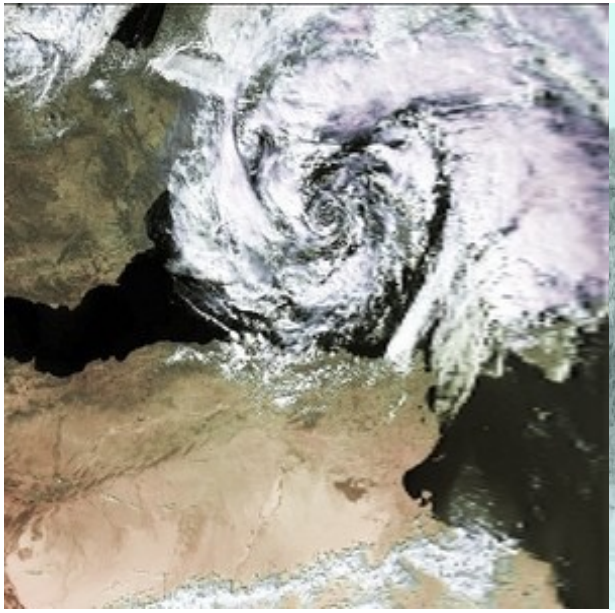
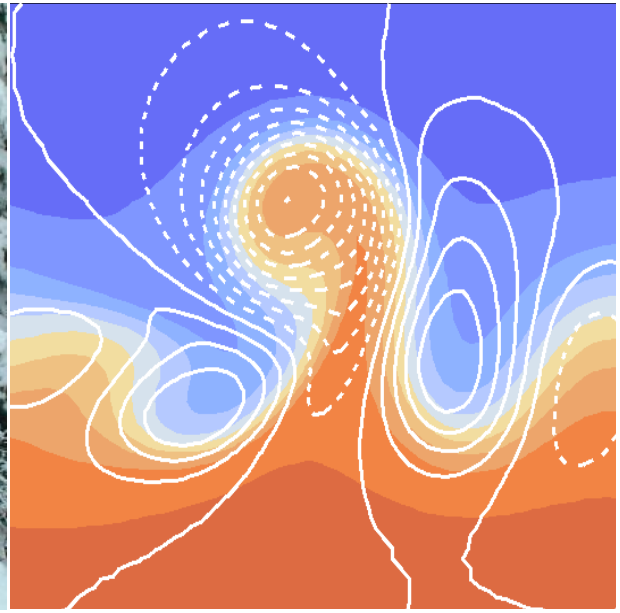
Atmospheric Dynamics Groups

Domeisen - Jnglin Wills - Schemm - Wernli

Bachelor Thesis Topics for 2024





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 2024 – please let us know if you like to do your project later (e.g., in summer or autumn 2024)

We strongly recommend a good time planning such that you can finish your project until about June/July 2024

Today, we offer 12 topics from 4 research groups (led by Daniela Domeisen, Sebastian Schemm, Robb Jnglin Wills, and Heini Wernli).

Research topics

Domeisen

1) Sub-seasonal predictability of the 2022 European heatwave
2) Forecasting rain in the Sahara

Jnglin Wills

3) Modification of midlatitude storms by Gulf Stream SSTs
4) Monsoon trends in high- and low-resolution simulations

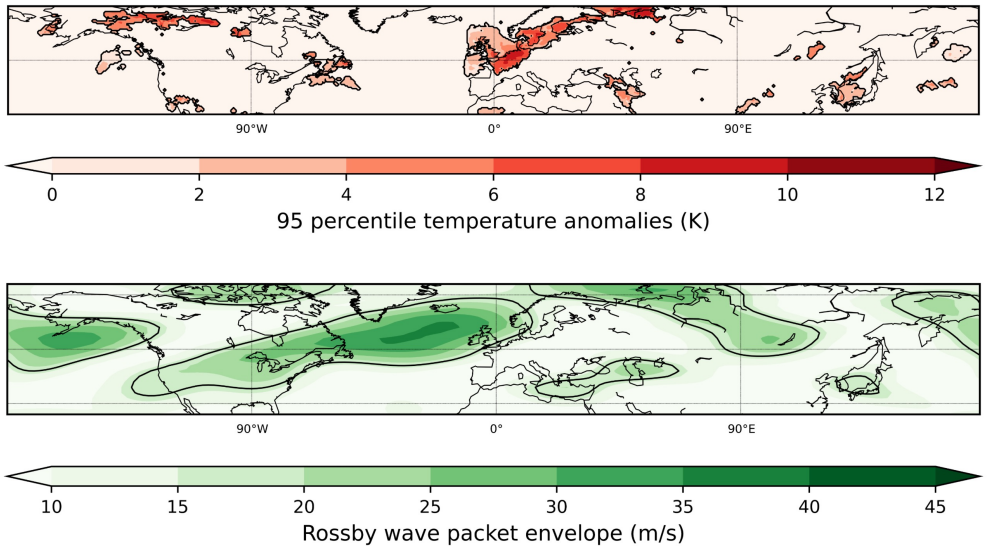
Schemm

5) Poleward energy transport in future climate
6) Mid-winter suppression of North Atlantic storm track

