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

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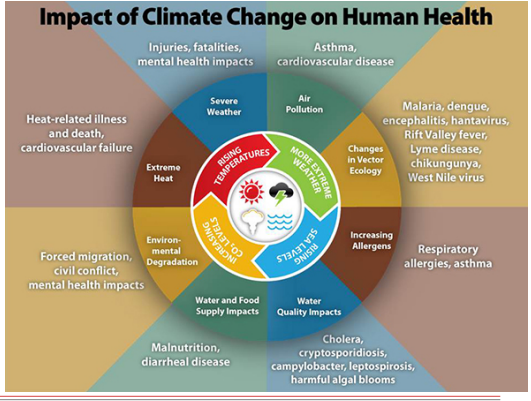
Denis Streitmatter

Abteilung für Bild- und Signalverarbeitung

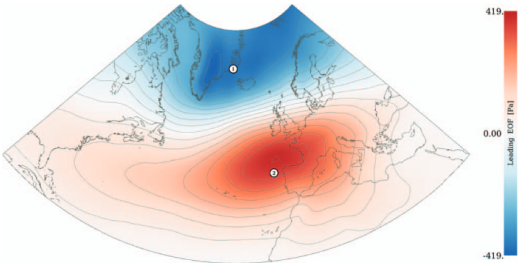
Introduction

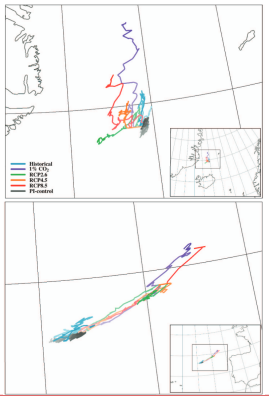
- global avg. temperature rising $\subset$ climate change
- climate change has a lot of complicated consequences (air pressure, winds, oceans ...)



Example: Change of North Atlantic Oscillation

See Vietinghoff *et al.* [17]



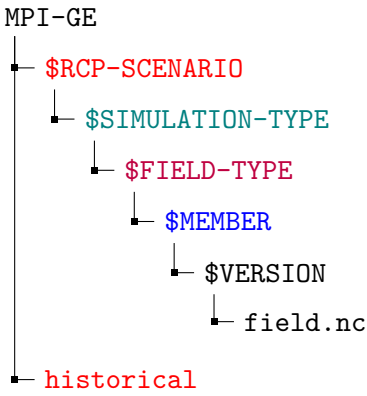


Research Questions

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

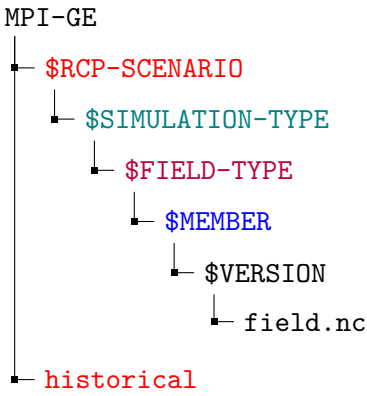
The Max Planck Institute - Grand Ensemble

- released in 2019 by Maher *et al.* [11]



The Max Planck Institute - Grand Ensemble

- released in 2019 by Maher *et al.* [11]
- RCP-SCENARIO: IPCC term of climate change intencity, 3 different levels available



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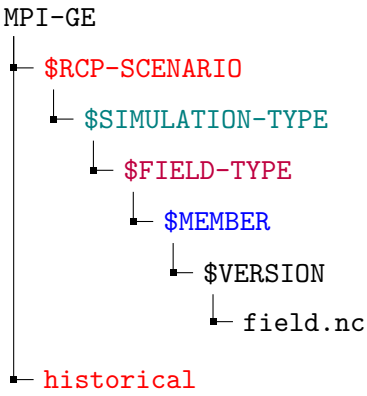

