Progress Towards a Predictive Eagle Behavior and Risk Modeling Framework: Overview and Recent Validation Efforts

Eliot Quon et al.

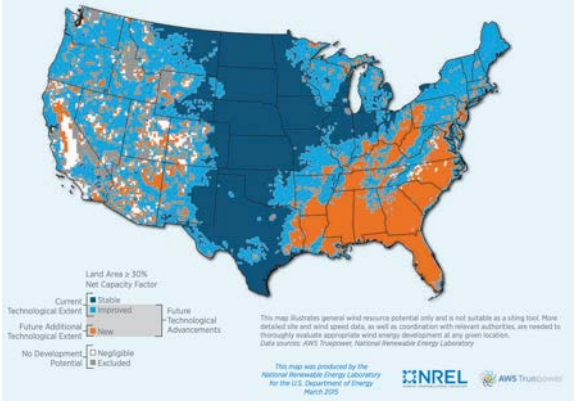
Wind Wildlife Research Meeting
November 15-17, 2022

Photo courtesy of D. Brandes

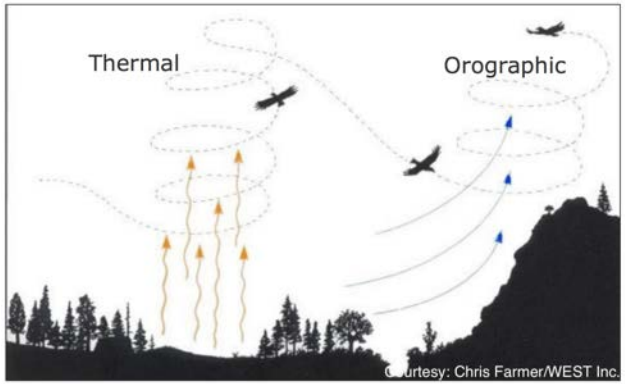
Overview

- Objective: Reduce wildlife barriers to wind deployment by developing informed technical solutions to wildlife impacts, based on
  - Eagle behavioral knowledge
  - Telemetry data
  - High-fidelity flow modeling and atmospheric science insights
  - Machine learning
- Solution: An **open-source eagle behavior and presence modeling tool**
  - Supports integrated design
  - Presence → risk

See also: March 2022 Webinar
nrel.gov/wind/eagle-webinar.html



NREL/TP-5000-63197, 2015.



Project Team ("et al.")

NREL — behavioral modeling, atmospheric modeling, data analysis, project management

- **Eliot Quon**
- **Charles Tripp**
- **Rimple Sandhu**
- **Regis Thedin**
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- Bethany Straw
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U.S. Geological Survey (USGS) — eagle biology and behavior expertise

- **Todd Katzner**
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Western EcoSystems Technology, Inc. — eagle behavior, data analysis

- **Chris Farmer**
- **Ted Owen**
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Conservation Science Global, Inc. — eagle biology and behavior, data collection and analysis

- **Trish Miller**
- Missy Braham
- Adam Duerr

Lafayette College — eagle behavior and modeling

- **David Brandes**

Industry Partners

- Duke Energy
- IdentiFlight International

Advisory Group

- Heather Beeler, U.S. Fish and Wildlife Service
- Douglas A. Bell, East Bay Regional Park District
- Scott Creel, Montana State University
- Ellen Crivella, Ørsted
- Patrick Hawbecker, National Center for Atmospheric Research
- Mona Khalil, USGS
- Laura Nagy, Avangrid Renewables
- Stephan de Wekker, University of Virginia
- George Young, Pennsylvania State University

Modeling Framework Overview

Initialization

Entity: **atmosphere**
Wind speed, direction
Turbulence intensity
Radiative heat flux

Entity: **land surface**
Terrain slope, aspect
Channeling, sheltering
Land cover, land use

Entity: **eagles**
Resident/migrant
Age, *Sex* } *Size*
Behavioral intent

Entity: **turbines**
Turbine height
Rotor diameter
Wind plant layout

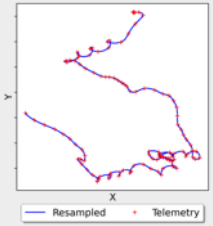
Entity: **prey**
Prey type
Spatial distribution

