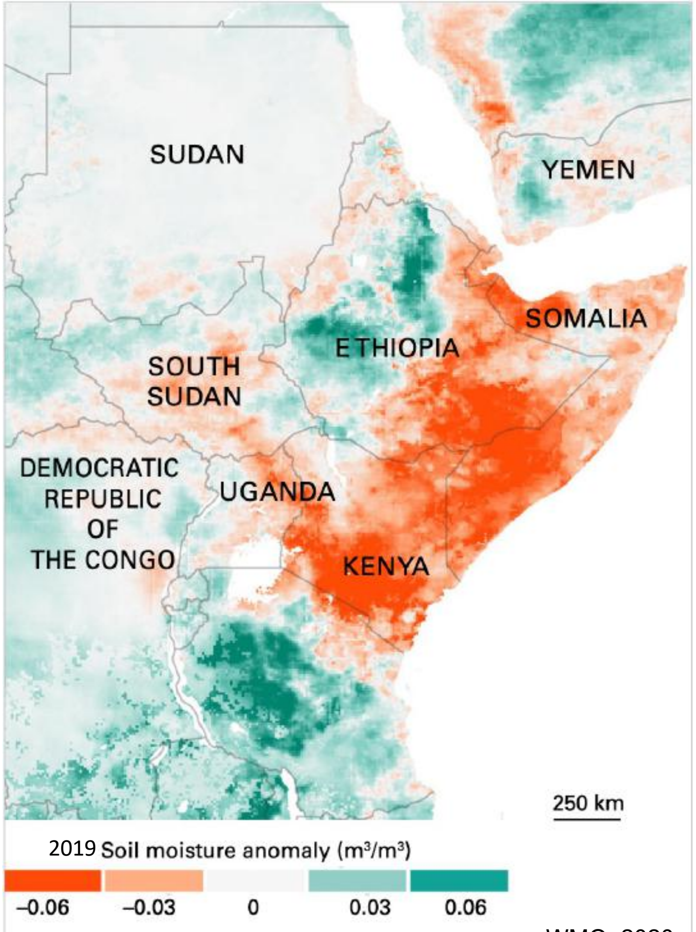
Classification of weather patterns for the Greater Horn of Africa using cluster analysis

Jan Weber

Motivation

- Climate services still weak in East Africa despite improved financing opportunities, according to WMO
- Rainfall distribution becomes more extreme
- Existing water availability problems are becoming more severe
- Ethiopia had third highest number of IDPs globally in 2019, most of them climate refugees

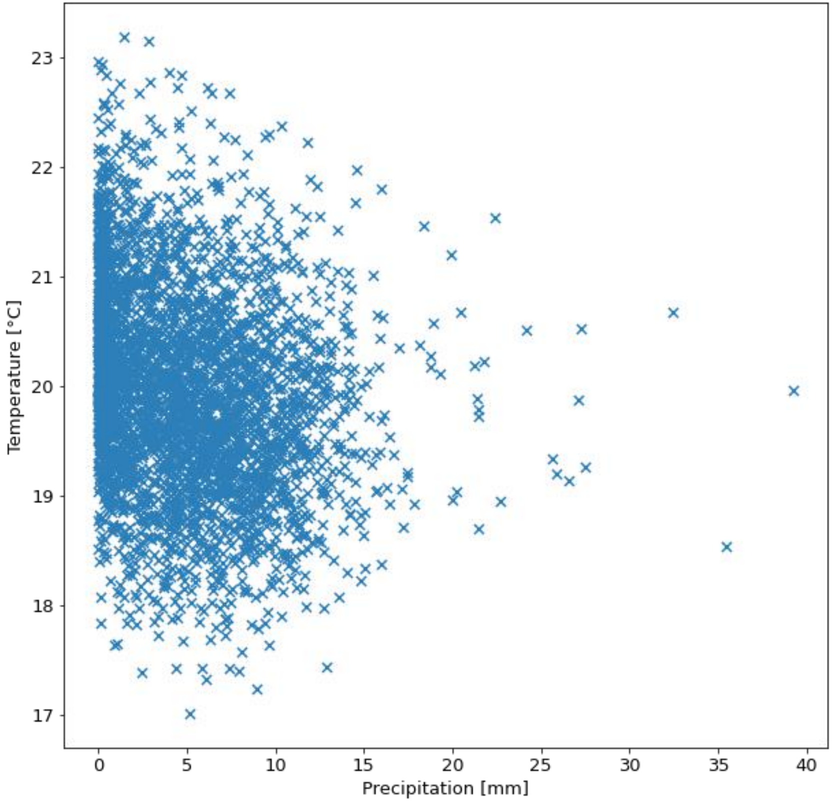


WMO, 2020

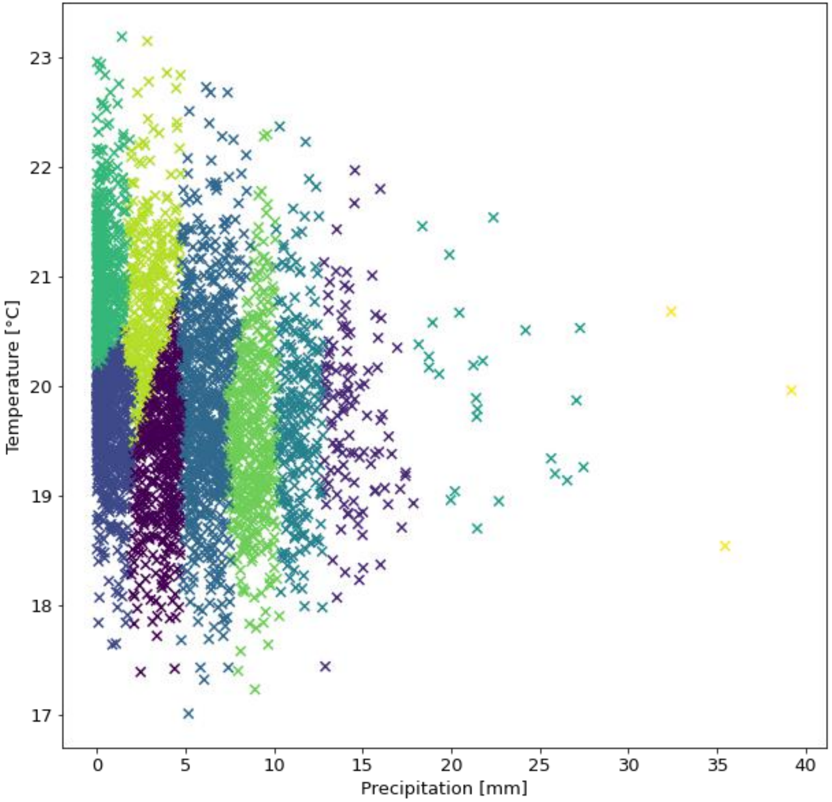
Method: Cluster Analysis

- Clustering is a good tool to study extreme weather events
- The cause for extreme periods with long-lasting impacts can be detected
- The crucial variables for these weather situations are determined

