

# Seasonal Vegetation-Hydrological Coupling across Land Covers in East Africa

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## Abstract

Understanding the linkages between climatic and surface properties that influence water uptake and loss by vegetation is essential for understanding the impact of drought on dryland regions. The Normalized Difference Vegetation Index (NDVI) is a common metric used to identify vegetation condition across LULC types. Here we employ empirical dynamic modeling (EDM) to forecast NDVI changes for savannas, grasslands, and croplands across East Africa at a dekadal (10-day) time scale using satellite-derived environmental forcing variables. The model relies on state space reconstruction with lagged coordinate embedding of multiple time series observations to recover the dynamic environmental system that links vegetation dynamics to environmental forcing. We apply convergent cross mapping based on Takens' Theorem to detect the impact of landcover on directional causal interactions and time delays between driving (e.g. LST, rainfall) and response variables (NDVI). The model brings to light that certain regions are highly consistent in their trajectories and therefore easier to project while other regions are more dispersive and thus more difficult to determine anomalies. In terms of land cover, we are able to make projections with high accuracy for grasslands out to 6 months ahead while croplands and savannas show reduced forecast skill overall and prove less useful after 3 months. The use of historical seasonal NDVI patterns to diagnose the manner by which landcover and land use determine climate-land surface couplings provides a means for defining critical areas of inquiry related to the impacts of future change, particularly the expansion of agricultural areas. In addition, the EDM approach provides a robust means for creating short term vegetation forecasts across LULC types in East Africa. These predictions can assist relief organizations in advising drought management, declaring food security classifications and providing early response to famine.

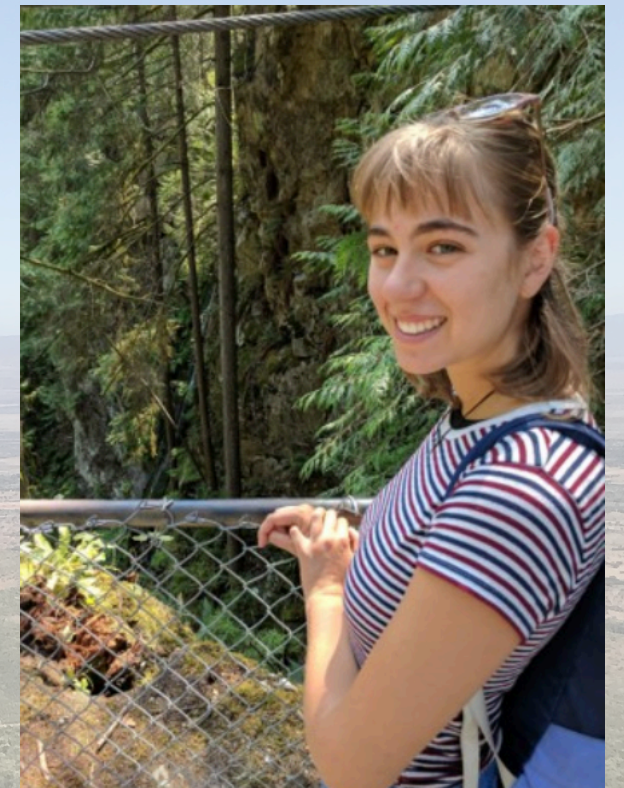


# SEASONAL VEGETATION- HYDROLOGICAL COUPLING ACROSS LAND COVERS IN EAST AFRICA

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# SEMI-ARID DYNAMICS IN EAST AFRICA

- Droughts impacts more people than any other hazard globally
- East Africa rainfall patterns are extremely heterogenous spatially and temporally, prone to droughts
- Vegetation is largely rain-fed and farming is a major source of livelihood where 90% of production comes from smallholders
- Back to back droughts contribute to severe food insecurity



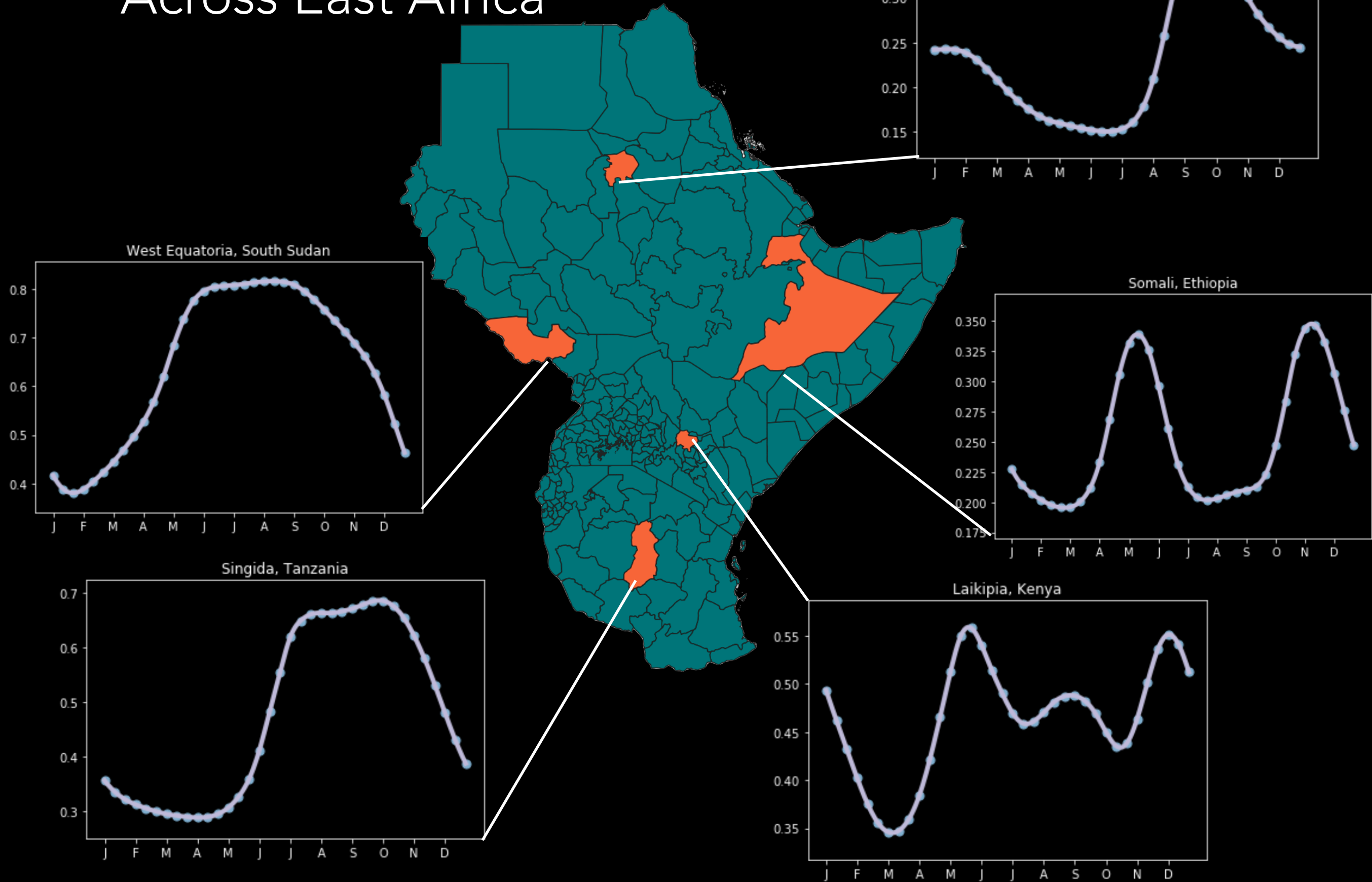


# PREDICTING NDVI

- Predictability of NDVI has not been done routinely
- Potential value may include early indicators of drought, crop failure, disease and pest outbreak
- Inform drought relief funding and index-based insurance payouts
- NDVI state dependent on antecedent precipitation and land surface temperature



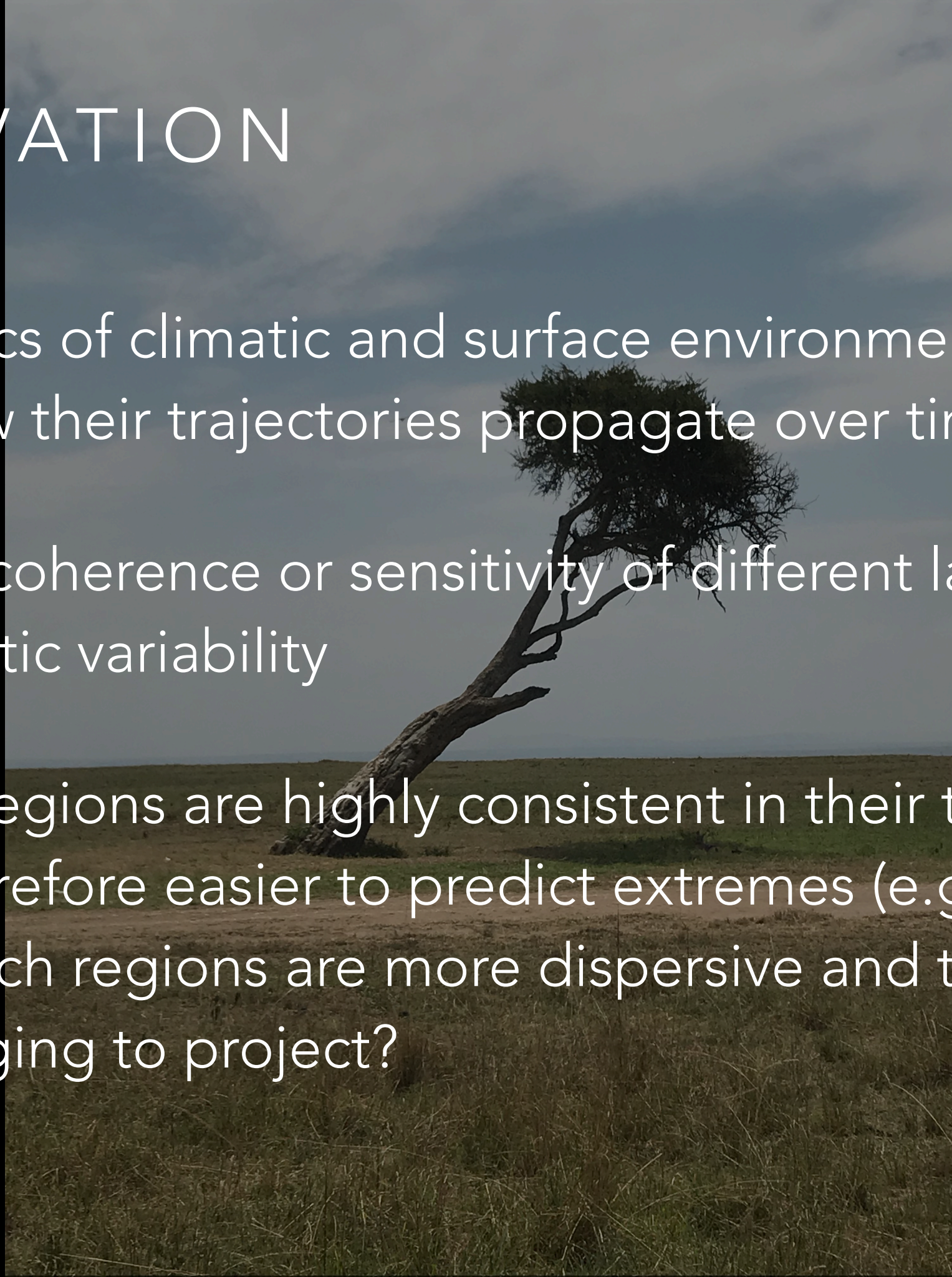
# NDVI Annual Variability Across East Africa





