Hydrology and Climate Impacts group

Master thesis topics

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HYCLIMM

WSL

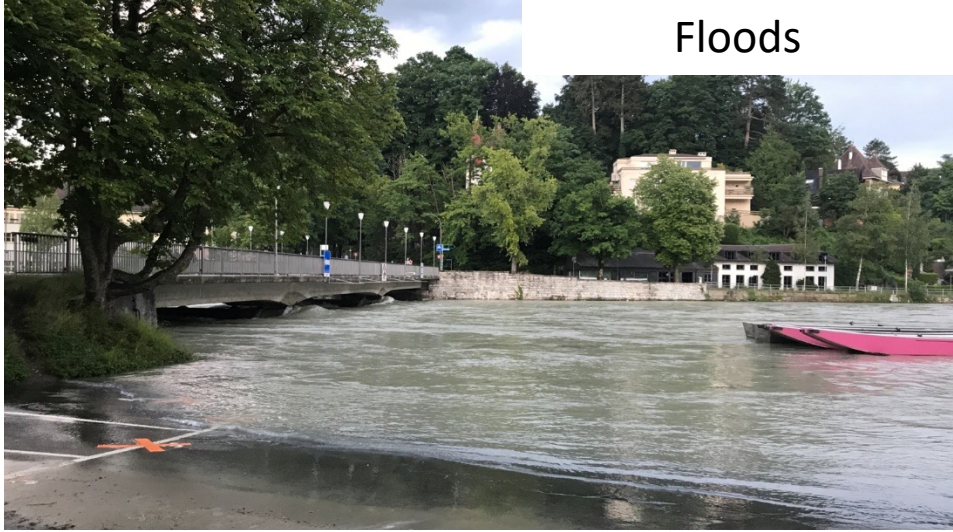
SLF

ETH zürich

Goal: Study water and climate extremes in mountain regions under global change

Droughts

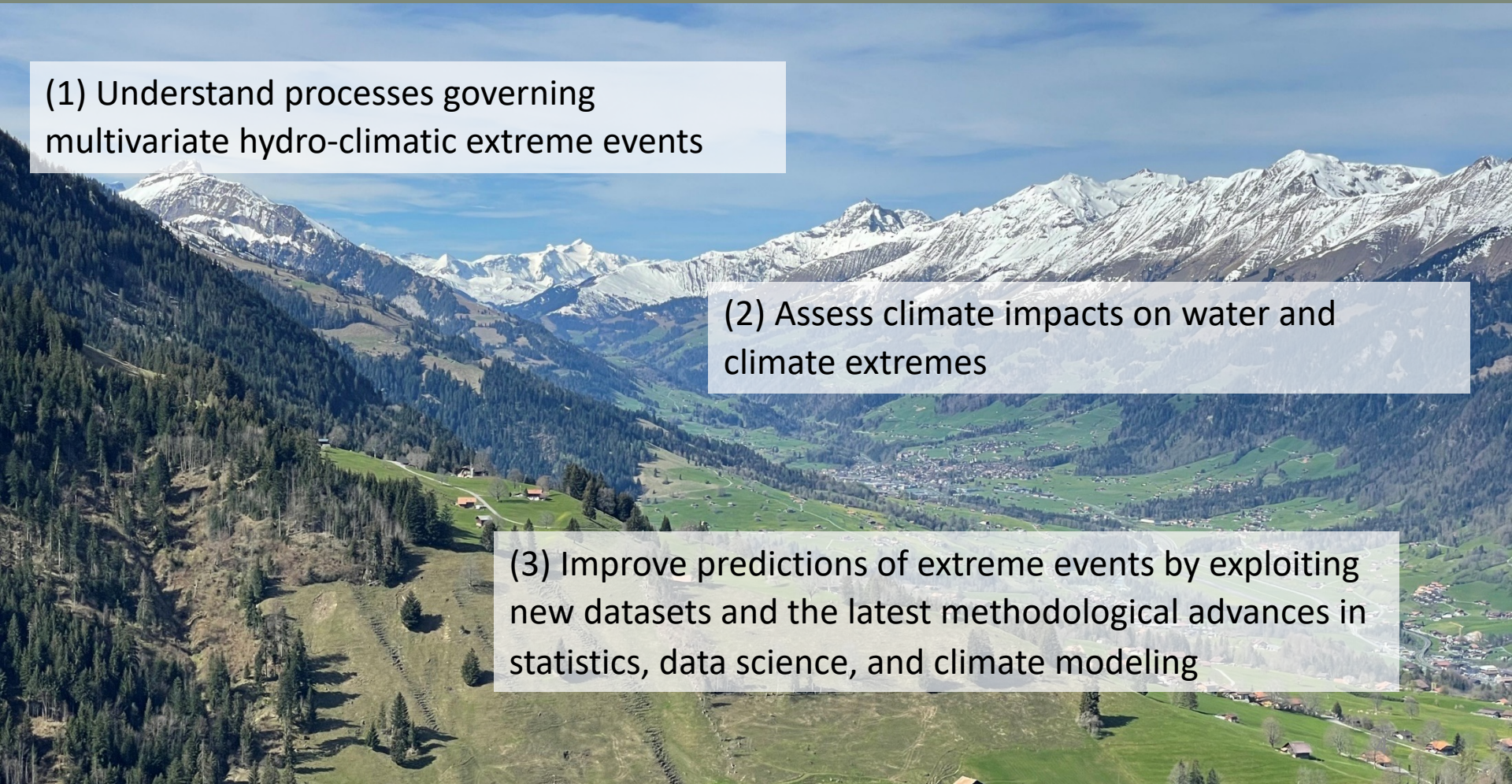
Floods



Riverine heatwaves

Forest fires

Aims



(1) Understand processes governing multivariate hydro-climatic extreme events

(2) Assess climate impacts on water and climate extremes

(3) Improve predictions of extreme events by exploiting new datasets and the latest methodological advances in statistics, data science, and climate modeling

Observed drought and flood trends in Switzerland

Which Swiss catchments show a similar behavior in terms of observed drought and flood trends?

Motivation

Hydrological extremes such as droughts and floods change in magnitude and frequency over time, which challenges water management. The direction and strength of change may depend on catchment characteristics.

Methods

Identify groups of catchments with similar drought and flood trends (+/+, -/-, +/-, -/+) by using trend analysis and classification approaches

Tasks

- Quantify trends in drought and flood frequency and magnitude for Swiss catchments using a large-sample dataset and identify groups of catchments with similar drought and flood trends
- Explain group membership by common catchment characteristics

Historical drought and flood patterns

How have spatial patterns in floods and droughts changed between 1750 and today in Switzerland?

Motivation

