Weather Monitoring in East Africa

Examples from CropMon and CommonSense

G4AW

Weather Impact BV
Stadsring 57
3811 HN Amersfoort
+31 33 4753535
weatherimpact.com

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Weather Impact

Contents

1 Summary

Weather Impact is the provider of weather information for several G4AW projects[1] in East Africa. The company delivers tailored weather forecasts to smallholder farmers in the region and monitors current weather patterns. By comparing actual data with historical patterns, the farmers are informed about the current situation: is it hot or cool, dry or wet?

This document describes the results of the research that formed the basis of the operational weather monitoring for temperature and rainfall. Weather Impact tested the feasibility of different data-sources to provide this service in East Africa. In the current operational version we make use of the CHIRPS dataset for precipitation. This dataset is with a lag of several days available, it has an extensive historical archive dating back to 1981 and it has spatial coverage on a resolution of 5 km. For temperature monitoring, the station data of NOAA's Global Summary of the Day are used. At the moment this product has the highest reliability for temperature monitoring compared to products based on Land Surface Temperature data from satellites and model output. This document also discusses different monitoring techniques based on the historical average, such as the Standardised Precipitation Index.

This research was done as part of Geodata for Agriculture and Water (G4AW) projects funded by the Netherlands Space Office (NSO). The methods to monitor weather can be used in other regions in Africa or the world because the datasets we use are semi-globally available.

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[1] www.g4aw.spaceoffice.nl

2 Data Sources

East Africa has a strong seasonal cycle for rainfall. This is because rainfall in this region is associated with the passage of the so-called Inter Tropical Convergence Zone (ITCZ). The ITCZ is a zone of rainfall which moves periodically up and down between the tropics along with the overhead sun. The overhead sun is heating the surface and because hot air is lighter than cool air, the air close to the surface starts to rise. This is called convection. When the air gets higher in the atmosphere, it cools again and the water that was contained in the air as water-vapour will condense; clouds are formed. When those clouds get too heavy, rain will start. Such rain is called convective rain, as it is caused by this convective process. The location where the clouds start to form and to rain out is mainly determined 'by chance'. Convective rain is therefore relatively localised: one part of the city might get very wet, whereas the other part stays dry. This characteristic of rainfall in Eastern Africa (and in all tropical regions) requires high resolution datasets to monitor it accurately.

Temperature follows a similar seasonal pattern. When the ITCZ arrives, just before the big rains start, it is around 5 °C warmer than during the other months. The inter-annual variability is rather small in most parts of the region, especially close to the coast, but still important for agriculture.

Different datasets are analysed for suitability of temperature and rainfall monitoring. The datasets need to meet the following criteria:

1. Available at near real time (or with a lag of maximum a week).
2. A consistent historical archive to make a robust statistical historical comparison
3. A good spatial coverage and high spatial resolution (especially for rainfall monitoring).
4. Open source or at low cost, to be also affordable for smallholder farmers.

2.1 Precipitation

For precipitation a good spatial coverage is very important. Satellite observations in the visible, infrared, and microwave spectrum can provide a wealth of information about the atmosphere. From these measurements the presence of clouds and precipitation can be derived as well as radiative budgets of the total atmosphere as well as separated layers within the atmosphere. Satellite observations have good spatial coverage and are often available in high spatial resolution. Local rain gauges were not considered because their spatial coverage is too low for these projects and data quality is not constant. Convective precipitation is a localised phenomenon, therefore a rain gauge is not representative for a large region. For this reason we decided to consider gridded products, preferably based on satellite measurements and assimilated with available ground measurements.

Different satellite datasets where reviewed, such as TAMSAT [3, 6], IMERG [9], CMORPH [10], but only the CHIRPS dataset meets all of the above mentioned criteria and was extensively tested for monitoring. We also analysed the Hydro-Estimator product of NOAA because of its high spatial and temporal resolution and the fast updating schedule, being hourly.

2.1.1 CHIRPS

The Climate Hazards group Infrared Precipitation with Stations (CHIRPS) is a gridded precipitation dataset at high resolution (0.05°x0.05°, about 5x5 km). It uses interpolation techniques of rain gauges and high resolution precipitation estimates from satellites for locations where the gauges are scarce. The dataset has a spatial coverage from 50°S to 50°N and runs from 1981 to present. CHIRPS was developed to deliver reliable, up to date, and more complete datasets for a number of early warning objectives such as trend analysis and seasonal drought monitoring [1]. The dataset was created in collaboration with scientists at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Centre. The dataset is extensively used, for example by the Famine Early Warning System Network (www.fews.net).

