Remote sensing of the land surface during the African Monsoon Multidisciplinary Analysis (AMMA)

Laurent Kergoat, Manuela Grippa, Alain Baille, Laurence Eymard, Roselyne Lacaze, Éric Mougin, Catherine Ottle, Thierry Pellarin, Jan Polcher, Patricia de Rosnay, et al.

ATMOSPHERIC SCIENCE LETTERS
Atmos. Sci. Let. **12**: 129–134 (2011)
Published online in Wiley Online Library
(wileyonlinelibrary.com) **DOI:** 10.1002/asl.325

RMetS
Royal Meteorological Society

Remote sensing of the land surface during the African Monsoon Multidisciplinary Analysis (AMMA)

Laurent Kergoat,[1]* Manuela Grippa,[1] Alain Baille,[2] Laurence Eymard,[3] Roselyne Lacaze,[4] Eric Mougin,[1] Catherine Ottlé,[5] Thierry Pellarin,[6] Jan Polcher,[7] Patricia de Rosnay,[8] Jean-Louis Roujean,[9] Inge Sandholt,[10] Christopher M. Taylor,[11] Isabella Zin[6] and Mehrez Zribi[12]

[1] *LMTG (CNRS/UPS/IRD), Toulouse, France*
[2] *Technical University of Cartagena, Spain*
[3] *LOCEAN (CNRS/IRD/UPMC/MNHN), Paris, France*
[4] *OMP, Toulouse, France*
[5] *LSCE (CNRS/CEA/UVSQ), Paris, France*
[6] *LTHE (IRD/CNRS/UJF), Grenoble, France*
[7] *LMD (CNRS/UPMC), Paris, France*
[8] *ECMWF, Reading, UK*
[9] *CNRM-GAME (CNRS/MeteoFrance), Toulouse, France*
[10] *IGUC, Copenhagen, Denmark*
[11] *CEH, Wallingford, UK*
[12] *CESBIO (IRD/CNRS/UPS), Toulouse, France*

*Correspondence to:
Laurent Kergoat, LMTG (CNRS/UPS/IRD), 14 av E Belin, 31400 Toulouse, France.
E-mail: Laurent.kergoat@lmtg.obs-mip.fr*

Received: 12 February 2010
Revised: 14 October 2010
Accepted: 14 December 2010

Abstract

This article summarises the scientific results gained from the satellite observation of the land surface during African Monsoon Multidisciplinary Analysis (AMMA). Validation of existing satellite products as well as developments of new algorithms are reported, spanning surface and total soil moisture, surface energy balance and radiation fluxes, vegetation properties and land cover (LC). The use of remote sensing data for investigating land–atmosphere interactions, for retrieving the components of continental water cycle and for evaluating Land Surface Models (LSM) is illustrated. The contribution of satellite data to the detection of decadal trends is also highlighted, revealing intriguing results and open questions.

Keywords: **remote sensing; land surface; AMMA; West Africa**

1. Introduction

Land surface studies during African Monsoon Multidisciplinary Analysis (AMMA) were motivated for three key reasons; the importance of land surface–atmosphere interaction in the monsoon system, the need to understand the response of ecosystems, agrosystems and hydrosystems to climate variability and the direct links to resources assessment issues. Thanks to their spatial and temporal coverage, remote sensing data give access to surface variables which are central players in these three fields of investigation. This proved to be particularly important in West Africa, where *in situ* data networks are sparse, whilst expectations of African scientists and societies are high in terms of developing monitoring capabilities.

The use of Earth Observation (EO) data during AMMA can be summarised by considering what the EO community learnt from AMMA, in terms of algorithms and validation for instance, and what the AMMA community learnt from EO data. Remote sensing of the land surface during AMMA follows the legacy of the International Satellite Land Surface Climatology Project (ISLSCP) experiments, especially HAPEX-Sahel in 1992. Pursuing the evolution initiated in the Boreal Ecosystem-Atmosphere Study (BOREAS) and Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA), AMMA progressed noticeably in two directions. Firstly, the observation strategy spanned a larger domain, and especially a large latitudinal gradient, with three supersites distributed on a north–south transect (Figure 1), in Mali, Niger and Benin and local sites in Burkina Faso and Senegal. Secondly, AMMA also moved toward more integration of the EO activities into thematic work-packages (e.g. Séguis *et al*., 2011; Taylor *et al*., 2011).