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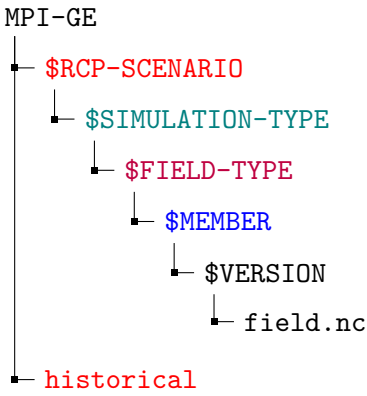
- RCP-SCENARIO: IPCC term of climate change intencity, 3 different levels available
- TYPE: area (land, ocean **atmosphere**)
- FIELD: different types of scalar fields



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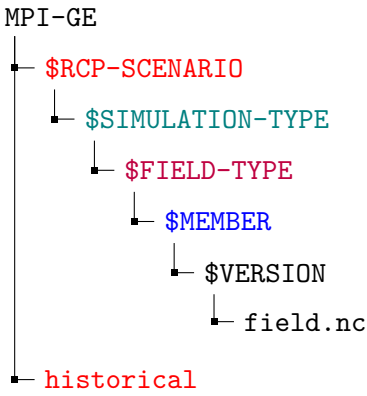
- RCP-SCENARIO: IPCC term of climate change intencity, 3 different levels available
- TYPE: area (land, ocean **atmosphere**)
- FIELD: different types of scalar fields
- MEMBER: 100 different simulations
  $\rightarrow$ uncertain scalar fields



Quantifynig Moisture (Transport) - Water Vapor Integration

1. Integrated Water Vapor (IWV) [3, 5, 7, 10]
2. **Integrated Water Vapor Transport (IVT)** [1, 2, 9, 12, 13, 16, 19]
3. Moisture Budgets [15, 18]

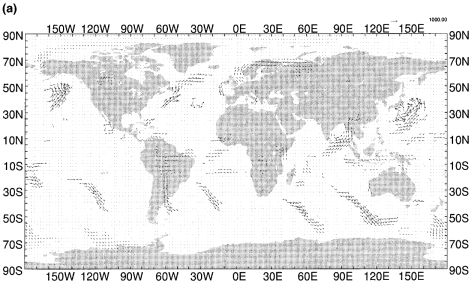
Integrated Water Vapor Transport

First proposed by Zhu and Newell, 1998 [19]:

- Goal: find **atmospheric rivers**

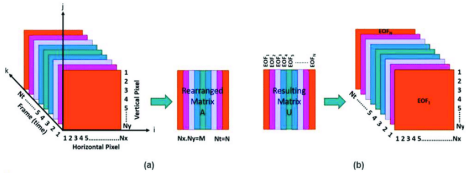
$$Q' = \hat{\mathbf{i}}\frac{1}{g}\int_{P_0}^{300hPa}\overline{q'u'}dp + \hat{\mathbf{j}}\frac{1}{g}\int_{P_0}^{300hPa}\overline{q'v'}dp$$

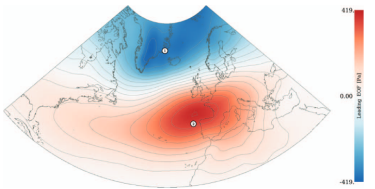
Since then in most cases: $||IVT||_2 \rightarrow$ Scalar field [1, 2, 9, 12, 13, 16]



Pattern Analysis with EOF

- For those familiar: it is related to PCA
- very widely used in geospatial sciences (see review paper from Hannachi *et al.* [8])
- can be used for dimensionality reduction, filtering, variability pattern recognition ...
- already been used for IVT fields (Ayantobo *et al.* [2])





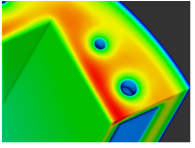
My current plan

1. Generate an IVT field from the MPI-GE
2. Implement a similar windowed EOF approach as in [17] to track changes in moisture transport patterns
   - maybe also implement/use some other analyses from similar work
3. Visualize the uncertain Scalar Fields over time

