Institution: University of Reading

Unit of Assessment: 7 Earth Systems & Environmental Sciences

Title of case study: Drought Monitoring and Early Warning for African Food Security Using Remote Sensing of Rainfall by the TAMSAT project

1. Summary of the impact: Over one quarter of the estimated 886 million undernourished people in the world live in sub-Saharan Africa and their lives and livelihoods depend critically on rain-fed agriculture. However this region has lacked the equipment and the infrastructure to monitor rainfall. Over the past 20 years, the Unit's **TAMSAT** (**T**ropical **A**pplications of **M**eteorology using **SAT**ellite Data and Ground-Based Observations) research group has developed a reliable and robust means for monitoring rainfall, appropriate for use in Africa. In addition, the Unit pioneered the use of such data to predict crop yields over large areas. TAMSAT data and methods are now used in food security (to anticipate drought and predict crop and livestock yields); in health planning (to predict outbreaks of rain-promoted diseases such as malaria); in aid (to guide the allocation and distribution of relief food and water); and in economic planning (to plan mitigation activities and investment in infrastructure). The Unit's programme of development and validation has extended the method to all of Africa, at all times of year. Our work with national meteorological services in Africa has helped them to build their own capabilities and to both contribute to TAMSAT and exploit it. The data provided by TAMSAT has had major impact in increasing the resilience of African populations to weather and climate, saving and improving the quality of lives, and strengthening economies in developing nations.

2. Underpinning research: In working with many local scientists[1] over many decades it was clear to Unit staff that rainfall data in Africa were inadequate. Africa has the lowest density of rain gauges for any continent apart from Antarctica and operational rain radars do not exist in most areas. TAMSAT uses spacecraft data to give maps of rainfall. The method requires a great deal of calibration, but this makes it more accurate and reliable than more complex rival methods. Work done before 1993 had demonstrated how satellite thermal infrared (TIR) imagery could be used to estimate rainfall from the observed Cold Cloud Duration (CCD) - the duration of a cloud-top temperature below a given threshold.[2] The technique is importantly simple: local, seasonally-varying temperature thresholds which best discriminate between precipitating and non-precipitating clouds of convective origin are empirically determined using the observed CCD and rainfall data from rain gauges on the ground (a process hereafter referred to as calibration). Using the sole input of TIR imagery, rainfall maps are produced in near-real time for each 10-day period and they have also been generated retrospectively for January 1983 onwards. Climatology-based calibrations now exist for a 28-year long archive (1983-2010) of simultaneous CCD and rain gauge observations. Work done since 1993 (which continues to the present day) has developed the technique and extended its geographical reach. Initial conceptual work after 1993 was driven by G. Dugdale (retired from the Unit in 2000 but still a visiting fellow) and J. Milford (retired 1998). From 1995 until his untimely death in late 2011, the research was led and coordinated by David Grimes, with developments by many PDRAs and PhD students under his supervision (including E. Tarnavsky, R. Maidment, H. Greatrex, E. Pardo-Igúzquiza, R. Bonifacio, V. Thorne, C. Teo and M. Assiri). Other staff who contributed to the work are J.Slingo, Challinor, and P. Crauford (all now left UoR) and Wheeler (SAPD). Following the death of Grimes, the work is led by E. Black with contributions by R. Allan, C. Williams (PDRA) and NERC KE Fellow R. Cornforth.

The key advantages of TAMSAT over other methods that rely on more complex algorithms and more modern satellite equipment are that: (1) it can be applied consistently to a long time series of data; (2) African Met services can both contribute to and use the data; and (3) through the calibrations, it can be adapted to cope with the required range of locations, times and applications. In order to cover all Africa at all times, an extensive programme of calibration development and validation, as well as rainfall time series development and comparisons with other approaches have all been needed and continue to the present day.

TAMSAT uses an extensive proprietary rain-gauge dataset obtained from local meteorological services. This improves its skill compared to other satellite products and facilitates sustained engagement with those Met. services, their funding agencies and governments. The continual improvements of the calibration techniques over the past 20 years have resulted in increased accuracy (e.g. Pardo-Igúzquiza et al., 2006) and extended the regions covered: for example, Thorne et al. (2001) in southern Africa and Assiri (UoR PhD thesis, 2011, supervised by Grimes) in the Arabian Peninsula.