Clustering

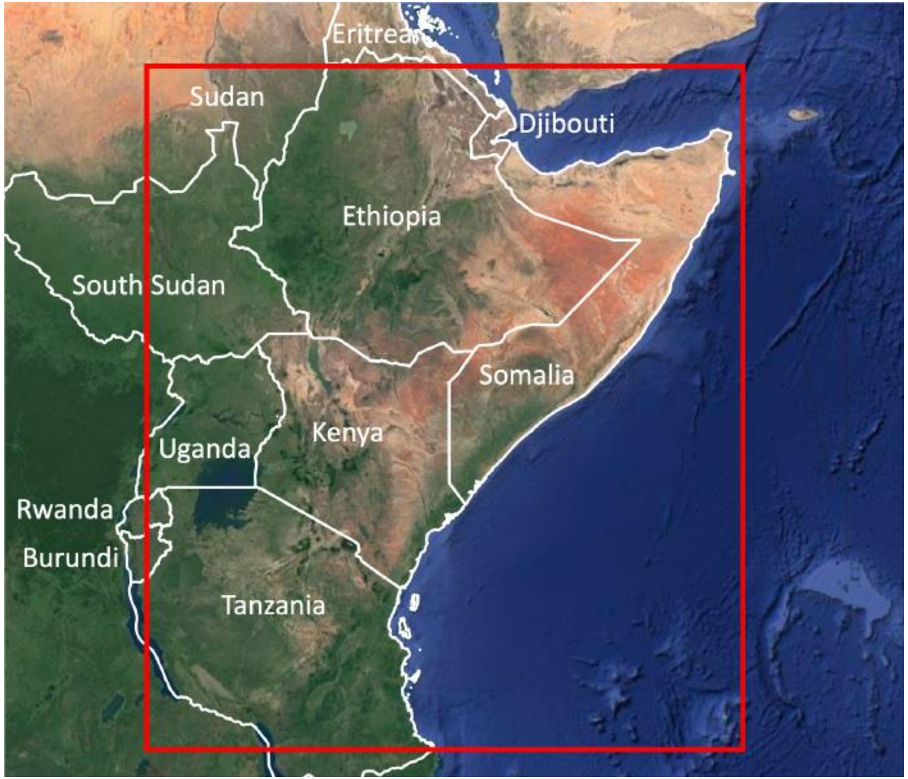


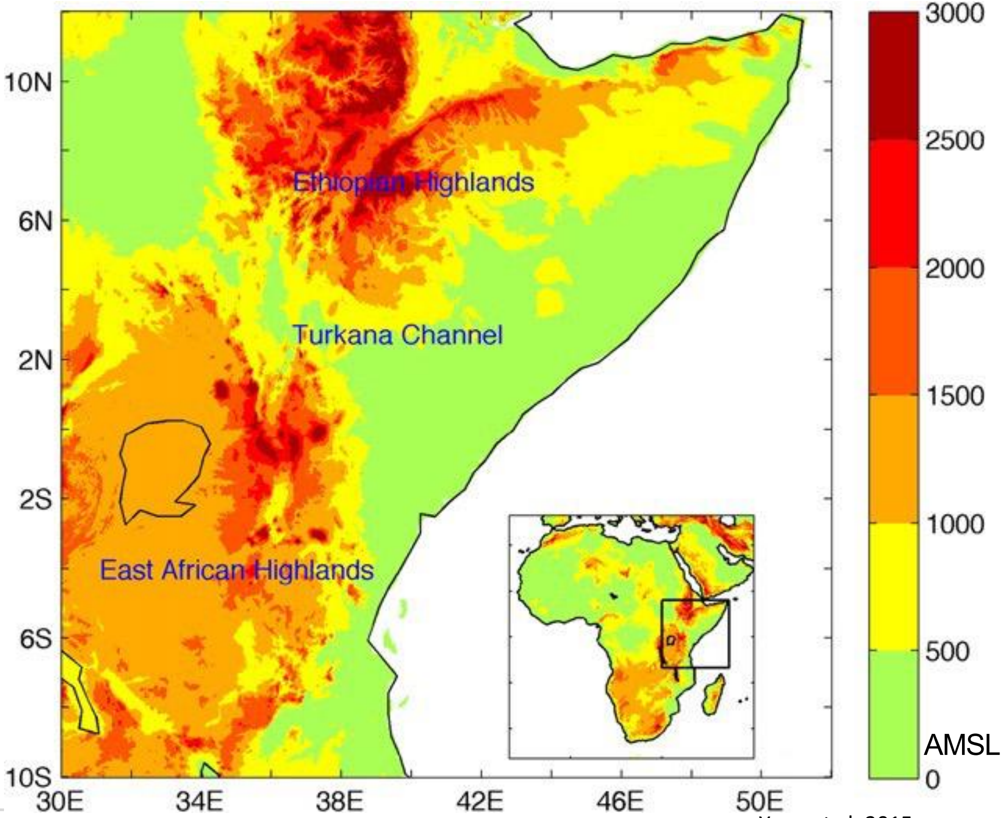
Temperature [°C]
Precipitation [mm]



Temperature [°C]
Precipitation [mm]

Study Area





YANG et al. 2015

Trends 1981–2018: Overview

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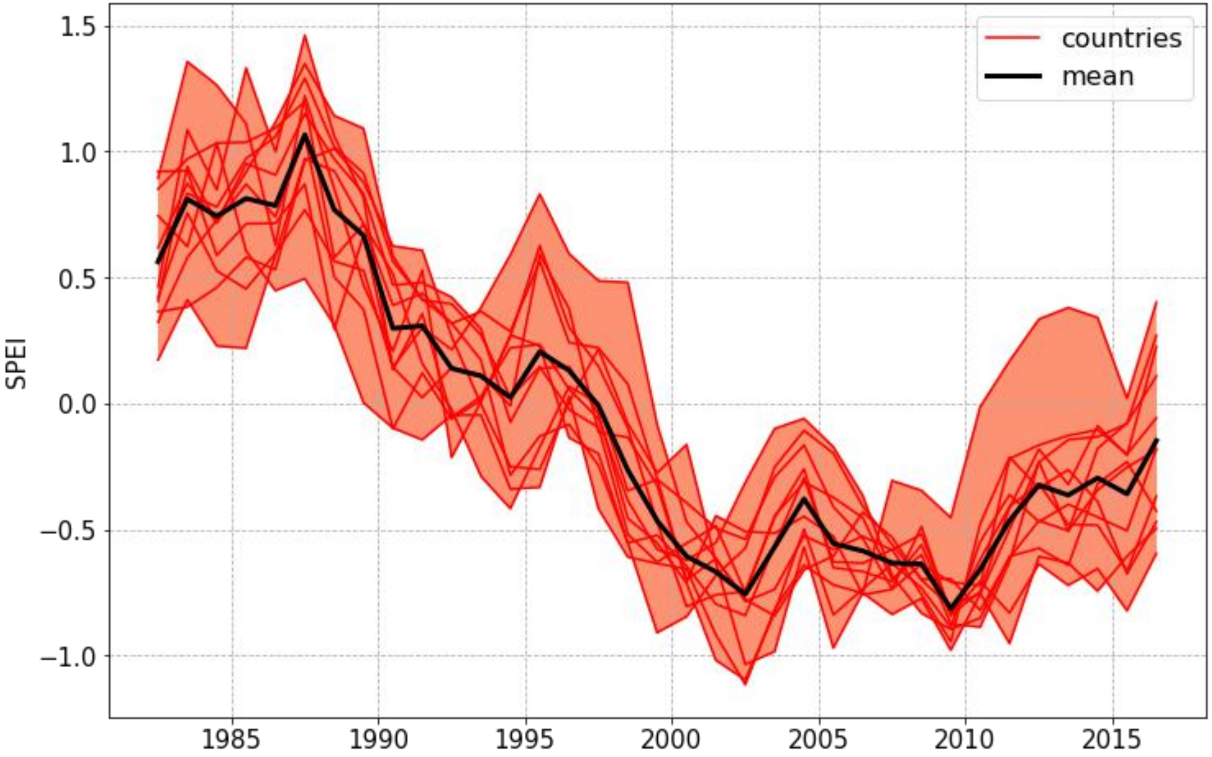
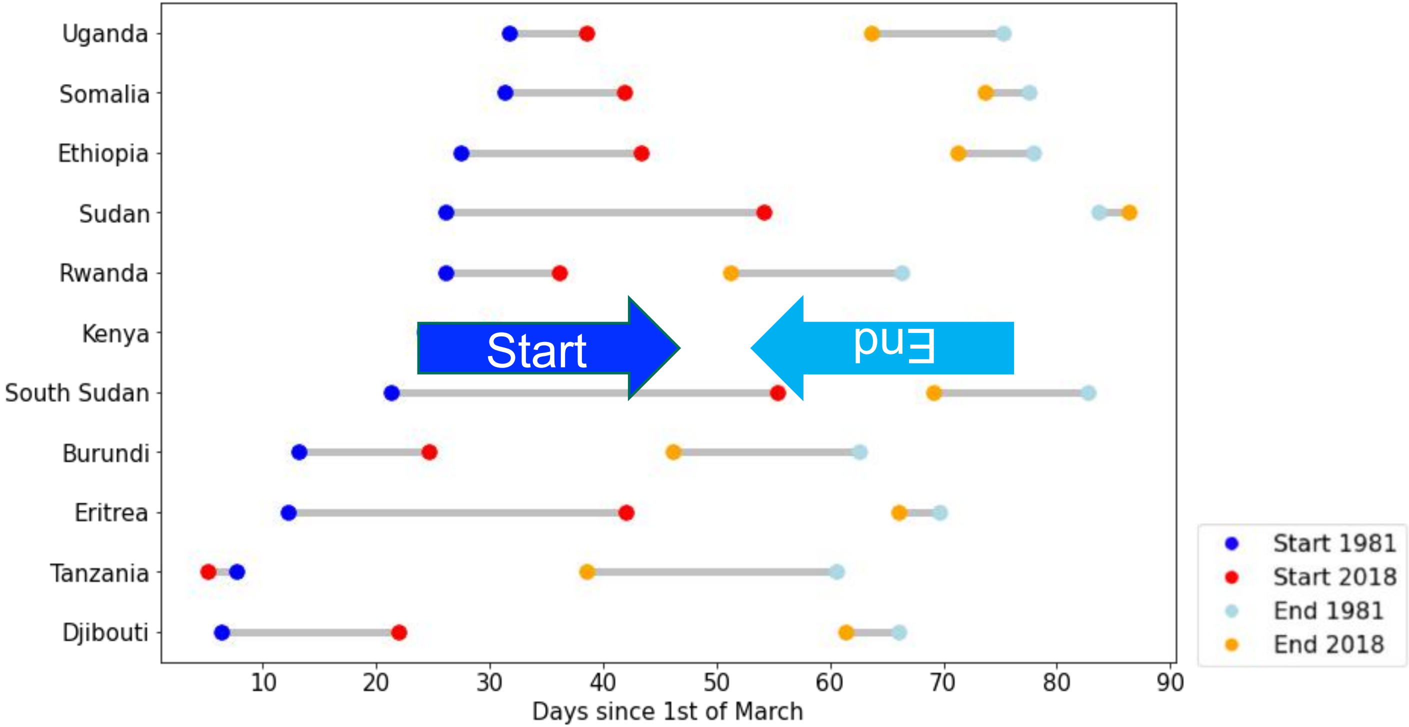
	Burundi	Djibouti	Eritrea	Ethiopia	Kenya	Rwanda	Somalia	Tanzania	S. Sudan	Sudan	Uganda
Temp.	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Prec.	↓	↓	↓	↘	↘	↓	↓	→	↓	↓	↓
SPEI	↓	↓	↓	↓	↓	↓	↓	↘	↓	↓	↓
Drought Days	↑	↑	↑	↑	↗	↑	↑	↑	↑	↑	↑
Freq. of extreme Prec.	↓	↓	↓	↓	↘	↓	→	↘	↓	↓	↓
Days above 95 % Temp	↑	↗	↑	↗	↑	↑	↑	↑	↑	↑	↑