EO in AMMA definitely started in the ENVISAT and TERRA/AQUA era, as sensors like ASAR, AMSR or MODIS onboard these spacecrafts were intensively used. Meteosat Second Generation also proved well suited for land surface observation. Most of these sensors have benefited from the important developments of the last decades, in terms of sensor definition, calibration and inversion methods. As a result, important datasets are available, e.g. surface soil moisture (SSM), leaf area index (LAI), surface radiation fluxes and land cover (LC). There is however an important step before using these products, namely validation. This is especially important for West Africa, for two main reasons. Firstly, there are very few validation

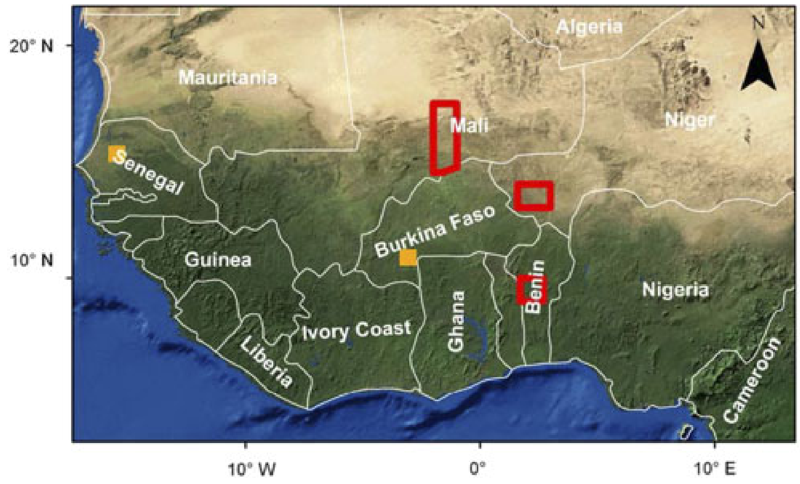

Figure 1. The main sites for land surface studies during AMMA superimposed on a colour composite from the AVHRR: the Mali, Niger and Benin meso-scale sites in red, the Dahra (Senegal) and Bontioli (Burkina Faso) local sites in orange.

Table I. Evaluation of satellite products and algorithms over AMMA sites.

Parameter	Reference
Surface soil moisture	Baup *et al*., 2007a, 2007b; Gruhier *et al*., 2008, 2010; Zribi *et al*., 2007, 2009; Pellarin *et al*., 2008, 2009a, 2009b; de Rosnay *et al*., 2009b
Total soil water, water bodies	Gardelle *et al*., 2010; Grippa *et al*., 2010
Evapotranspiration, surface radiation, albedo	Tanguy *et al*., 2007; Samain *et al*., 2008; Stisen *et al*., 2008b, Ramier *et al*., 2009
Land use and land cover	Kaptue Tchuente *et al*., 2010
Data processing	Fensholt *et al*., 2007; Proud *et al*., 2010

sites in Africa as a whole. Secondly, environmental conditions from the wet tropics to the Sahara margins raise a number of difficulties. For instance, aerosol loadings during dust events may be extremely high and may severely impair the quality of surface reflectance data. In addition, persistent cloud cover becomes a problem for the south of West Africa. The land surface in West Africa also differs from the more intensely observed mid-latitudes. For instance, landscape structure is generally more complex, with widespread mosaics of crops and trees, and topography and surface water pathways play an important role. There is an extremely strong seasonal cycle with marked dry and rainy seasons. The soil moisture regime is relatively specific to this region, in the sense that most rainfall occurs as convective squall lines. Moreover, in the Sahel, the soil dries and drains rapidly. As a consequence, SSM shows extremely high contrasts in space and time. Some of these properties may raise difficulties for land surface parameter inversion, but conversely, they may also provide important test beds for product development.

2. What has the remote sensing community learned from AMMA?

2.1. Product validation and development of new products

Existing SSM products have been inter-compared and evaluated (Gruhier *et al*., 2008; Pellarin *et al*., 2009a; Gruhier *et al*., 2010) using a network of ground stations (de Rosnay *et al*., 2009a) (Table I). All sensors (AMSR-E, ERS scatterometer, ASAR) displayed a high sensitivity to the SSM peaks following rainfall events, proving suitable for SSM monitoring in the Sahel. Yet absolute values of SSM were noticeably product-dependent. The seasonal development of vegetation impacted SSM retrievals in the Sudanian zone at least, and very dry soils produced significant differences between products. Nevertheless, all products performed well in delimiting areas of high SSM. AMSR-E data were used to improve the estimation of rainfall from satellite cloud top temperature data (Pellarin *et al*., 2008), by considerably reducing the number of 'false' rainfall detections. Finally, an interpolation procedure was developed in order to map SSM over the Sahelian region at the 10×10 km^2 spatial resolution and 30-min temporal resolution (Pellarin *et al*., 2009b).