Developments of the technique and its applications, made by the Unit between 1993 and 2012, have radically expanded the use of the TAMSAT (and other rainfall data) to quantitative estimates and forecasts of cultivated (crop) and natural vegetation growth over Sahelian pastures. Early development by Bonifacio et al. (1993) of pastureland growth used a regression model between biomass production and accumulated plant water use, derived from TAMSAT rainfall estimates through a simple soil water budgeting procedure. Further work in the Unit, in collaboration with the School of Agriculture Policy and Development (SAPD), developed a methodology for predicting national-level crop yield (using the GLAM model developed also in collaboration with SAPD) with gridded rainfall data (Challinor et al., 2003; Teo and Grimes, 2007) and also evaluated how uncertainties in the rainfall estimates propagate through to crop yield estimate (H. Greatrex, UoR PhD thesis, 2012, supervised by Grimes and Wheeler). There are now several models that routinely use satellite rainfall data to drive crop models: all build on the Unit's pioneering proof-of-concept work that laid down basic principles and demonstrated the potential.

Under a project supported by the EC[3], the Unit is part of a consortium with partners Alterra, MeteoConsult and VITO (Vision on Technology) for which they undertook the first Africa-wide calibration effort that led to the derivation of the 30-year TARCAT (TAMSAT African Rainfall Climatology And Time-series) dataset, as well as a library of methods for routine validation of the satellite based rainfall estimates. This is increasingly important as TARCAT is uniquely homogeneous, high-resolution dataset and so provides climatology, against which events and long-term changes can be compared).[4] TAMSAT also took part in a study of how climate change, and rainfall in particular, is likely to influence African economies (Washington et al., 2006).

1. A good example is A.Yeboah, senior agrometeorologist at the Ghana Agricultural Insurance Pool
2. Milford, J.R., & Dugdale, G. (1990). Estimation of Rainfall Using Geostationary Satellite Data. Applications of Remote Sensing in Agriculture, Butterworth, London Proceedings of the 48th Easter School in Agricultural Science, University of Nottingham. April 1989.
3. MARS (Monitoring Agricultural Resources) Unit of the European Commission (EC) AGRI4CAST and FOODSEC Action – project MARSOP3: http://www.marsop.info/marsop3/
4. TARCAT is already operational. The journal papers by Tarnavsky et al. (2013) and Maidment et al. (2013) describing its development were delayed by the sudden death of Grimes but have now been submitted for publication to JAMC (pre-prints available from Unit).

3. References to the research: References have been selected to illustrate various aspects of development over 20 years. A WoS search reveals that the 7 papers listed have been cited 183 times at an average rate of 3 cites per year per paper. Three papers which can be used to judge the research quality are marked with an asterisk.

The work over the past 20 years has been funded from a wide variety of sources: NERC (studentships, a Workshop KE Grant and a KE Fellowship); many agency contracts (such as the JRC, Defra and DfID) and philanthropic support (particularly from Google.org). The development of TAMSAT-driven crop models was funded by the UoR's Research Endowment Trust Fund.

*A. Challinor, J. Slingo, T.Wheeler, P. Craufurd, & D. Grimes, 2003: Toward a Combined Seasonal Weather and Crop Productivity Forecasting System: Determination of the Working Spatial Scale. *J. Appl. Meteor*., 42, 175 (55 cites)

*V. Thorne, P. Coakeley, D. Grimes & G. Dugdale (2001) Comparison of TAMSAT and CPC rainfall estimates with raingauges, for southern Africa, *Int. J. Remote Sensing*, 22, 1951 (26 cites)

*C.K. Teo & D. I. F. Grimes (2007), Stochastic modelling of rainfall from satellite data, *J. Hydrol.*, *346*(1-2), 33-50. (13 cites)

R. Washington, et al. incl. E. Black, A. Challinor, & D. Grimes (2006) African climate change - Taking the shorter route, *Bull Am. Met. Soc., 87*, 1355 (69 cites)

E. Pardo-Igúzquiza, D. I. F. Grimes, & C.-K. Teo (2006), Assessing the uncertainty associated with intermittent rainfall fields, *Water Resour. Res*., 42, W01412 (1 cite)

R. Bonifacio, G. Dugdale & J. R. Milford (1993) Sahelian rangeland production in relation to rainfall estimates from Meteosat, *Int. J. Remote Sensing*, 14 (14), 2695-2711. (11 cites)

R. Maidment, D. Grimes, R.P. Allan, H. Greatrex, et al. (2012) Evaluation of satellite-based and model re-analysis rainfall estimates for Uganda. *Met. Apps*., 20 (3) 308-317 (0 cites)

4. Details of the impact: TAMSAT's great impact stems from its skill, the longevity of the dataset it has produced, the near-real time nature of the data it produces and its direct links to decision-makers. Its impact extends beyond rainfall estimates to include food security; health planning; humanitarian aid; and in economic planning as well as in capacity building of local meteorological services and community resilience.