The final data are available at daily resolution after a couple of weeks. Every five days, a preliminary version of the data becomes available. The preliminary version combined with the historical archive is very suitable for monitoring purposes.

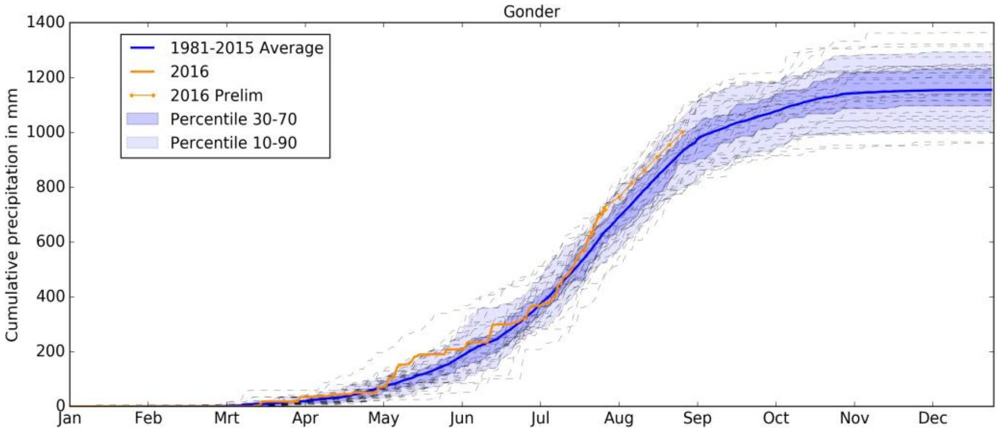

Fig. 1. Annual cumulative precipitation based on CHIRPS in Gonder, Ethiopia. The bold blue line shows the average of the period 1981-2015. The bold orange line shows the final data of 2016. The orange dotted line shows the preliminary data for August and September 2016. The blue shadings denotes the percentiles of the historical archive.

The extensive historical archive of CHIRPS provides robust statistics on detecting precipitation patterns and anomalies. Fig. 1 provides an overview of the possibilities of this dataset. At a specific location the actual precipitation (orange line) can be compared with:

1. Historical mean (bold blue line)
2. Historical percentiles (blue shadings)
3. Specific years in history (dotted grey lines)

It is also possible to map annual or average annual precipitation (see Fig. 2) and anomalies.

2.1.2 Hydro-Estimator

Hydro-Estimator uses infrared data to estimate precipitation rates. These estimates are produced at global scale using data over the Americas from NOAA's Geostationary

Operational Environmental Satellites (GOES) and available geostationary data over Europe, Africa, and western Asia (METEOSAT), and eastern Asia (MTSAT). The algorithm uses data from numerical weather prediction models to correct for evaporation of raindrops, topography and other factors [4]. The algorithm is based on the original Auto-Estimator algorithm that was developed for deep, moist convective systems. Hydro-Estimator is in operational use by the American National Weather Service since 2002 for monitoring potential flash flood events. Data are provided on a temporal resolution of 15 minutes at 4 km spatial resolution.