# MOTIVATION

- Dynamics of climatic and surface environmental states and how their trajectories propagate over time
- Spatial coherence or sensitivity of different land covers to climatic variability
- Which regions are highly consistent in their trajectories and therefore easier to predict extremes (e.g. drought) and which regions are more dispersive and thus challenging to project?





# MODELING COUPLED HUMAN-NATURAL SYSTEMS

	Empirical	Process Based
Low Dimensional	Autoregression	<ul style="list-style-type: none"><li>• Gravity Models</li><li>• Agent Based Models</li></ul>
High Dimensional	Machine Learning	System Dynamics General Circulation Models



# EMPIRICAL DYNAMIC MODELING

- Model simulations are computationally expensive and only represent an approximation representation of true physical processes
- Rely on correlation based inference

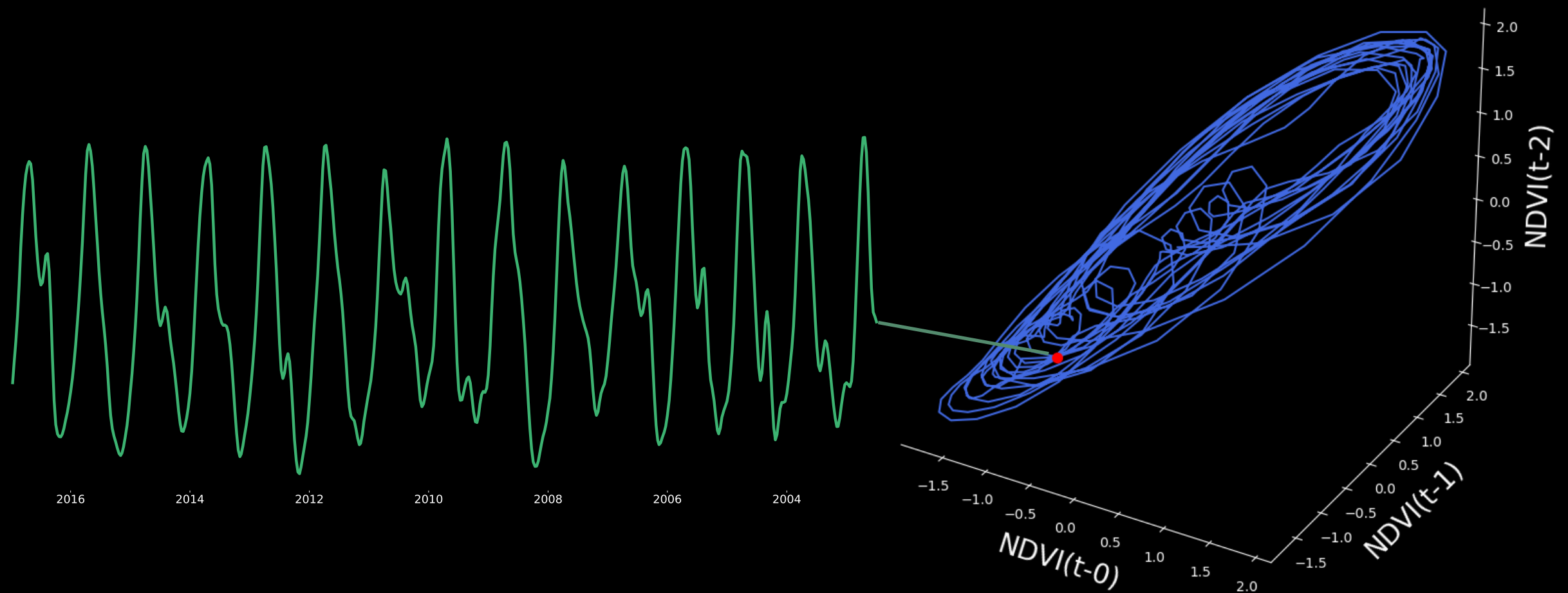
Instead

- EDM does not make any assumptions about relationship between variables
- Lightweight
- Can make inferences of the effects of actions on the observed system
- Prediction skill is therefore constrained by quantity and quality of data rather than imposed hypotheses