Rainfall estimates, drought and crop failure

The procedures developed have allowed the Unit to issue rainfall estimates every 10 days and every month, at very high spatial resolution (4 km nominally but reliable at around 10 km). These estimates now cover the whole of Africa and are widely considered to be, on average, as or more robust, skilful and reliable than from more complex methods.[5,6] It is particularly suited to identifying 10-day periods of above- and below-average rainfall in real time, making it ideal for drought and food monitoring. The TARCAT climatology allows events and anomalies to be defined. TAMSAT has been shown to provide early warning of crop failures caused by low precipitation during key stages of the crop growing cycle. A quote from the leader of the FOODSEC Action of the EC's Joint Research Centre (JRC)[5] explains the importance and quality of TAMSAT data and how its wider use came about: "*The JRC contracted TAMSAT to provide improved data of rainfall estimates over Africa. The TAMSAT approach was expected to yield more reliable estimates thanks to the local calibration approach compared to estimates derived from GCMs. At the Crop And Rangeland Monitoring workshop (Sept. 2011), it was demonstrated that TAMSAT data was superior to other sources for estimating accurately the extent of the drought that hit the Horn of Africa in 2010-2011. We started to use effectively the TAMSAT data in our Crop Monitoring Bulletins (later renamed Food Security Bulletins)*[7,8] *in 2012 because before then data suffered some artefacts in the calibration process. The recent release of a 30-year archive opens possible other uses such as weather index insurance in agriculture. The bulletins we publish are mainly used by other European Union services dealing with food aid, and food security in general. They are European Community Humanitarian Office (ECHO), DG Development and Cooperation and EU delegations in countries at risk of food insecurity (circa 15 countries in Sub-Saharan Africa). The bulletins are also used by UN agencies (FAO and WFP) ... and by some NGOs."*

Planning humanitarian aid

A clear example of the value of TAMSAT research was provided by the 2011/12 Sahel crisis:[9] 18 million people across nine countries were subject to drought-driven famine, and more than 1 million children's lives were at risk.[10] Warnings were initially broadcast in 2010 by USAID/FEWS-NET (a Famine Early Warning System)[11], based on the results of general circulation modelling. As rainfall monitoring became vital to understand the development of the crisis, TAMSAT was utilized by agencies such as the UN's FAO6 (via the JRC and the Africa Real Time Environmental Monitoring Information System), FSNAU (Food Security and Nutrition Analysis Unit, Somalia) and FSNWG (Food Security and Nutrition Analysis Working Group) (Nairobi)[12]. TAMSAT complemented independent rainfall monitoring by FEWS-NET and predictions of large-scale crop yields based on satellite imagery of rainfall, as pioneered by the Unit using TAMSAT data, became of vital importance. OXFAM and Save the Children consider the response was better than for previous crises (more children received treatment for acute malnutrition in the region than ever before, and the World Food Programme alone reached 5-6 million people with food aid[10]). Shortfalls in the response were defined to be political and organisational,[13] but the reliability and accuracy of the warnings was considered either "very good" or "excellent".[14] The IMPACT of TAMSAT data and science continues to grow as governments and aid agencies learn how to make best use of the warnings and rainfall monitoring.[9]

Distribution and use of estimates of crop and pasture yields

The Unit won the contract to provide data to the JRC's FOODSEC Action in 2008 because of targeted research (that was later published in Maidment et al. 2012), demonstrating the value of adding TAMSAT data to re-analysis data (e.g. from ECMWF). Since 2012, JRC and ReliefWeb bulletins[7,8] use TAMSAT data to estimate crop and pasture food yields. More than 40 regional and annual bulletins are published each year providing qualitative and, where possible, quantitative yield forecasts at least one month prior to harvest for the whole of Africa. All the main agencies and charities involved in African food security and aid (list available from the Unit) receive TAMSAT data as part of the set compiled by FOODSEC and used to help them define policy. The bulletins are also used by UN agencies to cross-check their own assessments. As part of the MARSOP project,[3] TAMSAT's operational rainfall estimates support the activities of the AMESD (African Monitoring of the Environment for Sustainable Development) thematic groups through their data broadcasting service, e-Station. Additionally, the TARCAT dataset is instrumental in the derivation of the Global Water Satisfaction Index (GWSI) for crop productivity analysis within the FOODSEC

Action. TAMSAT data are now also used by members of AfClix (the Africa Climate Exchange) set up by R. Cornforth, a NERC KE Fellow in the Unit since 2011, representing a diverse set of users across disciplines and sectors worldwide (for example, recently supporting a flash flood early warning system in Sudan piloted in the 2013 rainy season).

