Golden Eagle Behavioral Modeling Enabled by High-Fidelity Atmospheric Models

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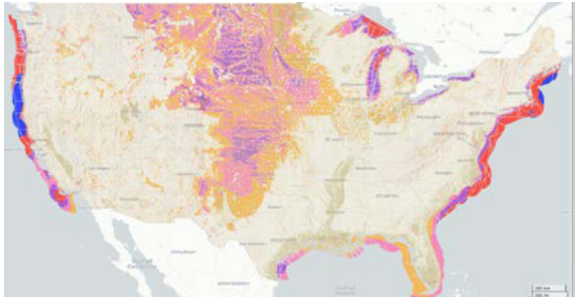
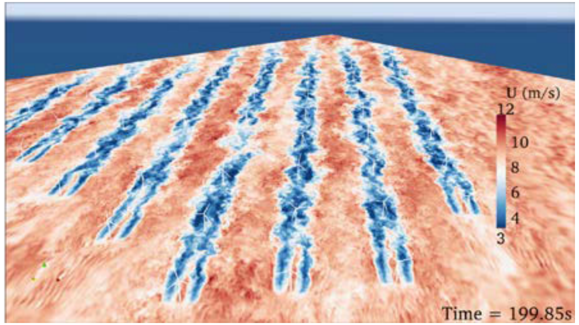
Objective: Combine knowledge of eagle behavior, eagle telemetry data, atmospheric and wind power plant flow models, and machine learning to develop tools that predict behavior and risk around wind power plants.

The U.S. Department of Energy Wind Energy Technologies Office funded a 2-year project that will develop two models:

Mesoscale model to characterize soaring habitat—*25% total effort*:
Characterize soaring habitat across the contiguous United States using atmospheric modeling methods and knowledge of golden eagle flight dynamics.

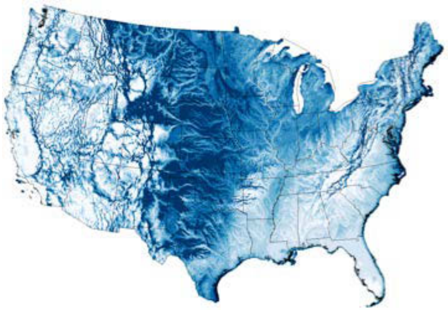


Microscale model to predict behavior and risk—*75% total effort*:
Wind power plant-scale eagle flight trajectory prediction tool that uses high-fidelity wind flow models, machine learning methods, and eagle telemetry data.



Mesoscale Methods

Flow modeling:



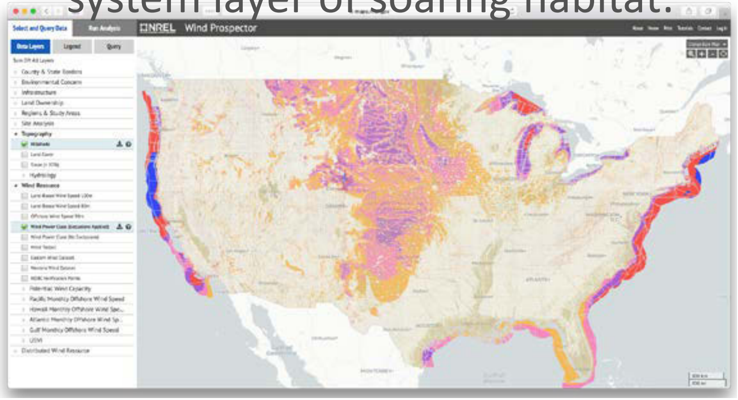
- Improved 20-year hindcast of flow across the United States
- 2-km spatial resolution
- 5-min temporal resolution
- Detailed terrain maps
- Parameterizations of thermals.

Eagle flight physics:

Photo by Lee Jay Fingersh / NREL

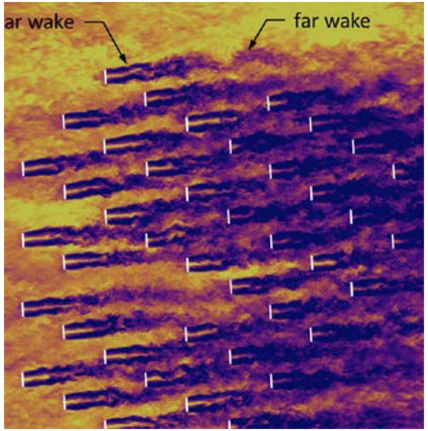
- Updraft velocity needed to sustain soaring flight
- Understanding atmospheric variables that influence flight.

Product: Geographic information system layer of soaring habitat:

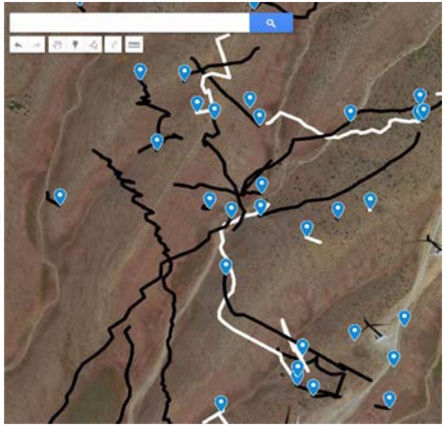


- Will be made available through NREL Wind Integration National Dataset (WIND) Toolkit
- Provide detailed information that can help improve existing mesoscale golden eagle presence, risk, and behavior models (e.g., USFWS models).

Microscale Methods



Numerical wind power plant modeling



Telemetry data and **knowledge of eagle behavior**

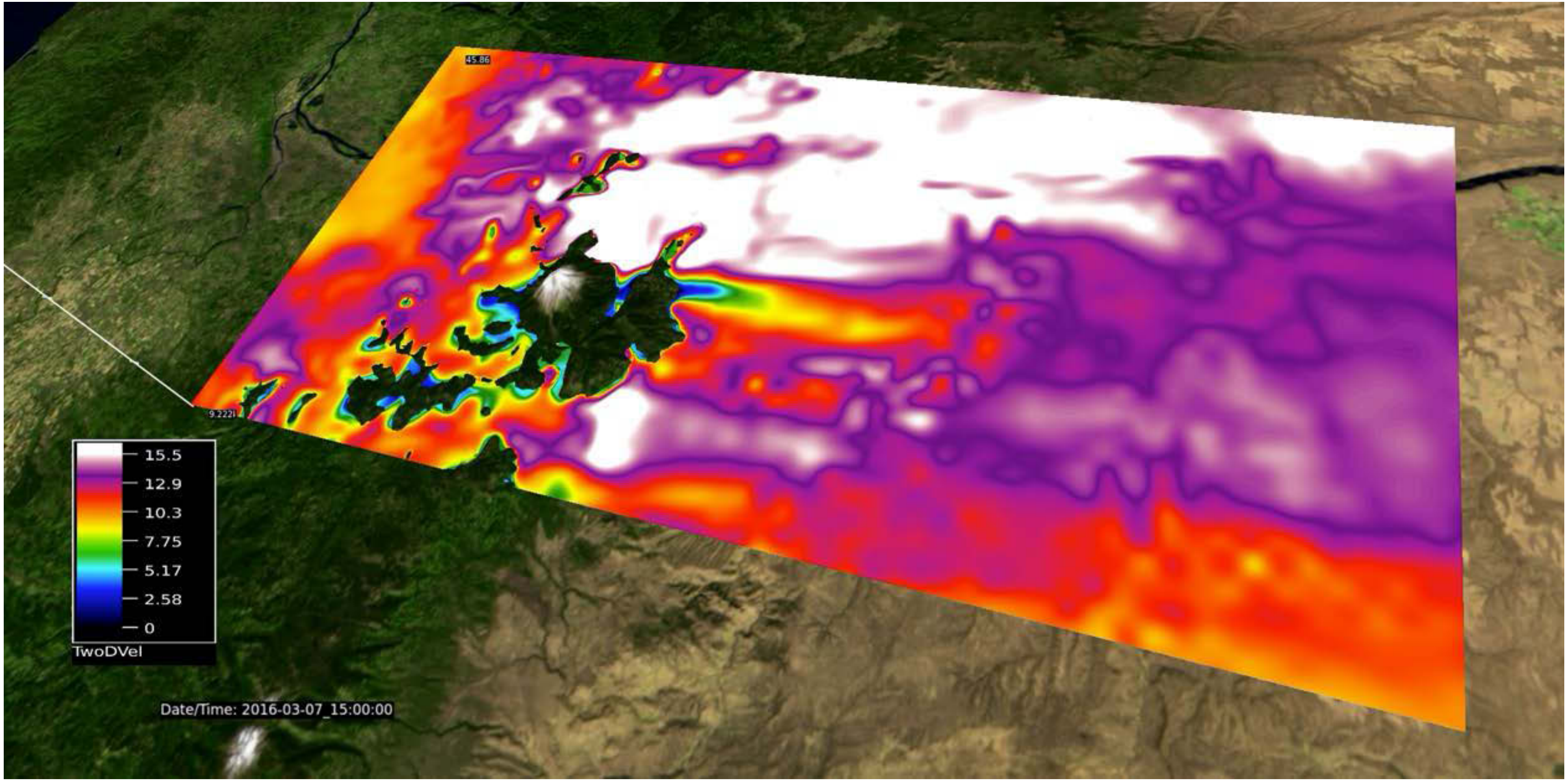
Machine learning and heuristics

An **open-source eagle behavior and risk modeling tool** that can:

