A Journey Towards Rescuing Historical Climate Data in Sub-Saharan Africa:
Inventorying the ACMAD Collection

Kevin Healion

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Climate Change.

Department of Geography, Maynooth University

July 2022

Head of Department: Dr. Helen Shaw

Research Supervisor: Dr. Peter Thorne

Contents

Acknowledgments

I want to thank Dr. Peter Thorne for his supervision of this thesis. The advice and encouragement given by him throughout has been invaluable. Without it the completion of this thesis would have been much more complex.

I want to also thank Dr. Simon Noone who I worked alongside inventorying the data for this project. His expertise on the topic of climate data rescue was incredibly helpful.

I want to thank Camila for her patience and support over the last few months. Her words of reassurance were of major comfort to me.

Finally, I want to thank my family for keeping me focused and for encouraging me throughout the past year. Their belief in me gave me a boost when I needed it most.

Figures and Tables

Figures

Tables

Abbreviations

- **ACMAD:** African Centre for Meteorological Applications for Development
- **C3S:** Copernicus Climate Change Service
- **DARE I:** Data Rescue Project for Africa
- **DRC:** Democratic Republic of Congo
- **GHCND:** Global Historical Climatology Network Daily
- **ICARUS:** The Irish Climate Analysis and Research UnitS
- **IDCC:** International Data rescue Co-ordination Centre
- **NCCA**: National Council for Curriculum and Assessment
- **NCDC**: National Climate Data Center
- **NOAA**: National Oceanic and Atmospheric Administration
- **RMI:** Royal Meteorological Institute of Belgium
- **WCP:** World Climate Programme
- **WMO:** World Meteorological Organisation

Note on Placenames

The following are the names of countries used in this paper which are no longer the official names of those countries.

- **Haute Volte**= Burkina Faso
- **Zaire=** Democratic Republic of Congo
- **Benin Dahomey**= Benin
- **French Sudan**= Mali

The names of numerous locations of weather stations have also changed especially in the post-colonial era. The names of the countries and stations in this thesis are as they were named on the documentation used to record the observations at each location.

People Mentioned in Thesis

Dr. Simon Noone: Post-Doctoral Researcher, ICARUS, Maynooth University

Dr. Hans Hersbach: C3S Reanalysis Team Leader

Dr. Stefan Graff: Climate Change and Earth Surface Processes Scientist, University of the Witwatersrand

Dr. Rick Crouthamel: Executive Director, International Environmental Data Rescue Organisation

Abstract

The recovery of instrumental climate data is vitally important when revising the climates of the past and predicting the climates of the future. Many parts of Europe have long standing collections of climate data that go back to the 17th and 18th centuries. However, in Africa known instrumental data only goes back to the late 19th and early 20th centuries for many of the continent's countries. There is therefore an urgent need to prioritise the discovery, rescue, and digitization of instrumental data that exists on unstable physical formats. Many parts of Sub-Saharan Africa are amongst the most vulnerable on the planet to the effects of climate change. Gaining a better understanding of the continent's past climate is dependent on the availability of a long record of data that can help the people of Sub-Saharan Africa adapt to their changing climate.

The documents being inventoried for this thesis are therefore of high importance. Originally rescued by the Royal Meteorological Institute of Belgium in the late 1980s and stored onto microfilm and microfiches, further rescue efforts were made in 2021 to image these observations and prevent the data from being lost forever from the decaying film and fiche. The result of this is a rich collection of an estimated four million images of data from forty-three Sub-Saharan countries. Using this information there is an opportunity to inventory and identify unique atmospheric data from weather stations that stretch back to the late nineteenth and earlier twentieth centuries. The process behind doing this will be explained as well as the future work that needs to be carried out on the collection. This thesis describes the first steps towards making an important collection available for researchers to gain a better understanding of the past climates of Sub-Saharan Africa and therefore what the future may hold for a very climate vulnerable region of the world.

1. Introduction

1.1 Background

“What you do not observe, you cannot understand”, is how Ryan et al. describe the importance of rescuing historical climate data (Ryan et al., 2018). Adding undigitised historical weather observations to datasets that underpin reanalyses of our climate is desirable and can help improve our understanding of meteorology and long-term climate changes (Lorrey et al., 2022). The International Data Rescue Co-ordination Centre (IDCC) also explain how large sets of daily and monthly climate data are required to “describe, study, and predict climate and climate change and their influence on our environment”. The rescue of climate data is an important activity that is required to prevent the loss of observations recorded on obsolete or fragile mediums. It is also required to assist researchers, national meteorological organisations, stakeholders and policy makers access data to fill gaps in climate research (Mateus et al., 2020). Long-term climate data series also aid paleoclimate reconstructions, climate modelling, climate change detection and attribution studies, to assist climate action, mitigation, and adaptation policies (Matheus et al., 2020). Research on issues such as outbreaks of disease, drought, heat stress and food production can also be encouraged with the availability and access to historical climate data.

This thesis will explain the steps carried out while assisting with a data rescue project being undertaken on instrumental climate data from Sub-Saharan Africa taken from the ACMAD collection by the Copernicus Climate Change Service (C3S). The aim of C3S is to “combine observations of the climate system with the latest science to develop authoritative, quality-assured information about the past, current and future states of the climate in Europe and worldwide” (Copernicus, 2022). The focus on Sub-Saharan Africa is of particular importance as long time series of weather observations are sparse in many countries of the region (Kaspar et al., 2022). This is of concern as low and middle-income countries will be disproportionally affected by climate change with consequences across many sectors, most notably health and agriculture (Sorgho et al., 2021). Inventorying the metadata inside the ACMAD collection, originally rescued by the Royal Meteorological Institute of Belgium in the late 1980s, brings an opportunity to rescue and identify unique data that can prove to be of high value by climate scientists for the reanalysis of the African climate and for gaining a greater understanding of how much the climate is changing across various African regions.

1.2 Value of this project

A brief history of weather observation highlights the sparseness of climate data in Africa. The creation of meteorological networks and services by nation states throughout the mid-nineteenth century has been attributed with the onset of new technologies and a drive to standardize methods of observations, data formats, and metadata (Brunet and Jones, 2011) (Thorne et al., 2017). Station coverage had extended to every inhabited continent by the end of the nineteenth century to the extent that it is now possible to calculate global climatic change across numerous variables (e.g., temperature) (Thorne et al., 2017). Despite this global coverage, many regions had a sparse number of stations available to collect weather observations meaning numerous parts of the world today have a poorer climatic record than others (Figures 1 and 2).

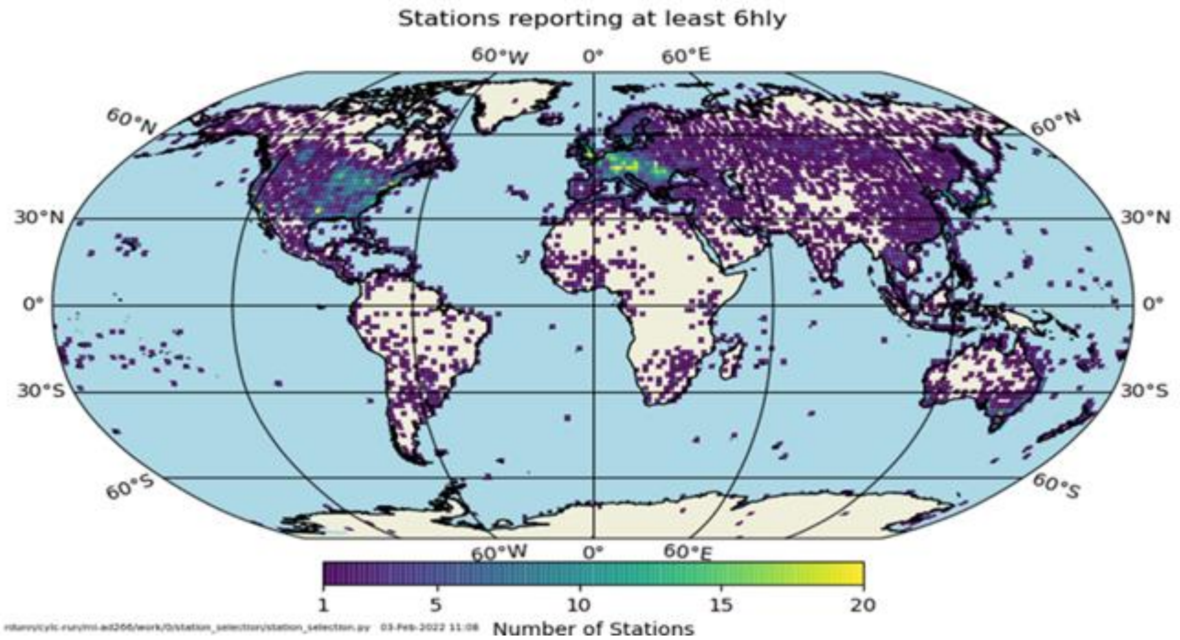


Figure 1: HadISD Stations with long records reporting at least every 6 hours. Note the lack of stations in Africa (Met Office, 2022)

