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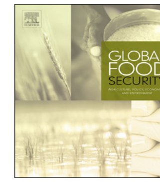

Drought and food security – Improving decision-support via new technologies and innovative collaboration

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ABSTRACT

Governments, aid organizations and people affected by drought are struggling to mitigate the resulting impact on both water resources and crops. In this paper we focus on improved decision-support for agricultural droughts that threaten the livelihoods of people living in vulnerable regions. We claim that new strategic partnerships are required to link scientific findings to actual user requirements of governments and aid organizations and to turn data streams into useful information for decision-support. Furthermore, we list several promising approaches, ranging from the integration of satellite-derived soil moisture measurements that link atmospheric processes to anomalies on the land surface to improved long-range weather predictions and mobile applications. The latter can be used for the dissemination of relevant information, but also for validating satellite-derived datasets or for collecting additional information about socio-economic vulnerabilities. Ideally, the consequence is a translation of early warning into local action, strengthening disaster preparedness and avoiding the need for large-scale external support.

1. Main text

Key characteristics of drought, such as their naturally large spatial and temporal extent, the high number of people affected or the tremendous economic loss create both logistic and financial challenges. Although droughts and subsequent food insecurity rank high on the priority list of humanitarian aid organizations, the majority of online disaster portals focus on rapid onset disasters (e. g. floods or thunderstorms). A major drawback of operational drought forecasting systems is their inability to make reliable predictions regarding the location, magnitude and the kind of assistance needed in the medium to long term, i.e. several months in advance. Yet even in those situations where predictions were made, e.g. warnings of extreme drought conditions in the Horn of Africa during 2010/2011, there was still insufficient response on the ground (Funk, 2011). Moreover, the predictions of large-scale droughts even fail in industrialized countries such as the United States (Schiermeier, 2013). This is compounded by the fact that there is no commonly accepted definition of drought (Belal et al., 2012) and climate change impacts on global drought patterns (Trenberth et al., 2014) and global food security remain controversial and uncertain (Wheeler and Braun, 2013). At the same time the consideration of teleconnections, for instance the impact of anomalies in the sea surface temperatures of the Indian Ocean on drought events in the Horn of Africa (Tierney et al., 2013), add complexity to already sophisticated models. Finally, there are different kinds of drought (i.e. meteorological, agricultural and hydrological) that have different socio-economic implications so it is not possible to have a single physically measurable "drought-parameter" for all of these situations. In this paper we therefore concentrate on agricultural drought as the direct

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successor of meteorological drought and the predecessor of food insecurity in many regions around the globe (Food and Agriculture Organization, 2013).

Despite all these aforementioned challenges we argue that the underlying problem lies in the large gap between scientific findings and the user requirements of government authorities and aid organizations. Research is primarily and intrinsically focused on creating knowledge, which does not necessarily lead to applicable information in a humanitarian aid context. In particular in the field of complex technologies, such as satellite applications, this knowledge tends to remain difficult to access and to utilize by aid organizations. Although satellite-derived products such as rainfall estimates or vegetation indices are used by some of the larger early warning organizations such as the Famine Early Warning Systems Network (FEWS NET) (Funk and Verdin, 2010), there are many aid agencies that cannot effectively utilize this information to transform early warning into action. Moreover, end users prefer information that is tailored to their needs rather than the generic output of continental or even global drought portals.

2. Sometimes being an expert is not enough

The crucial question is: What can science do to efficiently support the decision-making process? One logical and promising solution is the integrated combination and adaptation of existing technologies, including different satellite-based systems. Organizations such as EUMETSAT (the European Organisation for the Exploitation of Meteorological Satellites) or NOAA (National Oceanic and Atmospheric Administration) provide a vast variety of satellite-derived datasets that are available operationally, on a near real-time basis and free of charge (or with a minimal and low-cost receiving station). In addition to some of the more commonly used remote sensing products, datasets derived from microwave sensors can be provided at a spatial resolution that is worth considering in order to complement or replace in-situ measurements. These datasets often compensate for weaknesses of local measurements such as poor coverage and the lack of spatial consistency. Although a spatial resolution of 25 kilometers (e. g. for soil moisture derived from a radar sensor) does not allow investigations at a field scale, such datasets can nonetheless provide an added value, particularly in areas with incomplete or biased rainfall measurements (Dinku et al., 2007; Thiemig et al., 2012). Monthly weather predictions are available, for instance from the European Centre for Medium-Range Weather Forecasting (ECMWF). However, seasonal forecasts are extremely complex due to uninterrupted chaotic processes in our atmosphere (e. g. wind speed and direction, variations in air pressure or heat transfer) and only available to scientific users. All of these products require an in-depth understanding of atmospheric and biophysical processes along with the technical knowledge to deal with large datasets – an understanding and capacity that many users do not have.