Submodels

Data-driven behavioral modeling

Spatial scale: microscale

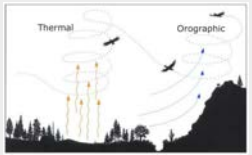
- Dynamic stochastic model
- State-space conditioning for flight variables



Updraft modeling

Spatial scale: landscape/mesoscale

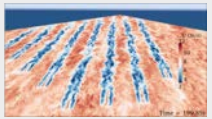
- Vector orographic model
- Statistical thermal model
- Derived corrections



Detailed atmospheric modeling

Spatial scale: meso–micro scales

- Large-scale weather
- Resolved microscale turbulence (~1 s time scale)
- Wind turbine aerodynamics



Analyses

Presence maps

- Migratory pathways
- Likelihood of conflict with wind plants

Stochastic movement tracks in 2D/3D

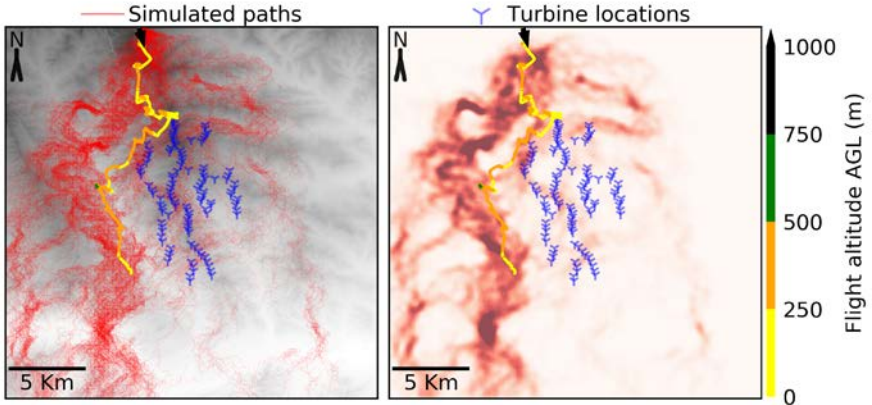
- Presence in rotor-swept zone
- Meso- and micro-avoidance
- Characterization of risky flights
- Post-mortem assessment of flight environment

Stochastic Soaring Raptor Simulator (SSRS)

Lead: Rimple Sandhu

- Advancement: **probabilistic presence prediction**
- Single behavioral heuristic, **energy minimization**, under orographic-lift dominant conditions
- Validation against selected GPS tracks

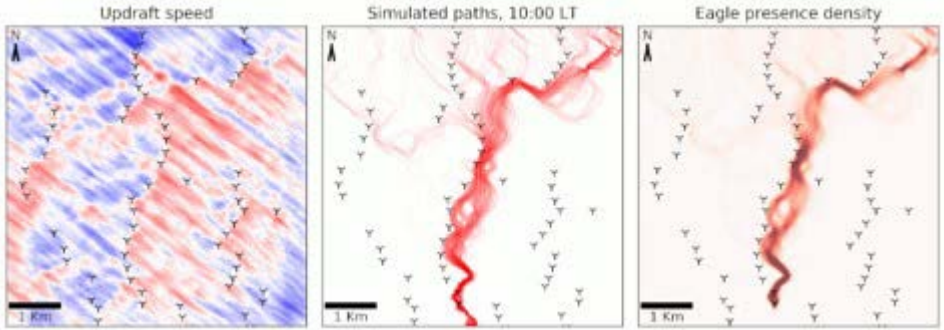
Initial Validation: GPS telemetry data, Top of the World (TOTW), WY



Sandhu et al, Ecological Modelling, 2022, doi://10.1016/j.ecolmodel.2022.109876.