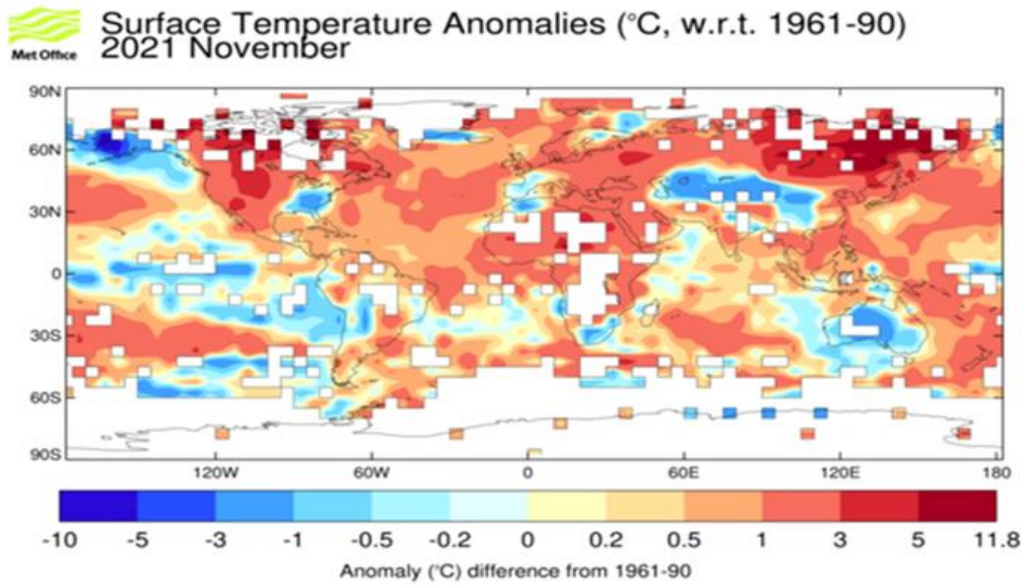


Figure 2: Global Surface temperature anomalies, showing gaps in data on the African continent (Met Office, 2022).

Historical data has been defined as the following:

i) data that are digitised and are already made available with workable or no usage restrictions,

ii) data that are digitised but are either not made available or made available with restrictive usage conditions and

iii) data that are only available presently as either hard copy or, at best, non-machine-readable image formats (Thorne et al., 2017).

The data that is going to be presented in this thesis falls under the third category. Long time series are of high relevance for climate analysis in Africa. They are needed for:

1. Model based reanalysis
2. Regional re-analysis of past weather patterns
3. Climate adaptation measures
4. Climate services for African stakeholders

There is an urgency to rescue this data and transfer it into a digital format as handwritten documents and images of documents saved onto microfilm, are vulnerable especially in hot climates such as Africa. It is therefore important that the data from these brittle sources are inventoried and digitised for longer posterity.

1.3 Aims

The aims of this thesis are:

1. Create new inventories to enable further data rescue.
2. Assess the quality of the images.
3. Identify countries that are short on historical climate data.
4. Compare with existing inventories to identify unique data

The first aim of this thesis aims to create inventories of countries that had not yet been inventoried within the ACMAD collection. This will be done using front matter material found in the ACMAD collection as well as images of forms from countries who were identified as not having front matter material. A second aim will be to carry out an assessment of the quality of these images for the purpose of identifying stations or countries who could be prioritised for future digitisation of data. The last two aims go hand in hand. The inventories of two countries created for this thesis will be compared to existing inventories of those countries to identify how much data is unique within the ACMAD collection. This comparison will also identify countries who are short on unique data within the collection.

1.4 Structure

This thesis will start off with a literature review, analysing why the rescue of historical climate data is important, its importance in an African context, efforts to rescue climate in Africa up to now and how citizen science has been utilized to help speed up the process of rescuing the massive amounts of data that exists. Next the provenance of the ACMAD collection will be described as well as the methodology used to create the inventories and to identify unique data for future digitization. Following this, the results of the analyses of the metadata rescued will be presented focusing on the types of data recorded in the inventories and the unique data identified from two selected countries. Finally, a discussion section will explain what future work needs to be carried out including identifying which countries are to be further analysed for unique data, the analyses of images to help with this prioritisation, the need to carry out geo-location to identify location issues and finally the potential for citizen science to aid the large amount work that is required to digitise the data in the ACMAD collection.

Literature Review

2.1 The Importance of Data Rescue

According to the IPCC (International Panel for Climate Change) instrumental observations of the atmosphere, ocean, land, biosphere and cryosphere underpin all understanding of the climate system (IPCC, 2021). Observations of the weather are recorded manually or automatically on pre-printed forms of paper or software programs during specific observation periods (Park et al., 2018). However, the availability and accessibility of long-term and high-quality instrumental climate data are limited (Brunet and Jones, 2011). Without long records of observations there can be no viable pathway to understanding climatic processes, climate variability, or climate and weather extremes (Thorne et al., 2018). According to the International Environmental Data Rescue Organization, the world loses thousands of records of historical climate data every day (Park et al., 2018). This is due to a variety of reasons including the poor conditions that the records are stored in, theft, obsolescent forms of media, and environmental conditions (Park et al., 2018). These hamper attempts to carry out more reliable and long-term climate assessments to better understand, detect, predict and respond to climate variability and change (Brunet and Jones, 2011). Data that exists in hard copy form needs to be rescued, digitised and quality controlled to prevent the loss of this important information. (Skrynyk et al., 2020).

The recovery of historical data from paper and obsolete electronic data is an ongoing process by the World Meteorological Organization, national meteorological services and other institutions. In 2017 the WMO created the I-DARE portal which “provides guidance on data rescue and climate data management specifications; an international portal as a single global infrastructure for providing information on rescued and to-be rescued archives” (WMO, 2017). The International Surface Pressure Databank meanwhile is home to the world’s largest collection of surface and seal-level pressure observations (Cram et al., 2015). The Copernicus Climate Change Service's (C3S) Global Land and Marine Observations Database aims to provide comprehensive access to the global archives of surface meteorological observations made over land and oceans through a common interface and data model (Noone et al., 2020). At a more regional level, numerous data rescue projects have been carried out including the Mediterranean Data Rescue (Brunet et al., 2014), the ClimateWNA (Western North America) project (Wang et al., 2012), the RECovery of Logbooks and International Marine data (RECLAIM) project (Wilkinson et al., 2011) and the DRAW project (Park et al., 2018).

Climate data can be used to support a variety of applications for specialist and non-specialist users. Internet based tools help visualize projected climate change to the user while software packages have been created for those who wish to query large climate databases (Wang et al., 2012). Some of this software packages and tools include the ClimateBC software package, the WorldClim program and the Climex model. High temporal resolution on these systems is important for agricultural and engineering applications while high spatial resolution climate data is important for ecological research across a variety of ecosystems (Wang et al., 2012). For these applications and software packages to be successful, long-term and high-quality instrumental climate data are required. To create a software package called ClimateWNA (Western North America), over “20 000 surfaces of monthly, seasonal and annual climate variables from 1901 to 2009” were used (Wang et al., 2012). The statistical downscaling required for more accurate future projections also needs long and reliable observed historical data series for calibration (Fowler et al., 2007).

