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Seasonal predictability of onset and cessation of the east African rains

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ABSTRACT

Advanced warning of delayed onset or early cessation of the rainy seasons would be extremely valuable information for farmers in east Africa and is a common request from regional stakeholders. Such warnings are beginning to be provided, however forecast skill for these metrics has not been demonstrated. Here the forecast skill of the ECMWF seasonal hindcasts is evaluated for onset and cessation forecasts over east Africa. Correlation of forecast with observed long rains anomalies only above a 95% statistical significance level for a small part of the domain, whilst short rains are significance a large part of the region. The added value of updating the forecast outlook with the extended range 46 day forecast is assessed and this gives a small improvement. For the short rains detection of early onset is better near the coast, and late onset detection is better over northwestern Kenya.

During exceptionally dry years the method to detect onset and cessation fails. Using this as a definition of a failed season, the model shows significant skill at anticipating long rains season failure in the northwest of Kenya, and short rains failure in Somalia and northeast Kenya.

In addition the strength of the correlation between long rains cessation and seasonal total is shown to be particularly weak in observations but too strong in the hindcasts. Predictability of onset and cessation for both seasons appears to arise primarily from the link with seasonal total and it is unclear that the model represents variability in onset and cessation beyond this. This has important implications for operational forecasting: any forecast of season timing which is 'inconsistent' with seasonal total (e.g. an early onset but low total rainfall) must be treated with caution.

Finally links with zonal winds are investigated. Late onset is correlated with easterly (westerly) anomalies during the long (short) rains, though the strength and spatial pattern of the relationship is not well represented in the model. Early cessation is correlated with easterly anomalies in both seasons for most of the region in both observations and hindcasts. However for the long rains the sign of the correlation is reversed along the coast in observations but not in the hindcasts. These dynamical inconsistencies may have a negative impact on forecast skill and have the potential to inform process-based development of climate modelling in the region.

1. Introduction

The population of largely semi-arid East Africa is exposed to climate variability and although climate change impacts are uncertain (Rowell et al., 2015), risks can be partially mitigated with shorter term forecasts (Washington et al., 2006). Variability in timing of the rains has a significant impact on agriculture and early warning of onset and cessation is a regular request from user needs assessments in the region [e.g. (Owusu et al., 2017), as it would allow farmers to better manage potential risks to their planting and harvesting activity. To this end, the IGAD Climate Predictions and Applications Centre has started to disseminate onset and cessation forecasts at the Greater Horn of Africa Regional Climate Outlook Forum (GHACOF), though no evaluation of expected skill is provided.

Over east Africa, onset and cessation have generally received less attention from the scientific community than have seasonal totals [e.g. (Nicholson, 2017a). Mean dates and variability of the start and end of the rains over Kenya/Tanzania has been determined for the two rainfall seasons (the March-May long rains, MAM, and October-December short rains, OND) (Camberlin and Okoola, 2003; Camberlin et al., 2009; Philippon et al., 2015). For this location it has been demonstrated that both onset and cessation are well correlated with seasonal total and correlated with each other during the short rains but not the long (Camberlin and Okoola, 2003; Philippon et al., 2015). Long rains cessation has been linked to Indian monsoon onset (Camberlin et al., 2010) and long rains onset here is linked to zonal winds, with anomalous easterlies (westerlies) leading to late (early) onset and an overall dry (wet) season (Okoola, 1999; Camberlin and Okoola, 2003). Though the skill of onset forecasts has been evaluated for west Africa (Vellinga et al., 2013) and it has been demonstrated using an atmospheric model

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forced by sea surface temperature (SST) that onset of the short rains is more reproducible than the long rains (Philippon et al., 2015), the level of forecast skill for east Africa has not been described in the scientific literature.

Here, the ability of the operational ECMWF seasonal forecast model to anticipate anomalous onset and cessation is determined. Forecasts issued roughly a month ahead of the season are considered, corresponding approximately to the lead time of the forecasts available at the time of the GHACOF. The added value of incorporating the ECMWF extended-range 46-day forecast (benefiting from increased spatial resolution and more frequent updates) is also assessed. The relationships of onset and cessation with both seasonal totals and zonal winds are also evaluated, extending the findings of (Camberlin and Okoola, 2003) from over Kenya and Tanzania to the whole of East Africa. Description of the forecasts, observational data and the method used to define onset and cessation are contained in the next section. Results and conclusions follow.

2. Methodology

2.1. Models, experiments and observations

The seasonal forecast system of ECMWF is an initialised dynamical simulation of the coupled atmosphere-ocean climate system and has recently been upgraded to System 5 (hereafter S5). The atmospheric model used is the integrated forecast system (IFS) CY43R1 at Tco319 spatial resolution (roughly 35km near the equator), with 91 levels in the vertical. IFS is coupled to the Nucleus for European Modelling of the Ocean (NEMO) ocean model v3.4 at 0.25° resolution with 75 vertical levels. Compared to the system it replaces, S5 uses newer versions of IFS and NEMO at higher resolution and introduces an interactive sea-ice model, LIM2.

