Bayesian State-Space Modeling Framework for Understanding and Predicting Golden Eagle Movements Using Telemetry Data

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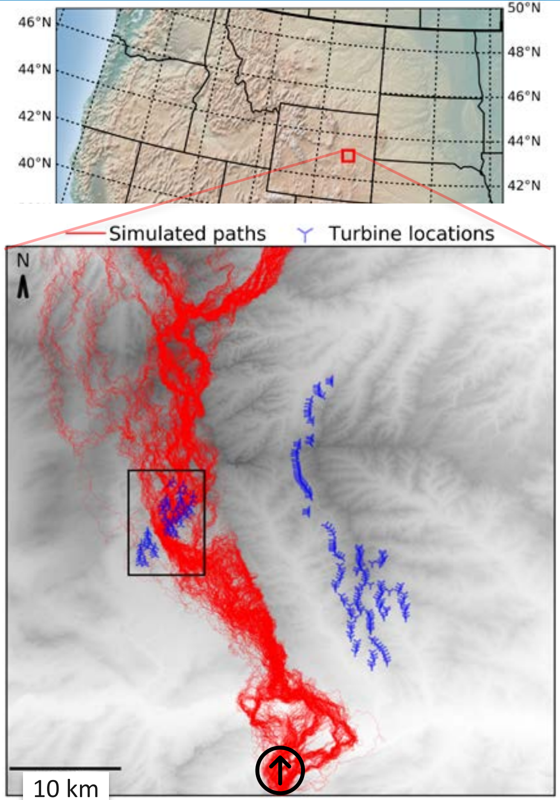
Goal of the Study

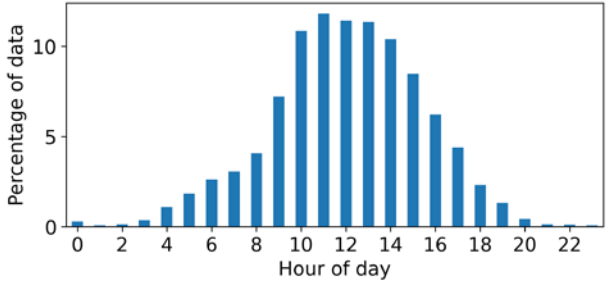
- The goal of the study is to construct a model to simulate golden eagle movements to predict potential conflict with operational/planned wind turbines under given atmospheric conditions that is:
  - Agent-based (simulates individual golden eagle movements)
  - Real time (detects an eagle approaching a wind farm)
  - Data-informed (uses telemetry/movement data)
  - Probabilistic (accounts for uncertainties in the data and model)
  - Generalizable (can be applied to different regions/raptors)
  - Turbine-scale (has a small-enough spatial scale).

