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The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

TECHNICAL BRIEF

CLIMATE CHANGE

Understanding hydroclimatic variability: From the world to the catchment

This WRC-funded study aimed to develop an improved understanding of the impacts of global climate change as well as the region's hydroclimatic variability.

Understanding climate variability: Progress made and gaps remaining

Over a period of almost two decades much knowledge has been gained on how the oceans can modify the global climate and affect the rainfall of southern Africa, at time scales ranging from the decadal to the inter-annual. It has been shown that the most severe summer droughts happen in southern Africa during the mature phase of El Niño, when the central and eastern Pacific and the Indian Ocean are warmer. Conversely, summer wet spells are more likely to happen during La Niña, when cooler conditions persist in the Pacific. However, apart from this impact of El Niño/ La Niña, also termed ENSO, there are a number of other modes of variability that also, to varying degrees, impact on the climate of southern Africa.

Some modes (such as the Antarctic Annular Oscillation, which is linked to climate change at Marion Island and dry winters in the western part of South Africa) have already been studied to a greater or lesser extent. However, all modes of variability, including lesser studied ones such as the Madden Julian Oscillation, the Quasi Biennial Oscillation and the sunspot cycle, need to be taken into consideration in order build a better understanding of the region's hydroclimatic variability.

While more information needs to be gained on how the main modes of variability interact with South African climate, there is also a strong need to improve our knowledge on how large-scale climate variations impact on smaller hydrological scales. Indeed, these smaller scales are more relevant for the manner in which ecosystems, water resources, and agriculture respond to climate variability.

Further research initiatives

Consequently, recent research (the MAHYVA project) has aimed at building on previous advances by furthering knowledge of large-scale climate variability and linking the large-scale variability to hydrological parameters at the catchment scale. This has necessitated refining investigations at both the spatial and temporal scales. These investigations have benefited from input of climatologists, meteorologists, oceanographers and hydrologists, not only from southern Africa, but also from Europe.

Briefly stated, the goal of the investigations was to enhance understanding of the impact of the oceans on climate variability, to document findings and to build capacity in analysing the impact of climate variability on rainfall, vegetation and streamflow at the catchment scale.

Some of the specific questions that needed to be answered were the following:

- What is the impact of the main modes of climate variability on southern African rainfall, vegetation and streamflow at the regional scale?
- What are the reasons of the recent warming of the Agulhas Current system?
- Can we improve conceptual understanding of ocean-atmosphere linkages to hydroclimatic variability in southern Africa at relevant spatial and temporal scales?
- What are the relative contributions and interactions of global, regional and local hydroclimatic drivers with regard to catchment-scale hydroclimatic variability?

Key findings

Dominant relationship between ENSO and rainfall

The MAHYVA project has confirmed the role of El Niño and La Niña as the major driver of southern African inter-annual climate variability and its impact on rainfall, vegetation and streamflow. However, the relationship between ENSO and rainfall is not linear, which means that the strength of El Niño is not proportional to the spatial extent and intensity of drought in southern Africa. The strongest correlations between South African rainfall and ENSO (Niño 3.4 index) are found in summer, mostly between December and February. Weaker negative correlations are also found in November, March and April for summer rainfall.

A previously unreported positive correlation between winter rainfall in South Africa's winter rainfall region and ENSO has emerged. For the winter rainfall regions, there is a weaker correlation between AAO and South African rainfall in winter. A positive correlation between the Antarctic Annular Oscillation (AAO) and rainfall in summer for the summer rainfall region is an artefact and merely reflects the effect of ENSO.

Further modes of climate variability such as the Quasi Biennial Oscillation (QBO) or the subtropical Indian Ocean dipole have proved to be, at most, very weakly correlated to South African rainfall and, again, merely reflect the impact of ENSO on those features.

At the decadal scale, it has not been possible to establish any correlation between sunspot numbers and South African rainfall.

Periodicity in rainfall statistics

A wavelet analysis of 80 years of South African rainfall data does not indicate any coherent periodicity for the whole period. Sporadic periodicity in the 2-3 years range and 4-5 years range period indicates a relationship with ENSO, which has exhibited the same, though often interrupted, periodicity over the last 100 years. A 20 year pseudo-periodicity can be found, but only between 1940 and 1980. This inconsistent periodicity is a major obstacle when attempting to do seasonal or decadal rainfall prediction on the basis of statistics alone.

Trends in sea surface temperatures and consequences

Since the 1980s, the sea surface temperature of the Agulhas Current system has increased significantly. As a result of this warming, substantial increases in evaporation and moisture transfer between the ocean and atmosphere have occurred in a region of the Southern Ocean as large as South Africa itself. The warming is due to an augmentation of Agulhas Current transport in response to an increase in trade wind speed and a poleward shift in westerly wind in the South Indian Ocean at relevant latitudes, which leads to an increase in wind stress curl.