Having a long record of data is important for carrying out climatic research at local and national levels. A 305-year continuous monthly rainfall series for the island of Ireland was created using a dataset of monthly rainfall data for twenty-five stations, and from a series called the Jenkinson series that contained tables of monthly and annual data for the island of Ireland between 1711 and 1977 (Murphy et al., 2018). However, even here where a long series of data was available, confidence in data used from before 1790 was low and the rescue of climatic data on records from this time was recommended (Murphy et al., 2018). Likewise in Africa, the use of high-resolution precipitation data from between the years of 1981 and 2016 and maximum and minimum temperature between 1979–2012 using datasets from international databases like the Climate Hazard Group (CHG) was used to assess the seasonal, annual, and decadal variability of the region (Gebrechorkos et al., 2020). Unlike the study carried out on rainfall variability in Ireland, which had access to data going back to 1711, the data used in the African study only went back to 1979. For assessments of long-term climate change the observational time series should be as long as possible, however in many countries of Sub-Saharan Africa long time series of weather observations are sparse (Kaspar, 2022).

2.2 The Importance of Climate Data Rescue in Africa

Unlike Europe, Africa has almost no instrumental meteorological measurements prior to 1850 while data from the second half of the nineteenth century has not been properly compiled (Bronnimann et al., 2019). In South Africa, the location of the Cape of Good Hope on a major shipping route meant that documentary and instrumental weather observations were recorded at a replenishment station since the seventeenth century (Picas et al., 2019) (Bronnimann et al., 2019). The Royal Astronomical Observatory in Cape Town South Africa has produced some of the oldest climate data available to climatologists with daily records beginning in 1834 and continuing to the present day (Bronnimann et al., 2019). Outside of South Africa, the longest series of data were recorded in stations located close to coasts while data from more inland regions appeared only from the mid twentieth century (Bronnimann et al., 2019). The Congo Basin is an illustration of this. Here, early measurements were sporadic and went largely unpublished, remaining in the personal archives of nineteenth century explorers such as Cyriaque Gillian and Francis Dhanis (Bronnimann et al., 2019). Missionaries, scientific expeditions, individuals and colonial administrations were responsible for producing some of the earliest climate measurements in Africa (Bronnimann et al., 2019). Of the types of climate variables measured rainfall records generally go back the furthest with Algeria installing its earliest rain gauges in 1837 (Bronnimann et al., 2019). This focus on rainfall illustrates how important rain is for the livelihoods of the African people.

Documentary sources have also been recognized as an important tool for the reconstruction of proxy climate records for periods prior to meteorological instrumentation (Endfield and Nash, 2002). Documents created by missionaries such as the Rhenish Missionary Society and the London Missionary Society have been used to get a better understanding of climate and weather events on the African continent (Endfield and Nash, 2002), (Grab and Zumthurm, 2020). Materials that date from the 1820s provide the only written record of the environment of Lesotho following the arrival of the earliest European missionaries in the region (Nash and Grab, 2009). Annual reports written by district officials and magistrates have also been used as documentary evidence for their summary of weather and climatic conditions for African sub-regions (Grab and Zumthurm, 2020). Using this documentary evidence has been invaluable for research as the “human experience and associated reporting of drought events depends strongly on social, environmental, spatial and societal developmental situations and perspectives" (Grab and Zumthurm, 2020). Finally, when these historical documentations are combined with instrumental observations, they produce a highly detailed picture of the past and present state of the whole climate system (IPCC, 2021).

The lack of records and data in Africa is not unique to meteorological measurements. Throughout the British Empire, archival institutions were not established in colonial territories until the independence of these colonies became inevitable (Dritsas and Haig, 2013). The creation of these archival institutions did begin the process of rescuing administrative documents created in the colonies pre- and post-independence. Amongst the most valuable records to be rescued by the newly established archival institutions were those created by local provincial governments and districts. These records were deemed worthy as they helped fill gaps in knowledge in local history as well as being the least likely documents to be duplicated in European archives (Curtin, 1960). The foundation of these archives helped kickstart the importance of rescuing historical records and documents in African countries. For example, despite only being established in 1935, the Archives of Southern Rhodesia quickly published the "Oppenheimer Series" of books which contained diaries, correspondence, notes and maps which was of interest to climate scientists amongst others (Dritsas and Haig, 2013).

Sub-Saharan Africa is a region that has been identified as being highly vulnerable to climate change (Aich et al, 2016). Dry and semi-arid tropical regions are characterized by strong interannual and decadal rainfall variability with a noisy natural signal which has implications for human livelihoods, particularly rural populations who are reliant upon rain-fed agriculture (Chagnaud et al., 2022) (Nash and Grab, 2009). However, our knowledge of the natural background of rainfall and drought variability in Africa is inadequate to allow a full understanding of future climate trends (De Cort, 2016). West Africa, which includes the Sahel, is a difficult region to accurately predict precipitation due to a strong sensitivity to tropical sea surface temperatures (SSTs) (Ahokpossi, 2018). Here, crops such as rice millet, maize, cassava, sorghum and sugar cane are amongst the most consumed foodstuffs, particularly in countries that exist along the Niger River Basin (Abdoulaye et al., 2021). The analysis of observations in West Africa points to an increasing trend in extreme rainfall over the last thirty years with a 5% decadal increase in extreme rainfall intensity (Chaugnaud et al., 2022). Stronger storm intensities are seen as the most likely cause of increasing annual maxima of daily rainfall totals over more frequent storm occurrences (Chaugnaud et al., 2022). Some dry continental regions are also projected to experience a reduction in nearsurface relative humidity primarily due to limited moisture availability (Fischer and Knutti, 2016).

The population across the whole Sahel region is expected to rise from a population of 90 million in 2015 to 240 million by 2050 and 540 million in 2100 (Panthou et al., 2018). Niger is predicted to have the largest natural increase of population on the planet with a total fertility rate of 7.6 births per woman (Panthou et al., 2018). This will put various pressures on the countries and peoples that depend on rain fed agriculture. The spread of disease is also a big concern for African countries with climate being seen as a big influence on the spread of illness including the ebola virus disease (Ng and Cowling, 2014). Ecosystems in Africa are also very fragile with a changing climatic regime influencing the distributional shift of species according to their thermal tolerance (Gatti et al., 2015). Climate data can contribute towards higher resolution forecasts that account for the spatial-temporal variability in climate and account better for the physiological responses of organisms to this variability which are needed to inform future conservation strategies (Trew et al., 2021).

2.3 Previous Data Rescue Projects in Africa

There have been various data rescue projects carried out on the African continent. Many of these focused on individual variables such as atmospheric pressure, rainfall, wind, etc. The recovery of barometer readings measuring atmospheric pressure has been a particularly major focus (Picas et al., 2019). Creating long daily series of atmospheric pressure readings can help climate scientists gain a better understanding of historical large scale tropospheric circulation (Picas et al., 2019). Historical barometric observations are also very valuable to scientists carrying out climate re-analyses (Picas et al., 2019) (Compo et al., 2011). A project carried out by Compo et al titled “The Twentieth Century Reanalysis (20CR) project” aimed to produce a comprehensive global atmospheric circulation dataset spanning the twentieth century (Compo et al. 2011). While completing this task successfully, the lack of long-term observations from African stations is apparent. In order to improve their dataset, further digitisation of pressure observations is required of which millions of additional surface observations from the nineteenth and early twentieth centuries exist, with observations from Europe even going back as far as the seventeenth and eighteenth centuries (Compo et al., 2011).

Rainfall records have also been prioritised for rescue. At 176 years, the South African Astronomical Observatory in Cape Town is home to the station with the longest known continuous single precipitation record for the southern hemisphere and Africa (Ndebele et al., 2019). However, outside of South Africa instrumental precipitation records are poor despite many colonists setting up stations in the late nineteenth century (Ndebele et al., 2019). Continuous precipitation records for modern stations that began observing in the nineteenth century also exist in Algeria, Tunisia, Senegal, Namibia (Nicholson et al., 2012). An archive of all known precipitation data extending back to the nineteenth century was created for Africa by Nicholson et al., in 2001. This archive was created using summary data created by various meteorologists in the late nineteenth century.

