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# Forecasting droughts in East Africa

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## Abstract

The humanitarian crisis caused by the recent droughts (2008–2009 and 2010–2011) in the East African region have illustrated that the ability to make accurate drought predictions with adequate lead time is essential. The use of dynamical model forecasts and drought indices, such as Standardized Precipitation Index (SPI), promises to lead to a better description of drought duration, magnitude and spatial extent. This study evaluates the use of the European Centre for Medium-Range Weather Forecasts (ECMWF) products in forecasting droughts in East Africa. ECMWF seasonal precipitation shows significant skill for both rain seasons when evaluated against measurements from the available in-situ stations from East Africa. The October–December rain season has higher skill than the March–May season. ECMWF forecasts add value to the statistical forecasts produced during the Greater Horn of Africa Climate Outlook Forums (GHA-COF) which is the present operational product. Complementing the raw precipitation forecasts with SPI provides additional information on the spatial extent and intensity of the drought event.

## 1 Introduction

Droughts have major economic impacts since rain fed agriculture is the backbone of most economies in East Africa. The agricultural sector accounts both directly and indirectly for approximately 51 %, 42 % and 25 % of Kenya's, Uganda's and Tanzania's Gross Domestic Product (GDP) respectively (Eguru, 2012). Over the last 5 decades East Africa experienced at-least one major drought per each decade (FAOSTAT, 2000) and there is a tendency of an increasing frequency and intensity of these events (AM-CEN, 2011). Damage to the agricultural sector leaves the region exposed to the risk of famine as demonstrated by the widespread famine and humanitarian crises caused by the two major droughts in the last decade (2008–2009 and 2010–2011). The ability to

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make accurate drought predictions with adequate lead time is therefore essential (Luo et al., 2008).

In a bid to ensure consistent access and interpretation of climate information, the World Meteorological Organisation (WMO) initiated Regional Climate Outlook Forums (RCOFs) in various parts of the world. To coordinate action over the Greater Horn of Africa region; in which the East African countries are part of, the Greater Horn of Africa Climate Outlook Forums (GHACOFs; <http://icpac.sbis.co.kr>) are held three times a year before the relevant rainy periods (March–May, July–August, October–December). In preparation to each forum meteorologists from the National Meteorological and Hydrological Services (NMHSs) of Kenya, Uganda, Tanzania, Rwanda, Burundi, Ethiopia, Somali, Djibouti, Eritrea, Sudan and Southern Sudan (Fig. 1) convene to issue a joint forecast for the incoming season. The forecast relies on a plethora of information. Firstly there is the valuable forecaster's subjective knowledge and experience based on the past relationship between large scale sea surface temperature (SST) pattern and rainfall amount. Secondly observed rainfall amount from the country's rain gauge networks is considered. Finally, data provided by dynamical forecast models from other international centres are taken into consideration. The outcome is consolidated into what is known as the *consensus forecast* for the Greater Horn of Africa (Ogallo et al., 2008). The main product is a map showing the probability for the rainfall of the incoming season to be in one of the terciles – above normal, near normal or below normal – of the rainfall distribution as observed by the local rain gauge network. The consensus forecast is then used by the national meteorological services to disseminate press releases with advisories of floods (droughts) expected in zones with forecasts above (below) normal conditions.

The consensus forecast is an excellent forum to share observed data and local knowledge to coordinate natural hazard related political actions in the region. It nevertheless mostly relies on precipitation monitoring and past experiences to construct drought scenarios for the upcoming season. Unexpected conditions, such as extreme events outside the climatology, are not taken into account in this approach and are

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likely to confound the forecaster's well established knowledge. Moreover, it does not contain information on the spatial extent and intensity of droughts as it is mostly based on station data. This study builds on the consensus forecast and explores the possible benefits of integrating the European Centre for Medium-Range Weather Forecasts (ECMWF) seasonal forecasting system product (SYS-4) into the system. SYS-4 is issued at the beginning of each calendar month and provides an ensemble prediction of precipitation up to seven months ahead. If used in an automated system it could extend the consensus drought prediction lead time and provide monthly updates in between the official forecasters' consensus meetings.

