Simulation-Based Model for Facility-Scale Eagle Presence Mapping

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Eagle Behavior and Risk Modeling for Wind Energy Workshop
29 March 2022

Problem Statement

Risk to soaring raptors from wind turbines

Problem Statement

- Eagles are a protected species under:
  - Bald and Golden Eagle Protection Act
  - Migratory Bird Treaty Act.

- Eagles face increased risk of turbine collision:
  - Obligate soaring birds and reliance on updrafts
  - Low-altitude flapping flight during hunting
  - Overlap between wind resource and eagle habitat.

Image from Todd Katzner, U.S Geological Survey

Image from Duke Energy

Golden eagles at the Top of the World Windpower wind farm near Casper, Wyoming

Research Objective: Predictive Movement Model

- Construct, implement, and validate an eagle behavior model that is:
  - **Predictive**: Predicts eagle paths given current location and atmospheric conditions
  - **Agent-based**: Simulates individual golden eagle movements
  - **Probabilistic**: Quantifies uncertainties to produce stochastic eagle risk/presence maps
  - **Generalizable**: Predicts eagle behavior across wind farms and eagle species
  - **Microscale**: Generates turbine-level eagle tracks and presence/risk maps
  - **Validated**: Compares performance against golden eagle telemetry data.

- Intended model usage:
  - Guide future wind power plant siting and smart curtailment strategies
  - Design tailored collision mitigation strategies for existing wind power plants
  - Implement real-time eagle path prediction and turbine control.

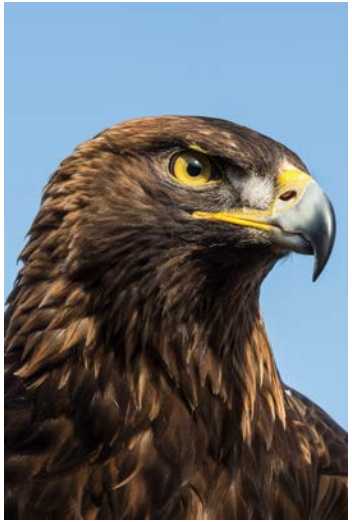


Photo by Dennis Schroeder, NREL 35732

Major Factors Affecting Real-Time Eagle Behavior

- Measurable factors
  - **Orographic updraft** (deflected by terrain features)
  - Thermal updraft (caused by differential heating of ground)
  - Ground cover (sagebrush/grass/forests/paved)
  - **Season and time of day**
  - Prey distribution
  - Vicinity to nest.

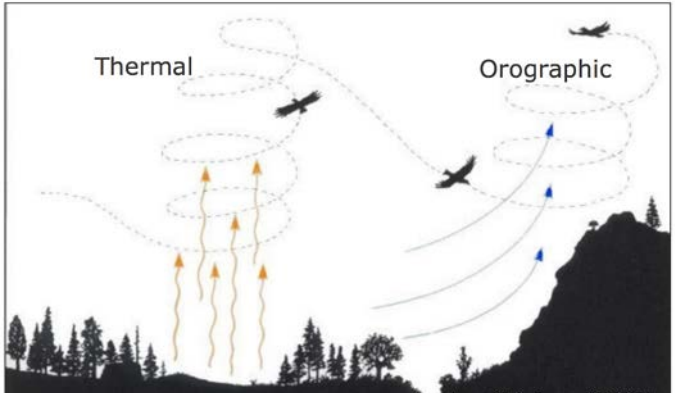


Image from Chris Farmer, WEST Inc.

- Unmeasurable factors
  - Eagle activity (hunting/perching/migrating/following others)
  - Eagle-to-eagle interaction.

Golden eagles using orographic updrafts are more likely to fly at lower altitudes than when using thermal updrafts!

