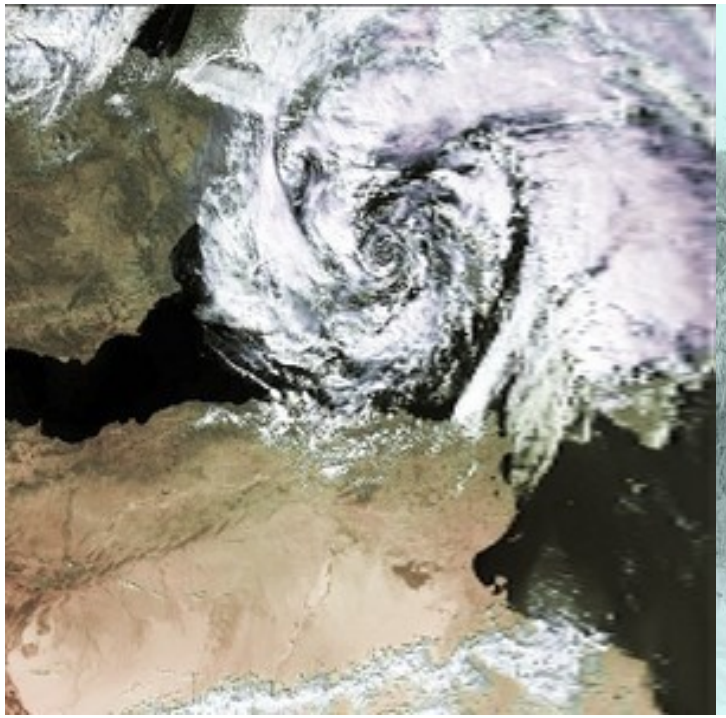
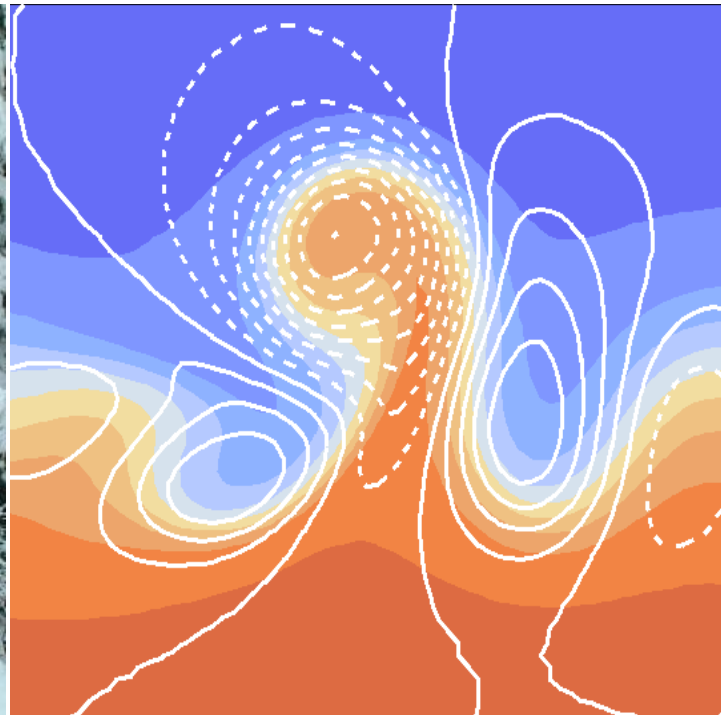
Atmospheric Dynamics Groups

Domeisen - Jnglin Wills - Wernli

Bachelor Thesis Topics for 2025





General remarks

All projects involve a lot of computer work (data handling, graphics, running a model, programming, …)

We work on linux computers (unix, python, R, …)

For most projects, it is not essential that you already have a lot of computer / programming experience – but you should be ready to learn a lot!

Strong interest in the “physics of weather and/or climate” is useful for all projects

The topics offered here are for the spring semester 2025 – please let us know if you like to do your project later (e.g., in summer or autumn 2025)

We strongly recommend a good time planning such that you can finish your project until about June/July 2025

Today, we offer 20 topics from 3 research groups (led by Daniela Domeisen, Robb Jnglin Wills, and Heini Wernli).

Research topics

Domeisen

1) The role of the stratosphere for the occurrence of extreme seasons over Europe
2) Forecasting storm clustering over Europe more than one week in advance
3) Predictability and biases of temperature extremes in data-driven models

Jnglin Wills

4) Low-frequency variability in the North Atlantic circulation and coupling with decadal SST variability
5) Mechanisms of decadal variability in the South Pacific

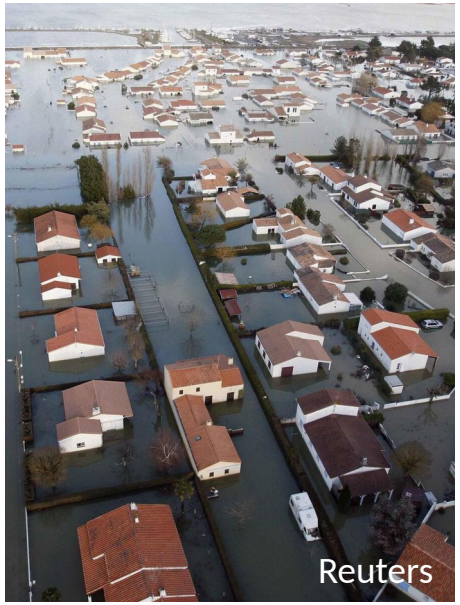
Wernli

6) Dynamics of megadroughts in the north of Spain in the CESM2 climate model
7) Investigating heat extremes over the ocean
8) Investigating heat extremes in a tropical and desert regions
9) Investigating the aspect ratio between the vertical and horizontal extent of heat extremes
10) June 2021 heatwave and large hail
11) Comparing cyclones associated with short and long duration extremes in the Eastern US
12) Dynamics of analogues of storm Boris in the CESM1 climate model
13) The influence of dry intrusions on boundary layer processes: a $COSMO_{iso}$ case study
14) Sensitivity of a WCB in an idealized cyclone to resolution
15) How cyclone influences WCB interaction with the Rossby waveguide
16) How dangerous is foehn for the Appenzeller Bahnen?
17) The Great Smog of London in January1952
18) The Battle of Moscow – How Weather changed the Course of WWII
19) Flight Path Analysis for the Swiss H_2O Hub Project
20) Atmospheric deposition of volatile ^{129}I emissions from nuclear reprocessing plants to the Mediterranean Sea

The role of the stratosphere for the occurrence of extreme seasons over Europe

Motivation:

Extreme events on the seasonal timescale can have severe socioeconomic impacts. A potential driver of extreme seasons is the stratosphere. Dynamical variability in the stratospheric polar vortex can exert a strong and long-lasting downward impact on surface weather.

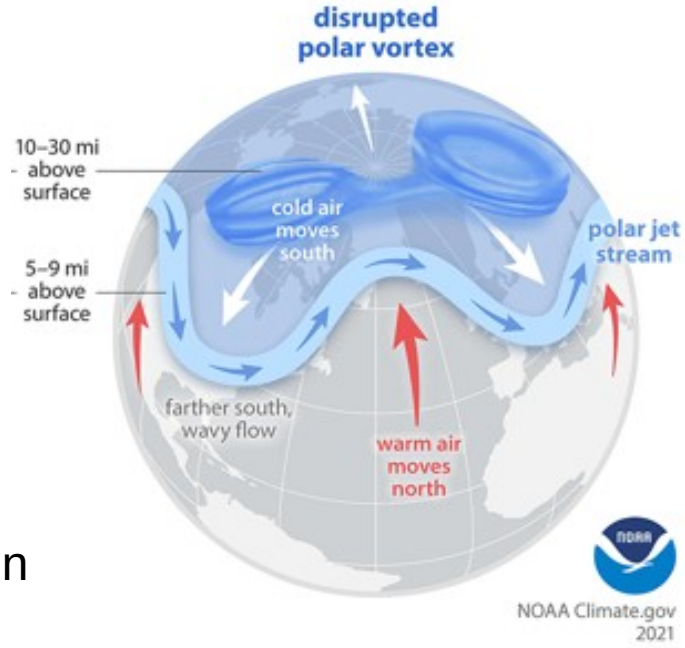


Research question:

What is the role of the stratosphere for the occurrence of extremely wet, dry, windy, calm, hot and cold seasons over Europe?

Approach:

- Case studies of extreme seasons in ERA5 reanalyses
- Systematic analysis of many extreme seasons in climate simulations (CESM-LE)



Prerequisites:

Interest in atmospheric dynamics, extreme seasons and the stratosphere

Supervision – an opportunity to work with two research groups:

Dr. Hanin Binder, Dr. Hilla Afargan-Gerstman, Dr. Rachel Wu, Prof. Daniela Domeisen

Forecasting storm clustering over Europe more than one week in advance

Motivation:

Serial clustering of extreme storms (storms that occur in close succession) can have substantial societal and economic impacts. A greater understanding of storm clustering in midlatitudes can improve our ability to predict these events on time scales beyond one week. Moreover, there is a need to test the reliability of new AI-based forecasts and examine how well they represent both physical processes and hazards.

Goals of this project:

- How well can we predict storms clustering over the North Atlantic and Europe?
- What are the sources of predictability of storm clustering events?

Data: ECMWF reanalysis (ERA-5) and S2S ensemble forecasts, including **AI-based forecasts**.

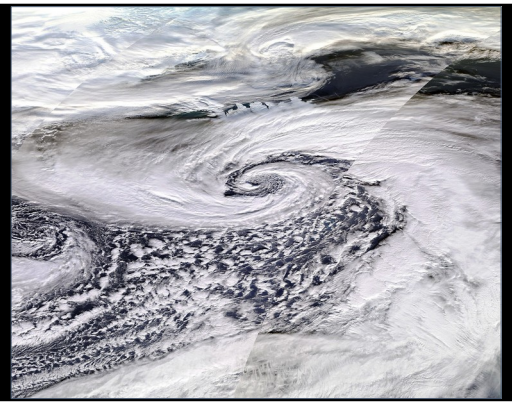
Prerequisites:

Interest in atmospheric dynamics, climate and weather,
Experience in data analysis.