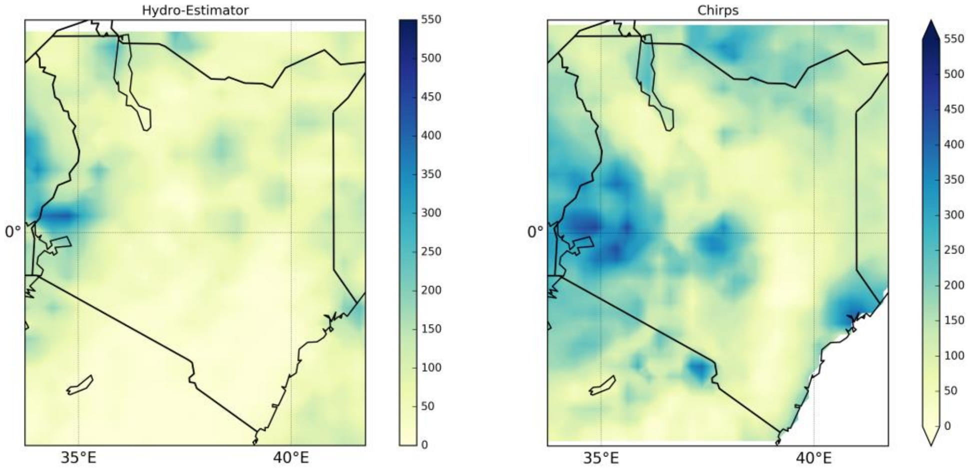

Fig. 2: Comparison of cumulative rainfall estimates between 15 April 2016 and 15 May 2016 for Hydro-Estimator (left) and CHIRPS (right).

2.1.3 Comparison

We compared rainfall estimates over Kenya from Hydro-Estimator with the estimates of CHIRPS. The results of cumulative values over the period 15 April – 15 May 2016 are shown in Fig. 2. This period falls within the rain season in Kenya. The pattern of CHIRPS shows most of the rainfall in the Southwest of Kenya around Lake Victoria. Also major mountains are characterised by more rainfall: Mount Kenya and Mount Kilimanjaro are marked by blue spots on this map. Hydro-Estimator shows a different pattern than CHIRPS. In general, the estimated rainfall of Hydro-Estimator is much less than CHIRPS. The mountains are not visible in the Hydro-Estimator data. The data sets are most similar around Lake Victoria, where also Hydro-Estimator shows most rainfall. We conclude there is a lack of consistency between the Hydro-Estimator and CHIRPS because of the different algorithms and data assimilation techniques used to construct both datasets. CHIRPS assimilates station data[2] and makes use of more advanced methods to estimate rainfall, thus we decided to use CHIRPS as a data source for operational precipitation monitoring.

2.2 Temperature

For near-surface air-temperature, three data sources were analysed:

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[2] 13 stations in Kenya in November 2016

1. The operational analyses from the ECMWF forecast model as real-time data, and the ERA-Interim reanalysis as climatology.
2. Land Surface Temperature (LST) measurements from MODIS.
3. Local weather stations for both real time data and climatology.

2.2.1 Operational ECMWF-forecast and ERA-Interim reanalysis

The operational analysis of the ECMWF-forecast model provides a high-resolution proxy of 2 m temperature, currently delivered on a 9 km grid. It is a proxy, because it is not directly measured, but modelled. The modelled proxy is expected to be close to actual values, because the model assimilates many different sources of observations in its initial stage.

However, the forecast model is updated and changed on a regular basis, therefore the archive is not consistent over time and space and it cannot be used as a reference climatology. As a possible alternative, we used ERA-Interim reanalysis as reference dataset. This reanalysis does in principle the same as the operational analysis, but with historical data and one fixed model configuration for the whole time-period. This model configuration is not the same as the current operational analysis, therefore the following corrections are necessary for comparing the current operational analysis with ERA-Interim:

1. Regrid both the reanalysis dataset and the operational analysis dataset to the same grid.
2. Correct for differences in grid-point elevation.

The grid-point elevation correction is analysed for the period May to June 2016. In this period both ERA-Interim and the ECMWF operational data are available to us. The left panel of Fig. 3 shows the differences in daily mean temperature between the two datasets without grid-point elevation correction. The right panel shows the differences after the correction was applied. It can be seen that the differences in daily mean temperature are reduced by the grid-point elevation correction, but they are still significant. The remaining differences turned out not to be systematic on this short timescale, therefore other bias correction methods could not be applied.