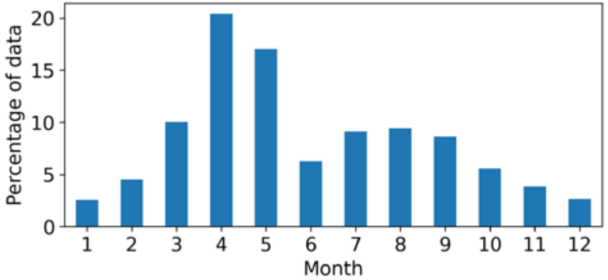


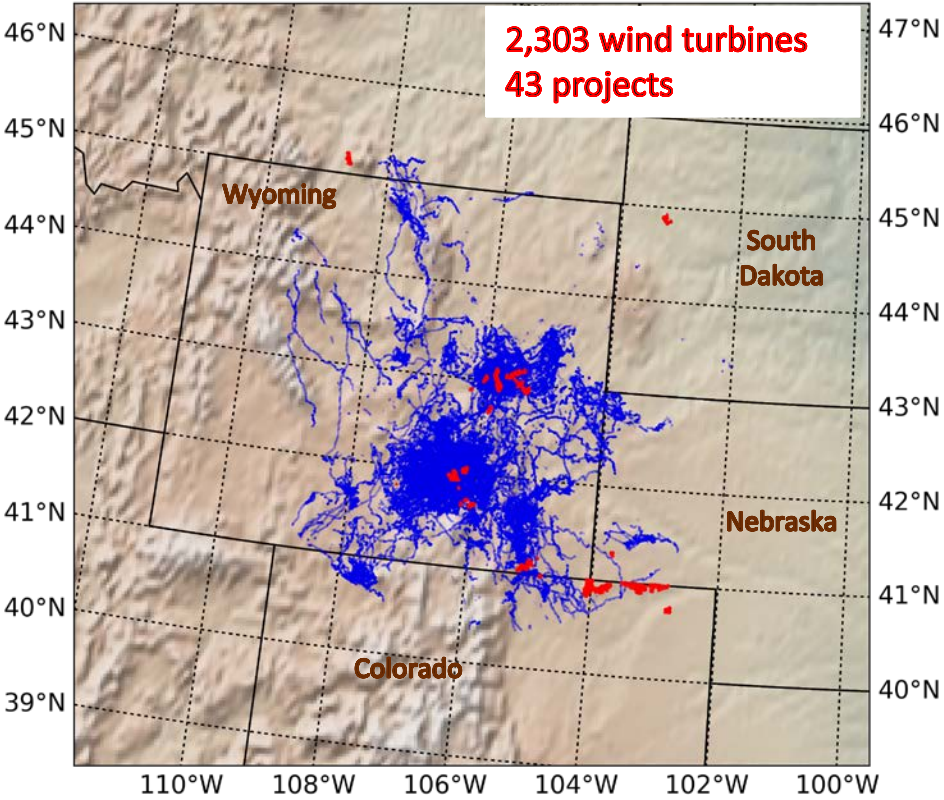
A stochastic, agent-based model predicts wind-turbine-scale raptor movements during updraft-subsidized, directional flights.
Figure from Sandhu et al. (Under Review). Ecological Modelling

Telemetry Data From the Western United States

- Up to 3.55 million data points (three-dimensional fixes)
- March 2019–August 2020
- Thirty-eight tagged golden eagles (21 male, 17 female)



