Atmospheric Modeling to Enable Prediction of Golden Eagle Interactions with Wind Power Plants

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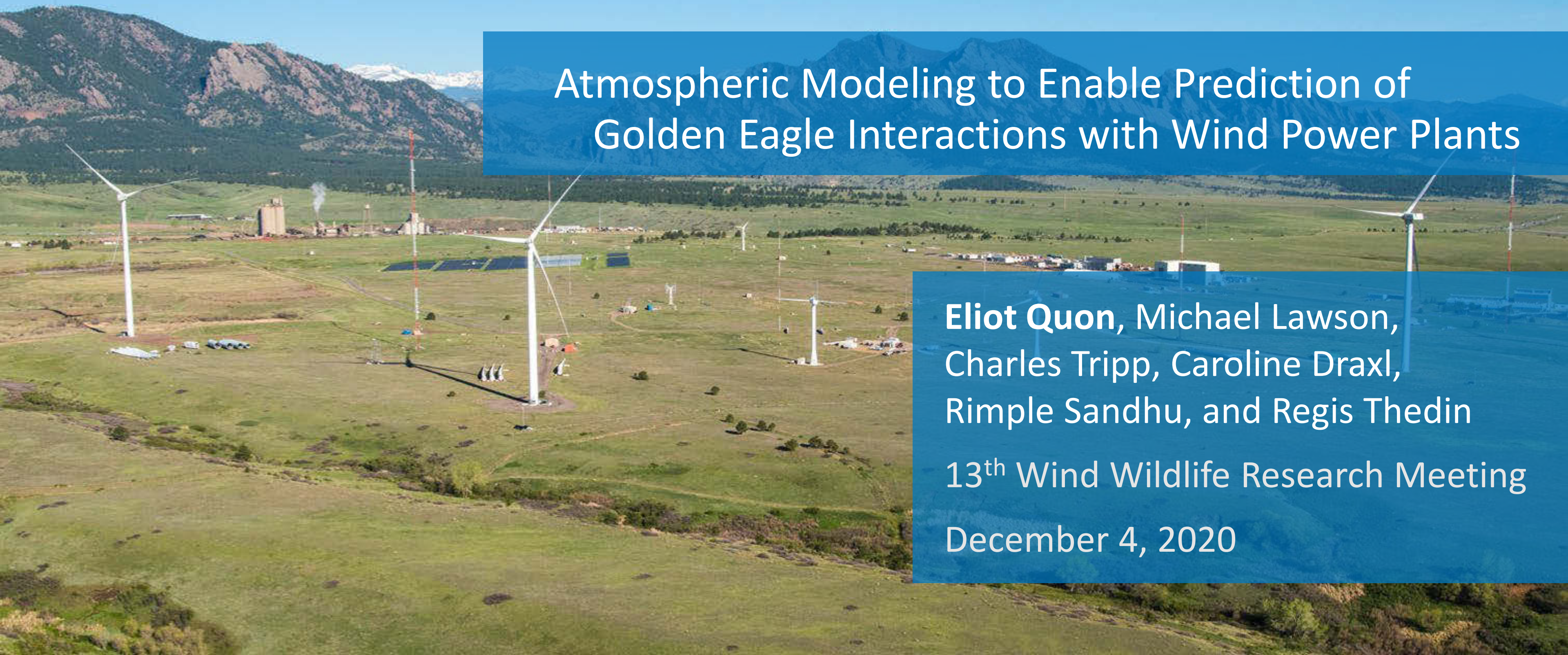
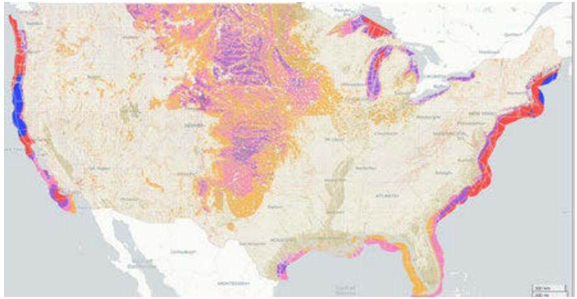
13th Wind Wildlife Research Meeting

December 4, 2020

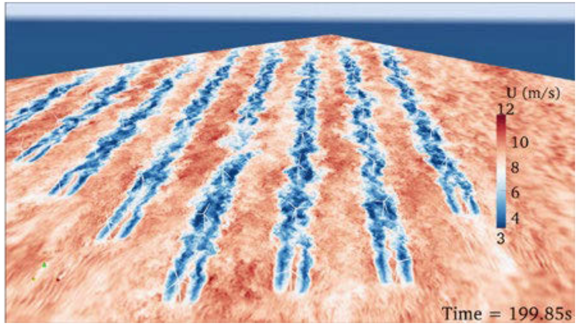


Objective: Combine knowledge of eagle behavior, eagle telemetry data, atmospheric and wind power plant flow models, and machine learning to develop tools that predict behavior and risk around wind power plants.

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



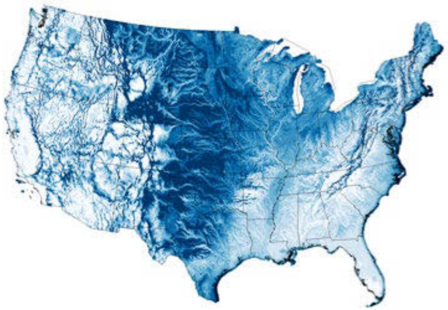
Mesoscale model to characterize soaring habitat—*25% total effort*: Characterize soaring habitat across the contiguous United States using atmospheric modeling methods and knowledge of golden eagle flight dynamics.



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:



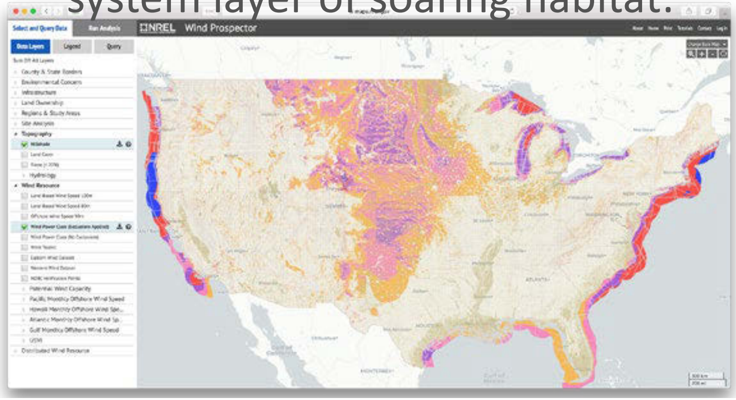
- Improved 20-year hindcast of flow across the United States
- 2-km spatial resolution
- 5-min temporal resolution
- Detailed terrain maps
- Parameterizations of thermals.

