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Search for an Astronomical Site in Kenya (SASKYA) update: Installation of on-site automatic meteorological stations

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Abstract. At present, there are few large telescopes (1-metre diameter mirror or larger) in sub-Saharan Africa, and the objective of the Search for an Astronomical Site in Kenya ("SASKYA") project has been find the best possible sites in Kenya for such an observatory. An initial study using ERA-interim reanalyses and high resolution meteorological model output identified three preferential sites, based on a selection of thirteen candidate mountain peaks across Kenya. These three sites are Mount Kulal (2.72°N, 36.93°E, 2293m); OlDonyoNyiro (2.09°N, 36.85°E, 2752m) and Warges (0.95°N, 37.40°E, 2688m). Recently (as of Spring 2014), an automatic meteorological station has been installed on the summit of Warges mountain, but security issues have prevented the installation of one on Mount Kulal. Furthermore, at the former site, the lack of suitable roadway through the heavily forested mountain-side will probably preclude further investigation. Hence, an additional but lower site, near to Warges (Ololokwe mountain, 0.83°N, 37.53°E, 1920m), which has a road to the summit, will be investigated for suitability in the near future. Following a period of successful meteorological observation at either or all of the above-mentioned sites, comparison and validation studies will be enacted using climate reanalyses. If further funding permits, all-sky cameras will be installed and high resolution EUMETSAT satellite imagery will also be consulted to determine local cloudiness coefficients.

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1. Introduction

The overall project goal of the Search for an Astronomical Site in Kenya ("SASKYA") project is to identify the best possible site in Kenya for astronomical observation, using state-of-the-art meteorological, climatological and geophysical datasets and other relevant information. Long-term cloud cover, integrated water vapour, relative humidity, air temperature, wind and vertical velocity datasets of the ERA-interim climate model reanalysis data were analysed in order to determine the best possible site(s). Data from the highest resolution meteorological model available for Kenya, namely the United Kingdom Met Office (UKMO) Africa Limited Area Model (LAM), was also used in an attempt to narrow an original shortlist of 13 potential candidate sites down to the most favoured sites. Aerosol data from the FriOWL software were also consulted [1].

2. Overview of Astroclimatological Parameters

In a comprehensive study on site selection for large telescopes, Graham [1] lists the main atmospheric constraints on astronomical viewing as the following:

a) Cloudiness
b) Atmospheric absorption due to atmospheric water vapour
c) Stability and turbulence of the atmosphere above an observatory
d) Observatory-level night-time relative humidity
e) Windspeeds at observatory level
f) Dust and aerosol loadings

In relation to (a), it is obvious in saying that night-time cloud-free skies are essential for successful operation of any astronomical observatory. It is important to add, however, that due to the typical long-exposure times, even partially clouded skies are detrimental to observations [2]. In northern Chile, total sky cloudiness fractions of less than 10% are widespread; in Kenya, we may consider sites only if they have a cloudiness fraction of 30% or less.

In the case of (b), because the primary absorber of infra-red radiation in the Earth's atmosphere is attributable to water vapour, the knowledge of total integrated amount of water vapour (IWV) in any atmospheric column is important for astronomical observation. Sarazin [2] quotes an IWV value of less than 5mm as being requisite for the satisfactory operation of large telescopes at visible wavelengths, and a value of less than 3mm at infra-red wavelengths. Such values will be difficult to achieve for lengthy periods in Kenya, except at high altitude.

The stability of the atmosphere and degree of microscale turbulence due to thermal effects largely controls the magnitude of astronomical "seeing" variable ("seeing" can be understood here as the "blurriness" of a stellar image over time). Although no author has yet been able to accurately reproduce seeing statistics based on solely micro-meteorological or climatological data for lengthy time periods, broad-scale correlation between gently subsiding (and adiabatically warmed) airmasses and areas of reduced seeing have been deduced by Graham [1]. Here, we will attempt to use this knowledge to infer spatio-temporal regions of improved seeing conditions across Kenya.