Stochastic Soaring Raptor Simulator (SSRS)

Proposed solution to prevent turbine collisions

Stochastic Soaring Raptor Simulator (SSRS): Overview

Entities

Entity: atmosphere

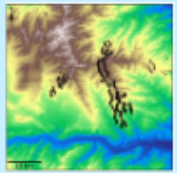
Temporal scale: Hourly

- *Wind conditions*
- *Solar radiation*
- *Pressure and boundary layer height*

Entity: land surface

Spatial scale: < 50 m

- *Elevation*
- *Slope*
- *Aspect*



Entity: golden eagles

- *Assumed direction of movement*
- *Location/region of entry*
- *Behavioral intent*

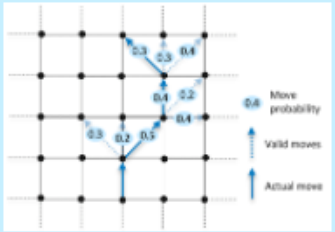
Submodels

Updraft model

- Vector-based orographic updraft model
- Thermal updraft statistical model
- Stochasticity in atmospheric conditions

Movement model

- Fluid-flow-based energy minimization
- Stochastic decision-making
- Uncertainty in starting location/region



Analyses

Model validation

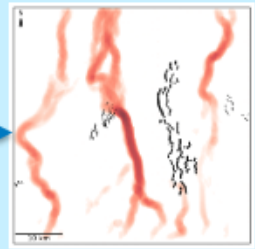
Telemetry data from Wyoming

- 2D presence versus observed tracks using likelihood ratio

Probabilistic predictions

- Seasonal or hourly analysis
- 2D relative presence probability
- Conflict with specific turbines

1,000 simulated paths



SSRS: Data Sources

- Atmospheric conditions:
  - The National Renewable Energy Laboratory's (NREL's) Wind Integration National Dataset (WIND) Toolkit at 2 km, hourly resolution (2007–2014)
  - The National Oceanic and Atmospheric Administration's (NOAA's) High-Resolution Rapid Refresh (HRRR) model at 3-km, hourly resolution (to be added to SSRS).
- Terrain features:
  - The National Aeronautics and Space Administration's (NASA's) Shuttle Radar Topography Mission (SRTM) data set at 30-m resolution (elevation only)
  - The U.S. Geological Survey's (USGS's) 3D Elevation Program (3DEP) data set at 10-m resolution (elevation, slope, aspect).
- Wind turbine locations:
  - USGS's United States Wind Turbine Database (USWTB).

All these data sets are publicly available!

SSRS Submodels: Updrafts

- Orographic updrafts (w_o) are computed using terrain slope (ϕ), terrain aspect (β), wind speed (v), and wind direction (α):

$$w_o = v \sin(\phi)\, cos(\alpha - \beta)$$

- Thermal updrafts (w_t) at height z above ground level are computed using boundary layer height (z_i), surface heat flux (H), and potential temperature (θ) via Deardorff (convective) velocity (w_*):

$$w_* = (g z_i H/\theta)^{1/3}$$

$$w_t = 0.85 w_* \left(\frac{z}{z_i}\right)^{1/3} \left(1.3 - \frac{z}{z_i}\right)$$

- Potential temperature (θ) is computed using pressure (P) and temperature (T) at hub height (100 m) and a P_0 value of 105 Pa

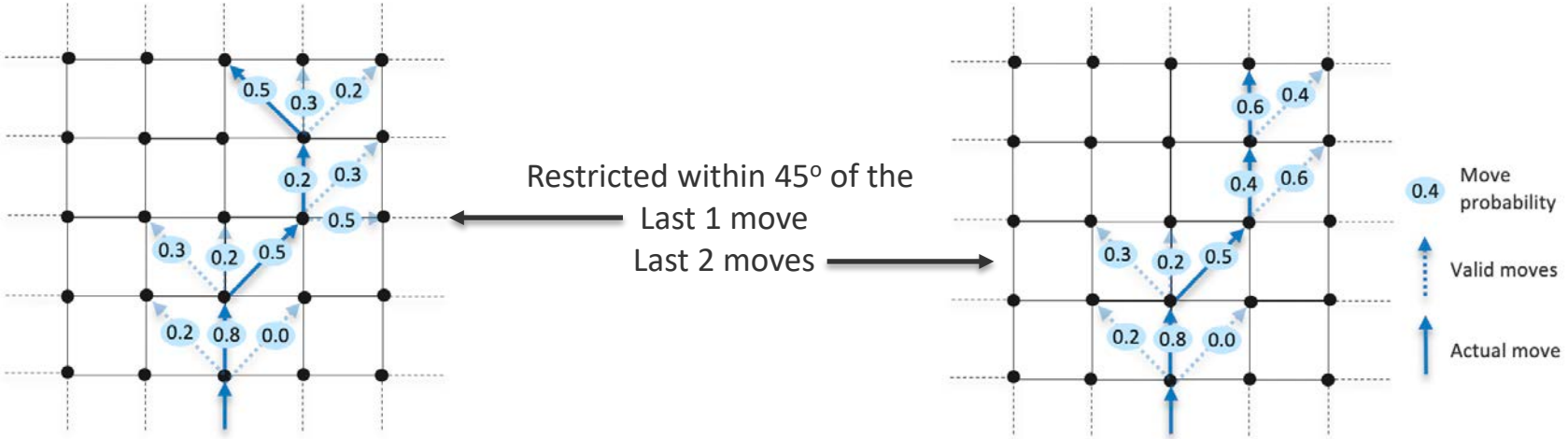
$$\theta = T \left(\frac{P_0}{P}\right)^{0.2857}$$

