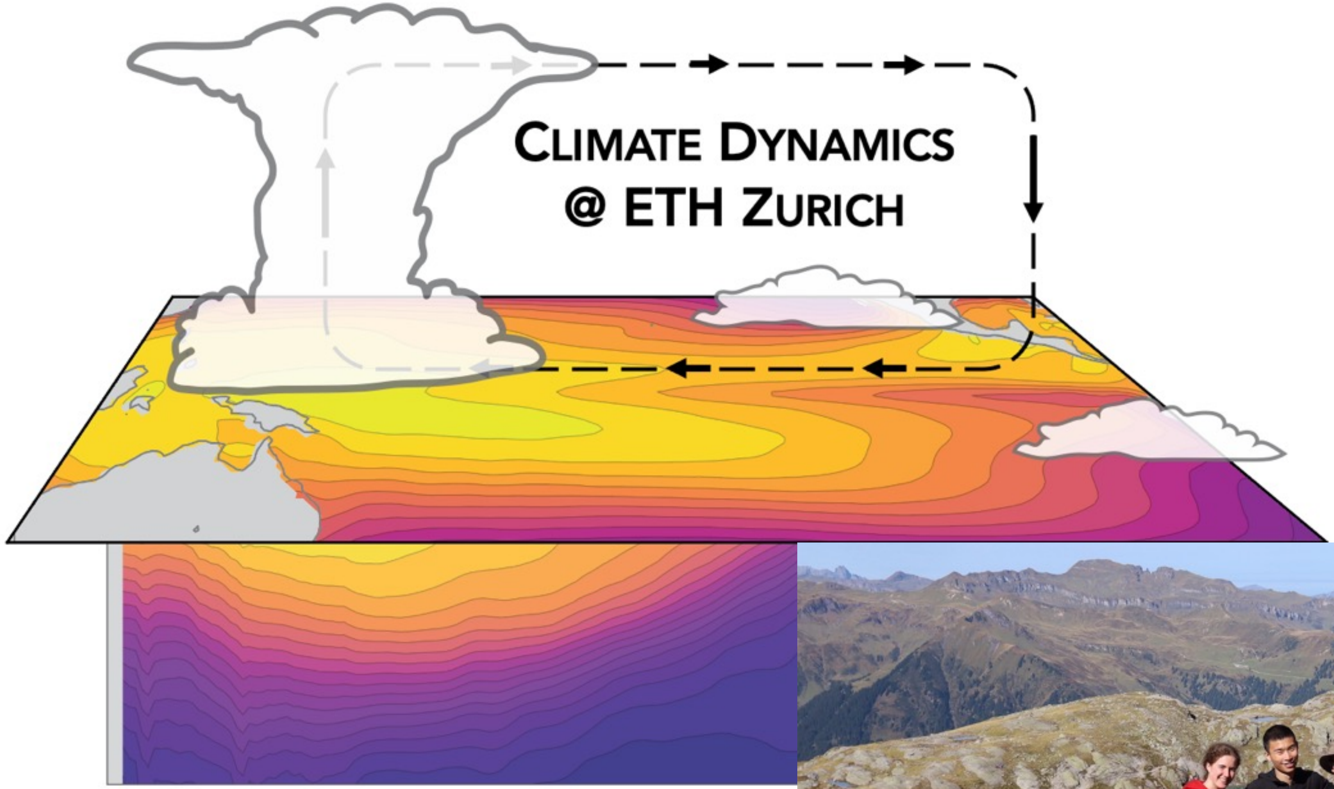
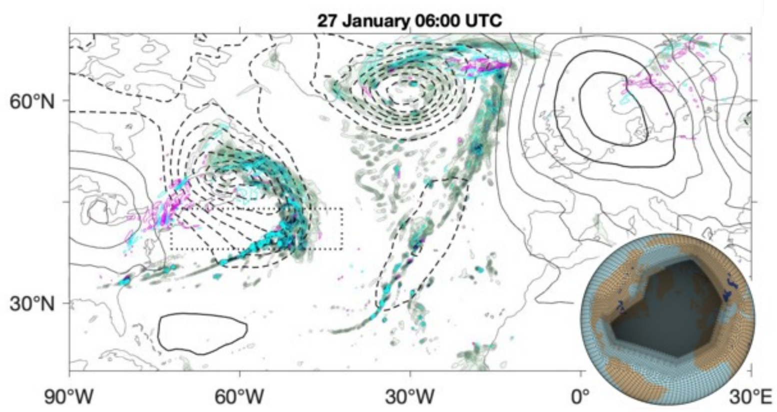
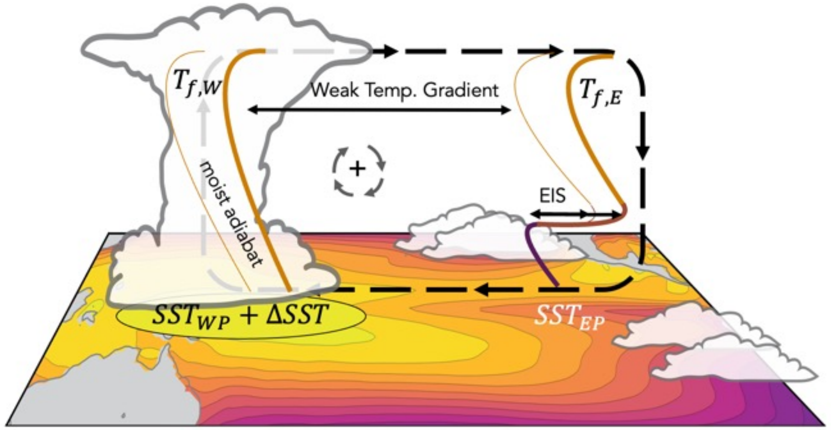