Eagle flight physics:

Photo by Lee Jay Fingersh / NREL

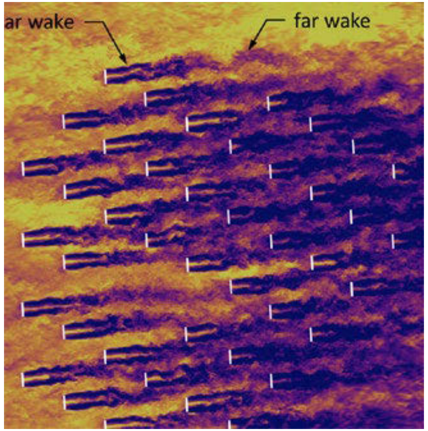
- Updraft velocity needed to sustain soaring flight
- Understanding atmospheric variables that influence flight.

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.

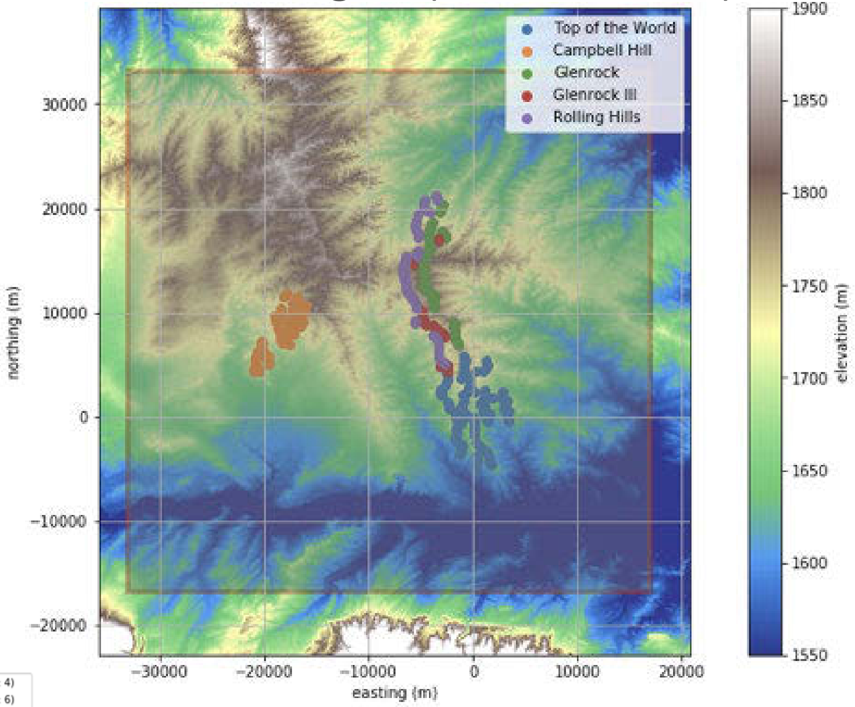
High-Fidelity Modeling Approach

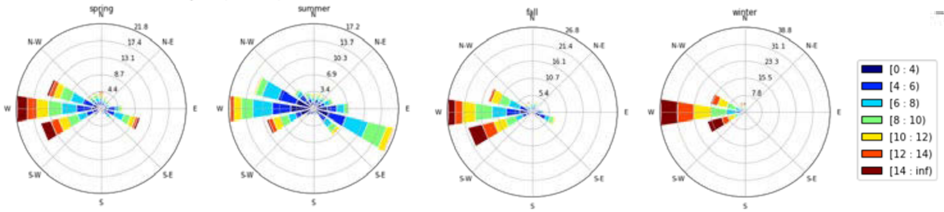
- Multiscale simulations applying mesoscale-to-microscale model coupling
- Large-eddy simulation over regions of unprecedented size
- Captures thermal updrafts.

Approach:

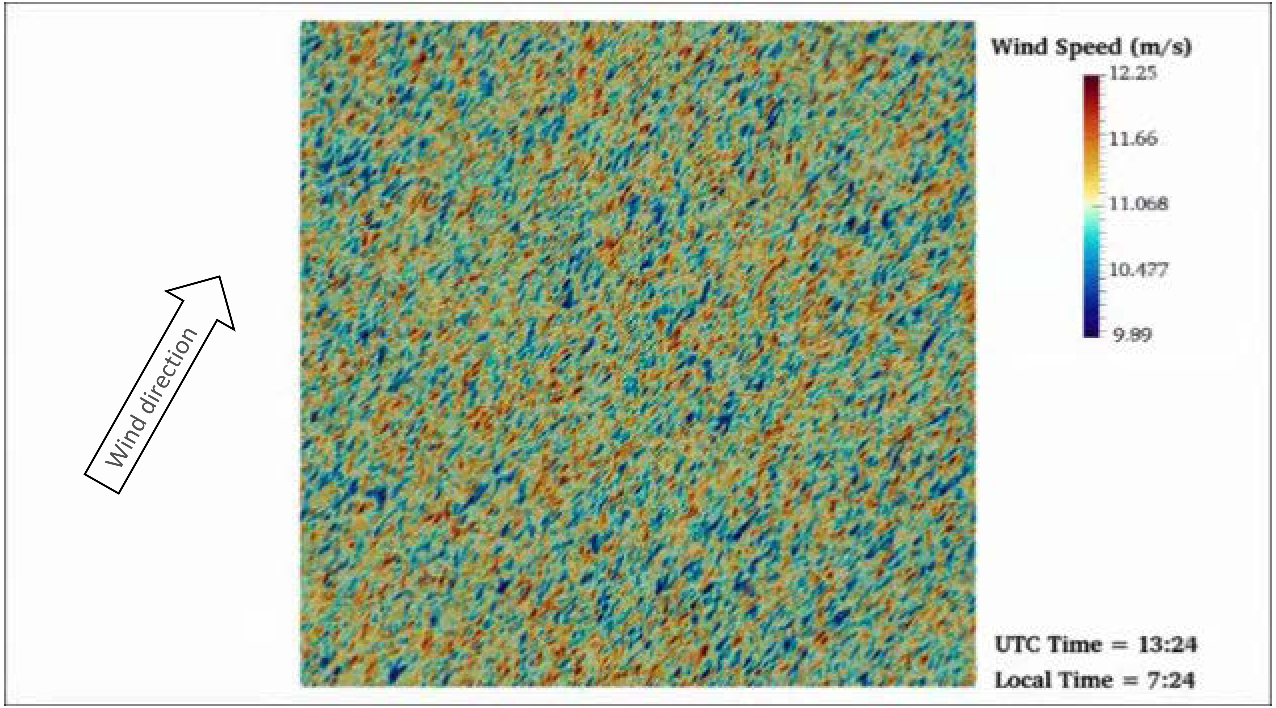
- Representative conditions from WIND Toolkit (see below)
- Simulate conditions with and without terrain
- Apply recently developed assimilation technique.