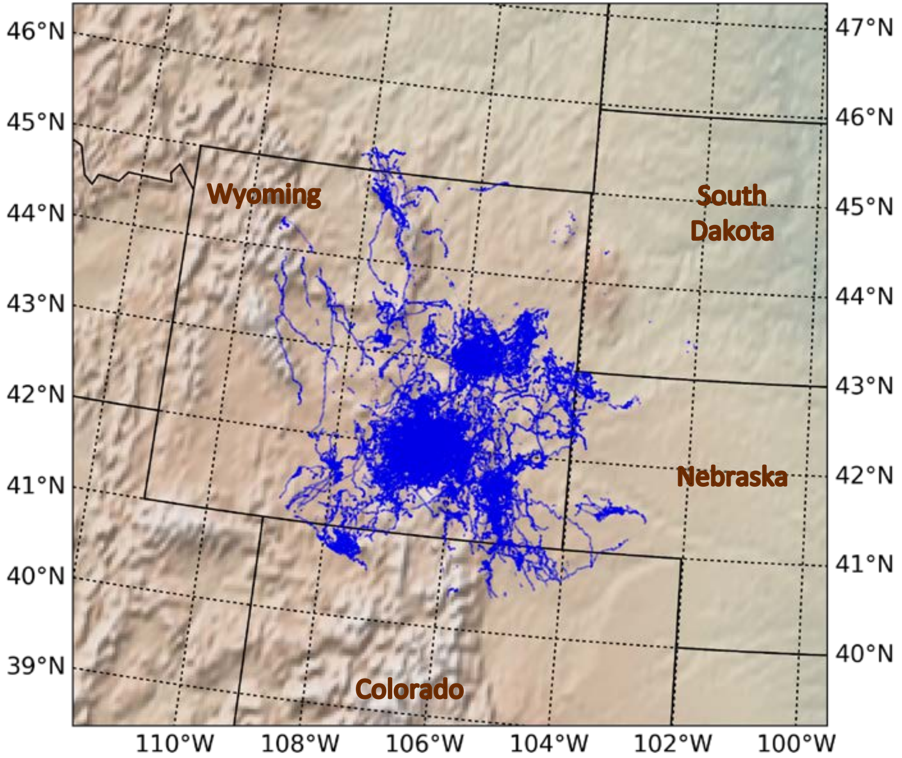




N=North; W=West; Source: Conservation Science Global

Telemetry Data From the Western United States

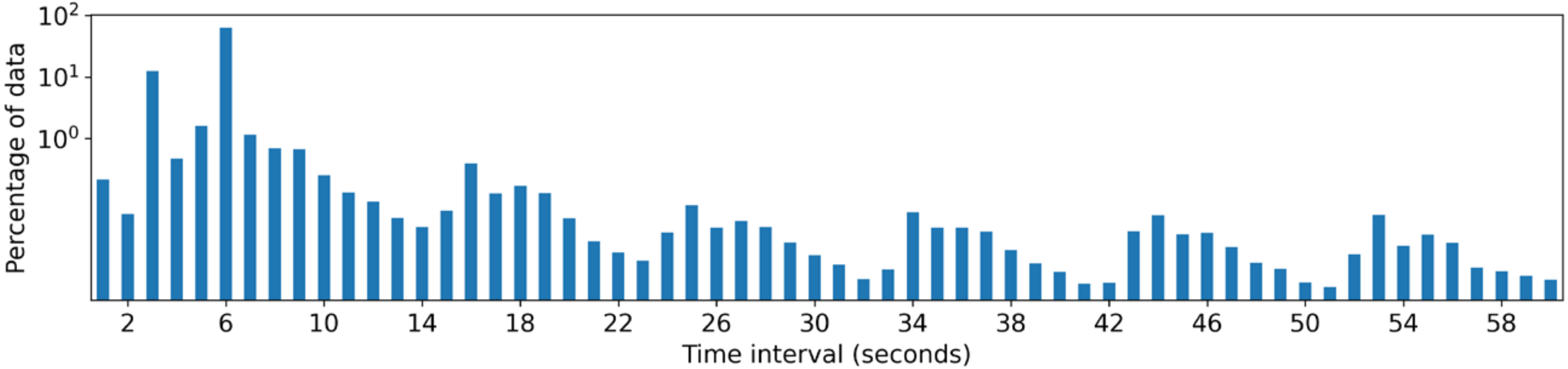
- The study aims to discover and quantify hidden relationships among these entities using simple statistical/probabilistic tools, such as:
  - **Telemetry variables** (altitude, speed, turn angle, time of day, season, age of the bird)
  - Atmospheric/topographical variables (wind speed, terrain features, temperature, solar radiation)
  - Hidden variables (intent, type of activity, mode of flight).



Source: Conservation Science Global

Resampling the Telemetry Data

- A challenge: Telemetry data samples need to be taken at constant intervals to apply statistical tools!
  - Eighty percent of the data samples are taken at less than or equal to 10-second (s) intervals.
  - Sixty-three percent of the data samples are taken at 6-s intervals.