Several surface energy flux products were also evaluated. MODIS albedo was found to agree well with *in situ* data collected over several years (Samain *et al*., 2008). Surface radiation fluxes from MSG (Land SAF) and the Surface Radiation Budget product were found to agree reasonably well with *in situ* data for down-welling shortwave but performed rather poorly for down-welling longwave when compared to ten stations over the latitude transect. The largest difficulties arose during the pre-rainfall period, with inadequate account taken of high and variable aerosol loadings

(Ramier *et al*., 2009). The comparison of eddy covariance surface fluxes with MODIS evapotranspiration product looks promising (Tanguy *et al*., 2007). Stisen *et al*. (2008b) developed a method combining thermal inertia, NDVI and radiation from MSG to estimate evapotranspiration in Dahra with good accuracy. For vegetation parameters, LAI products were found to be accurate in terms of temporal phasing, even in areas of relatively low LAI, which is an improvement of MODIS compared to previous sensors like the AVHRR (Mougin *et al*., 2009). Still, some difficulties were identified in deriving absolute values, with the products tending to have too flat a seasonal cycle and to display slightly biased and noisy dry season values. Overall, these products performed reasonably well in the Sahel, but cloud cover was an issue for the southern areas. The frequent temporal sampling of MSG proved to really reduce the cloud cover problem (Fensholt *et al*., 2007; Proud *et al*., 2010).

Several products were designed specifically for AMMA including new SSM products based on ASAR data over the Sahelian sites (Baup *et al*., 2007a, 2007b; Zribi *et al*., 2007). Compared to passive microwave, ASAR has reduced temporal sampling, but provides higher spatial resolution, of the order of 1–10 km, depending on the ASAR mode and filtering process. LAI and SSM products were also derived at the scale of the supersite, and LC classification was developed for crop monitoring (Traore *et al*., 2011).

All validation studies demonstrated the importance of co-localised datasets of LAI, soil moisture, diffuse/direct radiation, turbulent fluxes and aerosol optical depth, as well as up-scaling strategies for upward fluxes, to obtain accurate diagnostics of the factors responsible for the main errors and biases in satellite products. The validation studies therefore benefited from multi-product validation designed over the same sites. For instance, SSM validation requires accurate LAI values, up-scaled from *in situ* data or a locally validated satellite product. Accurate soil texture maps are also important for many products. Datasets covering several years were shown to significantly improve product validation (e.g. Samain *et al*., 2008; Grippa *et al*., pers. comm.). Detecting the interannual variability is indeed a particularly important step as the changes that EO is targeting in the frame of global environment changes are usually relatively subtle but of great consequence.

2. What did AMMA learn from remote sensing datasets?

Within a project like AMMA, EO is an important data source for integrated or process studies. Satellite products have been processed and stored in a satellite database (Fleury *et al*., 2011) or accessed directly through Distributed Active Archive Centers (DAAC) of Satellite Application Facilities (SAF). For the land surface, studies relying heavily on satellite data consisted of (1) short-term process studies, from hours to years, (2) model improvement and (3) decadal variability and trend analyses.

2.1. Process and integrated studies: from hours to years

Satellite data were crucial within AMMA for understanding the impact of soil moisture on convective storms (Taylor *et al*., 2011). The strong meso-scale moisture contrasts in the aftermath of storms can be detected using a number of techniques. Aircraft flights sampling the atmospheric response to soil moisture were designed using Land Surface Temperature (LST) data provided in near real time by the Land SAF. Compared to information from passive microwave, LST data from Meteosat have excellent spatial and temporal resolution, though unlike passive microwave, cloud limits their utility. During AMMA, the role of soil moisture gradients, typically over 10 km, emerged as an important factor in the triggering of convection (Taylor, unpublished). Radar-derived SSM, like ASAR in global monitoring mode may become one important data source for soil moisture/convection studies. There is good potential for improved forecasting from numerical weather prediction models if these data sources can be assimilated, even if there is uncertainty in the absolute values of soil moisture.