The paper is organised as follows: firstly the quality of the modelled precipitation is assessed by computing probabilistic skill scores against measurements from the available in-situ network. Then an automated proxy of the consensus forecasts maps was created using the seasonal forecast. Finally, the capability of the seasonal forecast to complement the information already contained in the consensus maps was assessed at different lead times as a prototype of a reliable product for the future monitoring and forecast of drought in East Africa.

## 2 Material and methods

### 2.1 Observations and model data

The East Africa region comprises five countries nevertheless we could source rain gauges data only from Kenya, Uganda and Tanzania. This dataset will be used for the verification of SYS-4. A large part of East Africa experiences two distinct rainfall seasons. "Long rains" extend during March to May (MAM) while the season with "short rains" takes place from October to December (OND). These seasons are linked to the movement of the Inter Tropical Convergence Zone (ITCZ) northward and southward (Nicholson, 1996). As a part of the consensus effort the three countries have been subdivided into 34 homogeneous regions (see Fig. 1 for the consensus forecast

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boundaries) in terms of the precipitation experienced. Monthly rainfall totals for each of these 34 homogeneous zones is available for the period 1961–2009 through dedicated synop stations located in positions to be representative for each sub region. This dataset provides both the climate information from which the consensus forecast anomalies are evaluated and the data against which the validation of the drought forecast itself was performed.

Past consensus outlooks and seasonal observation maps for the Greater Horn of Africa (GHA) region were sourced from the Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre (ICPAC). The observed precipitation is interpolated to areal means from synop stations and is given as a percentage of the long term mean; < 25 % severely dry, 25–75 % moderately dry, 75–125 % normal, 125–175 % moderately wet and > 175 % severely wet.

The model used in this study was the ECMWF seasonal forecast system-4 (SYS-4) which is a fully coupled system based on the Integrated Forecast System (IFS) cycle 36r4 atmospheric model version with TL255 corresponding to roughly 80 km spatial resolution and the Nucleus for European Modelling of the Ocean (NEMO) ocean model, which has a horizontal resolution of approximately 1°, and 42 levels in the vertical, 18 of which are in the upper 200 m. At the first of each month the system provides an ensemble of 51 simulations through initial condition perturbations coming from a combination of atmospheric singular vectors and an ensemble of ocean analysis. An extensive hindcast set of 30 yr is also available for model calibration and verification. The set of hindcast are initialised using ERA Interim reanalysis for the period 1981–2010 and have 15 ensemble members. Details of SYS-4 can be found (Molteni et al., 2011). Performances of the system to drive drought monitoring and forecasting in several African basins can be found in (Dutra et al., 2013b).

## 2.2 Quantitative assessment of the forecast skill

The skill of SYS-4 precipitation forecasts was evaluated using the standard skill scores methods based on the analysis of the correlation coefficient of the model and

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observations anomalies (ACC; Miyakoda et al., 1972) and the Continuous Ranked Probability Skill Score (CRPSS; Hersbach, 2000). The ACC provides information on the forecast skills of the ensemble mean (Hollingsworth et al., 1980; Simmons, 1986) while the skill of the range of possibilities or uncertainty about that forecast value, that is, that of the ensemble members is provided by the CRPS. The skill score that corresponds to the CRPS is the CRPSS.  $CRPSS = 1 - CRPS/CRPS_{ref}$ . The most commonly used reference forecasts are persistence and climatology. If  $CRPSS \leq 0$ , no skill compared with reference forecast and  $> 0$ , some skill observation dataset as a random sample of all years, to produce a climatological forecast with the same ensemble size as system 4. Another standard skill score employed is the area under the Relative Operating Characteristics (ROC) which is particularly effective if an estimate of false alarm occurrence is important. In probabilistic forecasting system, there are various thresholds for each forecast category. For each of the thresholds, the correspondence between the forecasts (a sequence of dry or non-dry) and observations (a sequence of events or non-events) is examined. The result is a two-component vector of the proportion of events for which a forecast was correctly issued (“hit rate”) and the proportion of non-events for which a forecast was incorrectly issued (“false-alarm rate”). The hit rate and false-alarm rate give the ROC curve. Details on ROC can be found in Mason and Graham (2002).