Direction of flight intent

Application: Updraft field from high-fidelity CFD



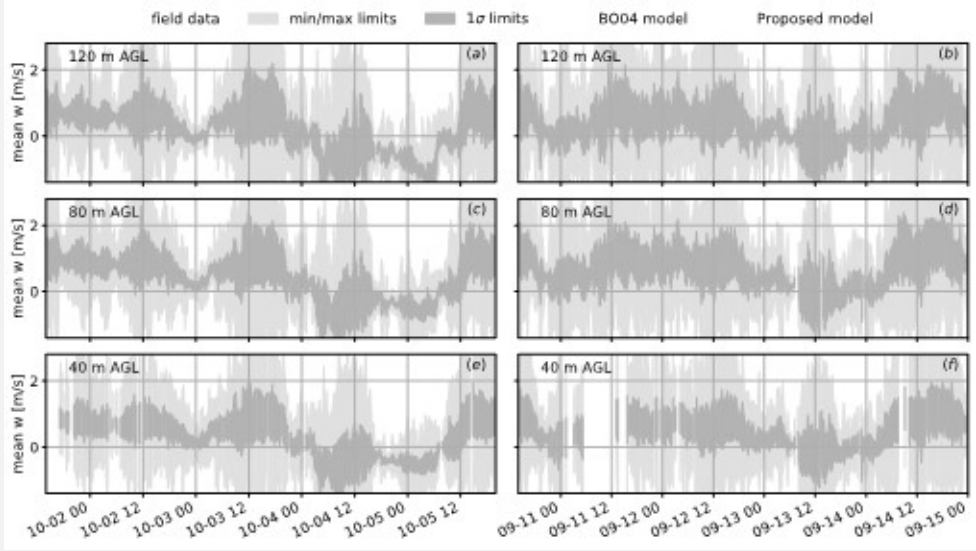
Approximate wind direction

SSRS Improvements: **Engineering Vertical Velocity Estimator** (EVVE)

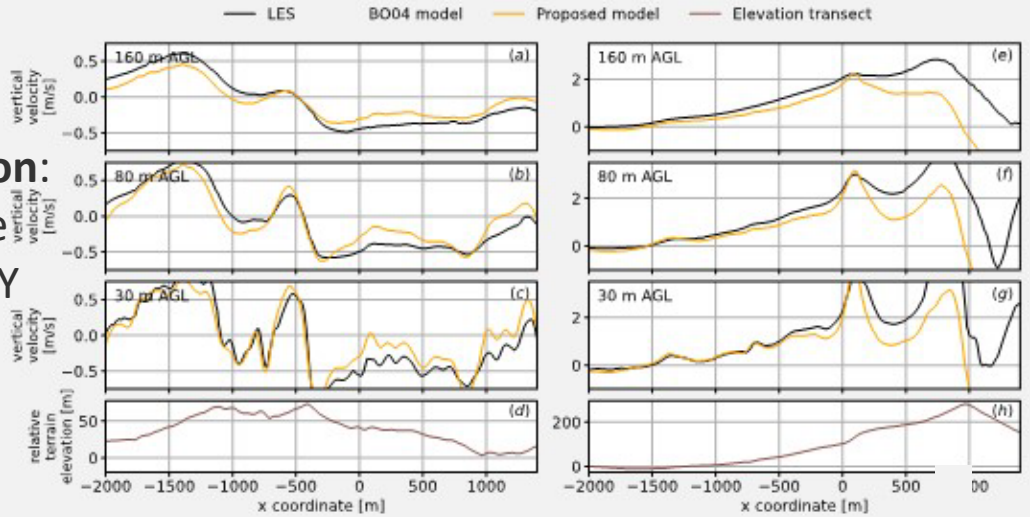
Lead: Regis Thedin

- Reference orographic updraft model (BO04) has known limitations
- Proposed model correctly captures **height variability**, accounts for **nonlocal effects**