Supervision:

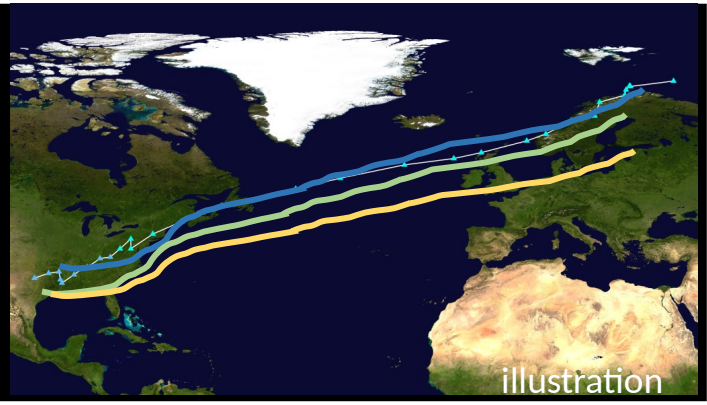
Dr. Hilla Afargan-Gerstman,
Dr. Rachel Wu,
Prof. Daniela Domeisen

Storm Ciara on February 7, 2020



Storm Dennis on February 15, 2020

Storm Jorge on February 27, 2020



NASA - https://worldview.earthdata.nasa.gov/

Predictability and biases of temperature extremes in data-driven models

Motivation:

Dynamical models exhibit biases in temperature predictions, particularly for extremes, even at relatively short lead times such as five days ahead. While machine learning models show promising forecasting ability, their performance in different seasons and under extreme conditions are not thoroughly examined. This project therefore aims to investigate how machine learning models compare to dynamical models in predicting temperature extremes.

Research objectives:

1. Compare the skill of machine learning models to dynamical models in predicting temperature extremes under different seasons and during extreme events
2. Assess skill of machine learning models in predicting a specific case study, e.g. 2018 cold air outbreak in Europe, 2021 heat wave over the Northwest Pacific

Prerequisites:

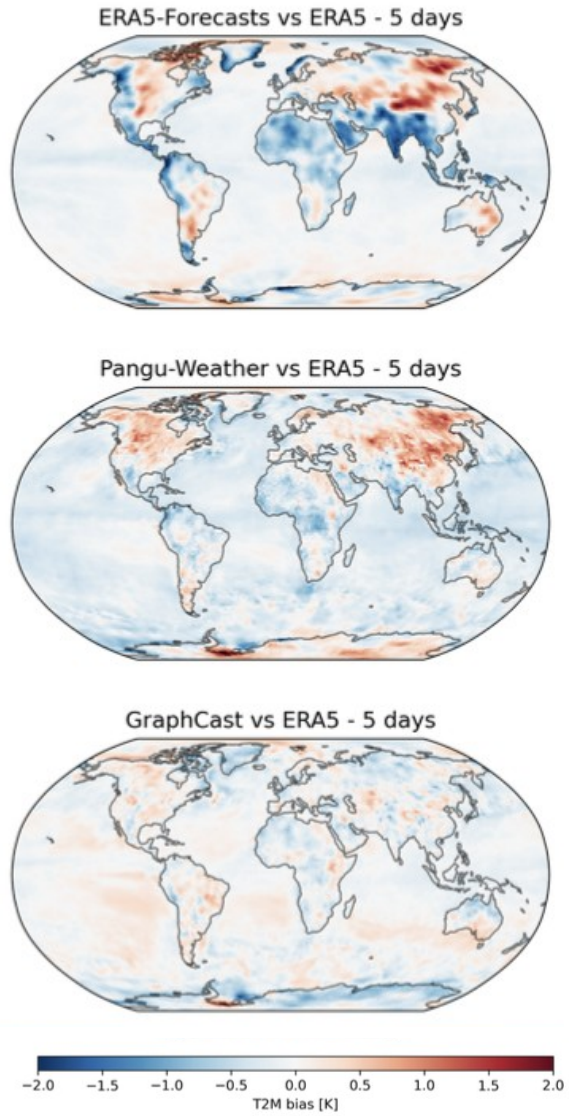
- Interest in atmospheric dynamics, weather forecasting and machine learning methods
- Experience in data analysis and readiness to learn programming

Data:

- Forecast data from machine learning models and dynamical models
- Reanalysis data

Supervision:

- Dr. Rachel Wu, Dr. Hilla Afargan-Gerstman, Prof. Daniela Domeisen



Dynamical model

Machine learning models

Biases of dynamical model (ERA5-Forecast) and machine learning models (Pangu-Weather and GraphCast) in predicting surface temperature. *(WeatherBench 2, Google research)*

Low-frequency variability in the North Atlantic circulation and coupling with decadal SST variability

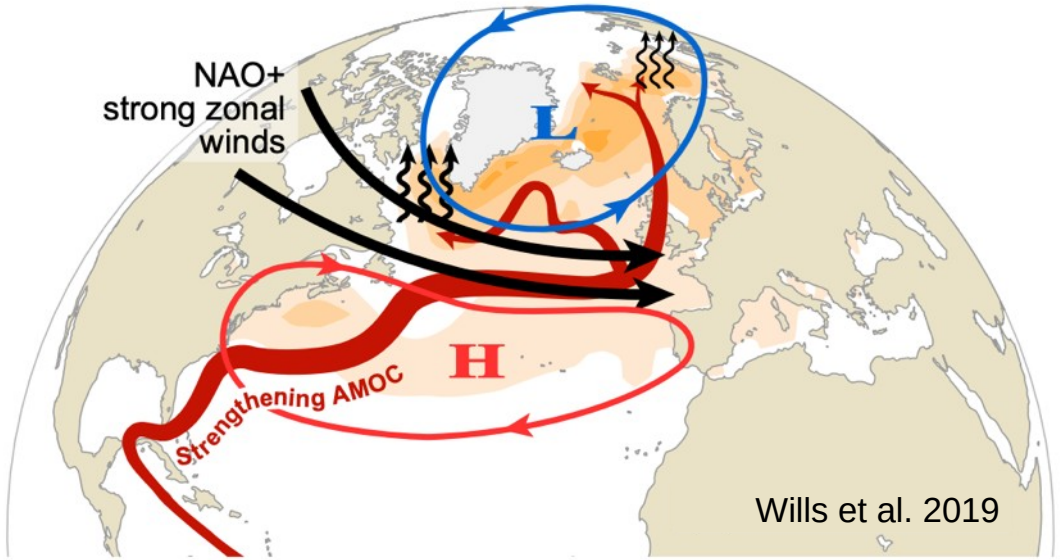
Background:

- Observations show much stronger decadal variability in the jet stream than climate models
- The weak decadal circulation variability in models is hypothesized to result from too weak coupling with sea surface temperature) (SSTs), a problem which might be alleviated in high-resolution models

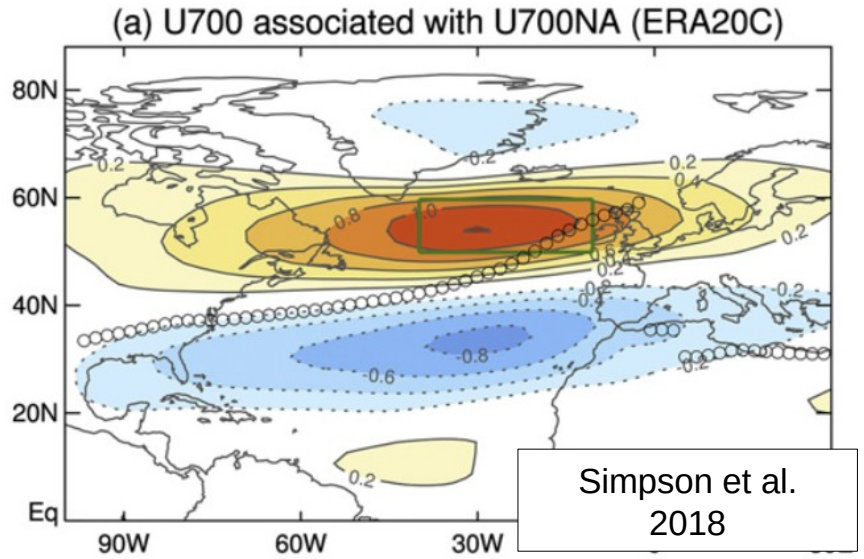
Research questions:

- What are the patterns of decadal atmospheric circulation variability in observations? What are their mechanisms?
- How do the decadal variability patterns and mechanisms differ across observations and high- and low-resolution models?