The interaction of environmental drought-inducing key parameters (rainfall, temperature, soil moisture, evapotranspiration, vegetation) is fairly well understood. One major problem is that large-scale preparations require reliable forecasts several months in advance, which are currently not certain enough. Another issue is that agricultural drought constitutes just one possible root cause of food insecurity. In many cases famine is promoted by high levels of vulnerability caused by interacting socio-economic issues, such as political unrest, and increasing or unstable food prices. In fact, the methods for monitoring environmental anomalies and their socio-economic manifestations hardly overlap. In order to create a holistic monitoring system it is recommended that researchers collaborate more closely with end users in a multi-disciplinary approach. Fig. 1 illustrates this approach and identifies the current weak connections.

3. The integration of three technological developments for improved decision-support

There are a number of ongoing technological developments that could support drought risk reduction. Here we will focus on three complementary tasks that could be better integrated to improve decision-support. The first is the improvement of agricultural drought monitoring through exploitation of satellite-derived soil moisture. The second is gaining a better understanding of the uncertainty of long-term weather forecasts and how this information can be integrated with satellite-derived soil moisture. The third is the integration of non-environmental information via smartphones. Each of these is discussed in more detail below.

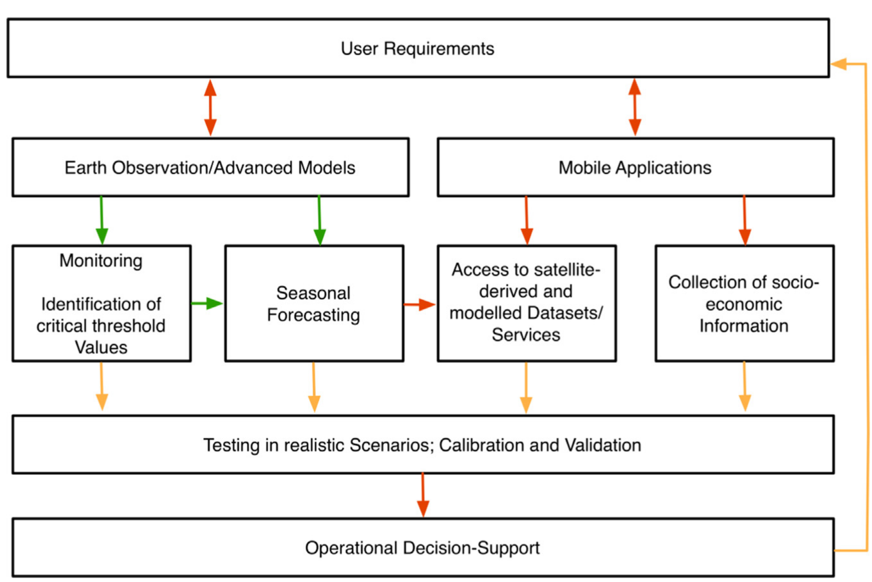

Fig. 1. Proposed framework for an operational decision-support system that considers state-of-the-art earth observation, advanced models and mobile applications based on user requirements (established connections are illustrated in green, moderate connections in orange and weak connections in red).

First, the full potential of state-of-the-art satellite-derived soil moisture measurements from space-based microwave sensors needs to be exploited for agricultural drought monitoring. Soil moisture is essential to close the gap between atmospheric processes and land surface interactions (Legates et al., 2010). It indicates plant water deficiencies earlier than conventional products estimating the vegetation status such as the Normalized Difference Vegetation Index. Zribi et al. (2010), for instance, have modeled the future vegetation dynamics during rainy seasons in semiarid regions using satellite-derived soil moisture only. Although the soil penetration of space-based microwave sensors is limited to a few centimeters, it is possible to estimate the soil moisture conditions in the root zone (Wagner et al., 1999; Albergel et al., 2008). Radar measurements are carried out independent from weather conditions and sunlight. Afterwards, they can either be used directly as an input for drought indicators or incorporated into advanced models via data assimilation.

