ETH zürich

# Climate physics group

Reto Knutti

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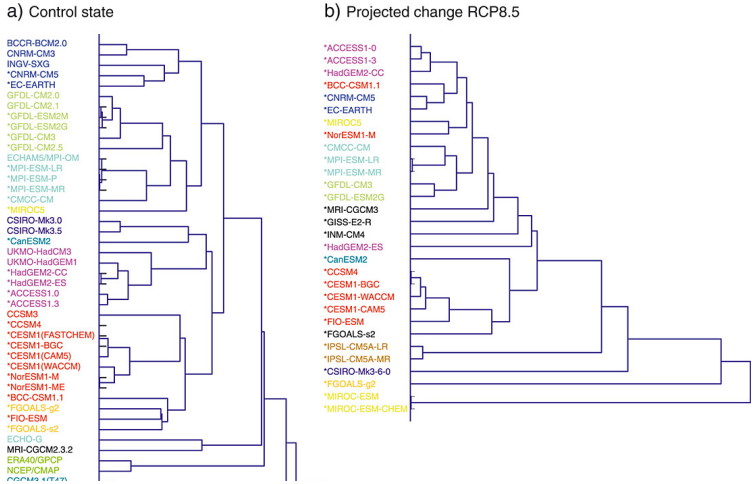
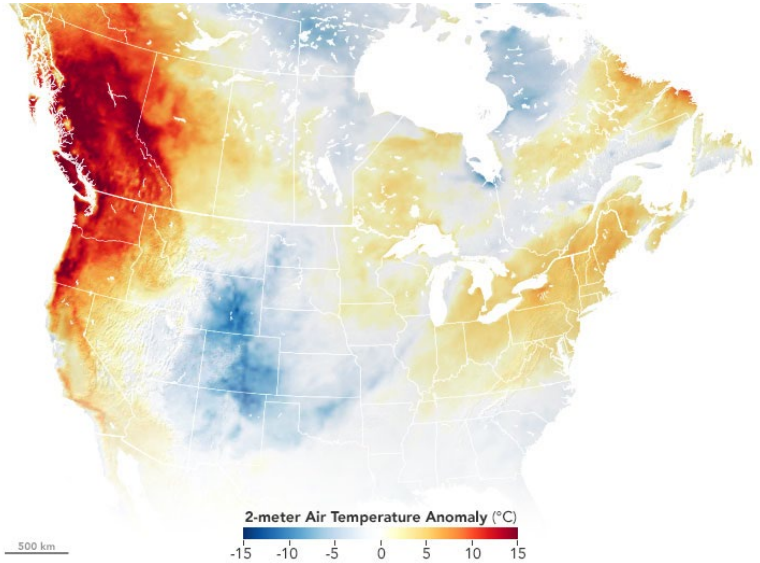
# Climate physics group

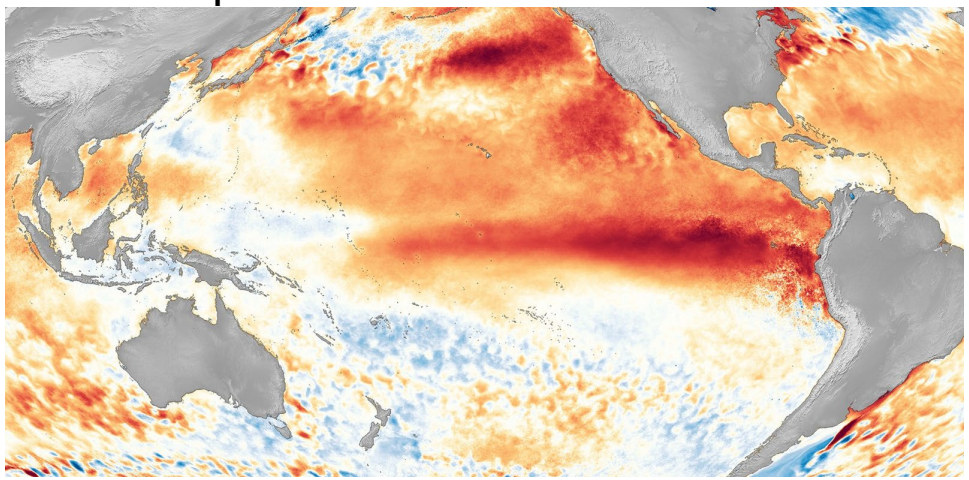
## Climate models and their interpretation