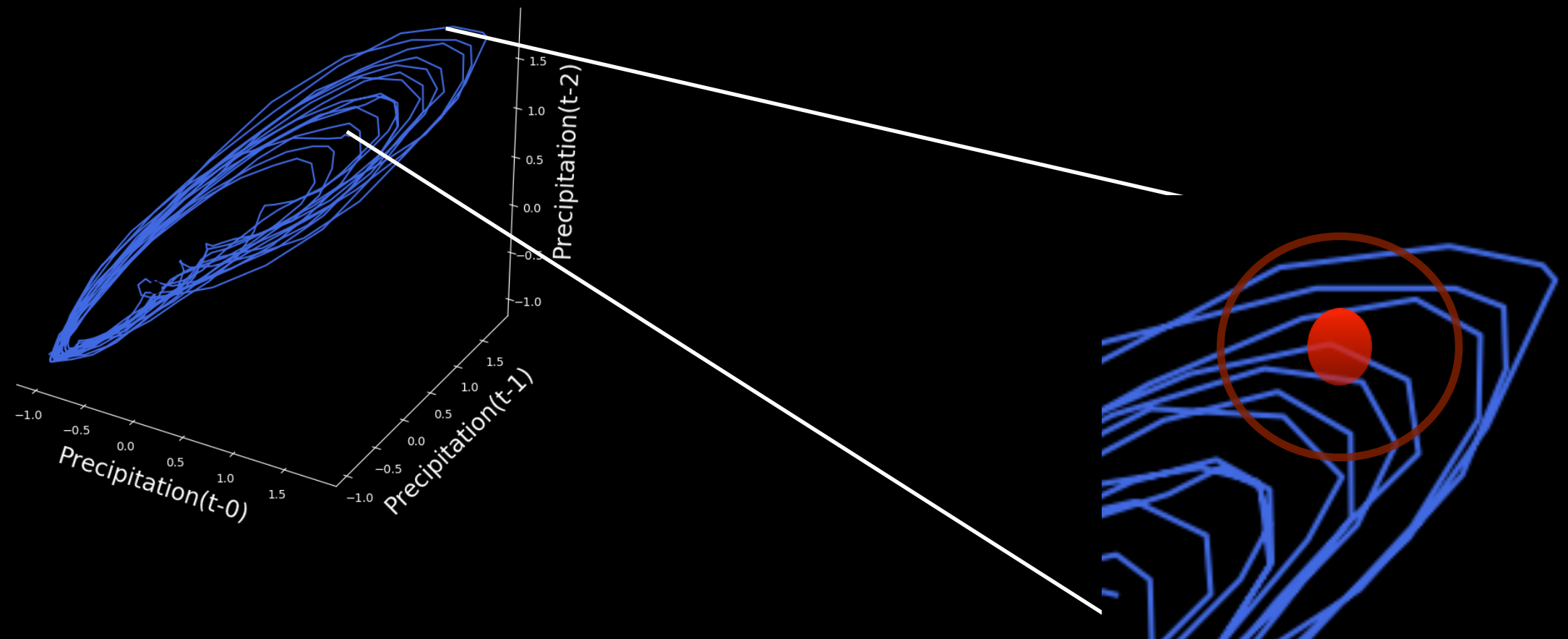


# EMPIRICAL DYNAMIC MODELING: ATTRACTOR RECONSTRUCTION



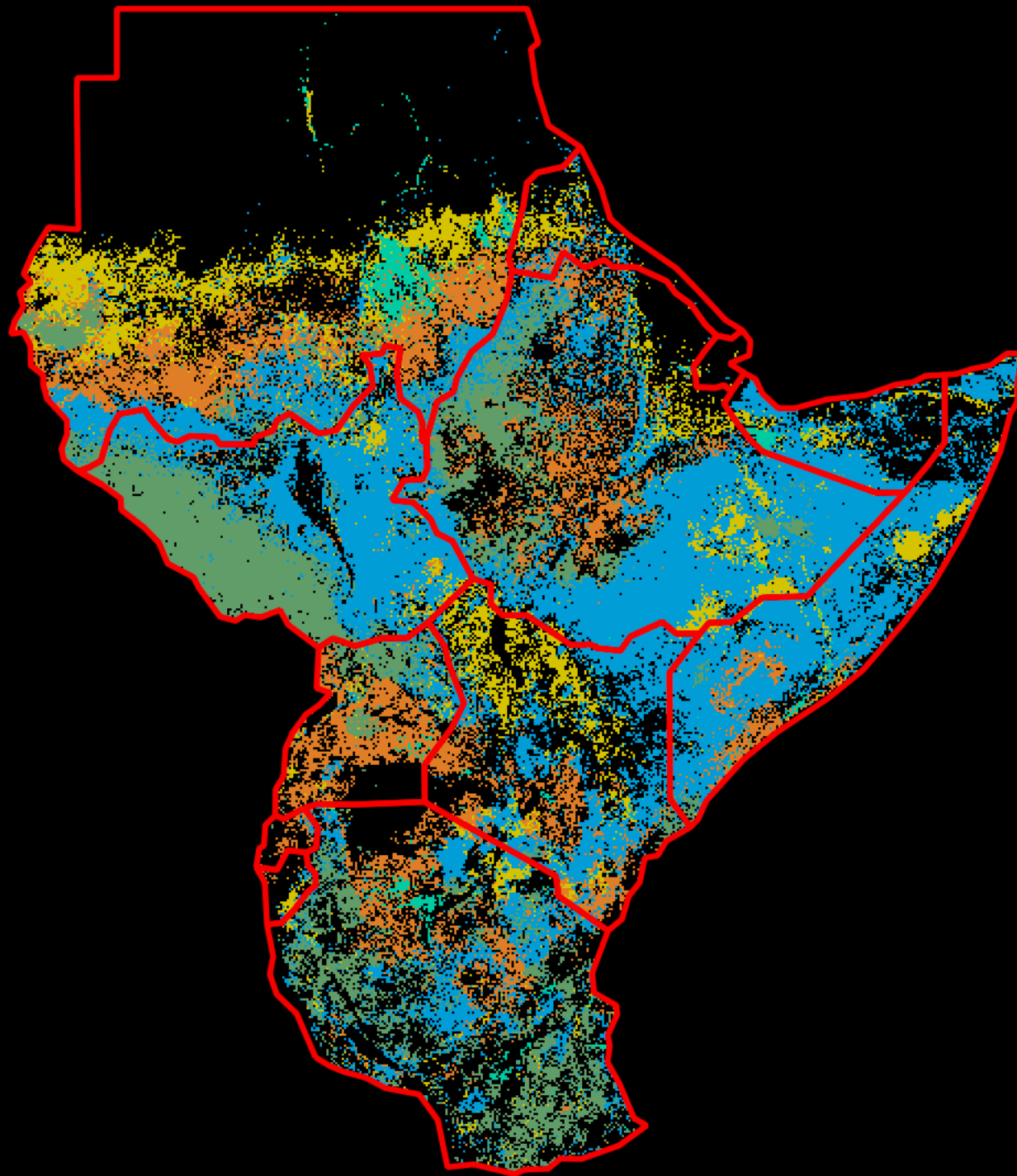


# SIMPLEX PROJECTION



Nearest neighbor forecasting  
method using manifold  
reconstruction

# Land Cover Classes



Rainfed Cropland



Grassland



Shrubland



Irrigated Cropland