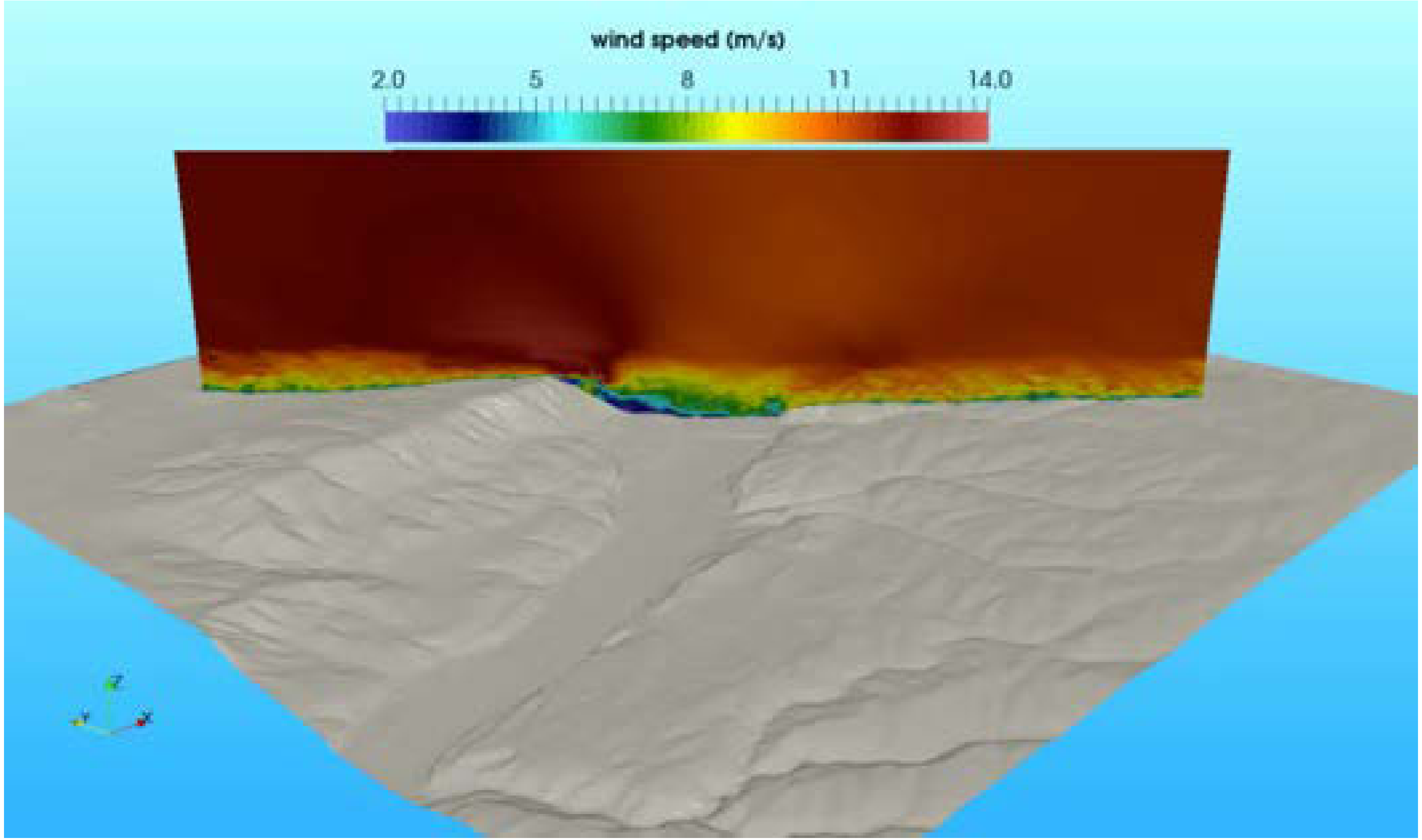
- Model **atmospheric flows and terrain**
- **Help site wind turbines within wind power plants to minimize** risk to **golden eagles**
- **Identify conditions associated with high likelihood of golden eagle presence and** risk
- **Optimize investments in impact minimization technologies**
- **Help develop golden eagle impact mitigation strategies.**