Wernli

7) Balloon flight planning support tool
8) The Battle of Moscow – How Weather changed the Course of WWII
9) Characterizing clear air turbulence
10) Water vapour isotope signature of BCARs
11) Heavy precipitation events in the Taklamakan
12) Idealized high-resolution simulations of cyclones and WCBs

Sub-seasonal predictability of the 2022 European heatwave: relation to local and remote physical mechanisms



Goals:

1. **Quantify the predictability** of the 2022 European heatwave in the ECMWF weather prediction system.
2. **Assess the role of processes** such as *Rossby wave packets, atmospheric blocking, and soil moisture conditions* for the accuracy of prediction.

Tools and Data:

ECMWF sub-seasonal forecasts, ERA5 reanalysis data, diagnostic tools developed in the Atmospheric predictability group and beyond.

Supervision & Contact:

Dr. Maria Pyrina: maria.pyrina@env.ethz.ch

Prof. Dr. Daniela Domeisen: daniela.domeisen@env.ethz.ch

Atmospheric predictability group

Bachelor and master thesis link:

https://iac.ethz.ch/group/atmospheric-predictability/bacherlor-and-master-thesis.html

Forecasting rain in the Sahara more than one week in advance?

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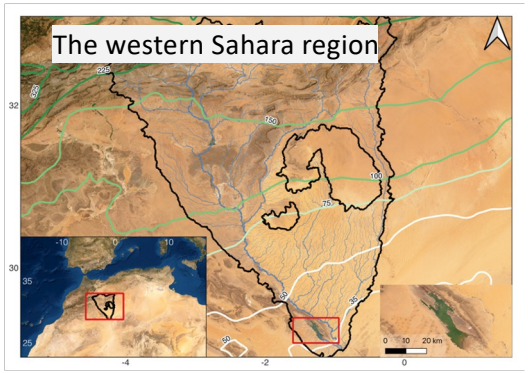
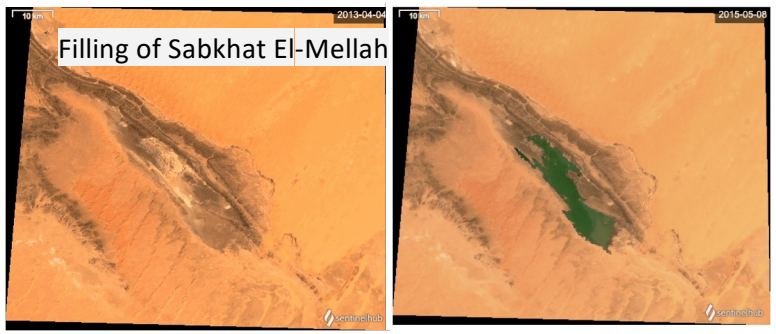
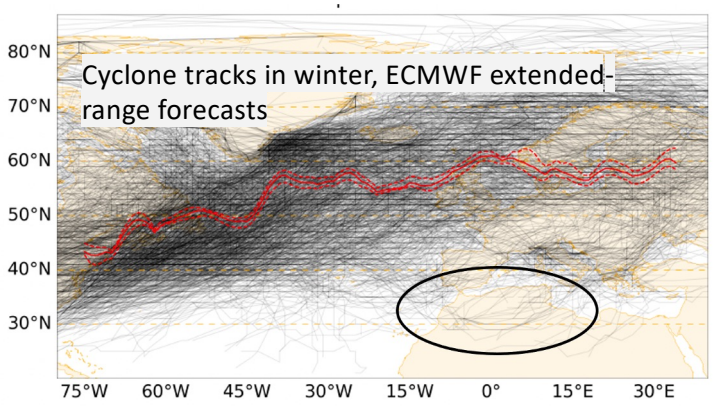


Overall project goal :
Rainfall in the Sahara region can pose a significant challenge for operational models. The project's goal is to analyze storms in the arid Sahara region, and assess their predictability on sub-seasonal timescales (more than one week in advance).



Goal of thesis:
- How well can we predict storms over the Sahara? What is their impact on water availability?
- What are the sources of forecast bias in this region? (e.g., dynamical processes that are not well represented in the models).

Data and Methods:
ECMWF reanalysis and ensemble forecasts (medium-range and extended-range), IMERG satellite-based precipitation estimates.
Methods: statistical data analysis, forecast verification techniques - in either or both **Python** and **Matlab**.