Approach: Statistical pattern-recognition methods (low-frequency component analysis, maximum covariance analysis) applied to reanalysis and climate model data (Python); lead-lag analysis to give insight into mechanisms and causality (Python)



Wills et al. 2019



Simpson et al. 2018

Supervision: Robb Jnglin Wills, Joas Müller

Mechanisms of decadal variability in the South Pacific

Background:

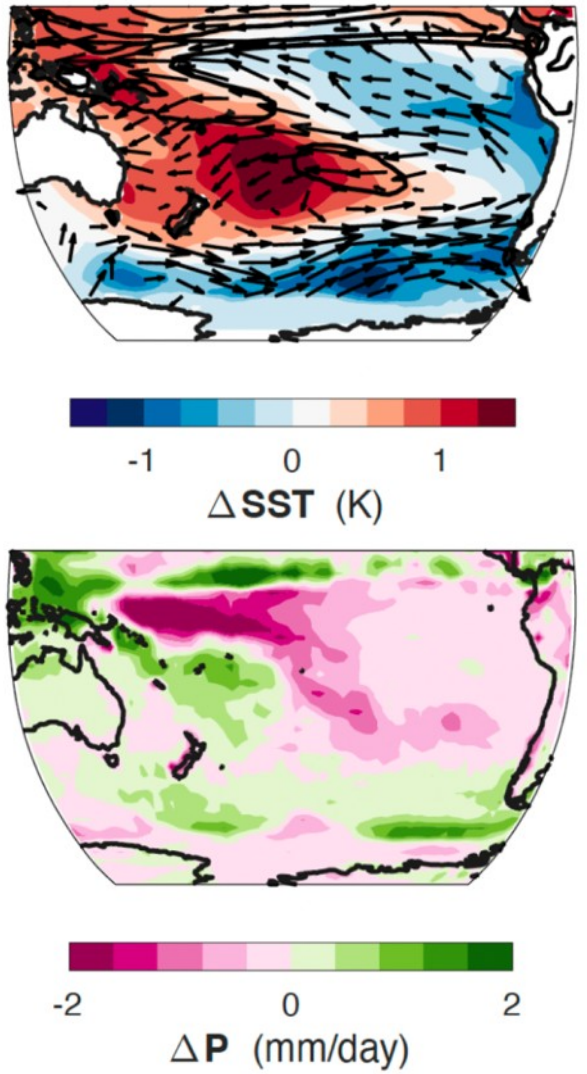
- Decadal sea-surface temperature (SST) variability in the South Pacific is relatively understudied compared to decadal variability in the Northern Hemisphere
- This region is increasingly recognized as playing an important role in trends over the last half century

Research questions:

- What are the mechanisms of South Pacific decadal variability (SPDV) and in particular the role of atmospheric and oceanic processes?
- Are climate models able to represent the observed pattern and mechanisms of SPDV?

Approach: Statistical pattern-recognition methods (low-frequency component analysis) applied to reanalysis and climate model data (Python); lead-lag analysis to give insight into mechanisms and causality (Python)

Austral Winter/Spring Changes (1980-2022)



DiNezio et al., in prep.

Supervision: Robb Jnglin Wills, Zhenghe Xuan

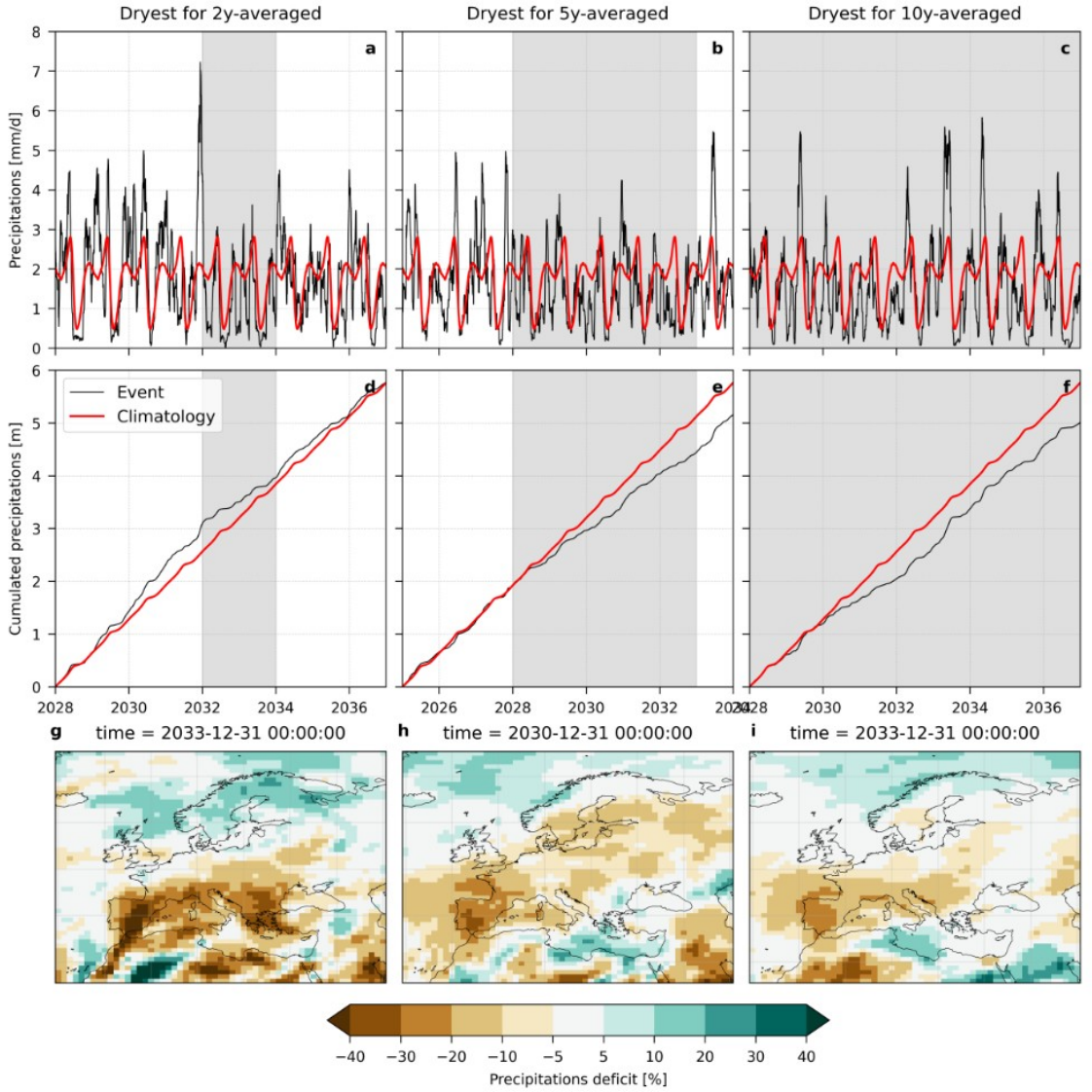
Dynamics of megadroughts in the north of Spain in the CESM2 climate model

Background:
Meteorological droughts are defined as extended periods with lower-than-average precipitations. Megadroughts are droughts which can last several years to several decades and therefore have tremendous impacts on societies and ecosystems. The atmospheric dynamics associated with these events is not well known because they are seldom seen in both real world and climate model simulations. We now have methods to simulate very extreme droughts with climate models.

Research questions:
- What are the synoptic conditions associated with megadroughts?
- What are the atmospheric mechanisms associated with low and very low precipitations?

Methods:
- Outputs of the CESM2 climate model
- Statistical data analysis (composites and statistics with Python)
- Lagrangian trajectory tracking

Supervision: Robin Noyelle (robin.noyelle@env.ethz.ch) & ...



Investigating heat extremes over the ocean

Background:

Heat extremes over land are an active field in research. However, heat extremes over the ocean remain understudied compared to those over land. Therefore, we want to better understand heat extremes over the ocean by investigating what processes lead to heat extremes.

Goal of this thesis:

- How do heat extremes develop over the ocean?
- What processes lead to extreme heat within the vertical profile?
- What role do sea-surface temperatures play in heat extremes?

Dataset and methods:

- Case studies of heat extremes (e.g., western North Atlantic, North Sea, …) using reanalysis data (ERA5)
- Create synoptic weather charts, vertical cross-sections, time series
- Calculate trajectories to determine the underlying processes leading to these heat extremes.

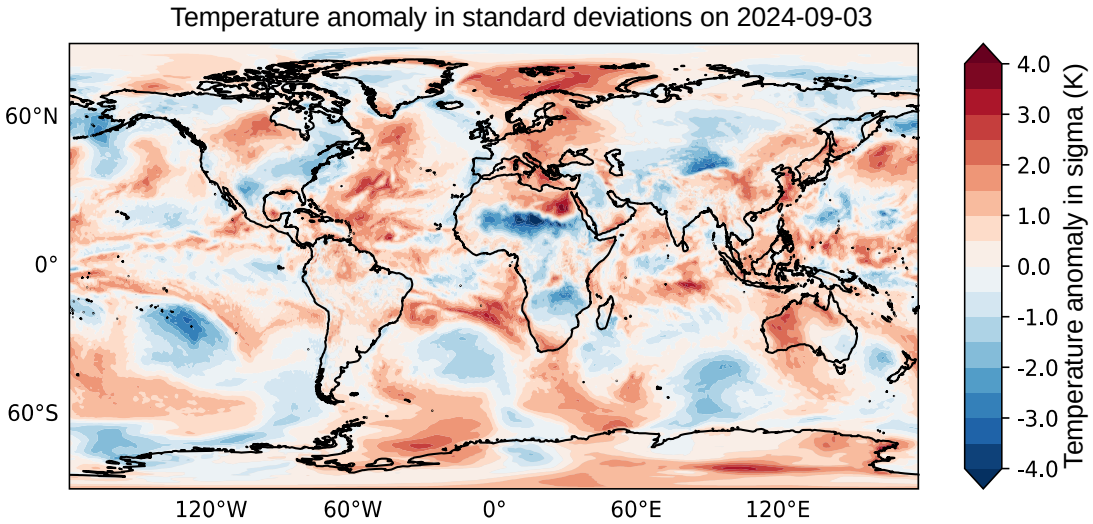


Figure: Global temperature anomalies in standard deviations from the mean on 3. September 2024 reveals large temperature anomalies above the ocean along the east coast of North America.

Supervision and contact:

Belinda Hotz (belinda.hotz@env.ethz.ch),

Robin Noyelle (robin.noyelle@env.ethz.ch)

Investigating heat extremes in a tropical and desert regions

Background:

While heat extremes over extra-tropical land are an active field in research, heat extremes in tropical and subtropical regions remain understudied. Therefore, a case study could lead to a better understanding of heat extremes in tropical and desert regions by investigating the processes behind heat extremes.