## Climate and weather extremes




## Climate variability, climate projections and quantification of uncertainties



## Mitigation of climate change

# The Multi-Model Large Ensemble Archive as a climate noise generator

## Motivation

Climate understanding is hindered by the length of the observational record. Combining model-generated climate noise with an observed signal increases the observational sample and provides additional climate storylines.

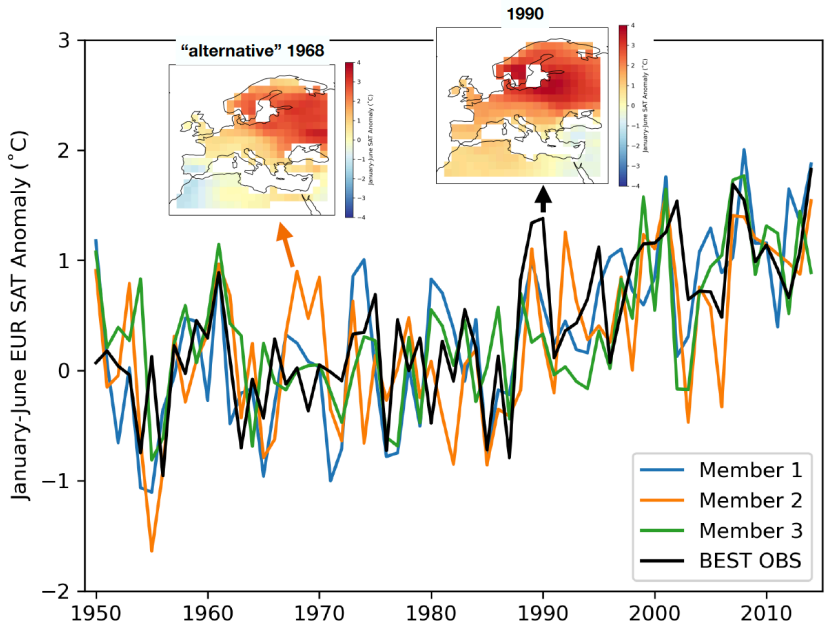
## Research Questions

*Validation:* How does the model-generated European climate noise compare to observed noise? How does the noise compare between different models? Are there regions of Europe where certain models perform better?

*Storylines:* Persistent heat events provide a potential preview of future average seasonal temperatures. Can you identify interesting European heat storylines (e.g., spatially extensive or especially persistent anomalies) within the larger observational sample?

## Tasks

Statistical analysis of new climate data, Mosaic visualization, Outlier detection

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# Model Selection for Swiss Stakeholders

## Motivation

The next generation of Swiss Climate Scenarios (CH2023) will benefit from a summary of which subsets of CMIP6 models should be used for each task.

