Graphical models to understand and predict bird migration in Europe (IBED)

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Background:

Bird migration is both an intriguing and important ecological phenomenon, relating to several key processes and open problems (Bauer et al., 2018). Since recently it has become possible to provide rough estimates of migration fluxes through the use of meteorological radar (Dokter et al. 2011, 2018b; Nilson et al. 2018 and 2019). This technique has been successfully applied to answer questions of conservation concern (e.g. Shamoun-Baranes et al. 2011; Weisshaupt et al., 2018). Nonetheless, the technique is still very much in its infancy, with challenges relating to observation artifacts, calibration and partial observability of the system under consideration (e.g. Dokter et al. 2018a). At the same time, a range of mechanistic bird migration models have been developed (e.g. Erni et al. (2002), Vrugt et al. (2007) and McLaren et al. (2012)). These contain a wealth of information and hypotheses about bird migration but have not yet been validated against observations and did not find their way to application areas. Contrasting with these mechanistic migration models there are also empirically based predictive models (e.g. van Belle et al. 2007). This class of models is site-specific and not able integrate any biological system knowledge nor observations from the entire European radar network. Hence the predictive potential of the combined data and knowledge base is under-utilized.

In the domain of bird migration modeling, graphical models have not been applied yet. This contrasts with other subject areas where these have been successfully applied for system identification and prediction (e.g. Alameddine et al. 2011; Haddawy et al. 2018; Uusitalo et al. 2018). Apart from applied studies, the theoretical underpinnings as well as effective algorithms for estimation of graphical models continue to be developed and shows great promise to become more suitable for prediction as well as identification of dynamic systems (e.g. Peters et al. 2014; Rubenstein et al. 2016; Mooij et al. 2016).

Based on this we see an opportunity to enhance the description and understanding of bird migration by analyzing the European radar data through a modeling approach which encapsulates the strengths of the available mechanistic and empirical models in a graphical modeling approach that uses state-estimation.

Our main research questions which will lead us to this desired advance are:

1) How can we better exploit radar observations to advance our knowledge about the spatio-temporal heterogeneity of large scale bird migration over Europe and the underlying exogenous and endogenous drivers for this.

2) How can probabilistic graphical models be effectively used for system identification and predictive modeling in a semi-structured dynamic system spatially distributed like bird migration.

Approach:

The project is build-up from 5 consecutive research steps, which each lead to models or model components and/or scientific publications as output. The research steps are summarized below (each of these has been worked out in more detail in a detailed research plan).

1. Identification of constraints and causal relations between phenology, weather and migration, for a selection of radar locations (e.g. four locations). And, based on this, build graphical models, which identify causal relations where possible by exploiting the best available data (meteorology as well as phenology) and existing system knowledge (from available models).
2. Extend results from aim 1 over space, whereby conditional dependencies over space and time are evaluated. For this step European-wide radar archive is used and where possible causal relations (e.g. due to the direction of migratory movement and limitations on speed) are identified.
3. Reformulate existing simulation models of bird-migration into a state-space form, comprising local models (for individual radars, result from aim 1) and linked to that a global structure (informed by aim 2) which constrains but also feeds the local models. The state space model will be cast in the form of a Dynamic Bayesian Net and initial interrogation of and inference by this model will be conducted.
4. Work out the observation models to link radar observations to state-variables in the model (output from aim 3), followed by model calibration with the existing radar data.
5. Apply the combined state-space model with the observation model (output aims 3 and 4) to the continental scale radar archive to reconstruct past migration. Leading to a blueprint for this type of task, identifying the weaknesses and providing solutions where possible, and create a continental-scale reanalysis set for bird migration.

The data required in each of the above research steps comprises gridded, 6-hourly weather variables, and a radar archive with over 30 radar stations covering Europe. These data sets have already been processed and stored locally at IBED. They are available at the start of the project and will be further updated and extended as part of ongoing projects at IBED.

Impact:

Bird migration/animal ecology: we expect that the methods developed in this project to cross the boundaries between statistical/empirical and theoretical models will have a lasting impact on the field, as well as the proof-of-concept to produce a reanalysis dataset.

Artificial intelligence: we expect that the novel methods required to develop and apply graphical models for the system under study (by integrating system properties and working at different scales, for dynamic semi-structured systems).

External parties are found in in the actors that relate to flight safety (reduce flight activity over areas with intense migration) as well as wind energy (incorporate bird migration in spatial planning or even temporary shutdown of windfarms).

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