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# Statistical Ecology Applied: How high do bats fly?

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## The Goal

Understanding and accurately tracking the vertical space use of the vulnerable Ghost bat (*Macroderma gigas*) is critical for informing conservation strategies, particularly in light of proposed wind farm developments in the Pilbara region of Western Australia.

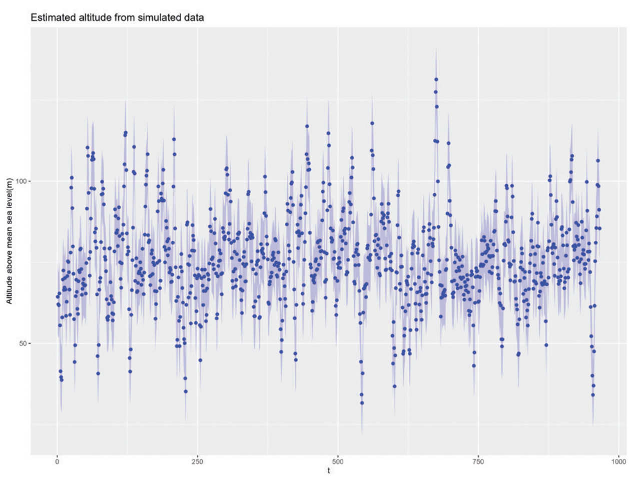
## The Challenge

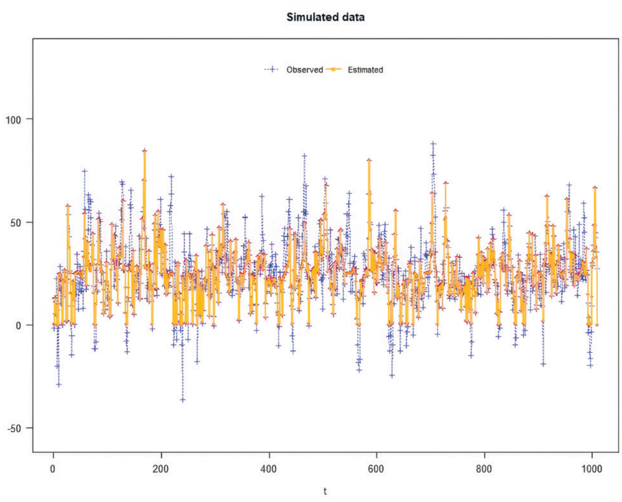
Determining flight altitude from GPS data requires careful consideration before drawing conclusions. GPS-derived altitude values are influenced by multiple sources of error, which propagate through to the final measurement. To obtain meaningful results, it is essential to disentangle these error sources and apply appropriate analytical methods based on the specific altitude metric of interest.

If the goal is to assess altitude relative to sea level, vertical movement models can help estimate uncertainty arising from telemetry errors. However, if flight height above ground is to be estimated, telemetry errors are compounded by additional DEM-related inaccuracies. These include mismatches between the actual true GPS coordinates and the DEM grid, as well as interpolation errors within the DEM itself [4,5], resulting in apparent negative values.

Simply eliminating negative flight heights from the dataset introduces bias toward higher values, as many negative readings correspond to actual low-altitude flights near the ground [4,5].

In this study, we estimate telemetry error in altitude and compare it with Péron et al. 's state-space modelling approach that accounts for multiple error sources in flight height above ground.[4]
We also discuss practical considerations for applying these techniques to typical datasets.




Please note that this simulation is purely theoretical and does not reflect any real-world data.

## Our Approach

### DATA SIMULATION

We simulated a 100-day flight path using a vertical Ornstein–Uhlenbeck position process—a continuous-time stochastic model representing a modified random walk. The process was parameterized with a mean altitude (μ) of 25 meters, a position autocorrelation time (τ) of 0.5 days, and a volatility rate (σ) of 40 meters.

### ALTITUDE ABOVE MEAN SEA LEVEL

A movement model fitted to the simulated data can be used to estimate uncertainty arising from telemetry factors such as satellite count, satellite geometry, and signal multipathing. To quantify telemetry error prior to a survey, it is recommended to deploy tracking tags—configured identically to those intended for the survey—at known x, y, z locations and record the resulting telemetry data.

This calibration step enables independent error estimation. In the absence of such calibration data, error estimation must rely solely on the movement data itself. However, because telemetry error is not independent of the movement process, this approach can lead to biased estimates. These methods are implemented in the R package ctmm [2].

### FLIGHT HEIGHT ABOVE GROUND

Despite efforts to correct for altitude, estimating flight height above ground level remains prone to error. Flight height estimates are affected by telemetry inaccuracies, and DEM-related errors such as interpolation artifacts and spatial mismatches between GPS coordinates and the DEM grid [2]. These compounded errors often result in apparent negative flight heights.

To address this, Péron et al.[5] introduced a state-space modelling approach that partitions the variance in flight height data into two components: an Ornstein–Uhlenbeck position (OU-p) movement process and a heavy-tailed, t-distributed measurement error. Additionally, a link function is applied to transform locations near the ground boundary, ensuring that heights remain above ground.

### PRACTICAL CONSIDERATIONS

**Coordinate Reference System GPS**
The altitude is typically referenced to the WGS84 ellipsoid. However, if your Digital Elevation Model (DEM) uses a different vertical datum—such as the Australian Height Datum (AHD)—you may need to apply a geoid correction using models like AusGeoid2020. This ensures that both GPS altitude and DEM ground elevation share a common reference frame, reducing systematic bias in flight height calculations.

**Data Requirements**
The volume and quality of data are critical. Sampling resolution and battery life of lightweight GPS tags—such as those used for bats—limit the number of usable fixes[6]. Insufficient data can undermine the reliability of state-space models, which require enough temporal coverage to distinguish movement from measurement error.

**Model Fit Assessment**
To evaluate how well the movement model fits the data, empirical variograms can be used to assess consistency with the Ornstein–Uhlenbeck (OU) process. This diagnostic is implemented in the R package ctmm[2], which provides tools for fitting and validating continuous-time movement models.

**Model Fitting Challenges**
In practice, fitting these models can be complex, especially with sparse datasets. We found that an iterative approach works best: fixing certain parameters at their current best estimates while optimizing others, and repeating this process until convergence is achieved[4]. This strategy helps navigate the high-dimensional parameter space and improves model stability.

## The Result

This approach improves the reliability of height estimates by explicitly modelling and separating sources of uncertainty [1] allowing for accurate tracking of the vertical space use of the vulnerable Ghost bat (*Macroderma gigas*) for our client in the Pilbara.

We're excited to harness the power of statistical ecology to drive smarter conservation solutions for our clients

### REFERENCES

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