Simulation Region (50 km x 50 km)



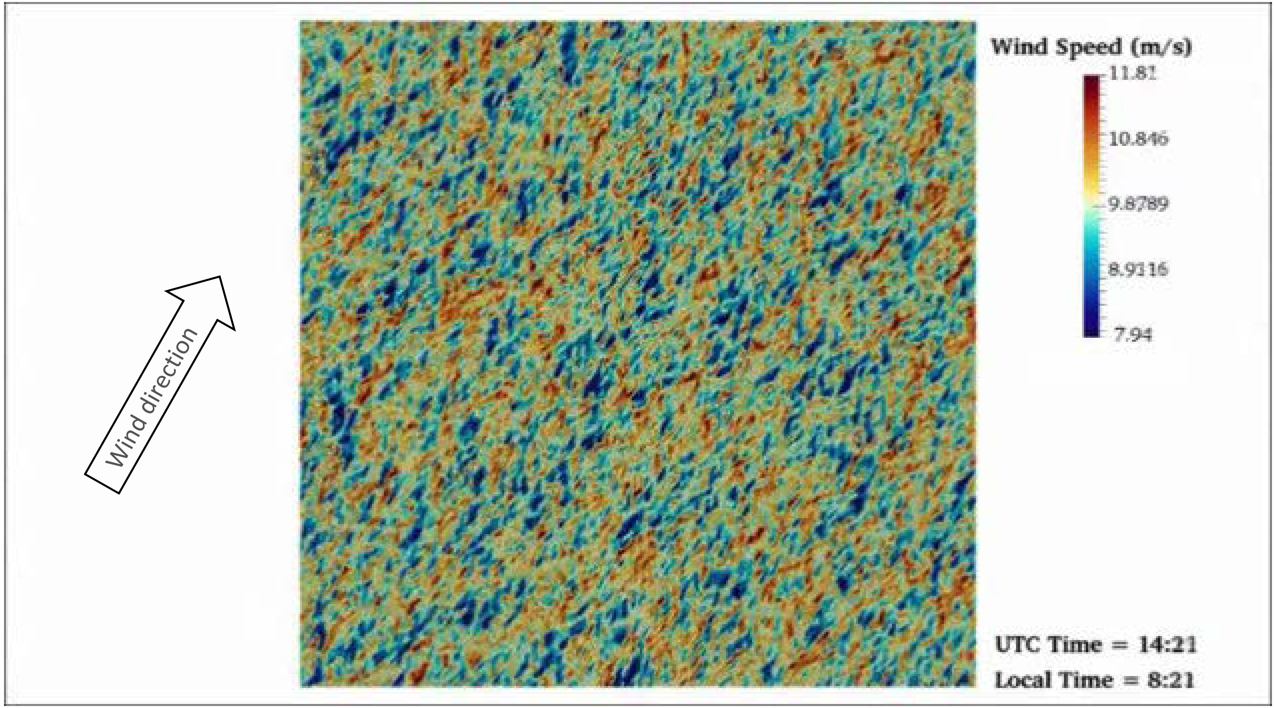


Canonical Daytime Atmospheric Boundary Layer 7:24 a.m.



5 km x 5 km shown

Canonical Daytime Atmospheric Boundary Layer 8:21 a.m.



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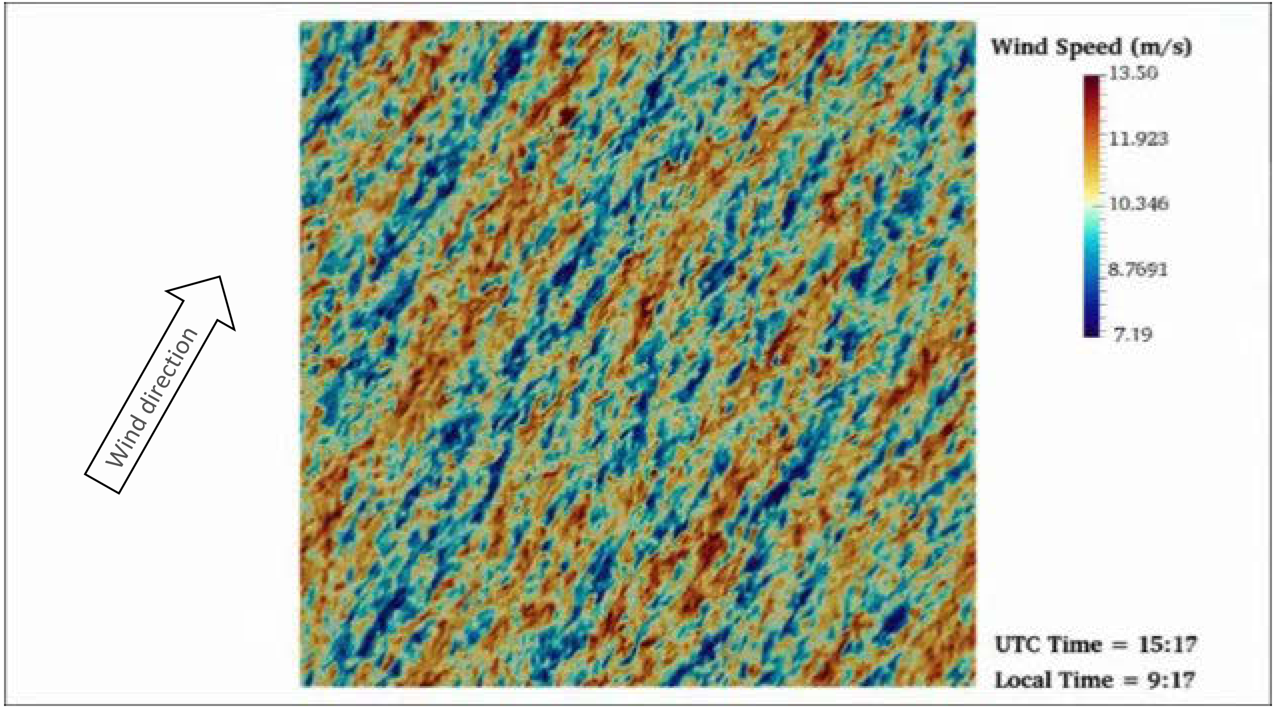
Canonical Daytime Atmospheric Boundary Layer 9:17 a.m.



