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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

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- Background
  - Dynamic Line Rating (DLR)
  - Computation Fluid Dynamics (CFD)
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  - General Line Ampacity State Solver (GLASS)
- Methodology
  - Case study region
  - CFD mesh
  - GLASS with different resolution
- Results
  - CFD flow field simulations
  - DLR ampacity results

Motivation

- Large interest by transmission operators to increase the ampacity of lines
  - Economic reasons
  - Dynamic Line Ratings (DLR)
    - Increase penetration of wind generation
    - Decrease wind curtailment
- DLR can vary along path of line
  - Dense weather devices needed to identify limiting section
  - Direct monitoring solutions often require outages to install
  - Can be very costly
- Coupling DLR forecast with CFD simulations
    - CFD provides wind field results at fine resolution

Background

Dynamic line rating

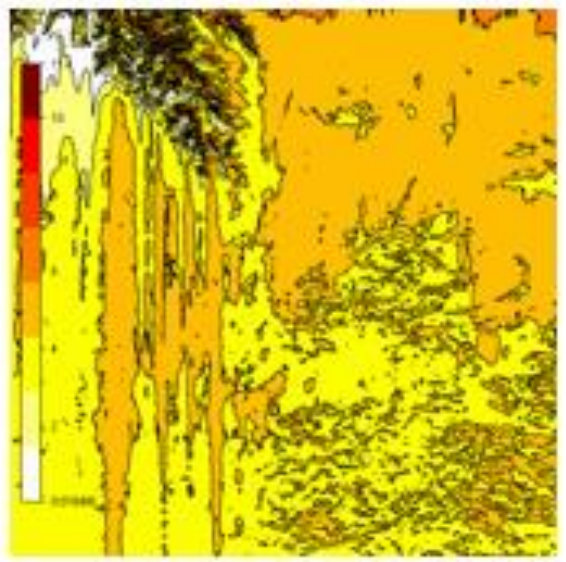
Computational fluid dynamics
High-resolution rapid refresh model
General line ampacity state solver

DLR Ampacity Calculations

- Ampacity is the maximum 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
- IEEE Standard 738 ampacity calculation
  - Convective & radiative cooling and solar & joule heating
  - Wind speed and direction are primary cooling factors
- Wind speed and direction can have large spatial variations
  - Limiting span, single point of highest temperature
  - Accurately identifying limiting span requires high spatial resolution
    - Researchers have been investigating CFD

