THE PERFECT STORM

Soil moisture patterns seem to be the trigger for new storms in the dusty Sahel. **Chris Taylor** recounts his experience of one such storm and discusses how the Sahel soil influences weather patterns.

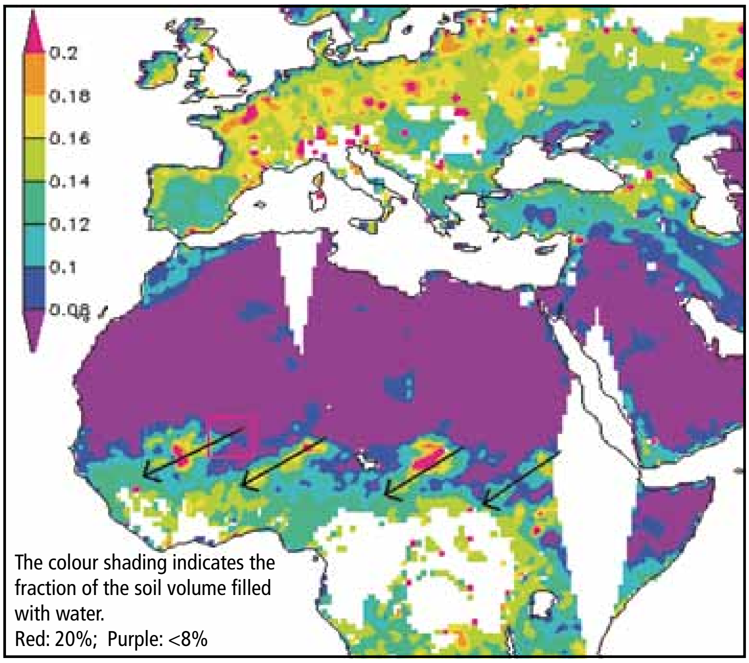

Figure 1. Soil moisture detected by satellite on a day in the 2006 wet season. Arrows denote the passage of recent storms. From Taylor C *et al.* (submitted) New perspectives on land-atmosphere feedbacks from the African Monsoon Multidisciplinary Analysis (AMMA). *Atmospheric Science Letters.*

No region has suffered more severely from drought in recent decades than the Sahel. This region, which stretches across northern Africa, separates the Sahara Desert in the north from moist tropical forests to the south. It is a key component of the global weather system – many storms in the Atlantic form over this region. The Sahel encompasses some of the least developed countries in the world – Niger, for example – and the impact of drought on agriculture, water resources and health has been profound. Dry conditions, set up by global and regional ocean temperatures, have been amplified by land feedbacks in the late 20th century. Models in the fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change do not offer a consensus about whether Sahelian rainfall will rise or fall in the coming decades. But feedbacks with vegetation and soil moisture are likely to influence future climate in the region, much as they have in the past.

Yet, predicting how soil moisture, vegetation, eva poration and rainfall interact with each other is fraught with uncertainty. Thanks to measurements over the past decades, we now understand how climate affects soil moisture and evaporation from the land. Less clear has been the extent to which the suppressed evaporation driven by the dry soils in turn influences rainfall. Recent measurements by the African Monsoon Multidisciplinary Analysis (AMMA) indicate that suppressed evaporation provides a potentially powerful positive feedback: the land can amplify and prolong dry periods, leading to more intense droughts.

Weather prediction and climate models have traditionally provided much of the insight into storm generation. However, we still missed some of the pieces of the jigsaw: detail of the processes going on within storms and detail about the huge variations in land conditions across a region. Within AMMA, we addressed this lack of basic knowledge with an observational campaign designed to measure the atmospheric response to different land conditions. We exploited a characteristic of the Sahelian wet season, the tendency for storms to occur typically every three or four days. These storms travel west across the region, depositing typically tens of millimetres of rain on the land in a swath that is often hundreds of kilometres across (Figure 1).

For the first day or two after rain, much of the solar energy reaching the ground gets used up evaporating water from the wet soil. However, once the soil has dried out after four or five days without rain, the energy goes into heating the atmosphere instead. On any given day in the rainy season, parts of the region will be wet and other parts dry. We used a combination of aircraft and satellite data to examine differences in the atmosphere above wet and dry surfaces to infer how soil moisture affects storms. Before the AMMA observational campaign, we had analysed satellite data and found, perhaps surprisingly, that