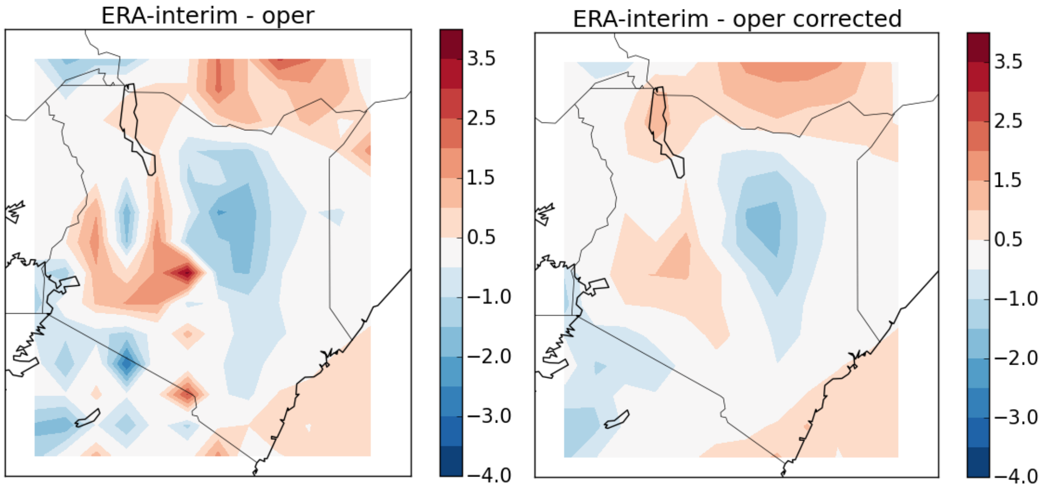

Fig. 3: Difference in daily mean temperature between ERA-Interim and the ECMWF operational analysis without (left) and with (right) grid-point elevation correction. Data was averaged over the period May and June 2016.The ECMWF operational analysis was subtracted from the ERA-Interim. The temperature scale is in degrees Celsius.

2.2.2 Land Surface Temperature measurements from Satellites

MODIS TERRA provides measurements of Land Surface Temperature (LST), which can be used as a proxy for 2 m temperature [7]. MODIS LST is a low-orbit satellite. In this study we used the data-stream MOD11C1 with 0.05 degree resolution and global coverage. One of the fundamental issues with the LST data from MODIS is coverage. The satellite passes over every 1-2 days, but measurements can only be made if there are no clouds because it makes use of optical sensors. Therefore, under unfortunate conditions, it may happen that no data can be gathered. For the reference climatology, this problem is of less importance. As long as the period over which the climatology is defined is long enough, then overall, sufficient data will be available. A fraction of missing days does not impair the climatology significantly. For the operational (real time) data, on the other hand, the temporal availability is a big limitation. If the whole area of interest is clouded for a couple of days, no monitoring can be done at all. Due to these temporal availability constrains, we cannot currently use satellite LST to deliver reliable near real time temperature monitoring.

2.2.3 Station Data

NOAA provides daily data from a couple of weather stations in Africa via its Global Summary of the Day (GSOD). We researched this product for monitoring temperature in Kenya. Data availability of GSOD for the historical archive and the operational delivery of current data is not complete. In October 2016 we found 11 operational stations for daily analysis and monitoring. These stations are shown in fig. 5 as black dots. Note that this number might vary from day to day because the data-upload is not consistent on a daily basis. Fig. 4 shows the climatology of 10-day mean temperature for one station. Such climatologies are used to compare actual temperature to the long term average.

Because temperature is less variable in the spatial domain than rainfall, the spatial resolution of the dataset is of less importance for temperature. To make temperature monitoring consistent with precipitation monitoring, we use the same grid of 25 km spatial resolution of the CHIRPS dataset. For each grid point we search for the closest station in the database of temperature stations in Kenya.

For this station, we compute the reference climatology from the historical measurements of the station. Then we use the near real-time observations from the last few days of the same station, and compare this to the reference. This gives us the current temperature classification of the grid-point. Fig. 5 shows an example of such a gridded classification. Note that some areas in Kenya are far away from a station. To do a reliable monitoring in for example the Northeast of Kenya, more stations are necessary in this area. To be able to monitor temperature in any African country or region it should be first researched whether there are enough operational weather stations.