Validation: Alaiz Mtn., Spain



Application: Top of the World, WY

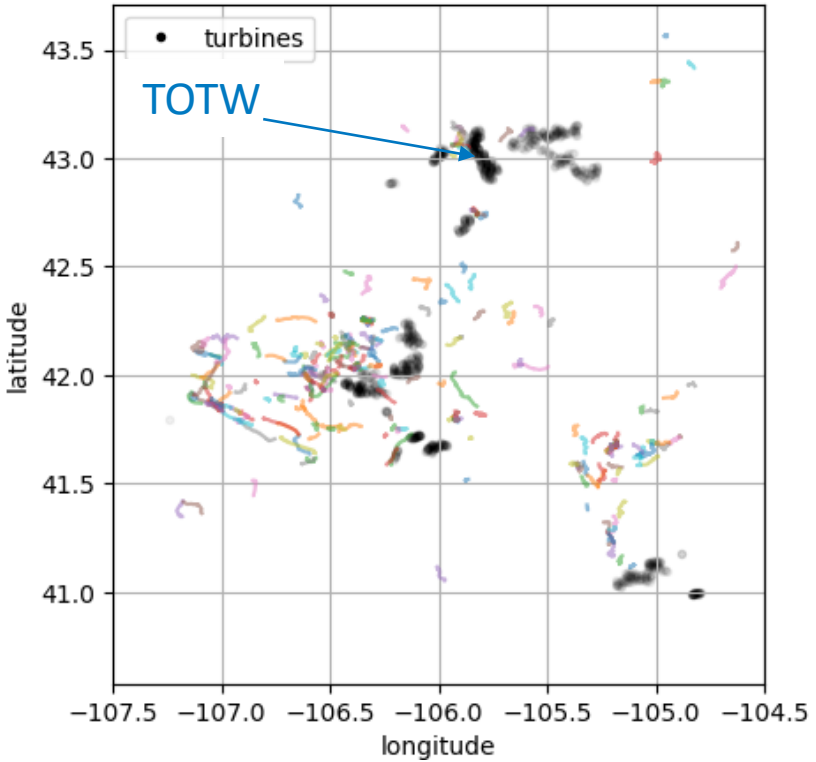


Further Validation of SSRS

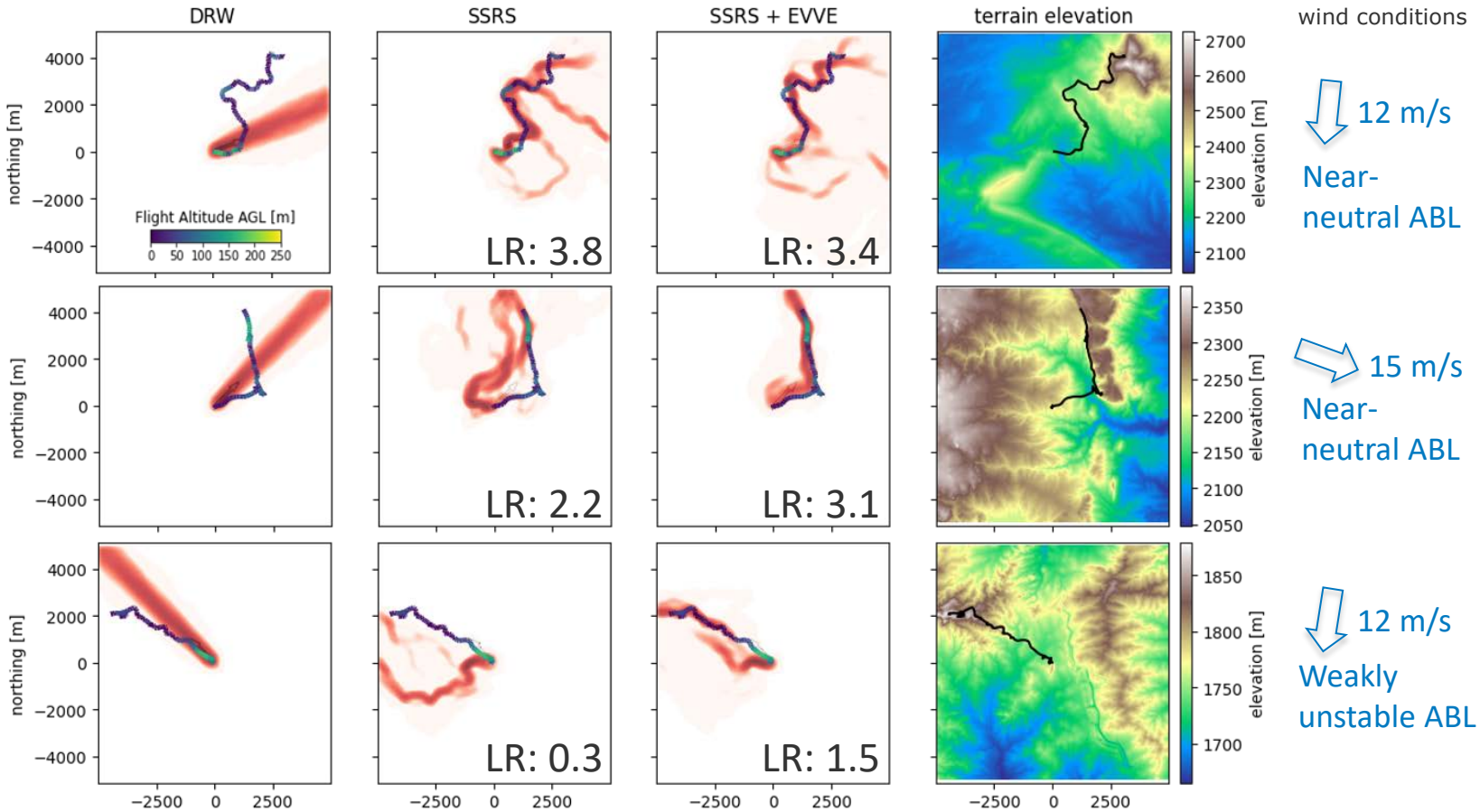
- Telemetry data filters
  - Movement in rotor-swept zone (max altitude < 250 m AGL)
  - Significant orographic updrafts (mean wind speed ≥ 10 m/s)
  - Weakly unstable / near-neutral atmospheric conditions
  - Track length > 10 min
- Modeling choices
  - Local intent estimated from track start
  - Smaller, higher-resolution domain (10x10 km^2, 20-m grid)