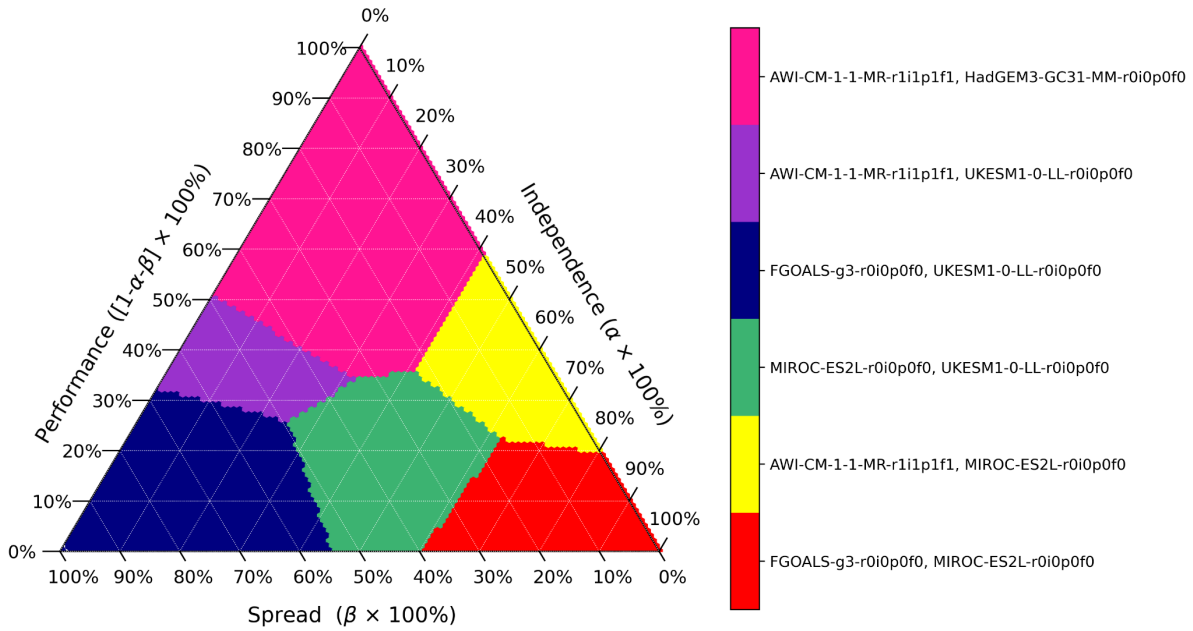
## Research Questions

*Stakeholder engagement:* What do downstream users need a model to do well? What projection time horizon is sought? What region/season is important? Does the task require a look at potential worst-case scenarios?

*Subselection:* Using Climate model Selection by Independence, Performance, and Spread (ClimSIPS), what sets of 3-5 CMIP6 models are suitable for each task discussed?

## Tasks

Designing a stakeholder questionnaire, running and helping develop the ClimSIPS python package, producing an informative fact sheet





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# CMIP6: Subset or Full Ensemble?

## Motivation

Many studies draw conclusions from multi-model archives without thinking about the individual models they are using. Intentionally selected CMIP6 subsets could reduce uncertainty in projections of future climate change and steer adaptation conversations.

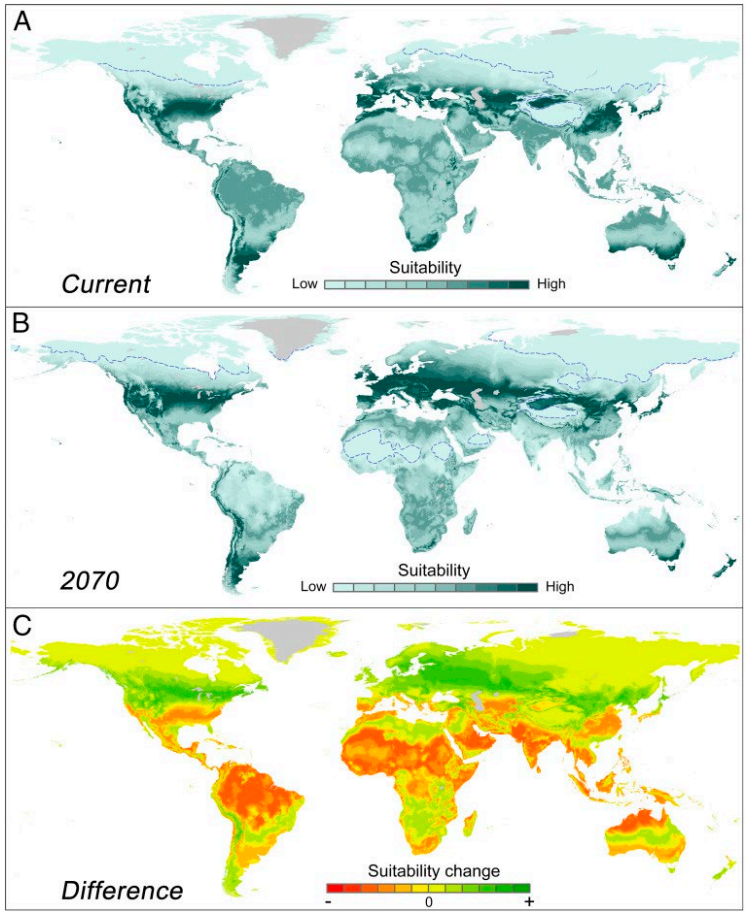
## Research Questions

How do subsets of climate models selected from CMIP6 compare to the full ensemble in representing absolute temperature-based metrics? Example metrics:

- human climate niche - ~11 °C to 15 °C mean annual temperature (MAT; Xu et al. 2020)
- Heating and Cooling Degree Days in Switzerland

## Tasks

Climate model subselection using a developing python package, metric calculation, full ensemble vs. subset comparison




Xu et al. 2020

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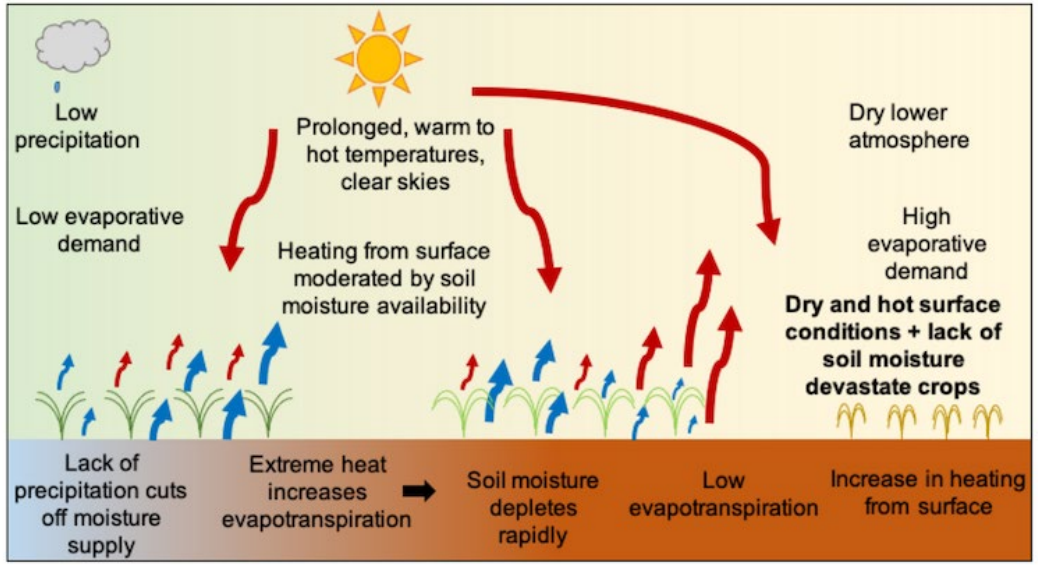
# Examining flash drought in high-resolution storm-resolving global climate models




Tess Parker

## Motivation

Flash droughts are extreme events combining low precipitation and extreme heat leading to rapid rises in evapotranspiration and soil desiccation. They pose a threat to agriculture and quickly amplify wildfire risks.

## Research Questions

Can the latest ultra high-resolution global climate models capture the complex land-atmosphere interactions leading to flash drought?

## Tasks

- Identify flash drought occurrences using IFS and ICON simulations within the framework of the NextGEMS project.
- Compare flash drought properties against CMIP6 models.
- Describe potential biases within the NextGEMS models using reanalysis and observations when applicable.

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# Deadly Humid Heat over Europe

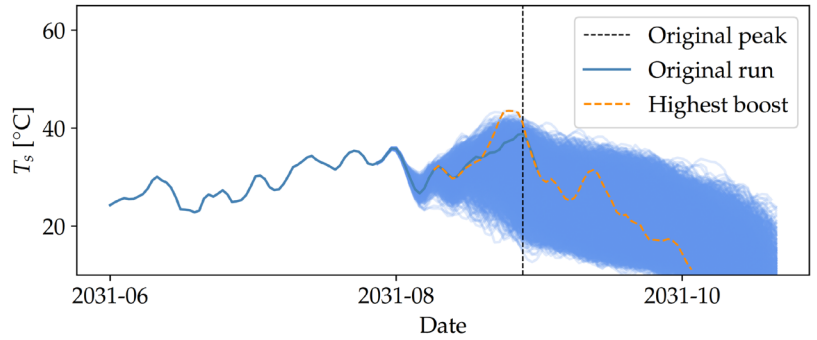
Photo by Keren Fedida on Unsplash

## Motivation

Together, extreme heat and humidity can be deadly. Exceeding these dangerous humid heat thresholds will occur more and more frequently over large regions. However, these conditions are thought to be extremely rare or even impossible over Europe in the near future.