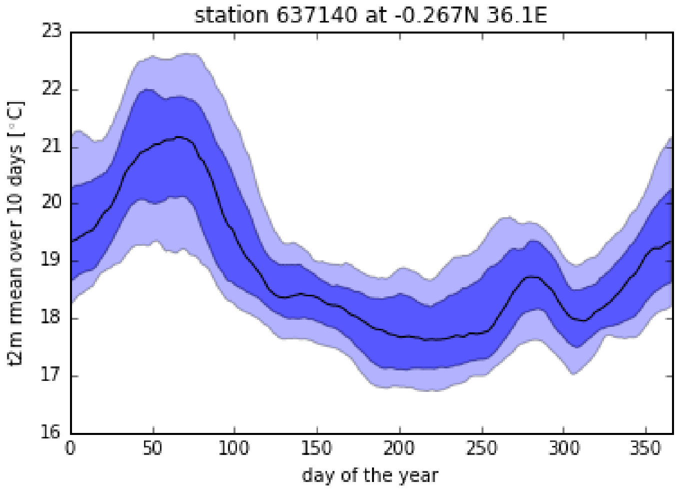

Fig. 4: Reference climatology (2002-2015) for 10-day mean temperature for one weather station in Kenya. The black line denotes the median, the dark blue shading denotes the average. The light blue shading shows abnormal high or low temperatures.

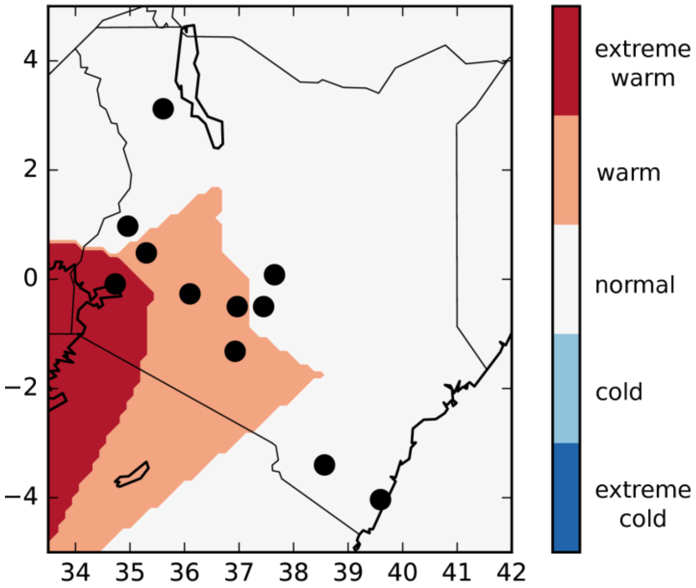

Fig. 5: Gridded temperature classification of the last 10 days, compared to 2002-2015. Computed from station data and projected on the same grid as was used for precipitation monitoring over whole Kenya.

3 Monitoring methods

In this section two different monitoring techniques are discussed. The first technique is monitoring based on percentiles of historical patterns. The second technique is the Standardised Precipitation Index (SPI), a method used to compare rainfall patterns to historical statistics. The latter is very scalable to other regions and climates. The example figures in this chapter are all based on CHIRPS data. As reference climatology we use a 30 year period from 1986 to 2015.

3.1 Percentiles

From the historical archive, an average annual "reference curve" can be determined by calculating the average rainfall for every 1st of January, 2nd of January etc. The same applies for percentiles. These percentiles can be used to set a threshold for exceptional dry or wet conditions. For example, the 90th percentile is equal or exceeded by three years in the historical archive. For the 50th percentile (the median) 15 years have an equal amount of rainfall or more and 15 years have been dryer.

The percentiles can be used to classify current rainfall. For example:

- Between the 30th to 80th : normal
- Above 80th: abnormally wet
- Above 95th: extremely wet
- Below 30th: abnormally dry
- Below 10th: extremely dry

Note that this choice of classes is not symmetrical with the percentiles because drought conditions are more harmful for stakeholders considered in this case than wet conditions. For temperature monitoring the same method can be applied.

3.1.1 Monitoring periods and smoothing

Drought or wet conditions are not related to one day of rainfall, but to longer periods of exceptional low or high accumulated rainfall. The same is true for temperature: one hot day does not mean that there was a harmful heatwave. We studied the impact of different periods of accumulation (rainfall) and averaging (temperature). Short periods of accumulation are not very informative to a farmer, because he knows that it did or did not rain for one or two days or whether it was hot or cool. For an accumulation period of 20 days, a monitoring service can be of added value. This length of the period might depend on crop type and the individual preference of farmers.

Fig. 6 provides an annual reference curve for 20 days accumulated rainfall. The curves where smoothened with a running mean filter. The filtering was done to improve the significance of the reference curves.