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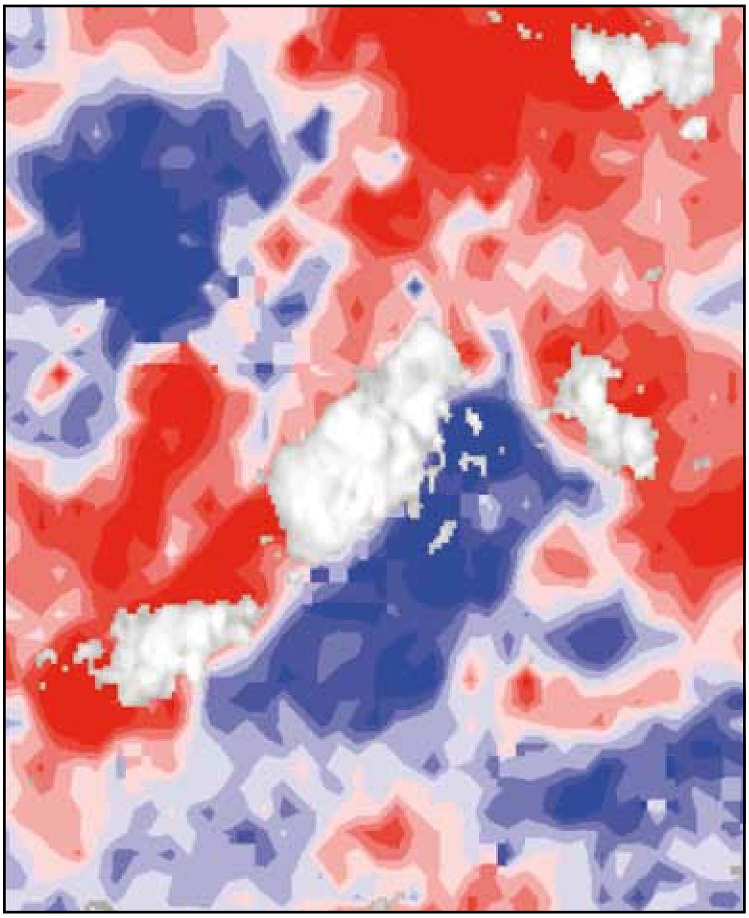

Figure 2. Early development of storm clouds (grey/white) above patches of soil moisture. The red and blue shading denotes dry and wet areas of soil, based on land surface temperature data prior to the storm. From Taylor C M, Harris P P, and Parker D J *et al.* (2010) Impact of soil moisture on the development of a Sahelian mesoscale corrective system: A case study from the AMMA Special Observing Period. *Quarterly Journal of the Meteorological Society* 136: 456-470.

afternoon storm clouds were about 40 percent more prevalent over dry soils when compared with wetter areas. However, we had been unable to isolate the mechanism underlying this feedback. We were hoping that the detailed *in situ* measurements from the aircraft campaign could provide this.

As anticipated, our aircraft data showed increased atmospheric temperature and reduced humidity in the areas where it hadn't rained. This was evident even when the dry areas were only five kilometres across, a surprising result given that turbulent eddies tend to mix the lower atmosphere rather effectively during the daytime. We also found that where dry soils met wet soils, the differences in temperature were large enough to affect the winds, in a manner analogous to sea breezes. Anyone who has ever sat on a beach watching the clouds will recognise the importance of such breezes for cloud development, and sometimes, sharp showers. Although generally unwelcome on the beach, the triggering of afternoon showers in the Sahel plays a critical role for the hydrology of the region. Some of these storms grow very rapidly, moving from a single cloud to a major storm covering an area the size of Wales in a matter of two or three hours. These systems produce the vast majority of Sahelian rainfall.

We had the good fortune to witness one such transformation during a research flight over northern Mali. We had set out that afternoon to take measurements above an interesting soil moisture pattern, anticipating calm conditions as had been forecast. But when we approached our target area, the radar indicated clouds directly ahead of us, forcing us to radically change our flight plan. Two hours later I was looking out of the airplane window and marvelling at the towering collection of cumulonimbus clouds that reached over 15 km above the ground. I was left wondering how a centimetre or two of water in the soil could possibly influence such a powerful phenomenon. Subsequent analysis of satellite data showed that soil water did indeed have a crucial role in the triggering of this storm. The storm subsequently travelled over 1500 km to reach the Atlantic Ocean. It had developed precisely where the breeze theory predicted, right along the boundary between previously wet and dry soils (Figure 2). It provided a powerful illustration of how rain on one day could trigger new storms in the region.

Conditions in the Sahel allowed us to isolate the impact of soil moisture on convective storms. Similar processes are likely to influence rain in the many parts of the world where soil moisture limits evaporation rates. But it is not easy to use our understanding to improve the representation of such feedbacks in climate and weather models, not least because of the coarse nature of models, which cannot represent individual clouds growing over locally realistic land conditions. An important ongoing development is the use of increasingly accurate land-surface data, acquired by satellites, in weather models. In particular, the recent launch of the Soil Moisture and Ocean Salinity (SMOS) mission is providing information globally about soil water that occurs several centimetres beneath vegetation. It is hoped that this will significantly improve predictions of rainfall in the near future. ▮

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