UNCOVERING BIFURCATIONS IN WEATHER DATA

Detecting Temperature Transitions using Machine Learning

Miles Kent

OVERVIEW

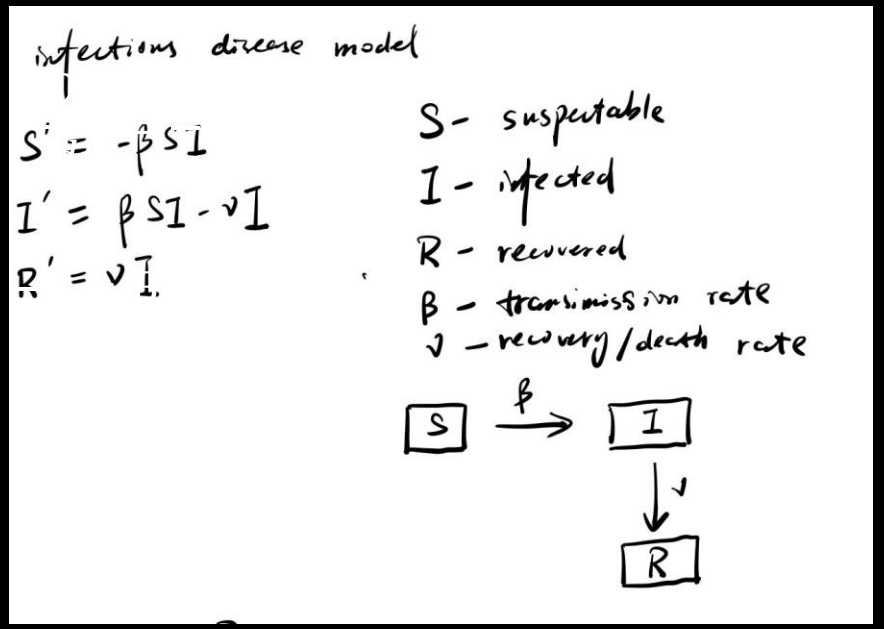
- Climate and weather models are very complicated.
- Extreme temperature transitions are extremely difficult to predict.
- Dynamical Systems may offer a “low-cost solution” to predict extreme transitions locally.

https://th.bing.com/th?id=OIP.AtHdD-UAPJNaA0YJsYy0PgHaD4&w=345&h=181&c=8&rs=1&qlt=90&o=6&dpr=3&pid=3.1&rm=2

DYNAMICAL SYSTEM

- An ordinary differential equations or a set of ordinary differential equations
- Has non-linear terms
- Models the behavior of a physical system through time

Example: Infectious Disease model



Courtesy of Dr. Zhongwei Shens MATH 432 notes

BIFURCATIONS

Bifurcation

Change in parameter past critical point = change in system state

Example: Hopf Bifurcation

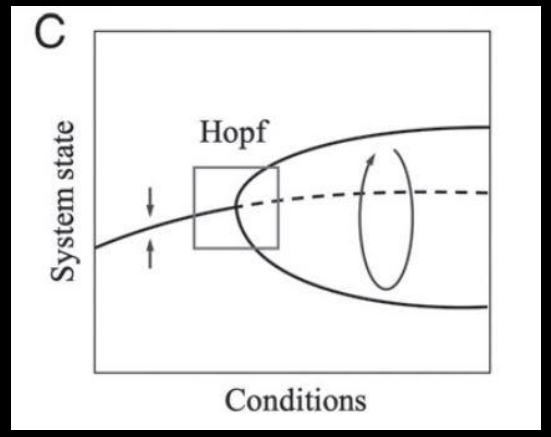


Image from Bury et at 2021

$$\frac{Df}{dx} = \mu x - y - x(x^2 + y^2)$$

$$\frac{Df}{dx} = \mu y - x - y(x^2 + y^2)$$

Early Warning Signals

- "Hints" given by system that forecast change in state.
- Example: Pitchfork Bifurcation