In this project you will use ensemble boosting – a method to push climate models to their limits – to assess the most extreme humid heat events that could occur over Europe, which mechanisms control its development, and the extent of its impacts.

**Ensemble Boosting: how extreme could extremes get?**




## Research Questions

1. Could the most extreme humid heat over Europe reach deadly levels in the near future?
2. What mechanisms need to converge for such extremes to develop?

## Tasks

- **Identify and analyze extreme humid heat** events from the CESM2 large ensemble
- Simulate the most extreme conditions that such events could reach using **ensemble boosting**
- **Investigate the drivers** of the most extreme events

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# Clustering extremes identification using Machine Learning

## Motivation

A better understanding of extreme events compound is critical for adaptation and mitigation strategies. A machine learning (ML) model could help us identify **when, where and how different univariate or multivariate extremes cluster** together in time or space.

Furthermore, investigating which variables and processes are useful for the ML model to identify and predict such clustering events could provide key insights to understand which mechanisms drive them, and potentially how to predict them in the real world.


Image credit: ARC, Australia

## Research Questions

1. Can a ML model identify clustering extremes in large ensembles of climate model simulations?
2. What processes inform the ML model to identify and predict such extreme clustering events?

## Tasks

Define **locations and clustering events of interest**

Develop a **ML model to identify clustering** extremes in large ensemble simulations.

Evaluate the **climate model performance** against observations and reanalysis

Investigate which processes the ML model needs to identify clustering extremes

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# Consecutive and Concurrent Drought Risk

## Motivation

Drought impacts can become even worse if droughts occur for several consecutive years over the same region, or concurrently over multiple regions in a single year.

Such consecutive and concurrent droughts are becoming more frequent, especially over vulnerable food basket regions. However, it remains unclear how precipitation, evaporation and soil moisture memory control these changes, and how well models represent them.

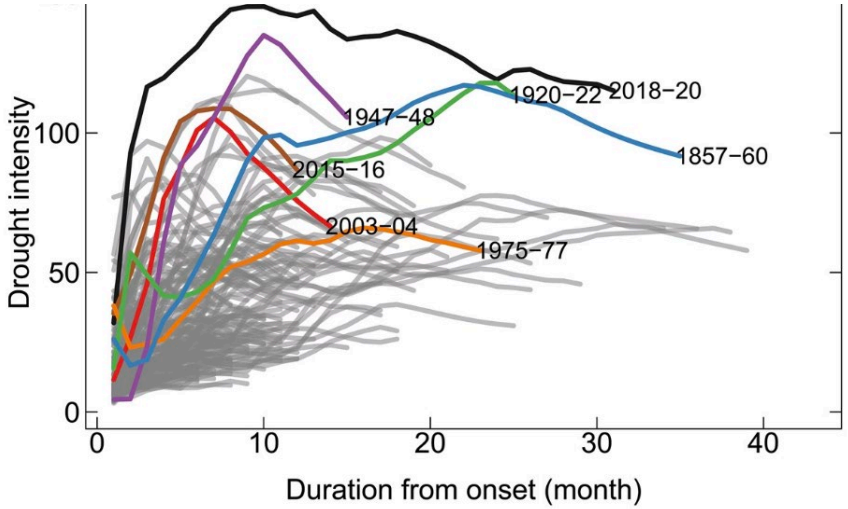
## Research Questions

1. What mechanisms control changes in consecutive and concurrent droughts?
2. How will such high-impact droughts change with warming, according to the models that simulate them best?