SSRS Submodels: Movements

- Simulate eagle paths based on the fluid-flow principle of minimizing energy expenditure (Darcy's law) using the estimated updraft field (K)

$$q_s = K\frac{\delta h}{\delta s}$$

- The directional potential (h) is computed using the assumed direction of movement (linear system solve)
- Eagle decision-making based on probabilities rather than along the maximum velocity (q_s) direction
- Further restrictions added to restrict sharp directional changes through a memory parameter.



Application and Validation of SSRS

The Top of the World Windpower wind farm in Wyoming

Application to the Top of the World Windpower Wind Farm

50-km by 50-km study area north of Casper, Wyoming, was chosen because:

- It contains three wind power plants including the Top of the World (TOTW) Windpower wind farm.
- There is documented evidence of golden eagle fatalities resulting from turbine collisions in this area.
- Golden eagle telemetry data and fatality data are available.

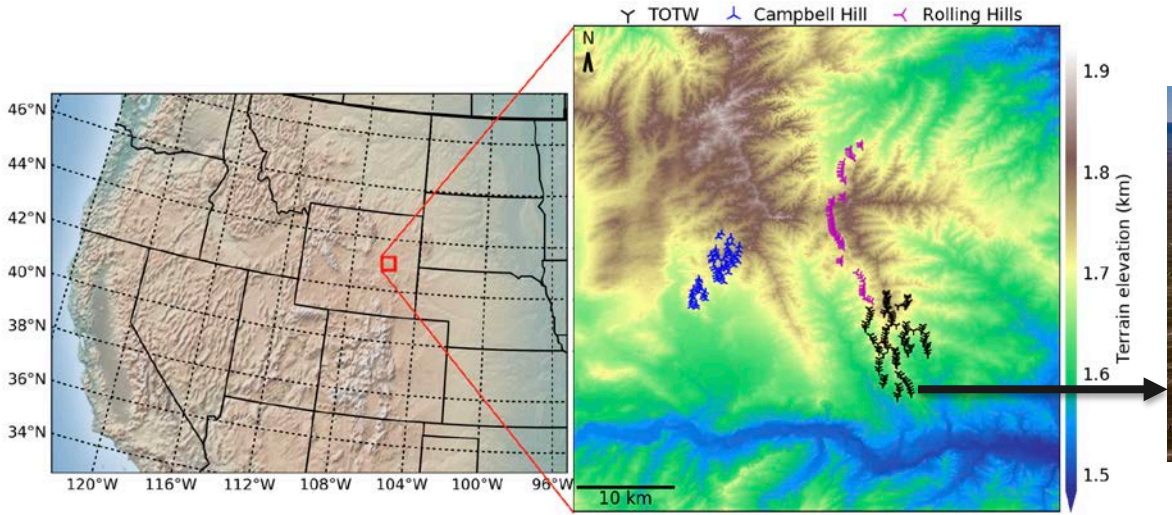
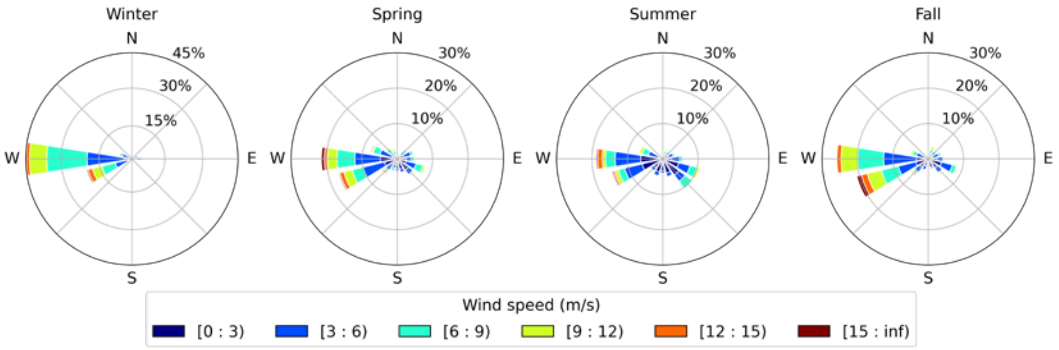
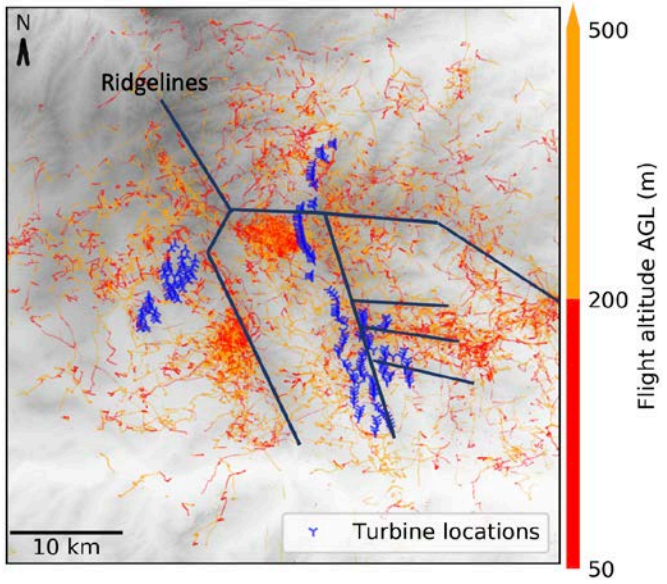