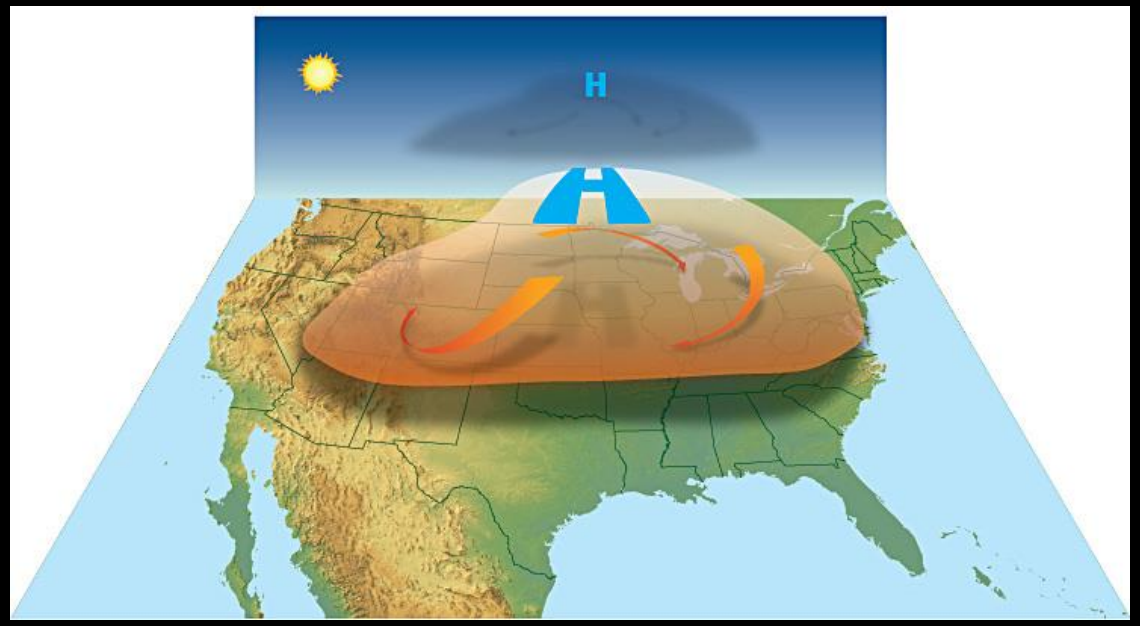
$$\frac{Df}{dx} = \mu x - x^3$$

μ to zero means x^3 dominates
Slow recovery from perturbations

APPLICATIONS TO CLIMATE SYSTEMS

Extreme Temperature Transition

- A transition to a state of very high or low temperature with little fluctuation.
- Caused set of parameters
- Transition into extreme high or low temperature state mimics a bifurcation
- Predict these transitions using early warning signals from bifurcations.



Heat_Wave.jpg (741×406) (wikimedia.org)

RESEARCH PROBLEM

Questions:

- Do normal form bifurcations exist in temperature data?
- Can early warning signals from these normal formal form bifurcations be detected before the bifurcation?

arctic - Bing images

Heat wave - Bing images

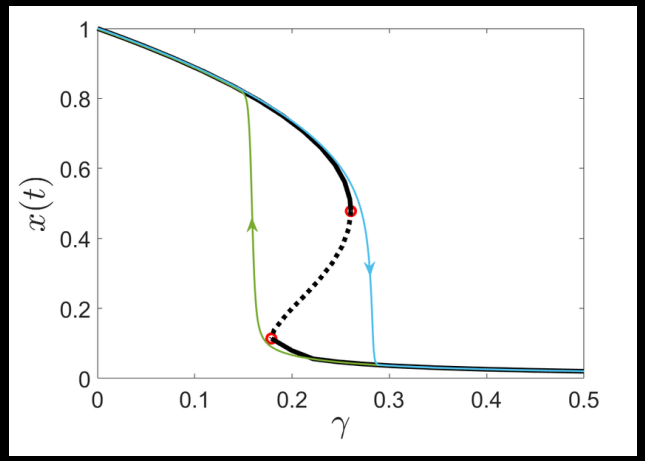
RESEARCH GOALS

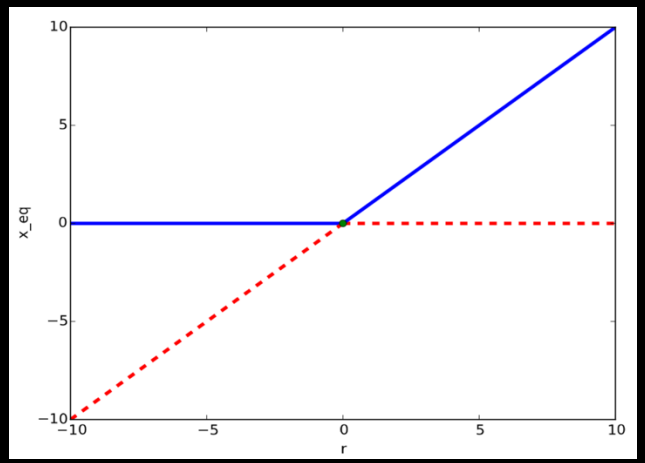
Fold (Supercritical)

$$\frac{Df}{dx} = \mu - x^2$$

Transcritical

$$\frac{Df}{dx} = \mu x - x^2$$





Variance

Increasing or decreasing

Lag_1 Autocorrelation

Becomes more or less like its previous state

(PDF) Rate-induced transitions for parameter shift systems (researchgate.net)