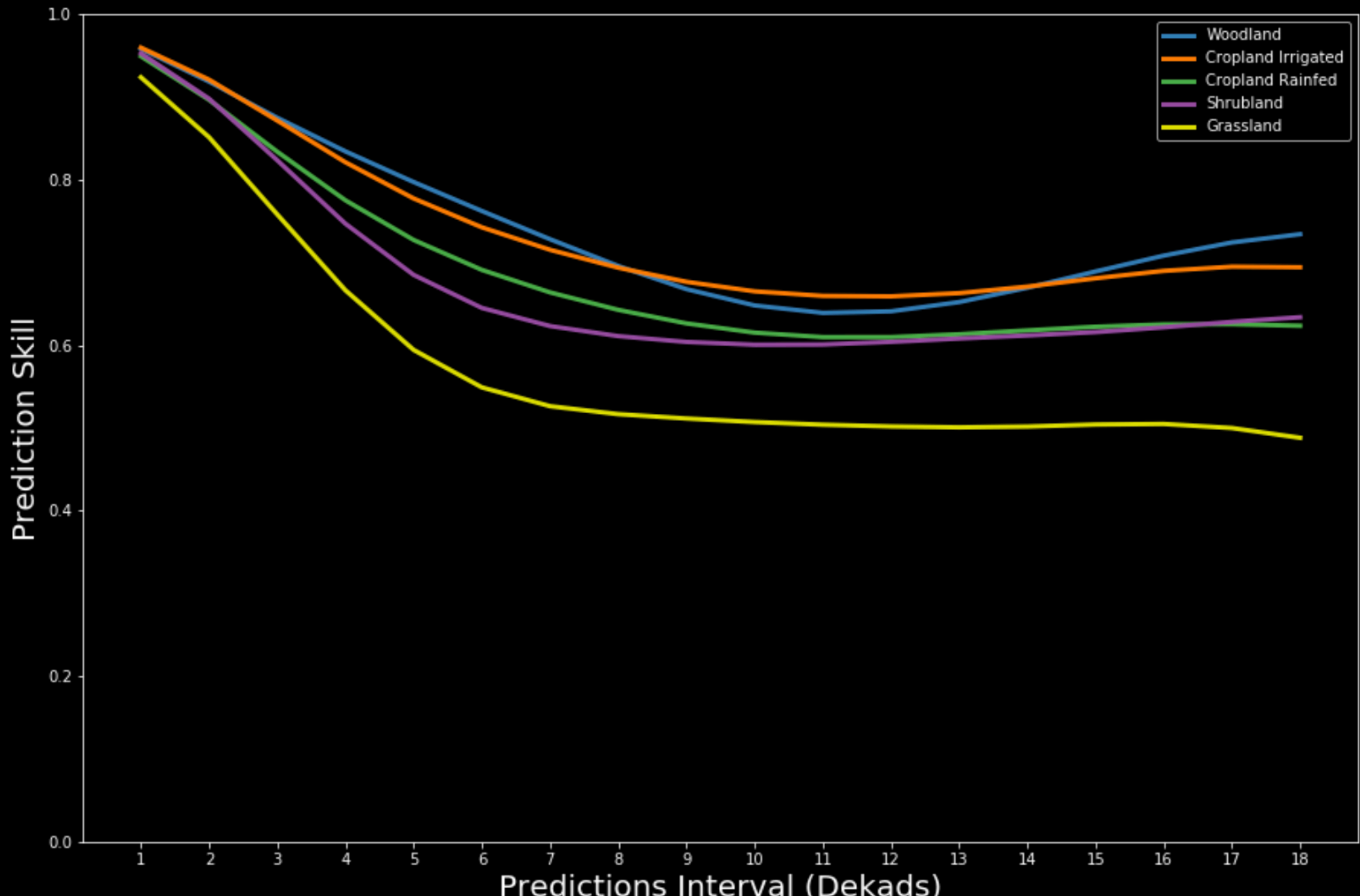


Woodland

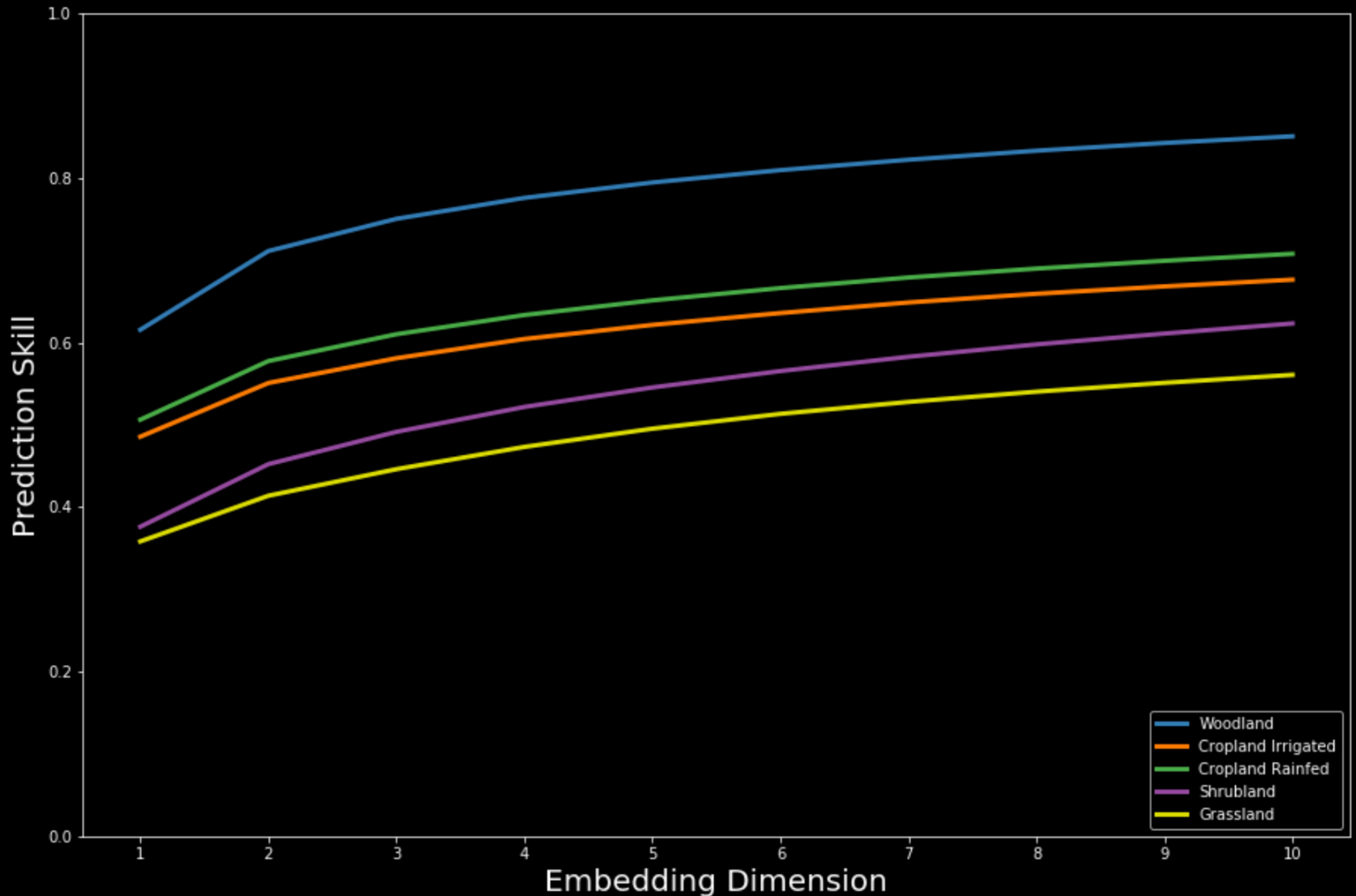




# PREDICTION INTERVAL

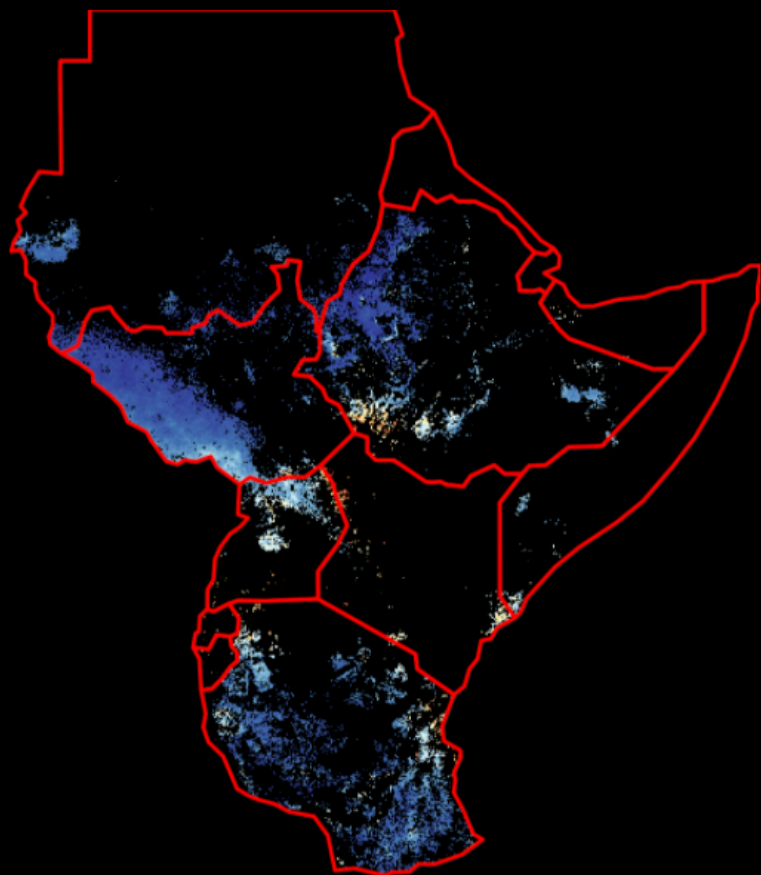


# EMBEDDING DIMENSION AND PREDICTION SKILL

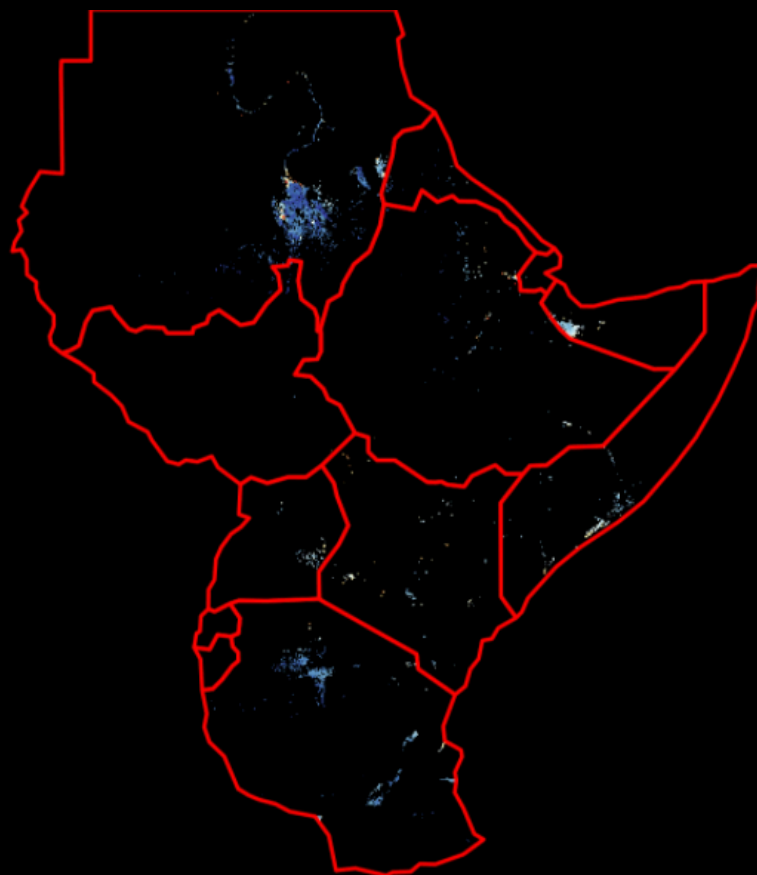




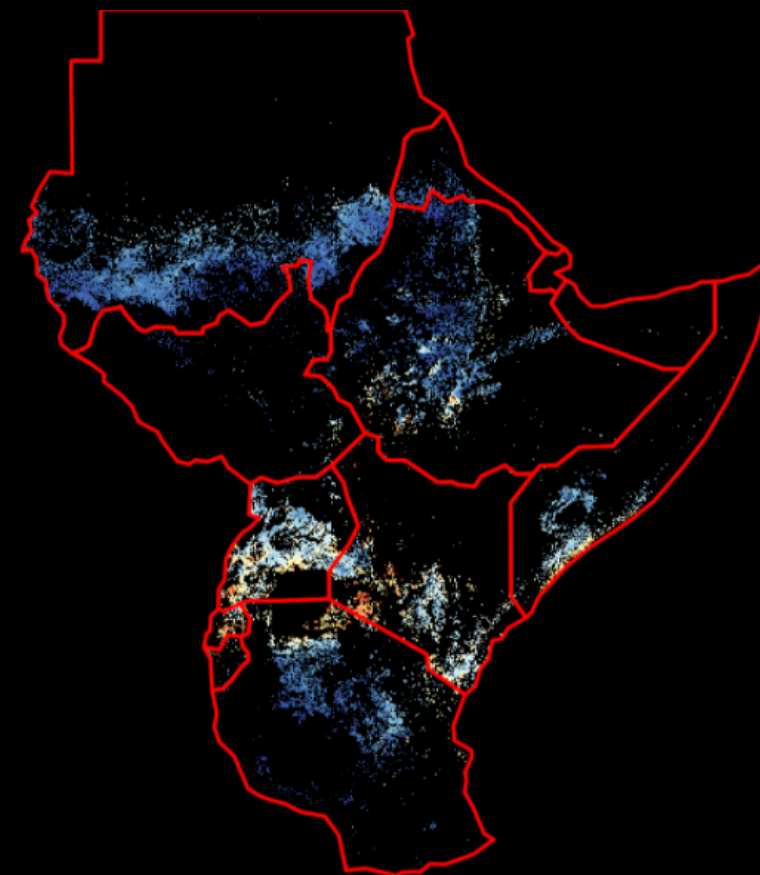
Woodland



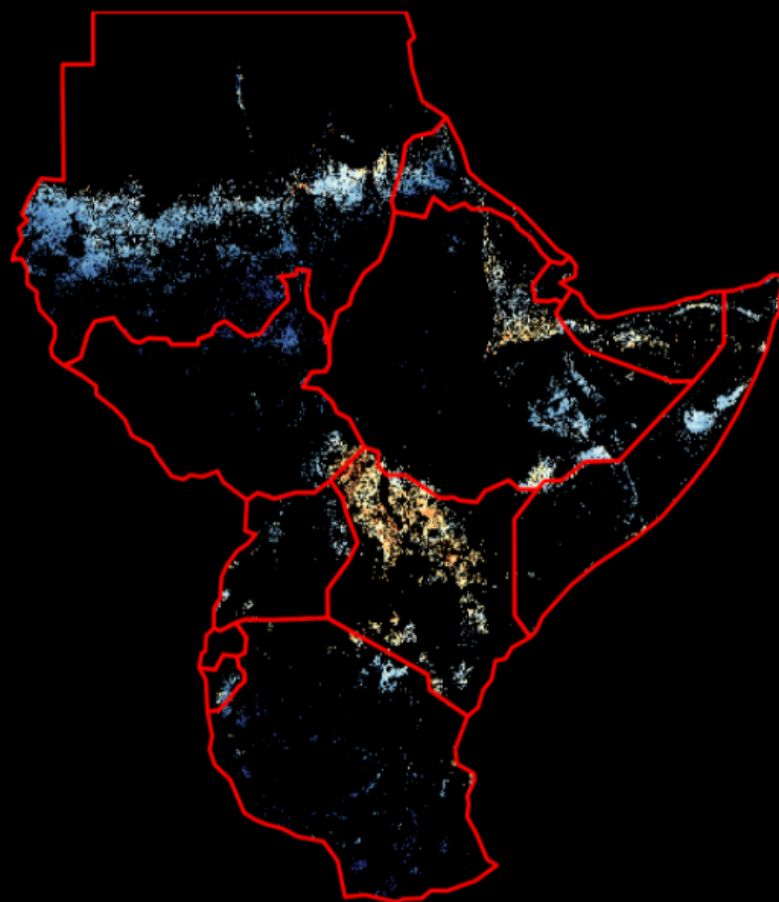