Using scanned images from data sources in worldwide online repositories, national archives, and the national meteorological agencies of former European colonisers, a surface climate dataset from station observations in Mediterranean North Africa and the Middle East was created and published in 2014 (Brunet et al., 2014). This project highlighted some of the issues experienced using images to rescue climate data including scanned images being too dark or faded, missing data pages and deviations in the chronological order of the images (Brunet et al., 2014). Like most data rescue projects involving African instrumental records, most record only go back to the early twentieth or late nineteenth centuries with gaps in the record remaining to be filled (Brunet et al., 2014).

Documentary evidence has been used as a source of data to help reconstruct climate variability from as far back as the nineteenth century. This type of analysis resulted in the first combined annual and seasonal reconstruction of rainfall variability over southeast Africa for the nineteenth century (Nash et al., 2016). The analysis of materials created by missionaries in the London Missionary Society and the Wesleyan Methodist Missionary Society resulted in the identification of six major droughts in the Kalahari region of central southern Africa between 1815 and 1900 while seven periods of above average rainfall were also identified during the same period (Nash and Endfield, 2002). The above average rainfall discovered by this documentary evidence was compared with available instrumental rainfall observations which resulted in a broad agreement confirming the wet periods (Nash and Endfield, 2002). However, the lack of instrumental data for some locations meant that a meaningful comparison could not be made to back up the evidence presented by primary sources created by the missionaries.

2.4 Citizen Science

Digitising climate data is a big task, both logistically and in terms of the sheer volume of records that need to be rescued (Ryan et al., 2018). Citizen science has therefore become an important way of helping to overcome these issues. Amateur volunteers may become interested in contributing to data rescue due to the wider social impacts and cognitive, affective, social, behavioural and motivational dimensions that the work provides (Hidalgo et al., 2021), (Phillips et al., 2019). There is also evidence that "research can be significantly shaped by the degree and quality of public participation in project design" (Shirk et al., 2012), (Hidalgo et al., 2021). Many citizen science projects rely on participation only for the collection and sometimes the analysis of large-scale observations to overcome the capacity of research structures (Hidalgo et al., 2021).

Projects like the Deep South Challenge, and Data Rescue: Archives and Weather (DRAW) have used online tools to allow citizen scientists to input data virtually (Lorrey et al., 2022), (Park et al., 2018). The capabilities of smartphones, tablets and mobile applications means that just about anyone can be a citizen scientist (Shah and Martinez, 2016). The advantages of using web-based citizen science for data rescue efforts are that human resources can be "drawn from all regions on earth, volunteer time is free and progress is made more or less continuously" (Lorrey et al., 2022). For example, the first phase of the Deep South Challenge project resulted in a total of 150,690 meteorological observations from shipping logbooks being recovered through replicate keying by citizen scientists online (Lorrey et al., 2022). The DRAW project discovered that using web-based citizen science increased the awareness of the impact of historical data archives on present-day scientific fields (Park et al., 2018). There were various issues acknowledged by the web-based path for citizen science. Knowledge about suitable tools and software to aid user involvement and engagement is needed to help overcome the complexity of scientific data sets and the lack of universal metadata standards during the transcription process (Park et al., 2018). There are also issues concerning the incorrect transcription of common digits (i.e. mistaking a 4 for a 7) and the omission of decimal points and other delimiters (Lorrey et al., 2022).

The motivational dimension to citizen science can also be applied to those wishing to gain a better understanding of historical climate data and their importance. Students at university and secondary school level can assist scientists in gathering data, while in return the scientist teaches them about research design, data analysis and critical thinking skills required to solve the problem presented (Shah and Martinez, 2016). This allows students to gain more knowledge concerning the rescue of historical climate data while improving access to instrumental data for climate scientists. The Irish Climate Analysis and Research UnitS (ICARUS), in Maynooth University, Ireland, has worked with undergraduate geography students on a couple of data rescue projects. The work carried out by the students aimed to give students important insights into processes underpinning research, first-hand experience in working with historical climate observations, develop group working and cooperation skills and develop further data collection, processing, computer, and presentation skills (Noone et al., 2019), (Ryan et al., 2018).

One such assignment, a geo-locate project first implemented in 2017, allowed students to work on resolving meteorological station location issues (Noone et al., 2019). Upon completing this assignment, 20 % strongly agreed and 74 % of students agreed that they had gained important insights into data issues; 11 % strongly agreed and 59 % of students agreed that they gained insight into citizen science; and 9 % strongly agreed and 62 % agreed that they were contributing towards a globally important project (Noone et al., 2019). In return, many of the stations that had incorrect location coordinates were in regions of the world with a sparsity for climate data such as South-East Asia and South America (Noone et al. 2019). The sheer amount of work and logistical difficulties that accompanies data rescue was overcame with the help of the students as the same work undertaken by the few service members available in ICARUS would have taken four to five months to complete (Noone et al., 2019).

In another project, undergraduate students were asked to transcribe more than 1,300 station years of daily precipitation data and associated metadata across Ireland over the period 1860–1939 (Ryan et al., 2018). Of the students who undertook this assignment 58% strongly agreed and 40% agreed that the project provided insights into the process of data rescue, 44% strongly agreed and 47% agreed that they had contributed to improving understanding of rainfall trends in Ireland, and 55% strongly agreed and 39% agreed that the project gave them an appreciation of the role of historical data in climate research (Ryan et al., 2018). This feedback indicates that these classroom-based projects were successful in terms of educational outcomes for the students (Ryan et al., 2018) and in terms of the trust gained by service members in ICARUS that undergraduate students can carry out data rescue projects in an accurate and timely manner.

3. Data and Methodology

3.1 Data

3.1.1 Source of data

The first process in this project was to get an understanding of the history of the ACMAD collection. The provenance of the ACMAD collection used in this project is as follows. Weather stations contained in the collection are in former Sub-Saharan African colonies of France, Portugal, Belgium and the United Kingdom. They observed atmospheric data throughout the twentieth century with some stations recording as far back as the late nineteenth century. The data was recorded on paper forms. In the 1980s and 1990s, the Royal Meteorological Institute of Belgium microfilmed as much climate data that they could from National Meteorological Services in Sub-Saharan Africa. The result of this data rescue is as follows:

- 1633 microfilms from 36 countries
- 5507 microfiches jackets from 7 countries

Stations are also included from island nations in the Atlantic and Indian Oceans including Sao Tome and Principe, Madagascar, Comoros and the Seychelles.

Due to the fragility of the microfilms and microfiches containing the climatic data, a project was carried out in 2021 to image the data contained in the two mediums. Four million images were estimated to have been taken. Access to these images were provided by Dr. Hans Hersbach and were accessed on the ecgate system, a Linux cluster operated by the ECMWF.

The images contained in the collection include those of front matter inventories of stations from most of the countries. Front matter documents contain fields of information that describe the content and the context of the whole collection. The fields of information contained in the front matter inventories discovered in ACMAD include the names of the stations, their inclusive dates and the types of observations they recorded including synoptic observations, climatic observations, rainfall observations, diverse observations and water/river levels. For the purposes of this project, it was decided that synoptic, climatic, rainfall and diverse data would be prioritised.

Images of the forms used to record the observed data are also contained in the ACMAD collection. These forms contain fields of information such as the names of the stations, the stations number, the inclusive dates, times of observation and the types of climate variables observed.

Before starting the project, the following details were provided. Senegal was identified as a country with records of long-term value with observations being recorded as far back as the mid-nineteenth century. Former British colonies didn't have data that predated the 1950s, while there was no data from colonies of the former German Empire.