Image from Duke Energy

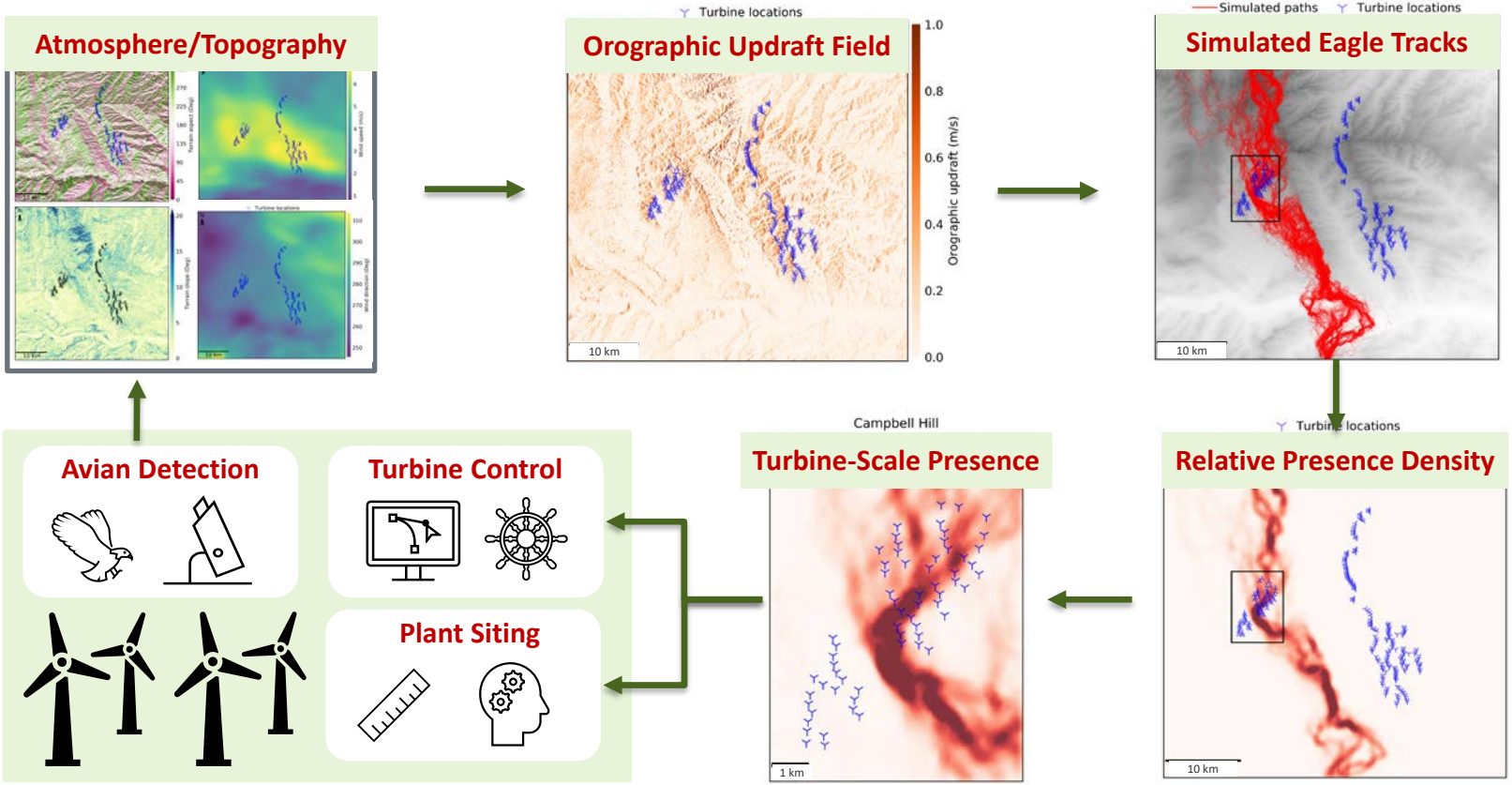
Evidence of Orographic Updraft Use at the Study Area