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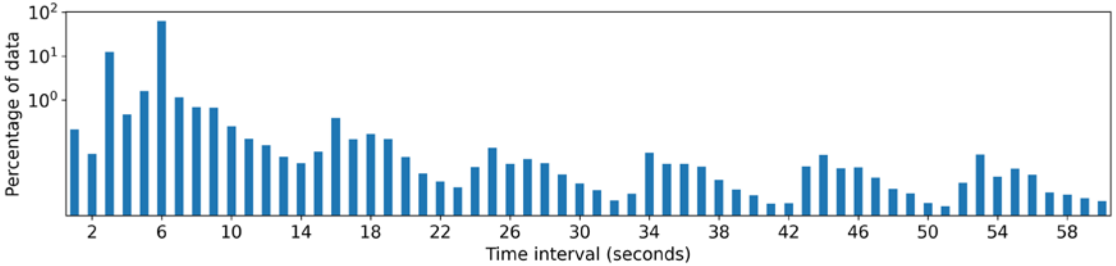
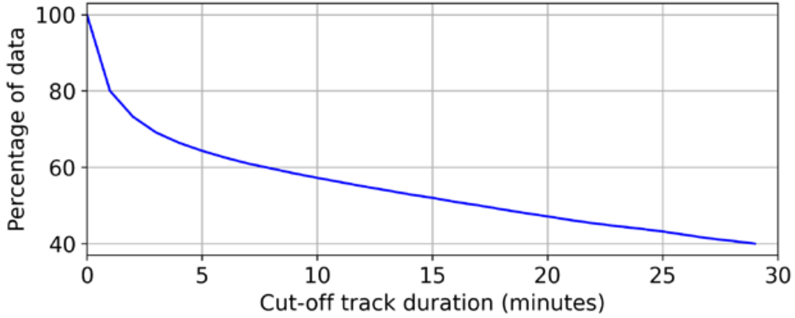


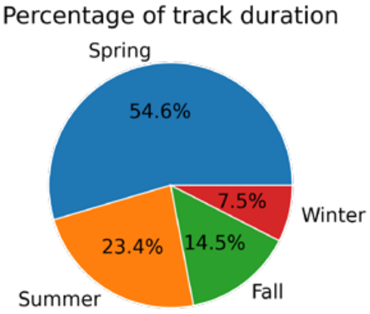
- A solution: Resample the data by following these steps:
  1. Segment the telemetry data into individual tracks separated by time intervals greater than 10 s.
  2. Consider only the tracks that are at least 10 minutes long.
  3. Perform spline interpolation for each selected track at 1-s intervals.
  4. Downsample the interpolated track at 2-s intervals.

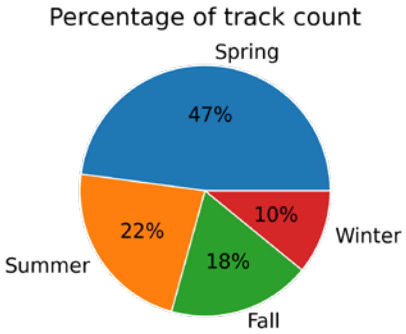
Resampled Telemetry Data

- Considering tracks with durations longer than 10 minutes results in **57% of data points, 5,324 tracks.**