3.1.2 Existing Inventories

In 2021, Dr. Simon Noone of ICARUS was provided by Dr. Rick Crouthamel numerous front matter inventories of historical climatological observations recorded in Sub-Saharan countries. These inventories were in pdf format and contained fields of information that also described the content and context of the data observed in each country. These include the names of stations, the end and start dates of the observations and the types of data that were observed at each station, the same as what was found on the front matter inventories in ACMAD. Dr. Noone used these fields to create a new master inventory on a spreadsheet, inputting the data manually. After analysing what existed in the ACMAD collection, we were confident that what Dr. Crouthamel provided Dr. Noone in 2021 equated to data that existed in the ACMAD collection. These inventories could therefore be used in the process of identifying unique data held in the ACMAD collection.

3.1.3 Chosen Countries

The countries of Angola, Benin-Dahomey, South Africa and a file titled Sahel, were identified as having no front matter inventories of their weather stations and therefore access to images of their forms on ecgate was required. These forms contain observations recorded at each weather station which are required to create the inventories for these countries.

Front matter inventories detailing stations in Gabon, Guinea, Guinea-Bissau, Lesotho, Tanzania, Uganda, Zaire, Zambia and Zimbabwe were found in the ACMAD collection. However, these countries were not included in the front matter inventories provided by Dr.

Rick Crouthamel. Accessing the images of the front matter inventories saved in the ACMAD collection would be required so that these countries could be added to the master inventory created by Dr. Noone.

Finally for the identification of unique data stored in the ACMAD collection, the countries of Lesotho and Côte d'Ivoire were selected as examples of this process for this thesis.

3.2 Methodology

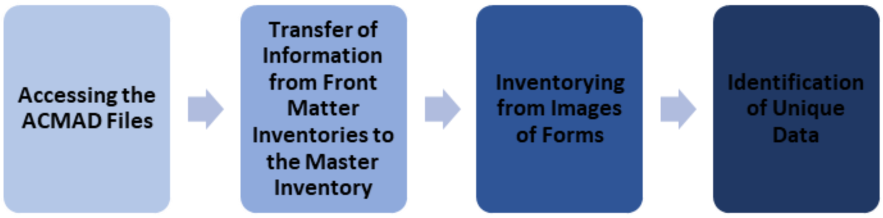


Figure 3:The order of actions carried out during this project

Once the data being inventoried was understood the next step was to plan how to carry this out. As mentioned, nine countries had front matter inventories stored in ecgate that needed to be transferred to the master inventory being created by Dr. Simon Noone. As well as this, the creation of inventories for the four countries in the ACMAD collection that did not have existing front matter inventories stored in the ecgate system needed to be completed. These two methods of creating inventories will help complete the aim to "complete new inventories to enable further data rescue".

There was also the need to identify unique data in the collection to prevent the risk of duplicating work that was carried out already elsewhere. To prevent this, a comparison needs to be made between the inventories created for countries in this project and existing inventories created from previous projects on Sub-Saharan African countries. Inventories from the GHCND dataset, the UK Met Offices HadISD dataset, and the NCDCs dataset was used for comparison to help identify unique data in the ACMAD collection for this thesis. These three steps will be explained further in this section.

3.2.1 Accessing the ACMAD files

Before the inputting of information into the inventories could begin, there was a short period of time needed to learn how to access the ACMAD files on the ECMWF ecgate system. This involved downloading a shell computer program into which suitable commands were entered to log into ecgate. Once logged in further commands were entered which allowed the files of the countries in the ACMAD collection to appear. Once the name of a country's file was known another command was entered to transfer the file to a local disk space named $SCRATCH where the images within the file could be downloaded. To view the images a viewer named XV had to be downloaded. A final command allowed the images of the forms and the front matter inventories to appear via a window opened by the XV software. It was then possible to browse the images that had been transferred over to the $SCRATCH local disk space.

3.2.2 Transfer of Information from Front Matter Inventories to Master Inventory

Following a comparison with the front matter inventories provided by Dr. Rick Crouthamel in 2021 with the front matter inventories discovered in the ACMAD collection it was discovered that there were nine new countries that existed in the ACMAD collection. Again, these countries were:

- Gabon
- Guinea
- Guinea-Bissau
- Lesotho
- Tanzania
- Uganda
- Zaire
- Zambia
- Zimbabwe

The inventory to be created for these countries would follow the same design as the master inventory created by Dr. Simon Noone when inventorying the countries provided by Dr. Rick Crouthamel. The headings included in the inventory would be the following:

- Name of the station
- Earliest date observed
- Latest date observed

- The type of data observed at each station

To differentiate the types of data observed at each station the following letters were selected as code:

- S=Synoptic Observations
- C=Climatological Observations
- R=Rainfall
- D=Diverse Observations

As information pre 1940 is of particular importance for future digitisation a brief analyses of stations from before this period will also be carried out.

3.2.3 Inventorying from Images of Forms

Upon looking at the files located in the ACMAD holdings, it was noticed that there were four countries that had no front matter inventories of their weather stations either within the ACMAD collection or within the front matter inventories provided by Dr. Rick Crouthamel. These countries were Angola, Benin-Dahomey, South Africa and a file titled Sahel. To create an inventory of these countries stations, the images of forms stored on the ecgate system had to be accessed. Due to the work involved it was decided that I would undertake the inventorying of Angola, Benin-Dahomey, part of South Africa and the file titled Sahel while Dr. Simon Noone would work on part of South Africa. South Africa was by far the largest of the countries to be inventoried and we had to work together to complete it. This involved keeping in close contact with each other in order not to duplicate our work.

When creating the new inventory for the chosen countries, suitable fields of information had to be chosen to be included in the design. It was also important for each inventory to closely mirror the Copernicus Phase 1 C3S Data Rescue Service metadata inventory and registry. Of the fields chosen the following were decided to be considered essential for inclusion. The first of these is the station name. This is the name of the city, town, or geographical feature that the station was named after. It was decided that if the name of a station changed that it would be considered a new station. Many larger cities contained more than one station and the name of the stations helped identify the location of the stations within these urban areas especially if the geographic coordinates of the station were not given.

The second essential field included was the location of the stations. This involved in-putting the latitude and longitude to give an exact location of the weather stations as well as being essential for the creation of maps containing the location of the stations in each country. The latitude and longitude can also help identify if the coordinates given are inaccurate and if further work is needed to fix this.

Start and end dates were also decided for inclusion. As previously explained, the longer the period the station covers, the more important the data collected is for researchers for future analysis. For Sub-Saharan, data recorded in the early twentieth century is particularly valuable. The dates are also important for the identification of unique data that hadn't been digitised before. This process will be explained later.

Due to time limits and the sheer number of images taken of the forms in each country it was not possible to go through each image one by one. It was decided to check every tenth image to get a good indication of the design of the form the data was recorded on, and the types of variables that were observed. This also allowed to get an indication of the quality of the forms, whether the images were clear or too dark, and if there was any damage to the forms. Doing this also allowed to see if there were any chronological irregularities in the order of the images.

Next there is a column for the inclusion of climate variables that were observed at each station. Only observed atmospheric variables were selected for inclusion including precipitation, dew, frost, thermograph observations, dry bulb temperature, relative humidity, maximum temperature and minimum temperature. The times of the observations were also selected as a field in the inventory. This field is important as sub-daily observations are highly sought after for climate analysis and to help with the identification of stations suitable for further data rescue.

A screenshot of each type of form of document was taken when discovered, and a link created to a local folder. To save time it was decided not to do this for every station and instead a note was left to direct the user to a station which used the same form and had a link to that form. The example used as a screenshot for each form was one from an image that had very good quality clarity and was very readable.

Finally, the quality of the images at each weather station was also noted. This is important to help identify suitable material for further data rescue as poor-quality images or images of damaged papers would not be suitable. This helped to complete another aim of this thesis which was to "assess the quality of the images of the fiches and films". The images were described as "high quality", "mixed quality", "poor quality", or "very poor quality". For this paper examples of poor-quality images will be provided.