3.5 million data points

> 300 risky tracks identified



SSRS Examples: Comparing Updraft Models in WY



DRW: directed random walk, ABL: atmospheric boundary layer, LR: likelihood ratio

Likelihood Ratio (LR) Statistics

	# Tracks	Mean	Median	Max
SSRS, original updraft model	100*	1.22	0.99	6.44
SSRS + EVVE	100*	1.20	0.95	6.83
SSRS, original updraft model	67**	**1.28**	**1.16**	**5.53**
SSRS + EVVE	67**	**1.35**	**1.05**	**6.83**

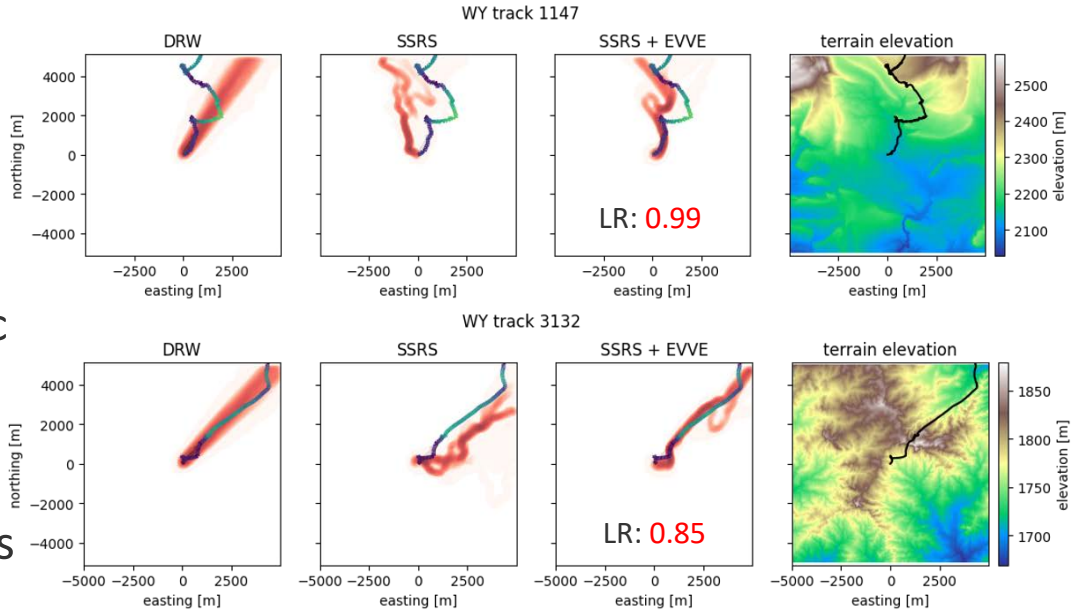
* Chosen at random from database of risky flights

** Selected tracks were manually excluded if:

1. There was a clear change in flight intent or mode, neither of which are accounted for in SSRS;
2. The range of travel within a track was limited or the movements were highly irregular, such that there was no clear flight intent; and/or
3. There was significant variation in flight altitude above ground level, suggesting mixed lift conditions and a combination of flight modes.