## Tasks

- Identify regions/ecosystem of interest (e.g., food baskets, forests)
- Quantify main drivers for consecutive and concurrent droughts: 1) precipitation patterns and variability and 2) evaporation and soil moisture memory
- Generate projections of consecutive and concurrent droughts based on the best performing models compared to observations

**Observed Multi-year Droughts over Europe**




Rakovec et al. (2022). The 2018–2020 multi-year drought sets a new benchmark in Europe. 10.1029/2021EF002394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# How will climate change impact different generations?

## Motivation

Due to rapid climate change, the climate experienced by different generations will be strikingly different. You'll extract point data from high-resolution regional climate simulations and calculate the cumulated life-time exposure to specific weather events for different generations of the population

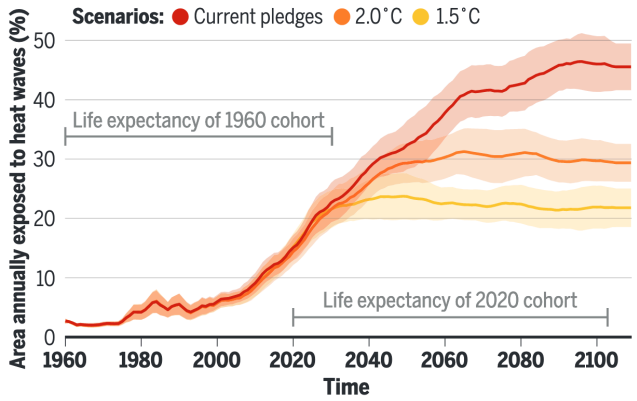
## Research Questions / Tasks

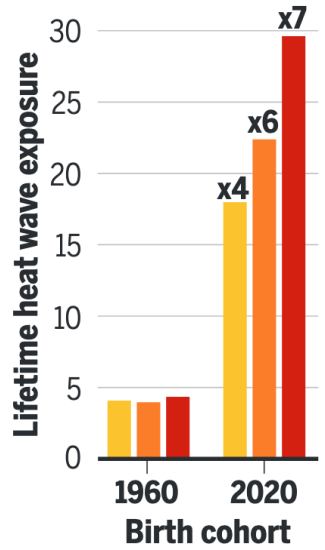
Develop robust event definitions for a topic of your choice (i.e. heatwaves, droughts, fire risk, cold spells, etc.) and calculate the cumulated exposure for different generations

Evaluate the uncertainty of these estimates and where do inter-model differences play the largest role

## Recommended skills

- You like analyzing and presenting results based on quantitative data
- Some python experience is a plus




Thiery et al. 2021, Science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# Is more always better? Investigating the value of climate projections

## Motivation

More than 60 climate models have published hundreds of historical simulations within the Coupled Model Intercomparison Project (CMIP6). However, many models share the same code and are in fact subversions of each other. Is each model truly providing an independent data point, or is this abundance of models an illusion?

## Research Questions

What metrics from statistics or information theory can we use to quantify the information content of a climate simulation?

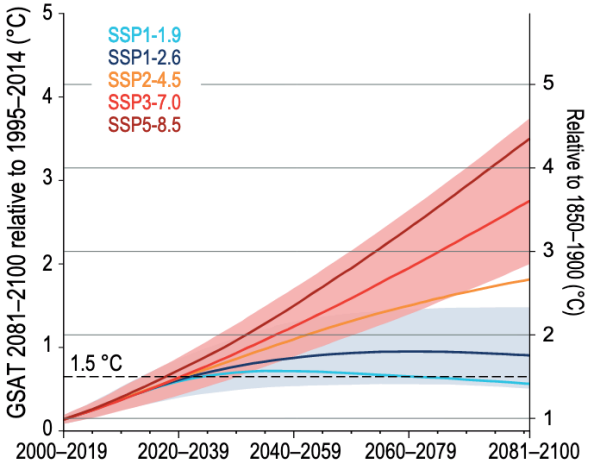
How many simulations are sufficient to characterize the full variety of CMIP6 historical warming trajectories?

