Institution: University of Reading

Unit of Assessment: 7 – Earth Systems and Environmental Sciences

Title of case study: Drought monitoring and early warning for African food security using remote sensing of rainfall by the TAMSAT project

Period when the underpinning research was undertaken: Between 2014 and 2018

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Emily Black	TAMSAT group lead, Professor and National Centre for Atmospheric Science senior scientist	2003 to Present
Ross Maidment	TAMSAT operations lead and Earth Observation core scientist	2014 to Present
Vicky Boult	TAMSAT knowledge exchange lead and research scientist	2019 to Present
Tristan Quaife	Associate Professor and National Centre for Earth Observation senior scientist	2012 to Present
Ewan Pinnington	National Centre for Earth Observation core research scientist	2017 to Present
Richard Allan	Professor	2014 to Present
Elena Tarnavsky	Senior Research Fellow	2014 to Present

Period when the claimed impact occurred: Between 1 August 2013 and 31 December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Over 200 million people in sub-Saharan Africa depend on rain-fed subsistence agriculture. Despite this, the ground rainfall monitoring network in Africa is so sparse that less than 2% of the population live in the vicinity of a rain gauge. Research at Reading has developed the TAMSAT (Tropical Applications of Meteorology using SATellite data) satellite-based rainfall estimation and drought forecasting system to address this problem. Accurate information on where, and how severe, adverse conditions are likely to be facilitates action that mitigates the impact of drought. For example, reliable, local monitoring supports people with risk-management methods, including drought insurance and agricultural decision support. Since 2015, pay-outs from TAMSAT-based drought insurance have compensated approximately 3 million farmers for drought-induced crop losses, with insurance pay-outs of an unprecedented USD14m (April 2020). At a regional scale, trusted monitoring and forecasting products enable organisations to invest smartly for long-term productivity. In 2019, TAMSAT-ALERT (AgriculturaL Early waRning sysTem) forecasts allowed 300,000 farmers to divert resources from drought preparedness actions to resilience-building activities in Kenya. The success of TAMSAT services in Africa has created demand elsewhere in the tropics. As of October 2020, TAMSAT-ALERT forecasts underpin a major new drought disaster relief fund in the Punjab and Sindh regions of Pakistan, reaching a population of 63.5 million.

TAMSAT-based drought risk management initiatives support millions of Africa's poorest farmers. Fundamental to this have been TAMSAT's high quality data and products, alongside a deep engagement with Africa's climate service providers.

2. Underpinning research

The Reading-led TAMSAT research focuses on the robust estimation of meteorological, hydrological and agricultural risk across Africa. At the heart of the programme is a high-resolution near real-time rainfall dataset, spanning all of Africa from 1983 to the present day.

Recent developments of TAMSAT's rainfall estimation technique undertaken at the University of Reading have substantially improved the utility of the dataset. Although previously skilful at detecting drought, the original dataset contained a persistent dry bias [R1] and the aggregation of regions into 'calibration zones' resulted in spatial artefacts [R2]. A revised calibration technique developed by Black and colleagues has eliminated these issues [R3], increasing the skill of the dataset and user confidence [R4]. Additionally, the coverage of the TAMSAT dataset has been extended to include all of Africa [R1, R2] and previous 10-day accumulations have been disaggregated into daily rainfall estimates [R3]. The culmination of this research has made TAMSAT data relevant for applications monitoring short-term risk and requiring cumulations over bespoke periods [R3]. Updated, Africa-wide rainfall estimates are now issued every five days, year-round (http://www.tamsat.org.uk).

The wide uptake of TAMSAT data stems partly from the historical calibration approach, which ensures a stable climatology, and hence robust identification of anomalous conditions. Alternative methods ingest real-time rain gauge observations, but as a result have a latency of up to six weeks and suffer instabilities caused by missing gauge records. Such instabilities cause large biases in estimated trends and complicate the identification of anomalous conditions [R5]. TAMSAT is therefore a clear choice for applications which depend on real-time reliable estimates of anomalous conditions, such as insurance and early action protocols, that can then trigger anticipatory pay-outs and preparatory action.