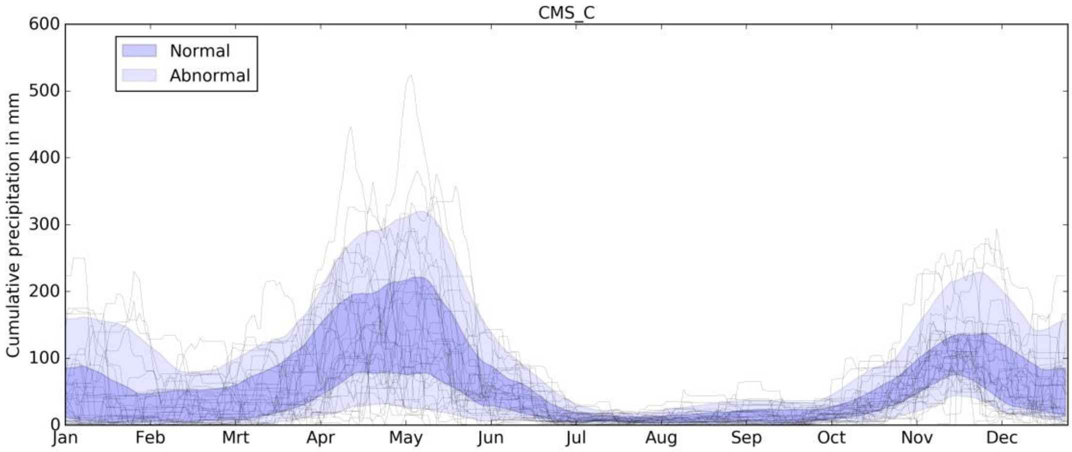

Fig. 6: Annual 20-day accumulated rainfall from CHIRPS at one grid point in Kenya. The thin grey lines indicate the separate years 1986-2015. The dark (light) blue curve indicates the normal (abnormal) band. Outside the light blue are extreme values. The reference values are smoothed by applying an additional running mean of 20 days. This filter smooths out irregular roughness in the reference curves to show a clearer signal.

3.2 Standardized Precipitation Index

The SPI is a meteorological index recommended by the World Meteorological Organization [8]. The index is based on the cumulative probability distribution of rainfall. Historical rainfall data are fitted to a mathematical (gamma) distribution. The actual rainfall is transformed in the same way, and can be classified as normal, abnormal or even extreme in terms of its standard deviation compared to the reference distribution. The SPI method allows to compare rainfall or drought values across seasons, regions and different climates. The index can be calculated for various periods of accumulated rainfall. It can be used to estimate drought of the last month, but also of the last year [2, 5].

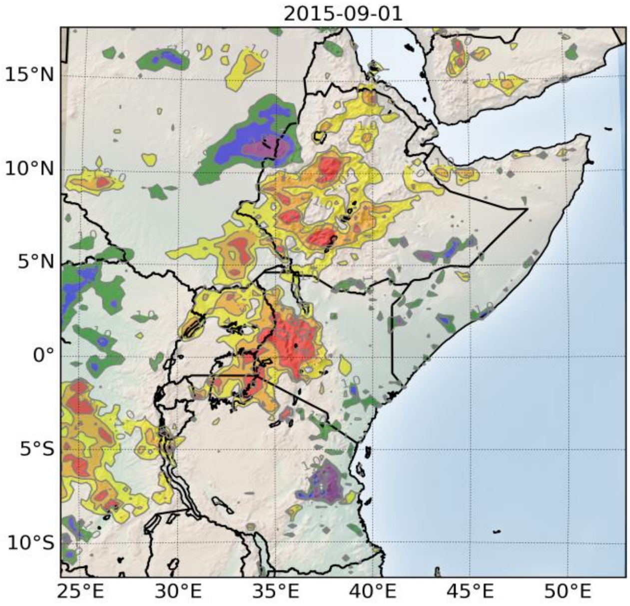

Fig. 7: Standardized Precipitation Index (SPI) for accumulated rainfall (CHIRPS) over one month ending at 01-09-2015 mapped over East Africa.

