Project: **1110**

Project title: **Simulating Southern African precipitation during the last 65 years with a high-resolution atmospheric CCLM simulation**

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This high-resolution CCLM simulation for Southern Africa, covering the period 1951-2013, driven by the global coupled model FOCI, is part of a set of three CCLM simulations performed in the BMBF-funded CASISAC project. The joint project of Helmholtz-Zentrum Hereon, GEOMAR, University of Siegen, and Christian-Albrecht-University in Kiel aimed to explore the current and future evolution of the Agulhas Current system around South Africa as a consequence of natural and anthropogenic drivers and its impacts for the climate in Southern Africa. In our subproject at Helmholtz-Zentrum Hereon, we studied the impact of the Agulhas Current System on the Southern African climate, especially precipitation.
After performing the simulations and being on maternity leave, we analysed the simulations focusing on two topics: the current and future precipitation trends in Southern Africa and the impact of the Agulhas Current System on them and extremes in precipitation, especially for coastal South Africa, changes in frequency and drivers.
The first set of results concerning mean seasonal precipitation has been just accepted for publication in Weather and Climate Dynamics. The second set concerning the behaviour of extremes is an advanced preparation stage.

We analysed past and future precipitation trends and the impact of the Agulhas Current System on precipitation over southern Africa in the regional atmospheric model CCLM. Three simulations were used: a simulation driven by an atmospheric reanalysis data set and two simulations driven by the global coupled climate model FOCI covering the past (1951-2013) and future (2014-2099). Our analysis has revealed the following main results:
- CCLM is capable of a good representation of the rainfall zones of southern Africa when comparing the hindcast simulation to observations and the driving reanalysis data set. Precipitation is underestimated over most of the domain.
- Precipitation trends in both the Summer Rainfall Zone and the Winter Rainfall Zone (SRZ and WRZ) were mainly positive in the past for the respective season. However, the trends were negative in some coastal areas of the SRZ, particularly on the southeast coast.
- Future precipitation is projected to decrease over South Africa in both rainfall seasons. However, trends in the future are relatively weak, which might be caused by the underestimation of precipitation amounts and trends by CCLM.
- We applied a simple linear regression model to attribute the trends of SST and precipitation to the strength of the Agulhas Current and the Agulhas leakage. Our results show that the Agulhas Current System is linked to the SST in the southwest Indian Ocean and the South Atlantic and contributes to precipitation in South Africa. The reduction in the strength of the Agulhas Current is linked to the reduction in precipitation along the southeast coast (Fig. 1). On the other hand, the intensified Agulhas leakage is linked to the reduction in precipitation in the WRZ (Fig. 1).
- In addition to the Agulhas Current System as an oceanic driver, changes in the atmospheric circulation lead to the drying in the southern parts of southern Africa. Westerlies are projected to shift southward and strengthen. This displacement and intensification will be accompanied by a poleward shift and intensification of the high-pressure systems of the oceans in austral winter. This shift implies a more southward passage of the frontal systems, responsible for rainfall in the WRZ, and thus can be linked to the drying in this region. In austral summer, changes in the SLP are smaller but may cause less moisture transport from the ocean to the southeast of our domain.
In summary, our simulations are suitable for analysing southern African precipitation, its changes and the impact of the Agulhas Current System. Coastal South African precipitation is projected to diminish over the 21st century and the strength of the Agulhas Current System is one of its drivers.

Regarding precipitation extremes, we analysed extremes (99th and 99.9th percentile of daily precipitation) over the whole Summer Rainfall Zone (SRZ) and Winter Rainfall Zone (WRZ) of our domain, over the South African coast, its SRZ and WRZ parts, as well as for the city of Cape Town and the Kwa-Zulu Natal province.