A second kind of land surface–atmosphere interaction operates through the surface energy balance and the radiation balance in particular. Historically, albedo over West Africa has received particular attention. Validated MODIS albedo has been shown to reproduce fairly well the synoptic, seasonal and interannual variabilities displayed by surface stations (Samain *et al*., 2008), being driven by vegetation on the seasonal and interannual scales (growth, grazing pressure, straws and litter, which produces 6-month-lag effect of the rainfall on albedo).

2.2. Model evaluation and improvements

EO has been used extensively to evaluate land surface models (LSM) and to build forcing database. Meso-scale land use and LC maps were used to test the sensitivity of climate to land surface changes between 1986 and 2006. At the regional scale, an improved land surface parameter dataset derived from SPOT-VGT, MERIS and MODIS has been derived for West-Africa (Kaptue Tchuente *et al*., 2010). This dataset provides consistent LAI and albedo variability. Furthermore, offline LSM simulations performed within an intercomparison exercise, which provides an ensemble 'best-guess' surface climatology for AMMA (ALMIP, Boone *et al*., 2009a), have been evaluated using EO data. Simulated LST was shown to match MSG data rather well on the seasonal timescale, but significant model/data differences were found at the three-hourly time step, implying weaknesses in the simulation of the diurnal cycle of the surface energy balance (Ottlé, unpublished). The simulation of total soil water (TSW) anomalies by the ALMIP models has been compared to six independent GRACE solutions (Grippa *et al.*, pers. comm.). The multi-model average matched the mean GRACE solution rather well, though the variability within models and the GRACE solutions was significant. The interannual variability of GRACE TSW was close to the simulated variability. This is promising for the use of gravimetry to monitor TSW on decadal timescale as a correct assessment of interannual variability is a pre-requisite to address the longer term trends. Significant models/data differences were found in the Sudanian–Guinean zone, and were ascribed to the lack of slow reservoirs in most ALMIP simulations. The ALMIP outputs were also fed into a suite of microwave radiative transfer schemes and compared with AMSR-E data (C-Band). Unexpectedly, the scatter due to the microwave schemes was at least as large as the scatter due to different ALMIP models (de Rosnay *et al.*, 2009b). The best microwave parameterisations were retained to be used in the ECMWF Land Data Assimilation System. Overall, many components of the continental water cycle were retrieved from satellite data: precipitation, surface fluxes and energy balance, surface and total soil moisture (e.g. Stisen *et al.*, 2008a), illustrating that a comprehensive monitoring is progressively emerging.

2.3. Looking backward

The satellite archives now commonly cover the last 30 years. For instance, Landsat data spans from 1972 to the present, and it can be complemented with declassified CORONA data and aerial photographs. As a result, looking backward to the 1960s and 1970s provides a view of the land surface in West Africa as it was before the current multi-decadal drought. Gardelle *et al.* (2010) established that the surface of ponds in the Gourma dramatically increased during the multi-decadal drought, despite lower rainfall amounts. This paradox, which is in line with the increased runoff in the Sahel (Descroix *et al.*, 2009; Séguis *et al.*, 2011), differs in the sense that it does not result from a change in cultivated area, as often advocated for runoff changes in the cultivated Sahel. Such an increase has a direct impact in water resource assessment and perception by local societies.

2.4. Looking forward

The network of *in situ* instruments, comprising SSM, TSW, LAI, surface fluxes, land use, LC, collocated with sun-photometers and dense rain-gauges network, together with the expertise acquired by the teams involved in AMMA plea for the continuation of remote sensing validation and calibration activities over the AMMA sites. Indeed, these sites offer unique opportunities for the preparation of new sensors, among which the SENTINELS, SWOT, Megha-Tropiques and SMOS, should be of particular relevance to scientific and societal issues in West Africa, where a remote sensing community is emerging (Woldai and Annegarn, 2010).

