Recovering the True Flight Path of Migrating Songbirds

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Description of Problem

Figure 1: A wood thrush songbird wearing a geolocator "backpack".

Geolocators are presently employed to track the flight path of songbirds by measuring daily sunset and sunrise times (Stutchbury et al., 2009), but these can produce highly erroneous and extreme observations. In addition, latitude data is unavailable during the equinox. A common practice to deal with extreme observations such as these is to apply filters to the original data set which can result in significant data and information loss. However, we would still like to harness the information provided by the longitude readings and thus propose the following method for dealing with erroneous observations and the reconstruction of the flight path.

Methodology

Our approach is similar to that of Jonsen et al. (2005), with modifications as appropriate. We model two separate behaviours for the birds: foraging and migration. We let α_1 (resp. α_2) represent the probability of being in behavioral mode 1 at time t given behavioral mode 1 (resp. 2) at t-1. Within each behavioural model, the movement of the bird is modeled according to a difference correlated random walk. Let x_t denote the (true) migration path, and let $d_t = x_t - x_{t-1}$. For a bird in behavioural mode i, the model is

$$d_t = \gamma_i T(\theta_i) d_{t-1} + N_2(0, \Sigma) \qquad (1)$$

where $T(\theta_i)$ is the rotation matrix

$$T(\theta_i) = \begin{pmatrix} \cos\theta_i & -\sin\theta_i \\ \sin\theta_i & \cos\theta_i \end{pmatrix}.$$

The γ_i term in (1) allows us to vary the degrees of autocorrelation. Finally, we assume that the observed data, y_t, is given by

$$y_t = x_t + \varepsilon_t$$

where ε_t are IID with a t-distribution with 2 degrees of freedom. To fit the model we use a Bayesian framework, and place vague priors on all unknown parameters. All fitting was done using WinBUGS, (Spiegelhalter et al., 1996).

Simulations

We illustrate our method on two simulated data sets. To mimic the inaccuracies that occur during the equinox, we chose two sets of twenty data points for each simulation to have a missing latitude component. These latitude components were assigned "NA" values when given to WinBUGS to fit the model. 250 data points (with 40 points missing a latitude component) were simulated per data set. The results are summarized below:

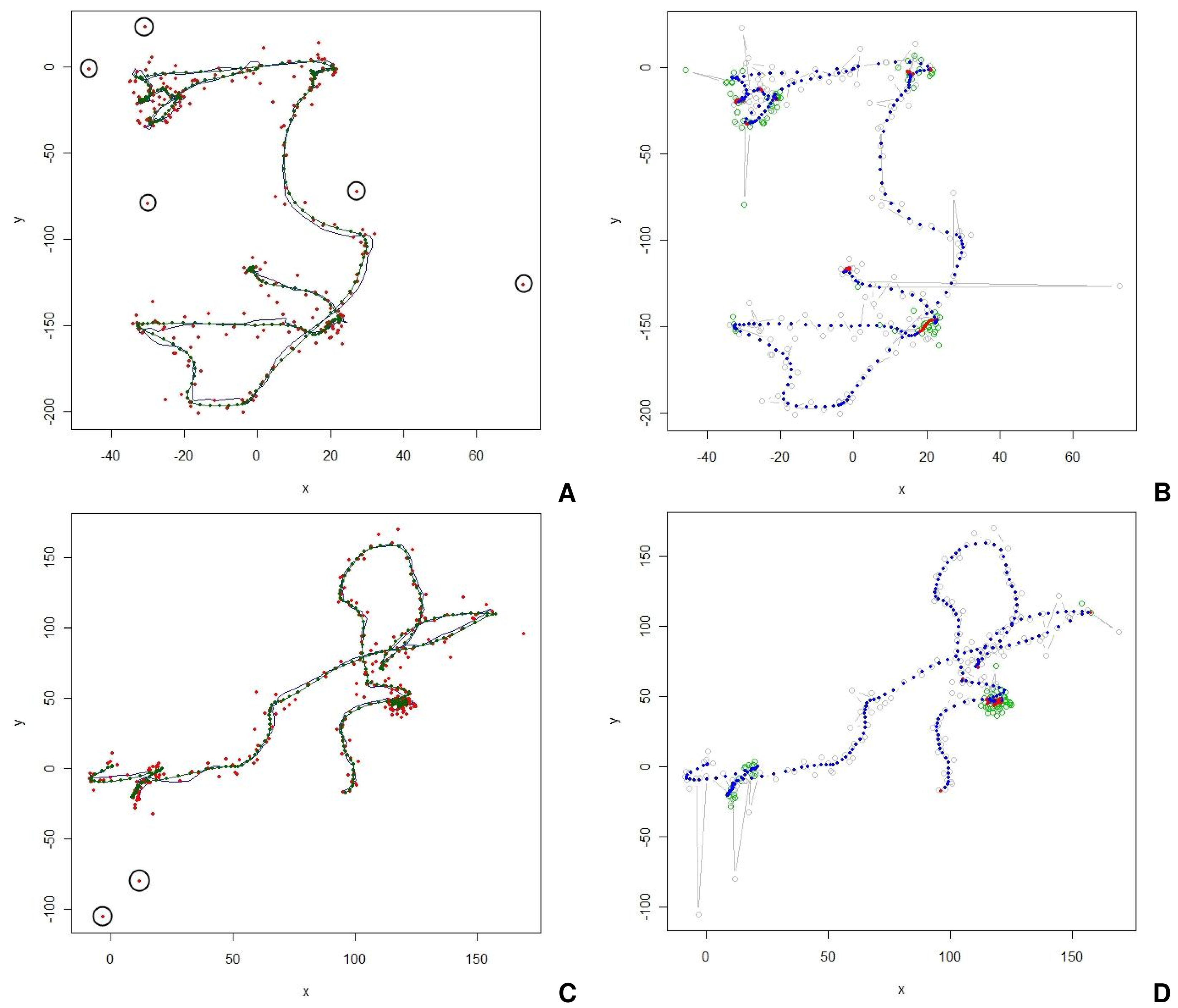

Figure 2: A/B and C/D represent two separate simulated data sets. A and C illustrate the simulated true path of the bird in blue, the distorted path with red dots, and the WinBUGS estimates of the true path in green. Highly erroneous observations are encircled in black. In B and D, the unfilled circles show the distorted path and the true mode of the bird where grey circles represent migration, and green, foraging behaviour. The filled circles represent the estimated path of the bird with blue indicating migration, and red, foraging behaviour.

parameter	true mean	Data Set A/B posterior mean	Data Set A/B 0.025 quantile	Data Set A/B 0.975 quantile	Data Set C/D posterior mean	Data Set C/D 0.025 quantile	Data Set C/D 0.975 quantile
σ_{lon}	1.00	0.91	0.70	1.16	1.07	0.79	1.37
σ_{lat}	1.41	1.17	0.82	1.61	1.17	0.74	1.59
ρ	0.21	0.31	-0.02	0.41	0.46	0.10	0.57
α_1	0.95	0.91	0.79	0.98	0.91	0.40	0.99
α_2	0.10	0.28	0.04	0.86	0.59	0.16	0.98
γ_1	0.90	0.94	0.87	1.00	0.92	0.84	0.99
γ_2	0.10	0.31	0.01	0.73	0.59	0.11	0.96
θ_1	0.016	0.02	-0.02	0.07	0.04	-0.14	0.11
θ_2	1.57	-0.06	-2.83	2.83	0.31	-2.63	2.89

Table 1: Posterior means and the 95% credible limits for parameters in the two mode switching model

In both examples, the estimates produce smooth paths that closely resemble the true simulated flight path of the bird. The estimated credible intervals show that for α_i and γ_i there is little overlap for the first data set. There is higher overlap for the second data set but the concentration around the mean is quite different. θ_1 estimates are considerably narrower than the θ_2 estimates which is inline with migration behaviour exhibiting forward movement with small turns and wider turning behaviour while foraging. Mode estimates for data set A/C yielded 205 correct assessments, and for data set B/D mode estimates resulted in 201 correct assessments. This suggests that a switching model gives a better fit than a model with no switching.