SYS-4’s precipitation skill over East-Africa was assessed employing the hind cast dataset for the period in which in situ measurements are available. Forecast interpolation at station location is done using the grid nearest-neighbour being the region by definition homogeneous in terms of precipitation. Analogous analyses were performed using the average of 4-nearest points, and mean precipitation over the region (using the outlines in Fig. 1) providing very similar results (not shown).

## 2.3 Qualitative assessment of skill

Much more challenging is instead the choice on how to quantify the added skill of using SYS-4 in the consensus framework. Both the observed and the outlook maps

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are manually “smoothed” and the original data-set to reconstruct them is not available. A quantitative assessment of the consensus maps is virtually impossible. Therefore, proxies of the consensus forecast maps were generated from SYS-4 forecasts for a subjective assessment on the basis of the added information they can provide in a hypothetical forecasters gathering. The exercise was repeated for the period 2000 to 2010 and for both seasons, MAM and OND.

From the raw SYS-4 precipitation outputs dry and wet conditions are defined as the probability (or number of ensemble members) below the percentile 30 and above the percentile 70 of SYS-4’s climatology for a particular season, respectively, and for the various lead times. To condense this information in a single map for each lead time, classes were defined as follows; moderately dry if 40 % of the members predicted dry conditions and the dry cases were more than wet cases, severely dry if 60 % of the members predicted dry conditions and extremely dry if 80 % of the members predicted dry conditions. The same classification was applied for wet conditions and the rest was classified as normal (or uncertainty).

In addition to raw precipitation forecasts, maps of SPI were calculated from SYS-4 precipitation. SPI is the index recommended by WMO for Meteorological drought monitoring (Press report December 2009, WMO No. 872). Its calculation is based on long-term precipitation record which is fitted to a cumulative probability distribution and then transformed into a standard normal distribution with mean zero for each month (Edwards and McKee, 1997). Since the SPI is normalized, wetter and drier climates can be represented in the same way where positive (negative) SPI values indicate wet (dry) conditions respectively. SPI can be calculated for any desired duration, typically ranging from 1 to 48 month to reflect the impact of drought on the availability of the different water resources. Recently there has been increased focus on the use of Standardized Precipitation Index, in drought forecasting. For example, Dutra et al. (2013b) proposed a methodology to forecast 3 month SPI for the prediction of meteorological drought over four basins in Africa: the Blue Nile, Limpopo, Upper Niger, and Upper Zambezi based on the SYS-4 forecasts of precipitation.

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### 3 Results and discussion

#### 3.1 System-4 verification against in situ observations

MAM and OND anomaly correlation coefficients (Figs. 2 and 3) and CRPSSs (Fig. 4) are shown as a function of lead times. As expected the prediction skill declines with increasing lead time. The skill is higher in the OND than in MAM. Notable is that for both methods, there is higher skill in lead time of 2 than lead time of 1 month in the OND season. This is because of a spurious SYS-4’s negative drift in SSTs over the NINO 3.4 region which highly impacts precipitation over East Africa. The fastest drift of SSTs occurs during the boreal summer months. A bias in the near-equatorial winds in the west and central Pacific is the dominant factor in driving an SST bias in the coupled model, whereby SSTs in the eastern equatorial Pacific drift to cold conditions (Molteni et al., 2011).

The skill of the categorical forecasts from ROC scores decline with increased lead time and there is higher skill for OND than MAM, as in the previous results (Figs. 5 and 6). Over 50 % of the stations have considerable skill for OND season for all lead times; this is the case from January for the MAM forecast (Fig. 5). SYS-4 has higher skill for the not dry (Normal and wet) category in MAM for all lead times (Fig. 6). Since SYS-4 has a cold pool over equatorial Pacific then the seasonal forecast always have a higher skill for La Nina conditions, which are associated with dry conditions over East Africa. Thus the higher skill for not wet (normal and dry) category in the OND season (Fig. 6).

The high predictability in the horn of Africa is well documented and is due to the teleconnection between the Indian Ocean Dipole and the ENSO. Generally, the prediction skill of SYS-4 is better in the OND season than the MAM season (Dutra et al., 2013a) due to the documented strong relationship between the OND season rains and SST and ENSO (Mutai et al., 1998; Nicholson et al., 1990; Ogallo et al., 1988). While the MAM season rains have been associated with complex interactions between many regional and large-scale mechanisms which generally induce large heterogeneities in

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the spatial rainfall distribution (Beltrando, 1990; Ogallo, 1982) and virtually negligible correlations with ENSO (Ogallo et al., 1988).