New SSRS Validation Summary

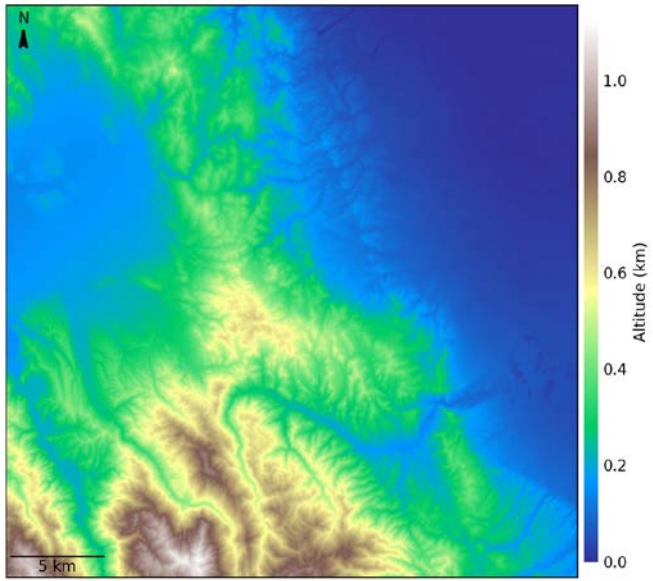
- SSRS (with or without EVVE) is generally predictive of orographic flight
  - Matching complexity of individual tracks is a challenge
- Likelihood is a conservative metric
  - Can *overrepresent* predictive performance of DRW
  - Can *undervalue* the predicted nuances of the simulated tracks
- EVVE updraft model
  - Performs similarly to original vector model (on average)
  - Can significantly outperform vector model under appropriate conditions

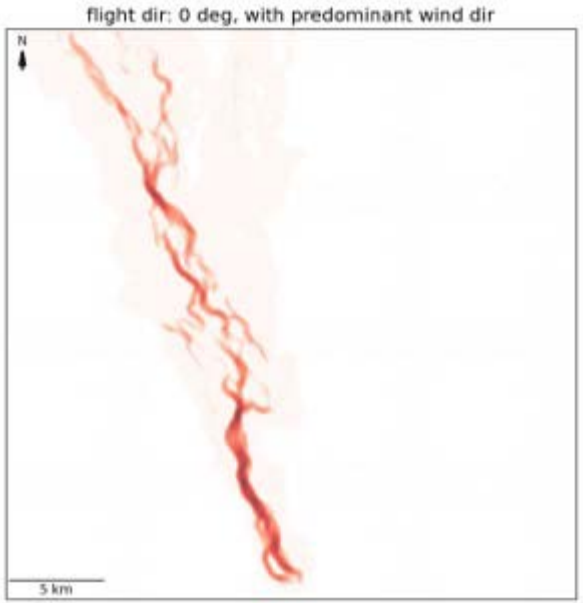


New Questions We Can Address With SSRS

- How do eagles approach a wind farm?
- How do we expect eagles to move within a wind farm?