## Tasks

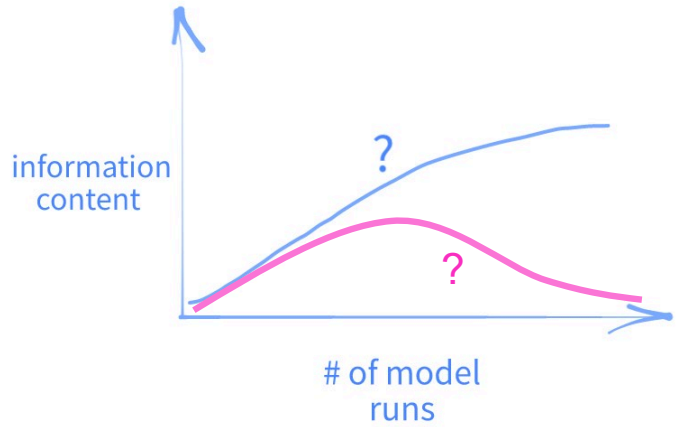
- Develop metric(s) to quantify information content and apply them to preprocessed CMIP6 climate simulations

## Recommended skills

- You enjoy coding and creating your own solutions




IPCC AR6, WG1, Technical Summary

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# Predictability of long-term wind fluctuations

## Motivation

Wind energy is essential to mitigate climate change and plays an increasingly important role in many energy systems. However, wind energy potentials vary over multiple decades [e.g., Wohland et al., 2019; 2021].

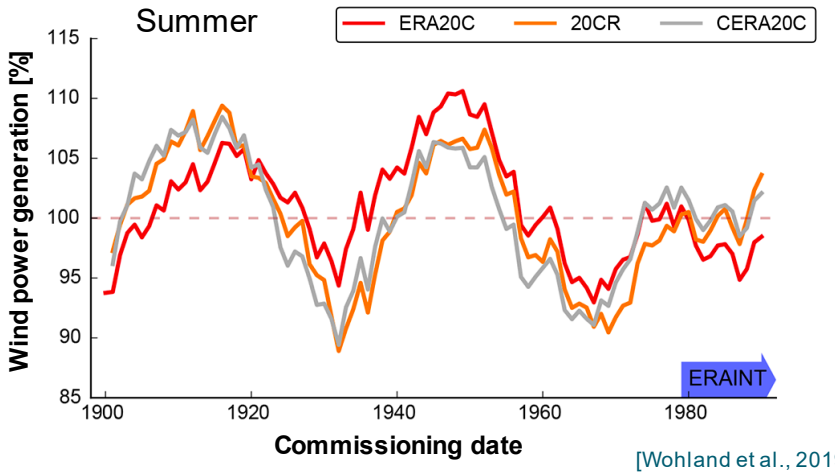
## Research Question

How predictable are long-term wind fluctuations with current tools?

## Tasks

- Understand current knowledge about wind resource variability
- Analyze data from the decadal climate prediction project
- Room for own refinements (training classifiers, defining metrics, choosing case studies, conditioning on NAO, …)


[ Doherty via unsplash ]



[Wohland et al., 2019]

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# Climate change impacts of individual flights

## Motivation

$CO_2$ is only a relatively small contributor to the overall climatic effects of aviation. Many of the non-CO2 effects are short-lived and depend on the technology and demand trajectory. Multiple plausible definitions of sector-wide climate neutral aviation exist [Brazzola et al., 2022].

## Research Questions

What is the climatic effect of a single flight? Should new flights be treated differently (CO2 + short-lived) than previously existing flights (only CO2)?

## Tasks

- Understand climate neutrality definitions and challenges to policy implementation
- Develop heuristics to estimate the climatic effects of single flights without knowledge of all other flights
- Test heuristics in the FAIR model


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# Reducing the climate impact of food in Switzerland

## Motivation

Globally, about 25-30% of all greenhouse gas emissions are due to our food. However, the Swiss climate strategy often does not address food-related greenhouse gas emissions.

## Research Questions

What reductions in greenhouse gas emissions can be expected from dietary changes, feed additives, or less food waste in Switzerland?


Source: Fabrice Coffrini

## Tasks

- Assess the climate impact of the current food supply chain
- Develop an interactive tool to assess the effect of future dietary changes, feed additives, or less food waste on the Swiss greenhouse gas emissions.

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