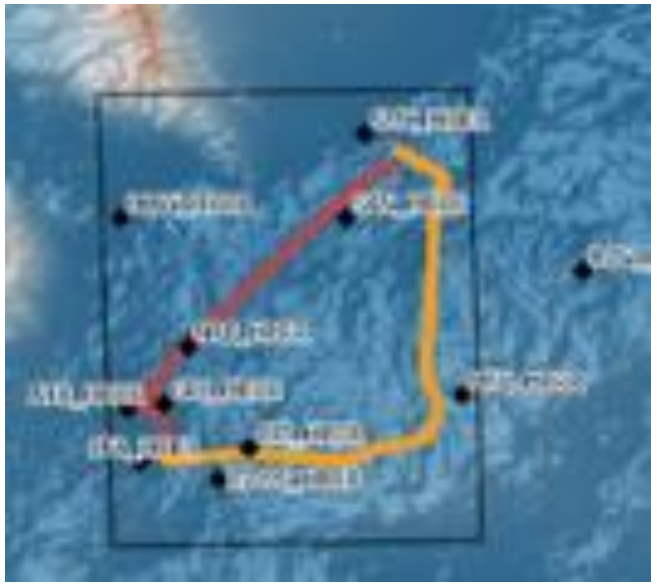
Computational Fluid Dynamics

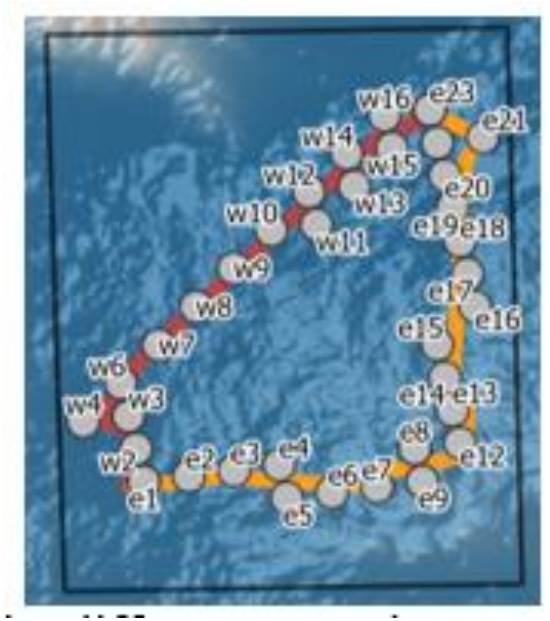
- Simulations to calculate the flow filed (speed and direction) of wind
- Computational mesh or points where flow field is calculated
- WindSim 9.0 Software
  - Steady-state Reynolds-averaged Navier-Stokes (RANS) turbulence model
  - Near ground effects are not resolved
    - Log-law model
    - Terrain data from national land cover database
    - Normalized from 0 to 1



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

- General Line Ampacity State Solver (GLASS) software
  - Inputs to glass (constants)
    - Multiple CFD simulation results
    - Transmission line structure locations
    - Conductor type
    - Assumes full sun
  - HRRR forecast data input based on number of model points
    - 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

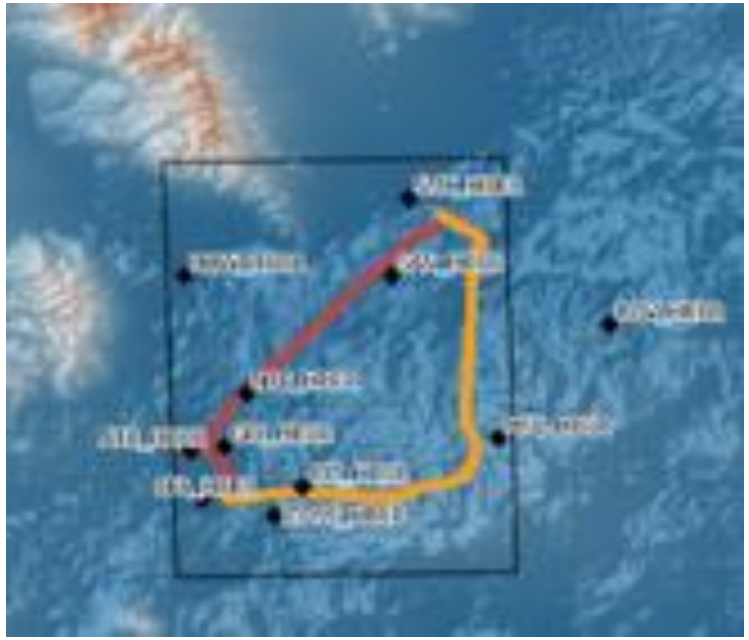
Methodology

Case study region
CFD mesh
GLASS at different resolution

General Line Ampacity State Solver

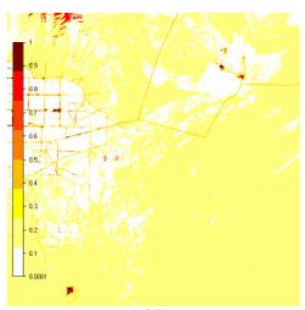
Case Study Region

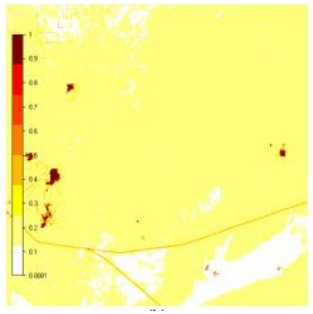
- INL desert is southeastern Idaho
- Area of study in black rectangle
  - 50km in north/south
  - 30km in east/west
- Two transmission lines
  - East Loop
    - 281 support structures
  - West Loop
    - 230 support structures
- Weather station location black markers
  - Not dense enough for study
 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