### 3.2 Use of system-4 in the consensus framework

For the subjective nature of the consensus forecasts a purely qualitative assessment of its skill was not possible. We therefore resorted to perform a qualitative analysis based on subjective examinations of 11 yr of forecast. These analyses were performed independently by the 5 authors with the aim of judging the advantage SYS-4 would bring as an added product to the consensus framework.

Three cases were selected and discussed in details to showcase the value SYS-4 could have added to the consensus outlook if it had been provided as precipitation probabilistic forecast and as SPI forecast. The three cases selected were seasons with: below normal, normal and above normal precipitation.

In OND 2000, the observed precipitation was normal over most parts of the Greater Horn of Africa, except for some extremely wet patches over Ethiopia, Sudan and Tanzania (Fig. 7). A significant area over north-eastern Kenya had moderately dry condition. SYS-4 precipitation forecast had a consistent signal for dry conditions over most of the region until August. September and October forecasts shift to normal conditions over the eastern part and wet condition on the northern and western parts. Notable is that the two forecasts maintain a dry signal over northern Kenya and the Tanzania and Kenyan coast. When the same analysis was repeated with the SPI, a similar forecast evolution to the precipitation is observed but spatially smoother. The consensus outlook predicted climatological conditions for the northern part; wet conditions for the upper coastline and a small section of the Western part; and normal conditions for the rest of the region. If SYS-4 September and October forecasts would have been incorporated in the consensus forecast, then the outlook could have been adjusted for the Kenya coast, Ethiopia and Sudan. That way the outlook would have been closer to the observations.

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OND 2006 was a moderately wet season, from the observations most of the region experienced moderately wet conditions and much of the coastal area experienced severely wet conditions (Fig. 8). The SYS-4 forecast had a wet signal far off in the ocean during June and August. The propagation inland happened in October. The same is seen in the SPIs however, the September forecast has a signal of moderately wet conditions inland. The consensus outlook forecasted normal conditions over most of the eastern part. If the consensus would have been updated in October using SYS-4 forecast, then the wet conditions observed on the eastern part could have been captured.

MAM 2009 was a moderately dry season for the Eastern equatorial part of the region. Most of the northern parts experienced severely dry condition and normal conditions were experienced on the western part (Fig. 9). SYS-4 consistently captured the dry signal but it only propagated inland in January and March for both precipitation and SPI. The consensus outlook predicted dry conditions over the eastern and a section of the northern part, the Western part had an above normal forecast. Combining the outlook and SYS-4's March forecast would have helped adjust the wet forecast over Ethiopia and Sudan to dry.

## 4 Conclusions

The Greater Horn of Africa Climate Outlook Forums takes place thrice a year before the rainy seasons. During the event, by means of statistical downscaling and local knowledge, forecasters from the the national meteorological centres of Kenya, Uganda, Tanzania, Rwanda, Burundi, Ethiopia, Somali, Djibouti, Eritrea, Sudan and southern Sudan issue what is known as the *consensus* forecast for the Greater Horn of Africa. It consists of a map showing the probability for the rainfall of the incoming season to be in one of the terciles – above normal, near normal or below normal – of the observed climatology.

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In this work we have analysed if the availability of long range forecasts from ECMWF and the use of more specific drought indicators such as the Standardised Precipitation Index would bring added benefits to what is already in place. As a first step ECMWF seasonal precipitation forecasts (SYS-4) were evaluated against station data over a vast part of the Great Horn of Africa using the historical dataset which is also the reference for the consensus climatology. Considering the paucity of data in this area and the difficulty to obtaining a long term dataset, this by itself has represented a reality check of the performances of the system in a critical region for drought monitoring. SYS-4 has significant skill in forecasting precipitation over East African with remarkably high skill in predicting the short rains (October–December) due to the strong predictability of the Sea Surface Temperature in the Indian Ocean and the ENSO teleconnection (Hastenrath et al., 2004). The good performance of the system over the region is a good starting point, nevertheless the interest here is in understanding if the availability of frequent updates from a dynamical model would add useful informations to the already existing forecaster's interpretation of the statistical forecasts. While the subjective assessment showed that there would be an added advantage, no particular lead time stood out in provision of more information for the entire period but in each season there was a lead time that would have made the consensus forecast better. The most interesting result is that if a drought index such as the Standardise Precipitation Index (SPI) is used in place of raw precipitation to generate "proxy" of the consensus maps than not only do the maps become spatially homogeneous as expected but information about the intensity of the conditions expected in the next season are available. Such information could then be used to support the decision process when issuing advisories for policy actions within the region.