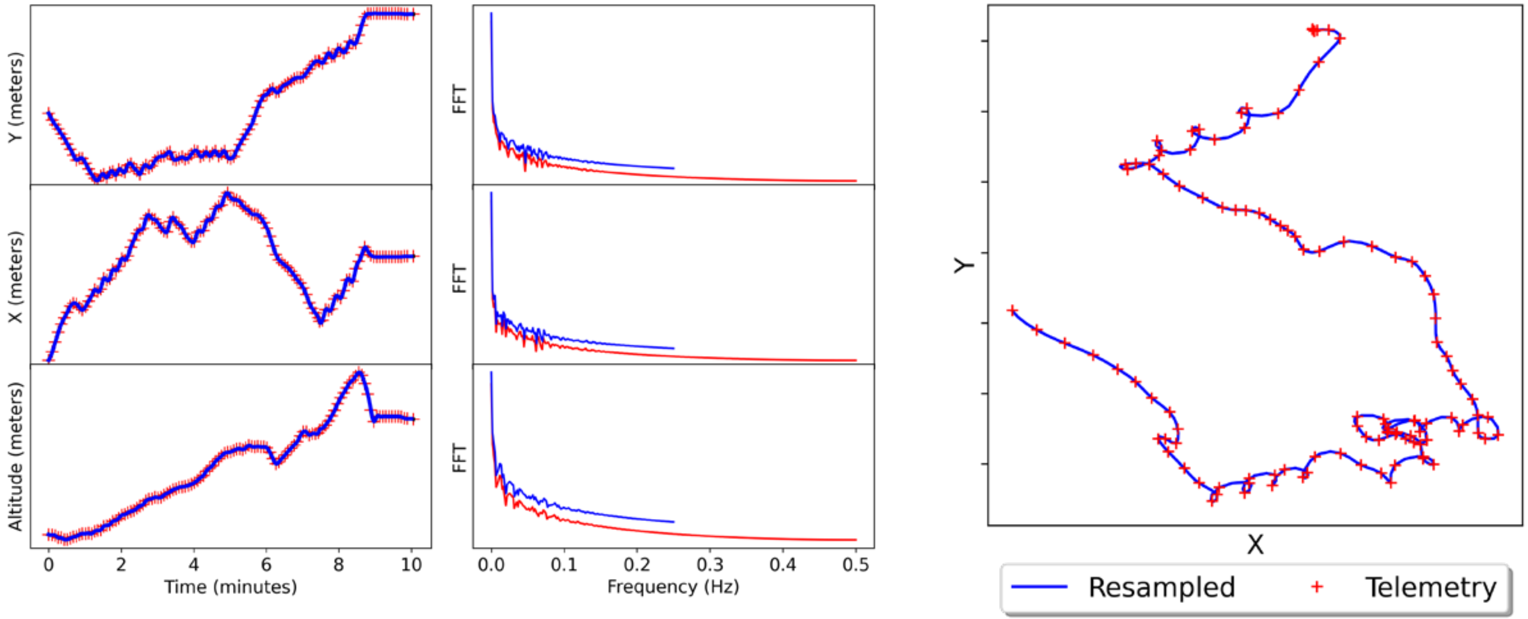
- A seasonal breakdown of chosen tracks shows that **tracks are longer in the spring and summer!**





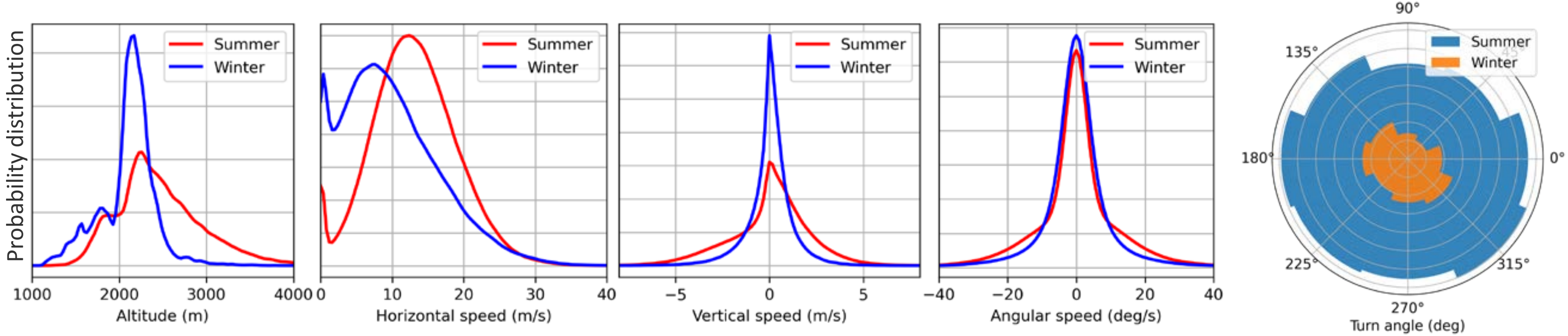
Resampled Telemetry Data

- We interpolate (at 1 s) and downsample (to 2 s) for (X, Y, Altitude) for each track.
    - X and Y (meters [m]) are the North America Albers Equal Area Conic Projection; altitude is above sea level.
    - Fast Fourier transform (FFT) quantifies the frequency (hertz [Hz]) content of the time history.