This causes an increase in the fluxes of salt and heat into the Atlantic Ocean and in the transfer of energy from the ocean to the atmosphere. Therefore, the changes being witnessed in the region could have global consequences, on top of the regional impacts on ecosystems and climate. Besides clarifying the warming of the Agulhas Current, significant progress has also been made in describing the ocean circulation in the Southwest Indian Ocean, the source region of the Agulhas Current.

Intra-seasonal rainfall variability in relation to the Madden Julian Oscillation

Important advances in climatology not only at the inter-annual but also the intra-seasonal time scales and at the catchment scale have been made as a result of a thorough analysis of the unique South African rainfall database, the development of which had been funded previously by the Water Research Commission. This database contains quality-controlled data from about 5 000 daily rainfall stations covering the period 1950 to 2000. The analysis has led to a better understanding of the sub-seasonal variability of convection and rainfall over South Africa during summer.

The intra-seasonal timescale has been studied with special emphasis on the 30-60 day variability related to the Madden Julian Oscillation (MJO). For the first time, the impact of the MJO on South African rainfall has been demonstrated, with intra-seasonal wet and dry spells being phase-locked to the MJO life cycle. This new insight is most important, given that the MJO is the dominant mode of atmospheric variability in the tropics at intra-seasonal timescales, just as ENSO is the dominant signal at the inter-annual scale.

Basically, the MJO consists of a slow eastward propagation of large-scale convective clusters along the equator, from the Indian Ocean to the Maritime Continent and then to the Western Pacific basin. The time taken by the MJO to rejuvenate over the Indian Ocean is typically between 40 and 45 days, but more generally it fluctuates between 30 and 60 days. Anomalous daily convective activity over the region has been classified into different regimes. The variability in the frequency of these daily regimes from one year to another appears to be related to large-scale signals in the ocean-atmosphere system, one of which is the ENSO signal. ENSO, in fact, modulates the frequency of 4 of the 7 identified regimes in a manner that affects the seasonal rainfall averages. These results provide clues to the causes of the non-linearities of the ENSO signal in the convection and rainfall fields over the region.

Variability in vegetation as a link between climate and hydrological variability

Recognising the importance of vegetation as a factor linking climatic and hydrological regimes, 18 years (1981-1999) of Normalised Difference Vegetative Index (NDVI) data from the Advanced Very High Resolution Radiometers (AVHRR) have been used to investigate the delayed responses of photosynthetic activity to rainfall in a semi-arid region of subtropical South Africa. Here, the early season NDVI has proved to be highly dependent on rainfall of the concurrent year and, to some extent, of the previous year. So-called "memory" effects, which represent the difficulty vegetation has in recovering from previous drought conditions as well as the capacity of semi-arid ecosystems to benefit from a water surplus at a one-year time-lag were recognised but need to be better understood.

The catchment scale

Linking climate and hydrology at the catchment scale demands appropriate hydroclimatic data resources for use as input into an appropriate hydrological model. Related hydrological research is being undertaken in the Liebenbergsvlei Catchment which has been used as a test site for the configuration and use of the TOPKAPI hydrological model. The MAHYVA project has supported the hydrological studies by conducting a thorough validation of the TRMM 3B42 product that is being used to provide near real-time rainfall data as input to the TOPKAPI model. The TRMM product is available every 3 hours with 0.25 degree resolution, with 10 years of historic data being available for analysis. The observed diurnal rainfall cycle has been found to be well represented in the satellite data, which also match observed daily rainfall totals relatively well.

In conclusion ...

Clearly, variability within the ocean-atmosphere-land system cannot be studied by looking at each component in isolation. The constitution of a multidisciplinary group of researchers is essential to future progress.

Particular issues which require further investigation with a view to developing better understanding are the following:

- The non linearity between ENSO and perturbations of the southern African hydroclimatic system.
- The diurnal cycle of rainfall and the behaviour of rain-bearing weather systems during ENSO events
- The occurrence of non-ENSO-related droughts
- The potential impact of ENSO on the relationship between rainfall and streamflow.
- The role of ENSO in winter rainfall variability
- The potential impact of the increase in the Agulhas current system's sea-to-air moisture flux on coastal flooding.

Further reading:
To obtain the report, *Multidisciplinary Analysis of Hydroclimatic Variability at the Catchment Scale* (**Report No: 1747/1/10**), contact Publications at Tel: (012) 330-0340; Fax: (012) 331-2565;
E-mail: **orders@wrc.org.za**; or
Visit: **www.wrc.org.za**