Institution: University of Sussex

Unit of Assessment: 9 – Physics

Title of case study: Satellite data processing and analysis techniques enabled better forecasting for improved drought resilience in Africa

Period when the underpinning research was undertaken: 2006 – 2020

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:
Seb Oliver	Professor of Astrophysics	2000 – present
Richard Savage	Research Fellow	2003 – 2007
Anthony Smith	Research Fellow	2008 – 2012
Ed Challis	Research Fellow	2013 – 2013
Peter Hurley	Research Fellow	2014 – 2018, 2020 – present
Steven Duivenvoorden	Research Fellow	2018 – 2019
Adam Barrett	Research Fellow	2009 – 2019

Period when the claimed impact occurred: Jun 2019 – Dec 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Droughts are a recurring hazard in sub-Saharan Africa that can wreak huge socioeconomic costs. Acting promptly through early warning systems (EWS) can provide substantial mitigation. Sussex research has improved the way drought forecast information is produced and used in Africa. Novel satellite-telescope data analysis by astrophysicists, collaborating with geographers and Kenya's National Drought Management Authority, has produced new, highly accurate, short-term forecasts. Through partnership between researchers, forecast producers and decision-makers, these forecasts are now included in EWS that are used by government agencies, national and international NGOs and populations at risk to trigger earlier and more appropriate action. This has supported improved capacity in these organisations to manage and interpret data, and a shift to anticipatory responses in near-term disaster risk management, with associated funding mechanisms.

2. Underpinning research

The Sussex-led 'Towards Forecast-based Preparedness Action' (ForPAc) research project deployed physics research that originated in satellite investigations of galaxies to co-produce new climate information with stakeholders, which is better able to support specific decision-making contexts in sub-Saharan Africa. A well-recognised barrier to effective anticipatory climate risk management, rather than mitigation, is the salience, credibility and legitimacy of weather and climate information, and the methods and capacities to use this inherently uncertain forecast information in decision-making. This research collaboration between Sussex physicists, geographers (Todd et al, UoA 14 e.g. [G6, R6]) and Kenya's National Drought Management Authority (NDMA) tackled an indicator of the direct impact of drought on vegetation – the Vegetation Condition Index (VCI) – which could be tracked through satellite imaging. The research focused on the potential to forecast this drought indicator accurately into the near future.

Astronomers at Sussex (Oliver, with Savage, Smith, Hurley and Duivenvoorden) have world-leading expertise in conducting and analysing satellite-telescope surveys of the celestial sky, in particular for the European Space Agency (ESA) observatory, Herschel. Through their research, they have: developed novel methods and software to process the noisy and incomplete raw satellite data [R1]; delivered software to enable astronomers to process data from satellite missions [R2]; delivered usable data products (maps and measurements of galaxies) from these data [R3]; and developed novel and sophisticated analysis techniques to extract information (such as classification) from these processed data for astrophysics research [R4].

Satellites produce raw data that need pre-processing to create intelligible maps and measurements of galaxy properties. For example, Savage and Oliver designed and developed

novel, Bayesian algorithms [R1] for processing data to extract galaxy flux measurements optimally from the Japanese Akari mission and the UK-led Herschel-SPIRE instrument. These were further developed by Smith and implemented as part of ESA's Herschel Interactive Processing Environment and were demonstrated to be better than other methods for faint galaxies [R2]. Oliver led the Herschel Multi-tiered Extragalactic Survey (HerMES), a major Herschel survey which produced, verified and delivered sky maps and measurements of galaxies [R3]. A key collaborative output from this research was an iterative map-making algorithm that produced high-fidelity maps and more sophisticated novel methods to accurately measure the brightness of known galaxies. These methods meet the needs of the HerMES science goals [R3] and continue to be developed, by Oliver, Hurley and others through the Herschel Extragalactic Legacy Project.

Once data have been cleaned and optimised, the best statistical and machine-learning methods for extracting usable information from the data are employed. For example, Sussex researchers fit a parametric model comprising a mixture of multidimensional Gaussian functions to the 3.6-8 μm colour and photometric redshift distribution of galaxy populations in NASA's Spitzer Wide-Area Infrared Extragalactic Legacy survey. They then applied the model to provide a galaxy classification scheme and developed a new technique to identify unusual objects [R4]. Realising that the techniques developed in astronomy such as classification [R4] could easily be applied to other areas of research, Sussex initiated interdisciplinary research through the Data Intensive Science Centre at University of Sussex (DISCUS, see REF5b). In one STFC-funded example, researchers applied a machine-learning technique, Gaussian Processes**,** to the classification of Alzheimer's and mild Cognitive Impairment in fMRI images [R5].