Arrows at 0° or 180°: Significant at $\alpha = 0.05$
Arrows at 45° or 135°: Significant at $\alpha = 0.10$

Trends 1981–2018: SPEI



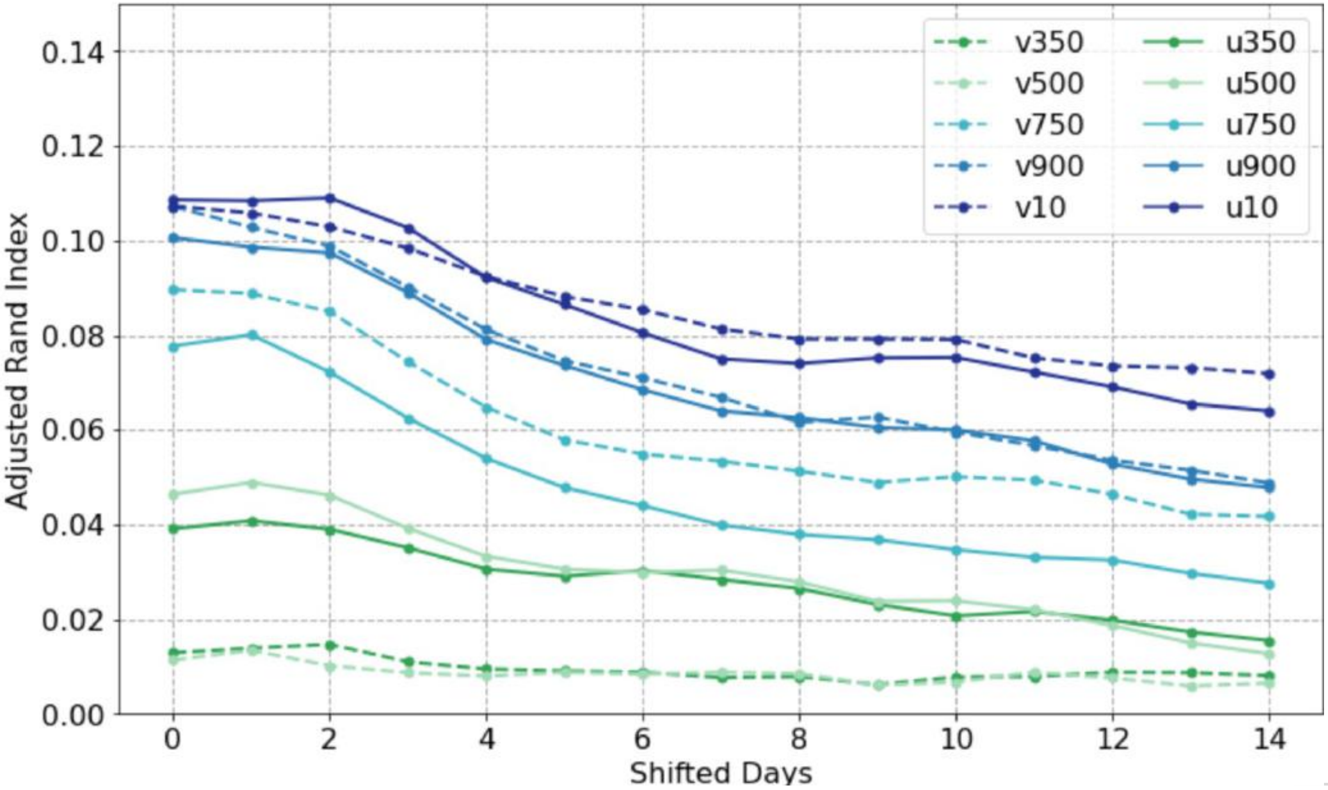
Trends 1981–2018: Start and end of the rainy season



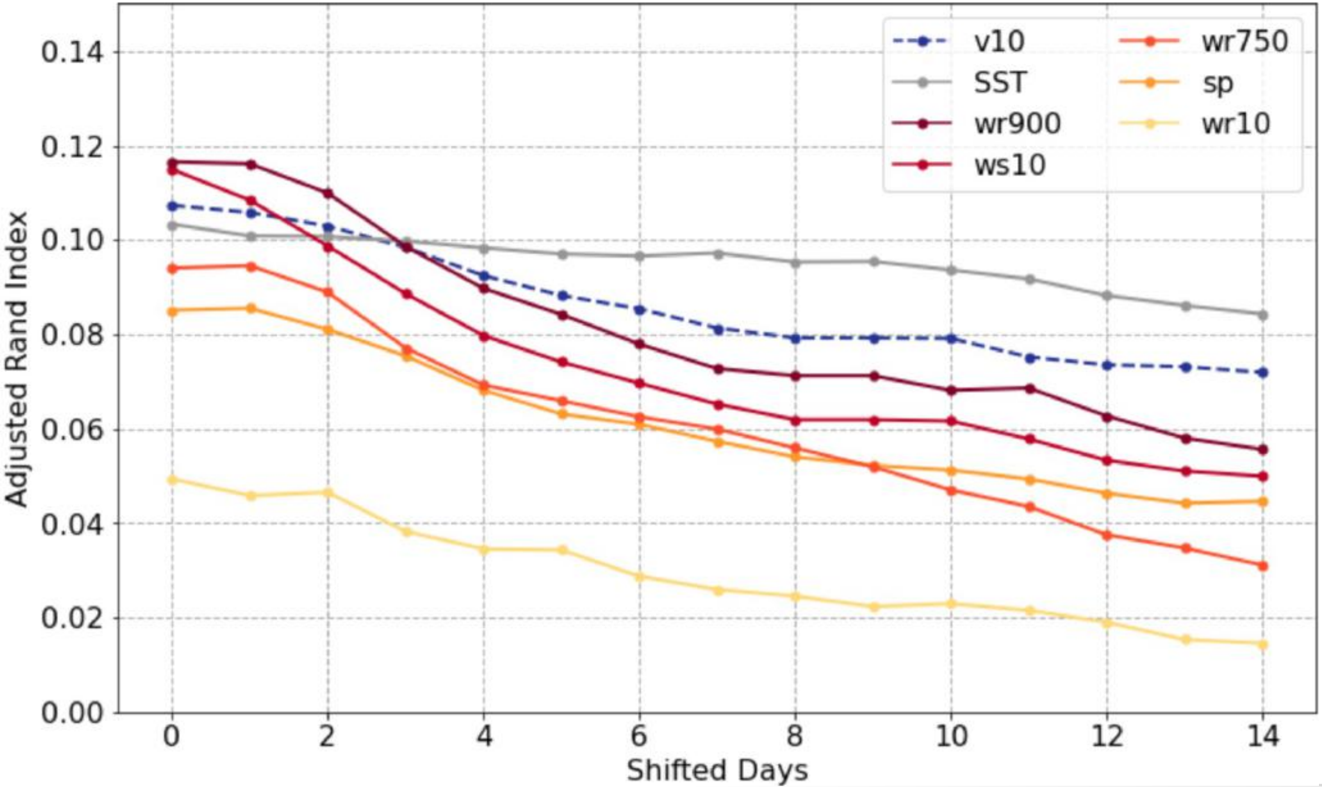
Clustering

- Algorithm used: Simulated ANnealing and Diversified RAndomization (SANDRA)
- Variables investigated: v- and u-Wind, wind direction and strength on different levels, SST and surface pressure
- The number of clusters is 11 for the precipitation and 9 for the variables