Supervision ➡️ **an opportunity to work with two research groups:**
Hilla Gerstman (ETH IAC, Atmospheric Predictability group)
Moshe (Koko) Armon (ETH IAC, Atmospheric Dynamics group)
Daniela Domeisen (ETH IAC, Atmospheric Predictability group)

Modification of midlatitude storms by Gulf Stream SSTs in simulations with and without resolved weather fronts

Background:

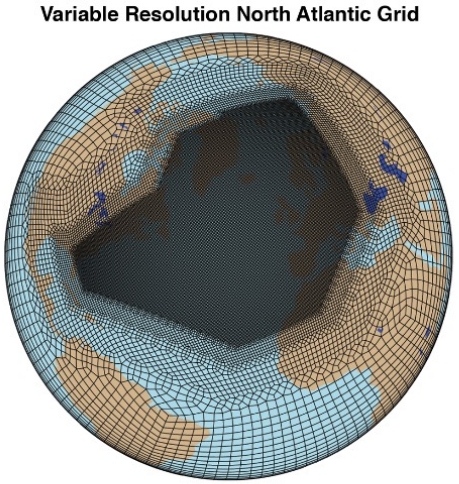
- Global climate models (GCMs) don't resolve frontal processes occurring on ~10-20 km scales
- A storm-resolving model with high-resolution over the North Atlantic shows a larger response (compared to typical GCMs) of the jet stream to Gulf Stream sea-surface temperature (SST) anomalies, due to greater ascent in fronts

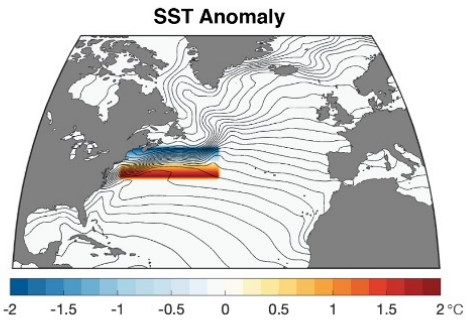
Research questions:

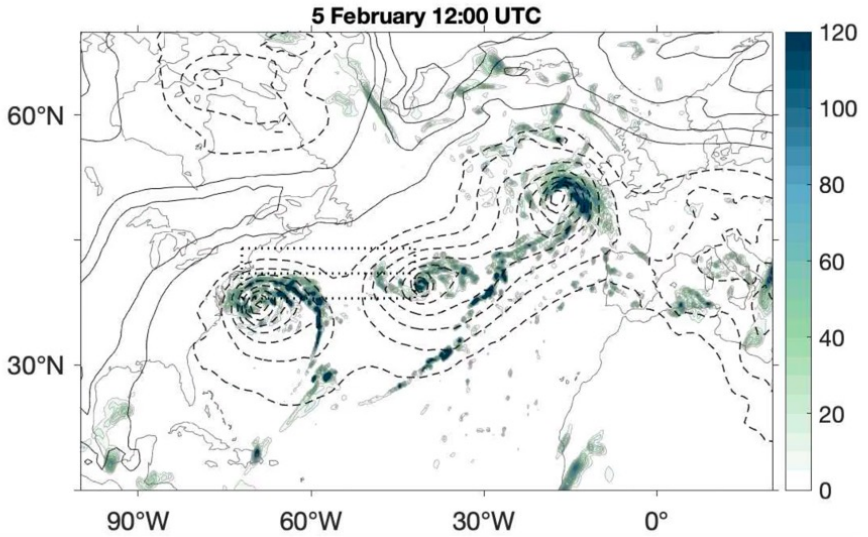
- How are the frequency and trajectories of midlatitude cyclones modified by Gulf Stream SSTs and how does this depend on resolution / whether weather fronts are resolved?
- What are the processes by which these storms shift the mean state (jet stream)?

Data and methods:

- Output from mesoscale-storm-resolving global climate model simulations with CESM2
- Methods: Lagrangian cyclone tracking (bash, Fortran, Python) and composite analysis (Python) of North Atlantic storms







Supervision: Joas Müller, Robb Jnglin Wills, and Michael Sprenger

Assessing monsoon trends in high- and low-resolution simulations

Background:

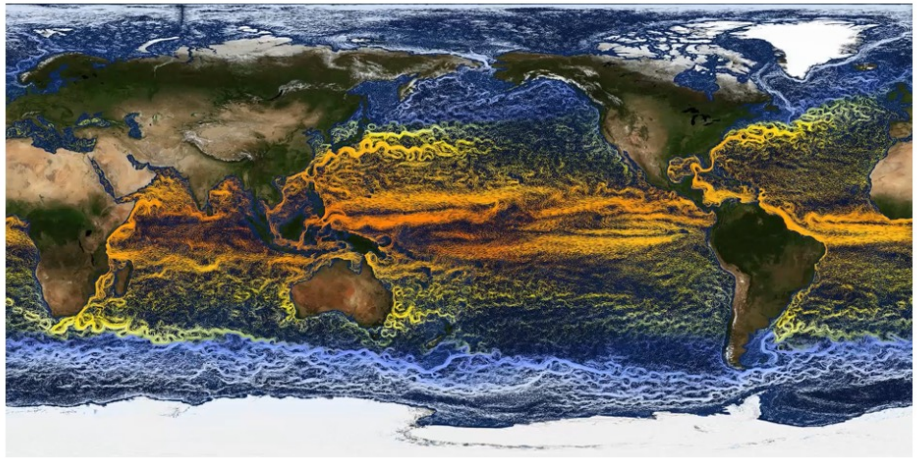
- The tropical oceans play a crucial role in the global climate system, affecting monsoon rainfall (which provides rainfall to ~½ of the world's population) and circulation patterns in both hemispheres
- Tropical Pacific SST changes over the last decades are poorly simulated by standard resolution global climate models but are more realistically captured by a high-resolution climate model

