BIRD MIGRATION UNDER CLIMATE CHANGE—A MECHANISTIC APPROACH USING REMOTE SENSING

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1. INTRODUCTION

The broad-scale reductions and shifts that may be expected under climate change in the availability and quality of stopover habitat for long-distance migrants is an area of increasing concern for conservation biologists [5]. Researchers generally have taken two broad approaches to the modeling of migration behaviour to understand the impact of these changes on migratory bird populations. These include models based on causal processes and their response to environmental stimulation, "mechanistic models", or models that primarily are based on observed animal distribution patterns and the correlation of these patterns with environmental variables, i.e. "data driven" models [1][6][7]. Investigators have applied the latter technique to forecast changes in migration patterns with changes in the environment, for example, as might be expected under climate change, by forecasting how the underlying environmental data layers upon which the relationships are built will change over time. The learned geostatstical correlations are then applied to the modified data layers.. However, this is problematic. Even if the projections of how the underlying data layers will change are correct, it is not evident that the statistical relationships will remain the same, i.e. that the animal organism may not adapt its' behaviour to the changing conditions. Mechanistic models that explicitly take into account the physical, biological, and behaviour responses of an organism as well as the underlying changes in the landscape offer an alternative to address these shortcomings.

The availability of satellite remote sensing observations at multiple spatial and temporal scales [3], coupled with advances in climate modeling and information technologies enable the application of the mechanistic models to

predict how continental scale bird migration patterns may change in response to environmental change [8]. In earlier work, we simulated the impact of effects of wetland loss and inter-annual variability on the fitness of migratory shorebirds in the central fly ways of North America [7]. We demonstrated the phenotypic plasticity of a migratory population of Pectoral sandpipers consisting of an ensemble of 10,000 individual birds in response to changes in stopover locations using an individual based migration model driven by remotely sensed land surface data, climate data and biological field data.
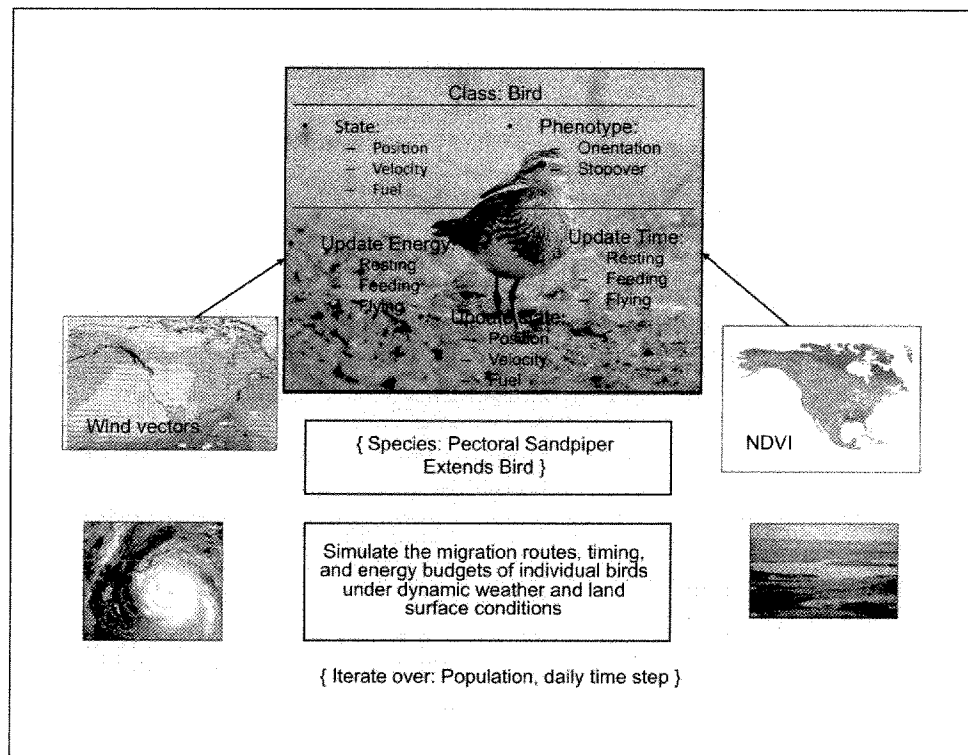
With the advent of new computing capabilities enabled by recent GPU-GP computing paradigms and commodity hardware [4], it now is possible to simulate both larger ensemble populations and to incorporate more realistic mechanistic factors into migration models. Here, we take our first steps use these tools to study the impact of long-term drought variability on shorebird survival [9].

2. APPROACH

The structure of our modeling framework is shown in the attached figure. We simulate the migration trajectories of individual bird "particles", including their positions, velocities, and fuel status using a spatially explicit, biophysical flight model. We fly birds over a user-specified Lagrangian grid and run the model at a daily time step to simulate spring or fall migration. The model is object-oriented, allowing the extension or incorporation of multiple species or mechanisms. We use evolutionary programming techniques to train the model [2]. In the future, we hope to include interacting species to capture potential phenological changes in movement patterns between predator-prey species under environmental or climate change.

We have applied the model to population sizes of 10,000 birds, a land-use grid consisting of 100,00 grid cells covering North America, and a daily time step. However, typical shorebird populations range in the millions and finer spatial resolution would provide further insight in areas of high variability under climate or land use changes. The evolutionary programming technique also calls for multiple simulations of bird ensemble movements in order to reach stability.

Several aspects of our individual base (agent modeling) approach lend themselves to GPU-GP computing [4]; for example, the vector addition of bird particle and wind velocities at each time step in the spatial grid. We are exploring the appropriate algorithms to distribute the computational tasks between the CPU and GPU architectures. However, preliminary experiments suggests an increase in the number of bird "particles" simulated by a factor of 100 or more and increase in grid cell resolution by a factor of 10 or more will be feasible.

3. CONCLUSIONS

To illustrate our approach we present several simulations of the migration patterns of shorebirds through the central North American flyways under varying periods of drought variability as experienced during the past 2000 years [9]. Analysis of the drought patterns from the historical and geological record suggest that the droughts of the twentieth century were eclipsed several times in the past by periods of longer duration and greater spatial extent. These events of extreme variability likely will occur in the future and may be enhanced by anthropogenic-induced increased rates of climatic change.

4. ACKNOWLEDGEMENTS

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