Cropland Irrigated



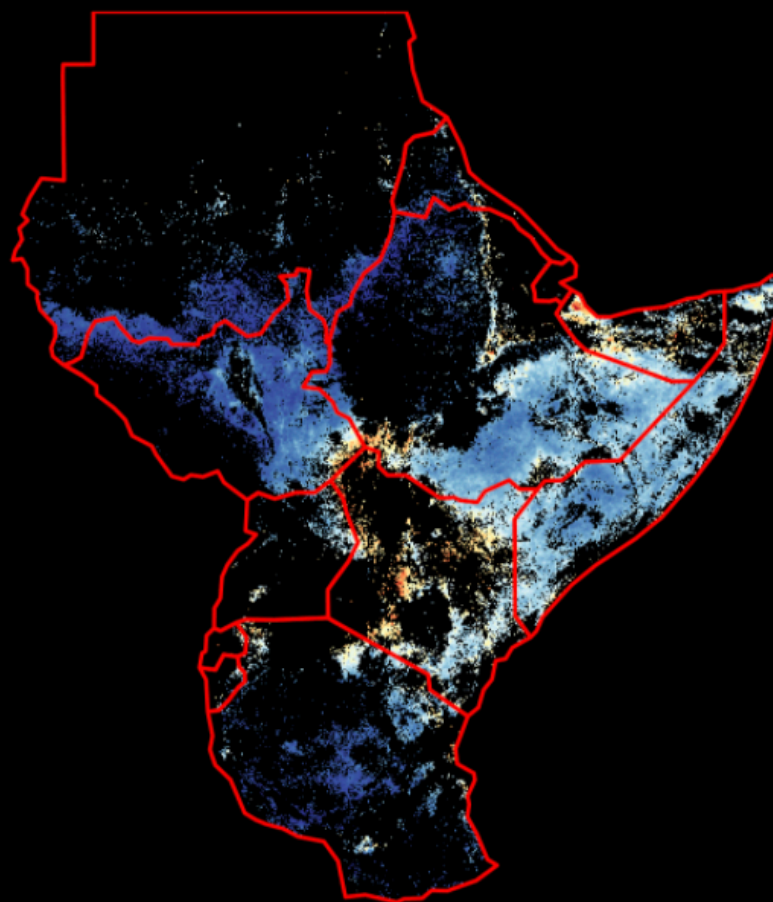
Cropland Rainfed



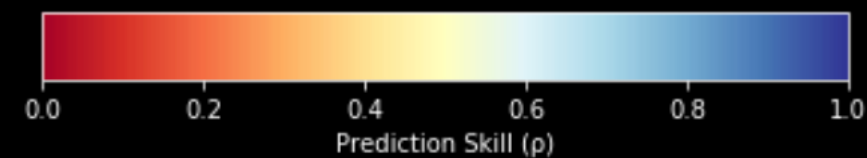
Grassland



Shrubland

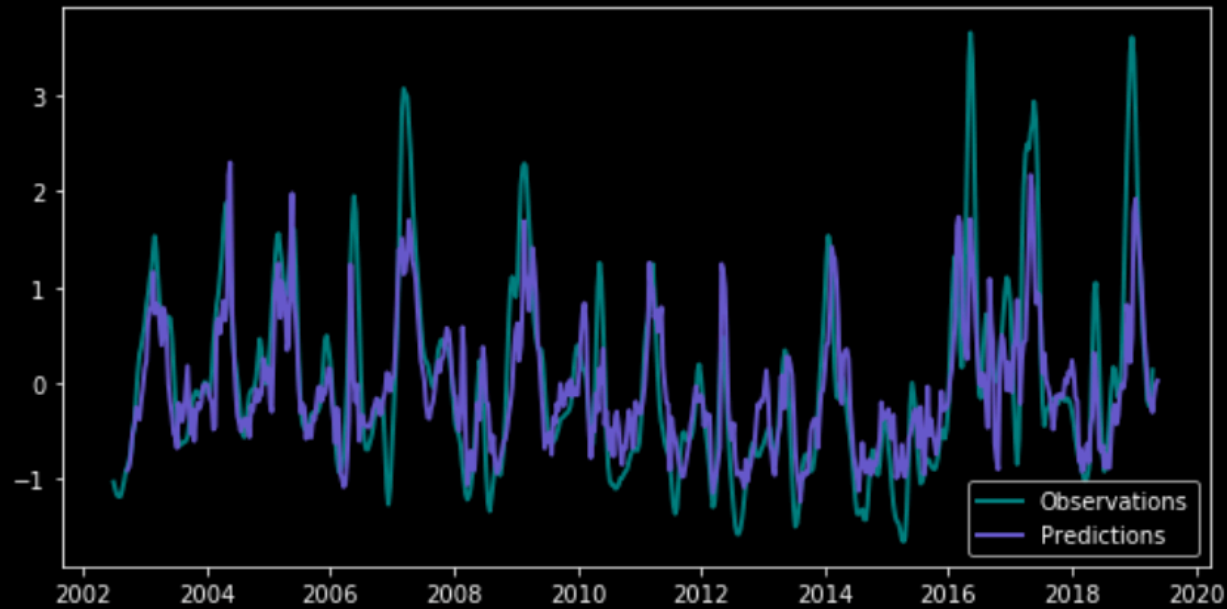


6 month  
Forecast Skill

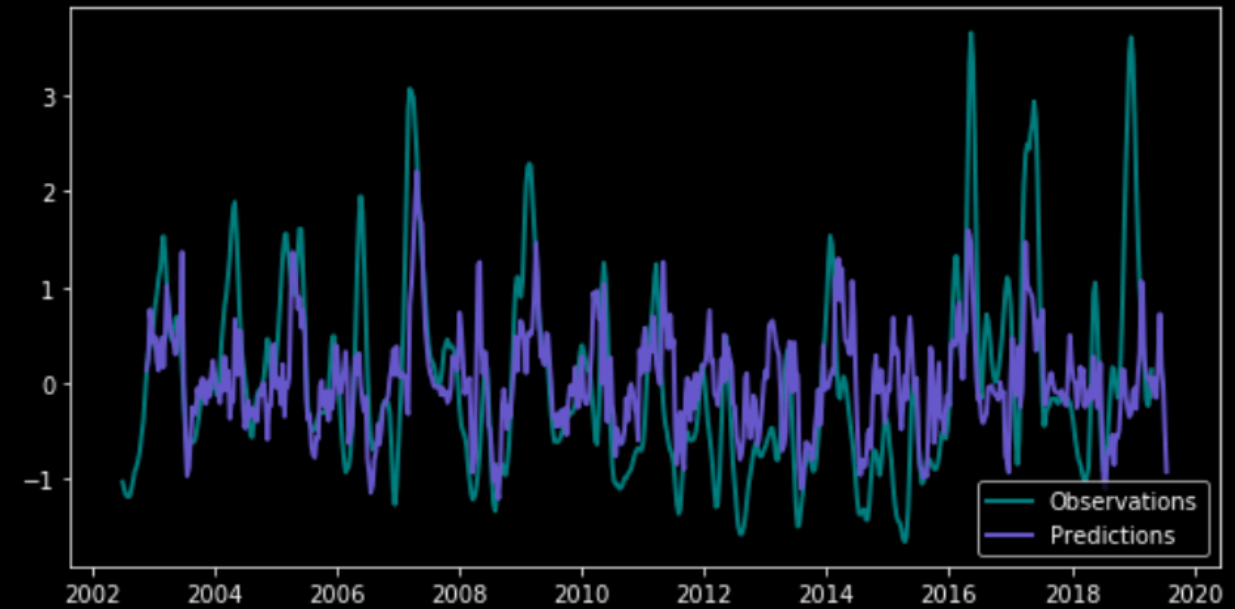


# NDVI Time Series in High and Low Predictive Skill Regions

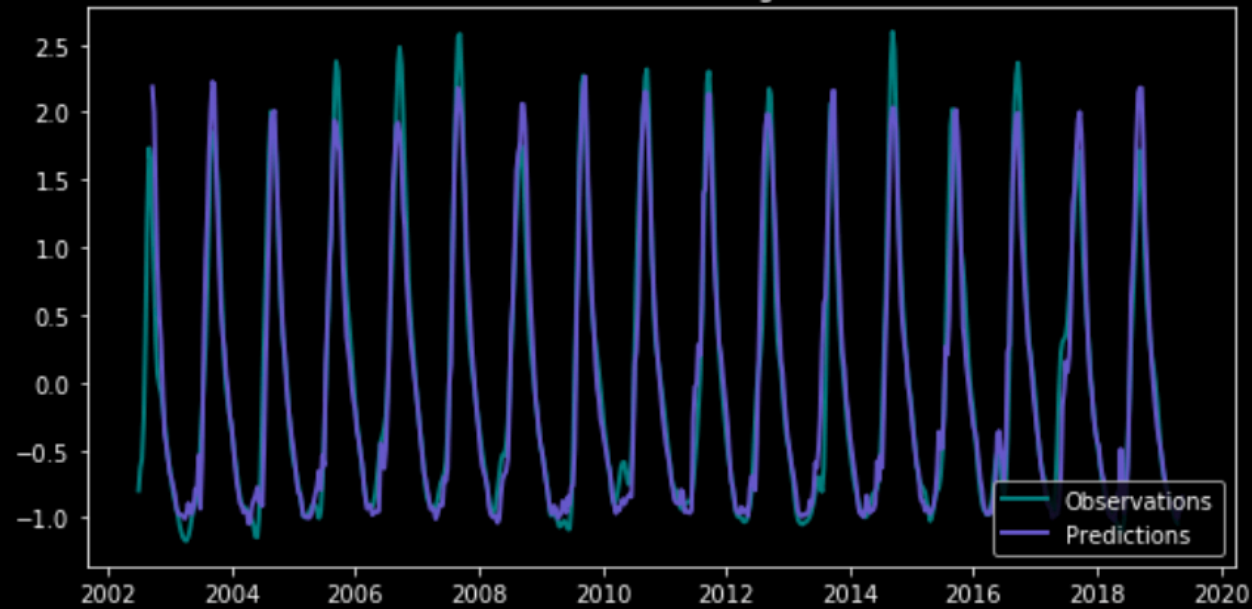