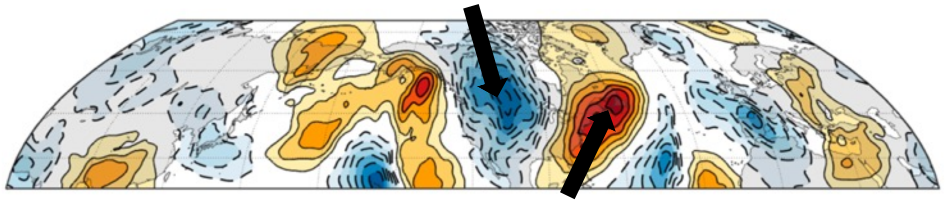
Climate Dynamics Group

Prof. Robb Jnglin Wills
Postdocs: Clarissa Kroll, Shuchang Liu
PhDs: Joas Müller, Nora Fahrenbach, Zhenghe Xuan

What we work on







- Influence of small-scale processes (fronts, convection) on the global atmospheric circulation and climate
- Sensitivity of global and regional climate to the pattern of ocean warming
- Pattern recognition methods to isolate anthropogenic climate responses from internal variability
- Influence of non-GHG forcing (anthropogenic and volcanic aerosols, land-use change, geoengineering) on tropical climate change
- Changes in atmospheric variability (e.g., jet stream waviness) and weather extremes

Cloud impacts on tropical circulations

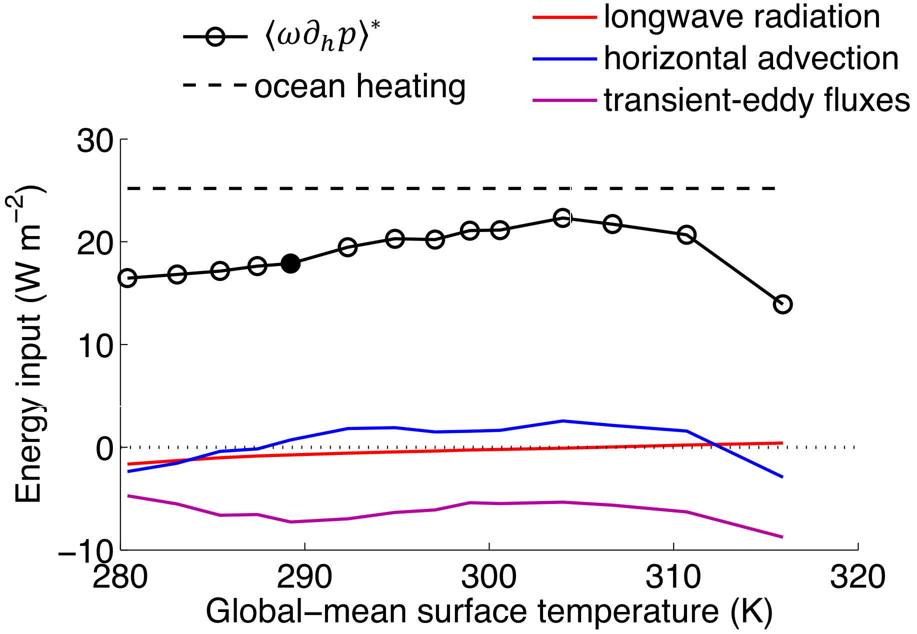
Background:
- Clouds change the balance of outgoing longwave and incoming shortwave radiation in the atmosphere
- Walker circulation is an E-W tropical circulation driven by energy imbalances and is predicted to weaken with climate change
- Clouds can alter the energy balance, thereby changing the Walker circulation's response to climate change