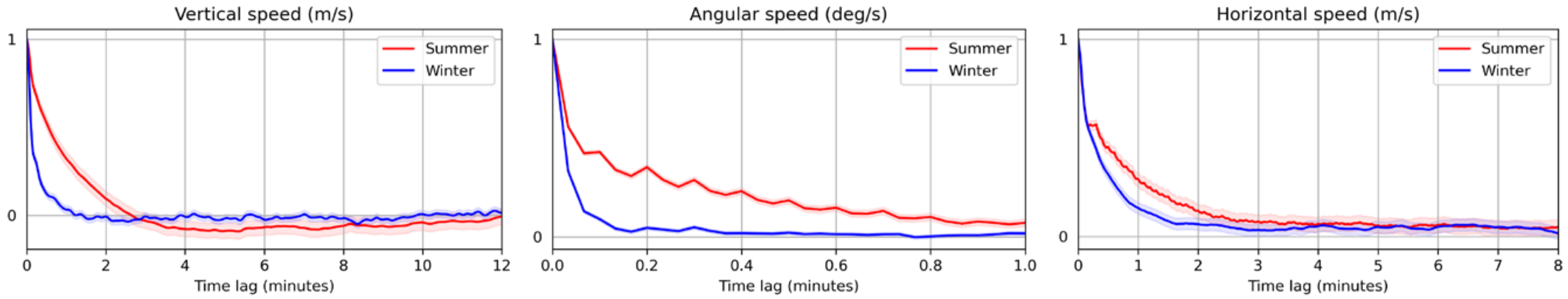
Marginal Probability Distributions

- Speeds are computed using finite difference on resampled location.
  (Altitude is above mean sea level; speed is in meters per second [m/s] or degrees per second [deg/s]).



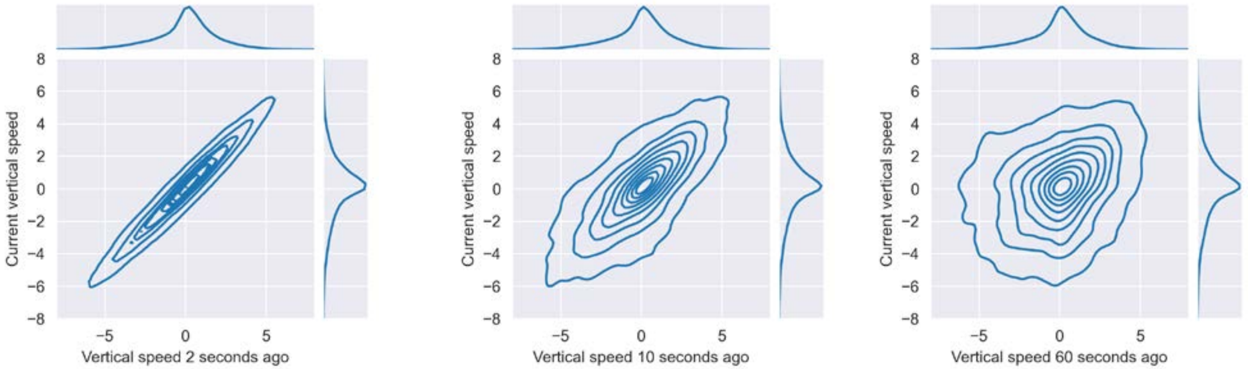
- Higher altitude and (horizontal and vertical) speeds suggest a greater proportion of thermal soaring in the summer.
- A greater proportion of negative vertical speeds in the summer suggests more sustained gliding/diving behavior.
- A greater proportion of large angular speeds in the summer suggests convoluted soaring behavior.
- A higher probability for turn angles at 0° (north) and 180° (south) in the winter suggests orographic soaring because terrain ridge lines are mostly north-south oriented in this region.