METHODS

The Data

- NOAA (National Oceanic and Atmosphere Administration)
- Ten cities across Canada
- Three-hour measurements
- Five hundred unbroken day timeseries
- FM-12: 26041

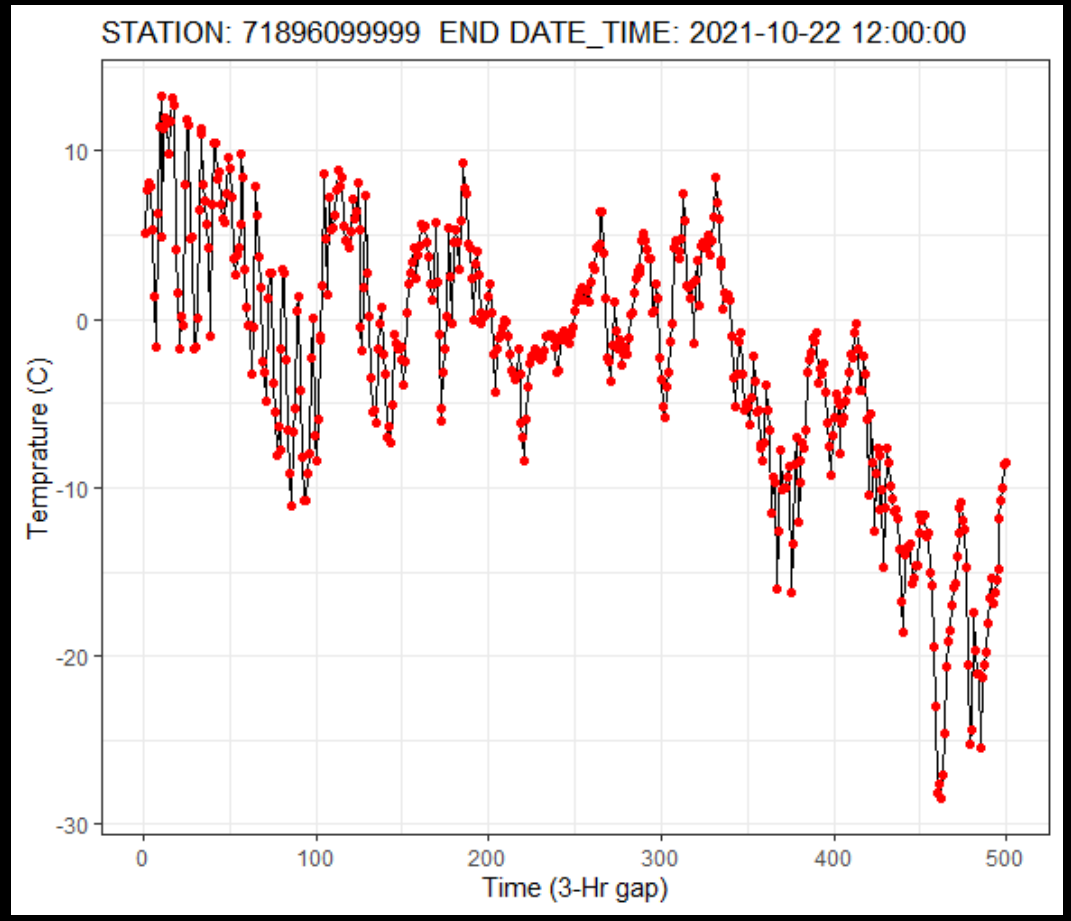
Timeseries Analysis

- Long Short-Term Memory (LSTM) Machine Learning Model
- 500000 Bifurcating timeseries as training data from Bury et al 2021
- 90% chance of bifurcation
- Gaussian Smoothing