Research questions:
- How do clouds and water vapor affect tropical overturning circulations?
- To what extent can gross moist stability changes explain Walker circulation weakening?

Data and methods:
- Analyze output from ICON aquaplanet climate model simulation using Python and Xarray
- Learn and apply energy balance and gross moist stability to analysis
- Potential to design and run simulations depending on questions arising from analysis

https://www.icon-model.org/

NASA



Wills et al. 2017

Supervision: *Zhenghe Xuan, Emmanuele Russo, Robb Jnglin Wills, Daniela Domeisen*

Understanding cloud cover differences in high- versus low-resolution simulations

Background:
High-resolution model simulations offer the unprecedented possibility to resolve small-scale processes explicitly. Of special interest are potential improvements in the representation of convection and cloud cover as clouds have a large impact on model derived estimates of the equilibrium climate sensitivity by modifying long wave and shortwave radiative fluxes.

Research Questions:
How do high-resolution and low-resolution simulations with different models compare to observations and reanalysis data as far as the capturing the mean cloud cover and distribution is concerned?
How does this impact the shortwave fluxes?
Which biases are improved in high-resolution simulations, which are unchanged and why?

Data and Tools:
Statistical analysis of low-resolution CMIP6 and high-resolution NextGEMS model output (bash, CDO, python) and observational products (CERES).