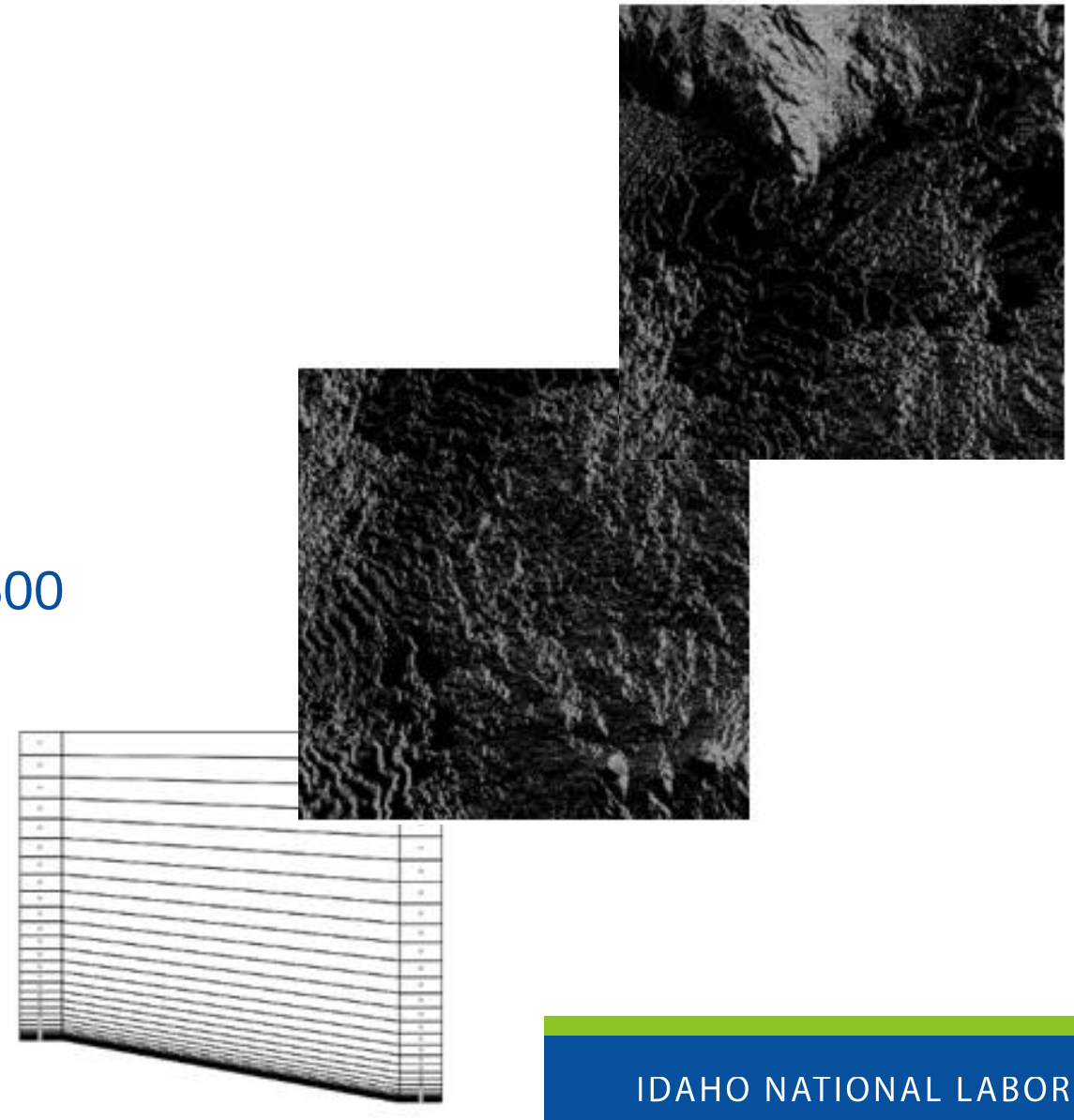


CFD Mesh and Surface Roughness

- Region split into two domains
  - 40 million computational cells
  - 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
  - Surface roughness