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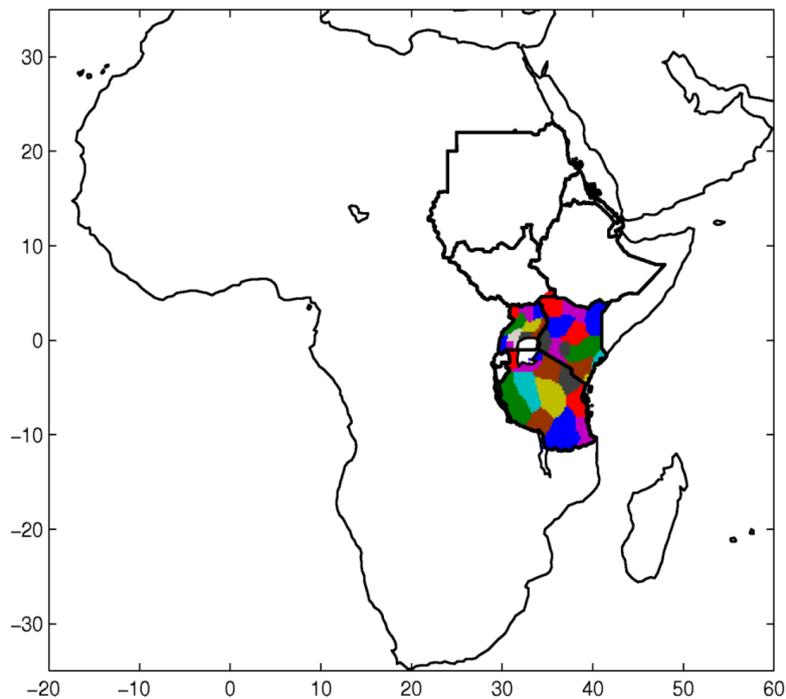
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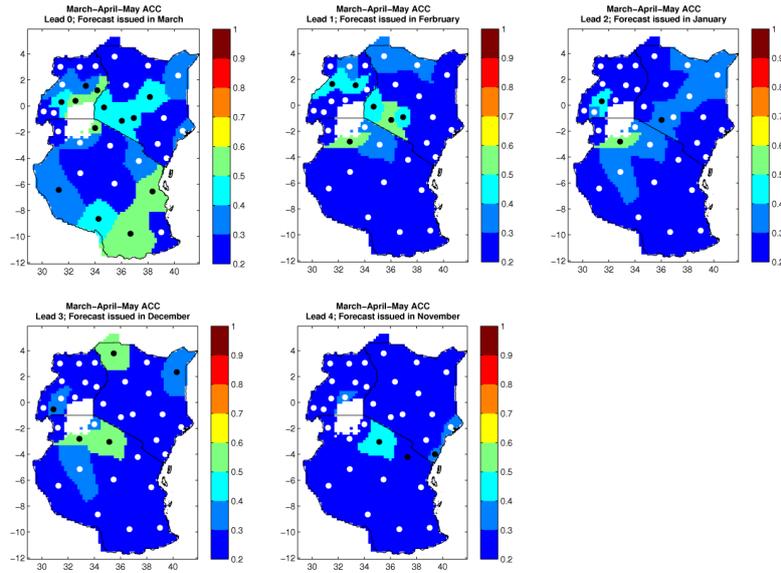
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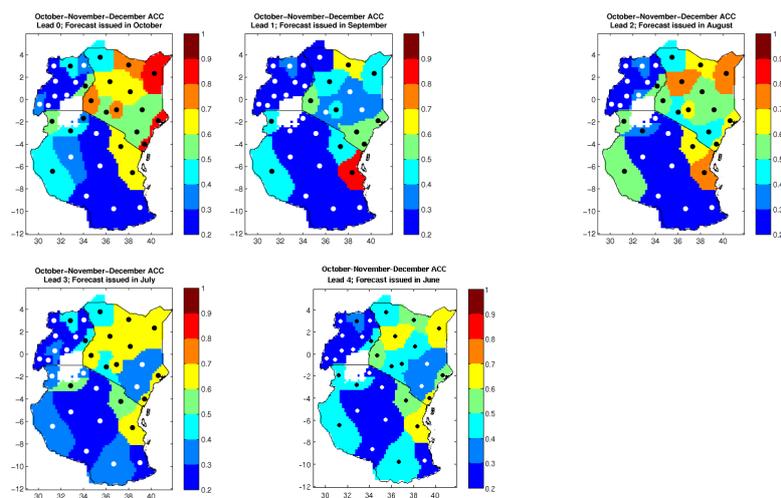
**Fig. 1.** Countries that participate in the Greater Horn of Africa Climate Outlook Forum (GHA-COF; outlined) and homogenous zones over East African Countries (coloured polygons) for which observations were available.