Autocorrelation Function and Conditional Distributions

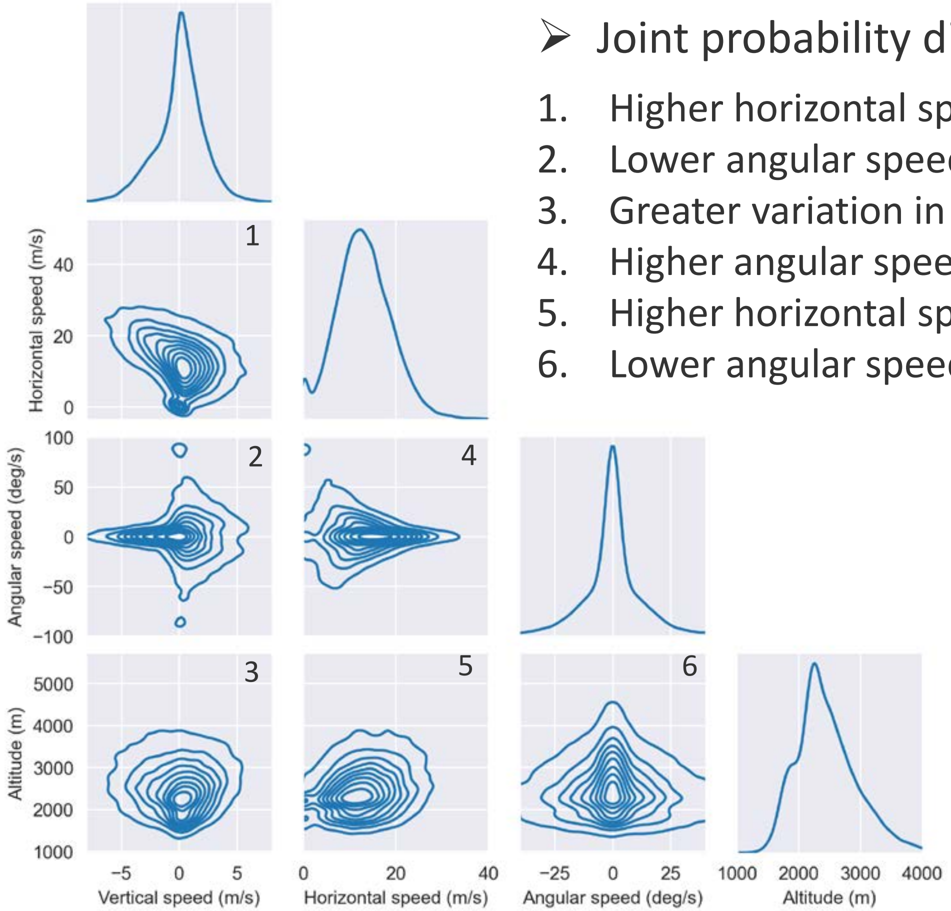


- Higher positively autocorrelated speeds in the summer suggest persistence in movement/activity.
- Negatively autocorrelated vertical speeds in the summer suggest periodic soaring and gliding/diving cycles.

Conditional distributions:



Joint Probability Distributions: Summer



- Joint probability distributions in the summer show:

1. Higher horizontal speeds when gliding/diving compared to soaring
2. Lower angular speeds when gliding/diving compared to soaring
3. Greater variation in vertical speeds at higher altitudes
4. Higher angular speeds at lower horizontal speeds
5. Higher horizontal speeds at higher altitudes
6. Lower angular speeds at higher altitudes.

- These joint distribution plots can be obtained by categorizing the resampled data based on:
    - Season
    - Age
    - Sex
    - Time of day.

