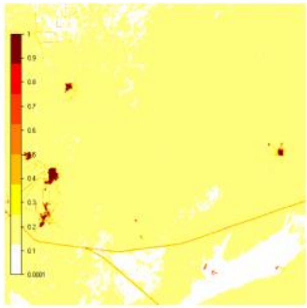
- INL desert is southeastern Idaho
- Area of study in black rectangle
  - 50km in north/south
  - 30km in east/west
- Two transmission lines
  - East Loop
    - 281 support structures
  - West Loop
    - 230 support structures
- Weather station location black markers
  - Not dense enough for study
  - Therefore, HRRR model points are used

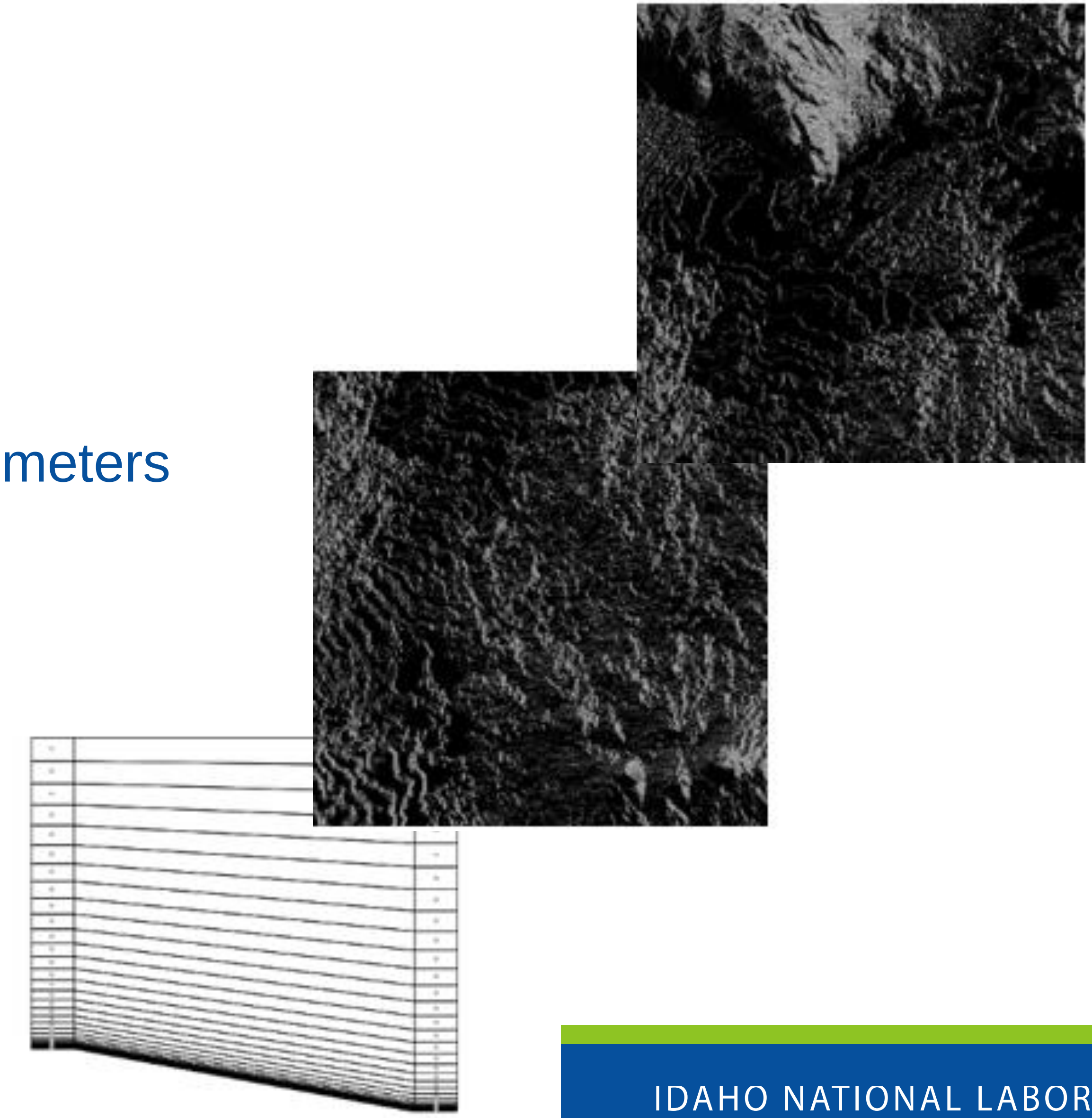


# CFD Mesh and Surface Roughness

- x-y mesh 30m resolution
- z mesh non-uniform resolution
  - 5m up to 50 meters
  - 10m up to 100 meters
  - Growing logarithmic up to 3,500 meters
- Region split into two domains
  - 40 million computational cells
- Surface roughness