3. New and open questions

Different areas of research appear especially promising for the next phase of AMMA. Firstly, many land surface studies were focused on the enhanced observing period (EOP) years (2005–2007), as the bulk of the *in situ* data were acquired during this period. Such studies provide a comprehensive investigation of the success and difficulties of the different satellite products in West Africa. This expertise can now be used to address the decadal scale and the interpretation of existing archives, in order to relate changes of satellite time-series to surface processes. The albedo time series from Meteosat, the NDVI series from the AVHRR, and the microwave archives are natural candidates to investigate the last three decades. It is already known that the AVHRR NDVI archive shows a remarkable upward trend from 1983 up to now, referred to as 'Sahel re-greening' (Herrmann *et al.*, 2005; Hutchinson *et al.*, 2005). Yet, there is still a debate on the causes of such a change and on the balance or Sahel 'greening' and desertification, which will only be solved using *in situ* data and state-of-the art reprocessing of the AVHRR archive.

At a smaller scale, EO data will feed the meso-scale ALMIP 2 model/data comparison to test LSM, hydrology and plant productivity models over the densely instrumented meso-scale sites of AMMA (Boone *et al.*, 2009b).

4. Conclusions

From the above examples, it can be seen that AMMA, although rooted in the ISLSCP experiments like HAPEX-Sahel, shows a marked evolution towards integration of EO in more thematic issues. AMMA has benefited from the maturity reached by several EO products during the elapsed time. As a result, EO data are now delivered operationally and included in 'integrated science' work-packages. AMMA also differs when sampling a much larger area, as well as when having a 3-year EOP. Efforts are being made to maintain ground networks in a 'long term' configuration, to fully benefit from the new satellite missions and to provide relevant calibration/validation sites. One lesson from the AMMA validation studies is that it is important to design multi-variable validation plans. Lastly, the structure established during AMMA, with a unique synergy of *in situ* sites, expertise, and modelling, provides a natural basis for global monitoring efforts in West Africa.

Acknowledgements

It is a pleasure to acknowledge the young scientists who contributed to this work as PhD or Postdoctoral fellows: Annette Norgaard, Armel Kaptue, Bakari Sanou, Claire Gruhier, Cyril André, David Ramier, Frédérique Baup, Julie Gardelle, Mamadou Diawarra, Maliko Tanguy, Maria-Carmen Gonzalez-Sampedro, Olivier Samain, Sarah Guibert, Simon Stisen, Stéphane Saux-Picart. Karim Ramage, Sophie Cloché and the POSTEL team developed and maintained the satellite database. Funding from space agencies (ESA, CNES) is also acknowledged. The support of the AMMA project is gratefully acknowledged (see http://onlinelibrary.wiley.com/doi/10.1002/asl.331/full for full acknowledgement).

References

Baup F, Mougin E, Hiernaux P, Lopes A, de Rosnay P, Chenerie I. 2007a. Radar signatures of Sahelian surfaces in Mali using ENVISAT-ASAR data. *IEEE Transactions on Geoscience and Remote Sensing* **45**: 2354–2363.

Baup F, Mougin E, de Rosnay P, Timouk F, Chenerie I. 2007b. Surface soil moisture estimation over the AMMA Sahelian site in Mali using ENVISAT/ASAR data. *Remote Sensing of Environment* **109**: 473–481.

Boone A, de Rosnay P, Balsamo G, Beljaars A, Chopin F, Decharme B, Delire C, Ducharne A, Gascoin S, Grippa M, Guichard F, Gusev Y, Harris P, Jarlan L, Kergoat L, Mougin E, Nasonova O, Norgaard A, Orgeval T, Ottlé C, Poccard-Leclercq I, Polcher J, Sandholt I, Saux-Picart S, Taylor C, Xue Y. 2009a. The AMMA Land Surface Model Intercomparison Project (ALMIP). *Bulletin of the American Meteorological Society* **90**: 1860–1880.

Boone A, Getirana ACV, Demarty J, Cappelaere B, Galle S, Grippa M, Lebel T, Mougin E, Peugeot C, Vischel T. 2009b. The African Monsoon Multidisciplinary Analyses (AMMA) Land surface Model Intercomparison Project Phase 2 (ALMIP2). *GEWEX News* **19**(4): 9–10.