Next Steps

- **The goal:** Construct a Bayesian state-space behavior model to simulate golden eagle movements and predict conflicts with wind turbines by:

  - Building a Markov model based on the established conditional relationships between observed entities

  - Annotating each telemetry data point with terrain features, wind conditions, and other atmospheric variables and including them in the model

  - Including hidden/unobserved variables, such as intent and type of activity, within the Bayesian state-space framework.

Thank you

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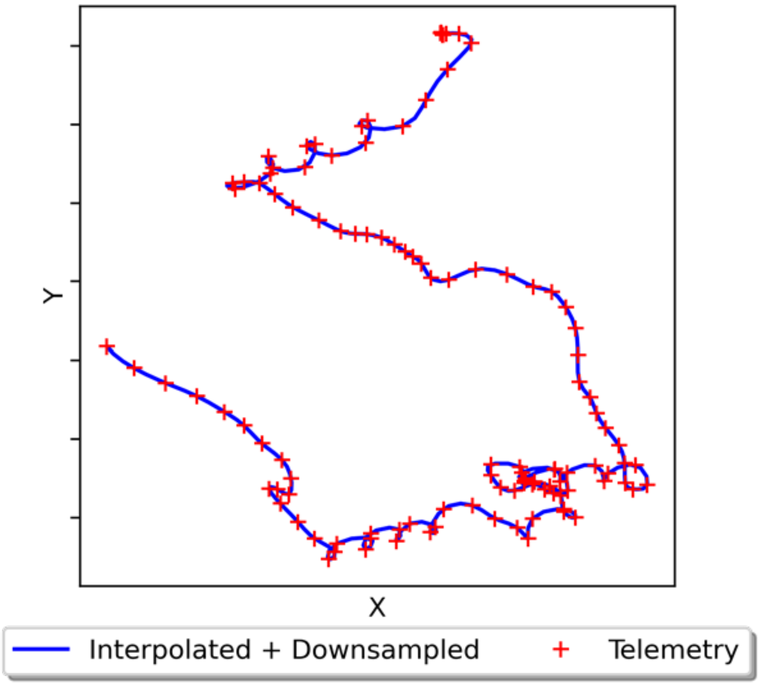
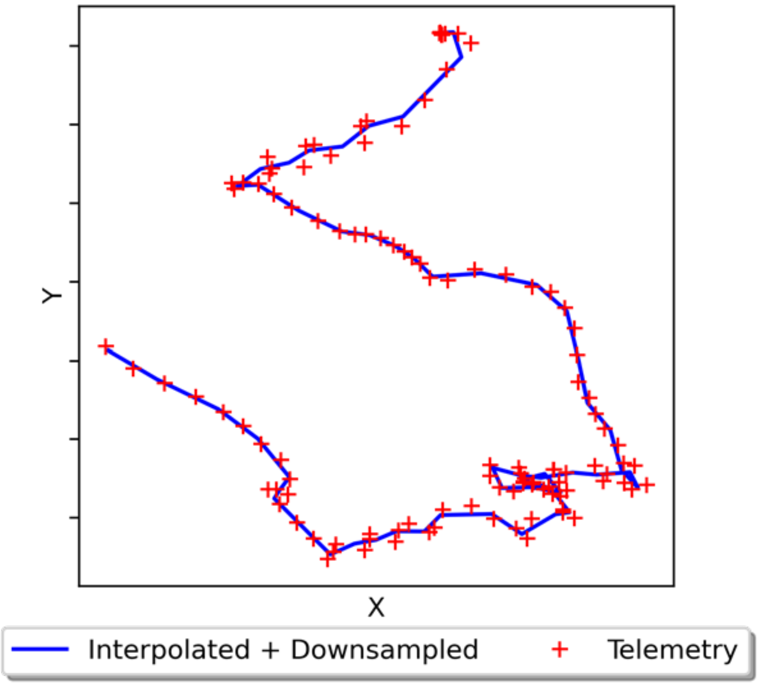
Extra: Resampled Telemetry Data

➢ The effect of downsampling factors:



Resampled at 2-s intervals



Resampled at 10-s intervals