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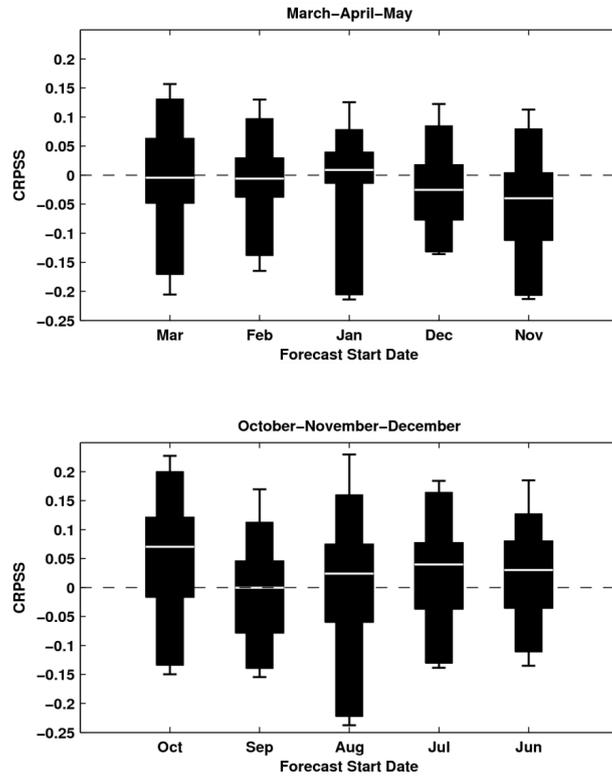
**Fig. 2.** Correlation Coefficients of MAM anomaly precipitation for the period 1982–2009, for different forecast lead times. Black and white dots represent regions with statistically significant ( $P < 0.05$ ) and insignificant ( $P > 0.05$ ) values respectively.

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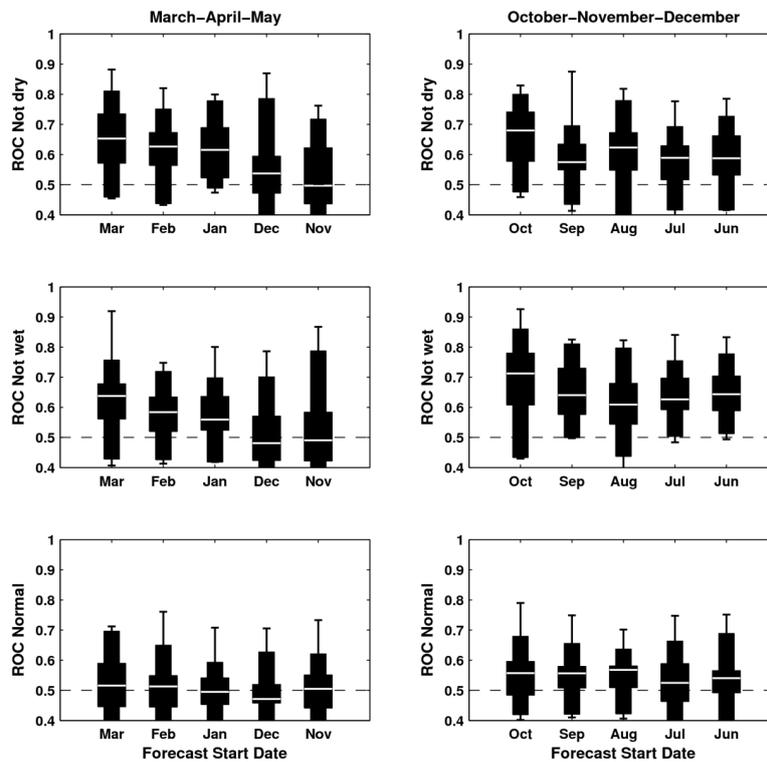
**Fig. 3.** As Fig. 2 but for the OND season.