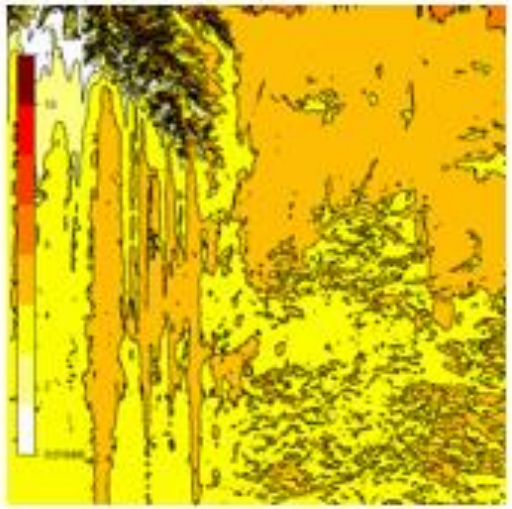
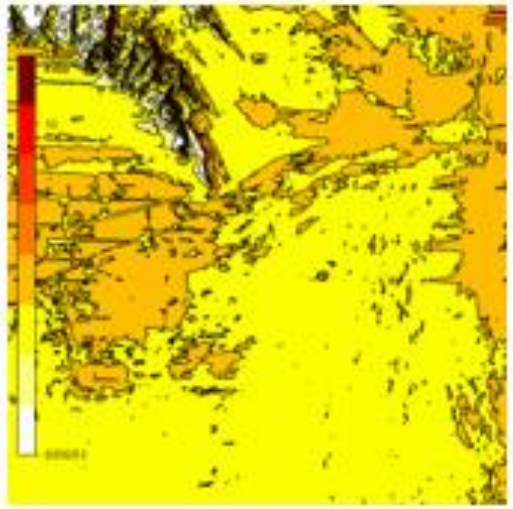
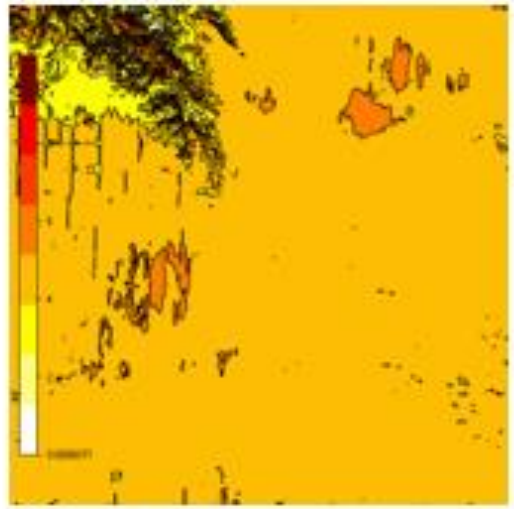
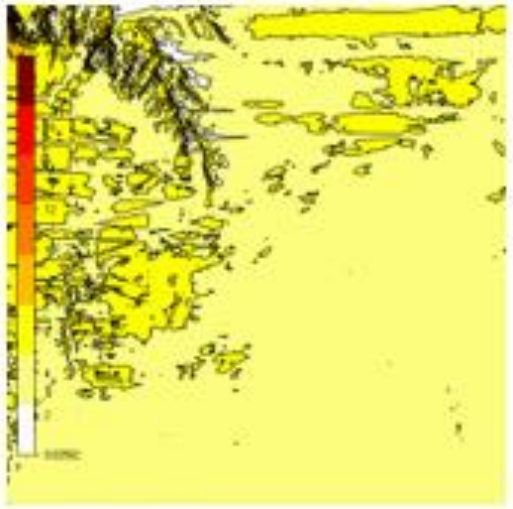


