



UNIVERSITÄT  
LEIPZIG

# **Visual Analysis of the Evolution of Moisture Transport Patterns in the North Atlantic for different Climate Scenarios**

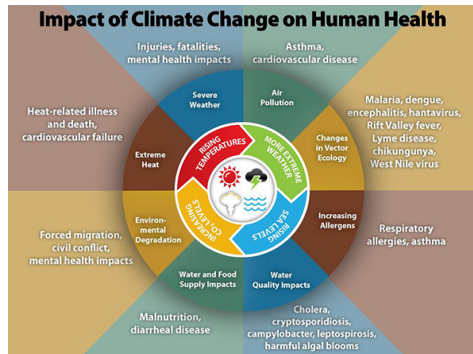
December 5, 2023

Denis Streitmatter

Abteilung für Bild- und Signalverarbeitung

## Introduction

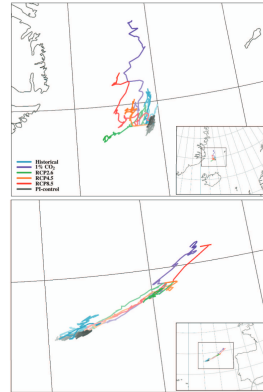
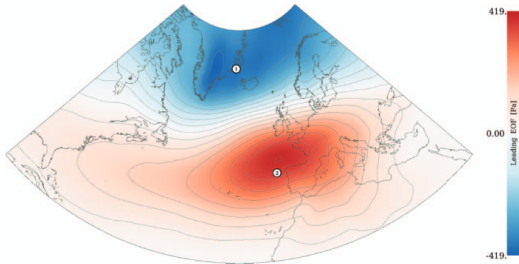
- climate change is far more than just global avg. temperature rising
- climate change has a lot of complicated consequences (regarding air pressure, winds, oceans ...)



Source: CDC

## Example: Change of North Atlantic Oscillation

See Vietinghoff *et al.* [20]

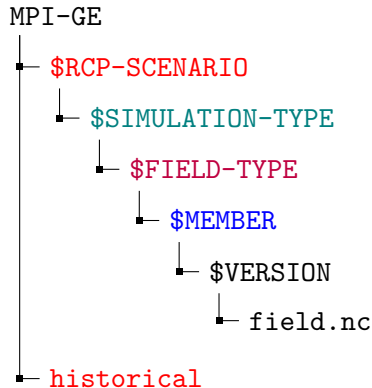


## Research Question

How do the Patterns of Moisture Transport change in the face of various climate scenarios in the North-East Atlantic?

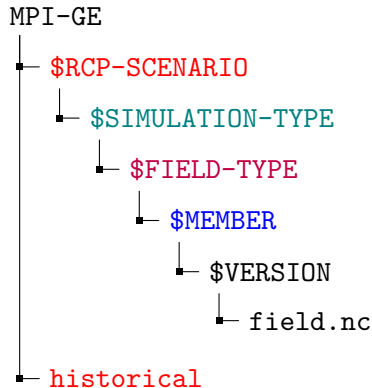
## The Max Planck Institute - Grand Ensemble

- released in 2019 by Maher *et al.* [13]



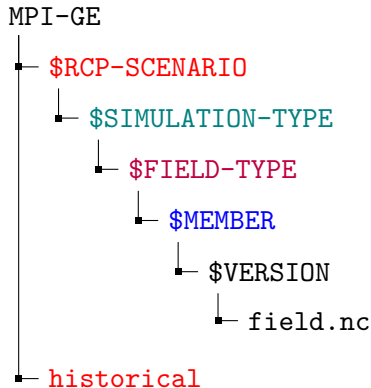
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- **RCP-SCENARIO**: IPCC term of climate change intensity, 3 different levels available



