CLIMATE SCIENCE

The mysteries of Sahel droughts

Past variability in Sahel rainfall is closely linked to global sea surface temperature distributions in observations and models alike. Climate simulations for the 21st century suggest that additional influences may become important in the future.

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Mortality risk from drought is extremely high across subtropical Africa in both hemispheres[1]. In the Sahel — the transition zone between the tropical climate of the Guinean coast region and the extreme aridity of the Sahara Desert — persistent drought from the early 1960s into the 1980s caused millions of deaths and hampered development. Early concern focused on the influence of land-use practices[2], but later observational[3] and modelling[4–6] studies related decadal-scale Sahel drought with sea surface temperatures. Particularly strong links were found with north–south temperature gradients in the tropical Atlantic and sea surface temperatures in the tropical Pacific and Indian oceans. Higher rainfall rates returned to the Sahel in the 1990s despite a continued warming of the Indian Ocean[7], but the population of the region remains vulnerable. Analysing state-of-the-art climate model simulations, Michela Biasutti and co-authors[8] found that the simple statistical model linking sea surface temperatures to Sahel rainfall in simulations of the past does not hold for simulated future climate.

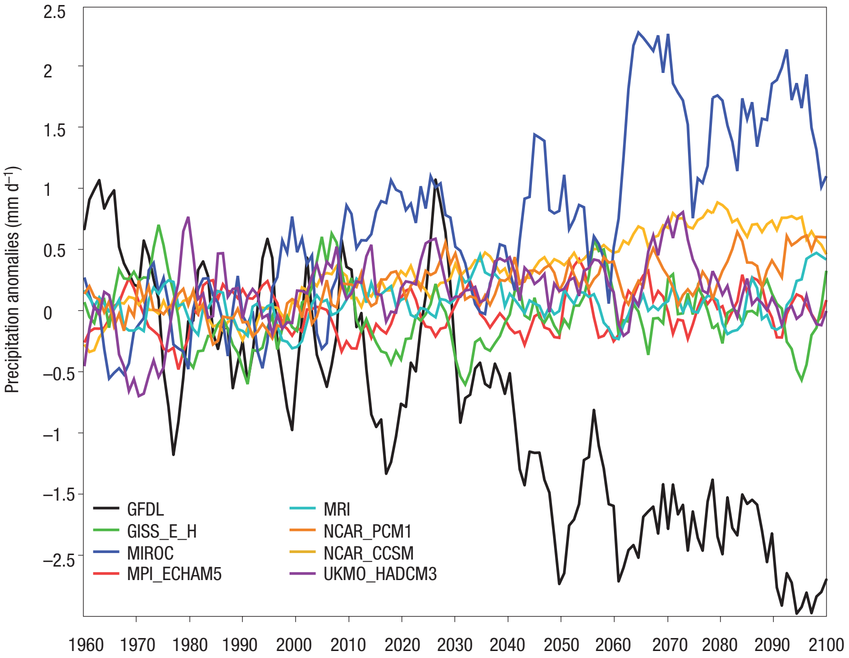

Figure 1 Future projections of Sahel rainfall. Time series of Sahel precipitation anomalies for 1960–2100 as simulated by eight coupled general circulation models of the global ocean and atmosphere. Precipitation is averaged over West Africa from 10–20° N and smoothed using a five-year running mean, and anomalies are the differences from the 1950–1999 mean for each model. Biasutti and colleagues[7] find a puzzling mismatch in the future evolution of sea surface temperatures and Sahel rainfall in the various models, unlike the simple regression model that explains past variability reasonably well.

While preparing the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)[9], climate modelling groups around the world ran standardized simulations of 20th and 21st century climate. More than 20 groups developed and ran coupled general circulation models (GCMs), that is, models of the global climate that include fully interactive atmospheric and ocean components. These models solve the governing equations of fluid dynamics — the Navier–Stokes equations, appropriately scaled for this application — in three dimensions, covering the globe and integrating forward in time. Horizontal grid spacing ranges from roughly 100 km to 400 km. The governing equations are accompanied by physical parameterizations to supply processes that are not explicitly treated in each model, such as sub-grid scale diffusion, radiation, cloud formation and precipitation processes. The output from these models has been archived and made available to the scientific community. It is an invaluable resource, allowing extensive model intercomparisons to improve our understanding of present and future climate.