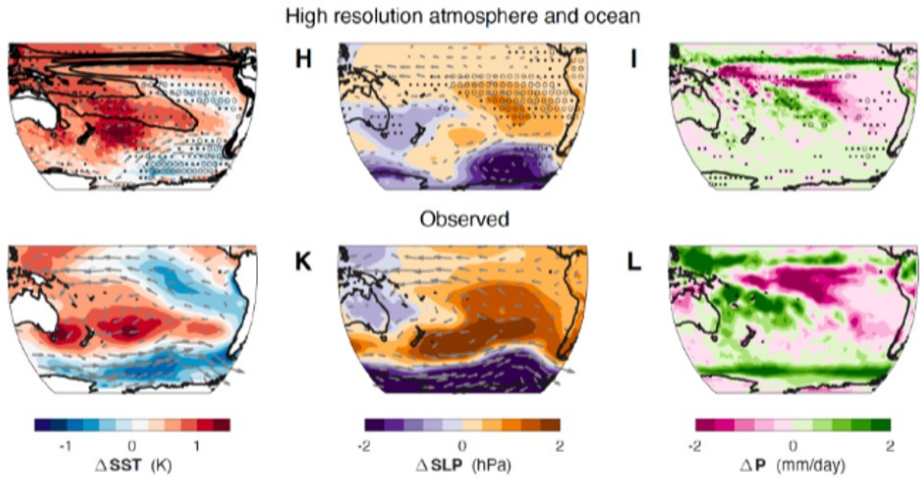
Research questions:

- How do the simulated (historical and future) monsoon trends in the Northern and Southern Hemispheres differ between standard and high-resolution models?
- How do the modeled historical trends compare to observations in terms of magnitude, spatial pattern, and seasonality?

Data and methods:

- Output from simulations performed with three configurations of the CESM1 climate model with different atmospheric and oceanic resolutions (of up to 0.1°); observational datasets of rainfall and SST
- Statistical data analysis (Python) to investigate monsoon rainfall trends and to analyze the mechanisms underlying their differences across datasets





Supervision: Nora Fahrenbach and Robb Jnglin Wills

How does energy flow poleward in a future climate simulation?

Motivation

Cyclones and anticyclones make the dominant contributions to atmospheric poleward energy transport in mid-latitudes. As climate change alters the equator-to-pole temperature gradients and moisture uptake capacity, we also expect to see changes in the energy flux. It is not understood how this relates back to weather phenomena.

The objective of this thesis is to investigate moist static energy flux in the vicinity of cyclones by composite analyses. The results than can be related to the global energy budget.

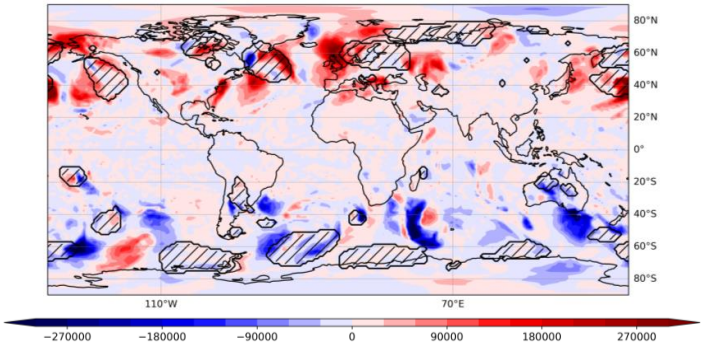


Fig 1: Poleward moist static energy flux (colors, in Jm/kgs) and identified cyclones (hatching) in reanalysis data.

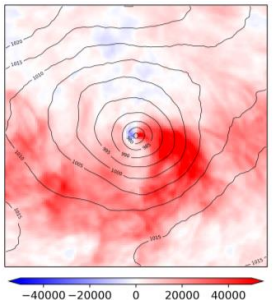


Fig. 2: Poleward moist static energy flux (colors, in Jm/kgs) around a sample of North Pacific extratropical cyclones during mature stage.

Research Questions

- Does high-frequency moist static energy flux change in a future climate simulation?
- What is the relative importance of the moist component compared to the dry component in a warmer climate?
- How does energy flux change across different cyclone intensities?