Historical changes in floods and droughts can teach us how hydrological systems respond to a changing climate and support model evaluation. However, model simulations are required to look far back in time as observations are no longer available.

Methods

Analyze change patterns in flood and drought events in model simulations over Switzerland (1750-2020) and compare them to changes in precipitation, snow and glaciers.

Tasks

- Identify flood and drought events in model simulations and compare to historical observations
- Quantify trends in drought and flood magnitudes and spatial extents from 1750-2020
- Assess how climatic processes (snow, precipitation, temperature…) influence the simulated changes.

Temporal drought clustering

Where and at which time scales do droughts cluster in time?

Motivation

Drought occurrence is not necessarily equally spaced in time and there may exist drought rich and drought poor periods. However, it is unclear at which longer time scales such drought clustering occurs.

Methods

Analyze long time series of drought occurrences that are derived from a tree-ring database to quantify the temporal drought clustering behavior at decadal time scales

Tasks

- Identify droughts for different European catchments using the old world drought atlas
- Quantify the temporal clustering behavior of drought using statistical measures and bootstrap experiments

Drought generation processes in Europe

Which combinations of processes generate hydrological droughts in Europe?

Motivation

Streamflow droughts have severe impacts on a variety of sectors such as energy production or river transportation. Such droughts are governed by different hydro-meteorological processes, including precipitation and snowmelt deficits and positive evapotranspiration anomalies.