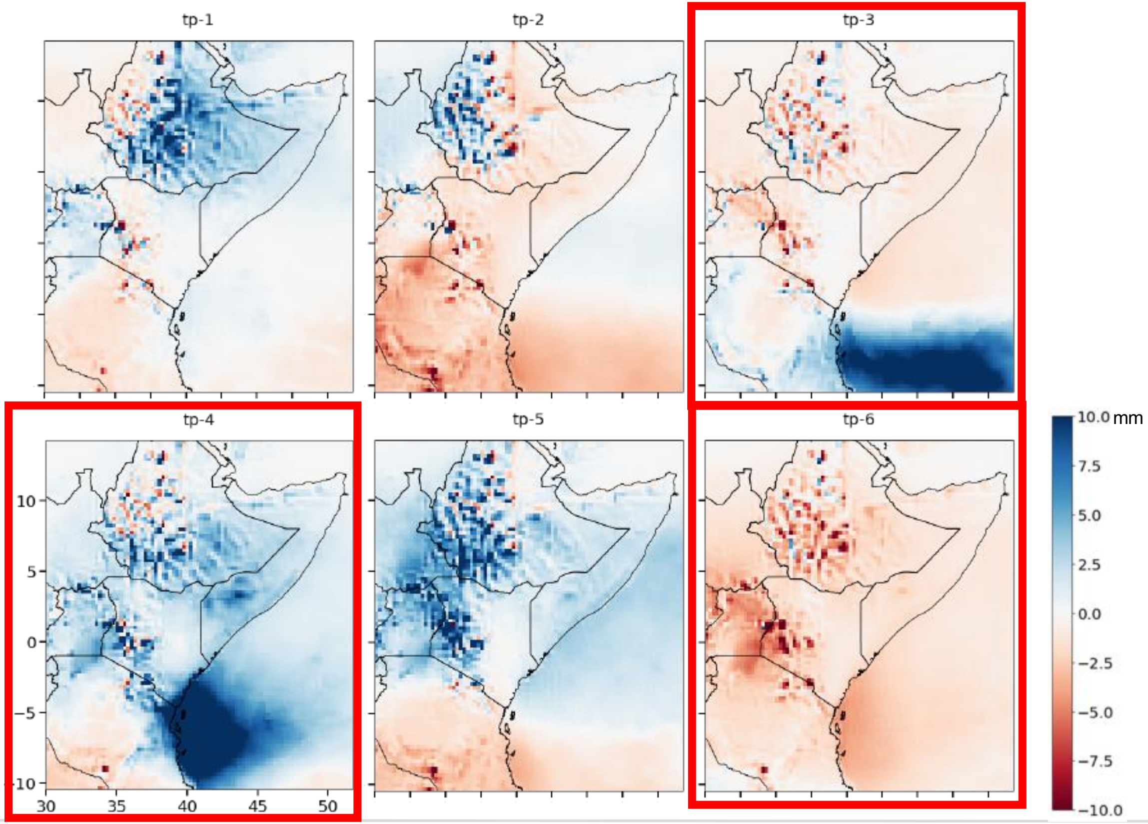
Selection of the variables – u-/v-Wind



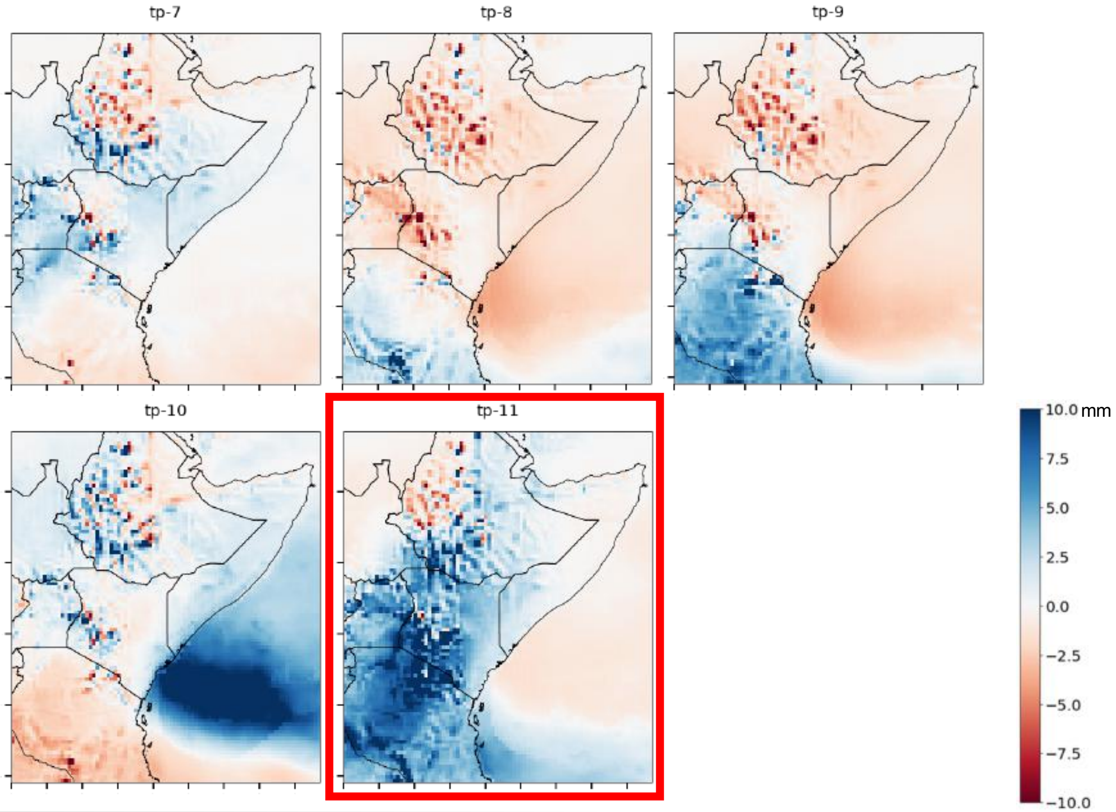
Selection of the variables



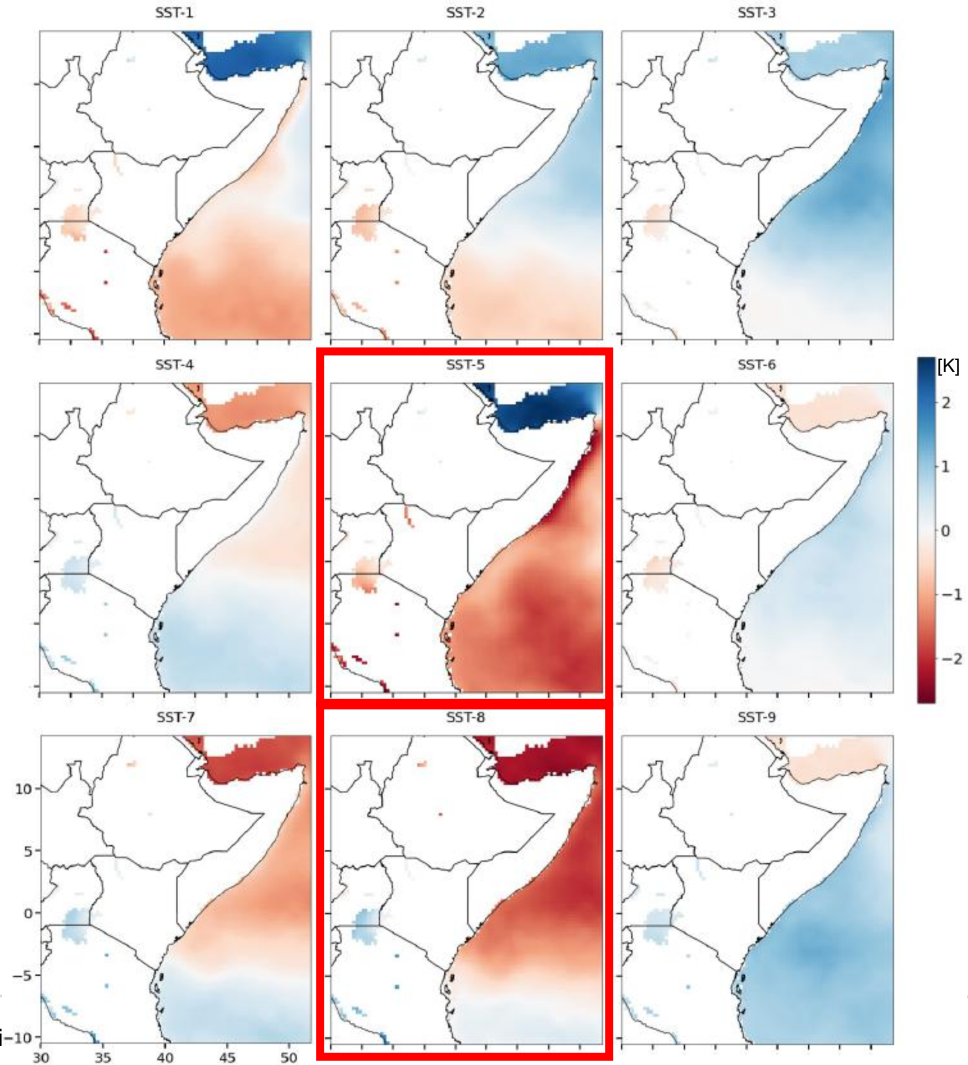
Precipitation Clusters



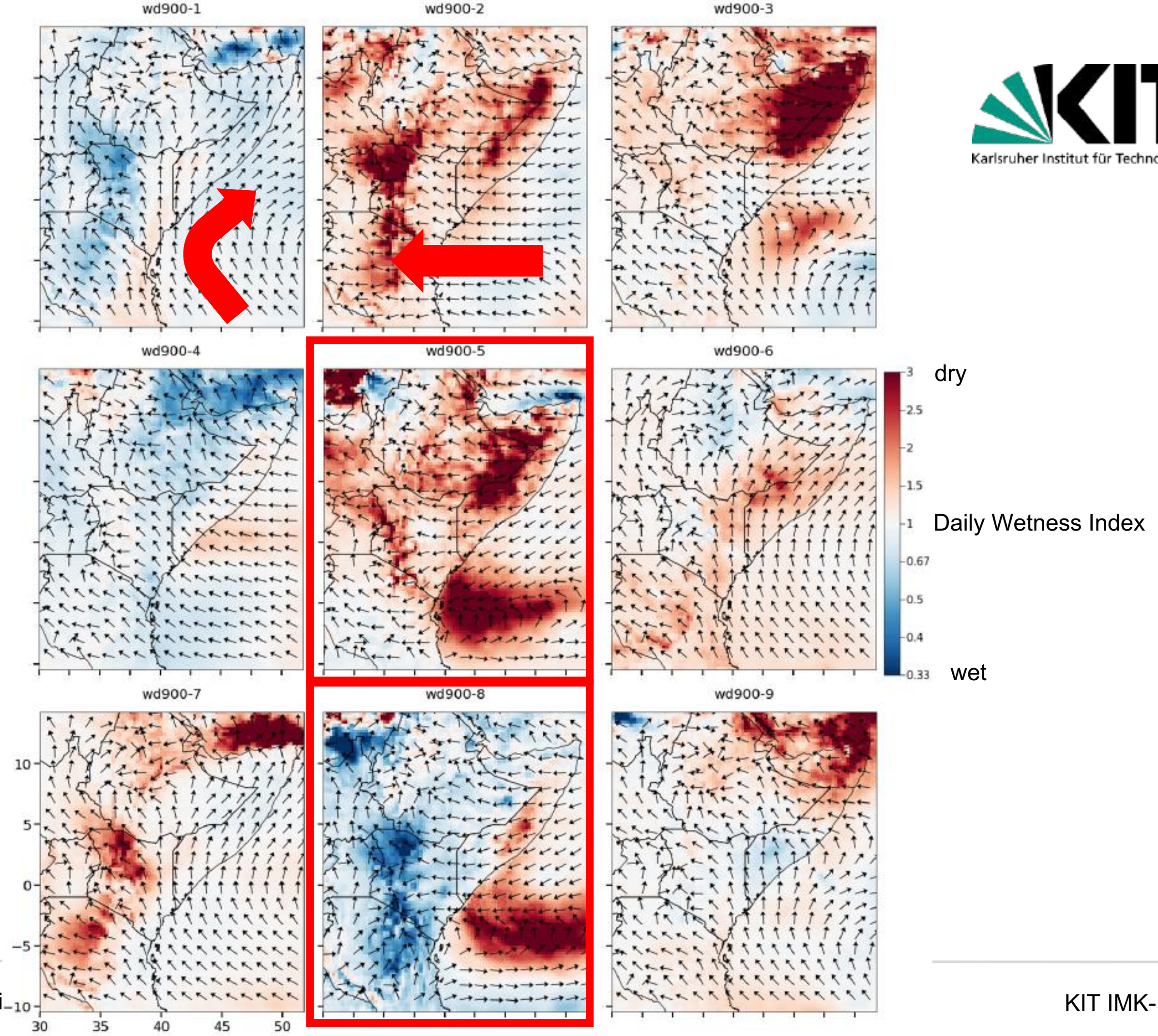
Precipitation Clusters



SST Clusters



Wind Clusters



Monthly occurrence of the clusters 1981–2018

CLUSTER	MARCH	APRIL	MAY	MEAN DAY
SST-1	0 %	0 %	100 %	79.8
SST-2	0 %	19 %	81 %	67.2
SST-3	0 %	65 %	35 %	57.8
SST-4	72 %	28 %	0 %	25.3
SST-5	0 %	0 %	100 %	85.7
SST-6	3 %	94 %	2 %	44.2
SST-7	99 %	1 %	0 %	13.2
SST-8	100 %	0 %	0 %	6.5
SST-9	28 %	72 %	0 %	35.5
WD-1	2 %	48 %	51 %	59.3
WD-2	75 %	23 %	2 %	22.0
WD-3	65 %	35 %	0 %	24.3
WD-4	40 %	54 %	6 %	35.1
WD-5	94 %	6 %	0 %	12.2
WD-6	0 %	4 %	96 %	80.0
WD-7	0 %	30 %	69 %	67.2
WD-8	95 %	5 %	0 %	13.3
WD-9	19 %	76 %	6 %	41.7
TP-1	17 %	56 %	27 %	49.8
TP-2	1 %	8 %	91 %	76.8
TP-3	43 %	49 %	8 %	34.8
TP-4	1 %	52 %	48 %	60.8
TP-5	0 %	33 %	67 %	65.8
TP-6	58 %	25 %	17 %	32.0
TP-7	10 %	61 %	28 %	50.8
TP-8	73 %	26 %	1 %	21.6
TP-9	77 %	23 %	0 %	19.4
TP-10	1 %	15 %	84 %	71.0
TP-11	49 %	50 %	1 %	30.0