RESULTS

Transcritical Bifurcation

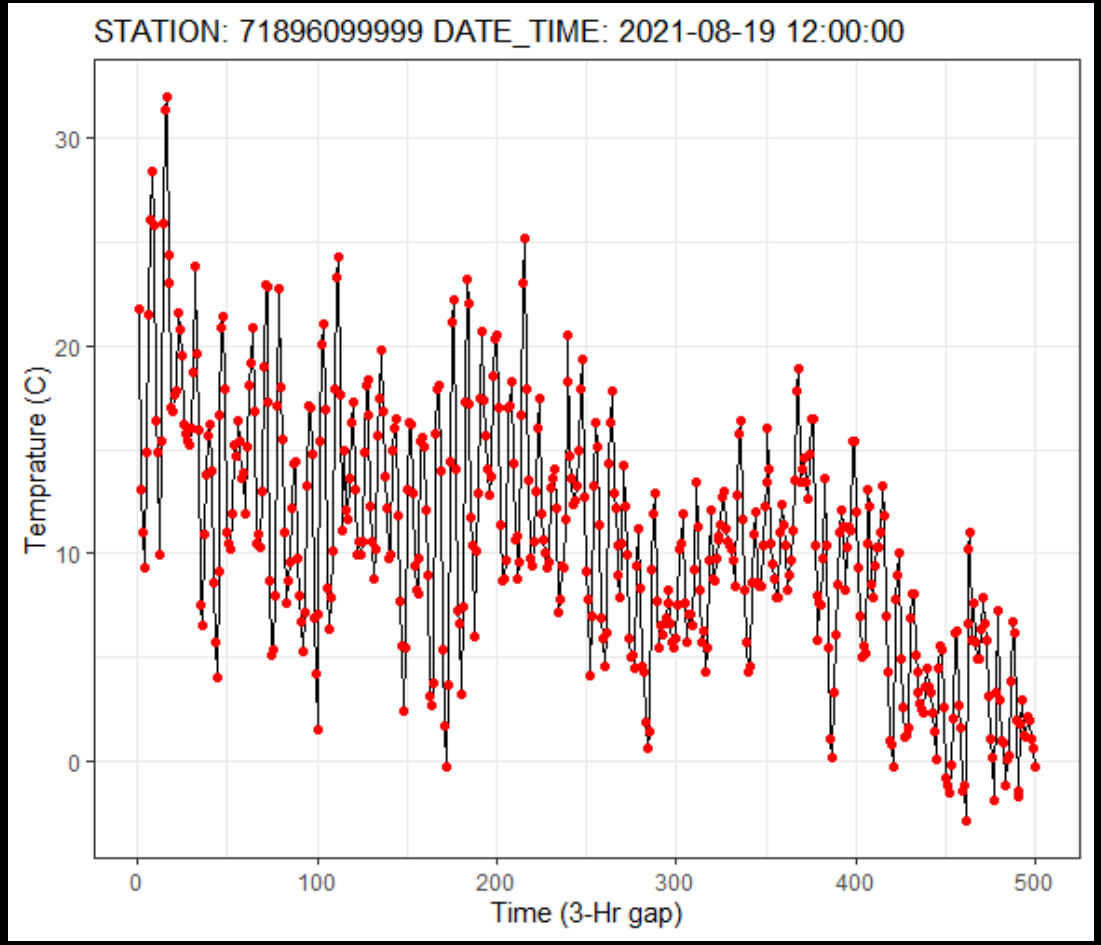
- Two Bifurcations
- Cold Snaps



RESULTS

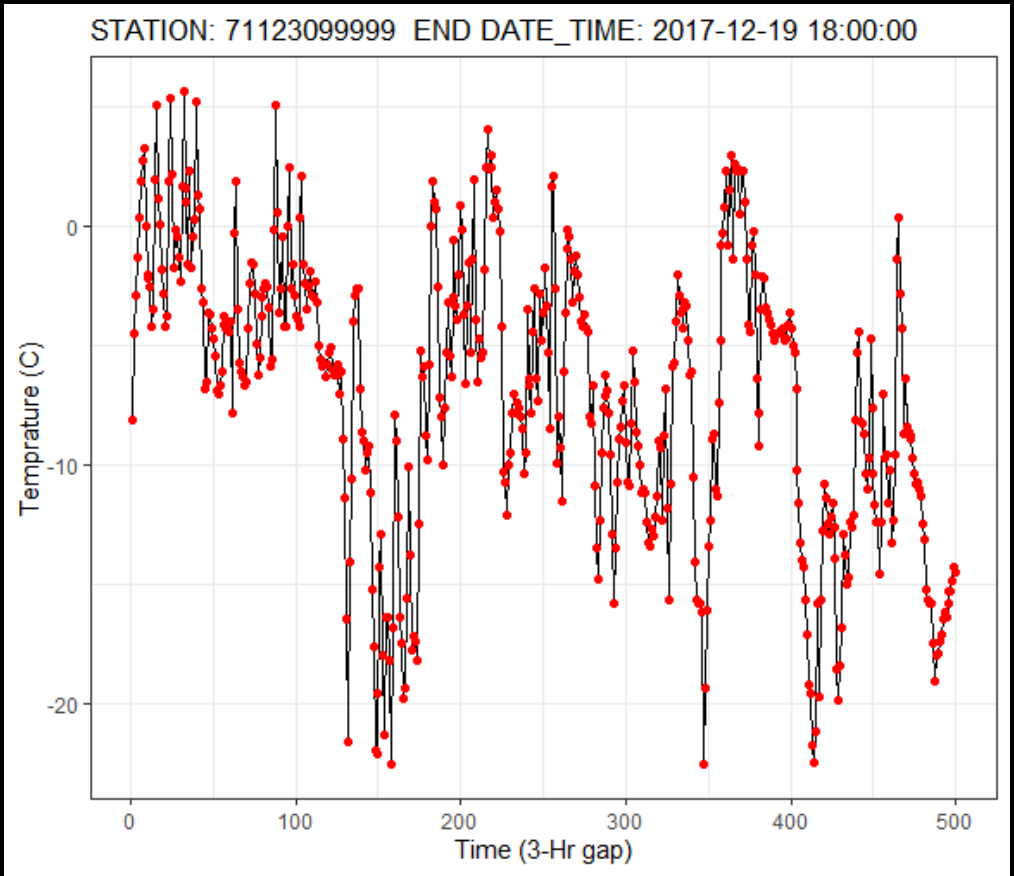