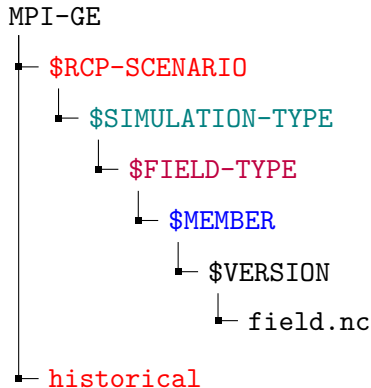
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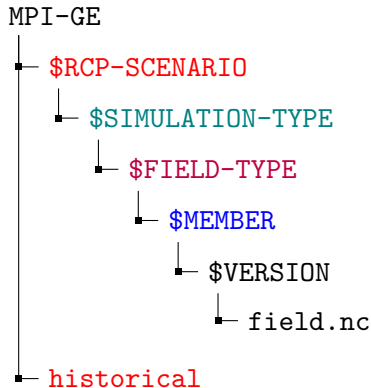
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- **TYPE**: area (land, ocean **atmosphere**)
- **FIELD**: different types of scalar fields





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- released in 2019 by Maher *et al.* [13]
- **RCP-SCENARIO**: IPCC term of climate change intensity, 3 different levels available
- **TYPE**: area (land, ocean **atmosphere**)
- **FIELD**: different types of scalar fields
- **MEMBER**: 100 different simulations  
→ uncertain scalar fields



## Quantifying Moisture (Transport) - Water Vapor Integration

1. Integrated Water Vapor (IWV) [3, 5, 7, 12]
2. **Integrated Water Vapor Transport (IVT)** [1, 2, 10, 14, 15, 19, 22]
3. Moisture Budgets [18, 21]



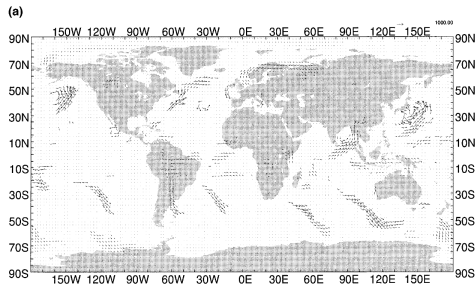
## Integrated Water Vapor Transport

Proposed by Zhu and Newell, 1998 [22]:

- Goal: find **atmospheric rivers**

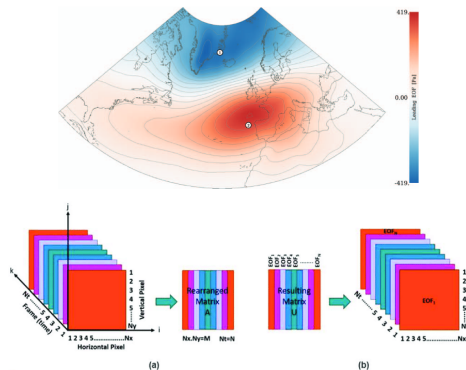
$$Q' = \hat{\mathbf{i}} \frac{1}{g} \int_{P_0}^{300hPa} \overline{q' u'} dp + \hat{\mathbf{j}} \frac{1}{g} \int_{P_0}^{300hPa} \overline{q' v'} dp$$

Since then in most cases:  $\|IVT\|_2 \rightarrow$  Scalar field [1, 2, 10, 14, 15, 19]



## Pattern Analysis with EOF

- very closely related to PCA
- very widely used in geospatial sciences (see review paper from Hannachi *et al.* [8])
- can be used for dimensionality reduction, pattern recognition ...
- applied to IVT fields [2, 9, 16]
- **Plan:** Apply a similar windowed approach as Vietinghoff *et al.*



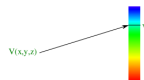
Source: researchgate

## Visualizing Uncertain Fields

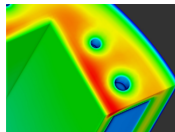
Problem of high dimensionality: 2D scalar field,  
100 members, change over time

### Ideas:

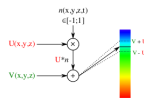
- reduce to mean
- Uncertain Isocontours (see first presentation)
- use animated Perlin noise to visualize uncertainty (see Coninx *et al.* [4])
- Visualizing Time: probably just an animation
- TODO: evaluate uncertainty vis. survey [11]