Results

Computational Fluid Dynamics
Dynamic Line Rating

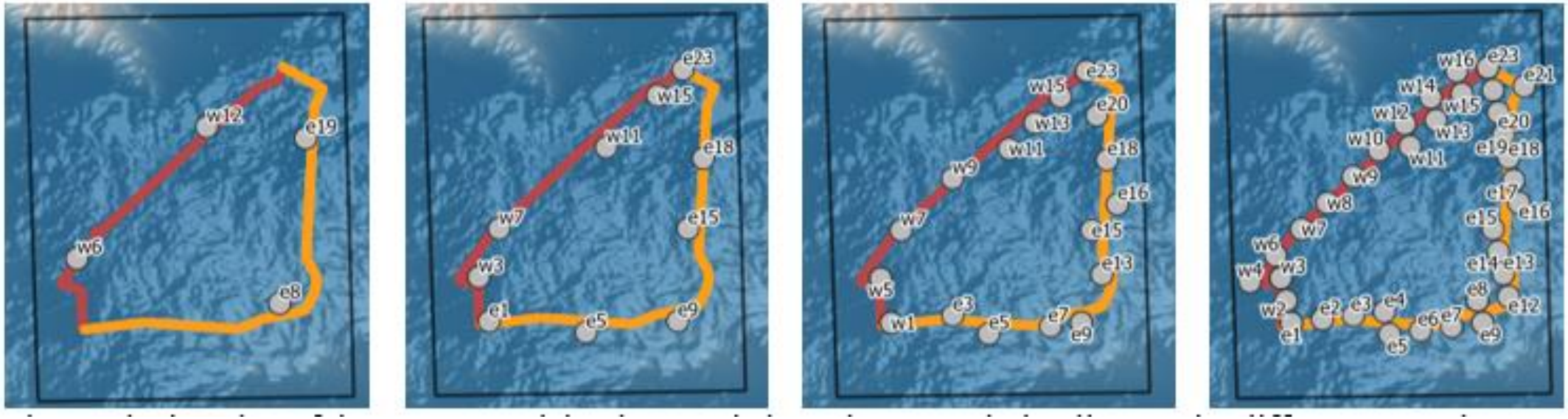
CFD Flow Field Results

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

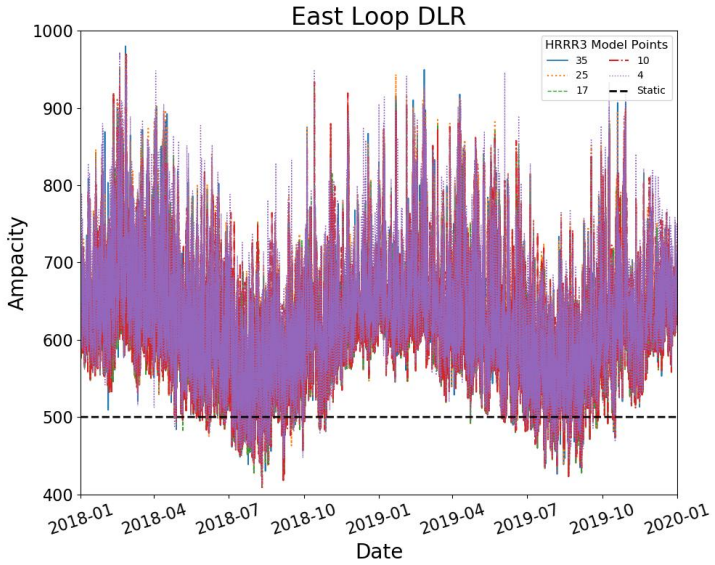





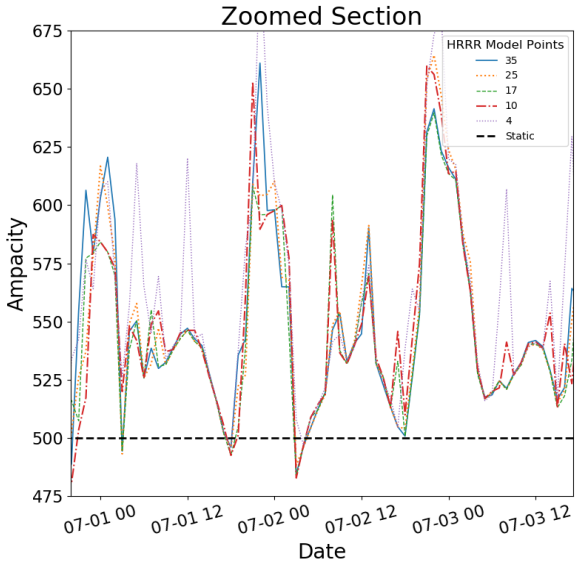
Transmission Line HRRR Model Points

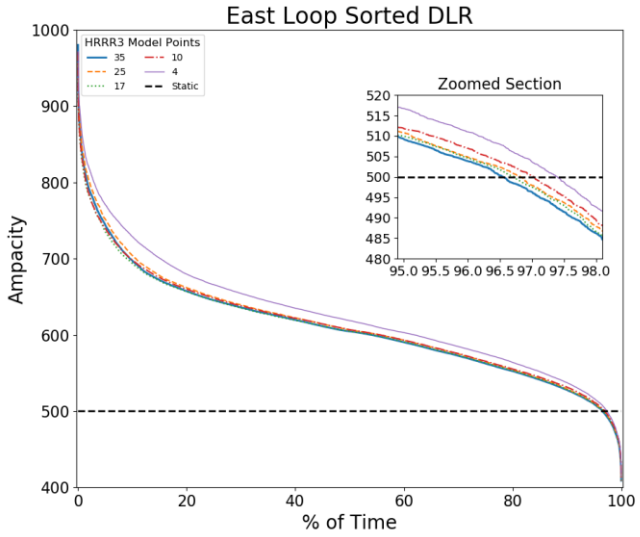
- Five different scenarios with different spatial resolution
  - 4, 10, 17, 26, and 35 model points
  - 25, 10, 6, 4, 3 km spacing between sites