3.2.4 Identification of Unique Data

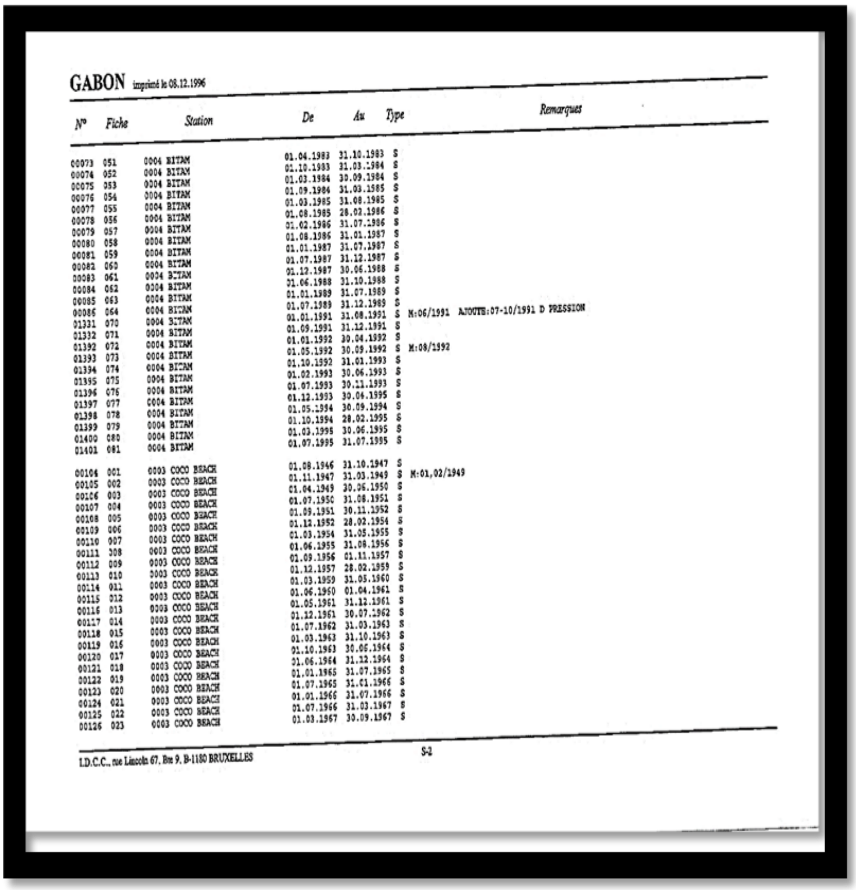
Comparing the data collected from the ACMAD collection with pre-existing data already inventoried is an important process that helps identify new, unique data. Two countries from the ACMAD collection, Lesotho and Côte d'Ivoire, were selected for the purposes of this paper to show how this comparison is conducted. Due to limits of time, these two countries were selected because of the manageable number of stations contained within their collection. Older inventories of climate data from Sub-Saharan countries which contain details of synoptic stations in Sub-Saharan countries were held by Dr. Noone of ICARUS. These include those from the Global Historical Climatology Network Daily (GHCND), the National Climate Data Center (NCDC), and the HadSID inventory of the UK Met Office. Using these inventories, it was possible to see which data was unique in the ACMAD file and how much data was already inventoried. This helped to complete the stated aims to "identify countries that are short on historical climate data" and to "compare with existing inventories to identify unique data". Contact was also kept with other climatologists involved in data rescue who also have access to the ACMAD collection to make sure that work was not also being carried out on Lesotho and Côte d'Ivoire, to help reduce the risk of duplication of work.

4.Results

4.1 Introduction of Findings

The literature review has highlighted how the lack of climatological data, over time and space, is hampering efforts to analyse the changing climate patterns in Sub-Saharan Africa. The process of creating the inventories of the data obtained in the ACMAD files have thrown up some interesting results that will benefit future data rescue efforts and analysis of the Sub-Saharan climate. As there were three steps to rescuing this data it is best to show the results of these processes individually.

4.2 Transfer of Information from Front Matter Inventories to Master Inventory



GABON imprimé le 08.12.1996

N°	Fiche	Station	De	Au	Type	Remarques
00073	051	0004 BITAM	01.04.1983	31.10.1983	S	
00074	052	0004 BITAM	01.10.1983	31.03.1984	S	
00075	053	0004 BITAM	01.03.1984	30.09.1984	S	
00076	054	0004 BITAM	01.09.1984	31.03.1985	S	
00077	055	0004 BITAM	01.03.1985	31.08.1985	S	
00078	056	0004 BITAM	01.08.1985	28.02.1986	S	
00079	057	0004 BITAM	01.02.1986	31.07.1986	S	
00080	058	0004 BITAM	01.08.1986	31.01.1987	S	
00081	059	0004 BITAM	01.01.1987	31.07.1987	S	
00082	060	0004 BITAM	01.07.1987	31.12.1987	S	
00083	061	0004 BITAM	01.12.1987	30.06.1988	S	
00084	062	0004 BITAM	01.06.1988	31.10.1988	S	
00085	063	0004 BITAM	01.01.1989	31.07.1989	S	
00086	064	0004 BITAM	01.07.1989	31.12.1989	S	
01331	070	0004 BITAM	01.01.1991	31.08.1991	S	M:06/1991 AJOUTE:07-10/1991 D PRESSION
01332	071	0004 BITAM	01.09.1991	31.12.1991	S	
01392	072	0004 BITAM	01.01.1992	30.04.1992	S	
01393	073	0004 BITAM	01.05.1992	30.09.1992	S	M:08/1992
01394	074	0004 BITAM	01.10.1992	31.01.1993	S	
01395	075	0004 BITAM	01.02.1993	30.06.1993	S	
01396	076	0004 BITAM	01.07.1993	30.11.1993	S	
01397	077	0004 BITAM	01.12.1993	30.04.1995	S	
01398	078	0004 BITAM	01.05.1994	30.09.1994	S	
01399	079	0004 BITAM	01.10.1994	28.02.1995	S	
01400	080	0004 BITAM	01.03.1995	30.06.1995	S	
01401	081	0004 BITAM	01.07.1995	31.07.1995	S	
00104	001	0003 COCO BEACH	01.08.1946	31.10.1947	S	
00105	002	0003 COCO BEACH	01.11.1947	31.03.1949	S	M:01,02/1949
00106	003	0003 COCO BEACH	01.04.1949	30.06.1950	S	
00107	004	0003 COCO BEACH	01.07.1950	31.08.1951	S	
00108	005	0003 COCO BEACH	01.09.1951	30.11.1952	S	
00109	006	0003 COCO BEACH	01.12.1952	28.02.1954	S	
00110	007	0003 COCO BEACH	01.03.1954	31.05.1955	S	
00111	008	0003 COCO BEACH	01.06.1955	31.08.1956	S	
00112	009	0003 COCO BEACH	01.09.1956	01.11.1957	S	
00113	010	0003 COCO BEACH	01.12.1957	28.02.1959	S	
00114	011	0003 COCO BEACH	01.03.1959	31.05.1960	S	
00115	012	0003 COCO BEACH	01.06.1960	01.04.1961	S	
00116	013	0003 COCO BEACH	01.05.1961	31.12.1961	S	
00117	014	0003 COCO BEACH	01.12.1961	30.07.1962	S	
00118	015	0003 COCO BEACH	01.07.1962	31.03.1963	S	
00119	016	0003 COCO BEACH	01.03.1963	31.10.1963	S	
00120	017	0003 COCO BEACH	01.10.1963	30.06.1964	S	
00121	018	0003 COCO BEACH	01.06.1964	31.12.1964	S	
00122	019	0003 COCO BEACH	01.01.1965	31.07.1965	S	
00123	020	0003 COCO BEACH	01.07.1965	31.01.1966	S	
00124	021	0003 COCO BEACH	01.01.1966	31.07.1966	S	
00125	022	0003 COCO BEACH	01.07.1966	31.03.1967	S	
00126	023	0003 COCO BEACH	01.03.1967	30.09.1967	S	

I.D.C.C., rue Lincoln 67, Bte 9, B-1180 BRUXELLES S-2

Fig 4: An example of front matter material from Gabon used to create the inventory. Shown is the name of the station, the start and end dates and the type of data observed.