Both the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) are focusing on new dedicated soil moisture sensors. The launch of NASA's SMAP (Soil Moisture Active Passive) mission is planned for late 2014. The first satellite of the new European flagship mission named “Sentinel” was launched in April 2014. Until Sentinel-1a has finished its “commissioning phase” there is only one operational soil moisture monitoring system. It is based on two advanced scatterometers (ASCAT), active microwave sensors, on-board the European MetOp A and MetOp B platforms. Soil moisture from ASCAT is distributed free of charge via EUMETCAST in near real-time, meaning that measurements are available with a timeliness of approximately 130 min.

Second, in addition to a large-scale picture of present conditions, decision-makers require estimates of future conditions, preferably over the duration of a season. Once the outputs of forecasting models are calibrated to regional conditions (forecasting centers usually provide uncalibrated forecasts), seasonal predictions can then provide an added-value. Therefore, the concept of uncertainty must be well-understood, clearly communicated and visualized. Seasonal forecasts (e. g. of rainfall) are usually based on a multitude of model outputs that ideally agree on a future trend. Consequently, it is not recommended to issue warnings for definitive events based only on seasonal predictions. Yet, information such as a “70 percent risk of rainfall below average during the growing season” can be used as an additional risk parameter. The predicted El Niño conditions for 2014 are a good example for long-range forecasts. Fig. 2 illustrates the anomaly in Pacific sea surface temperatures (SST), the most important indicator for the El Niño Southern Oscillation (ENSO), based on a variety of dynamical and statistical models (International Research Institute for Climate and Society, 2014). Virtually all of them agree on a strong positive anomaly.

From a user's point of view the retrospective analysis of forecasts, so-called “hindcasts”, can help to identify their performance with respect to past drought events (Dutra et al., 2014). If the forecast of one variable shows an added-value compared to its historic trend, it can potentially be considered as the input for an operational decision-support system. While seasonal forecasts for rainfall, temperature or soil moisture are available from different centers around the world, the vegetation status is not. However, the close temporal relationship between soil moisture and vegetation (Chen and RAM de, 2014; Dorigo et al., 2012) could allow estimations of the future vegetation status based on soil moisture predictions. Particularly in regions that show a high correlation between crop failure and food insecurity, the predictions of crop health are vital.

Third, mobile applications can directly link end users to drought-relevant information. On one hand, local farmers and aid organizations need to be able to understand and access all the above-mentioned information. On the other hand, these people are indispensable for validating satellite-derived drought indicators, for instance via taking GPS-tagged pictures of crops, or to collect information about socio-economic conditions that cannot be monitored from space. Recent examples of mobile data collection (so-called crowdsourcing) include the activities of the Humanitarian OpenStreetMap Team (HOT) during the aftermath of

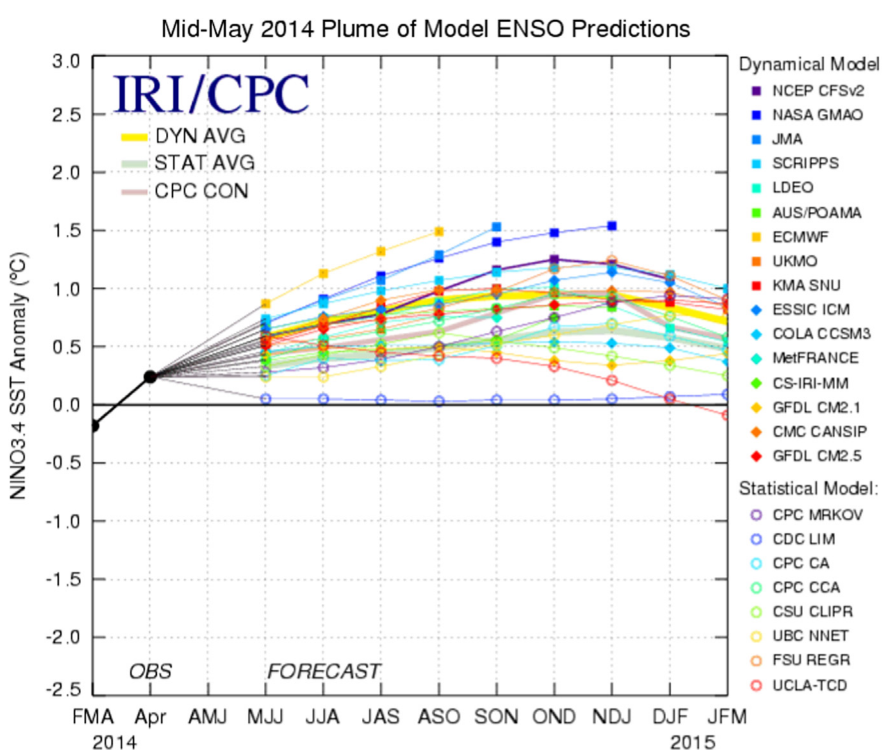

Fig. 2. Multi-model prediction of Pacific sea surface temperature (International Research Institute for Climate and Society, 2014).