A Multiscale Problem

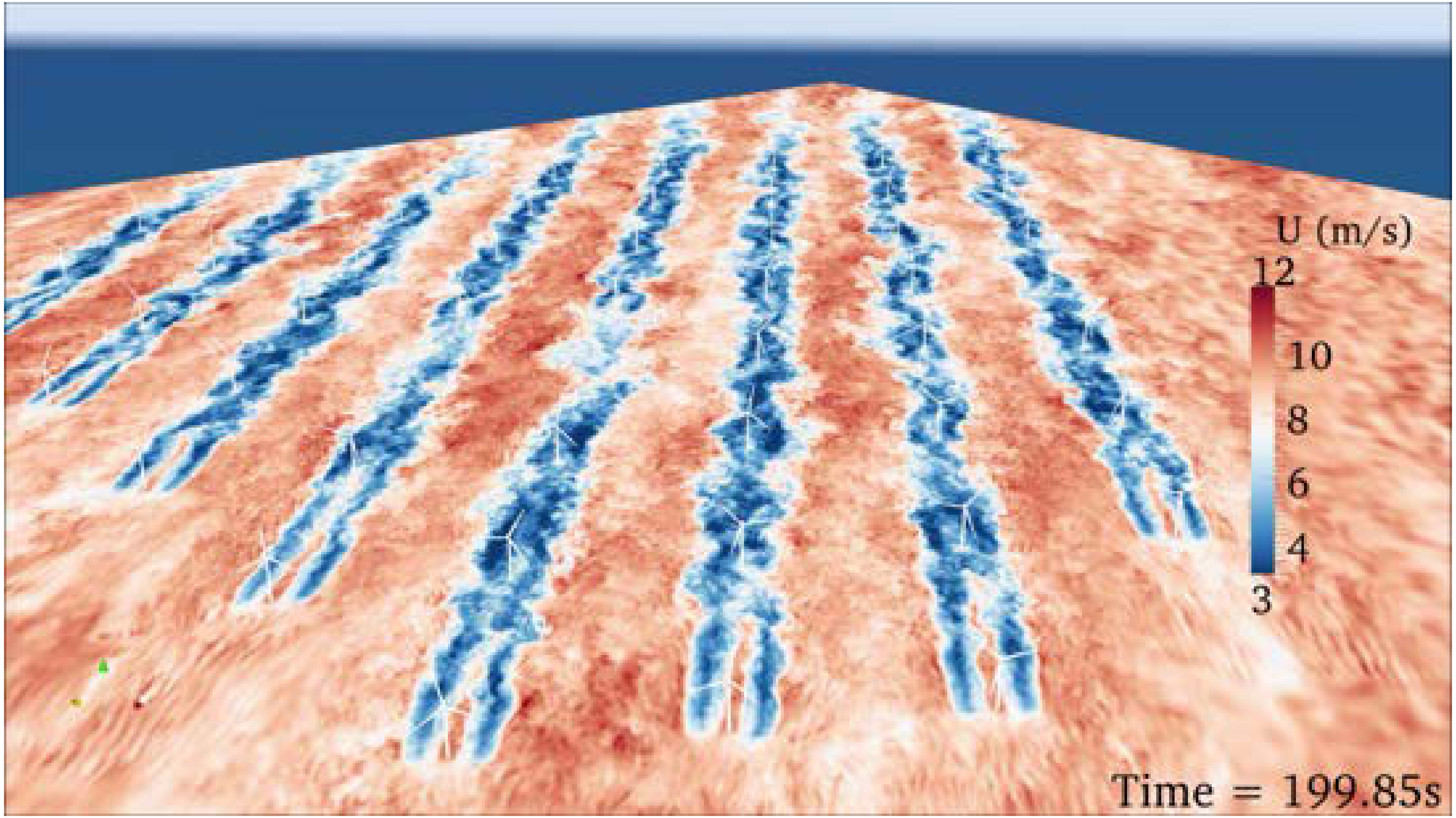
Mesoscale / Landscape Scale



Microscale / Local Scale



Microscale / Local Scale



Atmospheric Flow Modeling

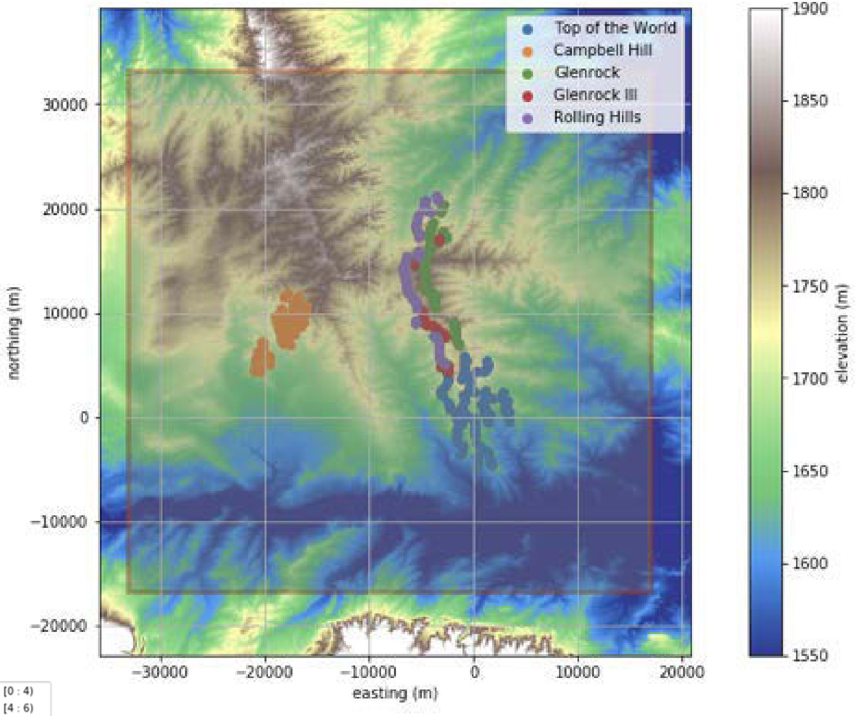
A High-Fidelity Approach

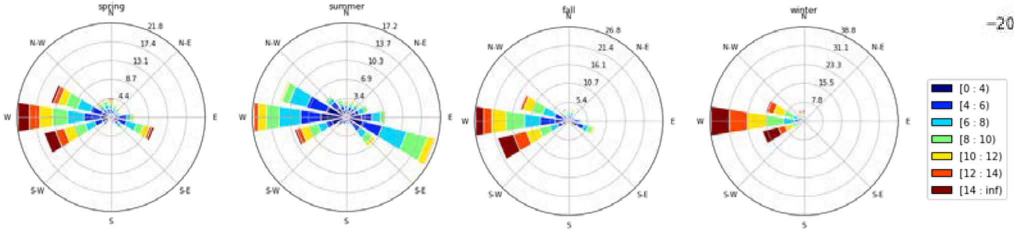
- Multiscale simulations applying mesoscale-to-microscale model (MMC) coupling
- Large-eddy simulation (LES) over regions of unprecedented size
- Captures thermal updrafts.

Approach:

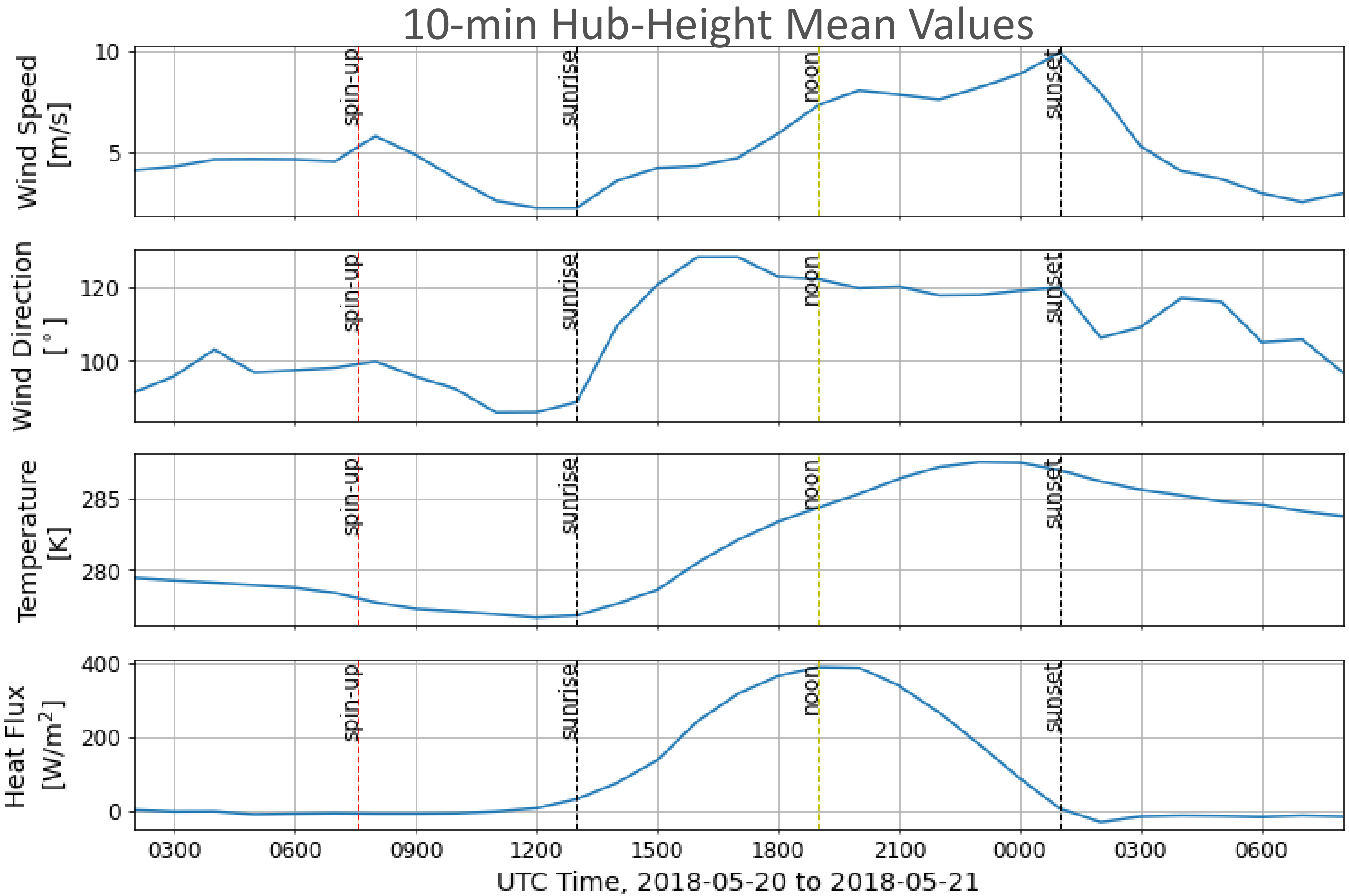
- Select representative conditions from WIND Toolkit (see below)
- Simulate conditions with and without terrain
- Apply recently developed MMC techniques.