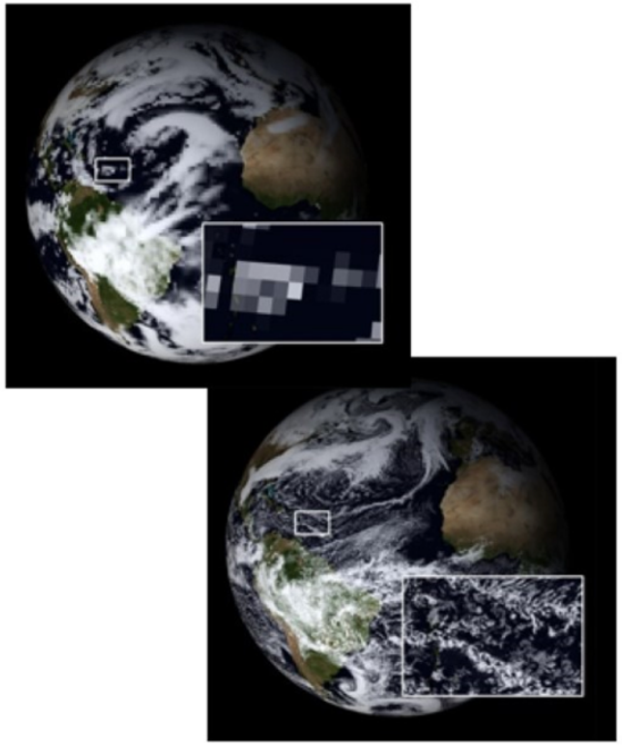


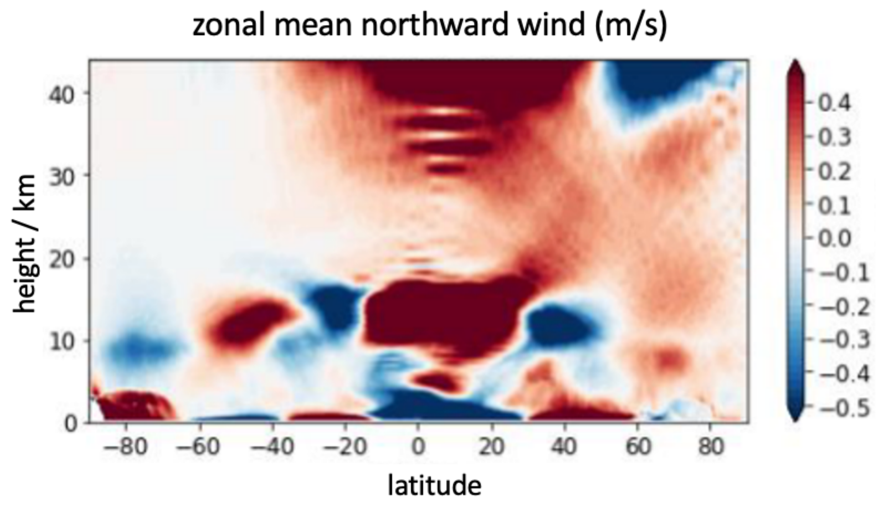
figure credit: esiwace.eu

Supervision: *Clarissa Kroll, Robb Jnglin Wills*

The impact of model boundary conditions in ICON on the atmospheric representation

Background:
Model boundary conditions require vertical velocities to be damped to zero at the topmost vertical model level. In the weather and climate model used by the Swiss and German weather services (ICON) this is achieved by introducing a damping layer in the higher model levels. However, the choice of damping settings can have severe impacts on the atmospheric state (compare figure).

Research Questions:
Which parameter configuration offers optimal damping results without compromising the general atmospheric circulation?
How do changes in the horizontal resolution and chosen parametrizations affect the optimal parameter configuration?
What would be a good metric to evaluate the boundary condition settings with short term simulations?



Data and Tools:
Analysis of different experimental ICON simulations (bash, CDO, python) with the potential to set up and run own sensitivity experiments with ICON.

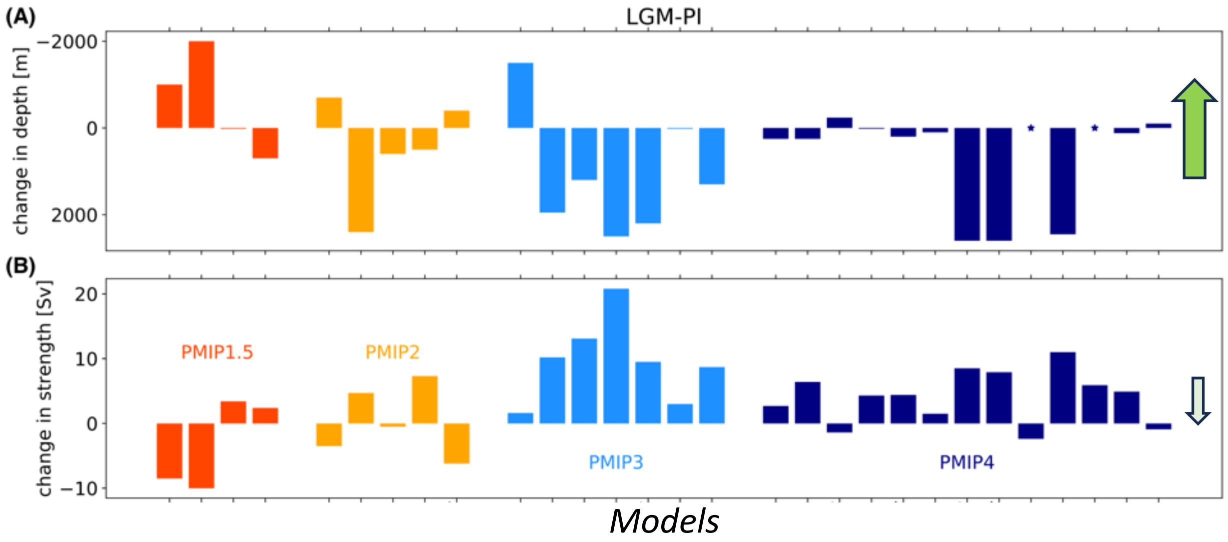
Supervision: *Clarissa Kroll, Robb Jnglin Wills*

