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Couplings between the seasonal cycles of surface thermodynamics and radiative fluxes in the semi-arid Sahel

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A good knowledge of surface fluxes and atmospheric low levels is central to improving our understanding of the West African monsoon. This study provides a quantitative analysis of the peculiar seasonal and diurnal cycles of surface thermodynamics and radiative fluxes encountered in Central Sahel. It is based on a multi-year dataset collected in the Malian Gourma over a sandy soil at 1.5°W-15.3°N (a site referred to as Agoufou) with an automated weather station and a sunphotometer (AERONET), complemented by observations from the AMMA field campaign.

The seasonal cycle of this Tropical region is characterized by a broad maximum of temperature in May, following the first minimum of the solar zenith angle by a few weeks, when Agoufou lies within the West African Heat-Low, and a late summer maximum of equivalent potential temperature within the core of the monsoon season, around the second yearly maximum of solar zenith angle, as the temperature reaches its Summer minimum.

More broadly, subtle balances between surface air temperature and moisture fields are found on a range of scales. For instance, during the monsoon, apart from August, their opposite daytime fluctuations (warming, drying) lead to an almost flat diurnal cycle of the equivalent potential temperature at the surface. This feature stands out in contrast to other more humid continental regions. Here, the strong dynamics associated with the transition from a drier hot Spring to a brief cooler wet tropical Summer climate involves very large transformations of the diurnal cycles.

The Summer increase of surface net radiation, Rnet, is also strong; typically 10-day mean Rnet reaches about 5 times its Winter minimum (~30 W.m-2) in August (~150 W.m-2). A major feature revealed by observations is that this increase is mostly driven by modifications of the surface upwelling fluxes shaped by rainfall events and vegetation phenology (surface cooling and darkening), while the direct impact of atmospheric changes on the total incoming radiation is limited to shorter time scales in Summer over this Central Sahelian location.

However, observations also reveal astonishing radiative signatures of the monsoon on the surface incoming radiative flux.
The incoming longwave flux does not reach its maximum during the monsoon season when the atmosphere is the most cloudy and humid, but earlier, prior to the onset of rainfall, as the dry and warmer atmosphere suddenly becomes moist. This feature points to the significance of the atmospheric cooling during the monsoon season and of the aerosol amounts in Spring. It also reveals that prior to the rainfall onset, the monsoon flow plays a major role on the diurnal cycle of the low-level temperature, due to its radiative properties.
Conversely, the incoming solar radiation at the surface increases slightly from late Spring to the core monsoon season even though the atmosphere becomes moister and cloudier; this again involves the high aerosol optical thickness prevailing in late Spring and early Summer against a weaker shortwave forcing by monsoon clouds.

The climatological combination of thermodynamic and radiative variations taking place during the monsoon eventually leads to a positive correlation between the equivalent potential temperature and Rnet. This correlation is, in turn, broadly consistent with an overall positive soil moisture rainfall feedback at this scale.

Beyond these Sahelian-specific features, and in agreement with some previous studies, strong links are found between the atmospheric humidity and the net longwave flux, LWnet at the surface all year long, even across the much lower humidity ranges encountered in this region. They point to, and locally quantify the major control of water vapour and water-related processes on the surface-atmosphere thermal coupling as measured by LWnet. Namely, they are found to be more tightly coupled (LWnet closer to 0) when the atmosphere is moister and cloudier.

Observational results such as presented here provide valuable ground truth for assessing models over a continental area displaying a challenging variety of surface-atmosphere regimes throughout the year, from a desert-like to a rainy tropical-like climate during the core of the monsoon. Indeed, the mechanisms emphasized by these data do not all comply to existing conceptual schemes.