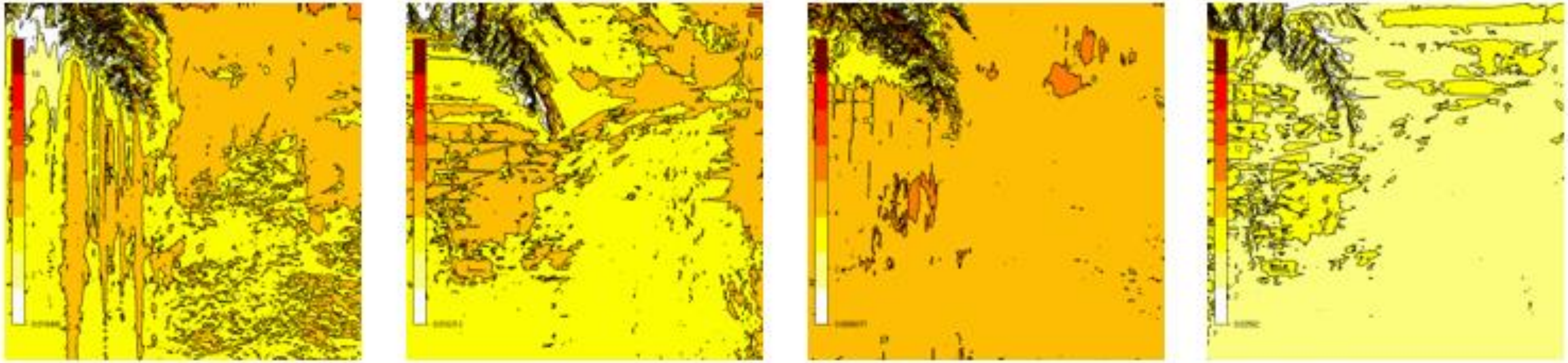




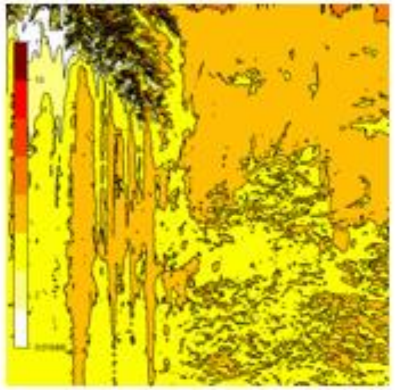


# CFD Flow Field Results

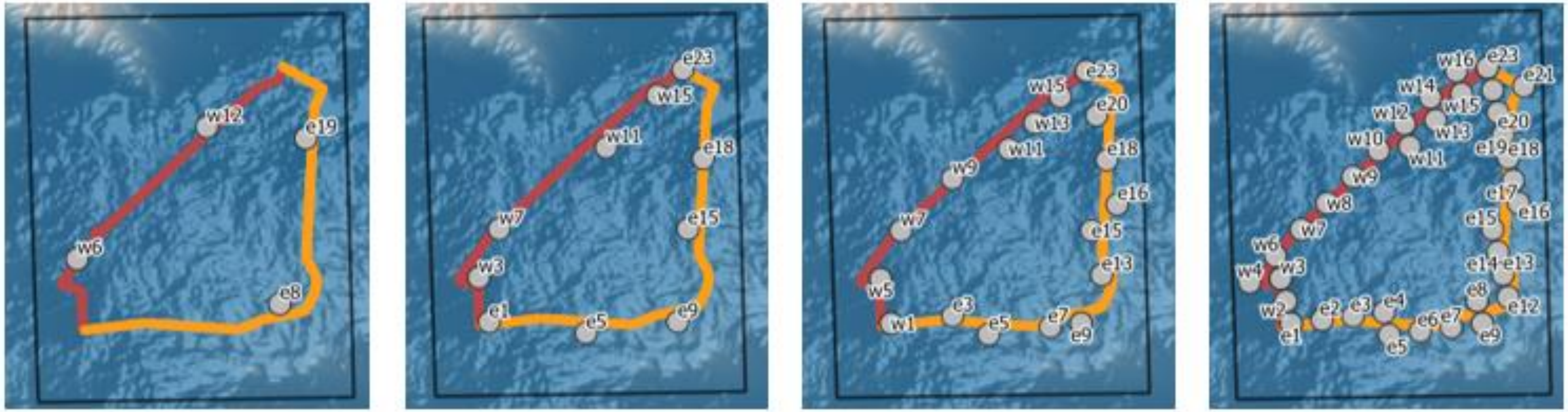
- 12 total simulations
  - 30-degree incoming wind direction
  - 10 m/s velocity
- 10 meter above ground level shown
  - 0, 90, 180, 270-degree incoming wind