Methods

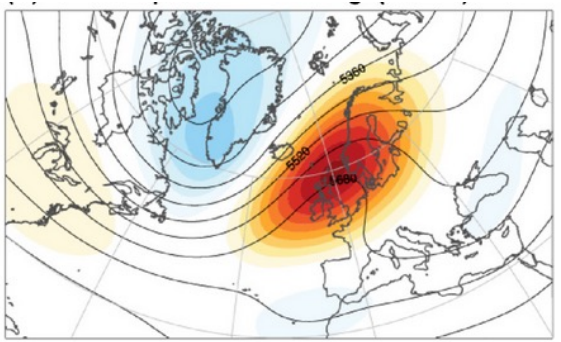
Analyze large-sample streamflow and meteorological datasets and apply clustering approaches (unsupervised learning)

Tasks

- Identify drought events with similar drought generation processes
- Identify regions in Europe with similar drought generation mechanisms

Drought-triggering weather regimes

Which weather regimes lead to streamflow droughts in Europe?



Motivation

Streamflow droughts develop under different atmospheric conditions but we know relatively little about which weather regimes lead to streamflow drought in different regions of Europe.

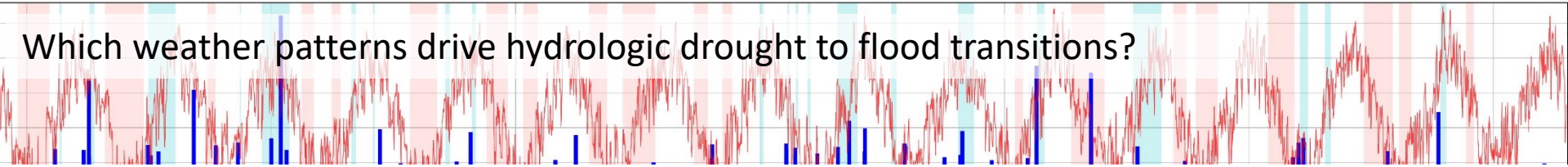
Methods

Analyze large-sample streamflow and weather regime datasets and apply clustering approaches (unsupervised learning)

Tasks

- Identify weather regimes frequently associated with streamflow drought occurrences in different regions of Europe
- Identify catchments that develop drought events under similar atmospheric conditions using clustering approaches

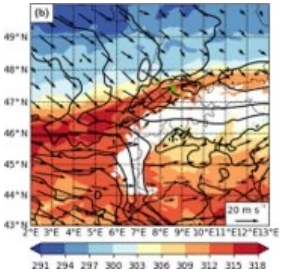
Drivers of hydrologic drought to flood transitions

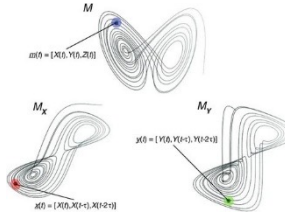


Which weather patterns drive hydrologic drought to flood transitions?

Motivation

Rapid transitions between hydrological drought and flood events have the potential to be highly destructive, but their drivers, in particular the weather patterns causing these events, are poorly understood.





Methods

Causal discovery methods offer an interesting avenue to understand the mechanisms which lead to consecutive hydrological extremes. Convergent cross mapping (CCM) is a method which can be used to map cause and effect relationships in dynamical systems using time series observations.

Tasks

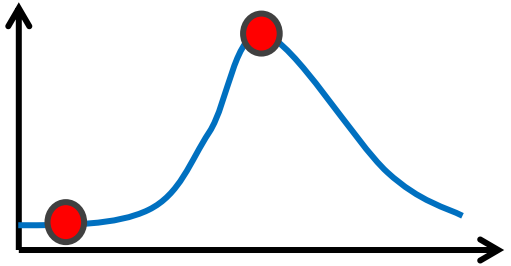
- Identify a small subset of catchments with a high occurrence of droughts, floods and rapid transitions
- Perform convergent cross mapping tests to relate synoptic weather pattern time series to hydrologic time series
- Additional investigation into the best approach, especially dependant on the number of events

Meteorological and hydrological drought-to-flood transitions

How do meteorological drought-to-flood transitions propagate to hydrological drought-to-flood transitions?

Motivation

Drought-to-flood transitions are both a challenge and opportunity for water management. While the two extremes are often studied separately, their close succession can have severe impacts.