1 Month Prediction Low Skill



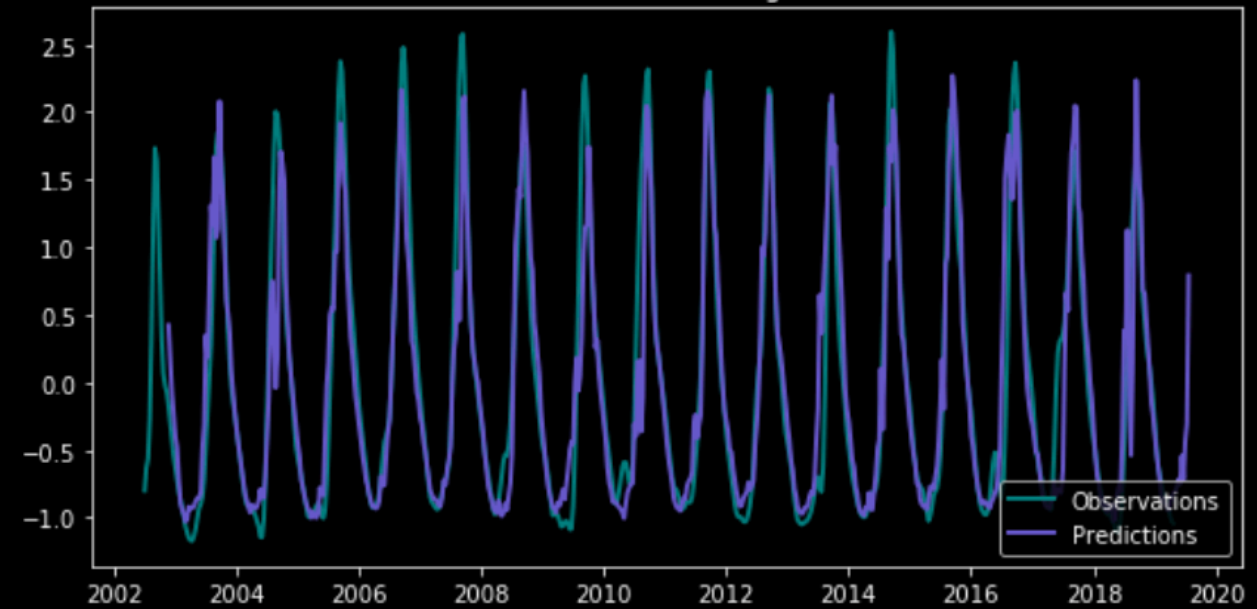
3 Month Prediction Low Skill



1 Month Prediction High Skill

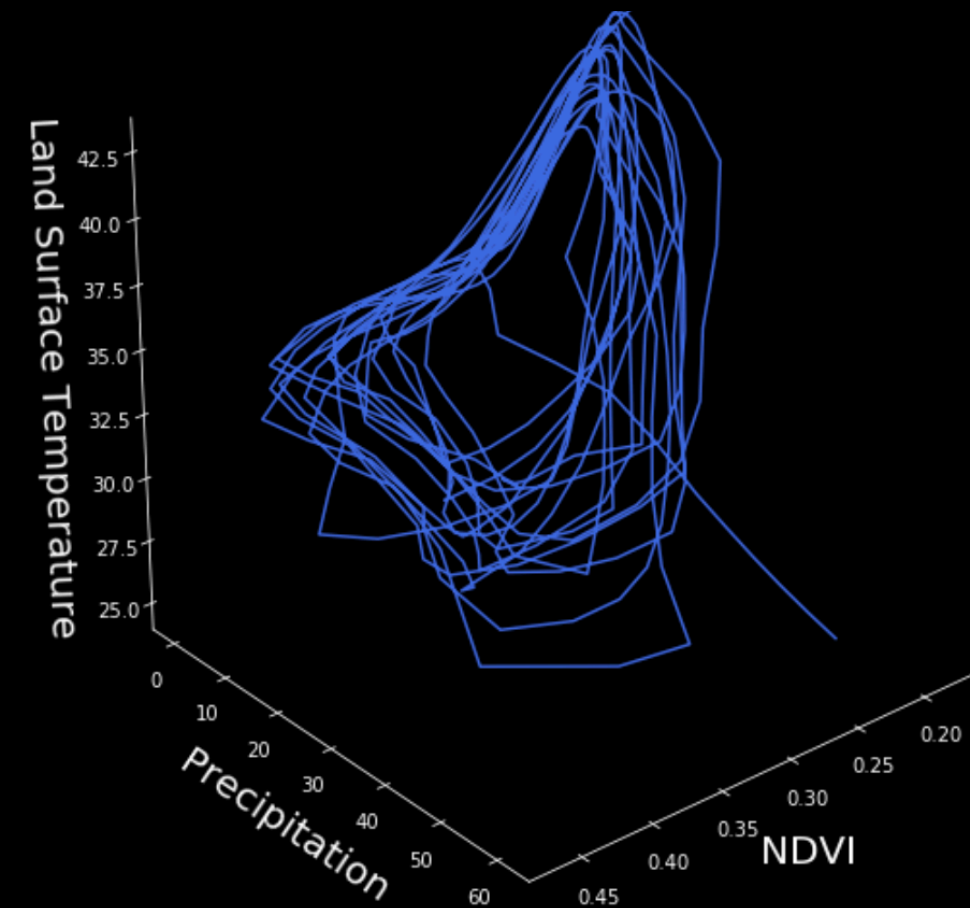
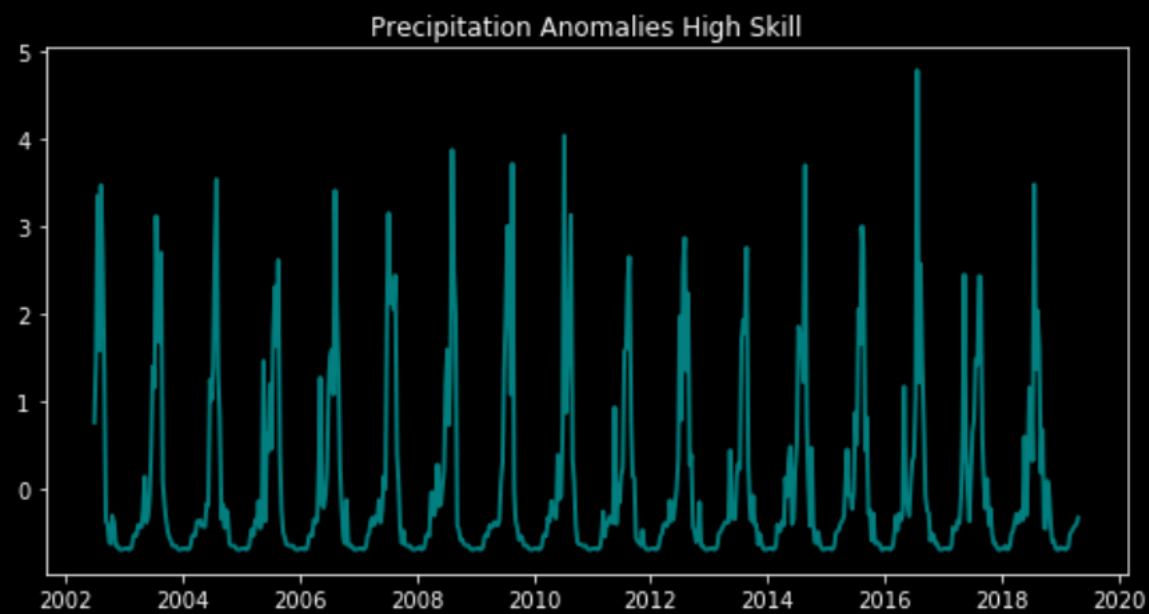
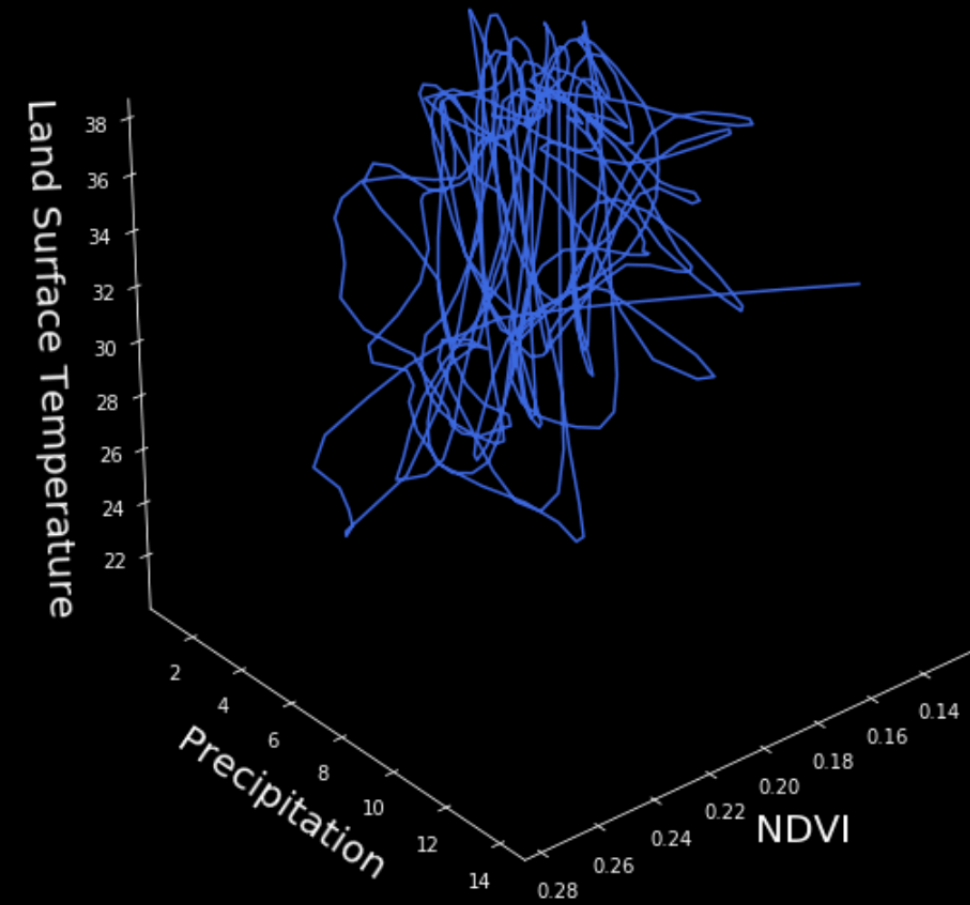
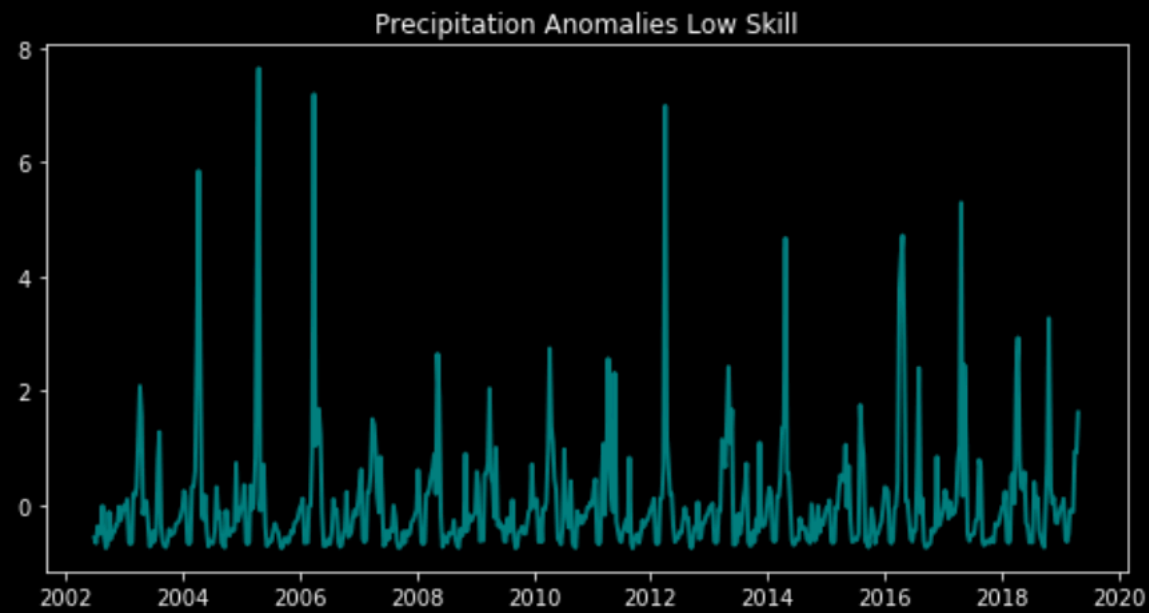