How does the ocean overturning circulation change in colder (LGM) versus warmer (4xCO2) climate states?

suggested sign of changes (by proxy data)

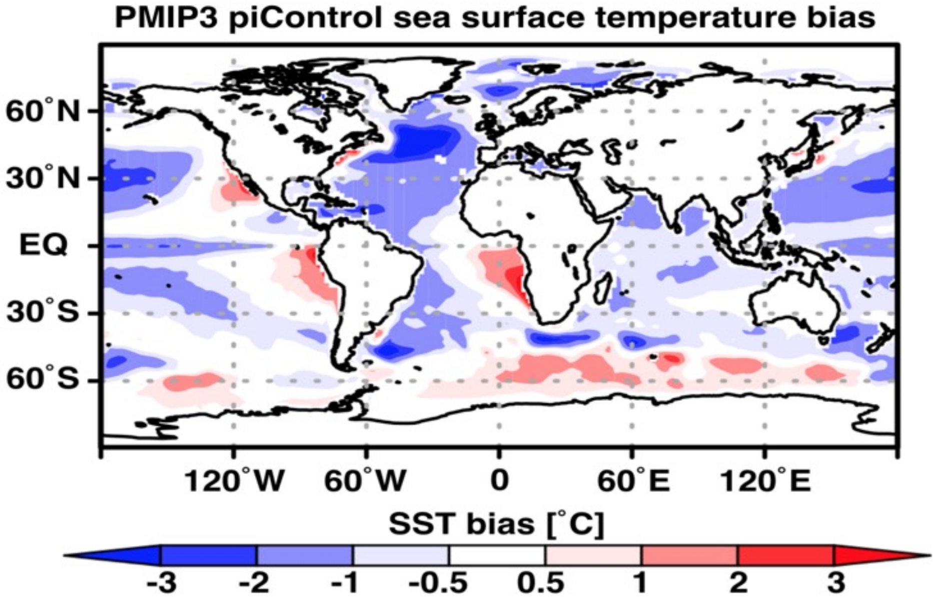
Background:

- It remains a challenge for climate models to reproduce an LGM AMOC in agreement with reconstructions from proxy data
- Potential reasons: SST biases in deep/bottom water formation regions; uncertainty in ice-sheet reconstructions; model difficulties in simulating AMOC
- Ocean circulations like the AMOC have itself a strong influence on SST patterns and how they change under different forcings



Research Questions:

- Do models always show the opposite sign of response in LGM versus 4xCO2, and if not, why not?
- Is the AMOC response dependent on base-state SST biases, and if so, can an emergent constraint be developed?
- What is the role of the AMOC itself in shaping the SST bias?
- And looking somewhere else … Do we observe a PMOC response?
- Too many ideas where this project could go to fit everything on one slide



Approach:

- Statistical analysis of data from CMIP and the Paleoclimate Modelling Intercomparison Project (PMIP), e.g., with Python and CDO

Supervision: Joas Müller, Robb Jnglin Wills

From: Scherriff-Tadano and Klockmann 2021

Dependence of climate sensitivity on continental configuration over the past 400 million years

Background:

Understanding past climatic shifts in Earth's history can help to understand the Earth system response to anthropogenic warming. One major factor that still needs to be understood is the effect of changing geographic configurations on the response of the climate system to an increase in greenhouse gases.

Research questions:

Why does the climate sensitivity to greenhouse gas changes depend on continental configuration? Which radiative feedbacks are important in the climate sensitivity differences? Is there a role for differences in ocean circulation? Why is the present climate near a sensitivity maximum?