Descroix L, Mahé G, Lebel T, Favreau G, Galle S, Gautier E, Olivry J-C, Albergel J, Amogu O, Cappelaere B, Dessouassi R, Diedhiou A, Le Breton E, Mamadou I, Sighomnou D. 2009. Spatio-temporal variability of hydrological regimes around the boundaries between Sahelian and areas of West Africa: a synthesis. *Journal of Hydrology* **375**: 90–102.

de Rosnay P, Gruhier C, Timouk F, Baup F, Mougin E, Hiernaux P, Kergoat L, Le Dantec V. 2009a. Multi-scale soil moisture measurements at the Gourma meso-scale site in Mali. *Journal of Hydrology* **375**: 241–252. DOI: 10.1016/j.jhydrol.2009.01.015.

de Rosnay P, Drusch M, Boone A, Balsamo G, Decharme B, Harris P, Kerr Y, Pellarin T, Polcher J, Wigneron J-P. 2009b. AMMA Land Surface Model Intercomparison Experiment coupled to the Community Microwave Emission Model: ALMIP-MEM. *Journal of Geophysical Research* **114**: D05108. DOI: 10.1029/2008JD010724.

Fensholt R, Anyamba A, Stisen S, Sandholt I, Park E, Small J. 2007. Comparisons of compositing period length for vegetation index data from polar-orbiting and geostationary satellites for the cloud-prone region of West Africa. *Photogrammetric Engineering and Remote Sensing* **73**: 297–309.

Fleury L, Boichard JL, Brissebrat G, Cloché S, Eymard L, Mastrorillo L, Oumarou M, Ramage K, Roussot O, Devic MP, Redelsperger JL, Polcher J, Ginoux K, Lafore JP, Ascenscio N, Favot F, Fiolleau T, Legouis S, Tytéca M. 2011. AMMA information system: an efficient cross-disciplinary tool and a legacy for forthcoming projects.

Gardelle J, Hiernaux P, Kergoat L, Grippa M. 2010. Less rain, more water in ponds: a remote sensing study of the dynamics of surface waters from 1950 to present in pastoral Sahel (Gourma region, Mali). *Hydrology and Earth System Sciences* **14**: 309–324.

Gruhier C, de Rosnay P, Hasenauer S, Holmes T, de Jeu R, Kerr Y, Mougin E, Njoku E, Timouk F, Wagner W, Zribi M. 2010. Soil moisture active and passive microwave products: intercomparison and evaluation over a Sahelian site. *Hydrology and Earth System Sciences* **14**: 141–156.

Gruhier C, de Rosnay P, Kerr Y, Mougin E, Ceschia E, Calvet J-C, Richaume P. 2008. Evaluation of AMSR-E soil moisture product based on ground measurements over temperate and semi-arid regions Geophys. *Research Letters* **35**: L10405. DOI: 10.1029/2008GL033330.

Herrmann SM, Anyamba A, Tucker CJ. 2005. Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change-Human and Policy Dimensions* **15**: 394–404.

Hutchinson CF, Herrmann SM, Maukonen T, Weber J. 2005. Introduction: the "greening" of the Sahel. *Journal of Arid Environments* **63**: 535–537.

Kaptue Tchuente AT, Roujean JL, Faroux S. 2010. ECOCLIMAP-II: an ecosystem classification and land surface parameters database of Western Africa at 1 km resolution for the African Monsoon Multidisciplinary Analysis (AMMA) project. *Remote Sensing of Environment* **114**: 961–976.

Mougin E, Hiernaux P, Kergoat L, Grippa M, de Rosnay P, Timouk F, Le Dantec V, Demarez V, Lavenu F, Arjounin M, Lebel T, Soumaguel N, Ceschia E, Mougenot B, Baup F, Frappart F, Frison PL, Gardelle J, Gruhier C, Jarlan L, Mangiarotti S, Sanou B, Tracol Y, Guichard F, Trichon V, Diarra L, Soumare A, Koite M, Dembele , Lloyd C, Hanan NP, Damesin C, Delon C, Serca D, Galy-Lacaux C, Seghieri J, Becerra S, Dia H, Gangneron F, Mazzega P. 2009. The AMMA-CATCH observatory site in Mali: relating climatic variations to changes in vegetation, surface hydrology, fluxes and natural resources. *J. Hydrol.* **375**(1–2): 14–33.

Pellarin T, Ali A, Chopin F, Jobard I, Bergès J-C. 2008. Using spaceborne surface soil moisture to constrain satellite precipitation estimates over West Africa. *Geophysical Research Letters* **35**: L02813. DOI: 10.1029/2007GL032243.

Pellarin T, Laurent JP, Cappelaere B, Decharme B, Descroix L, Ramier D. 2009a. Hydrological modelling and associated microwave emission of a semi-arid region in South-western Niger. *Journal of Hydrology* **375**: 262–272.