typhoon Haiyan that struck the Philippines on 8 November 2013 or during the civil unrest in South Sudan in early 2014. In both cases the HOT was activated to provide geographic baseline data for humanitarian response.

A smartphone application that concentrates on food security could help to complement traditional in-depth household assessments with more frequent monitoring of food prices, the availability of fertilizers and drought-resistant seeds. It could help to gather vital information about access to potable water, the level of malnutrition, the current prevalence of diseases or even incorporate local knowledge about recurring events. In addition, mobile applications might be the key to generating a feeling of ownership resting with end users that are responsible for data collection and validation. Rapidly expanding mobile phone networks are gradually facilitating the use of such tools in remote areas. Even in regions without internet access, information can be collected, stored on the device's local hard disk and uploaded once a network is available. Different organizations, such as the World Food Programme's (WFP) Vulnerability Assessment and Mapping (VAM) group or the Harvard Humanitarian Initiative are already experimenting with such applications. Yet, the combined use of information collected via smartphones, satellite-derived data and forecasts is still in its infancy. Fig. 3 shows a simplified schematic illustration of a fictitious scenario. It combines the current drought level (large colored squares) with the prediction of environmental conditions (indicated by arrows) and the assessment of socio-economic vulnerabilities (colored circles).

Such an integrated approach can support the gradual ongoing shift from emergency response to disaster preparedness, which requires continuous updates in addition to on-demand information. However, also when such an integrated scientific framework is established, the translation of information to action remains complex. Realistic use cases are a promising way of understanding the strengths and limitations of current systems. In order to create a trusted science-user relationship, collaborative projects that include research organizations and directly involve the end user, i.e. humanitarian aid organizations, are essential. An important step in this direction is the SATIDA (Satellite Technologies for Improved Drought-Risk Assessment) project. Lead by Vienna University of Technology and funded by the Austrian Research Promotion Agency, a team of scientists and food security experts from Doctors without Borders will identify the potential of an integrated approach linking new satellite products, long-range forecasts and mobile applications. The use cases will concentrate on food insecure countries in Africa. In addition to technological challenges, SATIDA will focus on answering questions related to the selection of information provided to users and the visualization of uncertainties in forecasts.

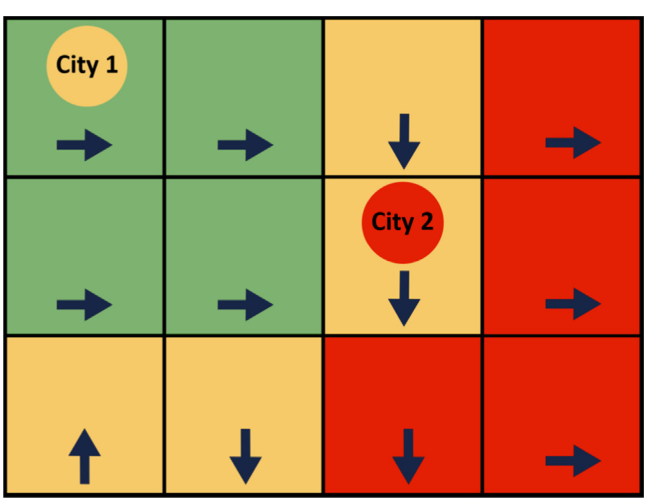

Fig. 3. Simplified schematic illustration of current drought conditions (green=watch level, yellow=warning level, red=alert level), future drought conditions (illustrated by arrows; arrows pointing up represent improving environmental conditions) and socio-economic conditions (current average of all assessments or output of trend analyses for each city according to the color code of the drought conditions).

Finally, the objective of all new initiatives must be to support disaster risk reduction via individual short-term solutions – also after the media attention is gone. The above-mentioned approaches and technologies are not the ultimate solution, but they can complement the existing knowledge base for decision-support. Moreover, if political initiatives such as the post-2015 phase of the Hyogo Framework for Action (HFA2), which concentrates on disaster risk reduction, acknowledge the added-value of new technologies, then there is a good chance that they will find their way into the decision-support toolboxes of the end-users.