A number of researchers have used this archive, or a subset of the full archive, to study Sahel rainfall[6,10,11]. They have found that many of the 20th century simulations produce strong rainfall in a relatively narrow band near the equator throughout the summer rather than reproducing the observed rainfall maximum over the African continent that accompanies the development of the West African monsoon[11]. In simulations of the future, most of the models project only modest increases or decreases in summer precipitation. However, one model — in both a higher and lower resolution version — produces extreme wetting, and another model (again, in two versions) produces extreme drying (Fig. 1). When these outlier simulations are included, the simulated range of future climate outcomes for the Sahel in the model archive is broader than for most other regions. It is not easy to dismiss these extreme simulations because they are produced by two of the handful of coupled models that give relatively accurate simulations of the West African monsoon system.

Biasutti and colleagues[8] statistically analysed 21 of the GCM simulations from the IPCC archive, including the four outlier simulations from the two aforementioned models. They used simulations of the pre-industrial era, with only natural climate variability and no anthropogenic climate forcing, to build a linear regression model that relates modelled Sahel rainfall to modelled sea surface temperatures. They found that the GCMs capture the observed sensitivity of Sahel rainfall to sea surface temperature patterns — at least "in broad outline" — in both the pre-industrial era and in the 20th century under observed greenhouse gas increases, in agreement with a previous study[10]. But despite this dependence on sea surface temperatures in the past, the differences in the models' projections of future rainfall are not explained by differences in their sea surface temperature projections. The relationship between sea surface temperatures and Sahel rainfall that holds for the 20th century and before does not seem to persist into the 21st century in the models. The authors therefore suggest that simulated future changes in Sahel rainfall are controlled by different mechanisms than in the simulations of the past — for example, by a direct influence of the change in radiative forcing on precipitation, without mediation from sea surface temperatures. It is also possible that interactions between the land surface and the atmosphere are playing an important role.

Biasutti and co-authors may be overly pessimistic about the level of agreement among the coupled GCMs as the large spread in the projected Sahel rainfall depends primarily on only two models (Fig. 1). These may be producing physically unrealistic results[11], but dominating the statistics. Nonetheless, this mysterious result highlights the need for a deeper understanding of the West African monsoon system and the processes that cause it to vary on all time scales. The region is particularly challenging for accurate representation in GCMs for several reasons. One is that, in addition to the influence of global sea surface temperatures in the region, West Africa exhibits particularly strong land–atmosphere coupling[12] and our ability to model these interactions is still relatively poor. Another challenge for GCMs arises because the model grids are still too coarse to fully resolve the tight north–south gradients in temperature and moisture that characterize the region and that exert significant control on the flow and precipitation fields, or to resolve the all-important tropical convective processes.

In order to get a better idea of what the future holds for the people of the Sahel, we will need to improve our basic understanding of precipitation and dynamical processes in West Africa. High-resolution modelling, physics-based analysis and a sophisticated and sustained observational network that is currently not in place are the means to this end.

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MINERAL PHYSICS

The spin deep within

The electronic configuration of iron impurities in lower-mantle minerals influences their physical properties, but it is not well constrained. New studies suggest that ferrous iron in silicate phases exists mainly in an intermediate spin state.

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The Earth's lower mantle, located between the depths of about 660 km to 2,890 km, is a region with a distinct mineralogical composition. The bulk of this region is made up of two mineral phases — silicate perovskite (~75%) and magnesiowüstite (~20%) — although in the lowermost few hundred kilometres, perovskite transforms into a denser phase termed post-perovskite. Both silicate perovskite and post-perovskite are magnesium silicates that incorporate a significant amount of iron and aluminium into their structures as impurities through substitution. The effect of iron impurities on the properties of their host phases, and therefore the lower mantle as a whole, is a subject of great interest for mineral physicists. In this issue, Lin and colleagues[1] (page 688) and McCammon and colleagues[2] (page 684) present experiments aimed at understanding the electronic configuration of iron in lower-mantle silicate perovskite and post-perovskite and suggest that ferrous iron mainly exists in an intermediate-spin state throughout this region.

Establishing the electronic configuration of iron impurities in lower-mantle minerals is important because it can affect the radiative thermal conductivity of their host phase[3], and this in turn could affect the structure and dynamics of the whole region[4]. Electronic configuration can also affect how iron is distributed between mineral phases[5] and their elastic properties[6]. Depending on pressure and temperature conditions, iron impurities can adopt three different electronic configurations, known as high spin, intermediate spin and low spin.