Anticipatory approaches to risk management can reduce impacts of adverse weather whilst also sparing limited resources. Moreover, the earlier a reliable risk assessment is made, the more effective risk mitigation strategies become. Whilst rainfall monitoring plays a key role in the early warning of drought, it is ultimately soil moisture on timescales from weeks (for germination) to months (for crop yield) which impacts agriculture and food security. The TAMSAT AgriculturaL EaRly warning 2ystem (TAMSAT-ALERT) was developed to provide reliable forecasts of land-surface conditions (including soil moisture) at timescales suitable to support anticipatory drought management (weeks to months). TAMSAT-ALERT is a statistical and land-surface modelling framework that provides an assessment of agricultural risk based on monitoring of the growing season, the historical climatology and the meteorological forecast [R6]. Data assimilation principles are applied to calibrate the model, integrating TAMSAT rainfall data with reanalysis and remotely sensed soil moisture, greatly improving the representation of soil moisture conditions [R7]. TAMSAT-ALERT can be applied at a range of timescales to assess the risk of seasonal crop failures or to provide decision-support within seasons, such as when to plant, fertilise and harvest.

3. References to the research

Research Quality Statement: All references were subject to peer review and meet or exceed the two-star quality criteria ("provides useful knowledge and influences the field"; "involves incremental advances"). Evidence of influence is indicated by (September 2020) Web of Science Citations in square brackets.

R1. Maidment, R.I., Grimes, D., Allan, R.P., Tarnavsky, E., Stringer, M., Hewison, T., Roebeling, R. and Black, E. (2014) The 30-year TAMSAT African rainfall climatology and time-series (TARCAT) dataset. *Journal of Geophysical Research: Atmospheres*, 119 (18). pp. 10619-10644. DOI: https://doi.org/10.1002/2014JD021927 [110]

R2. Tarnavsky, E., Grimes, D., Maidment, R., Black, E., Allan, R., Stringer, M., Chadwick, R. and Kayitakire, F. (2014) Extension of the TAMSAT satellite-based rainfall monitoring over

Africa and from 1983 to present. *Journal of Applied Meteorology and Climatology*, 53 (12). pp. 2805-2822. DOI: https://doi.org/10.1175/JAMC-D-14-0016.1 [89]

R3. Maidment, R.I., Grimes, D., Black, E., Tarnavsky, E., Young, M., Greatrex, H., Allan, R.P., Stein, T., Nkonde, E., Senkunda, S. and Alcántara, E.M.U. (2017) A new, long-term daily satellite-based rainfall dataset for operational monitoring in Africa. *Scientific Data*, 4. 170063. DOI: https://doi.org/10.1038/sdata.2017.63 [35]

R4. Dinku T., Funk, C., Peterson P., Maidment R.I., Tadesse T., Gadain H. and Ceccato P. (2018) Validation of the CHIRPS Satellite Rainfall Estimates over eastern Africa. *Q. J. R. Meteorol. Soc.,* 144 (Suppl. 1). pp. 292–312. DOI: https://doi.org/10.1002/qj.3244 [54]

R5. Maidment, R.I., Allan, R.P. and Black, E. (2015) Recent observed and simulated changes in precipitation over Africa. *Geophysical Research Letters*, 42 (19). pp. 8155-8164. DOI: https://doi.org/10.1002/2015GL065765 [91]

R6. Asfaw, D., Black, E., Brown, M., Nicklin, K.J., Otu-Larbi, F., Pinnington, E., Challinor, A., Maidment, R. and Quaife, T. (2018) TAMSAT-ALERT v1: a new framework for agricultural decision support. *Geoscientific Model Development*, 11 (6). pp. 2353-2371. DOI: https://doi.org/10.5194/gmd-11-2353-2018 [2]

R7. Pinnington, E., Quaife, T. and Black, E. (2018) Impact of remotely sensed soil moisture and precipitation on soil moisture prediction in a data assimilation system with the JULES land surface model. *Hydrology and Earth System Sciences*, 22 (4). pp. 2575-2588. DOI: https://doi.org/10.5194/hess-22-2575-2018 [12]

4. Details of the impact

Improvements in the TAMSAT estimation method, alongside the new TAMSAT-ALERT forecasting system, developed at the University of Reading, have demonstrably enhanced Africa's resilience to drought, through improved risk management and agricultural decision-making. Key to this is TAMSAT's engagement in national-scale climate services programmes, alongside a commitment to building a community that is confident in utilising novel observing and forecasting systems.

Risk management through drought insurance: Owing to the near real-time availability and skill in detecting anomalous conditions, TAMSAT data is increasingly used in the financial sector to provide weather-index insurance (WII) to farmers across Africa. Like traditional insurance, WII provides financial protection against crop losses caused by adverse weather, but rather than insurers having to verify crop losses, WII pays-out based on a breach of a weather threshold. This approach makes WII cheaper to administer and more affordable to farmers. Moreover, with the use of TAMSAT data, WII is no longer limited to those farmers who live close to weather stations, meaning more farmers have access to financial support should their crops fail.