Goal of this thesis:

- How do heat extremes develop in the desert and the tropics?
- What processes lead to extreme heat within the vertical profile?

Dataset and methods:

- Case studies of heat extremes, for example, in the Saharan desert, Atacama desert, Monsoon region in India (e.g., Delhi), tropical rainforest (e.g., Manaus) or tropical island (e.g., Galápagos Islands) using reanalysis data (ERA5)
- Create synoptic weather charts, vertical cross-sections, time series
- Calculate trajectories to determine the underlying processes leading to these heat extremes

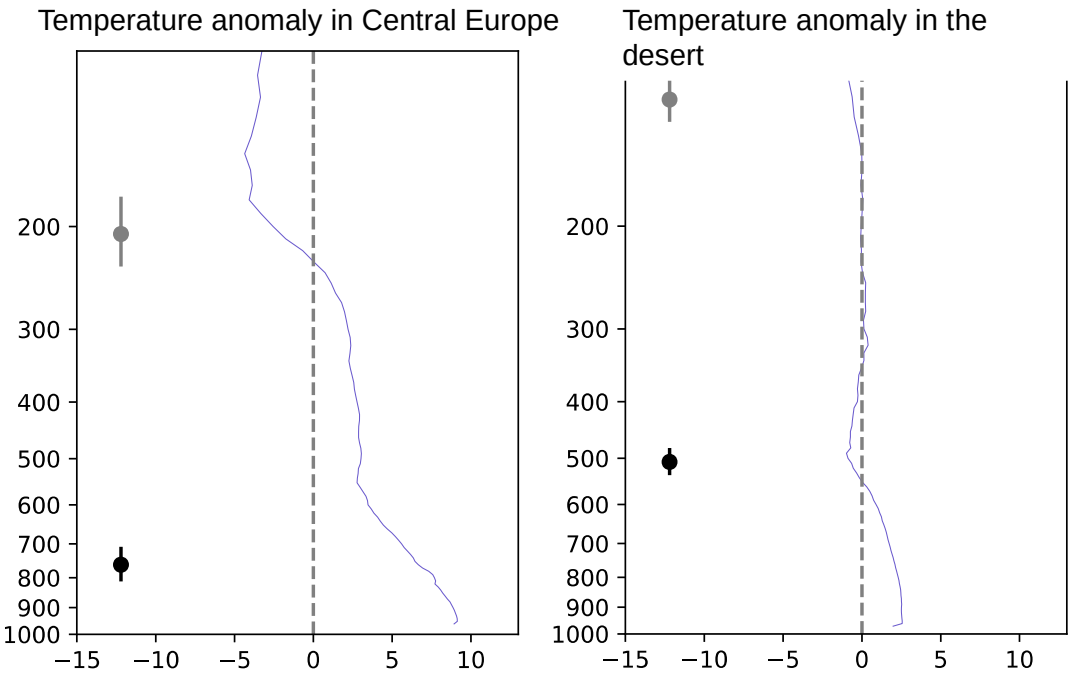


Figure: Temperature anomaly during the annual maximum temperatures on an extratropical (left) and desert (right) grid point over land.

Supervision and contact:

Belinda Hotz (belinda.hotz@env.ethz.ch),

Robin Noyelle (robin.noyelle@env.ethz.ch)

Investigating the aspect ratio between the vertical and horizontal extent of heat extremes

Background:

The temperature anomalies during heat extremes, defined as the warmest day of the year, extend up to the tropopause in extratropical regions, whereas heat extremes in the subtropics are shallower. Therefore, we wonder whether subtropical heat extremes have a smaller horizontal extent than those in the extratropics.

Goal of this thesis:

- What is the vertical and horizontal extent of heat extremes in the extra-tropics?
- How do the extents compare between extratropical and tropical regions?
- Is there an aspect ratio between heat extremes' vertical and horizontal extent?

Dataset and methods:

- Case studies of heat extremes using reanalysis data (ERA5)
- Create horizontal maps on the horizontal extent of temperature anomalies
- Calculate a ratio between the width and height of the temperature anomalies

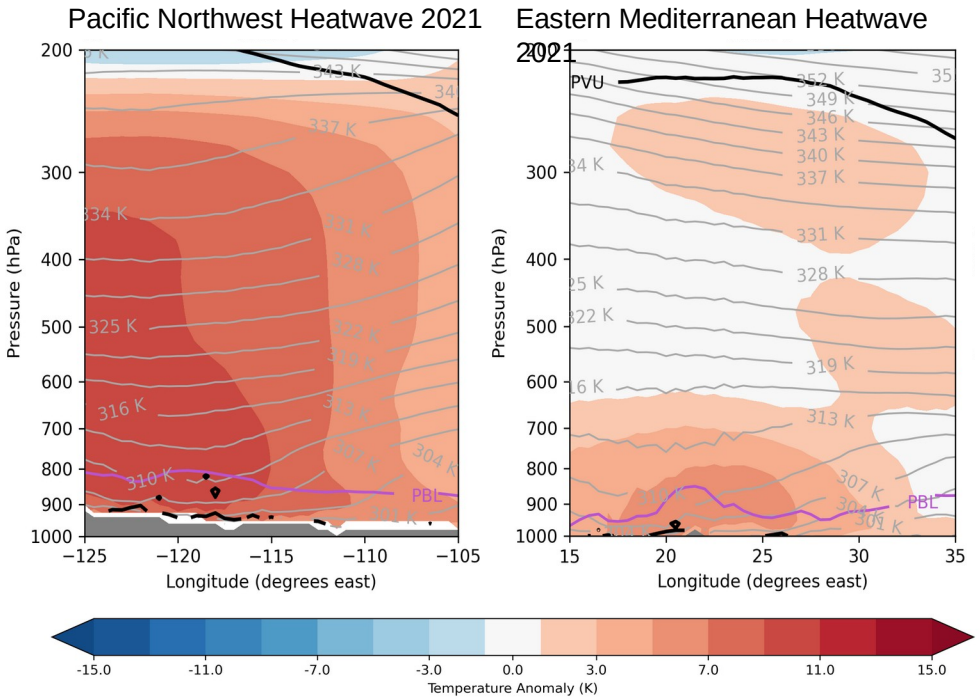


Figure: Vertical extent of temperature anomalies during heat extremes

Supervision and contact:

Belinda Hotz (belinda.hotz@env.ethz.ch),

Robin Noyelle (robin.noyelle@env.ethz.ch)

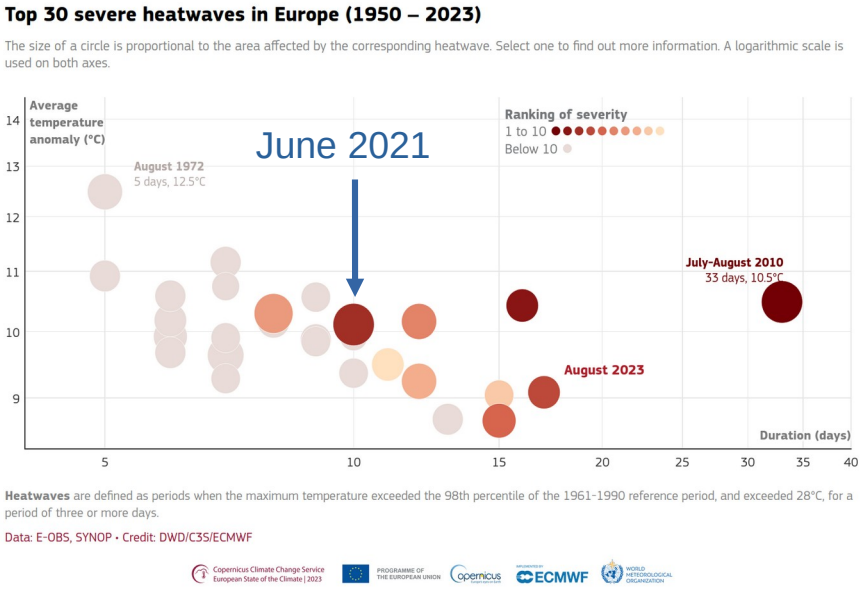
June 2021 heatwave and large hail

Background

Large hail events have a strong impact on infrastructure and agriculture. During the June 2021 heatwave, large hail events occurred continuously over various parts of Europe. We want to understand how this severe heat wave affected hail formation.

Research questions

- How well is the June 2021 heatwave represented in the climate simulation with respect to temperature extremes and hail occurrence?
- Where did hail occur?
- How was hail formation related to the heatwave evolution?