This expertise in pre-processing (reducing noise, completing missing data), measurement and analysis solutions, such as Gaussian Processes, led to a DISCUS-funded proof-of-concept study. Hurley demonstrated that Gaussian Processes could address the barrier to using satellite-based Earth observations of the Vegetation Condition Index (VCI) for forecasting, which was a challenge for the ForPAc project, being led by Sussex geographers. As a result, an STFC-GCRF funded research collaboration, AstroCast [G6], between Sussex physicists (Oliver, Barrett, Duivenvorden, later joined by PhD student Salakpi), geographers and Kenya's National Drought Management Authority was developed, to support the ForPAc project.

In AstroCast, the researchers used the novel astronomical data pre-processing, measurement and analysis methods [R1-5] to process and analyse satellite-based Earth observations of Kenya. Healthy vegetation absorbs most of the visible light that hits it and reflects a large portion of the near-infrared light. Unhealthy vegetation reflects more visible light and less near-infrared light. This is measured by the Normalized Difference Vegetation Index (NDVI) based on the visible and near-infrared maps. A recurring problem with Earth observation maps is gaps due to cloud cover, so the researchers developed a novel method (using Gaussian Processes) to fill these gaps. In this work, the novel method was applied to produce a time-series of NDVI and the related Vegetation Condition Index (VCI) over pastoral livelihood zones in Kenya. They then demonstrated that these novel Gaussian Processes modelling methods would produce accurate forecasting several weeks ahead. One metric used by the NDMA is a drought "alert" level at VCI=35. The Sussex models were able to predict this alert marker four weeks ahead with a hit rate of around 90% and a false alarm rate of around 5%, or 82% and 8% respectively six weeks ahead. These results were published in *Remote Sensing of Environment* [R6].

The methods developed here can thus identify a deteriorating vegetation condition accurately, and sufficiently in advance, to help disaster risk managers act early to support vulnerable communities and limit the impact of a drought hazard. The accuracy levels through these new VCI forecasts were higher than anything that had been published before. This accuracy was sufficient to command confidence in stakeholders and thus stimulated the adoption of these and other forecasting for anticipatory risk management in Africa.

3. References to the research

[R1] "Bayesian Methods of Astronomical Source Extraction" **Savage, R.S**, **Oliver, S**, The Astrophysical Journal, 661, 1339-1346 (2007) doi.org/10.1086/515393 (70 citations)

[R2] "SPIRE point source photometry: within the Herschel interactive processing environment (HIPE)" Pearson et al. (including **Smith**), Experimental Astronomy 37, 175-194 (2014) doi.org/10.1007/s10686-013-9351-4 (15 citations)

[R3] "The Herschel Multi-tiered Extragalactic Survey: HerMES" **Oliver** et al., Monthly Notices of the Royal Astronomical Society, 424, 1614-1635 (2012) doi.org/10.1111/j.1365-2966.2012.20912.x (471 citations)

[R4] "Parametric Modeling of the 3.6-8 μm Color Distributions of Galaxies in the SWIRE Survey", **Davoodi, P., Oliver, S**., et al., The Astronomical Journal, 132, 1818-1833 (2006) doi:10.1086/506385 (9 citations)

[R5] "Gaussian process classification of Alzheimer's disease and mild cognitive impairment from resting-state fMRI" **Challis E.**, et al. (including **Oliver** and **Hurley**), NeuroImage 112, 232-243 (2015) doi:10.1016/j.neuroimage.2015.02.037 (94 citations)

[R6] "Forecasting vegetation condition for drought early warning systems in pastoral communities in Kenya" **Barrett, A.B., Duivenvoorden S., Salakpi, E.**, Muthoka, J.M*., Mwangi, J**., **Oliver, S.,** Rowhani, P*., Remote Sensing of Environment 248, 111886 (2020) doi:10.1016/j.rse.2020.111886 (Published on arxiv:1911.10339 Nov 2019) (2 citations)

Researchers from Sussex Physics and Astronomy indicated in bold. *Sussex - Geography, **Kenya National Drought Management Authority (NDMA). All references were published in refereed journals. Citations are from Scopus 19 February 2021. [R3] was submitted as an Output to REF2014 and [R5] and [R6] to REF 2021.

Key research funding included:

[G1] Algorithm development for Akari [R1] was funded by PPARC PPA/G/S/2002/00481, Oct 2003 – Mar 2007, £148,435.

[G2] Software development for SPIRE at Sussex for [R2] and HIPE was funded by e.g. STFC PP/B501063/1, Oct 2006 – Mar 2009, £112,351.

[G3] Data processing, delivery and analysis for HerMES and [R3] was funded by STFC ST/F002858/1, Apr 2008 – Mar 2011, £1,935,273; ST/I000976/1, Apr 2011 – Mar 2014, £2,337,619; ST/L000652/1, Apr 2014 – Mar 2017, £1,355,893.