Zambian-based specialist insurance provider Risk Shield Consultants Ltd (RSC) have exclusively used TAMSAT rainfall data since 2013 to insure farmers in Angola, Ivory Coast, Kenya, Lesotho, Malawi, Namibia, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe [S1]. Through RSC, TAMSAT data was used in the Zambian Government's Farmer Input Support Programme, insuring over 2 million farmers since 2017, as well as to over 1 million farmers elsewhere. The impact of this programme is evidenced by insurance pay-outs, based on TAMSAT data, of approximately USD14M between 2015-2019 [S1]. This was an unprecedented amount for WII and gave farmers the opportunity to purchase replacement seed and food for their families.

RSC is just one example of TAMSAT's use in the financial sector. TAMSAT data is, for example, also used by Africa Risk Capacity, an agency that provides financial tools to all African Union countries to manage the risk of natural disasters. Other financial sector users of TAMSAT include OKO Crop Assurance. In addition, the World Food Programme uses TAMSAT-ALERT soil moisture forecasts within the operation of its R4 Rural Resilience Initiative insurance programme [S2].

Building resilience through robust agricultural decision-making: Despite its infancy, the demand for reliable forecasts of soil moisture is seeing TAMSAT-ALERT technology rapidly adopted by institutions across Africa. For example, TAMSAT-ALERT forecasts were piloted by Kenya's National Drought Management Authority (NDMA) in Kitui county during the 2019 short rainy season [S3]. Based on TAMSAT-ALERT forecasts indicating a low probability of drought, the 300,000 farmers in Kitui moved from the 'Alert' phase of food security into the 'Normal' phase, allowing limited resources to be diverted from short-term drought preparedness activities to long-term resilience building investments [S4]. The success of the pilot has seen TAMSAT-ALERT forecasts rolled-out to additional vulnerable counties (Marsabit, Nyeri, Taita Taveta and Turkana) in early 2020, with further plans to expand TAMSAT-ALERT forecasting in progress [S4].

Within shorter timeframes, TAMSAT-ALERT provided live planting date decision-support to the One Acre Fund (OAF) in early 2020. Advisories were shared with agricultural extension workers in Uganda, Kenya and Zambia via SMS, representing approximately 70,000 farmers [S5]. OAF's agricultural research director, Step Aston, relays: "*Feedback from the farmers suggested that the advice was provided at the correct time, and post-hoc evaluation indicates that the TAMSAT-ALERT advice correctly advised farmers to plant early, enabling them to benefit from an unusually long growing season*" [S5]. At national scales, the Nigerian and Ghanaian national hydro-meteorological services (NHMSs) are actively assessing the suitability of TAMSAT-ALERT based climate services, enabling them to provide soil moisture and crop yield forecasts for the first time.

In the humanitarian sector, the Red Cross is fine-tuning triggers based on TAMSAT-ALERT forecasts for use in Early Action Protocols in Kenya, Uganda, Ethiopia, Lesotho, Mozambique and Namibia. These planned protocols (to be piloted between 2021 and 2023) will enable the Red Cross to implement the first forecast-based finance (FbF) scheme in Africa for drought. Dr Asha Mohammed, secretary general of Kenya Red Cross Society, writes: "*The development of TAMSAT-ALERT has presented an opportunity to develop an FbF approach for drought and marks a clear change of practice within KRCS*" [S6]. The resulting anticipatory action will buffer several tens of millions of farmers against the impacts of severe drought [S6].

The successful adoption of TAMSAT-ALERT drought forecasts within the African humanitarian sector has created demand elsewhere in the tropics. From 2020, the Start Network (a global group of NGOs) has been operating a drought Disaster Risk Financing (DRF) scheme in the Punjab and Sindh provinces of Pakistan – based exclusively on TAMSAT-ALERT forecasts. Emily Montier, Head of Crisis Anticipation and Risk Financing at the Start Network, writes, "*TAMSAT's contribution has been crucial*…(as) *existing forecasting and monitoring systems do not provide the quantitative, probabilistic and granular output required for rapid release of pre-positioned funds via the DRF* (that TAMSAT provides)." She confirms how the "*TAMSAT-ALERT drought forecasting system enables the timely release of funds to the rural populations of the Punjab and Sindh (~63.4 Million people) … This effort plays a key role in Start Network's mission to protect some of the most vulnerable farmers in Pakistan against the devastating impacts of drought*" [S7].