Fig. 7 provides an example of SPI values over East Africa based on data from Chirps. A cumulative period of one month prior to the 1st of September 2015 was chosen. The red colours indicate that it was unusual to extremely dry over that period. This is very likely an effect of a strong El Niño. The map shows that it is possible to compare severity of drought over large areas, despite different rainfall pattern characteristics of that area.
Fig. 8 shows time series of SPI values at one location in Ethiopia accumulated over one year. Such time series can be useful when comparing the current year to a memorable wet or dry year in history. Fig. 8 shows that the last six years have been relatively dry compared to the long term average, whereas 2005, 2006 and 2007 have been relatively wet.
The SPI method allows to compare rainfall distribution in space and time. The method is most robust for periods longer than one month, because for shorter periods a low SPI does not necessarily coincides with a drought. E.g. it might have been dry for the last 5 days, but over the last month it even has been exceptionally wet.

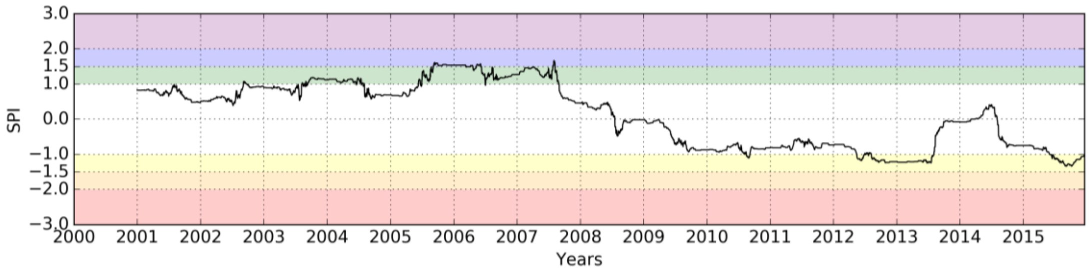

Fig. 8: Time series of SPI at one location in Ethiopia for an accumulation period of one year. Data from ERA-Interim. The colors indicate whether it is extremely dry (red), abnormally dry (orange/yellow), normal (white), abnormally wet (green/blue) or extremely wet (purple).

4 Conclusions and outlook

Weather Impact delivers a weather-monitoring service over Kenya within the CropMon project. In the current operational version we make use of the CHIRPS dataset for precipitation and the station data of NOAA's Global Summery of the Day for temperature. The monitoring can be expanded to other regions in Africa or the world because the datasets we use are semi-globally available.

For precipitation the CHIRPS gridded precipitation dataset is a very useful dataset to monitor rainfall patterns. CHIRPS is with a short time lag available (the lag is maximum 5 days), it has an extensive historical archive dating back to 1981 and it has good spatial coverage at a resolution of 5 km. The database is developed with the goal to be suitable for drought monitoring. Precipitation monitoring can be based on percentiles of the historical archive of 30 years (1986-2015), or on more sophisticated methods such as the SPI. Because the CHIRPS dataset is semi-global (between 50°S and 50°N) the monitoring method developed for Eastern Africa can be applied on a semi-global scale. For each user the thresholds for percentiles and classes can be adjusted accordingly to the users' needs.

Weatherstation data has the highest reliability for temperature monitoring. In the future, EUMETSAT land surface measurements might also be useful. EUMETSAT is a series of geostationary satellites with low spatial resolutions, but high temporal resolution. They provide measurements every 15 minutes. Currently no climatology of sufficient length is available, but this is scheduled to be released by EUMETSAT in 2017.

4.1 About G4AW

This research was done by Weather Impact as part of Geodata for Agriculture and Water (G4AW) projects funded by the Netherlands Space Office. The G4AW projects aim to improve food security in developing countries by using satellite derived information. Weather Impact is involved in several projects in South- and East Africa as the provider of weather information. Weather Impact is partner in CommonSense in Ethiopia, CropMon in Kenya and Rain for Africa in South Africa.

www.g4aw.spaceoffice.nl
www.spaceoffice.nl
www.weatherimpact.com/projects

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Data Sources

CHIRPS: http://chg.geog.ucsb.edu/data/chirps/
ECMWF: http://www.ecmwf.int/en/forecasts
ERA-Interim: http://www.ecmwf.int/en/research/climate-reanalysis/era-interim
HydroEstimator: http://www.star.nesdis.noaa.gov/smcd/emb/ff/HydroEst.php
LST MODIS: ftp://ladsweb.nascom.nasa.gov/allData/5/MOD11C1/
GSOD https://data.noaa.gov/dataset/global-surface-summary-of-the-day-gsod