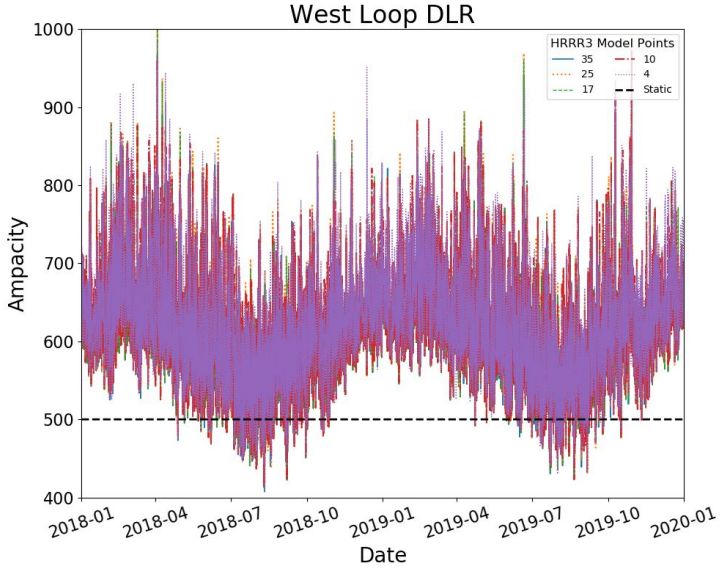


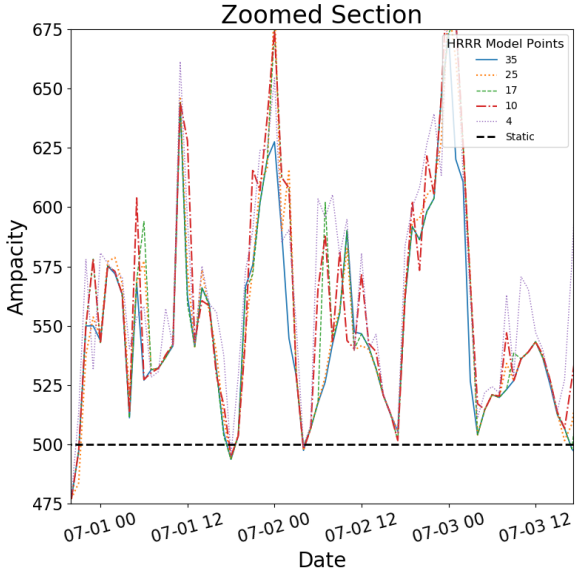
DLR vs Number of HRRR Model Points

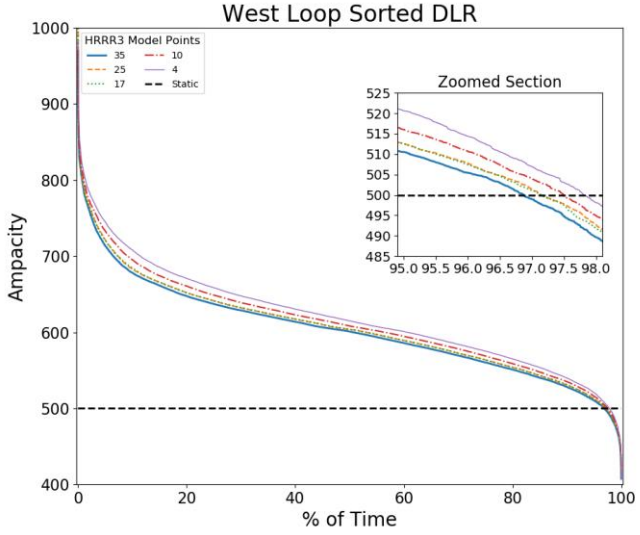






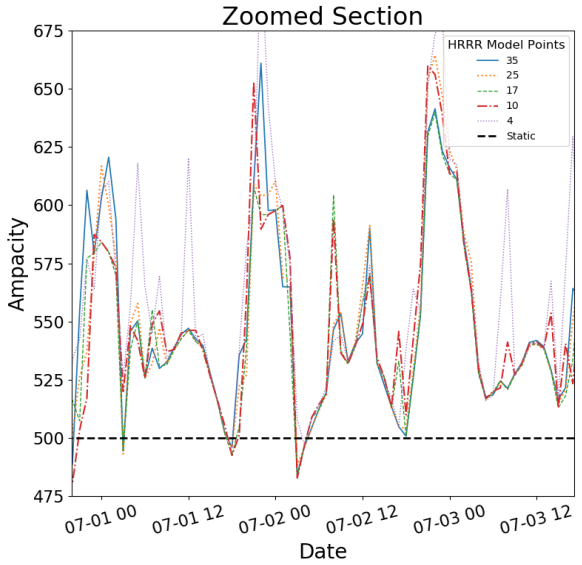


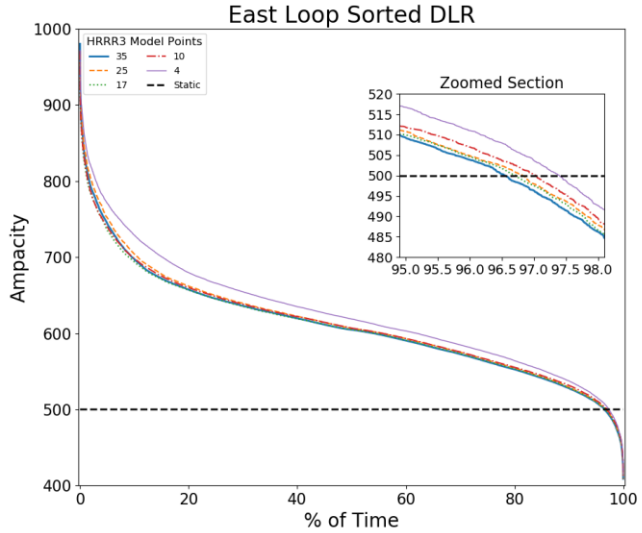




Tabulated Results

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





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 of ‘weather stations’
- Demonstrated that increasing stations decreased (more accurate) DLR
- Demonstrated that additional accuracy diminished with additional stations
- Showed that spacing of 6km most ‘economical’ resolution
  - Further study in cost/benefit needed

Questions