Night-time relative humidity, if too high, can be detrimental for astronomical observation due to the collection of dew or frost on optics and lenses. Similarly, too low or too high windspeeds can also preclude observation, due to (i) incomplete flushing of the telescope enclosure leading to thermal "dome" seeing, or (ii) telescope and enclosure shake due to strong winds, respectively. High aerosol or dust loadings are also problematic for the successful operation of telescopic optics in desert regions.

1.2 Data Sources

The data used in this study come from the European Centre for Medium Range Weather Forecasting (ECMWF), the UK Met Office and the National Center for Environmental Prediction / National Center for Atmospheric Research (NCEP-NCAR) in the USA. The various datasets used include the ERA-interim reanalysis [3], ERA40 reanalysis [4] and the NCEP-NCAR reanalysis [5]. High resolution data from United Kingdom Met Office (UKMO) Limited Area Model (LAM) for Africa is also used for the first time in this study. Presently, the UKMO is supporting a major technical co-operation project for Numerical Weather Prediction in Africa, and has therefore made the Africa-LAM available to academic researchers [6].

Reanalyses are the most accurate representations of the Earth's atmosphere for the past 50 years that are currently available. They are based on a state-of-the-art combined numerical weather prediction model and data assimilation scheme, using a wide range of observations such as satellites, ships, buoys and weather balloons. The scientific validation of the meteorological and climatological variables described by these reanalyses systems has been shown to be satisfactory in most circumstances [4, 5, 6]. Although recognising that no single reanalysis dataset is perfect in its representation of the Earth's atmosphere through time, these reanalysis datasets represent the culmination of an enormous effort by the meteorological and climatological communities across the globe over the past 50 years to accurately depict the state of the atmosphere.

The ERA-interim reanalysis product is currently publicly available at 0.75° latitude/longitude resolution (or about 75km horizontal scale), although much higher resolution data (e.g. EUMETSAT satellite data) has already been assimilated into the model using the data assimilation procedure known as 4D-VAR [4].

The Africa-LAM is a non-hydrostatic model (meaning non-geostrophic flow may be permitted in certain cases e.g. such as local mountain-valley winds or lake-breezes), with full prognostic equations used (meaning the best possible representation of the atmospheric state is determined). There are two configurations of the model, one with 38 vertical levels (L38) and another with 70 vertical levels (L70); output from the L70 model was used only in this study. The horizontal grid resolution of the L70 configuration is 12km [6].

1.3 The Candidate Sites

Initially, thirteen candidate sites were chosen across Kenya (Table 1). Of these, two lay at relatively high altitude to the west of the Rift valley (Kapcholio and Loita hills); the remainder were to be found across a range of altitudes to the east of the Rift valley, including Warges, Mount Kulal and Mount Marsabit in the Chalbi desert.

Immediately, because of the relative close proximity (0.3° lat/lon) between the Ndoto and OlDonyoNyiro mountains (the reanalysis data is unable to differentiate within this distances), it was assumed a priori that OlDonyoNyiro was the more favourable of the two peaks due to its higher altitude (and thus lower IWV), and thus the Ndoto peak was dropped from the list.

As the research progressed, however, it soon became apparent that some of the aforementioned sites as listed in Table 1 (e.g. Loita hills, Kapcholio) were not of high enough quality, and therefore could also be dropped from any further analyses. At the same time, however, closer inspection of the Kenyan terrain and vegetation (using Google Earth, site reconnaissance and other means) revealed new mountain peaks in the vicinity of the best performing sites. It was decided to conduct analyses for these additional sites as well.

Table 1. The thirteen candidate sites analysed during SASKYA. The latitude, longitude and altitude of each site are given.

