Universität Leipzig

Fakultät für Mathematik und Informatik
Institut für Informatik

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

Masterarbeit

Leipzig, Mai 2024

vorgelegt von

Denis Streitmatter
Studiengang Master Informatik

Betreuende Hochschullehrer:
Dr. Baldwin Nsonga
Universität Leipzig, Abteilung für Bild und Signalverarbeitung
Prof. Dr. Gerik Scheuermann
Universität Leipzig, Abteilung für Bild und Signalverarbeitung

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 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.

Atmospheric rivers (ARs) play a substantial role in moisture transport and are identified using integrated water vapor transport (IVT). The analysis employs Empirical Orthogonal Functions (EOFs) to examine changes in spatial patterns of ARs across different climate scenarios and time periods.

Contents

1 Preliminaries

2 Problem Analysis

3 Related Work

3.1 Climate simulation datasets

General infos from [4]:

-

3.1.1 RCP Scenarios

3.1.2 MPI-GE - The Max Planck Institute grand Ensemble

General information about the future scenarios (all based on the *rcp85* dataset available to me on the DKRZ cluster, I just assumed its the same for other scenarios. Maybe need to confirm this):

- **Time**: The time axis is compromised of 1128 values, which count the days since 01.01.2005. The first one is 380, so it actually starts somewhere in 2006, and all of those values are roughly 30 days apart. This axis is part of every dataset, all stored as floats.
- **Lat**: Vector of 96 Float Elements ranging from roughly -88 to 88. Results in a resolution of 1.875° in North-South direction.
- **Lon**: Vector of 192 Float Elements ranging from roughly 0 to 358. Results in a resolution of 1.875° in East-West direction.
- **Pressure Level** (plev): Is given for each dataset and consists of 26 Floats, ranging from 10 to 100,000. Unit is Pa.
- **Eastward/Northward Wind**: Given as Floats in the unit of ms^{-1} per *(lat, lon, time, plev)*. Each compromises the wind direction in one orthogonal direction. Eastward wind directory is named *ua*, northward *va*

- **Specific Humidity**: Specific humidity is given as a float without value. Reason is the unit is actually kg moisture per kilogramm air, which cancels out in the end. Is given for each *(lat, lon, time, plev)*. Directory name: *hus*
- **Surface Wind Speed**: Given as float per *(lat, lon, time, height)*, represents the wind speed in ms^{-1} (no Vector!!) near the surface level. Directory Name: *sfcWind*
- **Evaporation**: Given as a float and per *(lat, lon, time)*, represents the evaporation flux. Unit is $\frac{kg}{m^2 s}$, directory name *evspsbl*
- **Preciptation**: Given either as normal or convective flux ($\frac{kg}{m^2 s}$) per *(lat, lon, time)*. Directory name *pr, prc*.
- **Water Vapor Content**: Integrated over the colum, given per *(lat, lon, time)*, just the water vapor content, no wind(vector) involved. Directory name: *prw*.

In [4] there is much information available:

3.1.3 CMIP5 - Coupled Model Intercomparison Project

In [7]

3.2 Precipitation Literature

3.2.1 Saisonality in Precipitation variability

The work of Zveryaev

3.3 Means of moisture transport

3.3.1 vertically integrated water vapor transport

As proposed by Zhu and Newell in [9], 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 (see [2])
2. the lagrangian approach
3. stable oxygen isotope investigation

Usages of IVT and differences

In [5] they used a vector field of the IVT: $\int_{p_{low}}^{p_{max}} qV dp$, where p is the pressure level, q is the humidity and V the horizontal vector.

In [6] they used a scalar field based on the euclidian norm of the vector field used by [5].

In [1] they also used the euclidian norm on a similar field like [5] to measure the impact of ENSO on south-chinese weather.

3.3.2 Moisture Budget

Yang et al. showed in their report [8] 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.

3.4 Pattern analysis

3.4.1 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

4 Design

5 Evaluation

6 Conclusions and Future Work

6.1 Conclusions

6.2 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

Bibliography

1. O. O. Ayantobo, J. Wei, B. Kang, and G. Wang. "Integrated moisture transport variability over China: patterns, impacts, and relationship with El Nino–Southern Oscillation (ENSO)". *Theoretical and Applied Climatology* 147, 2021, pp. 985–1002. URL: https://api.semanticscholar.org/CorpusID:244492291.

2. L. Gimeno, R. Nieto, M. Vázquez, and D. A. Lavers. "Atmospheric rivers: A mini-review". *Frontiers in Earth Science* 2, 2014, p. 2.

3. A. Hannachi, I. T. Jolliffe, and D. B. Stephenson. "Empirical orthogonal functions and related techniques in atmospheric science: A review". *International Journal of Climatology: A Journal of the Royal Meteorological Society* 27:9, 2007, pp. 1119–1152.

4. N. Maher, S. Milinski, L. Suarez-Gutierrez, M. Botzet, M. Dobrynin, L. Kornblueh, J. Kröger, Y. Takano, R. Ghosh, C. Hedemann, C. Li, H. Li, E. Manzini, D. Notz, D. Putrasahan, L. Boysen, M. Claussen, T. Ilyina, D. Olonscheck, T. Raddatz, B. Stevens, and J. Marotzke. "The Max Planck Institute Grand Ensemble: Enabling the Exploration of Climate System Variability". *Journal of Advances in Modeling Earth Systems* 11:7, 2019, pp. 2050–2069. DOI: https://doi.org/10.1029/2019MS001639. eprint: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2019MS001639. URL: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019MS001639.

5. F. M. Ralph, S. Iacobellis, P. Neiman, J. Cordeira, J. Spackman, D. Waliser, G. Wick, A. White, and C. Fairall. "Dropsonde observations of total integrated water vapor transport within North Pacific atmospheric rivers". *Journal of Hydrometeorology* 18:9, 2017, pp. 2577–2596.

6. P. M. Sousa, A. M. Ramos, C. C. Raible, M. Messmer, R. Tomé, J. G. Pinto, and R. M. Trigo. "North Atlantic integrated water vapor transport—From 850 to 2100 CE: Impacts on western European rainfall". *Journal of Climate* 33:1, 2020, pp. 263–279.

7. K. E. Taylor, R. J. Stouffer, and G. A. Meehl. "An overview of CMIP5 and the experiment design". *Bulletin of the American meteorological Society* 93:4, 2012, pp. 485–498.

8. Y. Yang, C. Liu, N. Ou, X. Liao, N. Cao, N. Chen, L. Jin, R. Zheng, K. Yang, and Q. Su. "Moisture Transport and Contribution to the Continental Precipitation". *Atmosphere* 13:10, 2022. ISSN: 2073-4433. DOI: 10.3390/atmos13101694. URL: https://www.mdpi.com/2073-4433/13/10/1694.

9. Y. Zhu and R. E. Newell. "A Proposed Algorithm for Moisture Fluxes from Atmospheric Rivers". *Monthly Weather Review* 126:3, 1998, pp. 725–735. DOI: https://doi.org/10.1175/1520-0493(1998)126<0725:APAFMF>2.0.CO;2. URL: https://journals.ametsoc.org/view/journals/mwre/126/3/1520-0493_1998_126_0725_apafmf_2.0.co_2.xml.

10. I. I. Zveryaev. "Seasonality in precipitation variability over Europe". *Journal of Geophysical Research: Atmospheres* 109:D5, 2004. DOI: https://doi.org/10.1029/2003JD003668. eprint: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2003JD003668. URL: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2003JD003668.