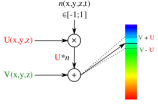
Visualizing Uncertain Fields

- Problem: 100 Ensemble Members → 100 different results
- reduce to mean
- Uncertain Isocontours (Countour Boxplot etc., see first presentation)
- use animated Perlin noise to visualize uncertainity (see Coninx *et al.* [4])
- Visualizing Time: probably just an animation

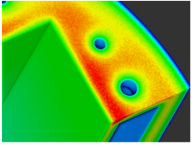
(a) *Classical color scale visualization*



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



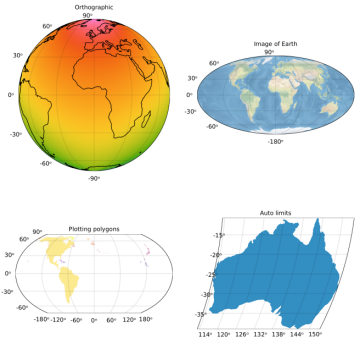
(c) *Our method: the color scale lookup is biased by a Perlin noise weighted by uncertainty data*



(d) *Example of our visualization*

Techstack

- Dataset preparation: CDO [14]
- algorithm implementation: Julia [6]
- Important libraries:
  - (Geo)Makie for Visualisation
  - KMarkert/EmpiricalOrthogonal-Functions.jl



Literature I

1. R. P. Allan, D. A. Lavers, A. J. Champion, en, *International Journal of Climatology* **36**, 3191–3206 (2016).
2. O. O. Ayantobo, J. Wei, B. Kang, G. Wang, en, *Theoretical and Applied Climatology* **147**, 985–1002 (2022).
3. J.-W. Bao, S. A. Michelson, P. J. Neiman, F. M. Ralph, J. M. Wilczak, en, *Monthly Weather Review* **134**, 1063–1080 (2006).
4. A. Coninx, G.-P. Bonneau, J. Droulez, G. Thibault, en, presented at the Proceedings of the ACM SIGGRAPH Symposium on Applied Perception in Graphics and Visualization, pp. 59–66.

Literature II

5. J. Eiras-Barca, S. Brands, G. Miguez-Macho, en, *Journal of Geophysical Research: Atmospheres* **121**, _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/2015JD023379, 931–948 (2016).
6. K. Gao *et al.*, *Computer Science Review* **37**, 100254 (2020).
7. L. Gimeno, R. Nieto, M. Vázquez, D. Lavers, *Frontiers in Earth Science* **2** (2014).
8. A. Hannachi, I. T. Jolliffe, D. B. Stephenson, en, *International Journal of Climatology* **27**, 1119–1152 (2007).
9. Z. Jiang *et al.*, en, *Journal of Geophysical Research: Atmospheres* **122**, 600–613 (2017).
10. Y. Ma, M. Lu, H. Chen, M. Pan, Y. Hong, en.

Literature III

11. N. Maher *et al.*, en, *Journal of Advances in Modeling Earth Systems* **11**, 2050–2069 (2019).
12. F. M. Ralph *et al.*, en, *Journal of Hydrometeorology* **18**, 2577–2596 (2017).
13. F. M. Ralph *et al.*, *Bulletin of the American Meteorological Society* **100**, 269–289 (2019).
14. U. Schulzweida, L. Kornblueh, R. Quast, *CDO user guide*, 2019.
15. R. Seager *et al.*, en, *Journal of Climate* **33**, 7179–7196 (2020).
16. P. M. Sousa *et al.*, en, *Journal of Climate* **33**, 263–279 (2020).
17. D. Vietinghoff *et al.*, en, presented at the 2021 IEEE 14th Pacific Visualization Symposium (PacificVis), pp. 71–80.
18. Y. Yang *et al.*, en, *Atmosphere* **13**, 1694 (2022).

Literature IV

19. Y. Zhu, R. E. Newell, en, *Monthly Weather Review* **126**, 725–735 (1998).