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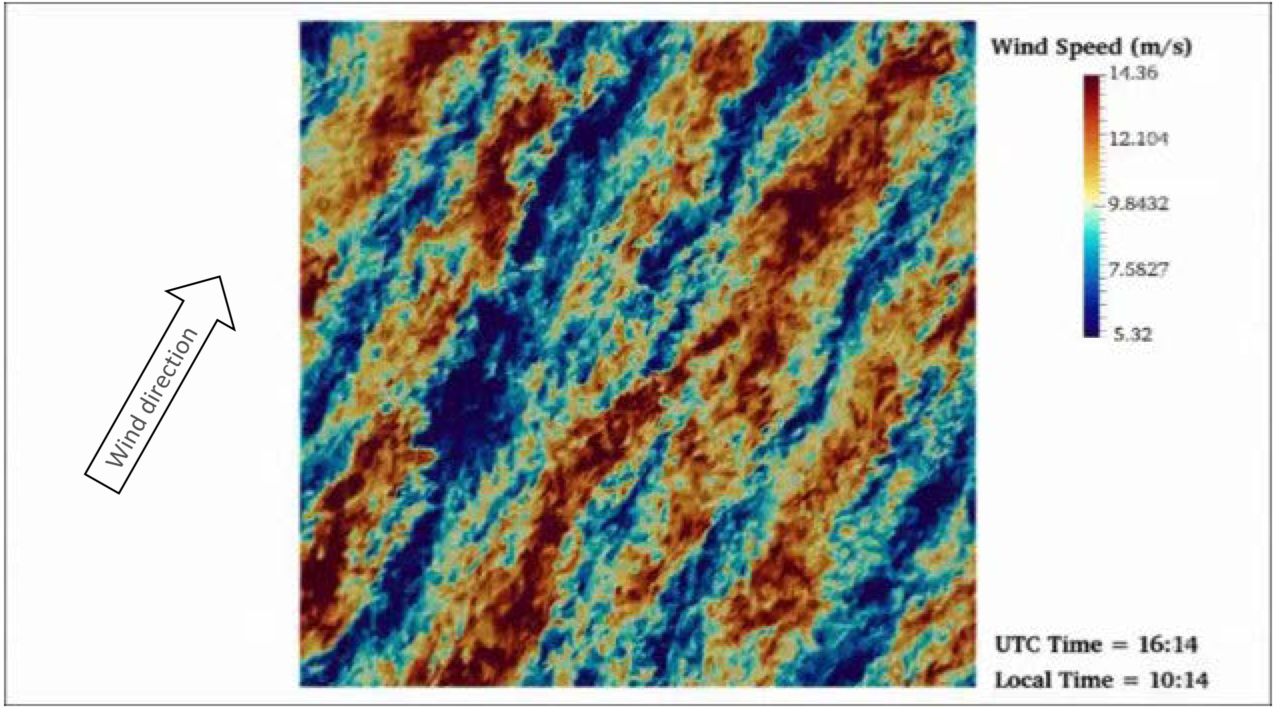
Canonical Daytime Atmospheric Boundary Layer 10:14 a.m.



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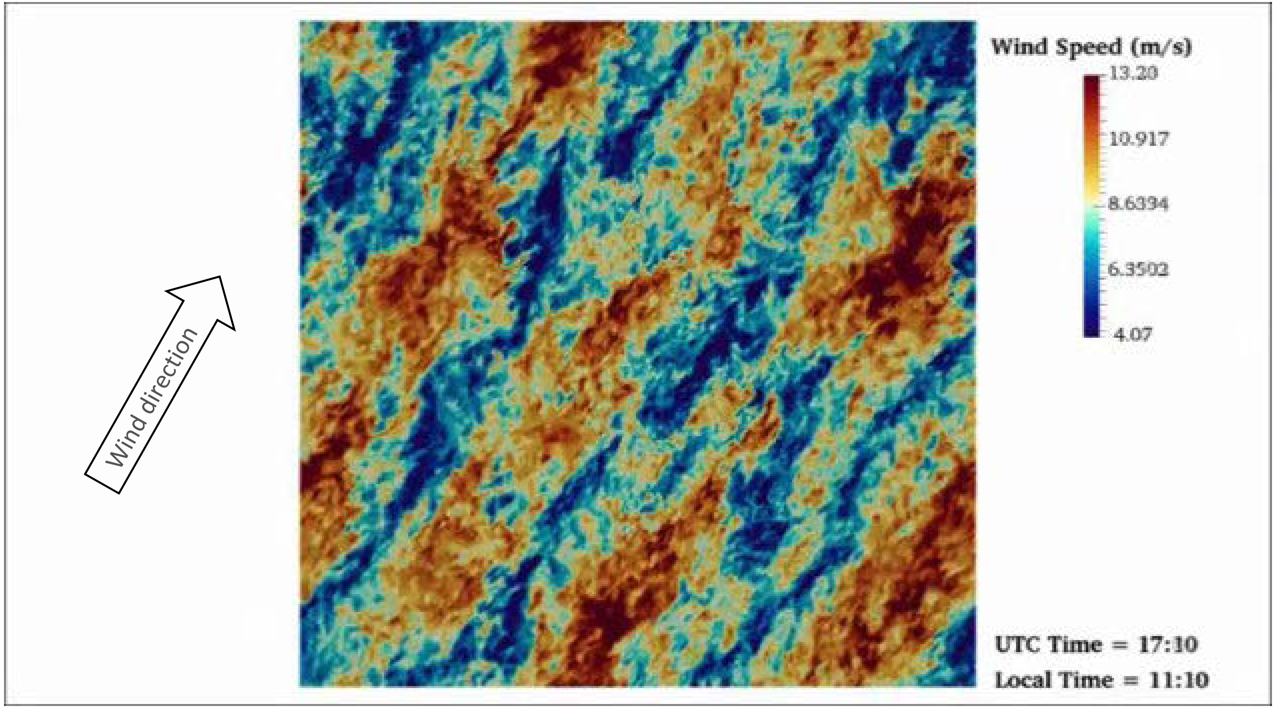
Canonical Daytime Atmospheric Boundary Layer 11:10 a.m.