Methods:

Combining an established cyclone tracking tool with energy flux data with the use of composites

Recommended skills:

Basic knowledge of atmospheric phenomena, interest in analyzing large datasets with python

Supervision:
jan.zibell@env.ethz.ch
sebastian.schemm@env.ethz.ch

Investigating the midwinter supression of storm track activity over the North Atlantic

Description

Extratropical cyclones generally intensify in regions of high background temperature gradients. Such high temperature gradients go hand in hand with a strong upper-level jet. We therefore expect high cyclone activity in regions of high jet velocities. However, especially over the Western North Pacific we observe a decrease and shift in storm track activity in midwinter, even though that is when the jet velocities are largest.

The goal of this thesis is to investigate how the pattern of storm track activity relates to the jet strength over the North Atlantic and to compare this to the North Pacific.

Methods

Statistical analysis of different measures of storm track activity (eddy kinetic energy, highpass-filtered potential vorticity, cyclone frequency) with ERA5 reanalysis data

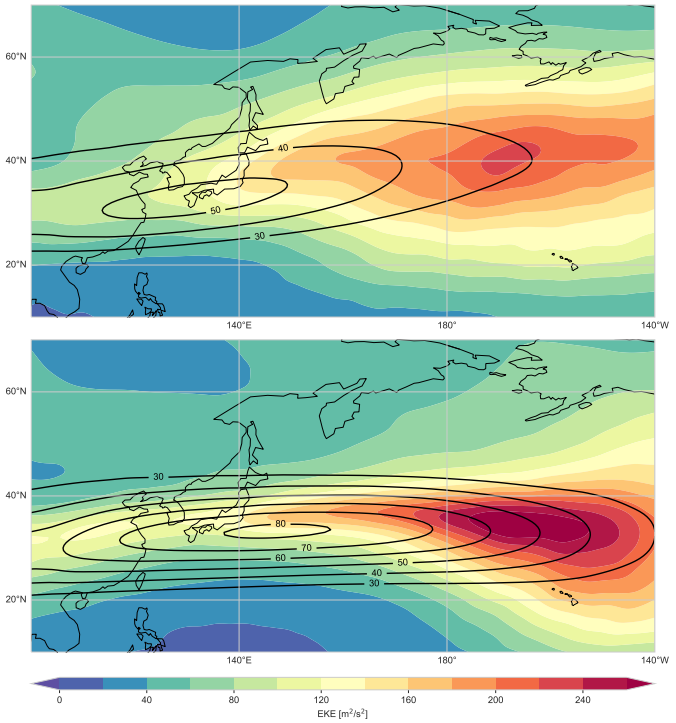
Research questions

How does the North Atlantic storm track respond to particularly strong jets in the winter months?

Does it show a similar behaviour to the midwinter North Pacific storm track?

Supervision:
nora.zilibotti@env.ethz.ch, sebastian.schemm@env.ethz.ch

Upper-level eddy kinetic energy for weak and strong jet days over the North Pacific



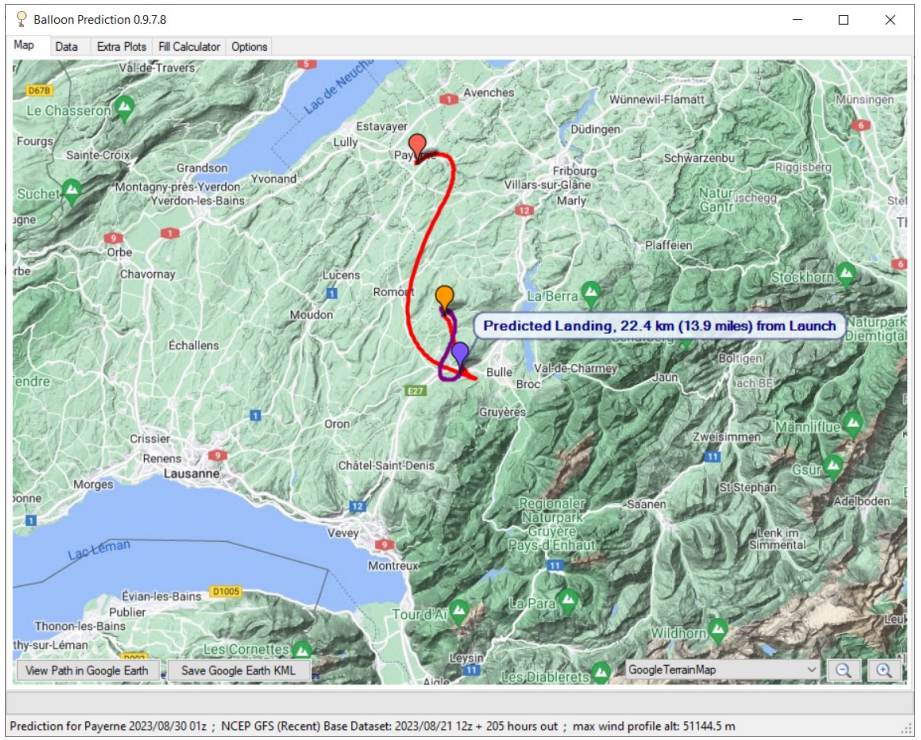
Flight Planning Support for the Swiss H_2O Hub Project

Research Questions

- How can we define the landing area with the aid of balloon flight prediction?
- Can existing balloon flight prediction tools be improved with actual ECMWF wind field forecasts?