Data Analysis of a Migrating Purple Martin

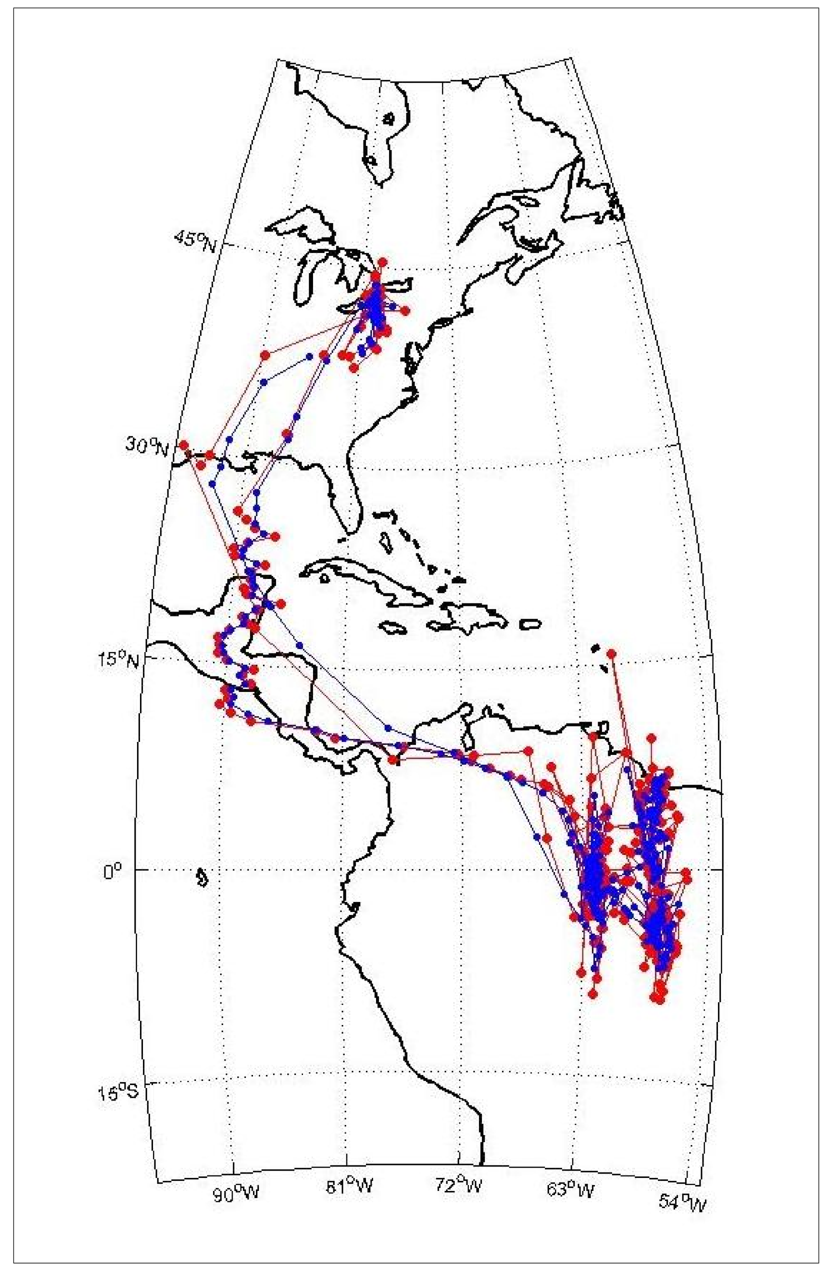

Figure 3: Observed geolocator data for a purple martin shown in red with the missing latitude values filled in using interpolation. The blue points form the estimated travel path.

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References

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