Data and Tools:

Analysis of simulations with the PlaSim intermediate complexity climate model (e.g., using CDO and Python/R); global climate feedback analysis

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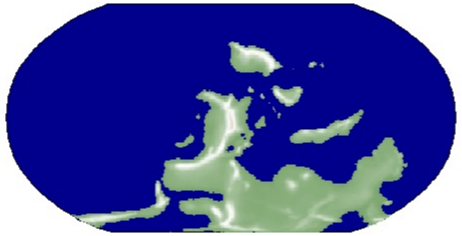

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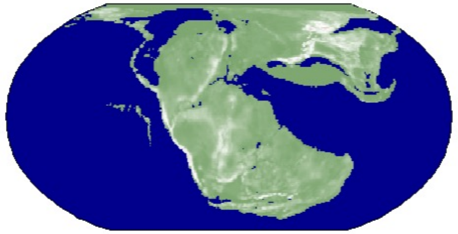

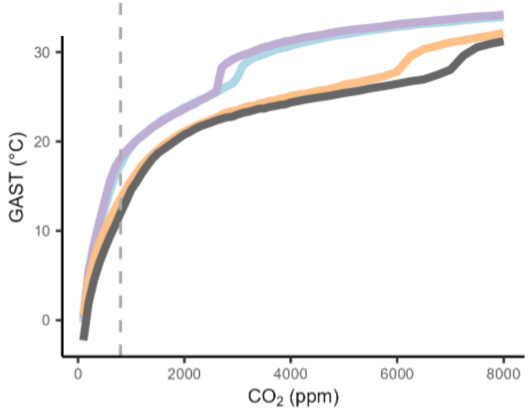

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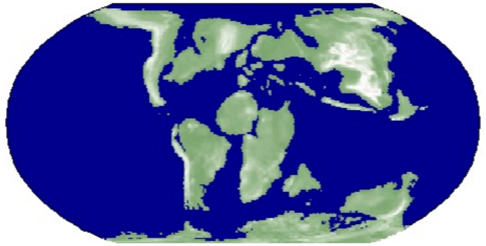

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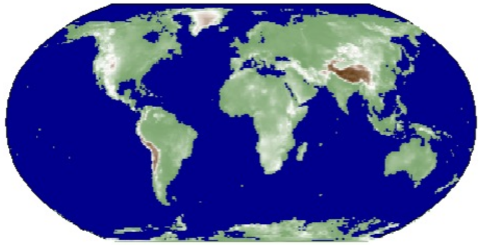


Supervision: *Niklas Werner (D-ERDW), Julian Rogger (D-ERDW), Robb Jnglin Wills, Taras Gerya (D-ERDW)*

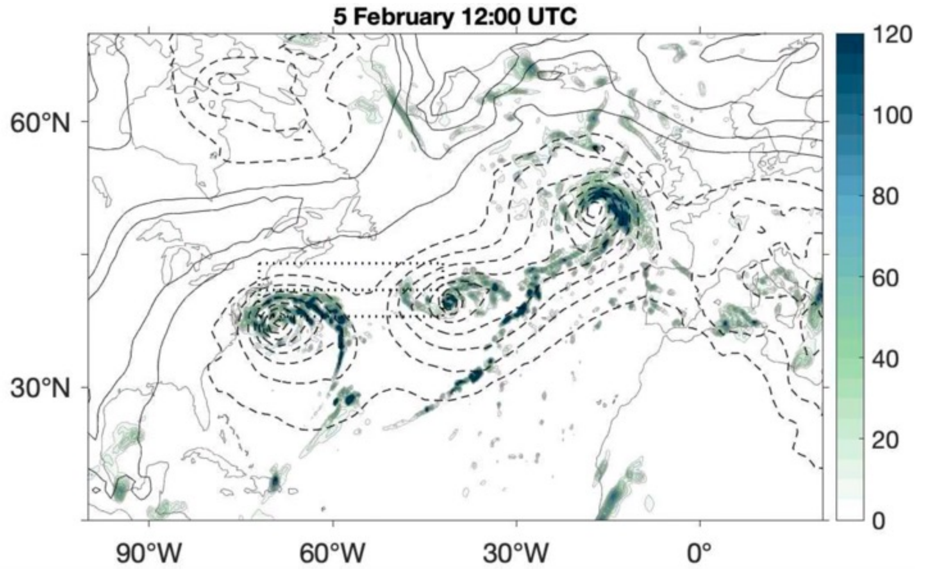
Machine learning parameterization of slantwise convection