Fold Bifurcation

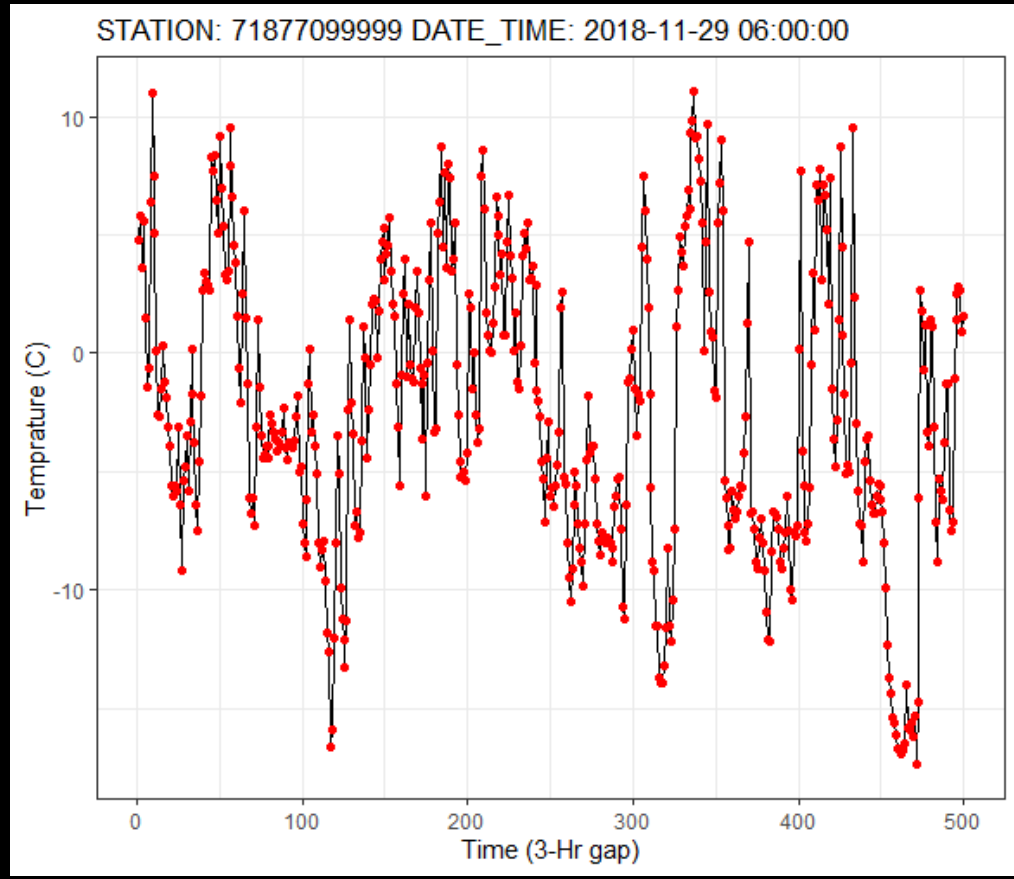
- 21 Bifurcations detected
- Cold Snaps and Heat waves
- Flickering
- Backwards