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**Fig. 4.** Continuous Ranked Probability Skill Score (CRPSS) for MAM (top panel) and OND (bottom panel).

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**Fig. 5.** ROC scores for MAM (left panel) and OND (right panel).

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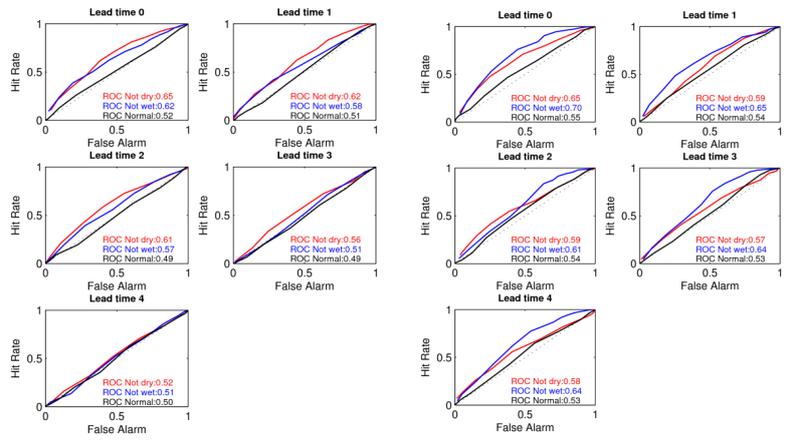


Fig. 6. Relative operating characteristics diagrams for MAM (left panel) and OND (right panel).

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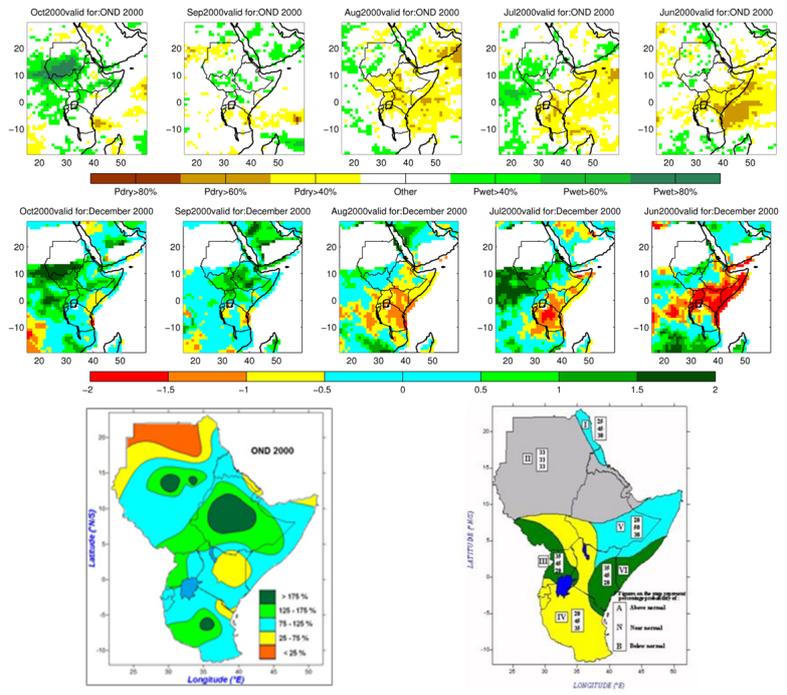
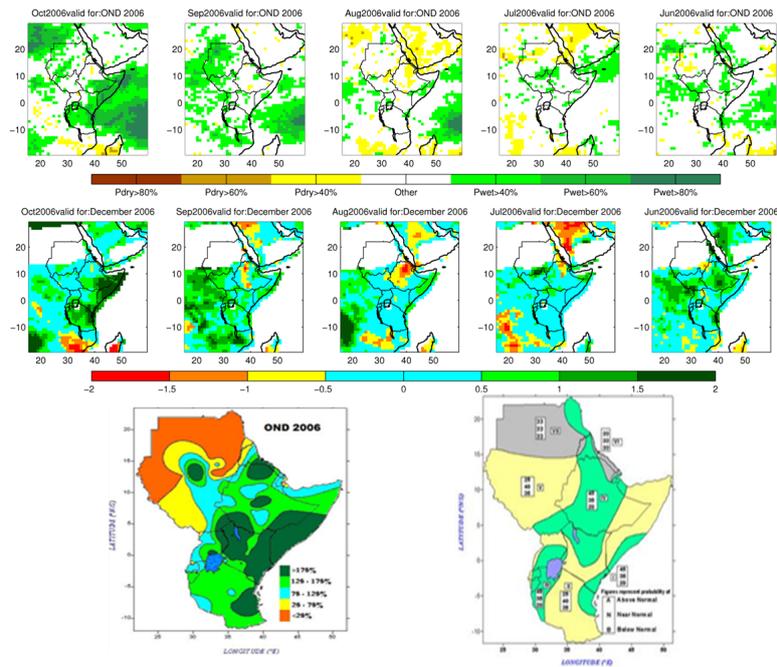