Climate services and capacity building: Building the capacity of NHMSs to develop and exploit TAMSAT-based products is crucial if TAMSAT products are to be widely adopted and robustly used. TAMSAT has offered internships and research supervision to more than 15 African students from 10 countries, many of whom now hold senior positions in African NHMSs. Former student, Edson Nkonde, is a good example: having completed his dissertation with TAMSAT in 2015, Mr Nkonde now heads the Zambian Meteorological Department and has worked with TAMSAT collaborators (RSC and WFP) to improve the use of satellite products for climate services, including the launch of Zambia's WII scheme (above). Uptake of TAMSAT data represents a fundamental change of policy in Zambia, with the previous Director opposed to using remotely sensed data.

Additionally, University of Reading staff have facilitated workshops and delivered training courses throughout Africa. These activities have established a culture open to the adoption and

development of innovative climate services. Examples include Rainwatch, led by the University of Reading's Walker Institute, and Enhancing National Climate Services (ENACTS) - a climate service project run by the International Research Institute for Climate and Society. Through ENACTS, TAMSAT data is combined with rain gauge measurements to provide high quality rainfall information to improve national drought contingency planning in Mali, Ghana, Zambia, Rwanda, Madagascar, Tanzania and Ethiopia, and regionally across West Africa [S8]. In turn, ENACTS formed an integral component of the 2018 Climate Smart Agriculture Project of the Year award-winning project, Rwanda's Climate Services for Agriculture that aims to improve the accessibility of climate information to improve agricultural planning and food security [S9].

TAMSAT has contributed to World Meteorological Organization courses on satellite rainfall estimation for several years, and more recently to Red Cross training on impact-based forecasting. Notably, based on training delivered by TAMSAT to County Drought Coordinators (CDCs) in Kitui, Kenya - Kitui CDCs were the first to carry-out their own Short-Rains Assessment without external support, representing a substantial financial saving for the NDMA and a significant increase in technical ability [S3].

During the Covid-19 pandemic, TAMSAT has established a series of remote workshops and a companion 'Virtual Academy' (https://tamsat.moodle.school/login/index.php), hosting courses on satellite rainfall estimation and impact-based forecasting. Our first such activities have reached over 100 participants from 19 countries [S9]. Feedback from these workshops highlights their importance in fostering a growing community of drought management stakeholders capable of exploiting available data (beyond TAMSAT alone) to improve climate services [S10].

As a matter of policy, all TAMSAT code and datasets are freely available without licensing restrictions and were developed to operate on low-specification laptops, of the power used by NHMSs. Supporting our user community in these ways has enabled commercial, governmental and non-governmental organisations to provide the robust climate services described above, significantly improving the lives of some of the world's most vulnerable people.

Summary: Reliable rainfall information is essential for individuals and organisations to manage the risks of drought. However, a sparse and inconsistent rain gauge network across Africa has hindered the development of effective drought risk management instruments. University of Reading-led improvements to TAMSAT satellite-based rainfall estimates, including: a revised calibration technique and disaggregation to the daily timestep; the development of the TAMSAT-ALERT soil moisture forecasting tool; and efforts to establish capacity within African institutions to utilise such information, has enabled new approaches to drought risk management. TAMSAT has reached millions of Africa's most vulnerable people via weather-index insurance programs, early-action protocols and agricultural decision support systems. Thanks to this ground-breaking innovation, much of Africa is now significantly less vulnerable to the impacts of drought.

5. Sources to corroborate the impact

S1. Testimonial from the Managing Director of Risk Shield Consultants, 22 April 2020.
S2. Report using TAMSAT-ALERT in World Food Programme's R4 scheme.
S3. National Drought Management Authority November 2019 Kitui county early-warning bulletin using TAMSAT-ALERT for seasonal prognosis.
S4. Testimonial from Kenya's National Drought Management Authority, 11 May 2020.
S5. Letter from Step Aston of One Acre Fund, 12 August 2020.
S6. Testimonial from the Secretary General of Kenya Red Cross Society, 17 August 2020.
S7. Testimonial from the Head of Crisis Anticipation and Risk Financing of the Start Network, 22 November 2020.
S8. Testimonial from the International Research Institute for Climate and Society, 24 August 2020.
S9. Report on Climate Smart Agriculture Project of the Year 2018 highlighting ENACTS.
S10. Report including statistics and feedback on TAMSAT workshop, July 2020.