Region of Interest (50 km x 50 km)

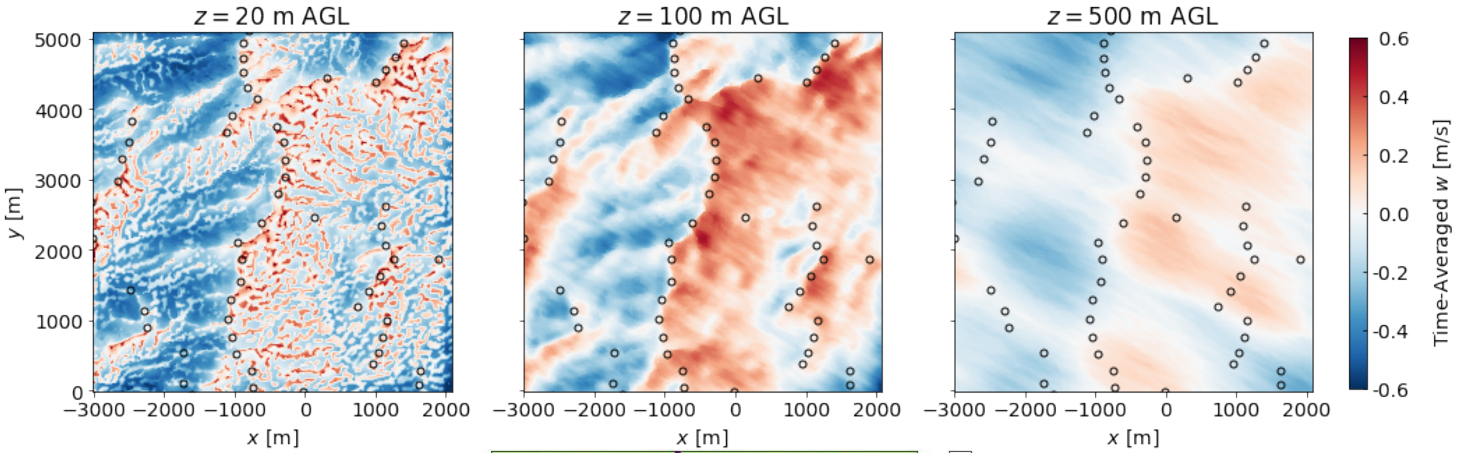




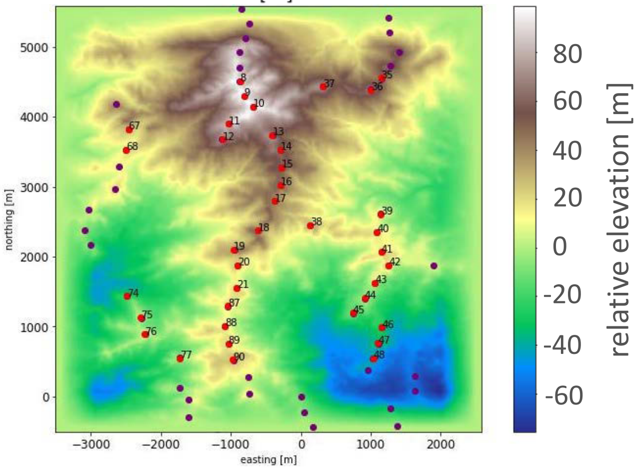
Example: Simulated Diurnal Cycle

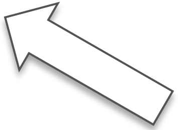


Effect of Terrain on Diurnal Cycle Average



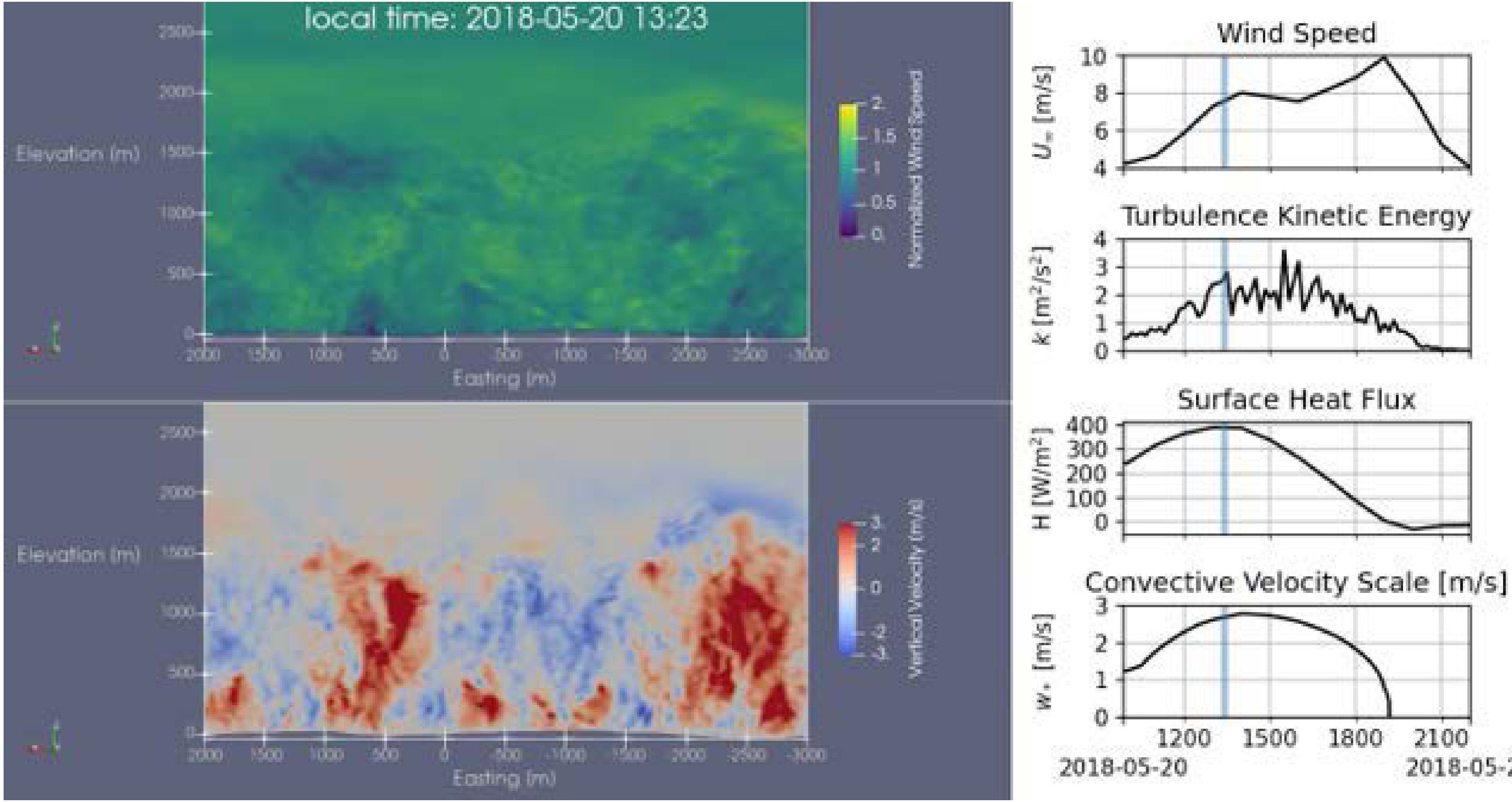
LES simulated terrain:





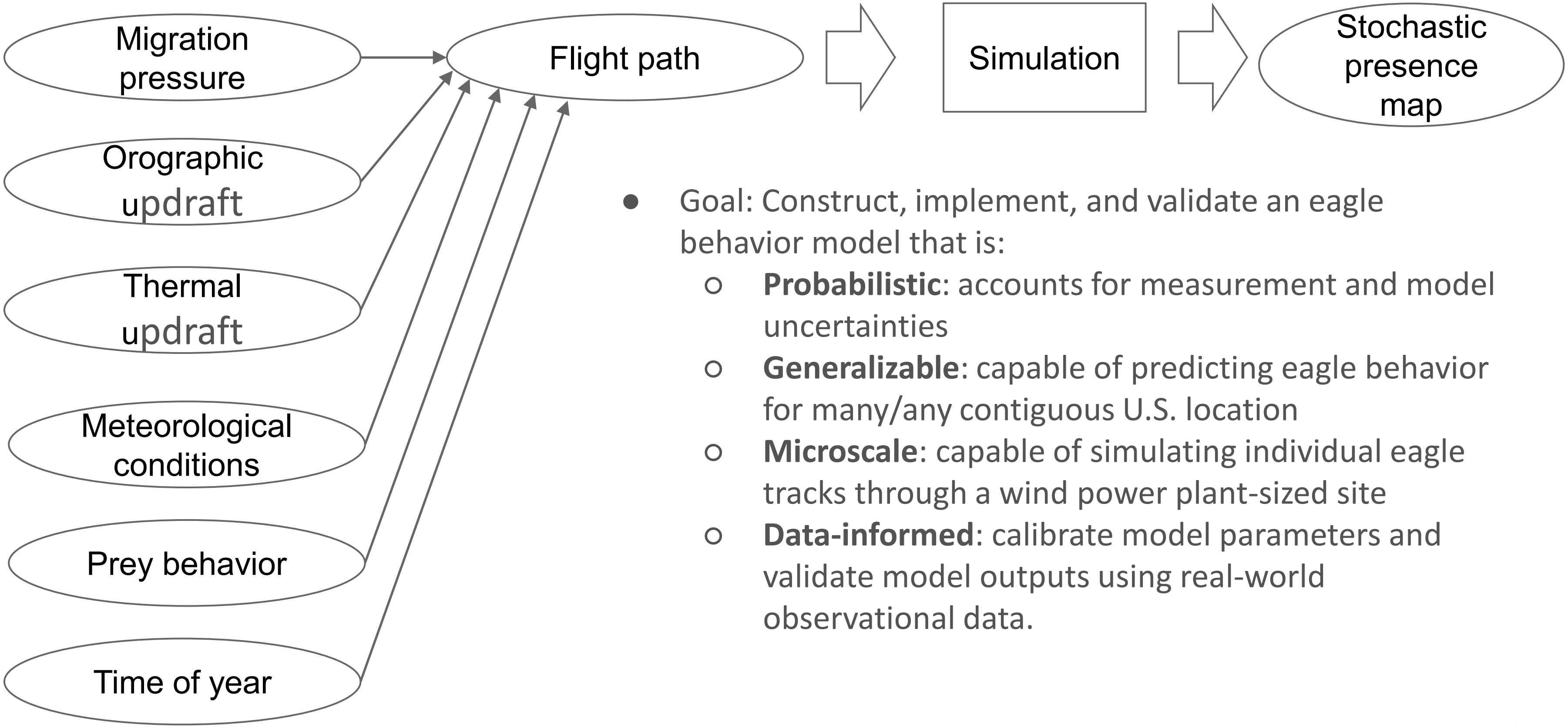
Afternoon wind direction

Atmospheric Boundary Layer Evolution



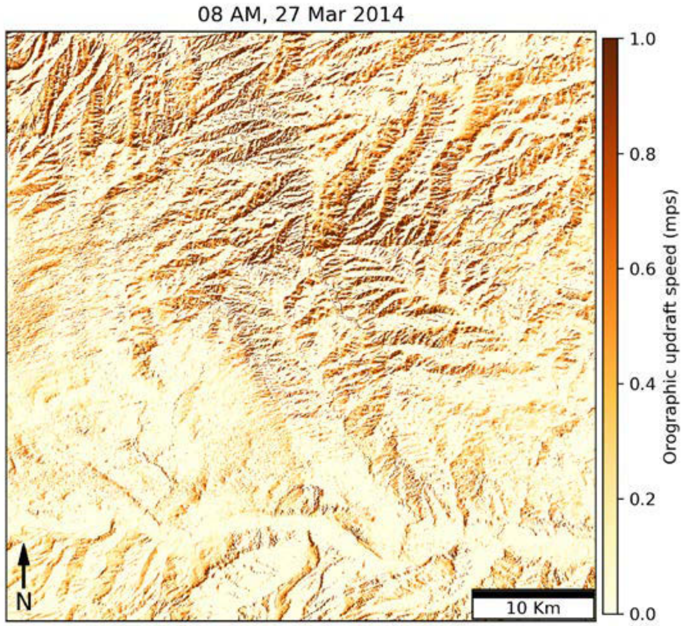
Behavioral Modeling

Development of a heuristic/machine learning-based eagle behavior model



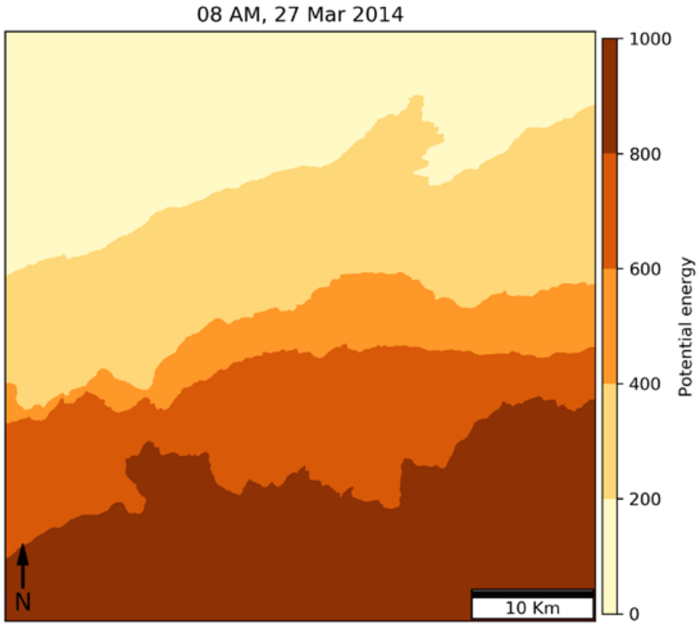
- Goal: Construct, implement, and validate an eagle behavior model that is:
  - **Probabilistic**: accounts for measurement and model uncertainties
  - **Generalizable**: capable of predicting eagle behavior for many/any contiguous U.S. location
  - **Microscale**: capable of simulating individual eagle tracks through a wind power plant-sized site
  - **Data-informed**: calibrate model parameters and validate model outputs using real-world observational data.

Behavioral Modeling Approach



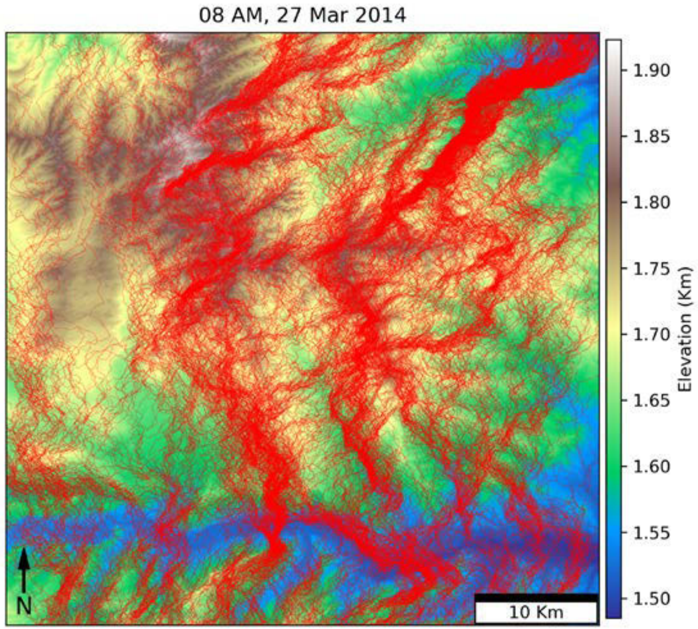
Orographic updraft speed computed using WIND Toolkit data.

- Could be deduced from microscale computational fluid dynamics simulations.

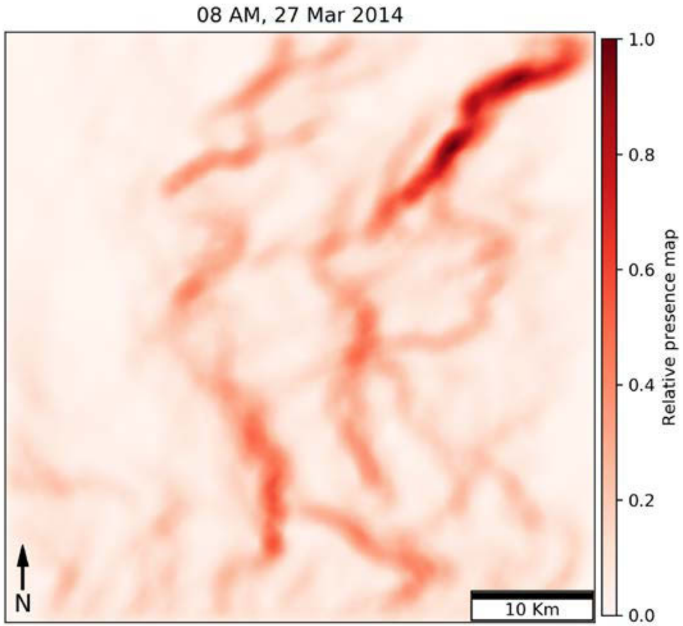


Migratory potential that drives eagle intent.