Pellarin T, Tran T, Cohard J-M, Galle S, Laurent J-P, de Rosnay P, Vischel T. 2009b. Soil moisture mapping over West Africa with a 30-min temporal resolution using AMSR-E observations and a satellite-based rainfall product. *Hydrology and Earth System Sciences* **13**: 1887–1896.

Proud SR, Fensholt R, Rasmussen MO, Sandholt I. 2010. A comparison of the effectiveness of 6S and SMAC in correcting for atmospheric interference of meteosat second generation images. *Journal of Geophysical Research* **115**: D17209.

Ramier D, Guichard F, Cappelaere B, Kergoat L, Galle S, Timouk F, Boulain N, Boucher M, Taylor C, Boone A. 2009. Impact of the monsoon on downwelling surface radiative fluxes across West Africa: an evaluation of ECMWF-IFS and satellite estimates with ground measurements. *Geophysical Research Abstracts* **11**: EGU2009-10586-1, 2009.

Samain O, Kergoat L, Hiernaux P, Guichard F, Mougin E, Timouk F, Lavenu F. 2008. Analysis of the *in situ* and MODIS albedo variability at multiple time-scales in the Sahel. *Journal of Geophysical Research* **113**: D14119. DOI: 10.1029/2007JD009174.

Séguis L, Boulain N, cappelaere B, Favreau G, Galle S, Hiernaux P, Mougin E, Peugeot C, Ramier D, Seghieri J, Cohard JM, Demarez V, Demarty J, Descroix L, Descloitres M, Grippa M, Guichard F, Guyot A, Kamagaté S, Kergoat L, Lebel T, Le Dantec V, Le Lay M, Massuel S, Timouk F, Trichon V. 2011. Contrasted land surface processes along a West African rainfall gradient.

Stisen S, Jensen KH, Sandholt I, Grimes DIF. 2008a. A remote sensing driven distributed hydrological model of the Senegal River basin. *Journal of Hydrology* **354**: 131–148.

Stisen S, Sandholt I, Nørgaard A, Fensholt R, Høgh Jensen K. 2008b. Combining the triangle method with thermal inertia to estimate regional evapotranspiration – applied to MSG-SEVIRI data in the Senegal River basin. *Remote Sensing of Environment* **112**: 1242–1255.

Tanguy M, Baille A, Gonzalez-Real M, Izaguirre I, Martinez V, Brüggemann N, Brümmer C. 2007. Retrieval of evapotranspiration from satellite: Validation and evolution of spatial distribution at Bontioli, Burkina Faso. In *AMMA 2nd International Conference*, Genau I, van den Akker E, Redelsperger JL (eds). Karlsruhe, November 26–30 2007.

Taylor CM, Parker DJ, Kalthoff N, Gaertner MA, Philippon N, Bastin S, Harris PP, Boone A, Guichard F, Agusti-Panareda A, Baldi M, Cerlini P, Descroix L, Douville H, Flamant C, Grandpeix J-Y, Polcher J. 2011. New perspectives on land–atmosphere feedbacks from the African Monsoon Multidisciplinary Analysis. *Atmospheric Science Letters* **12**: 38–44, DOI: 10.1002/asl.336.

Traore SB, Kouressy M, Muller B, Somé L, Alhassane A, Sultan B, Vintrou E, Sangaré S, Vaskmann M, Diop M, Bégué A, Dingkhun M, Baron C. 2011. Characterizing and modelling the diversity of cropping situations under climatic constraints in West Africa. *Atmospheric Science Letters* **12**: 89–95, DOI: 10.1002/asl.295.

Woldai T, Annegarn H. 2010. Remote sensing for Africa: a special collection from the African Association for Remote Sensing of the Environment, AARSE: editorial. *International Journal of Applied Earth Observation and Geoinformation: JAG* **12**(Suppl. 1): S1–S2.

Zribi M, Pardé M, de Rosnay P, Baup F, Boulain N, Descroix L, Pellarin T, Mougin E, Ottlé C, Decharme B. 2009. ERS scatterometer surface soil moisture analysis of two sites in the south and north of the Sahel region of West Africa. *Journal of Hydrology* **375**: 253–261.

Zribi M, Saux-Picart S, André C, Descroix L, Ottlé C, Kallel A. 2007. Soil moisture mapping based on ASAR/ENVISAT radar data over a Sahelian region. *International Journal of Remote Sensing* **28**: 3547–3565.