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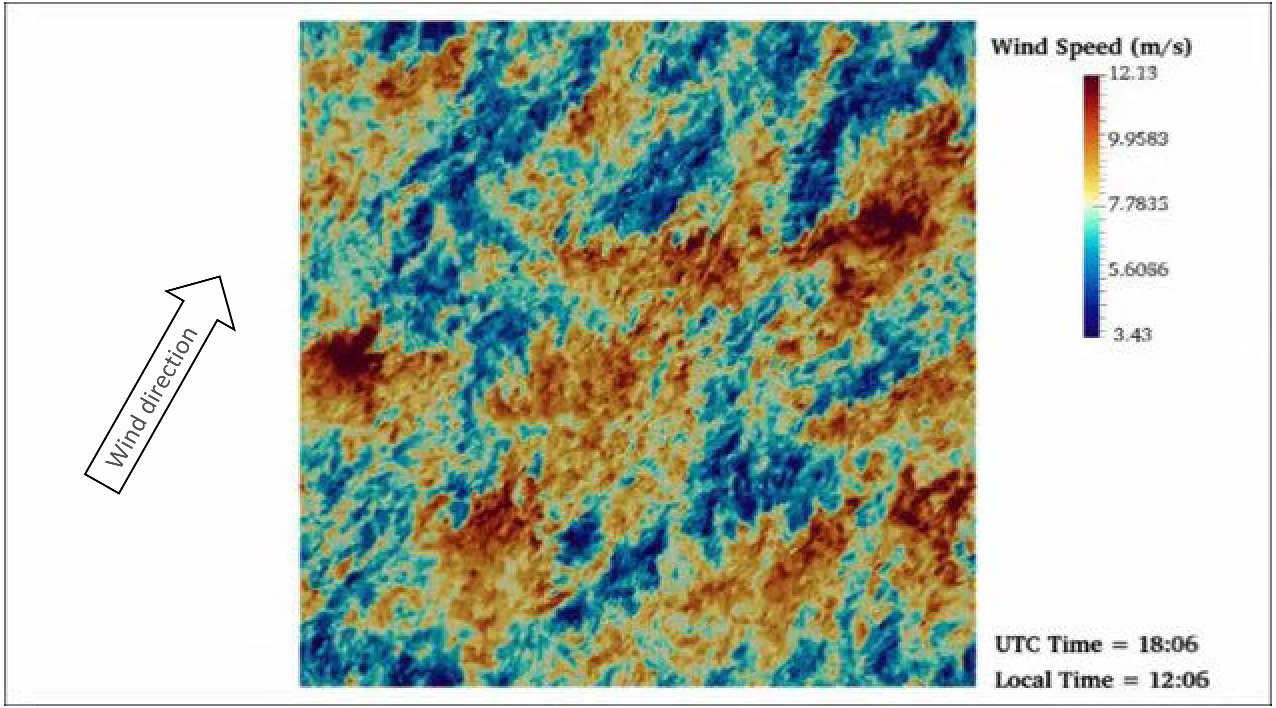
Canonical Daytime Atmospheric Boundary Layer 12:06 p.m.



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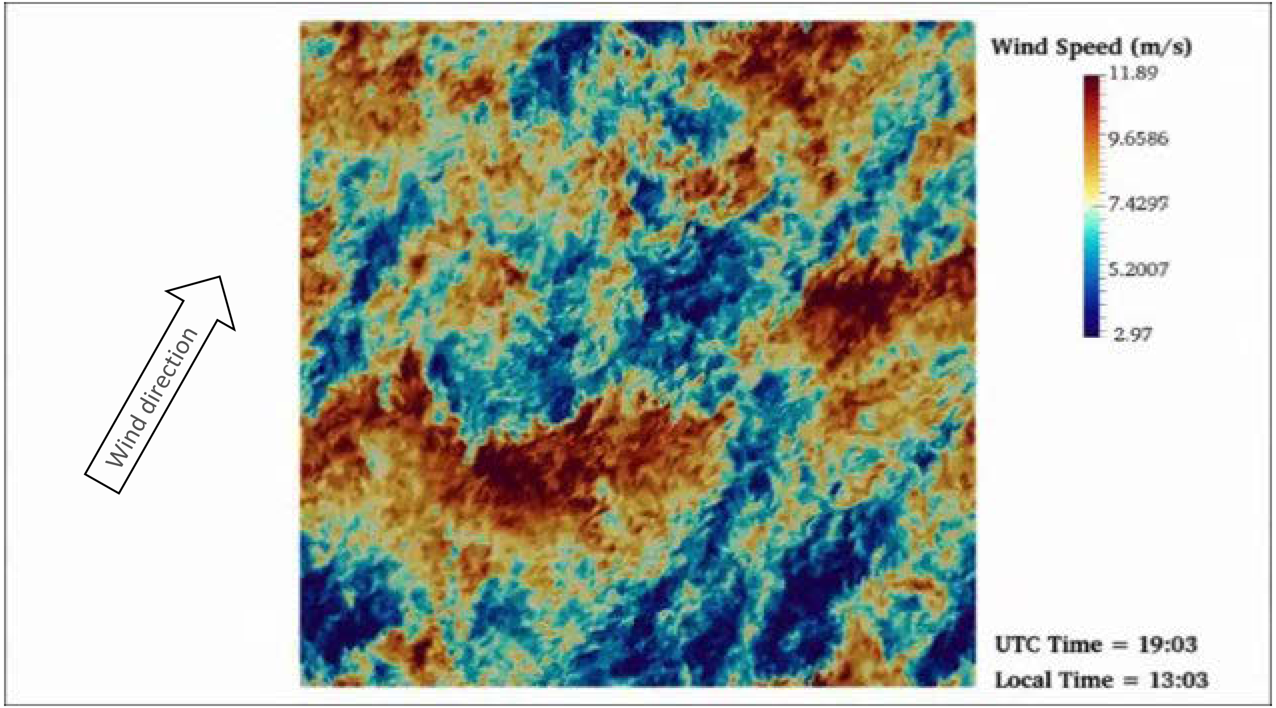
Canonical Daytime Atmospheric Boundary Layer 1:03 p.m.