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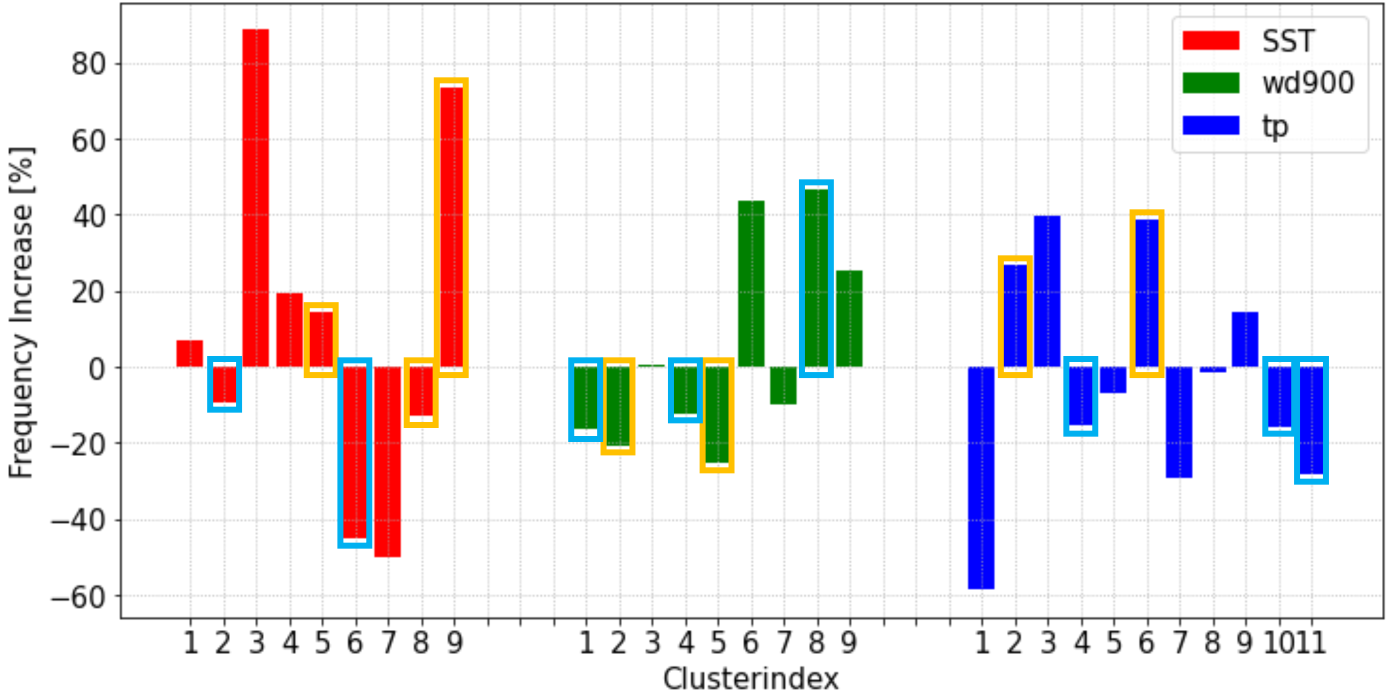
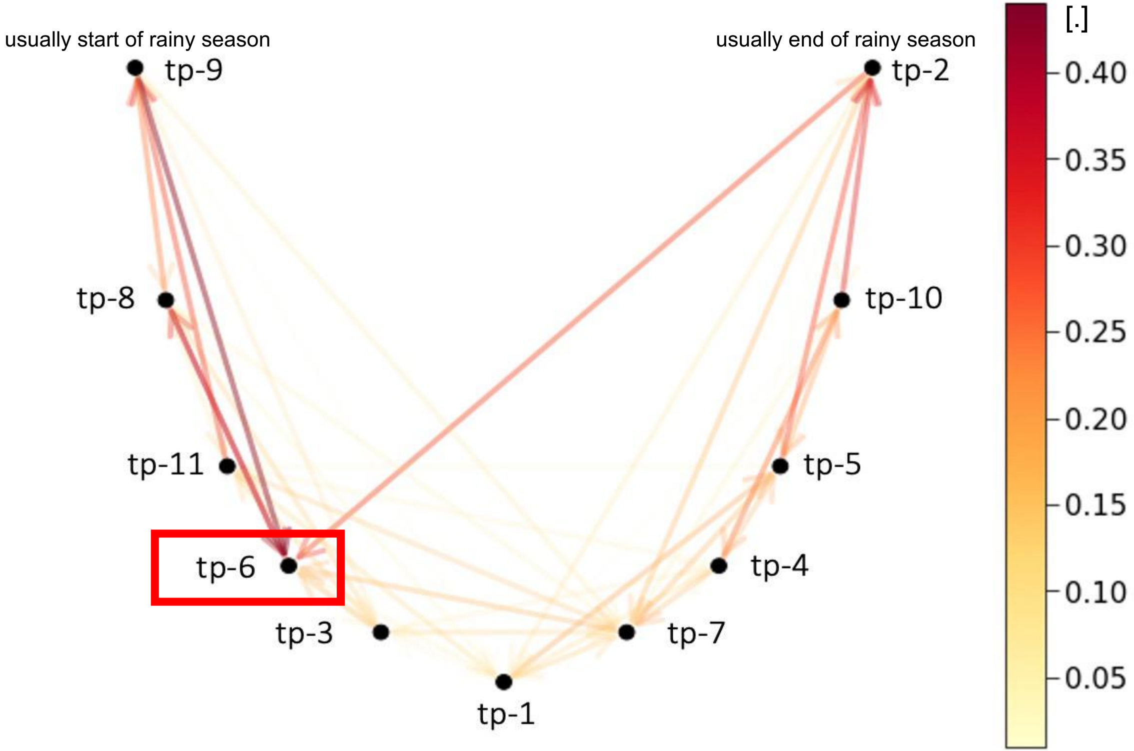
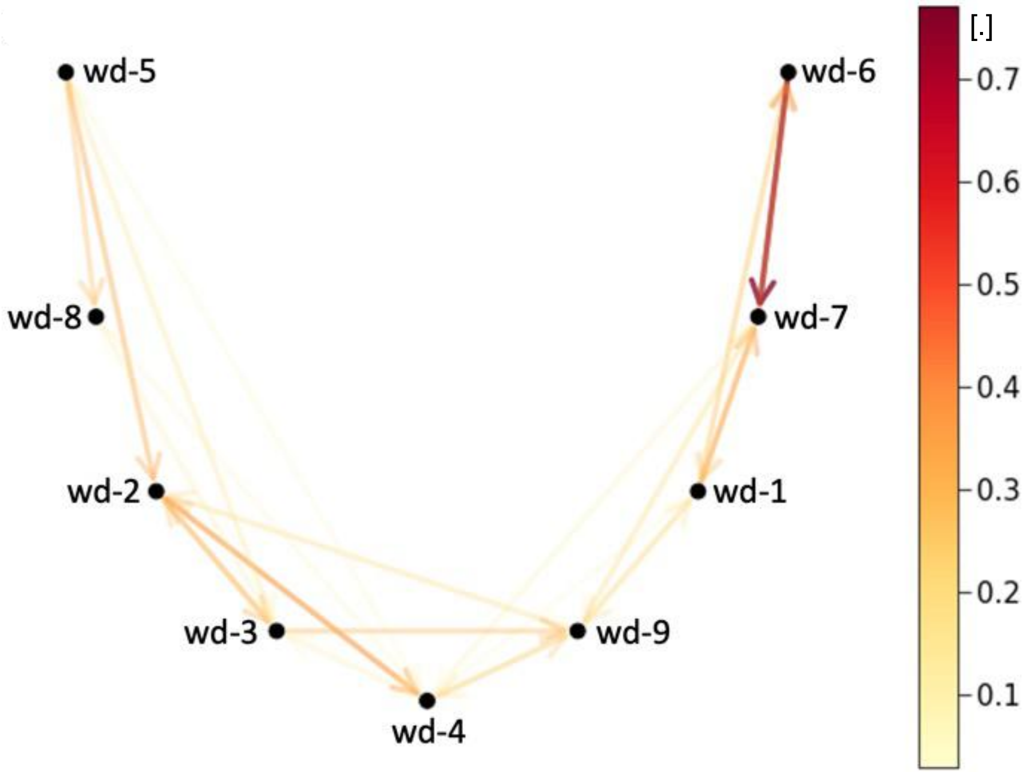
Frequency change in each cluster 1981–2018



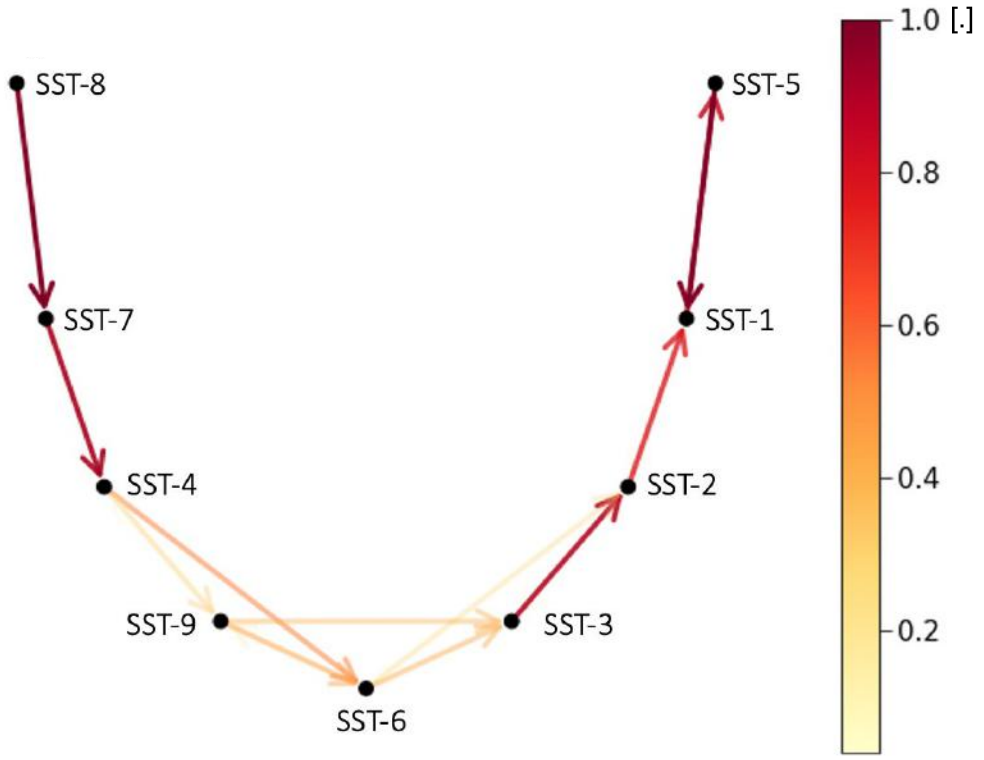
Transition probabilities – Precipitation