Methods

Analyze large-sample meteorological and hydrological datasets and perform statistical analyses

Tasks

- Identify meteorological and hydrological drought-to-flood transitions
- Analyze how meteorological and hydrological drought-to-flood transitions differ
- Link the relationship between meteorological and hydrological transitions to catchment characteristics

Simulation of rapid drought-flood transitions

How well do hydrological models simulate rapid drought-flood transitions in flashy catchments?

Motivation

Rapid drought-flood transitions cause severe damages and are still poorly understood. It is unclear how well they simulate flash floods after extended periods of droughts, which can change hydrological processes.

Methods

Benchmarking of hydrological models configured to simulate rapid drought-flood transitions in flashy catchments.

Tasks

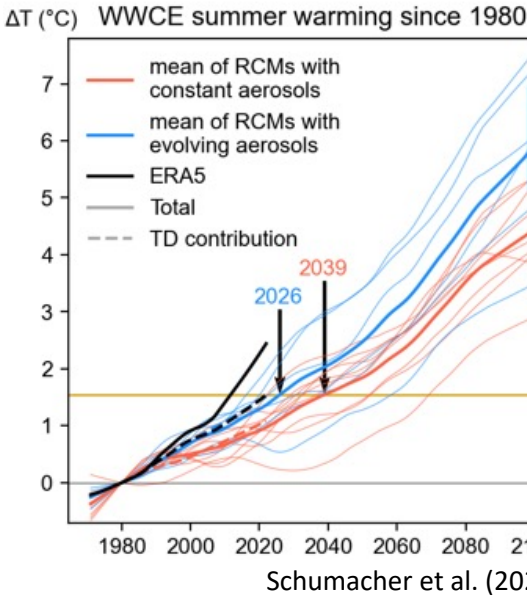
- Select a sample of catchments that have experienced drought to flash flood events
- Set up different hydrological models in these catchments, run them with observed forcing, and evaluate them with respect to consecutive drought-flood events

Hydro-meteorological extremes in regional climate models

How are hydro-meteorological extremes represented in pattern-scaled regional climate simulations?

Motivation

There is a widespread underestimation of the current warming rate in regional climate simulations (RCM). This mismatch is attributable to the processing of aerosols in the RCM models. For the new Swiss climate simulations (CH2025), two different adjustment techniques are developed to correct for the mismatch in warming. However, it is unknown how these adjustment techniques affect hydrological extremes (e.g., multi-year droughts, drought-to-flood transitions, or floods)?



Schumacher et al. (20

Methods

Analyze and compare hydro-meteorological extremes from two different adjusted regional climate model ensembles, using two variations of pattern scaling, with the original ensemble (no adjustment).

Tasks

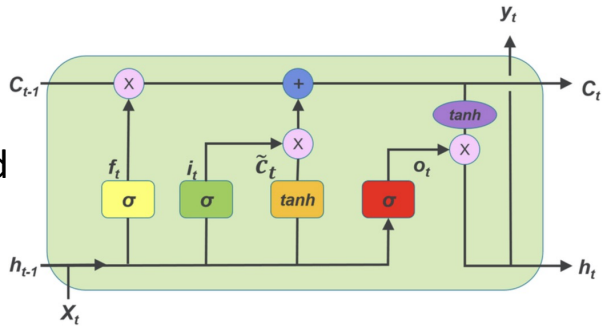
- Quantify simulated changes in hydrological extremes (floods, droughts, consecutive events) in the three ensembles
- Analyze differences between the ensembles in their representation of hydrological extremes

A long short-term memory model for simulating streamflow in Switzerland

What model performance can we achieve for streamflow and hydrologic extremes with a long short-term memory model (LSTM)?

Motivation

Simulating streamflow and hydrologic extreme events such as floods and droughts is challenging. Machine learning based models such as LSTMs represent an alternative to classical hydrological models and have been shown to have good predictive performance in catchments both with and without observations.



Methods

Set up an LSTM for Switzerland using a recently published large-sample dataset of streamflow, meteorological time series, and catchment attributes

Tasks

- Set up LSTM model structure and train the model for Switzerland
- Evaluate model performance for catchments with and without streamflow obesrvations

Hydrology and Climate Impacts in Mountain Regions

Visits in Davos possible

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