30	Kabwe (Broken Hill)	01.01.1932	30.06.1993	S		R	
31	Kafironda	01.10.1966	31.05.1991			R	
32	Kafue Polder	01.07.1957	30.10.1989			R	
33	Kalabo Boma	01.04.1918	31.12.1992			R	
34	Kalene Hill	01.10.1927	30.06.1992			R	
35	Kaoma (Mankoya)	01.09.1913	31.05.1991			R	
36	Kapatu Mission	01.07.1926	30.04.1990			R	
37	Kapiri Mposhi Rail	01.09.1926	31.12.1988			R	
38	Kasama Aero	01.11.1943	31.03.1946	S			
39	Kasama Met	01.05.1933	30.06.1991	S		R	
40	Kasama Town Agri.	01.07.1950	30.04.1991			R	
41	Kasempa	01.01.1938	30.06.1991	S	C	R	
42	Katete Agri	01.07.1950	30.06.1990			R	
43	Katibunga Mission	01.11.1938	30.06.1990			R	
44	Katondwe Mission	01.01.1925	30.06.1991			R	
45	Kayambi Mission	01.10.1926	30.05.1988			R	
46	Leopards Hill Ranch	01.11.1923	30.06.1990			R	
47	Lisitu Bridge	01.11.1960	31.01.1992			R	
48	Livingstone Met	01.11.1948	31.12.1991	S		R	D
49	Livingstone Rail	01.01.1910	30.06.1991			R	
50	Luampa Agri	01.01.1938	30.11.1990			R	
51	Luangwa Bridge	01.07.1938	30.06.1990			R	
52	Lubushi Mission	01.02.1933	31.08.1984			R	
53	Lubwa Mission	01.05.1929	28.02.1985			R	

Fig. 5: A section of an inventory for the country of Zambia created using front matter inventories from the ACMAD collection. Shown is the name of the station, the start and end dates, and the types of data the stations observed.

Analysing the data that is contained in the front matter inventories of the nine countries resulted in some interesting observations. Examples of the inventories created for this analysis can be found in Appendix A. The first is that rainfall was the variable most observed. This backs up previous research that highlighted how rainfall data had the longest record of observation in African countries, cementing its importance to peoples' livelihoods on the continent (Bronnimann et al., 2019). In order, 91% of stations in Zimbabwe recorded rainfall (Table 4), 89% in Zambia (Table 1), 88% in Zaire (Table 3), 87% in Guinea (Table 8), 83 % in Gabon and Guinea-Bisseau (Tables 6 and 7), 78% in Lesotho (Table 2), 75% in Uganda (Table 9) and 18% in Tanzania (Table 5). Despite having many stations, Zaire only had 10 stations that recorded synoptic data. This is only 0.9% of all the stations. Uganda was the country with the fewest stations with 4 while Zaire had the most with 1076.

Zambia (114 Stations)	
Variable	No. of Stations
S	24
C	3
R	102
D	1

Table 1

Lesotho (128 Stations)	
Variable	No. of Stations
S	13
C	33
R	100
H	1

Table 2

Zaire (1076 Stations)	
Variable	No. of Stations
S	10
C	415
R	945
D	27

Table 3

Zimbabwe (107 Stations)	
Variable	No. of Stations
S	9
C	2
R	97
D	2

Table 4

Tanzania (188 Stations)	
Variable	No. of Stations
S	23
C	20
R	34
D	184

Table 5

Guinea-Bisseau (54 Stations)	
Variable	No. of Stations
S	8
C	12
R	45
H	6

Table 6

Table 7

Gabon (116 Stations)	
Variable	No. of Stations
S	18
C	17
R	96
D	14

Table 8

Guinea (109 Stations)	
Variable	No. of Stations
S	25
C	30
R	95
D	5

Table 9

Uganda (4 Stations)	
Variable	No. of Stations
S	3
C	2
R	3
D	2

Tables 1 to 9: The number of stations from each country by type of variable observed.

Gabon

The station with the earliest date observed was Saint Anne which started observing on 1 June 1896. The station with the longest records is found in the station at Lambarene who observed from 1 December 1894 to 31 July 1995. Of the 116 stations inventoried, only 8% started observing data before 1940.

Guinea

In Guinea the station with the earliest observed data is Beyla from 1 March 1897. Beyla also has the longest record in Guinea starting on 1 March 1897 and ending on 31 December 1991. Other stations with long records include Boffa starting on 1 September 1900 and ending on 31 December 1993, Boke from 1 January 1922 to 31 December 1993, Labe Aero from 1 May 1902 to 31 December 1993. Of the 109 stations inventoried, 33% started observing data before 1940.

Guinea-Bisseau

In Guinea-Bisseau the earliest station which started observing is in Mansoa starting on 1 July 1940. Of the 54 stations inventoried, none started observing data before 1940.

Lesotho

In Lesotho the station located in Maseru had the earliest observation beginning on 1 March 1885. Maseru also had the longest record ending its observations on 31 July 1995. Of the 128 stations inventoried, 37% started observing data before 1940.

Tanzania

In Tanzania the earliest station which started observing is in Musoma which started on 1 November 1921. Of the 188 stations inventoried, only 5% started observing data before 1940.

Uganda

The earliest observation in Uganda was made in Gulu on 27 July 1931. Of the stations inventoried, 75% began observing data before 1940. However, this comes with a health warning as there were only 4 stations inventoried from Uganda.

Zambia

The earliest observation in Zambia was made in Abercorn (Mbala) on 1 January 1905. Abercorn also had the longest record ending observations on 30 June 1991. Of the 114 stations inventoried, 59% started observing data before 1940.

Zimbabwe

In Zimbabwe the earliest observation was on 1 July 1890 in the station at Agric Salisbury. The longest record comes from the station at Bulawayo which started observing on 1 July 1897 and ended on 30 June 1990. Of the 107 stations inventoried, 42% started observing data before 1940.

Zaire

In Zaire, a station named Stations Diverse had the earliest observations beginning on 1 January 1907. This is likely a combination of observations from various stations. Of the 1076 stations inventoried, 64% started observing data before 1940.

Zambia (114 Stations)	
Variable	No. of Stations
1900s	1
1910s	14
1920s	28
1930s	25
1940s	11
1950s	18
1960s	14
1970s	1
1980s	1
1990s	1

Table 10

Lesotho (128 Stations)	
Variable	No. of Stations
1880s	3
1890s	7
1900s	7
1910s	4
1920s	5
1930s	21
1940s	5
1950s	9
1960s	22
1970s	39
1980s	6

Table 11

Zaire (1076 Stations)	
Variable	No. of Stations
1900s	8
1910s	64
1920s	106
1930s	516
1940s	171
1950s	211

Table 12

Zimbabwe (107 Stations)	
Variable	No. of Stations
1890s	2
1900s	8
1910s	7
1920s	17
1930s	12
1940s	20
1950s	16
1960s	13
1970s	10
1980s	2

Table 13

Tanzania (188 Stations)	
Variable	No. of Stations
1920s	4
1930s	6
1940s	3
1950s	22
1960s	53
1970s	59
1980s	40
1990s	1

Table 14

Guinea-Bisseau (54 Stations)	
Variable	No. of Stations
1940s	6
1950s	17
1960s	5
1970s	10
1980s	16

Table 15

Gabon (116 Stations)	
Variable	No. of Stations
1890s	4
1900s	3
1910s	0
1920s	0
1930s	2
1940s	13
1950s	45
1960s	11
1970s	3
1980s	13
1990s	22

Table 16

Guinea (109 Stations)	
Variable	No. of Stations
1890s	3
1900s	10
1910s	2
1920s	15
1930s	6
1940s	4
1950s	12
1960s	8
1970s	8
1980s	40
1990s	1

Table 17

Uganda (4 Stations)	
Variable	No. of Stations
1930s	3
1940s	0
1950s	1

Table 18

Table 10-18: Number of Stations per decade from each country

4.3 Creating an Inventory of Countries from Their Forms

Examples of the inventories created for this section can be found in Appendix B.