- The study area experiences mostly westerly or southwesterly winds.
- North-south ridgelines and westerly winds promote orographic updrafts.
- Telemetry data suggest potential preference for orographic soaring flight within 50–200 m above ground level (AGL).
- Lower-AGL flight creates potential for turbine collision.



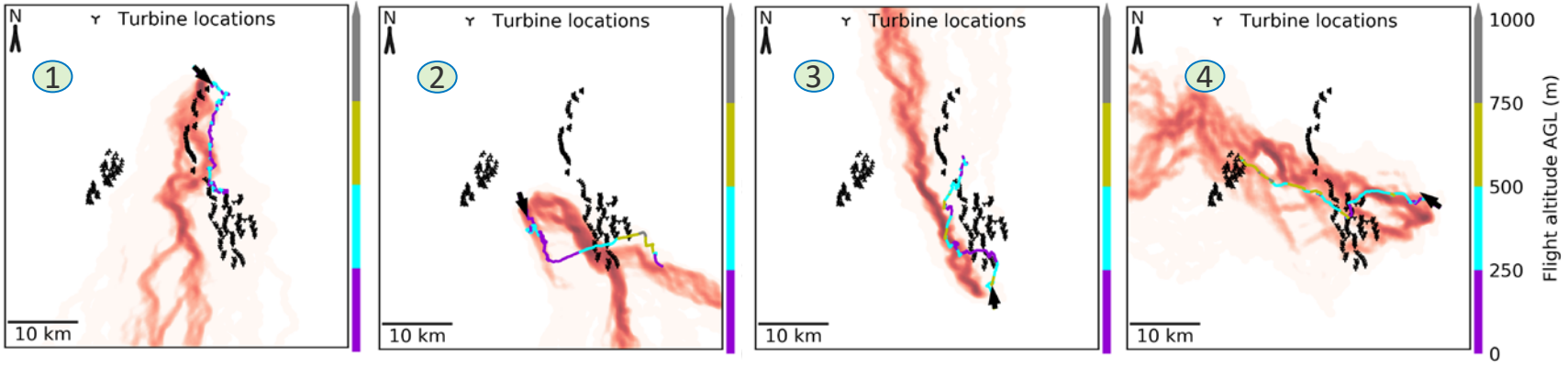


SSRS Workflow



Model Validation With Telemetry Data

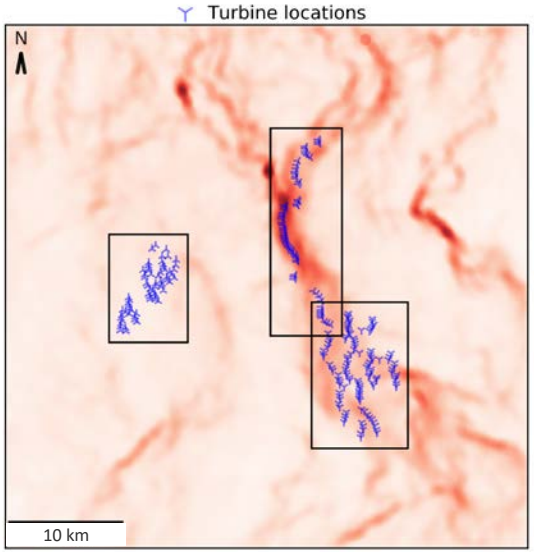
- 500 simulated paths initiated from the same location as the observed eagle path
- Likelihood ratio quantifies model performance compared to Directed Random Walk (DRW) or Uniform presence
- As the flight altitude increased, the predictive performance of the model degraded!



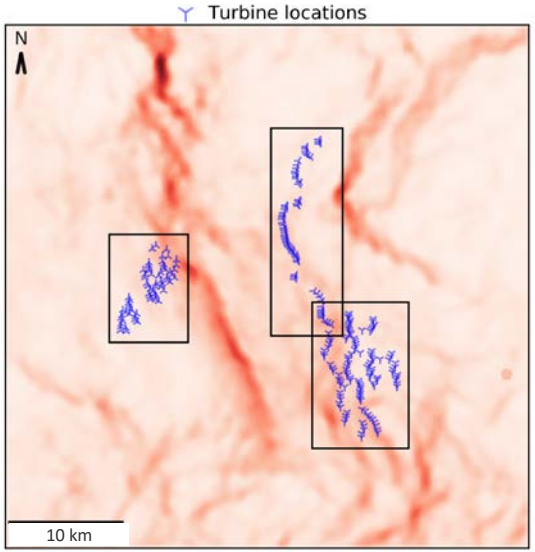
	Direction of movement and time of day	Likelihood of eagle presence			Likelihood ratio		Median flight altitude (m)	Wind speed (m/s) & dirn
		Model	Uniform	DRW	Uniform	DRW		
1	Southbound at 12:00 LT on March 18, 2020	1.94e–3	5.84e–4	1.40e–4	**3.33**	**13.56**	216	3.85, NW
2	Southwest bound at 13:00 LT on March 4, 2020	4.44e–3	5.74e–4	1.63e–3	**7.74**	**2.72**	86	14.98, SW
3	Northbound at 12:00 LT on July 3, 2019	4.86e–3	5.92e–4	3.27e–3	**8.21**	**1.48**	293	3.36, S
4	Westbound at 10:00 LT on April 18, 2020	2.85e–3	5.17e–4	3.55e–3	**5.52**	**0.81**	357	8.43, W

Model Predictions: Seasonal Migration

- Average of 300 randomly selected time instances from each season using WIND ToolKit (WTK) data for years 2007–2014
- Eliminated situations where usable thermals exist, and simulated 500 paths for the remaining time instances
- Higher presence of eagles near TOTW and especially Rolling Hills during fall than during spring.



Southerly migration in fall



Northerly migration in spring

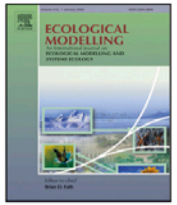
More Details in the Journal Publication

Ecological Modelling 466 (2022) 109876

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel



Check for updates

Stochastic agent-based model for predicting turbine-scale raptor movements during updraft-subsidized directional flights

Rimple Sandhu [a,*], Charles Tripp [b], Eliot Quon [a], Regis Thedin [a], Michael Lawson [a], David Brandes [g], Christopher J. Farmer [c], Tricia A. Miller [e,f], Caroline Draxl [a], Paula Doubrawa [a], Lindy Williams [b], Adam E. Duerr [e,f], Melissa A. Braham [e], Todd Katzner [d]

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Acknowledgements

- Conservation Science Global
- Western EcoSystems Technology, Inc.

Thank you

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NREL/PR-5000-82533

This work was authored in part 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. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.