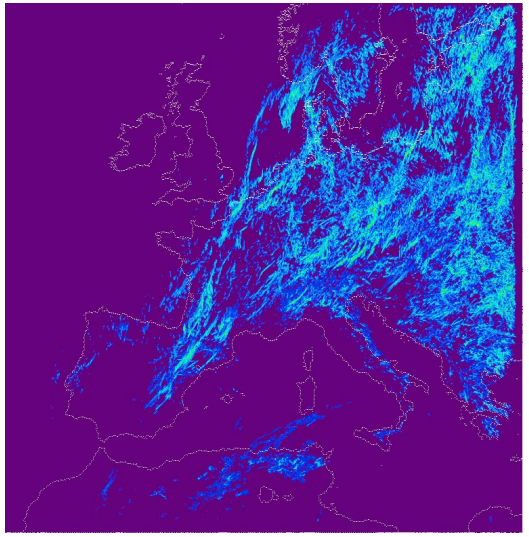


Data sets

- COSMO high-resolution climate simulation
- Crowd-sourced hail reports
- Radar-based hail estimates
- E-OBS surface temperature observations

Supervision

Iris Thurnherr (iris.thurnherr@env.ethz.ch)
Ellina Agayar (ellina.agayar@env.ethz.ch)



Simulated hail streaks in COSMO from 18. – 30. June 2021

Comparing cyclones associated with short and long duration extremes in the Eastern US

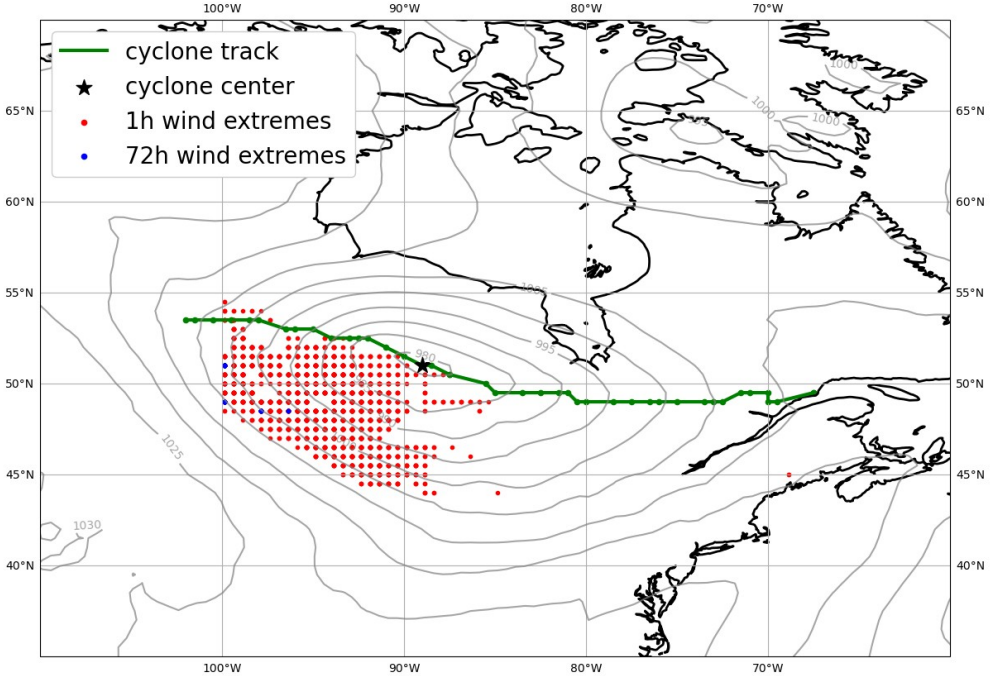
Extratropical cyclones are in most parts of the extratropics the main weather system responsible for extreme surface winds and precipitation. By evaluating the number of these extremes along different cyclone tracks, the most extreme cyclones according to this dimension of extremeness can be identified.
As wind and precipitation extremes of different time scales may have different impacts, the aim of this project is to compare cyclones associated with many long duration extremes with cyclones causing many short duration extremes.

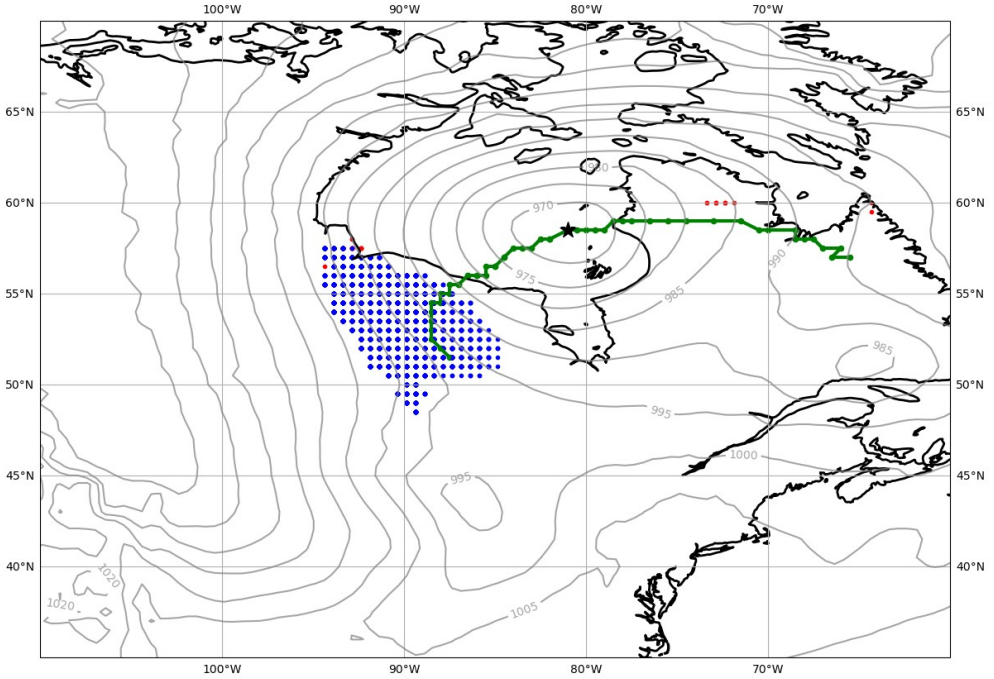
Approach:
Case studies of 2-3 cyclones per duration category(1h & 72h): Analyze the weather conditions associated with extreme cyclones, focusing on either wind or precipitation, using ERA5 reanalysis data

Research questions:
How do the synoptic conditions differ between the duration extremes?

Are extremes of different durations in the eastern US caused by “different types” of cyclones?

Supervision:
Sven Voigt (sven.voigt@env.ethz.ch), NN





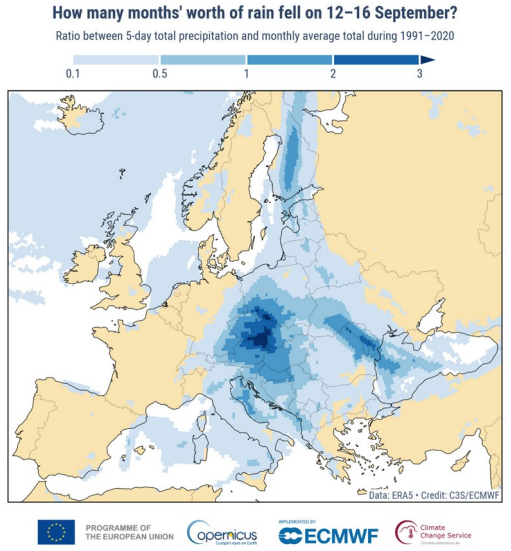
Dynamics of analogues of storm Boris in the CESM1 climate model

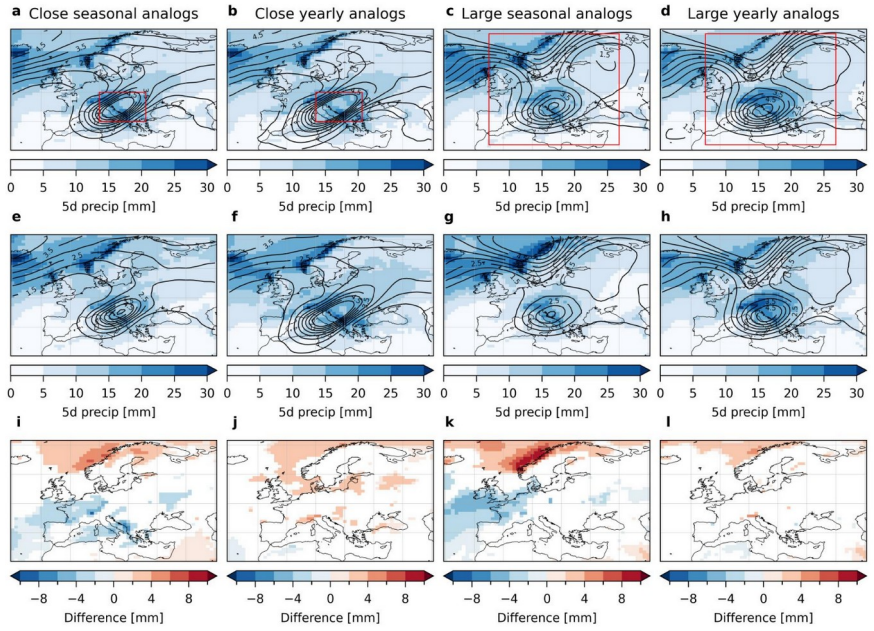
Background:
In September 2024, storm Boris brought record-breaking rainfall over central and eastern Europe, leading to devastating floods. Storm Boris was associated with a high-level cut-off low centered above central Europe. It is not clear whether climate models can simulate these kind of events and whether climate change impacts their dynamics.

Research questions:
- Do the circulation analogues for storm Boris in the model have the same dynamics as the event?
- Is there a dynamical change in the analogues of the storm between the present climate and a future climate in the model?

Methods:
- Analogues of circulation using both PV and Z500
- Statistical data analysis (composites and statistics with Python)
- Tracking of cyclones and cut-off lows

Supervision: Robin Noyelle (robin.noyelle@env.ethz.ch) & ...



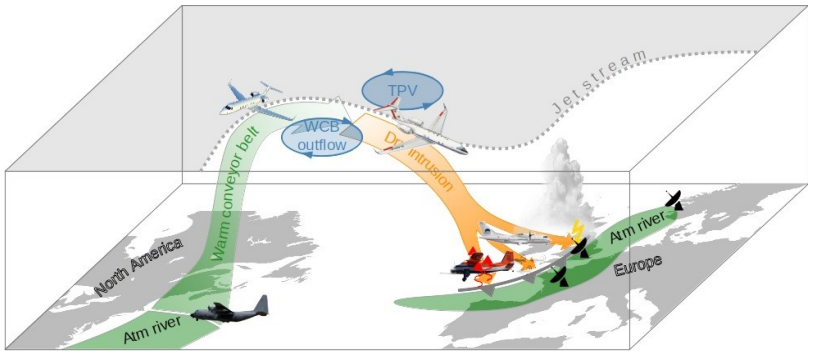


The influence of dry intrusions on boundary layer processes: a $COSMO_{iso}$ case study

Background

Dry intrusions are dry air streams that descend behind the cold front from the upper troposphere towards surface affecting boundary layer moisture and mixing. As preparation for the upcoming research campaign NAWDIC (*North Atlantic Waveguide, Dry Intrusion, and Downstream Impact Campaign*), we want to study the following research questions:

- What is the vertical structure of the water vapour isotope composition during dry intrusions?
- What is the role of clouds at the boundary layer top for the water vapour isotope composition?
- How does the vertical isotopic structure change during the case study?