[G4] The HELP project was funded by European Commission FP7-SPACE-2013-1-607254 SWIRE, Jan 2014 – Jun 2018, £842,795; and [R4] was funded by e.g. PPARC PP/C502214/1, Jul 2008 – Mar 2008, £143,987.

[G5] [R5] was funded by STFC Futures Panels (Global Challenges call) ST/K002279/1, Mar – Nov 2013, £48,455.

[G6] AstroCast, and subsequently [R6], was funded by STFC (GCRF) and STFC (ODA Institutional Award) ST/R004811/1, Apr 2018 – Jul 2019, £100,462.

4. Details of the impact

Early mitigation is essential to tackling the high socio-economic costs of drought. However, existing Early Warning Systems (EWS) have only monitored the current – rather than forecasting future environmental and socioeconomic – indicators of drought, and hence are not always sufficiently timely to be effective in practice. The improved accuracy and forecast timeframes developed through AstroCast for the ForPAc project have changed operational practices and effective responses for drought resilience in Kenya and across Africa.

Improving drought forecasting and response in Kenya

Since January 2020, AstroCast have produced regular Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI) forecasts and reports (like that shown in Figure 1) for every county in Kenya. These show the past history and forecast range into the near future. In close dialogue with partners (especially Kenya's National Drought Management Authority, NDMA, and Kenya Red Cross Society, KRCS) these reports have evolved to present the information in the most accessible form to decision makers, e.g. in graphical, geospatial and tabulated form, coloured with recognised coding scheme and broken down to sub-county regions.

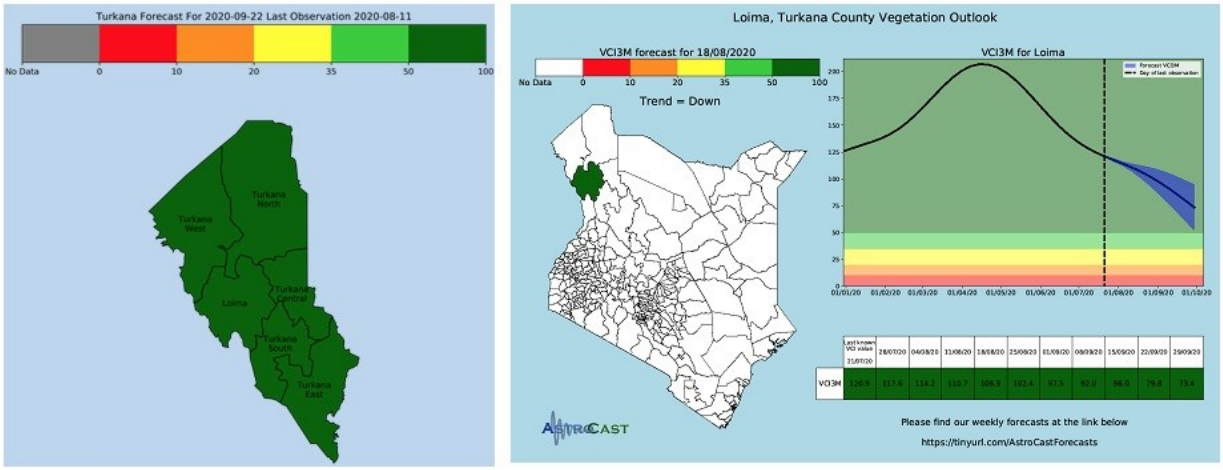

Figure 1. An example report produced by AstroCast and included in Kenya's National Drought Management Authority's Turkana County Drought Early Warning Bulletin for August 2020 [S1]

Kenya's drought EWS is a key part of the drought risk management mechanism operated by the NDMA. It is designed to monitor key indicators of households' and individuals' well-being in the 23 counties in the Arid and Semi-Arid Lands (ASALs) in Kenya, which account for 80% of the landmass, over 50% of Kenya's livestock and 30% of the human population. To this end, the EWS aggregates data from several sources, and presents them in these monthly early warning bulletins for each county. The resulting classification is in turn used to trigger the implementation of a set of interventions specific to county-level contingency plans, and to release funding for these activities through the Drought Contingency Fund (DCF). Prior to the research, the bulletins contained only contemporary data and limited seasonal rainfall forecasts. By integrating the research into the EWS "the NDMA has developed a new template for its monthly drought bulletins, which will be implemented in all 23 counties" [S2].

To November 2020, seven counties had included the enhanced information in monthly bulletins making them "better equipped to manage drought risk". Specifically, drought managers have been able to make recommendations for anticipatory action to "reduce the impact, recovery time and costs associated with traditional drought response" [S2]. The drought information manager at NDMA reported on the example of Kitui County, which was able to receive October-December drought warnings as early as July, "thus giving stakeholders ample time to initiate drought preparedness action," [S2] and summarised that "these projects have substantially advanced our drought Early Warning System" [S2].

