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Evolution of Moisture Transport Patterns in the North Atlantic in different Climate scenarios

Masterarbeit

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vorgelegt von

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Abstract

The distribution and variability of precipitation in Europe are significantly influenced by moisture transport over the north(east)ern Atlantic. The objective of my master thesis is to analyze the evolution of moisture transport patterns in various future climate scenarios. The foundation of this research lies in the MPI-GE, the Max Planck Institute Grand Ensemble Dataset, comprising an ensemble of 100 members for different RCP (climate) scenarios up until 2100. Each member provides multiple fields of relevant climate data. A challenge will be the visualization of uncertainty stemming from 100 different simulations, which will not be straightforward.

To quantify moisture transport, an integrated water vapor transport (a combination of wind and specific moisture) scalar/vector field will be generated from the MPI-GE. Windowed Empirical Orthogonal Functions (EOFs) will be used to extract spatial-temporal patterns and simplify the data, making it easier to evaluate pattern evolution over time.

Contents

1 Introduction and Motivation

1.1 Motivation

1.2 Structure of this Thesis

Structure:

1. **Preliminaries**: explain what climate simulations are, what cmip(6) is and its relation to the IPCC reports and what that means for the global fight against the climate crisis. This chapter should prepare the reader to understand all of the related work in Chapter 4.

2. **Problem Analysis**: explain what I want to do using the CMIP6 simulations: Describe what the general plan is: Visualisation of the moisture transport in Europe with the help . Also define what the goals of the visualisations are: Visualize different scenarios for comparison, visualize uncertainties of different members, visualize evolution over time, also try combining those. Here should be a graphic that explains the workflow that transforms a simulation into some nice pictures

3. **Related Work**: Show what efforts have already been done regarding analysis of moisture transport, future and past. Maybe preparing a comparison table would be good.

4. **Realization**: Describe in a step by step way what measures had been taken.

5. **Evaluation**: A little bit unsure how far I (as a CS person) can evaluate this, have to come up with a concept

6. **Conclusion**: Same as step before, but there will be something to write about after everything else is written

2 Preliminaries

2.1 Weather and Climate Simulation

Explain here, on a general concept, what climate simulations/reanalysises are and how they are made. Not too specific, but also not too broad.

Find some literature to source this chapter!

Points to touch:

- What are ensemble simulations? Why are they necessary?
- What are reanalyses?
- What is usually contained in such a simulation?
- How are they made? (General concept, not too specific)

2.2 IPCC & Climate Model Intercomparison Project (CMIP)

In this section the polical/global aspect should be explained, but also how the global science community works together to build intercompareable projects. [5, 8, 10]

Points to touch:

- What is the relation of IPCC and CMIP?
- What are the SSPs?
- What are the specifications of the latest version?

2.3 Mathematical Background

This section should explain the basic math to understand the aforementioned topics, not that much needed but still needs to be there.

2.3.1 (Uncertain) Fields

2.3.2 Empirical Orthogonal Functions

3 Problem Analysis

Explain what I want to do using the CMIP6 simulations: Describe what the general plan is: Visualisation of the moisture transport in Europe with the help . Also define what the goals of the visualisations are: Visualize different scenarios for comparison, visualize uncertainties of different members, visualize evolution over time, also try combining those. Here should be a graphic that explains the workflow that transforms a simulation into some nice pictures

4 Related Work

This chapter builds on the foundation of Chapter 2, explaining what dataset is actually used, the reason for this and its properties. Furthermore it summarizes the current state-of-science in quantifying and calculating (patterns of) moisture transport and the usage of it.

4.1 Climate simulation datasets

This section should explain what datasets are available and why I chose the MPI-GE CMIP6 [6]

Maybe but the comparison table from [6] here and expand it a bit.

4.2 Moisture Transport

This section should explain in what ways moisture transport can be quantified and used, give a few examples for each and maybe motivate why we do it like we want to.

To computationally study the change of moisture transport it first needs to be quantified. The vast majority of literature use some form of vertically integrated humidity, the variants will be explained in the following section. The main usage of these algorithms was to find a filamentary structure called "Atmospheric Rivers", a prominent way of water vapor transportation in the extratropic regions [2].

Create a table showing how different quantification were used in different algorithms

See Section 4.3 for further explanation.

There are also some notable other algorithms, namely stable oxygen isotope investigation [4] and langragian backwards trajectories [12], but both rather look for the origin of the WV instead of its destination and are therefor out of scope for this thesis.

4.2.1 Vertically Integrated Water Vapor (IWV)

4.2.2 Vertically Integrated Water Vapor Transport (IVT)

As proposed by Zhu and Newell in [13], one way of measuring moisture (p) transport is by vertically integrating over the different pressure levels the zonal and meridional fluxes $\overline{pu}$ and $\overline{pv}$.

An example of using this method can be found in [1] with many more references why this method is working well for these kinds of approaches.

Also, this paper lists some other methods of moisture transportation which are also used

1. integrated water vapor distributions
2. the lagrangian approach
3. stable oxygen isotope investigation

Usages of IVT and differences

In [7] they used a vector field of the IVT: $\int_{p_{low}}^{p_{max}} qVdp$, where p is the pressure level, q is the humidity and V the horizontal vector.

In [9] they used a scalar field based on the euclidian norm of the vector field used by [7].

In [1] they also used the euclidian norm on a similar field like [7] to measure the impact of ENSO on south-chinese weather.

4.2.3 Moisture Budget

Yang et al. showed in their report [11] the directions of moisture flux on the continent borders based on the big ERA5 reanalysis. They measure the moisture based on a equation called the *Moisture Budget*, which is based on multiple Faktors:

It seems related to the IVT the other authors used, but utilizes the gradient and some other differences. The complete formula is:

$$\frac{1}{g}\frac{\delta}{\delta t}\int_0^{P_s} qdp = -\nabla \cdot \frac{1}{g}\int_0^{P_s}(qv)dp + E - P$$

With:

1. p is the pressure, P_s is the surface pressure
2. q is the specific humidity

3. v is the horizontal wind vector
4. E is the evaporation
5. P is the Precipitation

In the actual analysis they used mostly other metrics:

1. Vertically integrated Moisture Convergence (*VIMC*): It is basically the gradient of the specific moisture in the air times the Wind vector
2. P is the precipitation
3. E is the evaporation

Furthermore they evaluateded the correlation between the moisture transport and the precipitation variability, which correlate to a significant extent.

4.3 Atmospheric Rivers

This section should explain atmospheric rivers, but since we dont know if they are even relevant so i write it in the end.

I dont know where to put this, maybe it should go into the preliminaries

4.4 Pattern analysis

Explain some usages of EOF in data, but extremely important: Explain what [1] did since its quite similar.

4.4.1 Empirical Orthogonal Functions

See [3] for a big overview of EOF in atmospheric science.

See [1] for an similar approach as we plan it, except it only focuses on the past. They

5 Design

5.1 Overview

5.2 Preprocessing

This should explain how you get a proper IVT field from a CMIP6 simulation, what the caveats are and what calculations are done.

6 Evaluation

7 Conclusions and Future Work

7.1 Conclusions

7.2 Future Work

Acronyms

PCA	Principal component analysis
SNF	Smith normal form
TDA	Topological data analysis

Glossary

$\LaTeX$	A document preparation system
$\mathbb{R}$	The set of real numbers

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