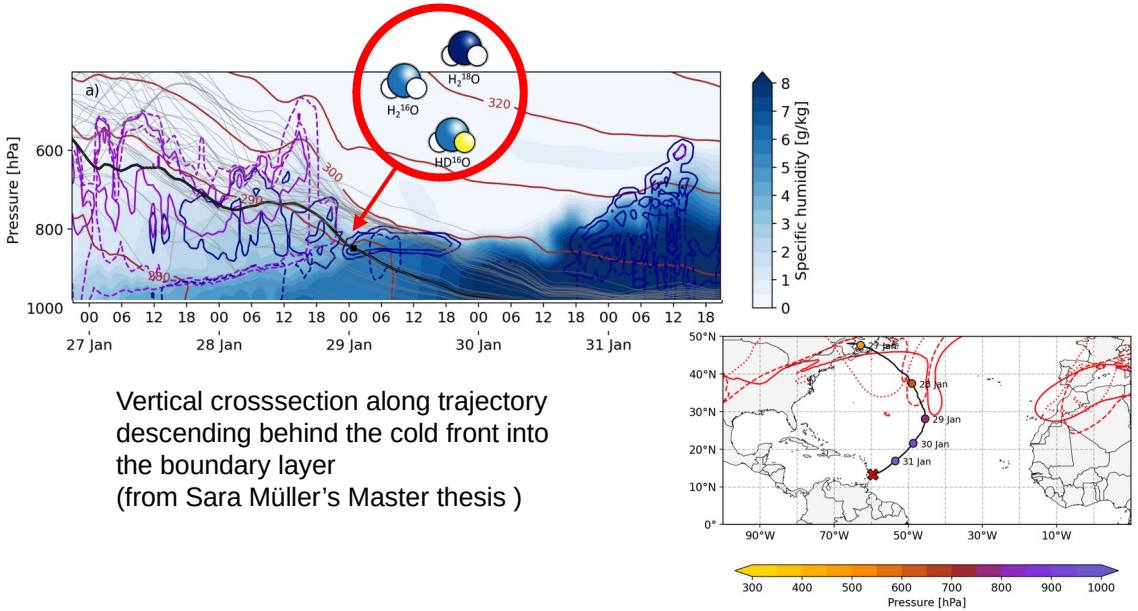
Idealized schematic showing the potential deployment of research aircraft and ground-based observational facilities during NAWDIC. (from https://www.nawdic.kit.edu/)

Data set

Output from a simulation over the North Atlantic using $COSMO_{iso}$, an isotope-enabled numerical weather prediction model

Contact

Iris Thurnherr (iris.thurnherr@env.ethz.ch)
Franziska Aemisegger (franziska.aemisegger@unibe.ch)
Shira Raveh-Rubin (shira.raveh-rubin@weizmann.ac.il)



Vertical crosssection along trajectory descending behind the cold front into the boundary layer
(from Sara Müller's Master thesis)

Sensitivity of a WCB in an idealized cyclone to resolution

Background:
Warm conveyor belts (WCBs) are coherent airstreams in extratropical cyclones that ascend from the planetary boundary layer in the cyclone's warm sector to the upper troposphere within about two days. They are the primary cloud and precipitation-producing flow in extratropical cyclones and the diabatic processes during the WCB ascent influence the dynamics of extratropical cyclones. In numerical weather prediction models, the accurate representation of WCBs is crucial for the quality of the forecasts.

Research questions:

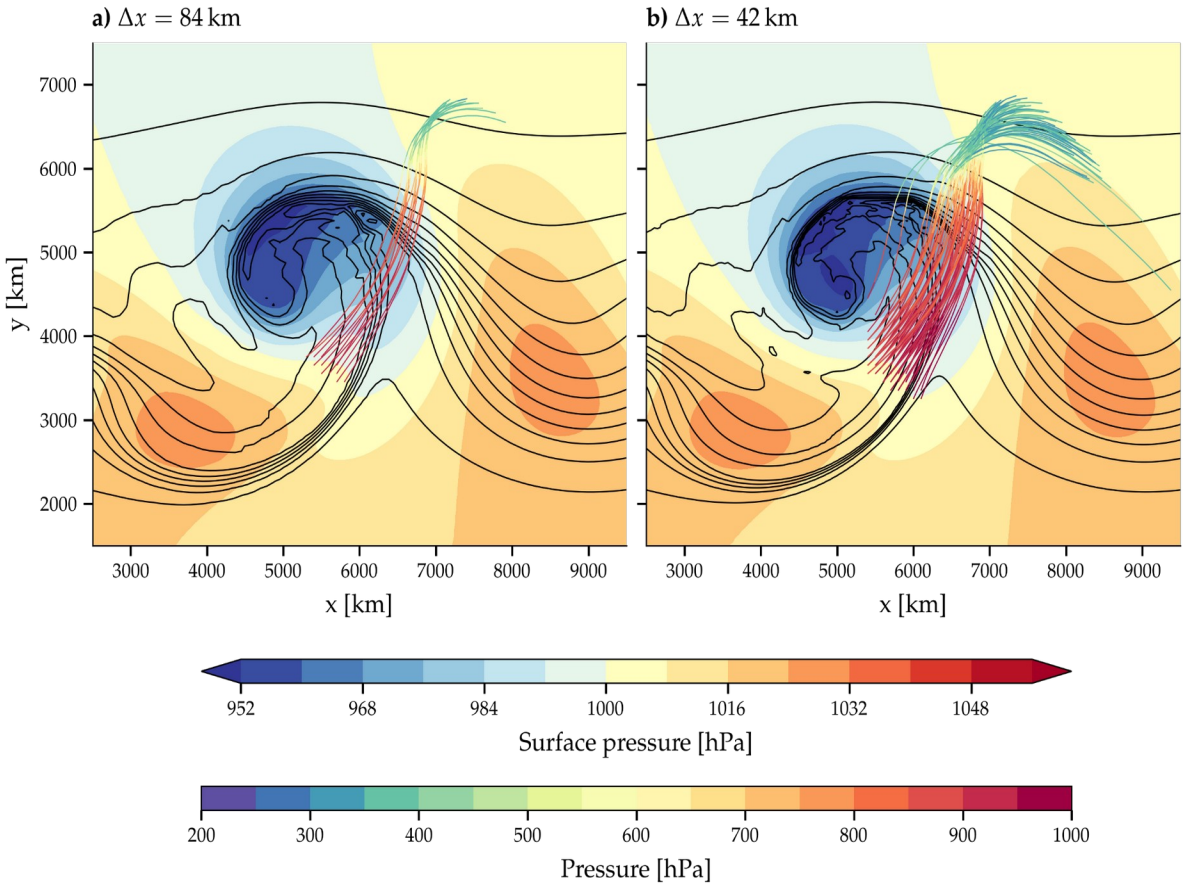
- How does the representation of the WCB in an idealized cyclone change with model resolution?
- What is the role of high-resolution vs. low-resolution input data for the WCB trajectory calculation?

Methods:

- Calculation of trajectories in different simulations and datasets (e.g., coarse-grained)
- Selection and analysis of WCB trajectories.

Prerequisites:

- Interest in application of trajectory calculations
- Interest in (idealized) synoptic meteorology



Representation of a WCB in two idealized cyclone simulation with different horizontal grid spacings (84 km and 42 km). Shown are surface pressure (shading) and contours of surface potential temperature (black lines) at day 4 as well as WCB trajectories starting at day 3 (coloured lines).

Supervision: Nicolai Krieger (nicolai.krieger@env.ethz.ch) & N.N

How cyclones influence WCB interaction with the Rossby waveguide

Description:
The position of WCB outflow is crucial in deciding the intensity of its interaction with the Rossby waveguide. The WCB outflow (dots) and its interactions (color) are shown in the figure.
However, the cyclone properties associated with the different interaction types are yet to be studied. The goal of this thesis is to investigate how the cyclone properties influence the WCB properties and thereby its interaction with the Rossby waveguide.