Northerly Migration through Wyoming in Spring



Probabilistic eagle tracks
(900 equally spaced eagles initiated from southern boundary)



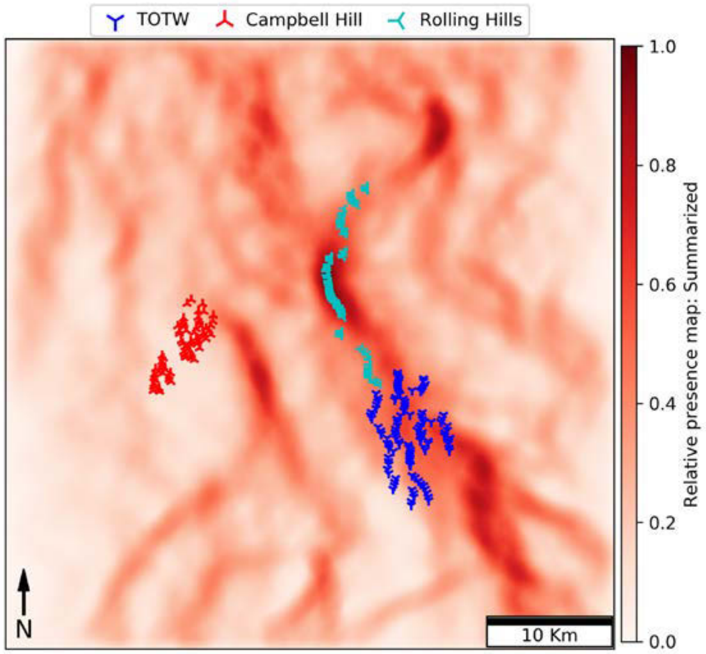
Eagle presence probability
(50-m resolution)

Summarized Eagle Presence Map

The summarized eagle presence map:

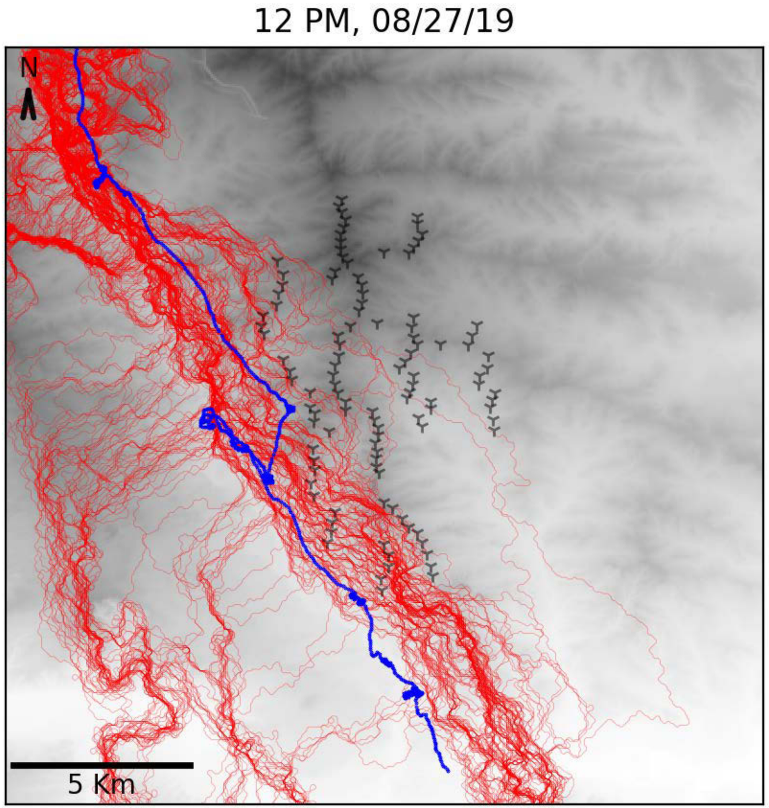
- Incorporates **spatiotemporal uncertainty** in wind conditions by simulating many time instances for a given season across **different migratory seasons**
- Incorporates **uncertainty in eagle decision making** by allowing few missteps
- Captures **uncertainty in how eagles approach a particular wind power plant** by simulating large numbers of eagles.

The developed tool provides a **probabilistic map without requiring prohibitive data collection**.

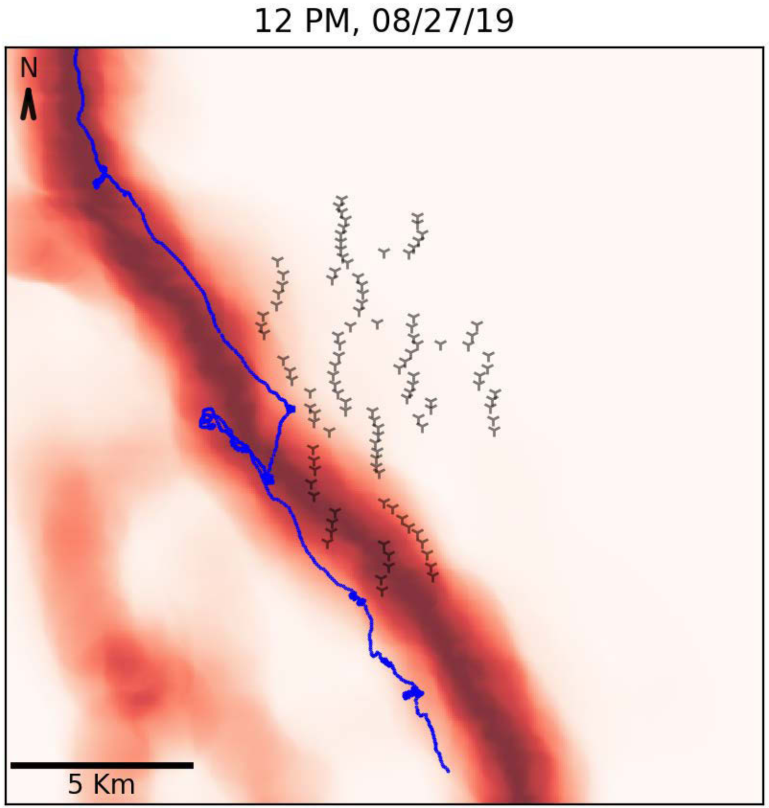


Southerly migration through Wyoming in fall: computed from 200 model runs

Example: Comparison with Telemetry Data



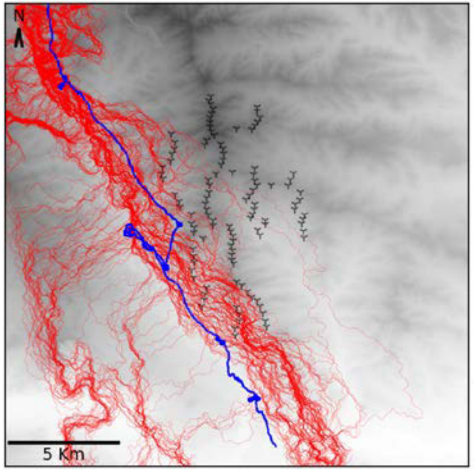
Simulation of 500 eagles

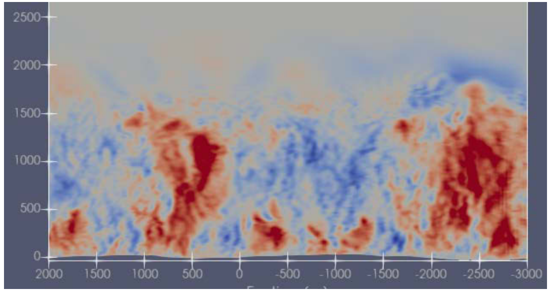


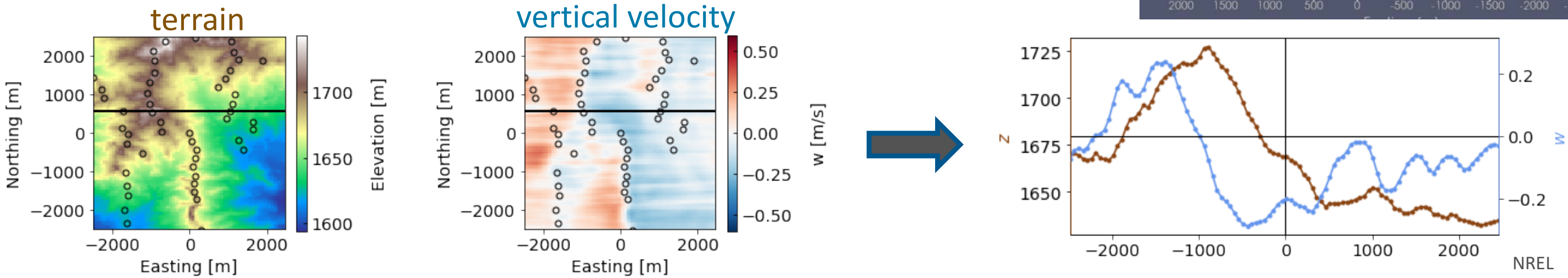
Presence map

Work in Progress

- Conclude evaluation of Top of the World
- Further behavioral model validation at other sites
- Extract flow and turbulence statistics from high-fidelity flow model
- Add additional atmospheric, environmental drivers to behavioral model







Thank you!