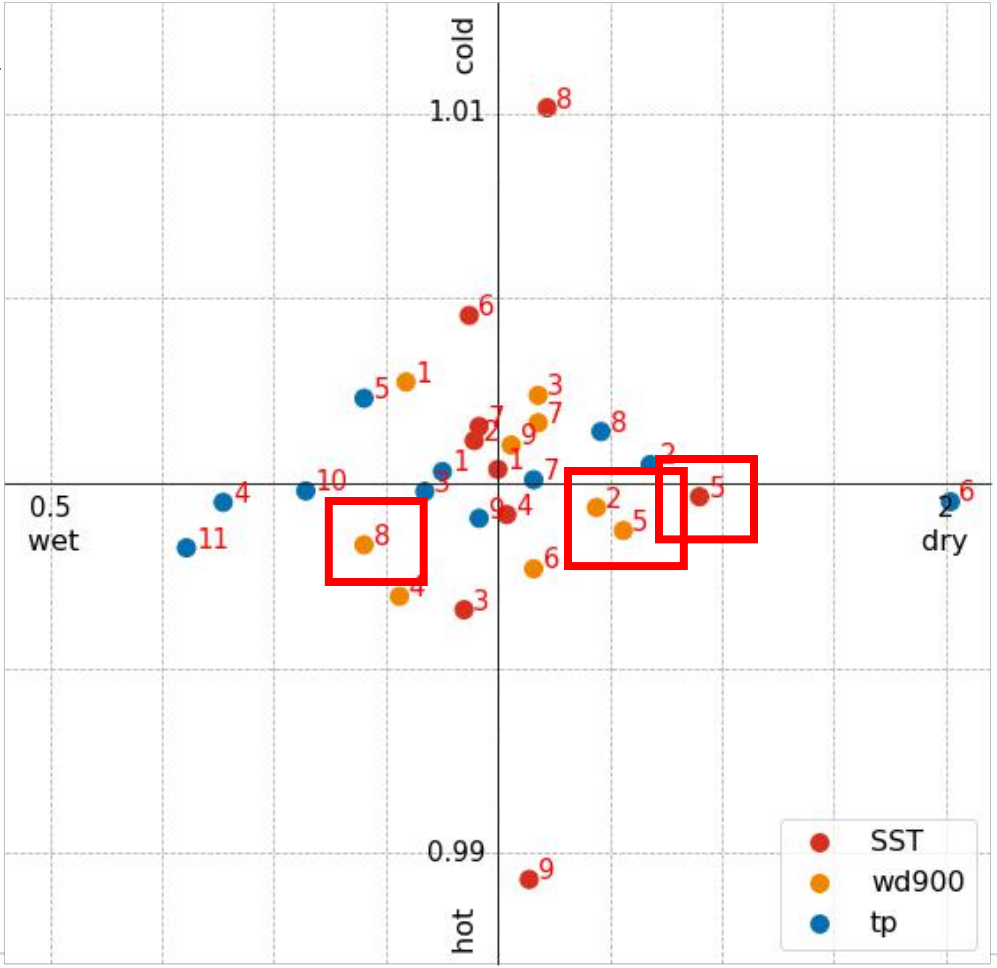
Transition probabilities – Wind 900 hPa



Transition probabilities – SST



Daily Wetness & Temperature Index



Correlation frequency Wind-/ Precipitation-cluster

	wd-1	wd-2	wd-3	wd-4	wd-5	wd-6	wd-7	wd-8	wd-9
tp-1	0.20	-0.11	-0.15	0.25	0.09	0.10	-0.21	-0.16	-0.10
tp-2	-0.36	-0.01	0.19	-0.16	-0.29	0.33	0.34	-0.16	0.08
tp-3	-0.11	0.33	0.22	0.11	0.05	-0.16	-0.01	0.05	-0.33
tp-4	0.22	-0.04	-0.30	0.16	0.04	-0.31	-0.10	0.16	0.18
tp-5	0.46	-0.01	-0.22	0.04	0.13	-0.04	-0.42	0.15	-0.13
tp-6	-0.18	0.20	0.28	-0.04	0.26	0.04	-0.02	-0.09	-0.34
tp-7	0.00	-0.04	-0.10	0.04	-0.27	-0.01	0.05	-0.18	0.45
tp-8	-0.39	0.02	0.04	-0.11	0.32	0.02	0.30	-0.22	0.10
tp-9	-0.16	-0.15	0.08	-0.09	-0.22	-0.02	0.20	0.57	-0.13
tp-10	0.25	-0.13	-0.13	-0.27	0.25	-0.42	0.04	0.17	0.16
tp-11	0.37	-0.20	-0.23	0.10	-0.28	0.11	-0.28	-0.01	0.24

Significant correlations (α = 0.05) are marked in red

Correlation frequency SST to precipitation

	tp Burundi	tp Djibouti	tp Eritrea	tp Ethiopia	tp Kenya	tp Rwanda	tp Somalia	tp Tanzania	tp S. Sudan	tp Sudan	tp Uganda	tp Indian Ocean	tp Area
SST-1	-0.27	-0.19	-0.17	-0.04	-0.24	-0.28	-0.02	-0.39	-0.03	-0.01	-0.13	-0.23	-0.25
SST-2	0.03	0.10	-0.02	0.05	-0.14	0.06	0.03	-0.03	0.13	0.03	-0.03	0.07	0.02
SST-3	-0.03	-0.17	-0.02	0.06	0.25	-0.01	0.16	-0.04	-0.11	-0.07	0.00	0.15	0.14
SST-4	-0.32	-0.11	-0.25	-0.32	-0.36	-0.30	-0.29	-0.39	-0.31	-0.34	-0.21	-0.26	-0.41
SST-5	0.00	0.02	0.05	-0.06	0.20	0.01	0.02	0.23	-0.13	-0.15	0.05	-0.27	-0.03
SST-6	0.28	0.24	0.09	0.17	0.12	0.18	-0.01	0.35	0.27	0.16	0.21	-0.03	0.15
SST-7	0.37	0.27	0.22	0.18	0.05	0.30	0.13	0.25	0.38	0.44	0.24	0.19	0.19
SST-8	-0.06	-0.15	-0.13	-0.14	-0.22	0.01	-0.12	-0.08	0.09	0.14	-0.11	-0.10	-0.26
SST-9	-0.10	-0.04	0.09	-0.01	0.07	-0.07	0.00	-0.07	-0.22	-0.16	-0.08	0.19	0.14

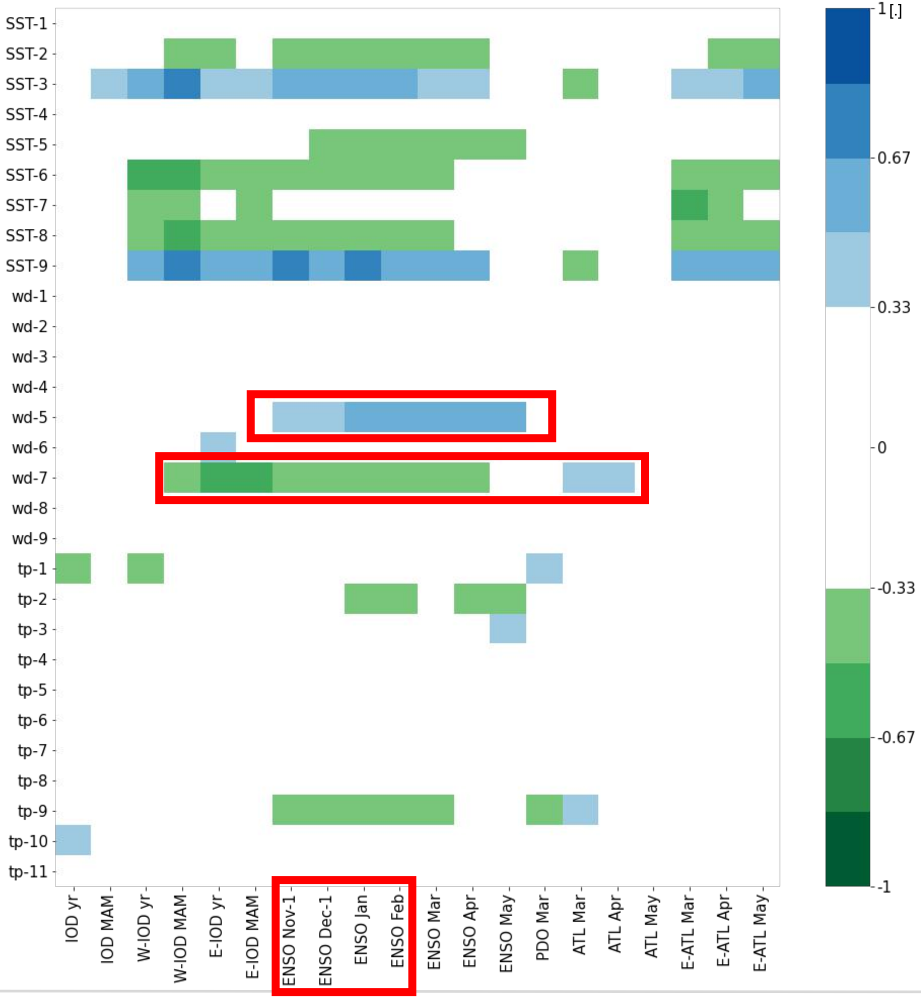
Significant correlations (α = 0.05) marked in red