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References

Albergel, C., Rüdiger, C., Pellarin, T., Calvet, J.-C., Fritz, N., Froissard, F., et al., 2008. From near-surface to root-zone soil moisture using an exponential filter: an assessment of the method based on in-situ observations and model simulations. Hydrol. Earth Syst. Sci. 12 (6), 1323–1337.

Belal A.-A., El-Ramady H.R., Mohamed E.S., Saleh A.M. Drought risk assessment using remote sensing and GIS techniques. Arab. J. Geosci. (Internet). October 30 (cited 2013 June 11), 2012. Available from: ⟨http://link.springer.com/10.1007/s12517-012-0707-2⟩.

Chen, T., RAM de, J., 2014. Using satellite based soil moisture to quantify the water driven variability in NDVI: a case study over mainland Australia. Remote Sens. Environ. 140, 330–338.

Dinku, T., Ceccato, P., Grover-Kopec, E., Lemma, M., Connor, S.J., Ropelewski, C.F., 2007. Validation of satellite rainfall products over East Africa's complex topography. Int. J. Remote Sens. 28 (7), 1503–1526.

Dorigo, W., de Jeu, R., Chung, D., Parinussa, R., Liu, Y., Wagner, W., et al., 2012. Evaluating global trends (1988–2010) in harmonized multi-satellite surface soil moisture. Geophys. Res. Lett. 39 (18) (n/a–n/a).

Dutra, E., Pozzi, W., Wetterhall, F., Di Giuseppe, F., Magnusson, L., Naumann, G., et al., 2014. Global meteorological drought – Part 2: seasonal forecasts. Hydrol. Earth Syst. Sci. Discuss. 11 (1), 919–944.

Food and Agriculture Organization, 2013. State of food insecurity in the world, 2013 the multiple dimensions of food security. Food Agric. Organ..

Funk, C., 2011. We thought trouble was coming. Nat. News 476 (7358) (7–7).

Funk, C., Verdin, J.P., 2010. Real-Time Decision Support Systems: The Famine Early Warning System Network ([cited 2014 Jan 29]. p. 295–320. Available from). In: Gebremichael, M., Hossain, F. (Eds.), Satellite Rainfall Applications for Surface Hydrology [Internet]. Springer, Netherlands.

International Research Institute for Climate and Society. IRI/CPC ENSO Predictions Plume (Internet). 2014 (cited 2014 Jun 20). Available from: ⟨http://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/⟩.

Legates, D.R., Mahmood, R., Levia, D.F., DeLiberty, T.L., Quiring, S.M., Houser, C., et al., 2010. Soil moisture: a central and unifying theme in physical geography (Nov 29). Prog. Phys. Geogr. 35 (1), 65–86.

Schiermeier, Q., 2013. Climate models fail to predict US droughts (Apr 16). Nature 496 (7445) (284–284).

Thiemig, V., Rojas, R., Zambrano-Bigiarini, M., Levizzani, V., De Roo, A., 2012. Validation of satellite-based precipitation products over sparsely gauged African river basins (Dec). J Hydrometeorol. 13 (6), 1760–1783.

Tierney, J.E., Smerdon, J.E., Anchukaitis, K.J., Seager, R., 2013. Multidecadal variability in East African hydroclimate controlled by the Indian Ocean. Nature 493 (7432), 389–392.

Trenberth, K.E., Dai, A., van der Schrier, G., Jones, P.D., Barichivich, J., Briffa, K.R., et al., 2014. Global warming and changes in drought. Nat. Clim. Change 4 (1), 17–22 (Jan).

Wagner, W., Lemoine, G., Rott, H., 1999. A method for estimating soil moisture from ERS scatterometer and soil data (Nov). Remote Sens. Environ. 70 (2), 191–207.

Wheeler, T., von. Braun, J., 2013. Climate change impacts on global food security (Aug 2). Science 341 (6145), 508–513.

Zribi, M., Paris Anguela, T., Duchemin, B., Lili, Z., Wagner, W., Hasenauer, S., et al., 2010. Relationship between soil moisture and vegetation in the Kairouan plain region of Tunisia using low spatial resolution satellite data. Water Resour. Res. 46 (6) (n/a–n/a).