Operationally S5 is initialised once per month. Skill is assessed using the hindcast: 25 member ensembles initialised on the first of every month 1981–2016, with each member starting from slightly perturbed initial conditions in order to sample the uncertainty in knowledge of the exact state of the atmosphere (see (Leutbecher et al., 2017) for details). The atmosphere, land surface and ocean are initialised with ERA-Interim (Dee et al., 2011), ERA-Interim land (Balsamo et al., 2015) and ORA-S5 [an updated version ORA-S4, described in (Balmaseda et al., 2013). Model uncertainty is represented with stochastic perturbation schemes (Leutbecher et al., 2017). Here the first five months of the S5 hindcasts initialised on 1st February and September are used to assess the skill of onset and cessation forecasts for the two seasons, approximately equivalent to those available at the start of the GHACOF.

In addition to assessing the skill of the operational seasonal model, the added value of the shorter-range subseasonal system is also considered. A lot of attention has been given recently to the subseasonal (10–40 day) timescale [e.g (White et al., 2017; Vitart et al., 2017)], though ECMWF has issued a forecast at this timescale for many years. The ECMWF 46 day extended-range forecasts (hereafter ER) are combined here with S5 to assess the benefit of incorporating this information.

There are three potential benefits to ER compared with the first 46 days of the seasonal system. Firstly, ER tracks IFS cycle upgrades, whilst the cycle of the seasonal system is only updated infrequently. In the hindcasts used here however, there is no difference between the ER and S5 model version due to the recent upgrade, though over time the ER cycle will leave S5 behind, until the next seasonal system upgrade.

A second difference is the higher spatial resolution for the first 15 days in ER. To estimate the added benefit of this, the ER hindcasts issued on the first of February and September are combined with S5 by simply replacing the first 46 days of the S5 hindcast with ER data (experiment S5 + ER).

Finally, the start dates of ER are more frequent, twice per week instead of once per month. To assess the potential value of an updated forecast, the ER forecasts issued on the 15th of February and September are combined with S5 (S5 + ER + 14d). Mimicking an operational context in which the accumulated rainfall from 1 to 14th is known by the time of the forecast initialised on the 15th; in the S5 + ER + 14d experiment days 1–14 are daily observations scaled by the ratio of the long term mean of S5 with observations. Days 15–61 are then replaced with the ER forecast issued on the 15th. As they are run more frequently, computing constraints limit the size of the ER hindcast to 20 years (here the 1996–2015 hindcast is used) and 11 members. When compared with S5 + ER and S5 + ER + 14d, the S5 hindcast is limited to the same period and only the first 11 ensemble members are used. That this combined forecasts may improve on S5 alone if the ER simulation diverges from S5 and the skill of the ER forecast in the first 46 days is better than that in the equivalent S5 period.

The Climate Hazards group Infrared Precipitation with Stations (CHIRPS) dataset (Funk et al., 2015) is used for verification and to fill in the first 14 days of the S5 + ER + 14d hindcast. This is a blend of station and satellite information, providing daily precipitation estimates at 0.05° spatial resolution from 1981 to the present. CHIRPS and all model hindcasts are interpolated to a 1° grid before analysis.

2.2. Defining onset and cessation

Many methods exist to determine rainy season onset and cessation dates; at least 18 have been applied to west Africa alone (Fitzpatrick et al., 2015). Most require definition of thresholds, e.g. onset defined as the first of two consecutive days receiving at least 1 mm of rain whose total is greater than 20mm (Marteau et al., 2009), whilst an additional criterion of having no seven day period of total rainfall receiving less than 5 mm in the succeeding 20 days is added to avoid detection of false onset.

Threshold-based measures are appropriate for local agronomic studies based on station data, as they are designed to take into account availability of soil moisture. However thresholds cannot be universally determined (Fitzpatrick et al., 2015). They are also sensitive to bias and resolution, a significant issue for climate models with biases not just in overall totals but in daily rainfall distributions (Dai, 2006), such that even defining a dry day in a model is nontrivial. Given these issues applying threshold-based measures to model data, and the fact that the calculated dates are quite sensitive to thresholds (Boyard-Micheau et al., 2013), this approach is not used here.

An alternative method is based on diagnosing the date of shifts in large-scale dynamics. This has been applied to seasonal forecasts of the west African Monsoon (Vellinga et al., 2013), where onset is defined as the timing of the jump of the maximum rainfall band from the Gulf of Guinea to north of 10^oN. This method is insensitive to model biases, can be diagnosed from variables other than precipitation (such as outgoing longwave radiation) and is appropriate for west Africa, where onset is associated with large-scale circulation changes. However it is not clear how to implement this method for east Africa, where no such large-scale changes have been identified.

Of the studies which have considered onset over parts of east Africa, most follow a method similar to that first used by Liebmann (Liebmann and Marengo, 2001), hereafter the Liebmann method]. This defines onset and cessation as the global minima and maxima of a timeseries, either a principal component timeseries based on station rainfall (Camberlin and Okoola, 2003; Camberlin et al., 2009) or an accumulation of daily precipitation anomalies (Dunning et al., 2016). The method is local, appropriate for gridded and model data and recently has been applied across Africa, where it has been shown to be robust across observational datasets and consistent with local agronomic threshold-based definitions (Dunning et al., 2016). In addition, using global minima and maxima ensures false onset is taken in to account. The reader is referred to (Dunning et al., 2016) for a graphical representation and further discussion of the Liebmann method.

The Liebmann method is applied here to a window centred on each