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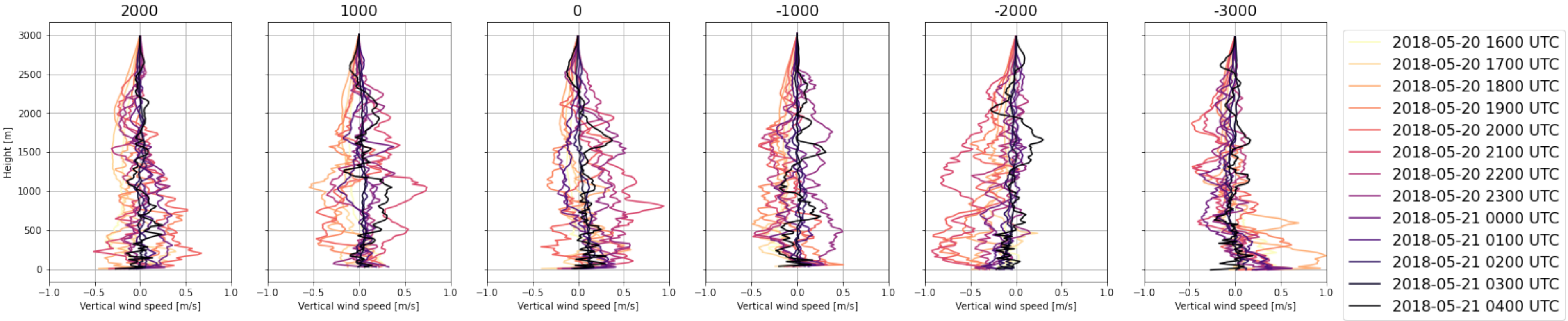
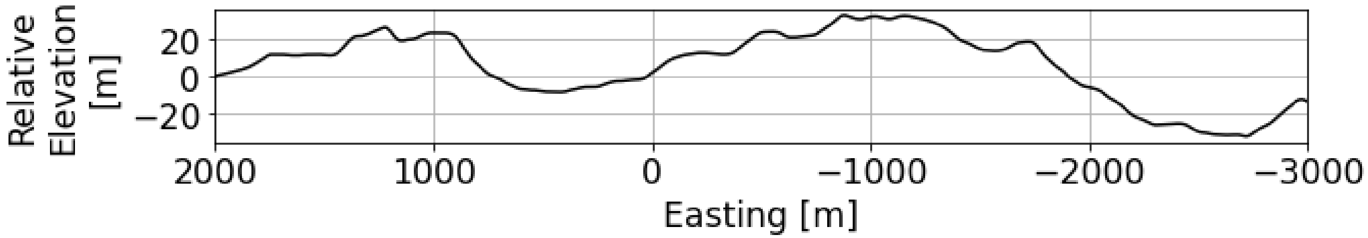
Backup slides

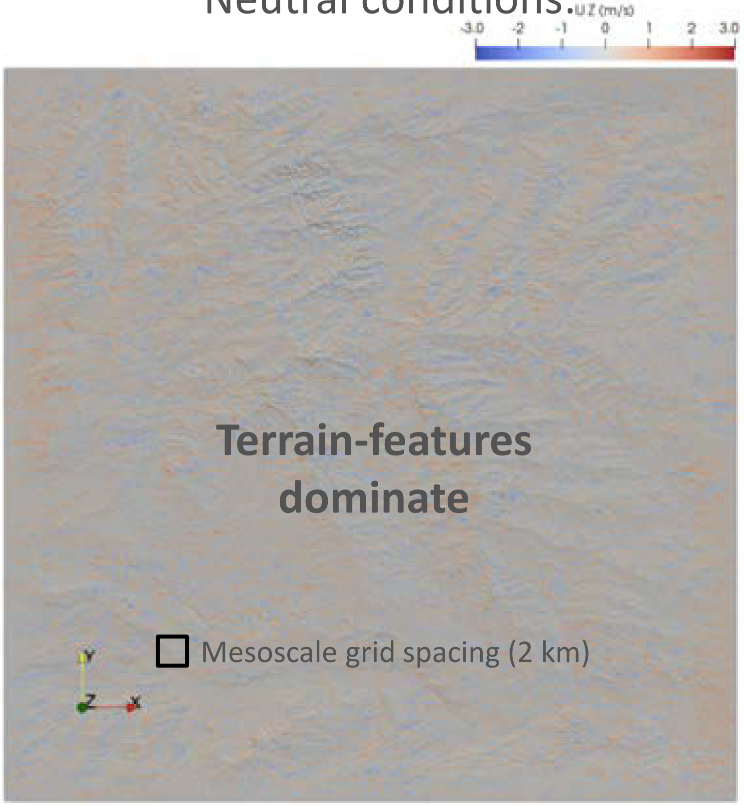
Vertical Velocity Profiles



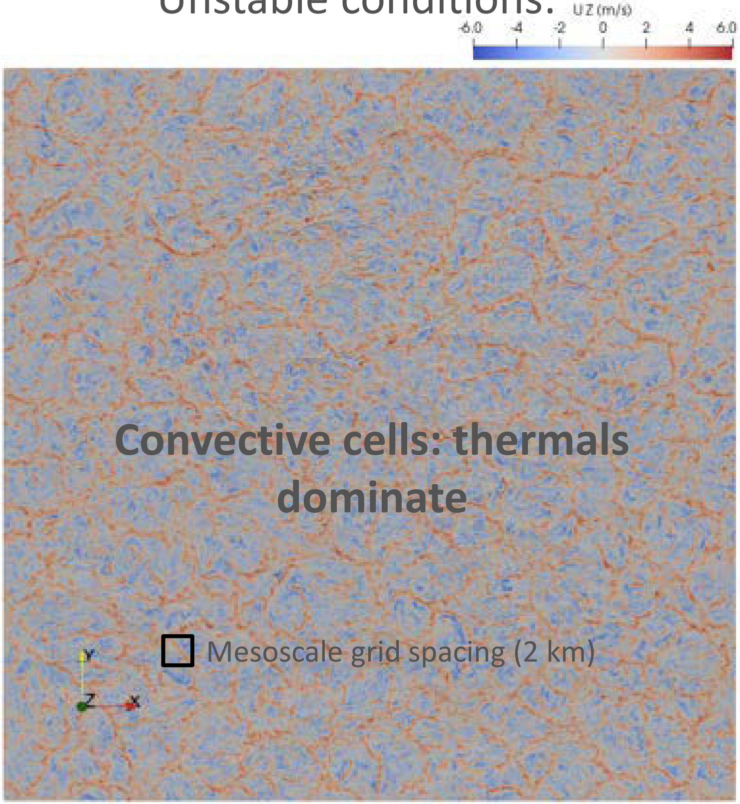


Impact of Atmospheric Stability

Neutral conditions:



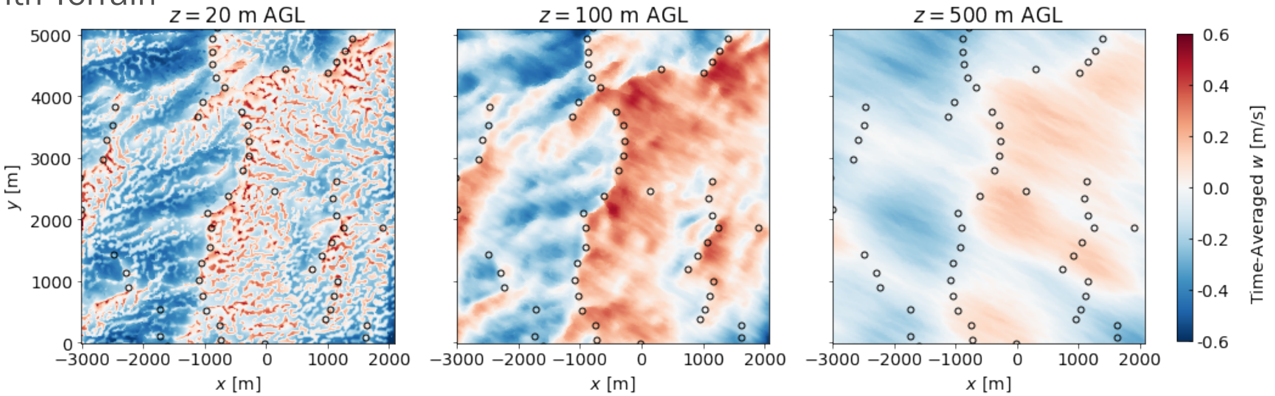
Unstable conditions:



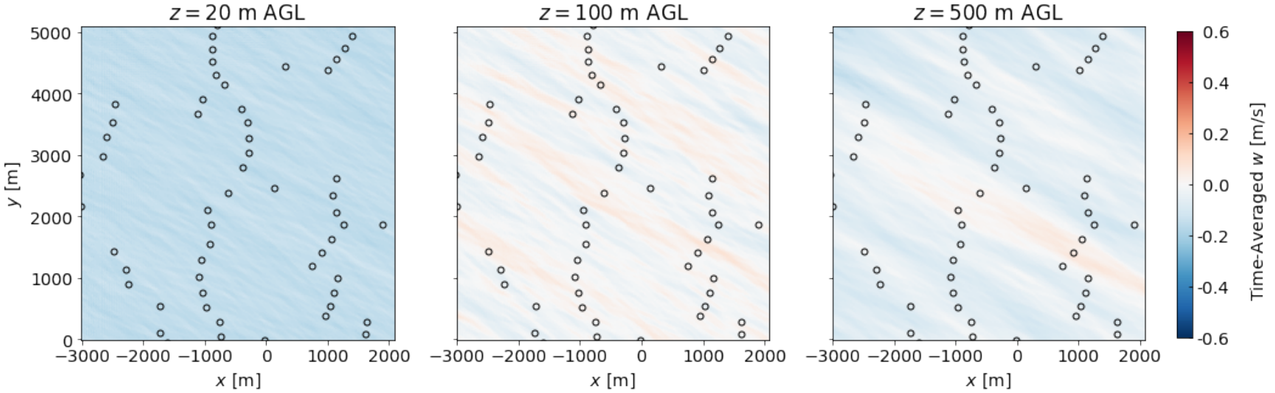
50 km x 50 km shown

Effect of terrain on diurnal cycle average

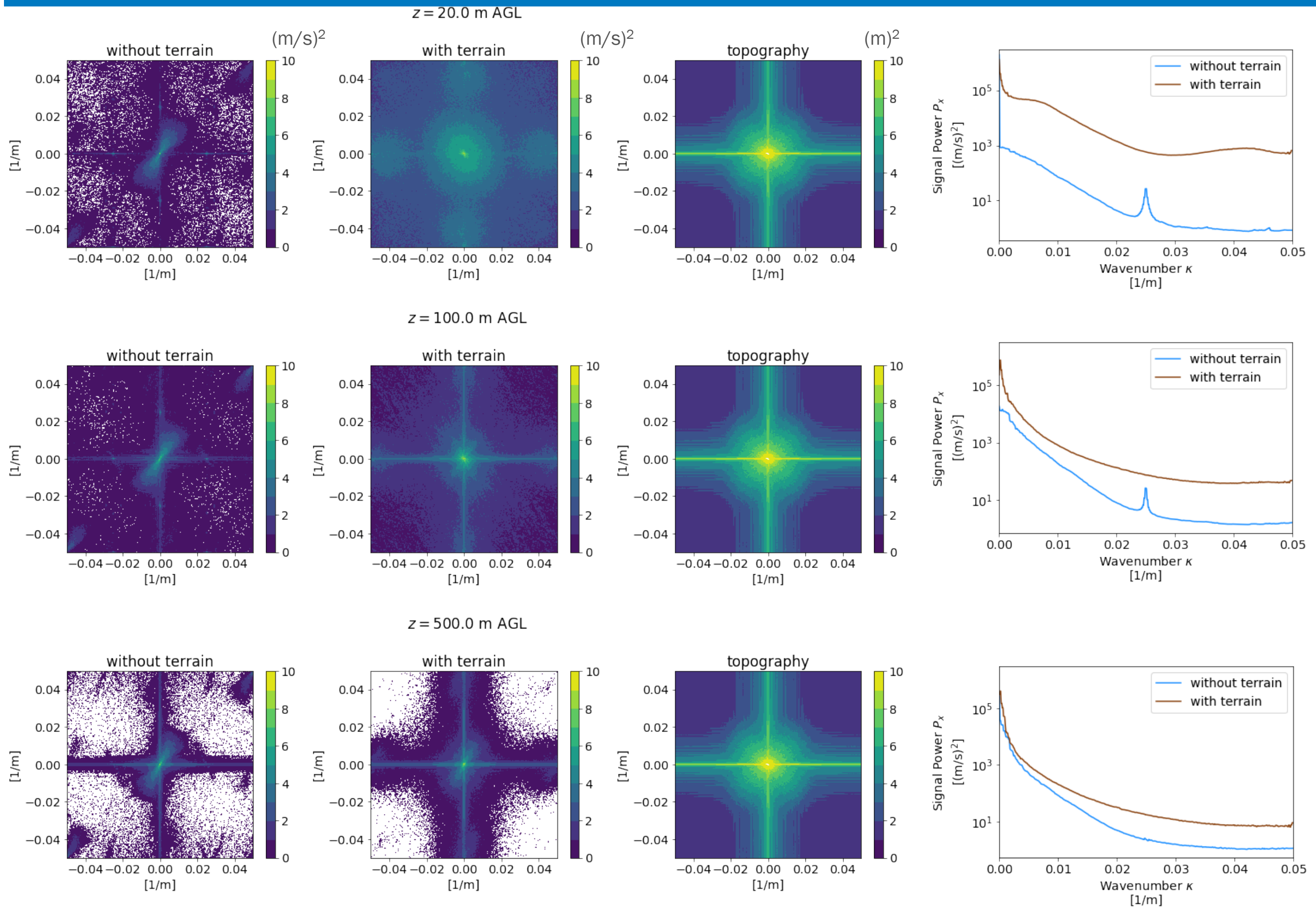
Simulation with Terrain



Simulation without Terrain



Effect of terrain on diurnal cycle average



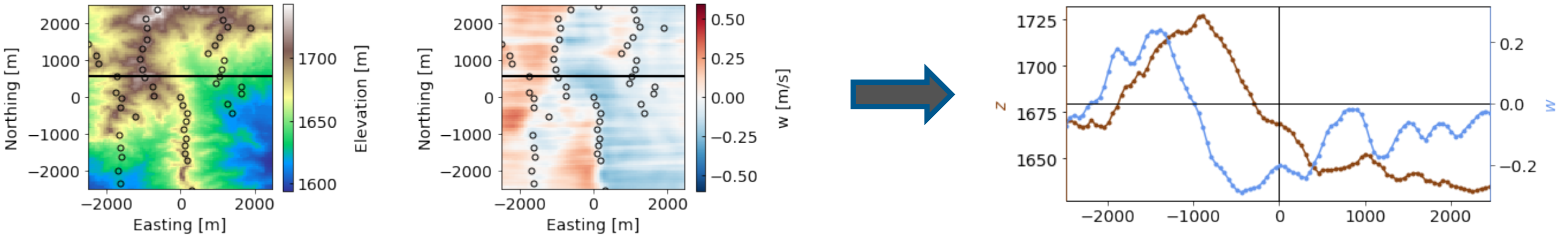
Close to the ground, the spatial distribution of vertical velocities for the terrain simulation has a spectral signature that closely matches the terrain. The simulation without terrain has a different spectral signature, peaking at a wavelength of ~40 m.

Near hub height, the simulation with terrain continues to have more spatial variation across the entire spectrum than the simulation without terrain. However, the signal power at low wavenumbers starts to approach for the two simulations – i.e. the effect of terrain on the flow starts to diminish on the large wavelength end of the spectrum.

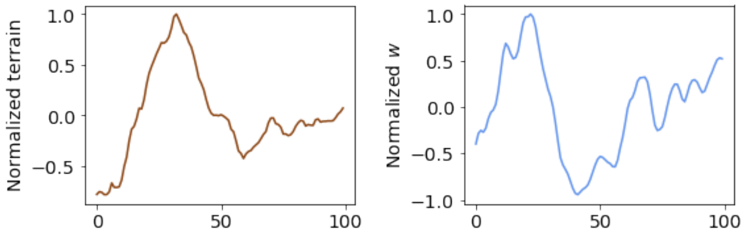
Far above the ground, the spectral power of the mean w field for the simulation with terrain starts to resemble that of the simulation without terrain. The ground effects overall are less pronounced for both simulations. The preferential flow direction (i.e. the streaks following the mean wind direction) dominate the entire flow field.

Implications to eagle presence modeling

1. Take a slice through the terrain and w field



2. Detrend and normalize these transects to reveal similarities



Next steps:

- Can transects of the terrain be used to predict approximate spatial distribution of topographic updrafts?
- Is there a constant fetch that relates the influence of the terrain upwind to the topographic updraft downwind?