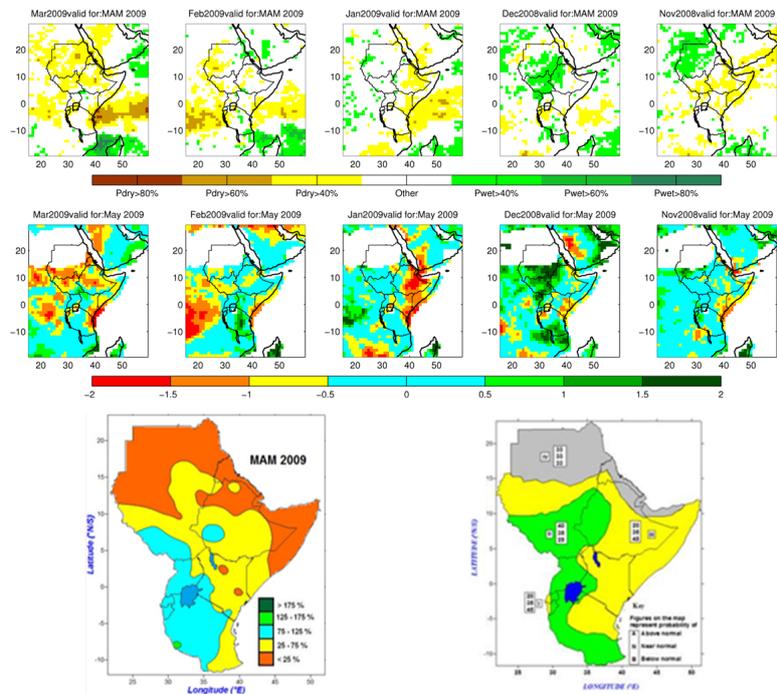
Fig. 7. SYS-4 probabilistic precipitation forecast for 5 lead times (top panel), ECFS4 3-month SPI forecast for 5 lead times (middle panel), observed precipitation (lower panel, left) and GHA-COF consensus (lower panel, right) all for OND 2000.

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**Fig. 8.** SYS-4 probabilistic precipitation forecast for 5 lead times (top panel), ECFS4 3-month SPI forecast for 5 lead times (middle panel), observed precipitation (lower panel, left) and GHA-COF consensus (lower panel, right) all for OND 2006.

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**Fig. 9.** SYS-4 probabilistic precipitation forecast for 5 lead times (top panel), ECFS4 3-month SPI forecast for 5 lead times (middle panel), observed precipitation (lower panel, left) and GHA-COF consensus (lower panel, right) all for MAM 2009.

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