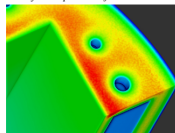
(a) Classical color scale visualization



(b) Example of color scale visualization of a temperature field



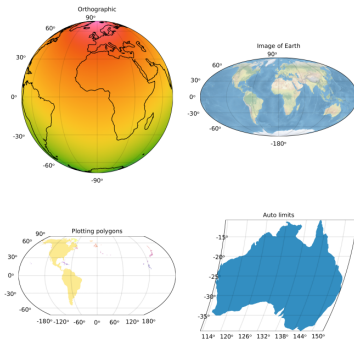
(c) Our method: the color scale lookup is biased by a Perlin noise weighted by uncertainty data



(d) Example of our visualization

## Techstack

- Dataset preparation: CDO [17]
- algorithm implementation: Julia [6]
- Important libraries:
  - (Geo)Makie for Visualisation
  - KMarkert/EmpiricalOrthogonal-Functions.jl



## Literature I

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## Literature II

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## Literature III

10. Z. Jiang *et al.*, en, *Journal of Geophysical Research: Atmospheres* **122**, 600–613 (2017).
11. A. Kamal *et al.*, en, *Journal of Visualization* **24**, 861–890 (2021).
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14. F. M. Ralph *et al.*, en, *Journal of Hydrometeorology* **18**, 2577–2596 (2017).
15. F. M. Ralph *et al.*, *Bulletin of the American Meteorological Society* **100**, 269–289 (2019).
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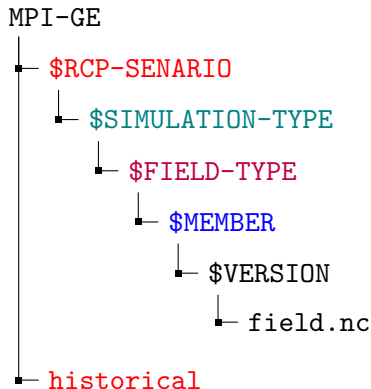
## Literature IV

17. U. Schulzweida, L. Kornblueh, R. Quast, *CDO user guide*, 2019.
18. R. Seager *et al.*, en, *Journal of Climate* **33**, 7179–7196 (2020).
19. P. M. Sousa *et al.*, en, *Journal of Climate* **33**, 263–279 (2020).
20. D. Vietinghoff *et al.*, en, presented at the 2021 IEEE 14th Pacific Visualization Symposium (PacificVis), pp. 71–80.
21. Y. Yang *et al.*, en, *Atmosphere* **13**, 1694 (2022).
22. Y. Zhu, R. E. Newell, en, *Monthly Weather Review* **126**, 725–735 (1998).

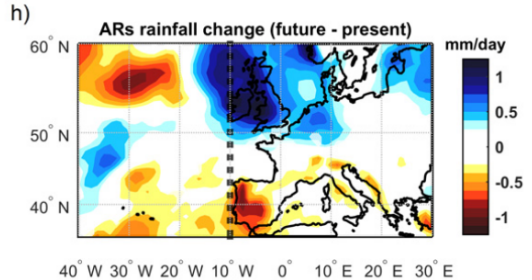
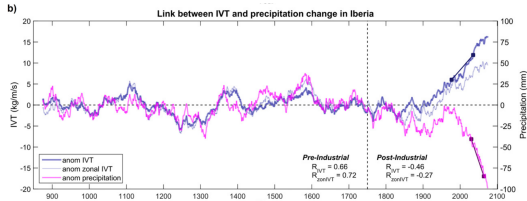
## The Max Planck Institute - Grand Ensemble [13]

### Field Types

- 32 different fields for the atmosphere
- Resolution: Lat/Long:  $1.875^\circ$  , Time: monthly averages, Vertical: 26 Levels from 10 to 100000 *Pa*
- Examples: evaporation, precipitation, horizontal wind speed, specific humidity



# Integrated Water Vapor Transport



## My current plan

1. Filter the MPI-GE for my needs
2. Generate an IVT field from the MPI-GE
3. Implement a similar windowed EOF approach as in [20] to track changes in moisture transport patterns
  - maybe apply concept of atmospheric rivers to the analysis
  - maybe also implement/use some other analyses from similar work
4. Visualize the uncertain Scalar Fields over time