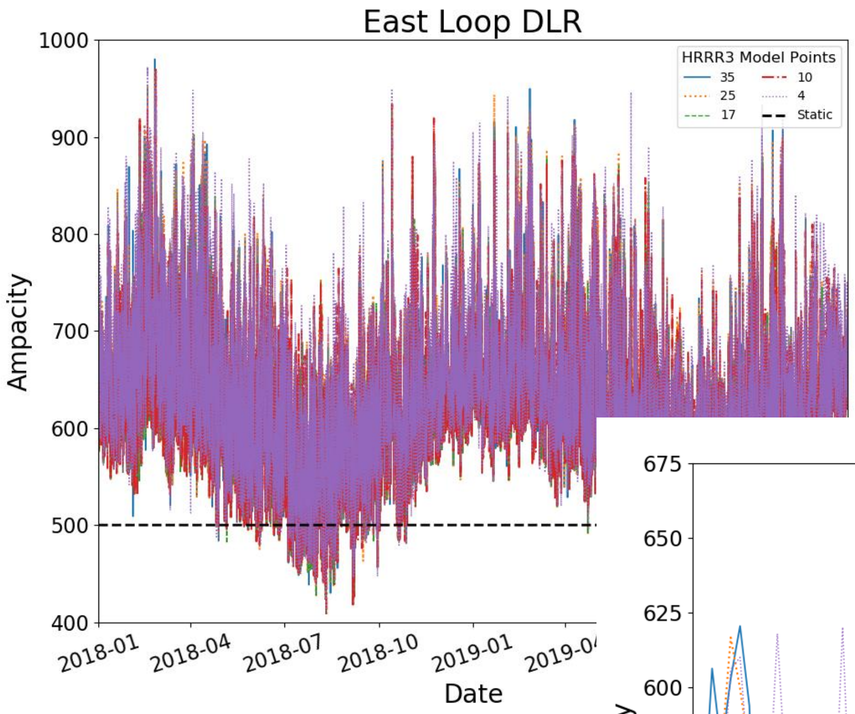
# GLASS Spatial Resolution
# HRRR Model Points