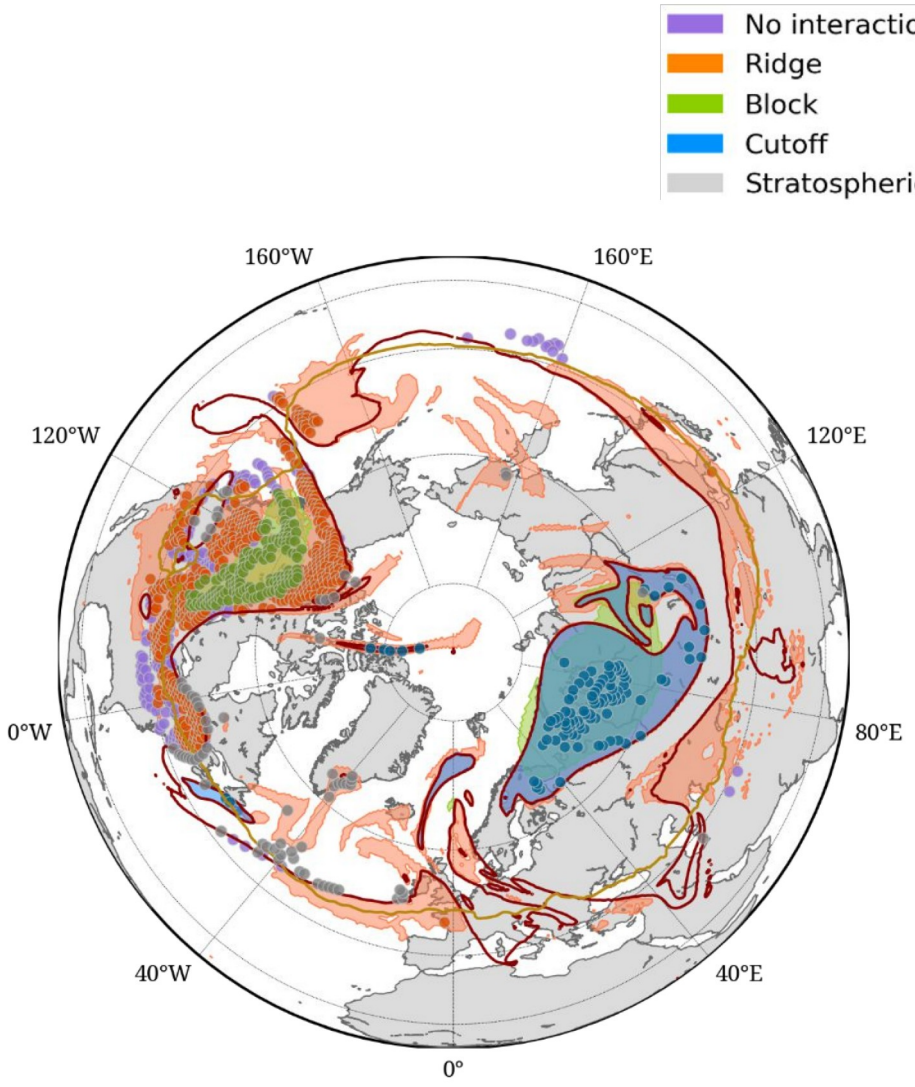
Research questions:

- How does the cyclone propagation direction influence the WCB outflow position?
- Does the cyclone's properties (such as intensity and deepening rate) differ across the different interactions types?

Data: Cyclone tracks and WCB interactions events identified using ERA5 reanalysis data

Methods: Case study and composite analysis using Python or Matlab

Supervision:
Vishnu Selvakumar (vishnupriya.selvakumar@env.ethz.ch)
Michael Sprenger (michael.sprenger@env.ethz.ch)



How dangerous is foehn for the Appenzeller Bahnen?

Background:
In the narrow Schwende valley, **extreme gusts** perpendicular to the valley axis can occur under north-westerly ambient wind conditions. These south-easterly winds are known as the **Laseyer** and are **dangerous for the Appenzeller Bahnen** (AB, the local train). Additionally, southerly winds at Wasserauen can occur during ambient southerly winds (typically foehn conditions). The aim of the BSc thesis is to investigate whether these foehn winds also pose a risk to AB.

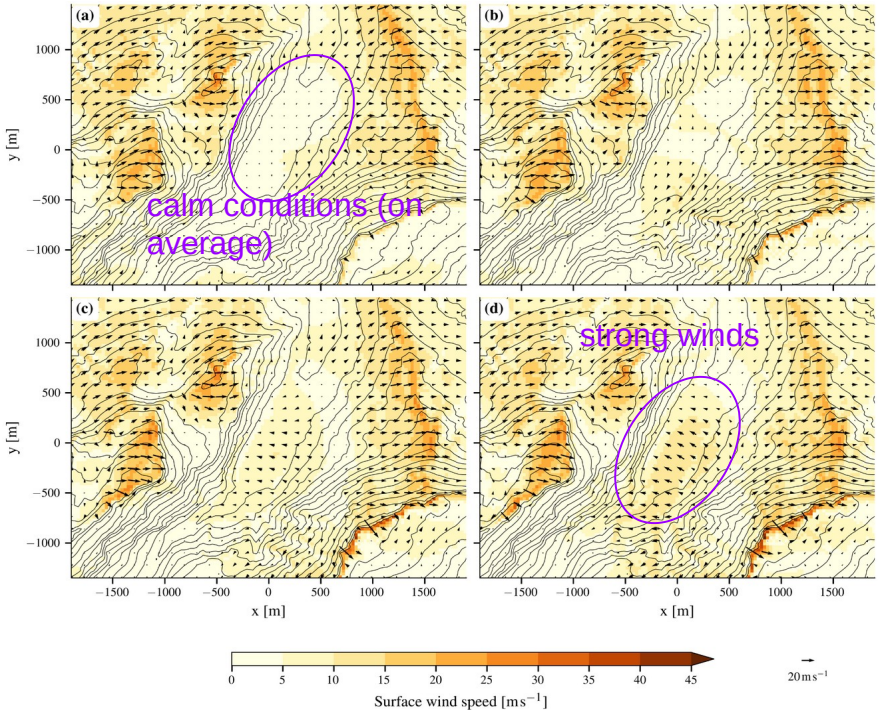
Research questions:
- Under which ambient conditions do strong winds occur in the narrow Schwende valley?
- Are there ambient conditions that lead to extreme gusts perpendicular to the train?

Methods:
- Investigation of measurement data and a set of idealized high-resolution large-eddy simulations (LES).

Prerequisites:
- Interest in mountain meteorology and local phenomena
- Interest in idealized investigations

Supervision: Nicolai Krieger (nicolai.krieger@env.ethz.ch) & Michael Sprenger

Sensitivity of the mean surface wind in the Schwende valley to westerly ambient winds with wind directions of (a) 270°, (b) 275°, (c) 280°, and (d) 285°. The black lines indicate the height of the topography (interval is 50m).



The Great Smog of London in January1952

*The **Great Smog of London,** or Great Smog of 1952, was a **severe air pollution** event that affected London, England, in December 1952. A period of **unusually cold weather, combined with an anticyclone and windless conditions**, collected airborne pollutants—mostly arising from the use of coal—to form a thick layer of smog over the city. It lasted from Friday 5 December to Tuesday 9 December 1952, then **dispersed quickly when the weather changed**.*

*The smog caused major disruption by **reducing visibility and even penetrating indoor areas**, far more severely than in previous smog events, called "pea-soupers". [...] Recent research suggests that the total number of fatalities was considerably greater, with estimates of **between 10,000 and 12,000 deaths**.*

Wikipedia

Research Questions:

- How did the synoptic (anticyclone) and mesoscale situation evolve?
- What was the vertical structure of the atmosphere? Inversions?
- What flow situation finally dispersed the smog? Where did the smog go to?
- How does the January 1952 compare to other years? How extreme was the anticyclone?

Datasets and Methods:

- ERA5 reanalysis (hourly, 0.5 latitude/longitude grid, 137 vertical levels)
- Create synoptic weather charts, vertical cross sections, time series,...
- Calculate trajectories to determine the trapping of air masses over London?

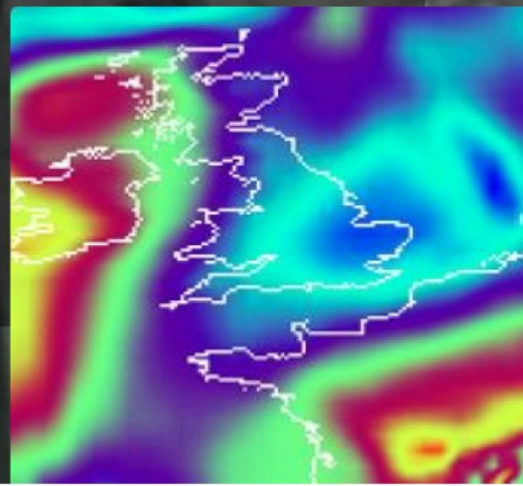
Prerequisites:

- interest in synoptic meteorology as the driver for the Great Smog
- interest in the historical context

Supervision:

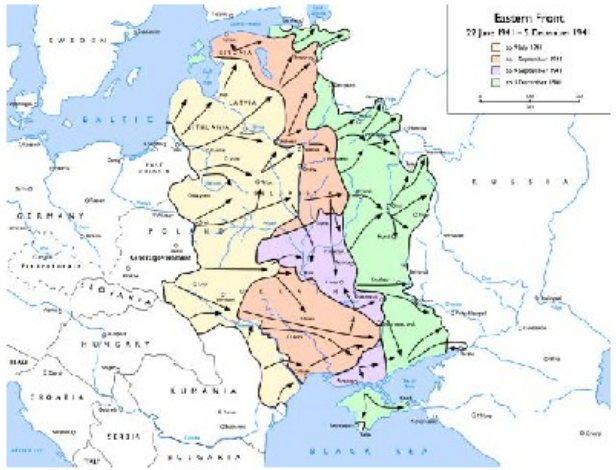
- Michael Sprenger (michael.sprenger@env.ethz.ch)
- NN

ERA5 VEL @ 850 hPa



The Battle of Moscow – How Weather changed the Course of WWII

*"The **Battle of Moscow** started in early **winter of 1941**, and was over just a few short weeks later. Hitler ordered troops to march into the area under-prepared, under-dressed and under-fed for the brutal winter that was before them. The **winter would become the worst in over 140 years**, with the December temperatures reaching around **negative 24 degrees Celsius** according to German Daily Weather archives. As winter went on, the Soviet troops kept going further and further back into their Siberian territory, drawing the Germans further away from their supplies, leading to many deaths and turned into what would be the **beginning of the end for Nazi Germany**."*



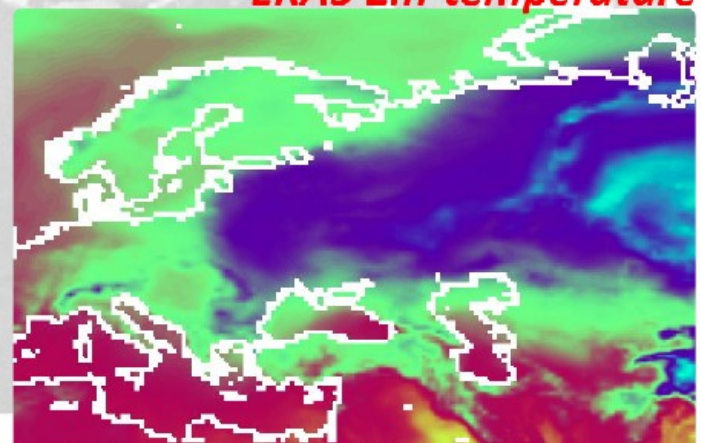
Research Questions:
- How extreme was the temperature in winter 1941/42?
- How did the temperature evolve from October 1941 until January 1942
- What was the synoptic and mesoscale meteorology leading to the extreme temperatures?
- How does the winter 1941/42 compare to other winters?