As well as improving responsiveness of the drought management authority, the research has also improved responsiveness of drought first responders, the Kenya Red Cross Society (KRCS). The research led to the society increasing "use of climate forecasts probabilities and uncertainty... leading to a change in KRCS's Multi-hazard Contingency Planning system …to a likelihood approach... [using] multi-model forecasts" [S3]. Improved lead times gave months of extended planning time in 2020 when drier-than-usual seasons were forecast [S3]. The research is also contributing to the Innovative Approaches to Response Preparedness (IARP) Forecast Based Financing programme, enabling KRCS to trigger early action [S3]. This approach is also being scaled across other countries in Africa.

Improving drought forecasting and response across Africa

The Regional Centre for Mapping of Resources for Development (RCMRD) is an intergovernmental organization which promotes sustainable development through the generation, application and dissemination of Geo-Information and allied technology services and products. It currently has a membership of twenty countries in the Eastern and Southern Africa region. One of their core projects focuses on the monitoring and predicting of forage quality and availability to support pastoralist communities, for which they are reliant on VCI and NDVI data. The organisation also provides and manages a Rangeland Decision Support Tool (RDST) to support decision making in livestock farming. Their original products were monthly, the data were noisy due to cloud cover and there was no forecasting ability [S4]. The Sussex research

has enabled the RCMRD to replace its VCI and NDVI data with that based on the research findings [S4], leading to reduced noise, more reliable NDVI and higher frequency, 10-day VCI reports. As a result, the "forecast product is qualitatively different from anything we've been able to do before and provides our stakeholders with a decision-making tool with much greater power" [S4].

Anticipatory action based on improved forecasting has also been a benefit for the Red Cross Red Crescent Climate Centre (the Climate Centre), which is responsible for technical leadership of the Forecast based Financing (FbF) and anticipatory action concept, and for mainstreaming this within the development and humanitarian sector. The research has influenced the Climate Centre's best practice advice and guidance notes to National Societies in terms of developing drought-specific early action and providing "a template of how to move towards anticipatory risk management within existing national frameworks" [S5, S6].

Capacity building for increased drought responsiveness

To ensure long-term sustainability of these advances, the projects built national institutional capacity by design. ForPAc funded staff embedded in the agencies with drought mandates in Kenya and regionally (NDMA, KRCS, RCMRD), and carried out an extensive training programme, including physical and virtual training events run by the AstroCast team. These activities "built trust of the decision makers in these forecasts and the capacity of stakeholders in the counties to interpret... forecast indices and probabilistic information has greatly improved" [S2].

At the Regional Centre for Mapping and Resource Development (RCMRD), "the training... and interactions... have increased the skills... and thus the capacity of the organisation and the subsequent impact on… Kenya, and the regions that RCMRD serve. Additionally... the algorithms are open source, RCMRD can modify and adapt the code… which increases our… capacity to deliver new and improved products to our member countries" [S4]. [Text removed for publication] at KRCS also noted that the Sussex projects had "supported decision-making in KRCS" leading to "concrete changes in its practices in disaster management and underpinning a paradigm shift towards a more anticipatory approach" [S3].

Through co-production, the research projects enhanced coherence and alignment across the mandated national agencies. All partner agencies report that the Sussex projects "strengthened linkages" [S4] and "interactions" [S2] between the forecast producers (RCMRD) and the risk management agencies (NDMA, KRCS). This has cemented continued and further production of decision-relevant forecasts for use in operational systems, and "ensured better alignment of [KRCS] Early Action Protocols with [other] existing early warning systems such that indicators and triggers will be consistent with those of national mandated agencies" [S3].

As a result of Sussex research – that originated in making sense of data on galaxies – agencies, organisations and communities in Kenya and across Africa are now more responsive to, and resilient in the face of, drought.

5. Sources to corroborate the impact

[S1] National Drought Management Authority (NDMA), Kenya. Turkana County Drought Early Warning Bulletin for August 2020. PDF.
[S2] Testimonial, J. Mwangi, Drought Information Manager, on behalf of the CEO, National Drought Management Authority (NDMA), Kenya.
[S3] Testimonial, [text removed for publication], Kenya Red Cross Society (KRCS).
[S4] Testimonial, [text removed for publication], Regional Centre for Mapping of Resources for Development (RCMRD).
[S5] Testimonial, Maarten van Aalst, Director, Red Cross Red Crescent Climate Centre.
[S6] Forecast-based Financing And Early Action For Drought — Guidance Notes For The Red Cross Red Crescent: https://www.forecast-based-financing.org/wp-content/uploads/2020/07/Guidance-Notes-A-Report-on-FbA-for-Drought.pdf