Name	Latitude (°N)	Longitude (°E)	Altitude (m)
Ol Donyo Nyiro	2.09	36.85	2752
Mount Kulal	2.72	36.93	2293
Mount Marsabit	2.28	37.95	1420
Kapcholio	2.12	35.15	2790
Ndoto	1.75	37.17	2297
Warges	0.95	37.40	2688
Loita Hills	-1.70	35.80	2642
Mtelo	1.39	35.21	3325
Cherangany hills	1.21	35.27	3369
Mt. Furroli	3.45	38.02	1869
Ol DonyoLenkyo	1.45	37.09	2550
Nr. Sololo	3.36	38.39	~1300
Mt. Kenya	-0.09	37.19	4417

3. Results and Discussion

Thirty years (1981-2010) of ERA-interim, ERA40 and NCEP-NCAR climate model reanalyses data were analysed in detail (for the Kenyan region), and two years (2010-2011) of Africa-LAM high resolution meteorological model, made available by the UK Met Office, were also consulted. The results of this part of the study have been presented in more detail by [7, 8, 9, 10, 11].

With respect to cloud cover, findings suggest the mountain peaks of Mount Kulal and OlDonyoNyiro are the most favourable, although the whole region bordering and including the Chalbi desert (from Warges north to Mount Marsabit) appears reasonably cloud-free, with annual averages of about 30% of cloud cover. Significant seasonal variation in cloud cover can be expected, however, as well as notable inter-annual and interdecadal oscillations. The prevalence of high ice cirrus cloud across Kenya may be problematic.

Annual averaged integrated water vapour values for all sites (except Mount Kenya) are uncomfortably high, ranging from approximately 10 to 14mm over the 2,000 to 2,500 metre altitude range. Lowest IWV values are found in the south-east of Kenya; highest values in the north-west, and lower IWV values are to be found east of the Rift valley. One must ascend to a level of at least 4,000 metres in order to obtain consistent IWV values of 5mm or less – and Mount Kenya is the only site in Kenya where this is achieved for large parts of the year. Because the presented IWV values are almost uniformly high, it is recommended that ground-truthing of the reanalyses IWV values be conducted on the same peaks.

The vertical velocity variable was used as proxy to help determine areas of improved “seeing” conditions, by identifying regions of gently descending air. The results confirm that the whole area lying between Mount Kulal, OlDonyoNyiro and the Chalbi desert is again the most favourable region in Kenya. There is a deep turbulent surface boundary layer, however, and any site selection would need to take this into account. Furthermore, there are important seasonal variations in the variable, so good astronomical seeing conditions cannot be expected anywhere all-year round.

Based on the results of the above studies, at a SASKYA project meeting in South Africa in December 2012, the peaks of Mount Kulal, Warges and Ol Donyo Nyiro were selected as the three most preferable sites to date. More recently (as of Spring 2014), a solar powered automatic meteorological station has been installed on the summit of Warges mountain, and it currently transmitting live data every 5 minutes to a central server in South Africa by means of the 4-G cellular phone network. Unfortunately, security issues have prevented the installation of an automatic weather station on the summit Mount Kulal, following the theft of some initial equipment. Furthermore, at the former site, the lack of suitable roadway through the heavily forested mountain-side will probably preclude further investigation. Hence, an additional but lower site, near to Warges (Ololokwe mountain, 0.83°N, 37.53°E, 1920m), which has a road to the summit, will be investigated for suitability in the near future. It is worth noting that it would be impossible to build an observatory on the very high slopes of Mount Kenya because it lies within a national park (the construction of any buildings is prohibited).

Following a period of successful meteorological observation at either or all of the above-mentioned sites, comparison and validation studies will be enacted using climate reanalyses. If further funding permits, all-sky cameras will be installed and high resolution EUMETSAT satellite imagery will also be consulted to determine local cloudiness coefficients.

Outlook

After the initial climatological studies took place (as described above), infrastructural and cultural issues are expected to begin to play a more important role in the final site selection process. Trade-offs between the best possible site in climatological terms, and the practicalities of installing remote equipment in isolated, inaccessible areas will become important considerations. Once 12-24 months of weather data have been collected and analysed (ideally after comparison with reanalyses products), and also a complementary study completed using EUMETSAT satellite cloud mask data, it should become reasonably clear which final site(s) in Kenya are most preferable for SASKYA.

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