

southerly winds usually accompany warmer air masses. Other important predictors included altitude, longitude, surface pressure, latitude, and wind (fig. S2).

The model provides informative predictions several days in advance. We evaluated its utility as a true forecast system with archived weather forecasts from the North American Mesoscale Forecast System (NAM) and Global Forecast System (GFS). NAM has higher spatial resolution but is a shorter-range forecast (12-km grid, 3-day range) than GFS (0.5° grid, >7-day range). We made predictions up to 3 days in advance with NAM and up to 7 days in advance with GFS, expecting performance to degrade with time because of the decreasing accuracy of longer-range weather forecasts. Predictions on the basis of 24-hour NAM forecasts explained 75% of variation in migration

intensity, 3-day NAM forecasts explained 71%, and 7-day GFS forecasts explained 62% (fig. S5).

The model captures patterns of bird migration across the United States with high spatial accuracy, particularly in the central and eastern regions (fig. S6). We evaluated spatial accuracy over areas without radar coverage by iteratively removing the data from each radar station, retraining the model on the remaining data, and testing performance on the withheld station. Median R^2 for withheld stations was 0.72, and R^2 was 0.60 or higher for 75% of stations (fig. S7). Spatial variation in performance likely stems from local influences on migratory behavior (e.g., topography), which our model did not explicitly incorporate.

Previous research suggests that migration behavior and weather conditions in the days immediately preceding a migration event can predict

its intensity [e.g., (10)]. We found that including atmospheric data from the preceding night and 24-hour changes in conditions did improve performance, but not markedly. A model that included atmospheric conditions 24 hours before an event explained 80.1% of variation in migration intensity, and further including observed migration intensity from the previous night increased R^2 to 81.3%.

Finally, we used model predictions to estimate the total number of birds actively migrating each night across the United States. Summing predictions countrywide, we infer that nightly movements frequently exceed 200 million birds (Fig. 3B). Peak passage occurred in the first half of May, when the median predicted movement size was 422 million birds per night. Although our model tended to underpredict the largest observed movements (Fig. 3A), a conservative forecast system

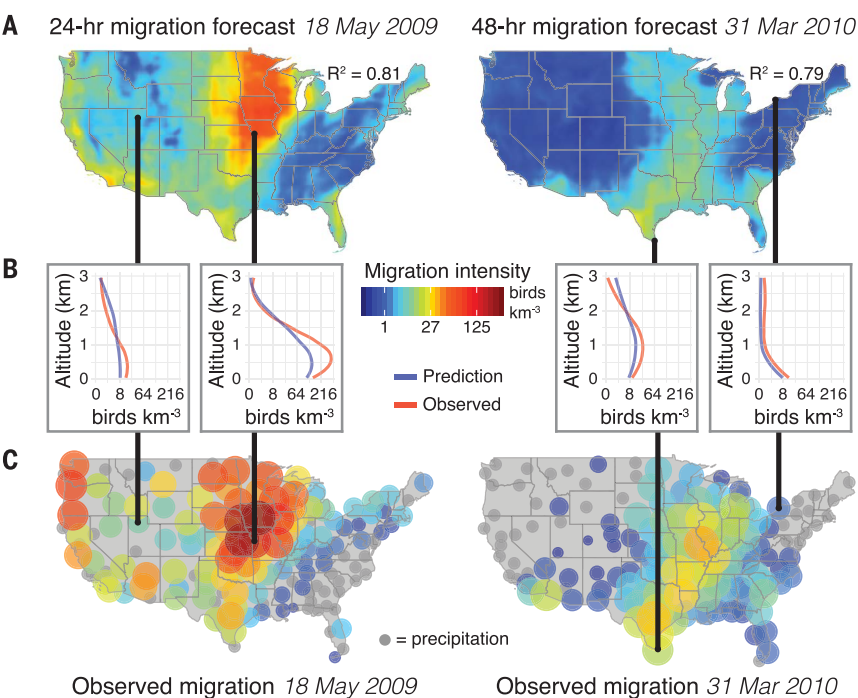


Fig. 2. Migration forecasts and corresponding observed migration.

(A) Countrywide migration forecast surfaces showing predicted mean migration intensity across altitudes. (B) Altitudinal profiles at four stations, showing predicted and observed intensity values. (C) Mean migration intensity observed at all radar stations. Gray circles indicate stations where migration intensity could not be measured because of precipitation.

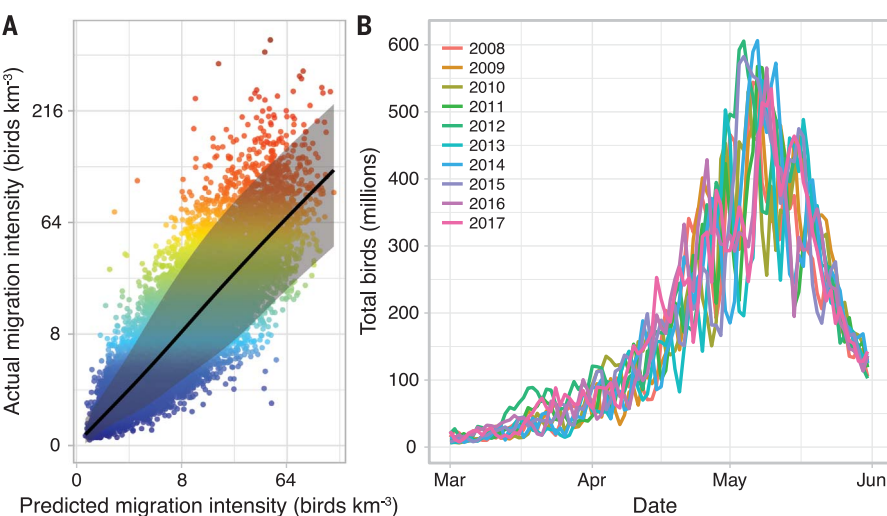


Fig. 3. Accuracy of forecasts and nightly continental predictions.

(A) Mean predicted and observed migration intensities for test data, with points colored by observed migration intensity (y axis). The scatterplot shows values after averaging across altitudes. Shading shows empirical 90% prediction intervals, which covered 90.5% of observed values. (B) Nightly peak migration magnitude estimated across the continental United States for 2008 to 2017. The size of migratory movements varied markedly from night to night during the peak of the migration season.