- Extremes are less intense in the WRZ than in the SRZ. They are not projected to become more intense in the future and tend to occur equally spread throughout time.
- In contrast to the inland, precipitation has been getting more extreme over the South African coastline over the last decades, whereas mean precipitation has weakened. Thus, more extreme precipitation falls on generally drying soil, which is more prone to flooding and erosion.
- Considering the extremes along the South African coastline separately in its SRZ and WRZ parts, the SRZ part mainly mirrors the characteristics of heavy rainfall events of the whole coastline. The extremest heavy rainfall events become more intense in the future than they have been, and extremes occur more often in the second half of the historical period. Additionally, extremes are more intense when looking at only the SRZ of the coastline than the whole coastline. Furthermore, seven of the 10 strongest extremes are simulated in the second half of the 21st century. Also, for the smaller coastal WRZ part, extremes become more extreme in the scenario simulation than in the historical simulations but do not display an upward trend during the 21st century.
- We found a negligible impact of the strength of the Agulhas Current System on extreme rainfall over the South African coast.
- For the Cape Town area, precipitation extremes are projected to weaken in the future, as for the whole WRZ except for its coastal areas.
- The extreme event in April 2022 in the Kwa-Zulu Natal province was of the same magnitude as the extreme rainfall simulated in the historical simulation. The simulated maximum daily precipitation for the future is around double the rainfall amount simulated by CCLM or displayed ERA5 in the past decades. However, the atmospheric circulation in these 4 cases of extreme precipitation in KwaZulu-Natal (the strongest rainfall event of the historical simulation, the future simulation of ERA5, and ERA5 for April 2022) is not always the same. Generally, an intensified subtropical high over the Indian Ocean and a low located over the rainfall region favour the transport of wet and moist air from the Indian Ocean to coastal KwaZulu-Natal, causing intense precipitation events. Cut-off lows, like in April 2022, and tropical cyclones, like in April 2019, are two main atmospheric patterns related to extreme rainfall events in KwaZulu-Natal and along the coast further north.

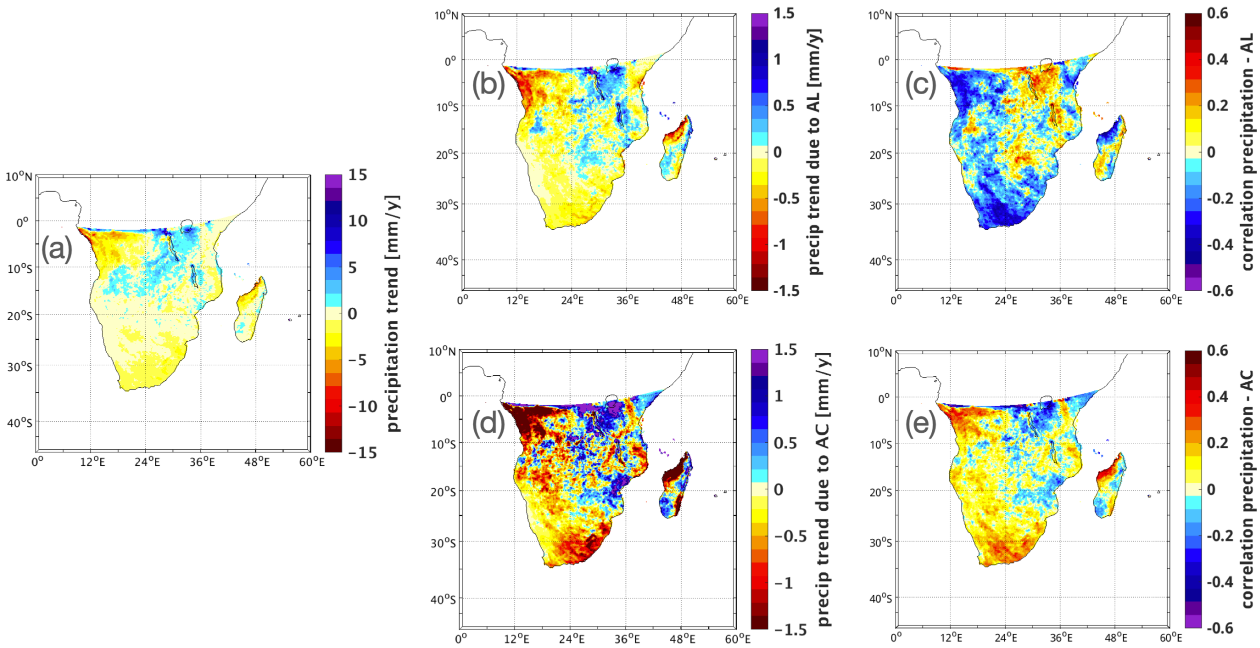

Figure 1. Impact of the Agulhas leakage (AL) and Agulhas Current (AC) on precipitation over southern Africa in the scenario simulation. (a) The trend in precipitation, (b) the portion of the precipitation trend attributed to the Agulhas leakage, (c) the correlation pattern of precipitation and the strength of the Agulhas leakage, (d) the portion of the precipitation trend attributed to the Agulhas Current, and (e) the correlation pattern of precipitation and the strength of the Agulhas Current. Colour bars of the correlation patterns (c, e) are reversed compared to the colour bars of the other subplots.