Background:
- Global climate models (GCMs) don't resolve frontal processes occurring on ~10-20 km scales
- Storm-resolving model simulations show a larger response (compared to typical GCMs) of the jet stream to Gulf Stream temperature anomalies, due to greater frontal ascent

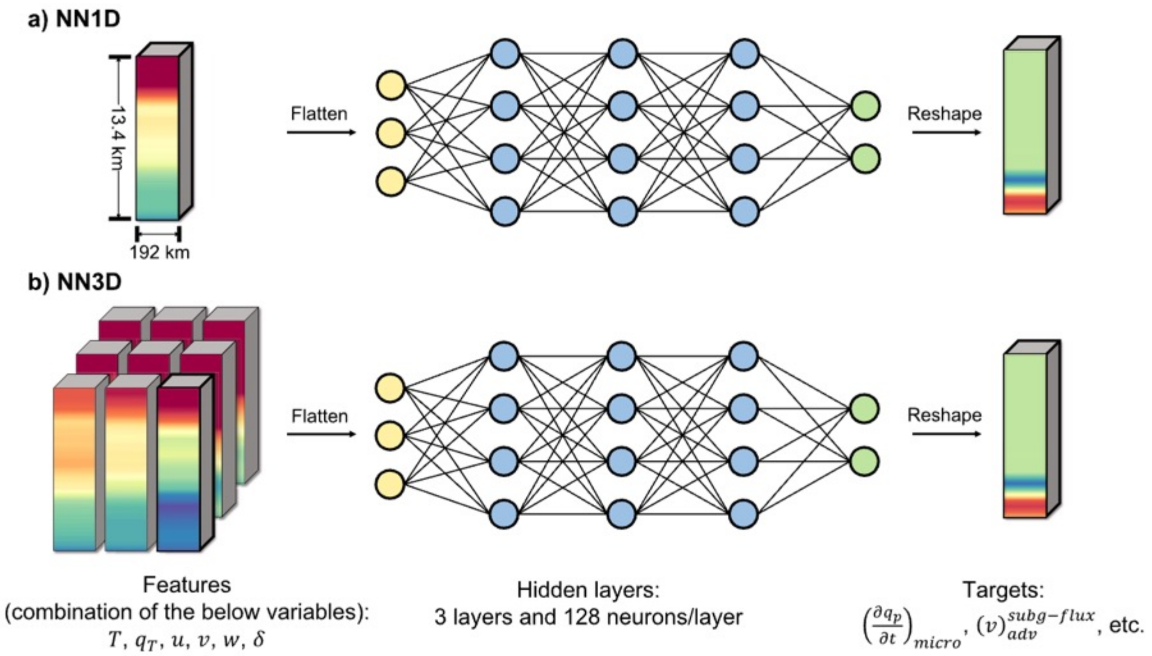
Research questions:
- Can an offline neural network learn the frontal (slantwise) convective processes from the storm-resolving model simulations?
- How do sub-grid tendencies depend on the large-scale atmospheric state?

Data and Methods:
Analysis of storm-resolving simulations with the CESM2 climate model (e.g., using Python and CDO); designing and implementing a neural network (PyTorch or TensorFlow)

Requirements: Previous experience with machine learning or statistical modeling



Wills et al. 2024 (submitted)



Wang et al. 2022

Supervision: Tom Beucler (UNIL), Robb Jnglin Wills

Summary of Master's Topics in Climate Dynamics

1. Cloud impacts on tropical circulations
2. Understanding cloud cover differences in high- versus low-resolution simulations
3. The impact of model boundary conditions in ICON on the atmospheric representation
4. How does the ocean circulation change in colder versus warmer climate states?
5. Dependence of climate sensitivity on continental configuration over the past 400 million years
6. Machine learning parameterization of slantwise convection

- Note that while we have listed 6 potential topics, we only have capacity to supervise up to 5 MSc theses, and project 6 requires previous ML or statistics experience
- For questions about these topics or if you want to discuss other possible topics, please contact Robb Jnglin Wills (r.jnglinwills@usys.ethz.ch)