Capacity building and community resilience

In addition to providing data, an important aspect of TAMSAT is capacity building of African national meteorological agencies. In this, the relative simplicity of the TAMSAT method is a major asset. The Unit's team now collaborates with 21 partner organisations, 10 of which are in Africa. TAMSAT is also used by AGHRYMET[15] to provide key and timely information on the rainy season. As, for example, noted by the Ethiopia national meteorological agency "*TAMSAT played an important role in building capacity to generate quality rainfall products for both real-time and historical data use in Ethiopia*."[16] The Unit has run workshops in Africa, attended by 7 African nations, installed custom-made training software and websites and taught MSc and PhD students.

TAMSAT also has had a key role in building community-centred resilience, as noted in a recent review[9]. Specifically, TAMSAT allows African meteorologists to monitor the progress of rainy seasons and to give early warning of floods and droughts. When allied to the 30-year TARCAT dataset, TAMSAT data are already having applications: supporting government and commercial insurance schemes for small farmers (for example, index-based insurance contracts based purely on TAMSAT data are now providing insurance cover for 8500 farmers in Kenya, Uganda and Zambia[17]); limiting insect and fungal infestations; healthcare (there are very promising programmes to exploit TAMSAT in predicting malaria outbreaks[18], the efficacy of which are now being tested), managing soil erosion, planning drought and flood resilience programmes, crop diversification and appropriate crop selection, planning strategic animal fodder reserves and agricultural infrastructure, informing human and livestock vaccination programmes.

The reach and the significance of TAMSAT's impact are huge. The number of under-nourished people in sub-Saharan Africa is estimated to be 234 million. Through its role in increasing the resilience of African populations to weather and climate shocks, TAMSAT has had major impact. In 2010, TAMSAT received the *IBM award for Meteorological Innovation That Matters* from the Royal Met. Soc. The citation states: "*TAMSAT continues to deliver massive benefits to Africa in terms of essential rainfall predictions …[it] … is used extensively by African weather services, providing a unique and essential source of data. This technology providing precipitation information is of such importance in developing regions, that it merits this recognition. From its inception, TAMSAT have shown how even the early generations of satellite technology can be harnessed quantitatively to provide vital rainfall information over a wide region*."

5. Sources to corroborate the impact:

5.. Testimonial letter from FOODSEC Action Leader, European Commission's Joint Research Centre (JRC), Institute for the Environment and Sustainability (IES), Monitoring Agricultural Resources Unit (MARS), Ispra, Italy. Available upon request.

6. for example, I. Jobard et al. (2011) An intercomparison of 10-day satellite precipitation products during West African monsoon, *Int. J. Remote Sensing, 32:* 9, 2353-2376.

7. An example of a direct use of TAMSAT data is on page 3 of ftp://mars.jrc.ec.europa.eu/bulletin/HornAfrica/MARS_FoodSecurityBulletin_HornOfAfrica_July2012.pdf

8. Data passed from JRC to the UN's ReliefWeb, e.g. see Map 2 of http://bit.ly/1dPAGD9

9. E. Boyd, R. J. Cornforth, et al. (2013) *Nature Climate Change*, 1–17 doi:10.1038/nclimate1856.

10. Oxfam Briefing Paper 168, 16/4/2013: http://bit.ly/1a29wHx

11. http://www.fews.net/docs/Publications/EA_Regional%20Alert%20Oct%202010_Final.pdf

12. http://www.fsnau.org/downloads/East_Regional_Alert_03_15_2011.pdf

13. Oxfam/Save the Children Joint agency briefing paper, 18 January 2012. http://bit.ly/184bCnd

14. Assessment Capacities Project (ACAPS) East Africa Food Security Crisis ,12 July 2011, annex 1: Early-warning and information systems in east Africa http://bit.ly/1fdQnV1

15. AGHRYMET is a specialized agency of the 13-nation CILSS drought-mitigation collaboration. http://www.preventionweb.net/english/professional/contacts/profile.php?id=1561

16. T. Dinku & J. Sharof, ENACTS Ethiopia, Aug 31st, 2012, http://bit.ly/1bAK4H7

17. Vice President for Agricultural Insurance, MicroEnsure (contact details provided separately)

18. http://www.ral.ucar.edu/csap/events/climatehealth/2011/Malaria%20EWS-Nature.pdf