Method

- parametrize balloon ascent and descent rates using existing flight data
- compare the parametrization with those of the NOAA Balloon Prediction tool
- implement the parametrization in the Lagranto model
- use the forecasts for real flight planning and recovery



Prerequisites

- interest in application of trajectory calculations
- motivation to participate in field campaigns

Supervision: Frank Wienhold, Yann Poltera and Michel Sprenger

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**."*

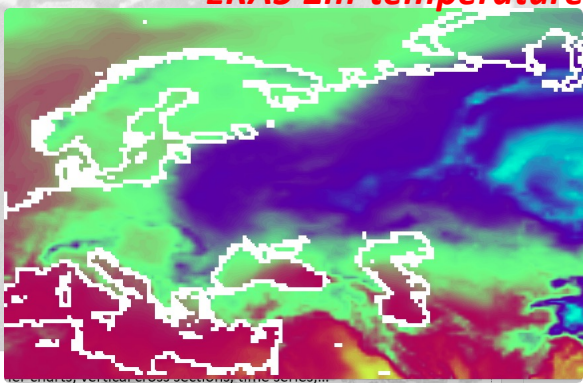
Research Questions:
- How extreme was the temperature in winter 1941/42?
- How did the temperature evolve from October 1941 until January 1942
- What was the synoptic and mesoscale meteorology leading to the extreme temperatures?
- How does the winter 1941/42 compare to other winters?

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



Characterizing Clear Air Turbulence (CAT)

CAT refers to turbulence encountered by aircraft in clear-air.

The measurements from aircraft and reanalysis data allow you to investigate CAT in various aspects and you can decide which one to explore!

Possible topics of the bachelor thesis:

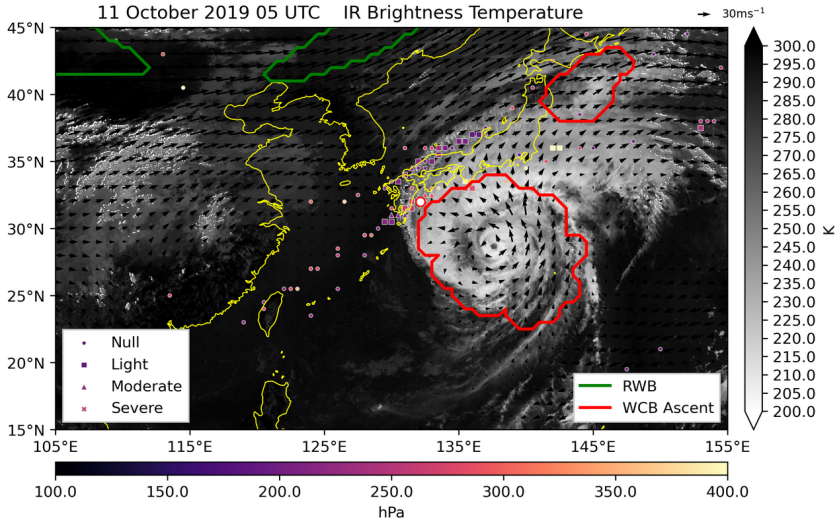
- Is there a subcategory of CAT related to TC outflow or frontal systems?
- Are there common characteristics for the CAT events that occur in mountainous regions?
- How does a CAT episode evolve in time and space together with the synoptic flow?

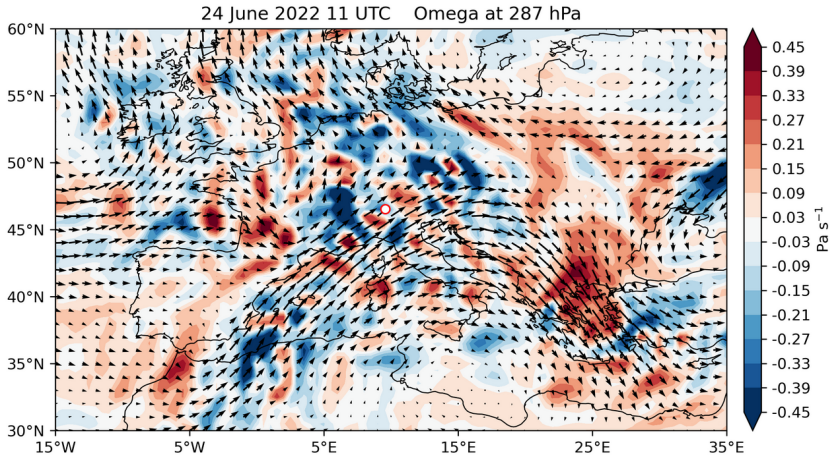
Method:

- Analyze the synoptic weather conditions associated with the CAT events using ERA5 reanalysis

You can also come up with your own idea and discuss with us.