3 Month Prediction High Skill



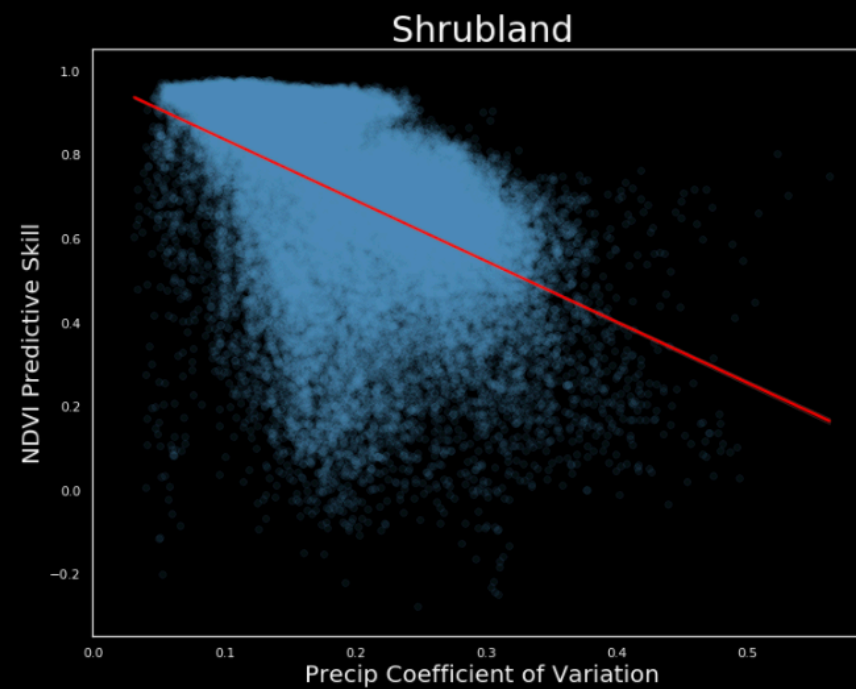
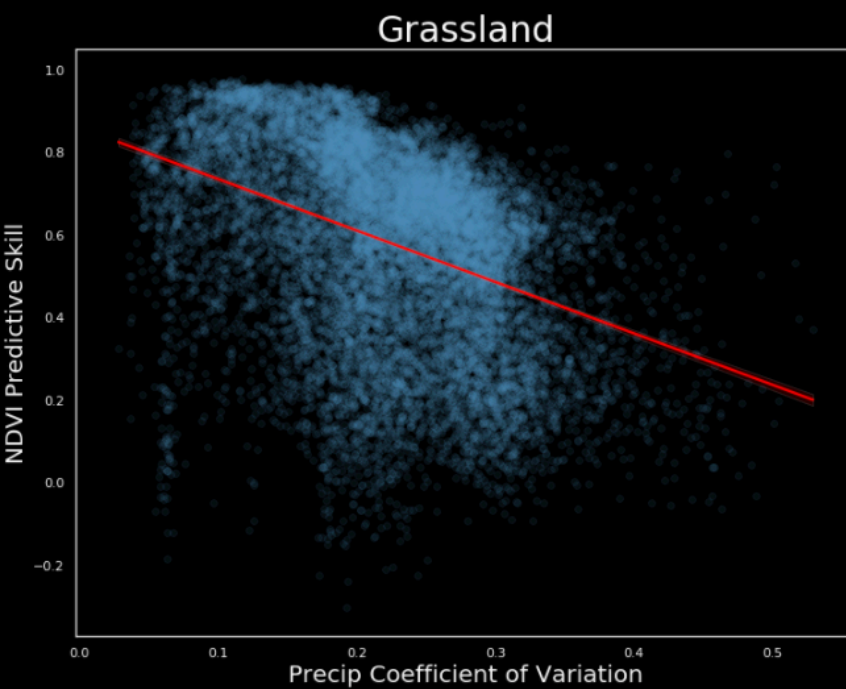
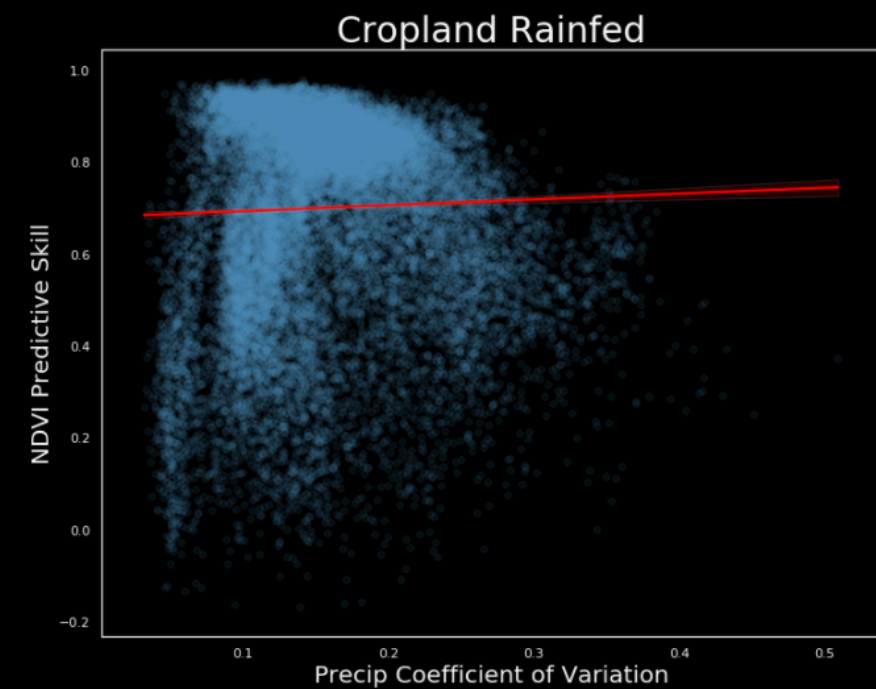
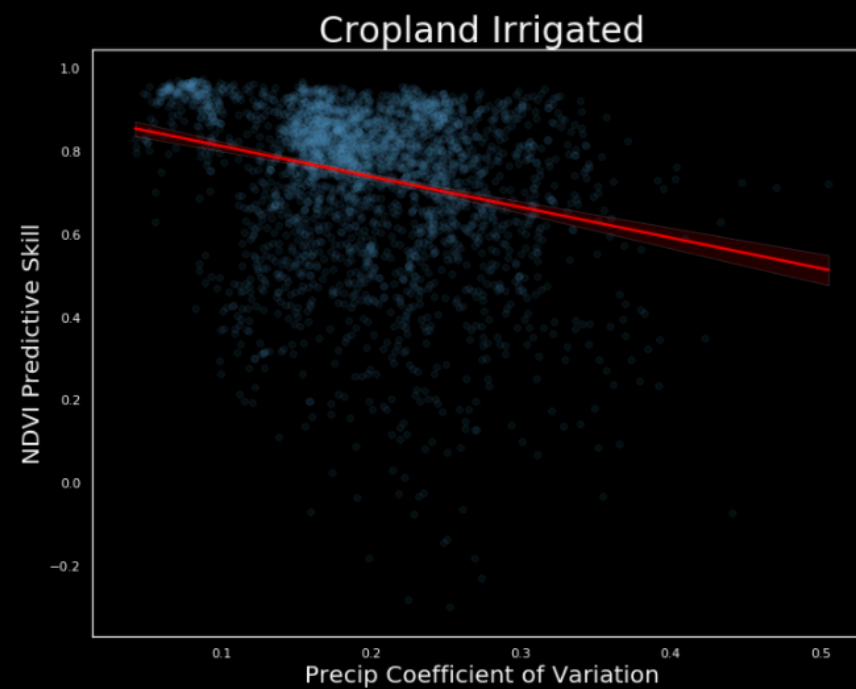
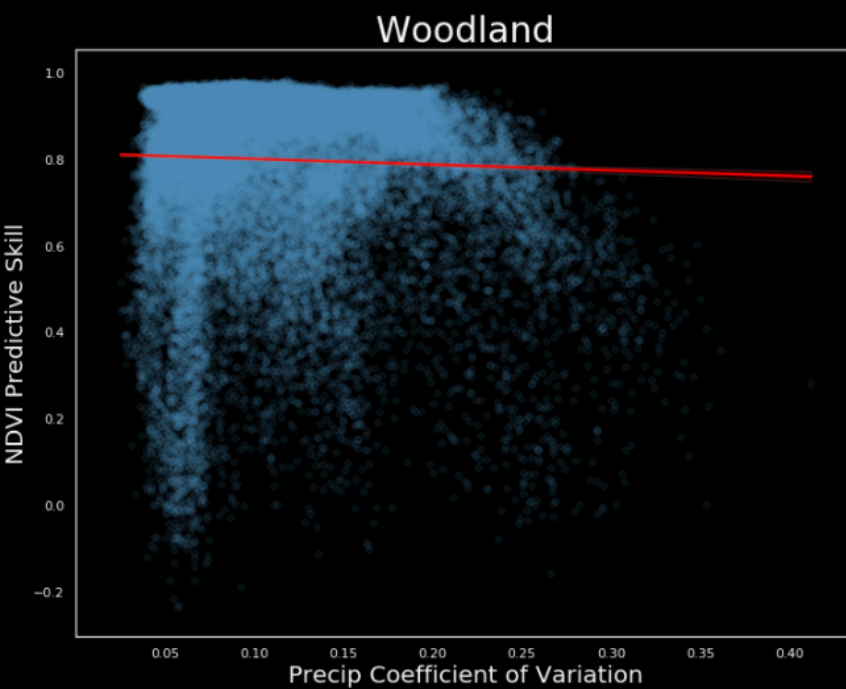