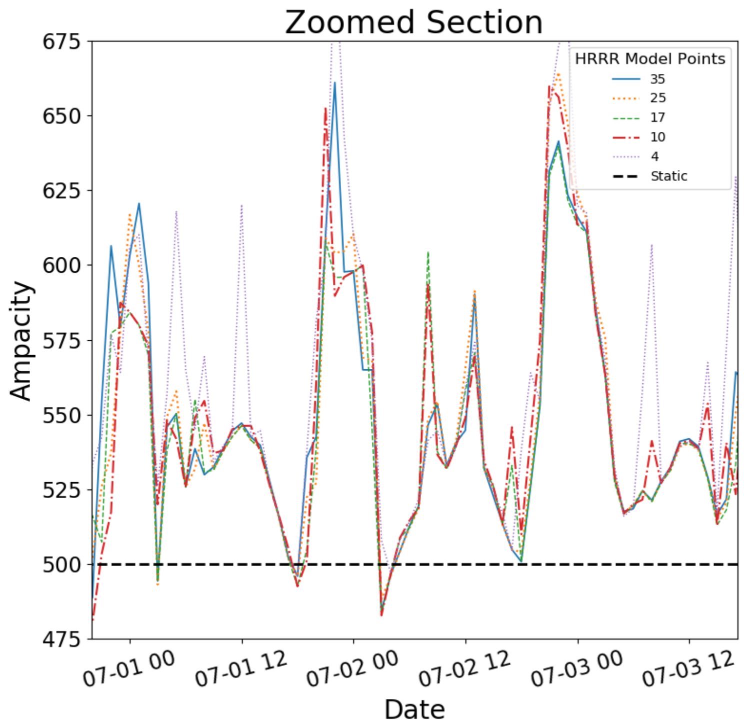


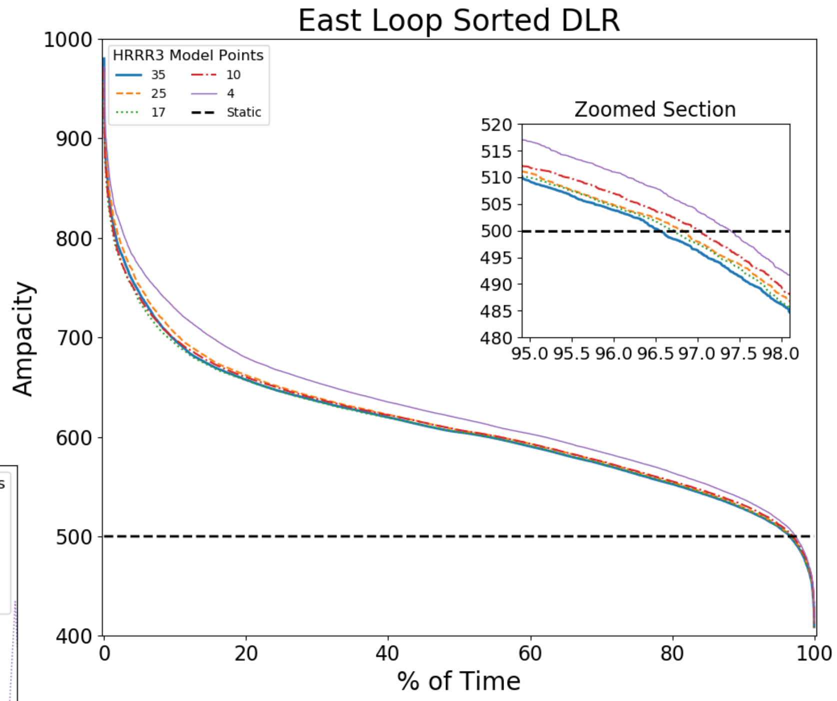
- Five different scenarios with different spatial resolution
  - 4, 10, 17, 26, and 35 HRRR points
  - 25, 10, 6, 4, 3 km spacing
- Points used in GLASS to ‘scale’ CFD result



# DLR vs Number of HRRR Model Points

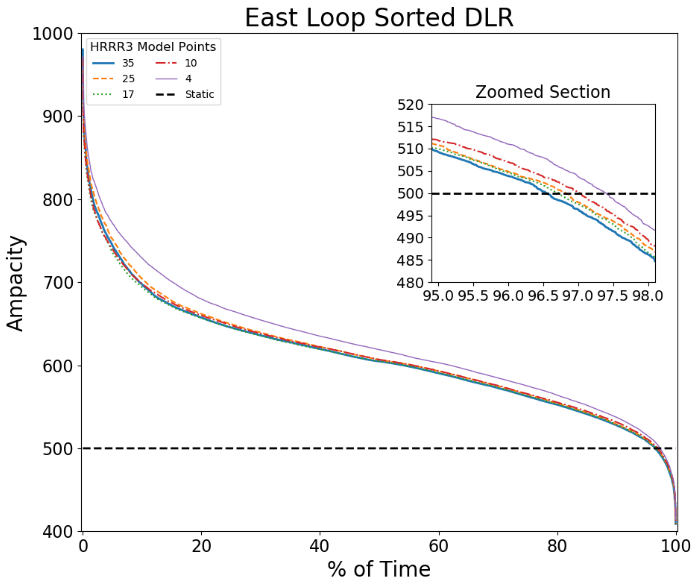


# Tabulated Results

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(x_i - y_i)^2}{n}}$$




| HRRR Model Points | Spacing (km) | East Loop DLR > SLR (% of time) | East Loop RMSE | West Loop DLR > SLR (% of time) | West Loop RMSE |
|---|---|---|---|---|---|
| 4 | 25 | 97.4 | 39.9 | 97.8 | 38.9 |
| 10 | 10 | 97.0 | 27.5 | 97.5 | 26.0 |
| 17 | 6 | 96.7 | 19.1 | 97.1 | 14.5 |
| 26 | 4 | 96.8 | 16.1 | 97.1 | 14.0 |
| 35 | 3 | 96.5 | - | 96.9 | - |

# Conclusion

- Conducted a coupled DLR/CFD case study
  - Spatial resolution HRRR forecast wind data
- Demonstrated that increasing HRRR points decreased DLR
- Demonstrated that additional accuracy diminished with additional HRRR points
- Indicated little change after 6km spacing
  - Spacing of weather stations for validation

# Questions