Datasets and Methods:
- ERA5 reanalysis (hourly, 0.5 latitude/longitude grid, 137 vertical levels)
- Create synoptic weather charts, vertical cross sections, time series,…
- Calculate trajectories to determine the origin of the cold air masses

Prerequisites:
- interest in synoptic meteorology as the driver for the extreme winter
- interest in the historical context

Supervision:
- Michael Sprenger (michael.sprenger@env.ethz.ch)
- NN

ERA5 2m-temperature



Flight Path Analysis for the Swiss H_2O Hub Project

Motivation

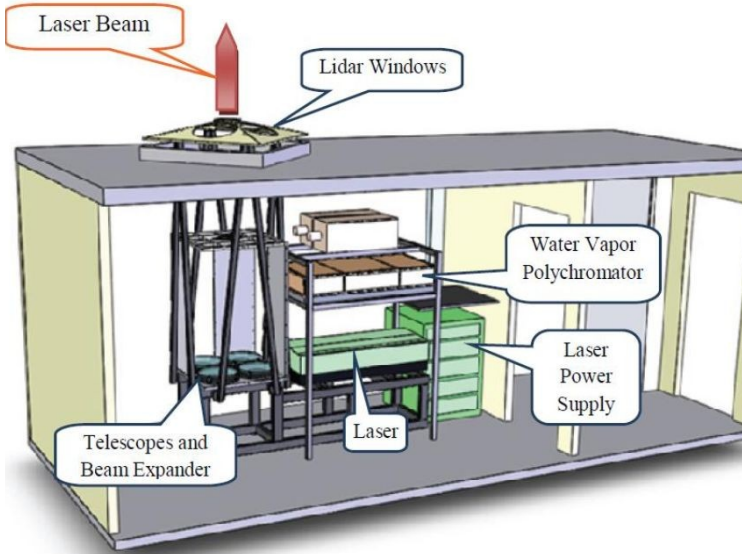
The Swiss H_2O project aims to compare different measurement techniques for atmospheric water vapor – on (separate) balloons or remote sensing

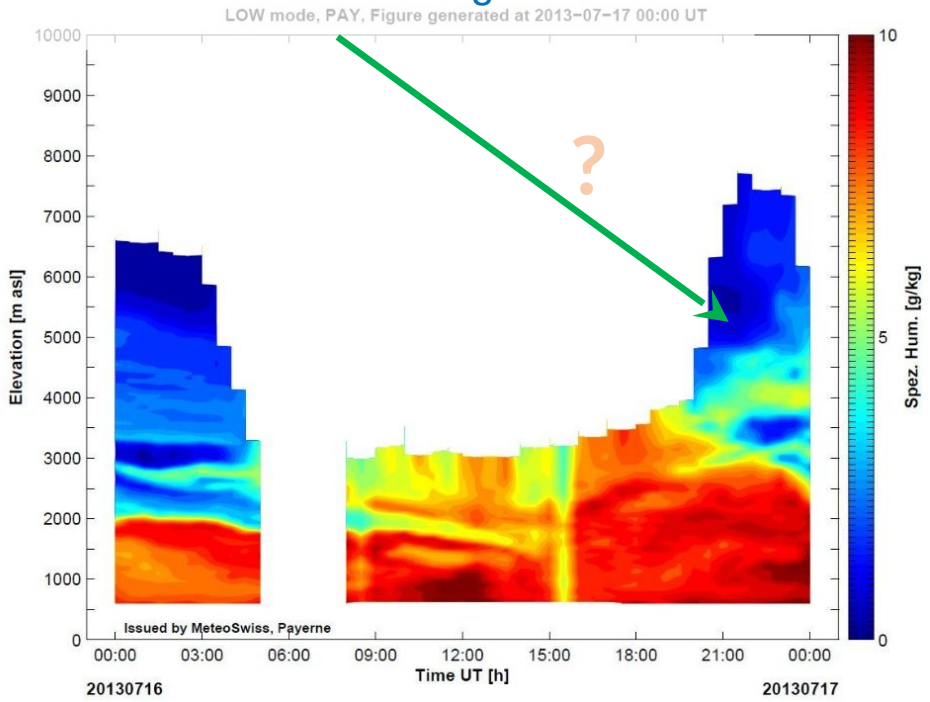
Research Questions

- How can the overlap of the origin region between different measurements be quantified?
- What is the adequate time slice for the remote sensing instruments to match the flight track?

Method

- characterize the measurement source region by LAGRANTO backward trajectories
- define an overlap criterion based on ECMWF (ensemble) model data
- quantify the overlap extent and deliver the remote sensing instrument match time





Prerequisites

- interest in application of trajectory calculations
- motivation to collaborate with external partners (MeteoSchweiz, Empa)

Supervision:

Frank Wienhold, Hanin Binder, and Michael Sprenger

https://www.meteoschweiz.admin.ch/wetter/messsysteme/atmosphaere/lidar-und-

Atmospheric deposition of volatile ^{129}I emissions from nuclear reprocessing plants to the Mediterranean Sea

Background

Nuclear reprocessing plants release known amounts of the artificial radionuclide ^{129}I to both the ocean (as liquid releases) and to the atmosphere (as gaseous releases). To study the fate of atmospheric ^{129}I, a Lagrangian case study of ^{129}I transport and wet deposition from the European reprocessing plants La Hague and Sellafield will be calculated. A diagnostic will be used to identify the moisture transport and loss along the trajectories using changes in specific humidity.

Research questions

- How far is ^{129}I transported in the atmosphere?
- How does the moisture loss diagnostic compared to precipitation patterns along the trajectory

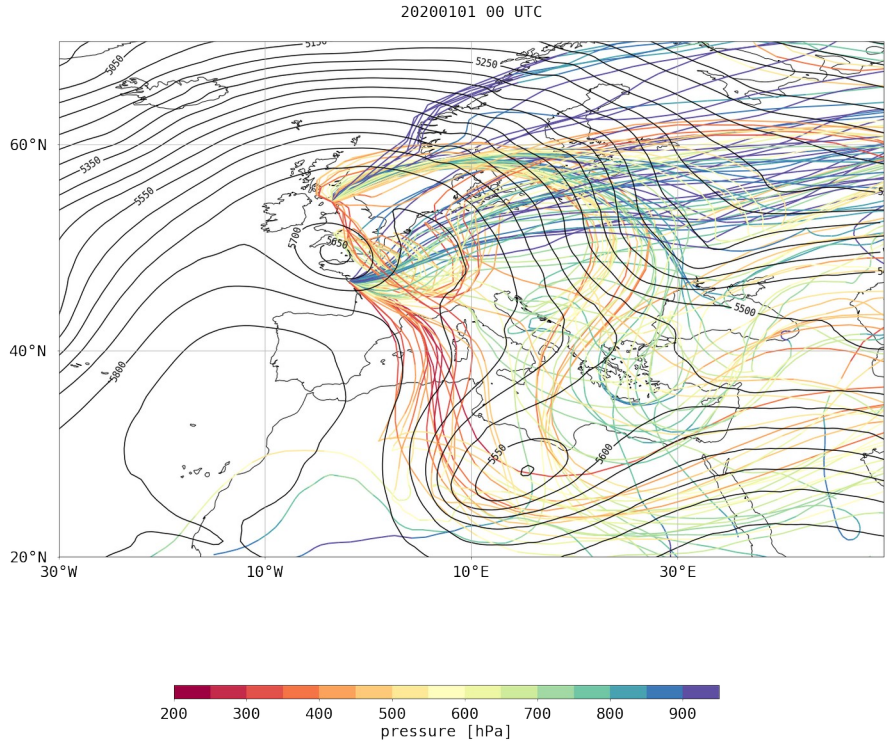
Methods

- Analysis of air parcel trajectories calculated with the LAGRANTO tool (Sprenger & Wernli, 2015)
- Moisture “loss” diagnostic (based on Sodemann et al., 2008)

Prerequisites

- Interest into Lagrangian perspective of moisture transport and technical topic

Figure: Forward trajectories released from the location of La Hague and Sellafield at 0 UTC 01/01/2020



Supervision

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- Nuria Casacuberta Arola (nuria.casacubertaarola@usys.ethz.ch)
- Lorenza Raimondi (lorenza.raimondi@usys.ethz.ch)

Further topics for Bachelor thesis projects

You can also contact other groups at IAC

- Ulrike Lohmann (Atmospheric Physics)
- Sonia Seneviratne (Land-Atmosphere Interactions)
- Reto Knutti (Climate Physics)
- Colette Heald (Atmospheric Chemistry)
- Andreas Prein (High-resolution weather and climate modeling)
- Manuela Brunner (Hydrology and Climate Impacts)
- Claudia Mohr (Aerosol Chemistry)

Next steps

1) Ask more questions about the projects (please just contact the supervisors)

2) Send an Email to iris.thurnherr@env.ethz.ch until Fri 29 November if you would like to work on one of these projects with the following information:

   - department
   - possible start date of your project
   - preference for up to 3 topics
   - short statement why you are interested in each of these topics
   - relevant lecture courses you are visiting

3) The supervisors will then discuss and do their best to find a good and fair distribution of the topics