Supervisors:
Franco Lee (franco.lee@env.ethz.ch)
Michael Sprenger (michael.sprenger@env.ethz.ch)

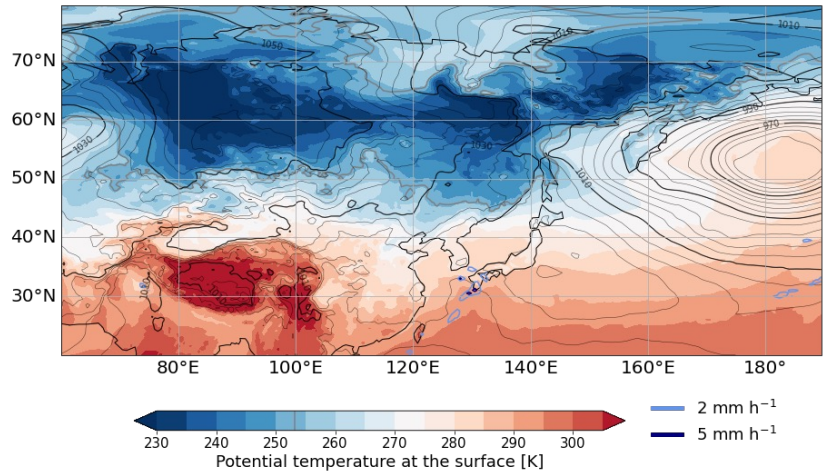




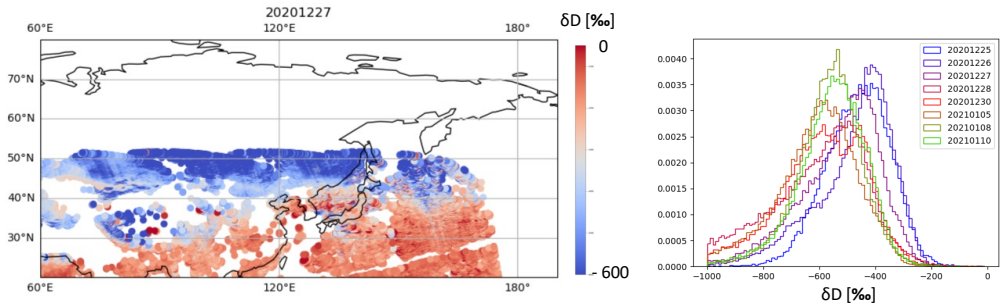
Investigating the water vapour isotope signature of BCARs

Background:
BCARs (Boreal Cold Air Reservoirs) are extremely cold, shallow anticyclones that form at high latitudes, specifically in Canada and Siberia, during the winter time. With temperatures as low as -50°C at the ground, they can have a large effect locally, but also on surrounding regions through e.g., cold air outbreaks.

On the other hand, water vapour isotopes offer valuable insights into the processes affecting atmospheric moisture – such as the moisture uptake, condensation, ice nucleation etc. Due to the very low temperature in BCARs, a distinct isotopic signature is expected within these systems, making water vapour isotopes a potential BCAR tracer.



Research questions:
- Do BCARs show a distinct signature in water vapour isotopes?
- What can we learn about the age of water vapour inside BCARs?
- Can we use this isotopic signature to trace BCAR air?



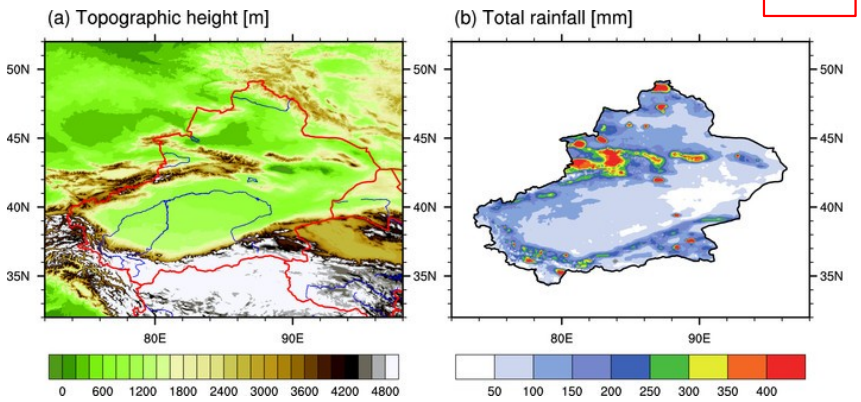
Approach:
Case studies of particularly strong/weak BCAR events using satellite data (obtained by TROPOMI on Sentinel 5) and reanalysis data (ERA5)

Supervision:
Iris Thurnherr (iris.thurnherr@env.ethz.ch), Jacopo Riboldi (jacopo.riboldi@env.ethz.ch), Franziska Schnyder (franziska.schnyder@env.ethz.ch)

The dynamics of heavy precipitation events in the Taklamakan desert

Research Questions:

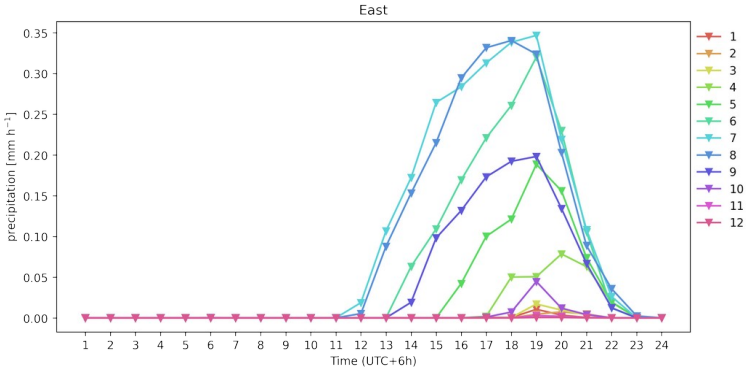
1) What is the frequency and location of HPE in the Taklamakan?
2) Which meteorological systems prevail during these events?
3) How do the trajectory origin, moisture sources and water vapour flux differ between HPE and non-HPE episodes?



Taklamakan desert and surrounding topography (left) and rainfall climatology (right)

Approach and Tools:

1) Identification and characterization of HPEs using satellite observations (IMERG).
2) Association of events with weather patterns using ERA5 reanalyses.
3) Backward trajectory calculation and moisture source identification.



Diurnal cycle of precipitation in Taklamakan in different months.

Prerequisites:

Wide interest in different aspects of meteorology and tools – the dynamics of weather systems in deserts (here over the Taklamakan), remote sensing, rainfall generation and characteristics. Familiarity with programming and working with large datasets would be of great help, however, motivation for learning these skills is enough.

Supervision:

Koko (Moshe) Armon and Iris Thurnherr (moshe.armon@env.ethz.ch, iris.thurnherr@env.ethz.ch)

Sensitivity of a WCB in an idealized cyclone to resolution

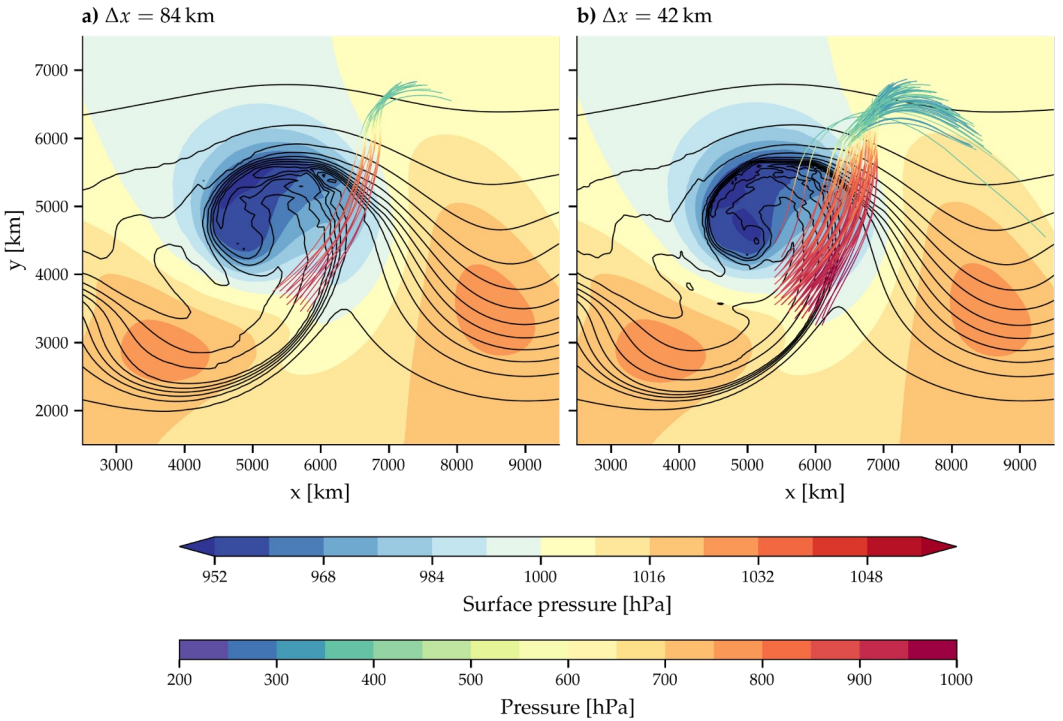
Research questions:

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

Methods: Calculation and analysis of WCB trajectories.

Prerequisites: Interest in (idealized) synoptic meteorology

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



Representation of a WCB in two idealized cyclone simulation with different horizontal resolution. Shown are Surface pressure (colours) and contours of surface potential temperature (black contours) at day 4 and WCB trajectories starting at day 3.

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, starting at ETH in January 2024)

Next steps

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

2) Send an Email to heini.wernli@env.ethz.ch until Fri 8 December 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