Altamont Pass

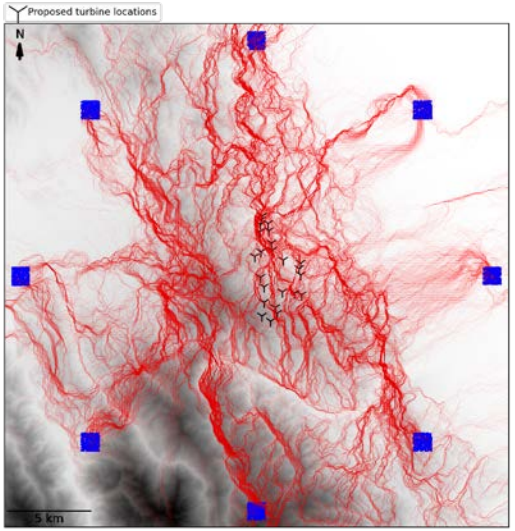




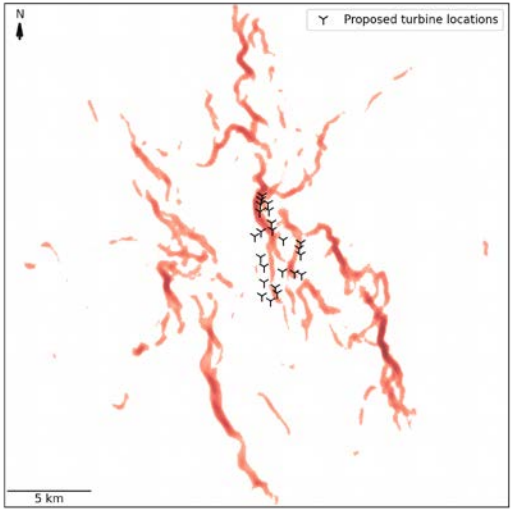
Adapting SSRS for Facility-Scale Movements

- Sensitivity study
  - Number of trajectory origins?
  - Radial distance representative of facility-scale movement?
  - Representative domain size to capture landscape-scale effects?
  - Are predominant wind conditions representative?
- Further validation in progress: compare with Altamont Pass telemetry data

Tracks with inward radial trajectory



Combined presence map

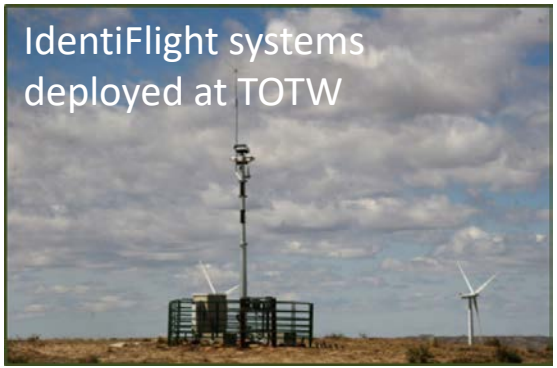


Beyond SSRS: Two Advanced Capabilities

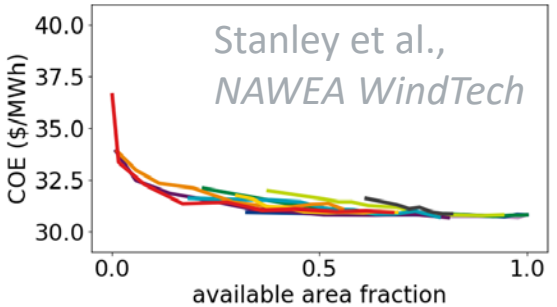
- Heuristics-based SSRS (H-SSRS) — Lead: David Brandes
  - Formalizes multiple heuristics
  - Testbed for modeled behaviors
  - Model scale: landscape–facility
- Bayesian State Space model — Lead: Rimple Sandhu
  - Data-driven approach
  - Scale: microscale
  - Key building block: nonlinear Kalman Filtering

Outlook

- A set of models is being developed for modeling **behavior** and **presence**
- Ongoing validation
  - SSRS: Altamont sensitivity study (in progress)
  - Bayesian model: comparison with IdentiFlight recorded microscale movements (in progress)
- Applications
  - **Bayesian model: 3D presence and risk**
  - Environmental siting constraints based on presence models (see right)
- Stakeholder engagement
  - Meetings after WWRM



Minimizing Cost of Energy (COE)



Code Availability and Accompanying Talks

Stochastic Soaring Raptor Simulator: github.com/NREL/SSRS

Engineering Vertical Velocity Estimator: github.com/NREL/EVVE

On-Demand Presentations

#10: Brandes et al, A heuristic agent-based model for simulating golden eagle flightpaths and mapping potential collision risk

#13: Sandhu et al., Decoding golden eagle movement behavior from high-resolution, variable-rate telemetry data through Bayesian filtering

#57: Thedin et al., Engineering models for orographic and thermal updrafts for movement simulators of eagles at risk of collision with wind turbines

Thank you!

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