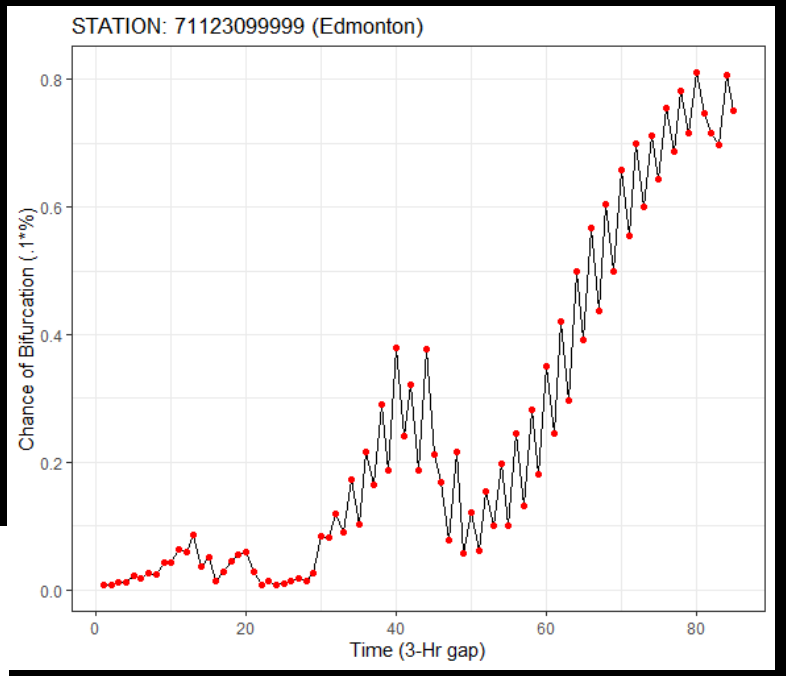
RESULTS

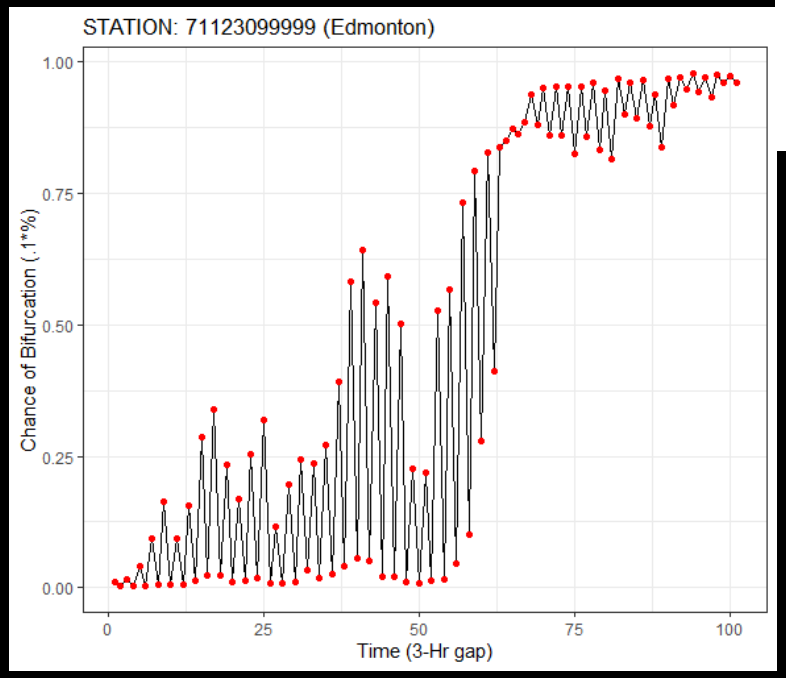
- **Fold Bifurcations**





RESULTS





Early Warning Signals

- As we get closer to bifurcation, an increase in percentage is detected on average approximately 6 days in advance
- Increase in variance
- Decrease in Lag_1

RELEVANCE AND FUTURE RESEARCH

Future Research

- Large scale study ~300 global cities
- Multiple dimensions
- Dynamical system

Relevance to the Field

- Local climate predictions
- Builds on previous climate models

THANK YOU

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