Correlation frequency wind to precipitation

	tp Burundi	tp Djibouti	tp Eritrea	tp Ethiopia	tp Kenya	tp Rwanda	tp Somalia	tp Tanzania	tp S. Sudan	tp Sudan	tp Uganda	tp Indian Ocean	tp Area
wd-1	0.33	0.11	0.14	0.23	0.58	0.49	0.44	0.18	0.11	-0.09	0.25	0.46	0.41
wd-2	0.06	-0.01	-0.07	-0.12	-0.20	0.06	-0.19	-0.11	0.15	0.05	-0.05	-0.04	-0.20
wd-3	-0.26	-0.27	-0.07	-0.36	-0.44	-0.28	-0.35	-0.24	-0.32	-0.10	-0.40	-0.30	-0.40
wd-4	0.27	0.30	0.40	0.34	-0.04	0.19	-0.01	0.19	0.25	0.24	0.16	-0.15	0.04
wd-5	-0.10	0.25	0.16	0.02	-0.21	-0.13	-0.14	-0.18	0.08	0.17	-0.09	0.05	0.05
wd-6	-0.27	-0.07	-0.05	0.01	-0.05	-0.31	-0.14	-0.07	-0.26	-0.21	-0.14	-0.33	-0.10
wd-7	-0.25	-0.20	-0.28	-0.24	-0.40	-0.26	-0.09	-0.17	0.10	0.15	-0.10	-0.15	-0.30
wd-8	0.05	-0.07	-0.15	-0.06	0.17	0.06	-0.11	0.21	-0.02	0.03	0.07	0.22	0.14
wd-9	0.15	0.01	-0.06	0.15	0.41	0.09	0.36	0.21	-0.07	-0.16	0.26	0.14	0.29

Significant correlations (α = 0.05) marked in red

Correlation with Teleconnections



Conclusion

- The shift in the start of the rainy season can be attributed in part to changes in ocean temperatures
- Forecasts of ENSO and W-IOD can provide clues to the path of the Long Rains up to 3 months in advance

→ Cluster analysis brings a deeper understanding of the action of the various factors that affect the rainy season

→ BUT: One must not only be guided by single factors like the W-IOD, one has to keep an eye on many factors, which also differ locally and temporally, sometimes significantly.

Outlook

- Since ERA5 recently expanded their data base to 1950, the findings can be validated against the years 1950–1980
- Transfer of the findings to SEAS5
  - Possibility of clustering the individual ensemble predictions
  - A bias correction may increase the skill of the forecasts
  - BUT: Non-trivial, as each ensemble member must be assigned individually, so analysis of about 40 years will be laborious
  - And ensemble spread may not allow to make clear statements

This research was supported by the European Union’s Horizon 2020 research and innovation programme under grant agreement no. 869730 (CONFER).

Thank you for your attention

List of sources

- Weber, J.N. (2021): Classification of weather patterns for the Greater Horn of Africa using cluster analysis. Master Thesis. Available from: https://github.com/JanNWeber/Master_Thesis_Data

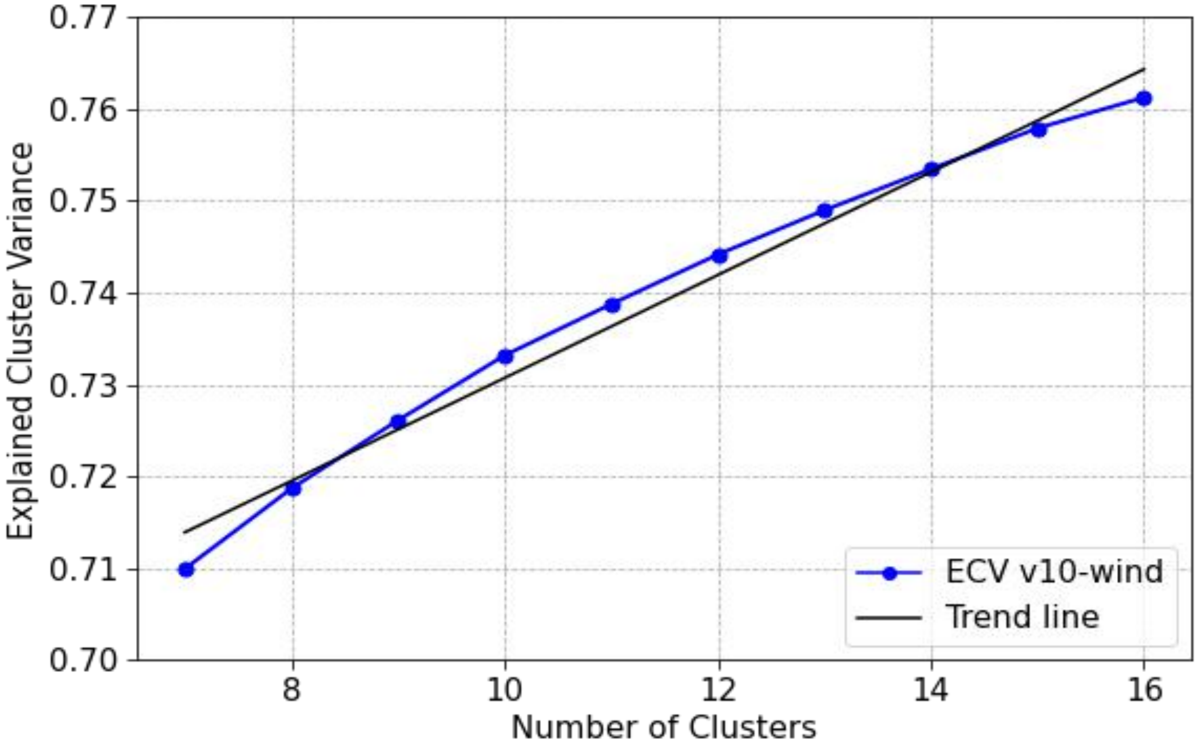
- World Meteorological Organization (WMO) (2020): State of the Climate in Africa. Available from: https://library.wmo.int/doc_num.php?explnum_id=10421.

- YANG, W., R. SEAGER, M.A. CANE and B. LYON (2015): The annual cycle of East African precipitation. In: Journal of Climate 28 (6): 2385–2404. DOI: 10.1175/JCLI-D-14-00484.1.

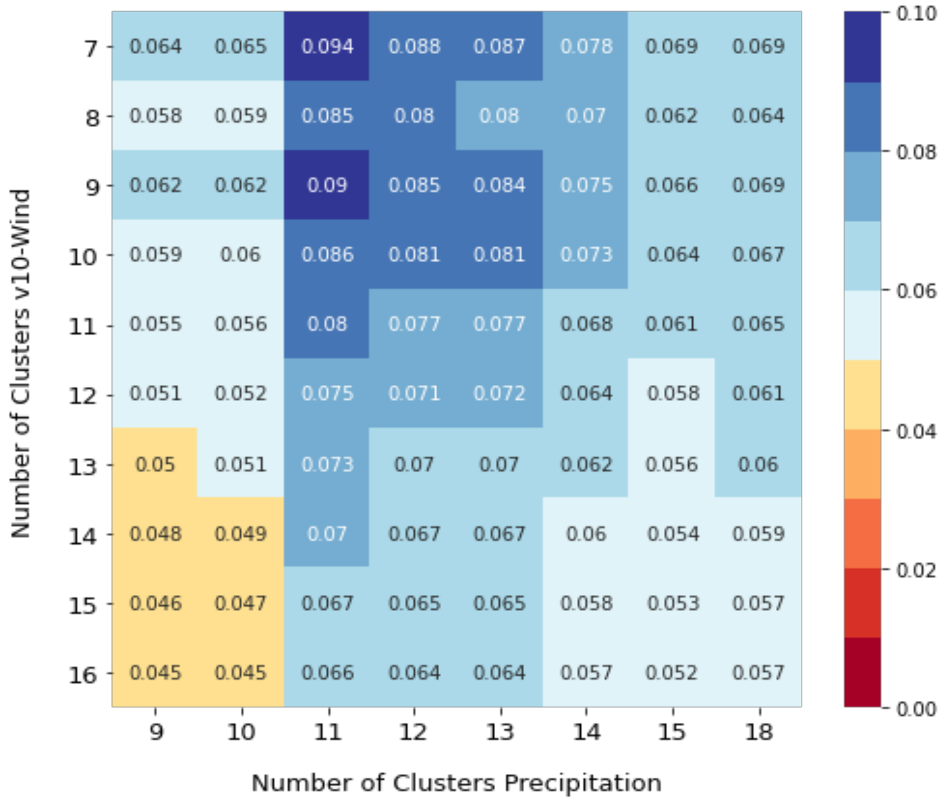
- The pictures on the title and end page are courtesy of myself.

Additional slides

Cluster selection – Explained Cluster Variance



Cluster selection – Adjusted Rand Index



Daily Wetness Index (DWI)

- $DWI(cl) = \frac{\sum_d \overline{z}_{d,cl}(x)}{\sum_d z_{d,cl}(x)}$

- Calculates the average rainfall for each day and then compares for the selected cluster the actual precipitation that fell on that day with the expected precipitation and draws the quotient

- Improvement over the "normal" wetness index:
  - The clusters of dry and rainy season become comparable