# Rainfall Anomalies and Manifolds of High and Low Skill

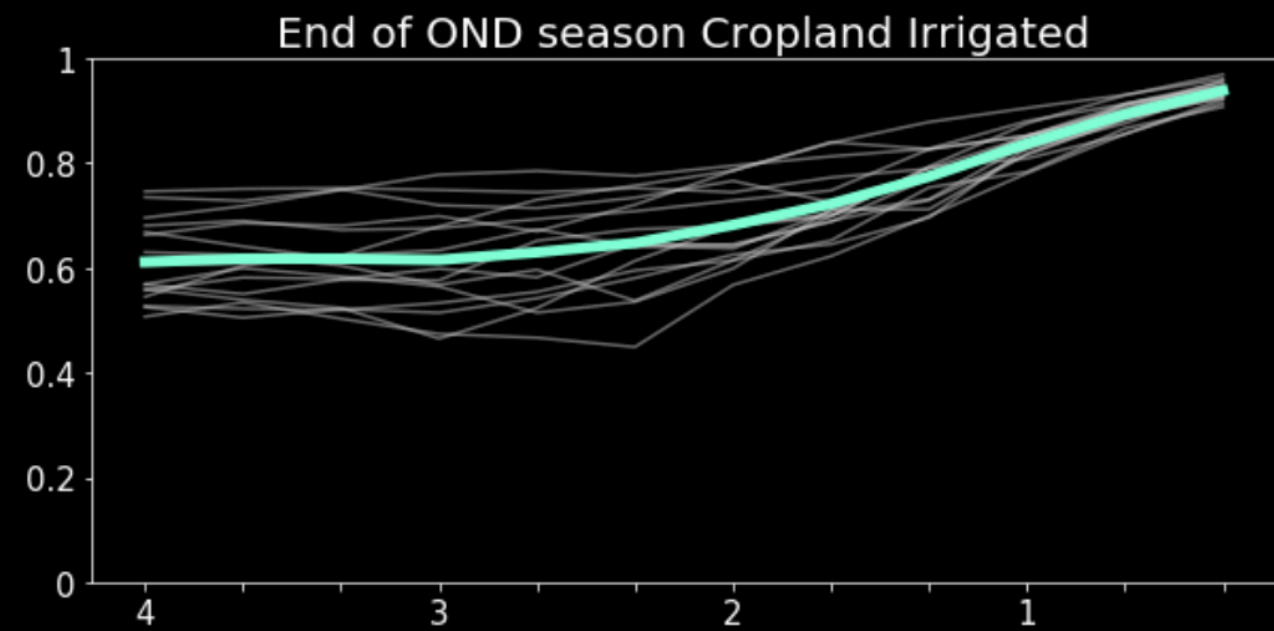
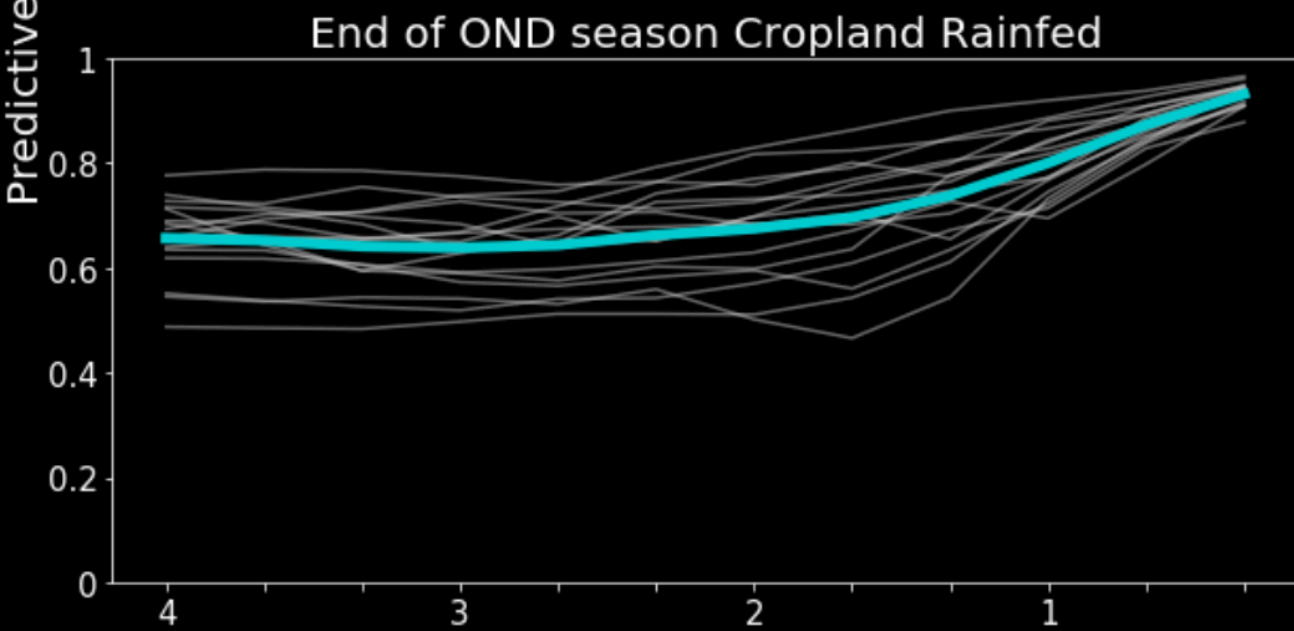
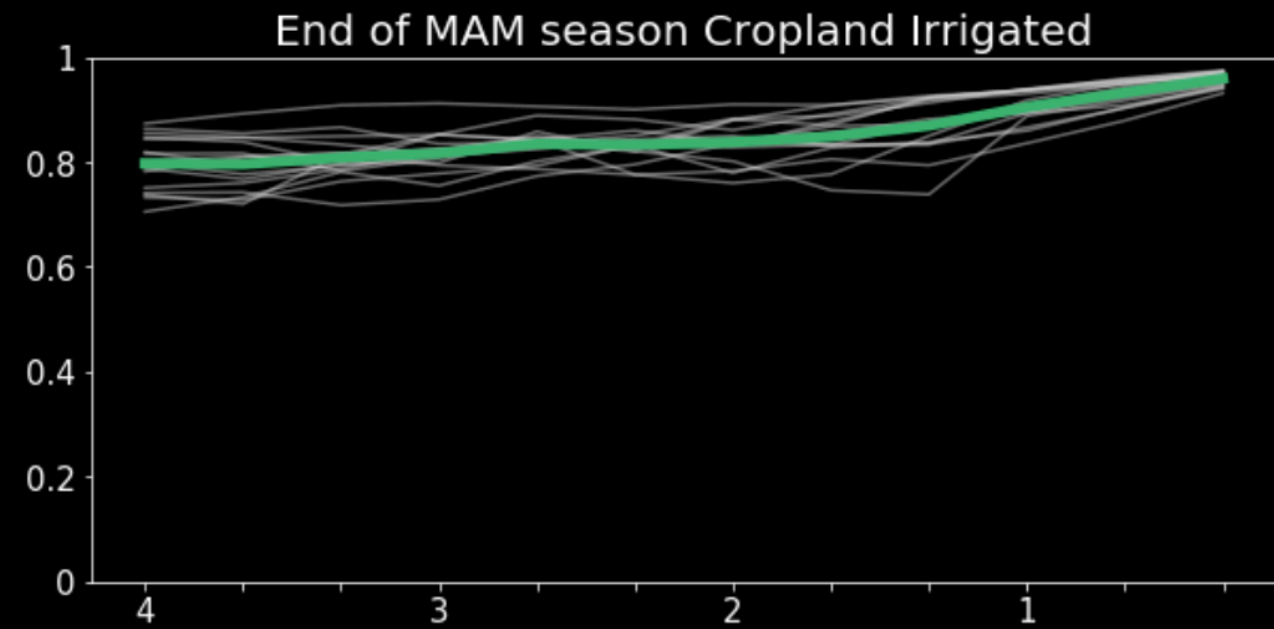
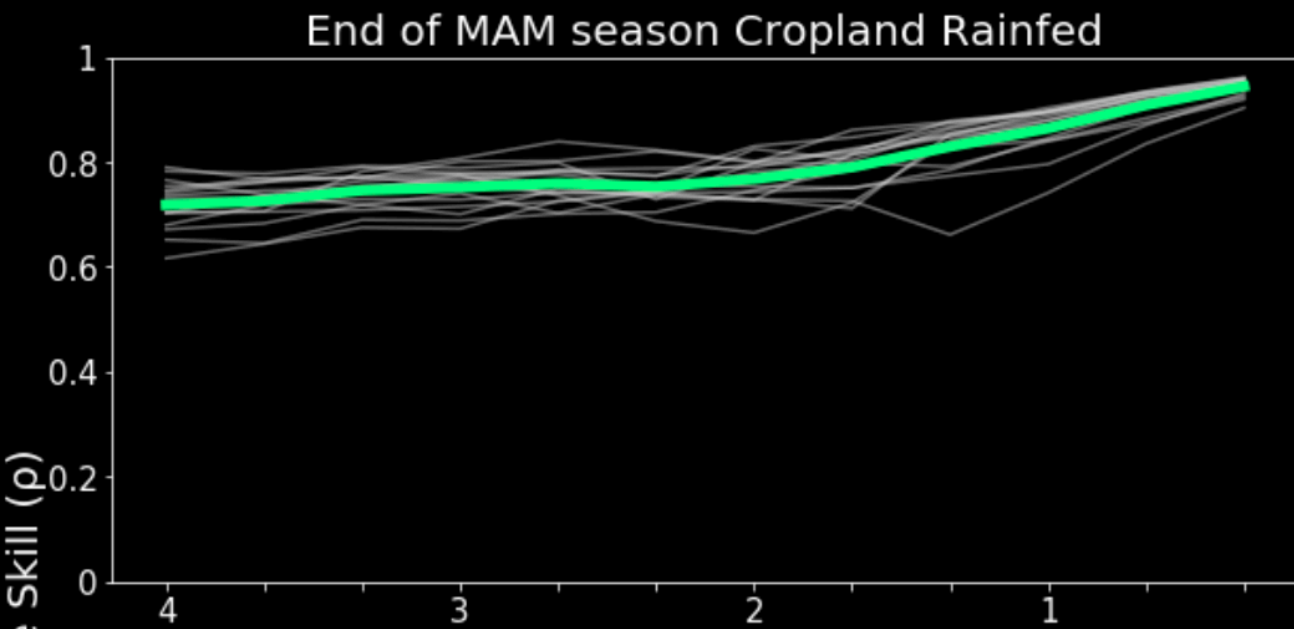




# RAINFALL VARIATIONS AND NDVI PREDICTIVE SKILL



# SEASONAL SKILL



Lead Time (Months)



# APPLICATIONS

- Proactive decision making
- Implications for food security outcomes
- Understand how semi-arid areas respond to stress from weather
- Bridge observation community with forecast community
- Transform data into actionable guidance for uptake by development organizations