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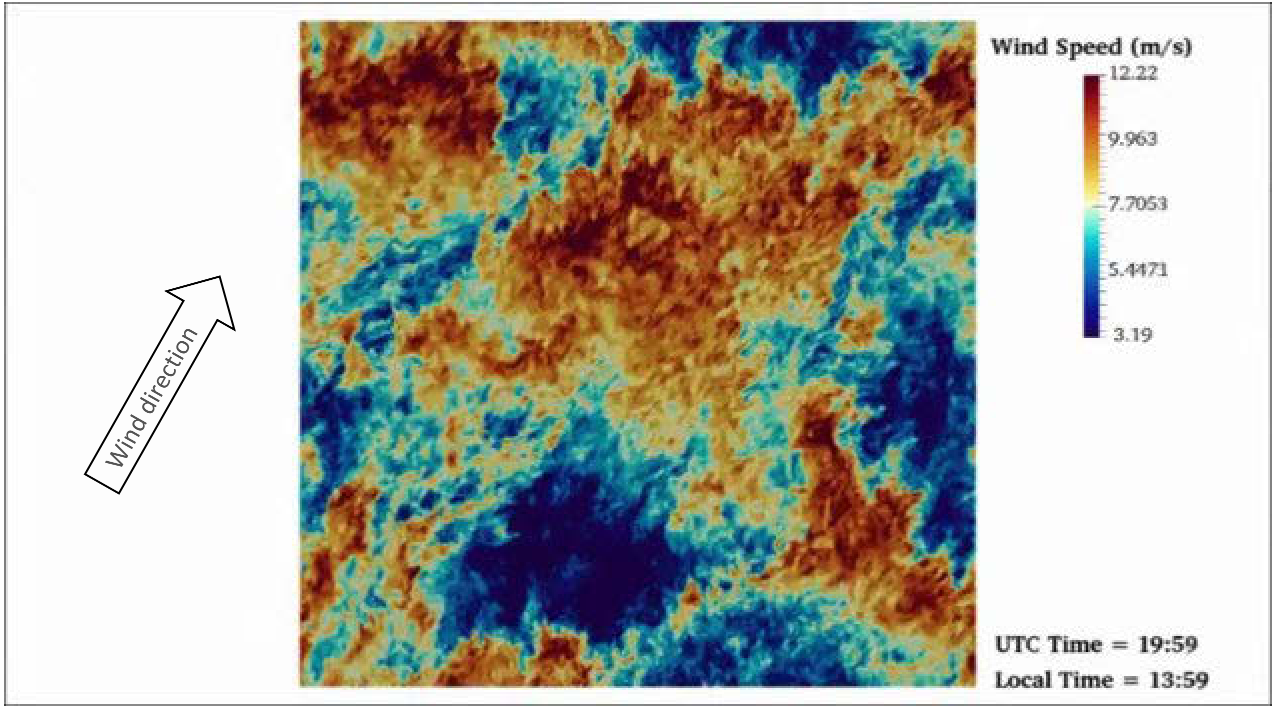
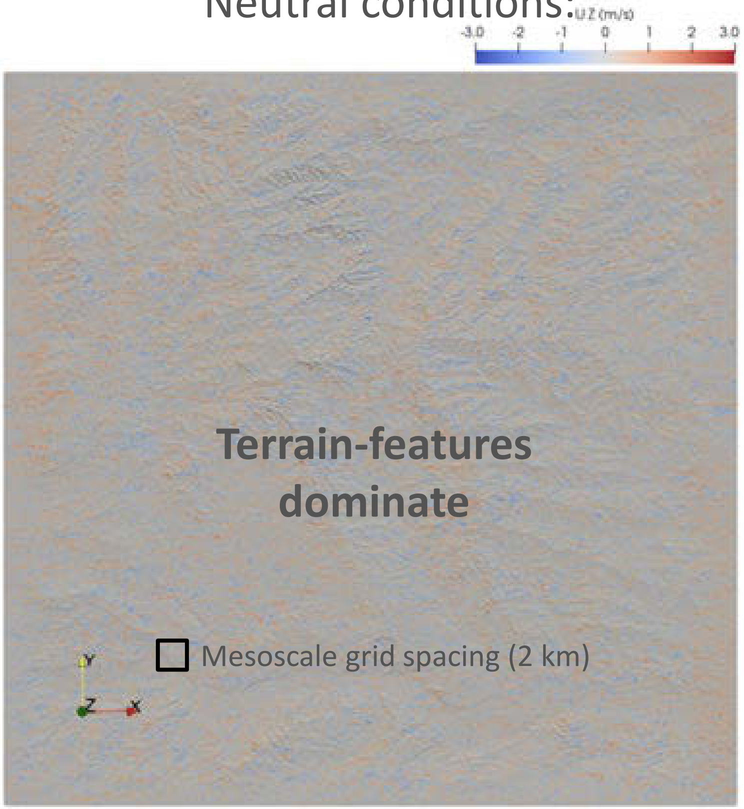


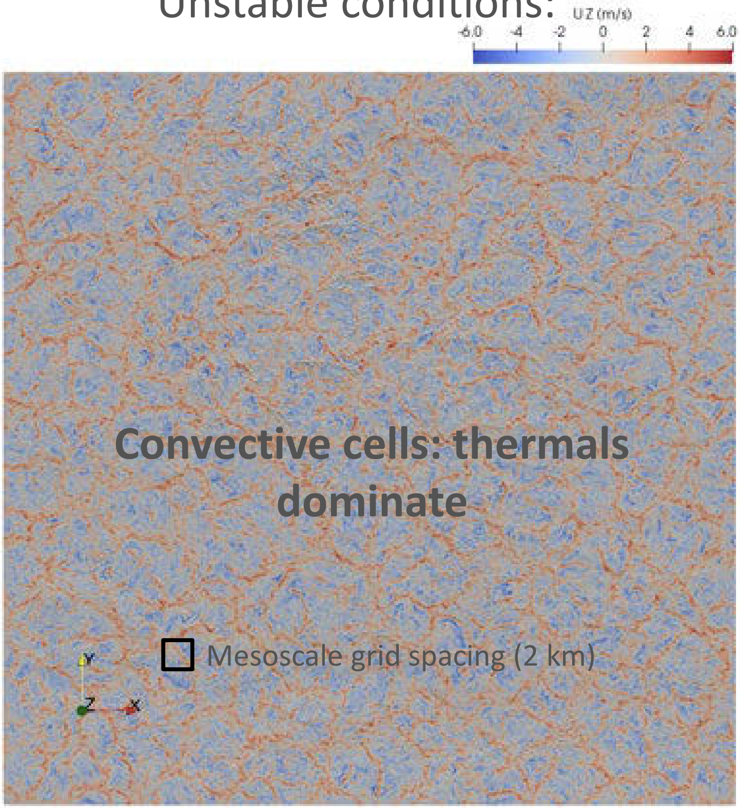
5 km x 5 km shown

Impact of Atmospheric Stability

Neutral conditions:



Unstable conditions:

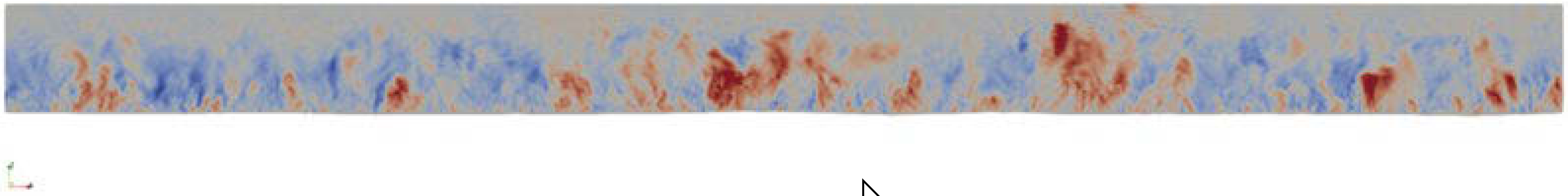


50 km x 50 km shown

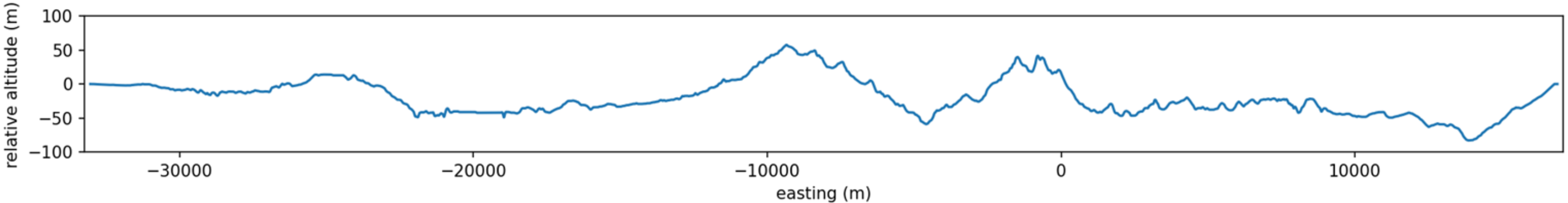
Impact of Atmospheric Stability

Neutral conditions:

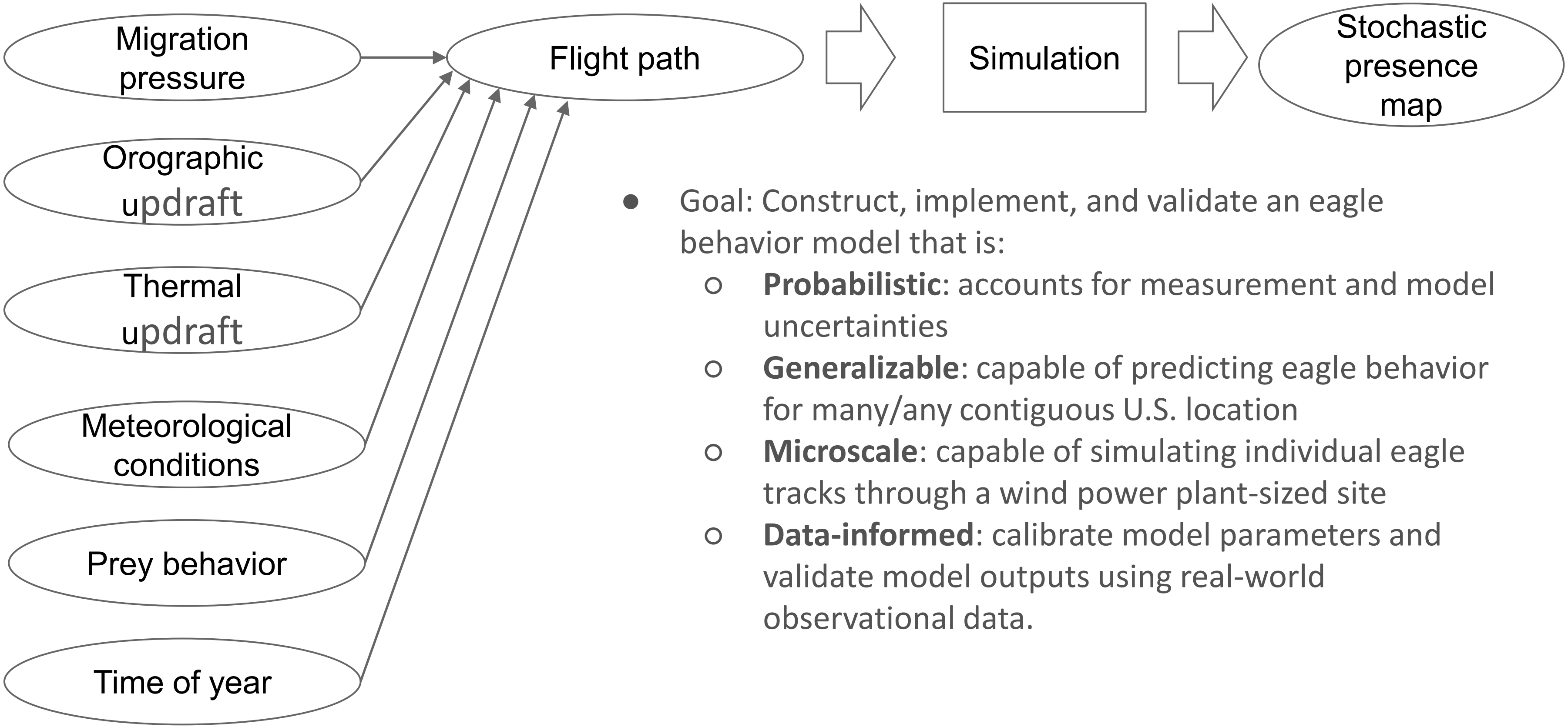
Unstable conditions:



Wind direction

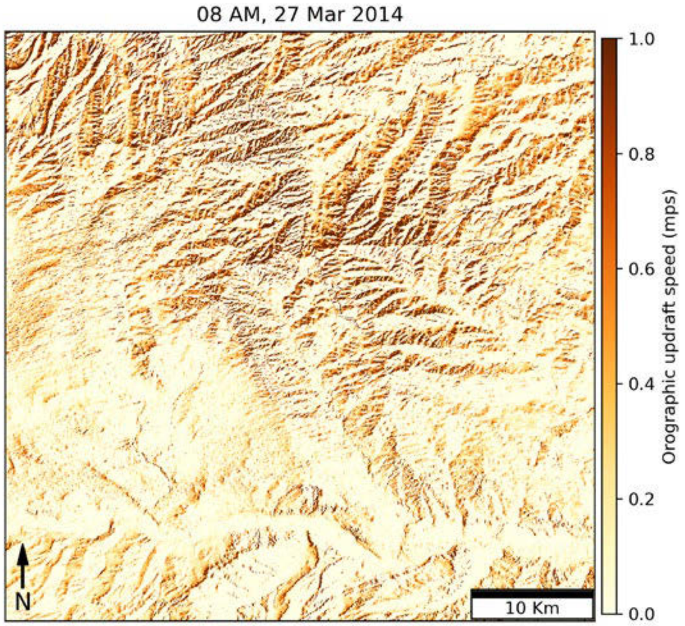


Development of a heuristic/machine learning-based eagle behavior model



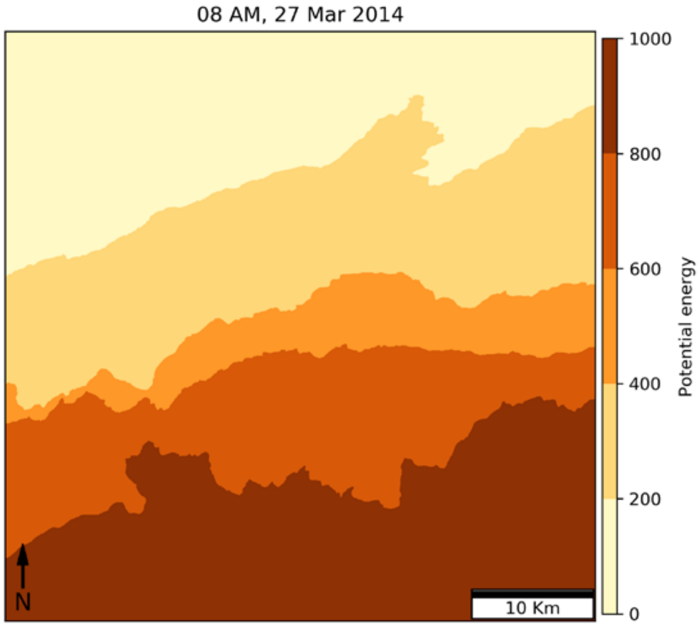
- Goal: Construct, implement, and validate an eagle behavior model that is:
  - **Probabilistic**: accounts for measurement and model uncertainties
  - **Generalizable**: capable of predicting eagle behavior for many/any contiguous U.S. location
  - **Microscale**: capable of simulating individual eagle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

Northerly Migration through Wyoming in Spring



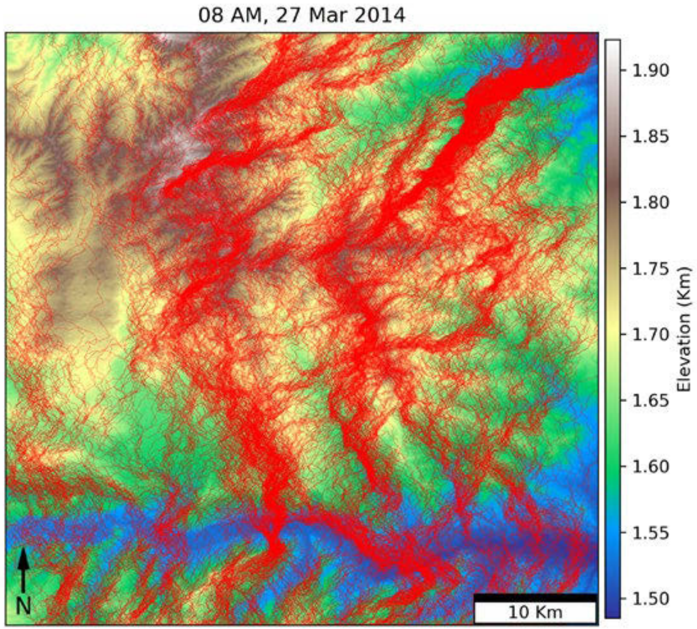
Orographic updraft speed computed using WIND Toolkit data.

- Could be deduced from microscale computational fluid dynamics simulations.

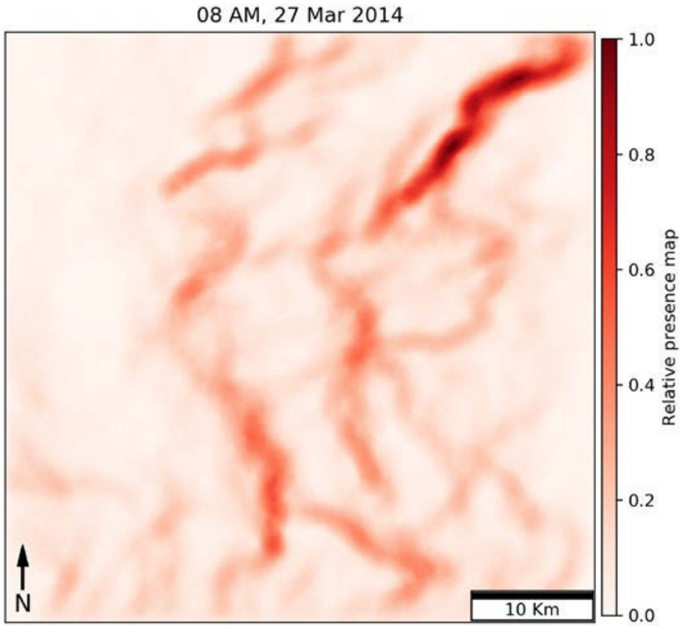


Migratory potential that drives eagle intent.

Northerly Migration through Wyoming in Spring



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



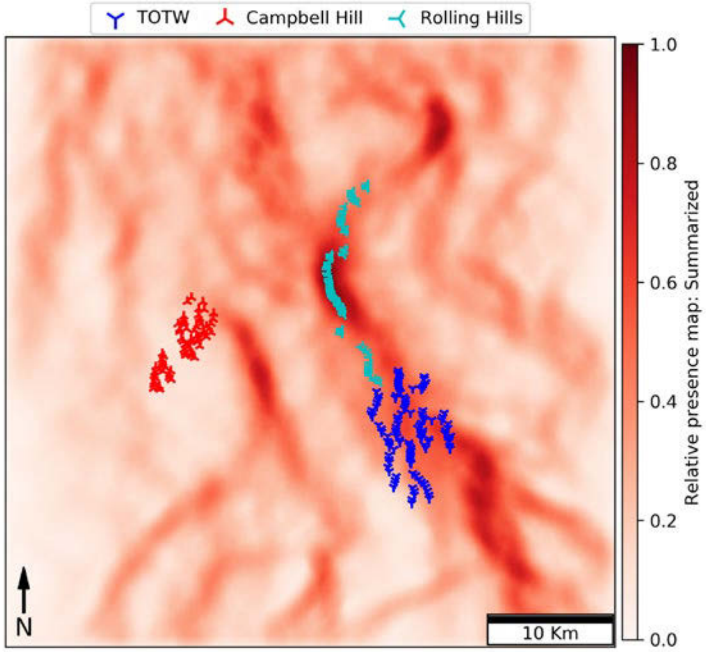
Eagle presence probability
(50-m resolution)

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

Presentations at WWRM:

- Sandhu et al., “Quantifying Turbine-Level Risk to Golden Eagles Using a High-Fidelity Updraft Model and a Stochastic Behavioral Model”
- Thedin et al., “High-Fidelity Modeling of Eagle Soaring Habitats Near Wind Plants in Complex Terrain”
- Draxl et al., “Mesoscale Modeling to Characterize Eagle Soaring Habitat”

Thank you!

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NREL/PR-5000-78464

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Wind Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

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