South Africa

South Africa was by far the largest country to be inventoried with 267 stations recorded from the images that I analysed alone. These were added to a similar number of stations inventoried by Dr.Simon Noone. The date ranges for South Africa start in January 1904 at a station called Pietersburg-WK. The latest date is December 1992 which was recorded at many stations. No geographic co-ordinates were given for the location of the stations in South Africa. There were a couple of stations inventoried that are important to highlight. The stations of Tristan da Vunha, Marion Island, and Gough Island are all located in the Southern Atlantic Ocean in some of the most remote places on the planet and are operated by the South African National Antarctic Programme. Also, a station named SANAE (South African National Antarctic Expedition) forms part of the collection and is located at a base on the continent of Antarctica.

	A	B	C	D	E	F	G	H	I	J	K
1	film_id_sequenc	station_id		other_ det	start_years	end_years	variables	time_ of_observation	frequency	remarks	
2	FILM_SOUTH_AF	595/95	Acorn Hoek		01/01/1941	31/12/1948	weather conditions, t	08.00	1xDAILY	data readable	
3	FILM_SOUTH_AF	595/95	Acorn hoek		01/12/1941	31/01/1948	temp,rainfall, wet bu	08.00 08.30 14.00 20.	3xDAILY	data readable	
4	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1981	31/12/1983	cloud, wind, weather	08.00 14.00	2xDAILY	data readable but so	
5	FILM_SOUTH_AF	35/334	Addo-AGR		01/12/1981	31/01/1983	cloud, wind, weather	08.00 14.00 20.00	3xDAILY	data readable	
6	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1984	31/12/1984	wind, weather condit	08.00 14.00	2xDAILY	data readable	
7	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1984	31/12/1984	cloud, wind, weather	08.00 14.00	2xDAILY	data readable but so	
8	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1985	31/12/1985	wind, weather condit	08.00 14.00	2xDAILY	data readable	
9	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1985	31/12/1985	cloud, wind, weather	14.00 18.00	2xDAILY	mostly blurred image	
10	SOUTH_AFRICA_	035/334	Addo-AGR		01/01/1986	01/12/1988	cloud, wind, visibility,	08.00, 14.00	2XDAILY	poor quality images	
11	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1986	31/12/1986	wind, weather condit	08.00 14.00 20.00	3xDAILY	data readable	
12	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1987	31/12/1987	wind, weather condit	08.00 14.00	2xDAILY	data readable	
13	SOUTH_AFRICA_	003/020	Addo-AGR		01/01/1988	01/12/1988	cloud, wind, visibility,	08.00, 14.00, 20.00	3XDAILY	data mostly readable	
14	FILM_SOUTH_AF	035/334	Addo-AGR		01/01/1988	31/12/1988	wind, weather condit	08.00 14.00	2xDAILY	data readable	
15	FILM_SOUTH_AF	246/613	Aggeneys		01/01/1981	31/12/1983	weather conditions, t	08.00	1xDAILY	data readable but so	
16	FILM_SOUTH_AF	246/613	Aggeneys		01/12/1981	31/01/1983	weather conditions, t	08.00	1xDAILY	data readable	
17	FILM_SOUTH_AF	765/599	Alaska	louis Trich	01/01/1931	31/01/1946	cloud, wind, weather	08.30	1xDAILY	data readable but so	
18	FILM_SOUTH_AF	274/34	Alexanderbaai		01/01/1985	31/12/1985	wind, weather condit	08.00 14.00 20.00	3xDAILY	data readable	
19	FILM_SOUTH_AF	274/34	Alexanderbaai		01/01/1985	31/12/1985	cloud, wind, weather	08.00 14.00 20.00	3xDAILY	mostly blurred image	
20	FILM_SOUTH_AF	274/34	Alexanderbaai		01/01/1986	31/12/1986	wind, weather condit	08.00 14.00 20.00	3xDAILY	data readable	
21	SOUTH_AFRICA_	274/034	Alexanderbaai		01/01/1986	01/12/1987	cloud, visibility, weath	08.00, 14.00, 20.00	3XDAILY	data mostly readable	
22	FILM_SOUTH_AF	274/34	Alexanderbaai		01/01/1987	31/12/1987	wind, weather condit	08.00 14.00 20.00	3xDAILY	data readable	
23	SOUTH_AFRICA_	589/594	Alma		01/07/1985	01/12/1989	cloud, visibility, weath	08.00, 14.00	2XDAILY	data mostly readable	
24	FILM_SOUTH_AF	589/183	Alma Die Laaste Wat		01/07/1985	31/12/1985	wind, weather condit	08.00 14.00	2xDAILY	data readable	

Fig 6. A section of the inventory containing the names of South African stations, their start and end years, the variables observed, the times of observation, and the frequency of those times.

<u>Angola</u>

Angola had 25 stations inventoried with Nova Lisboa being the station with the earliest observations beginning in January 1945. Of the 25 stations, 23 had co-ordinates, 23 recorded data three times a day, 1 which recorded twice a day (Camaxilo) and 1 which only recorded only once a day (Pereira dEca). All the stations observed temperature, atmospheric pressure, relative humidity, cloudiness, insolation, precipitation, wind and weather type. Examples of the inventories can be found in figures 8 and 9 while an example of a form used to create the inventory can be found in figure 7.

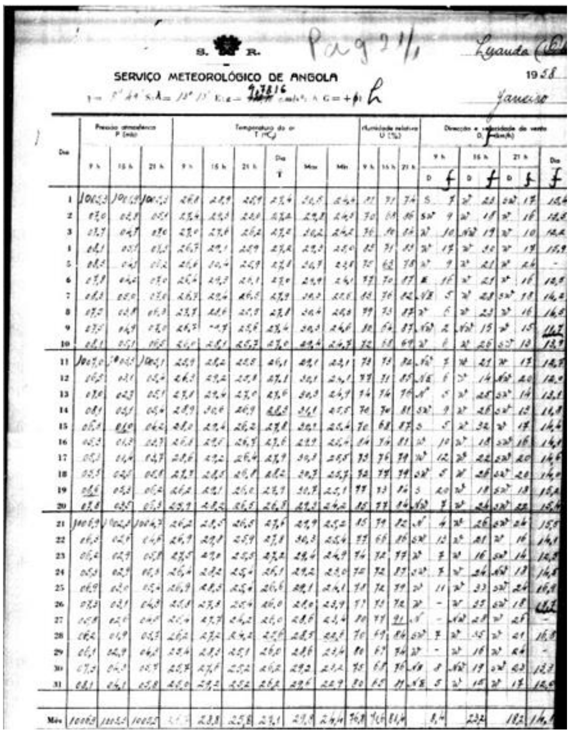


Fig. 7: An example of a form from Angola containing information used to create the inventory. Shown is the name of the station, the times the variables observed, and the types of variable observed (temperature, precipitation etc.).

<u>Benin-Dahomey</u>

Benin-Dahomey had 21 stations inventoried with Whydah/Ouidah being the station with the earliest observations beginning in May 1893. Interestingly the station at Parakou-Aero recorded its observation 7 times a day, every three hours. After some research four stations were discovered to be in the country of Guinea and not Benin-Dahomey. These were Tamara, Tolo, Siguiri, and Seredou. There was one station that could not be properly inventoried due to the poor conditions of its images.

film_id_sequence	station_id	station_name	address details	start_years	end_years
ANGOLA_001_001_001-ANGOLA_001_001_004	8	Ambizete	07°14' S 12°52' E	01/01/1972	31/12/1972
ANGOLA_001_002_001-ANGOLA_001_002_004	7	Baia dos Tigres	16°36' S 11°43' E	01/01/1972	01/12/1972
ANGOLA_001_003_001-ANGOLA_001_003_034	9	Cabinda	05°33' S 12°11' E	01/01/1957	01/12/1973
ANGOLA_001_004_001-ANGOLA_001_004_004	10	Camaxilo	08°22' S 18°56' E	01/01/1972	01/12/1972
ANGOLA_001_005_001-ANGOLA_001_005_026	11	Carmona	07°35' S 15°00' E	01/01/1961	01/12/1972
ANGOLA_001_006_001-ANGOLA_001_006_012	12	Cela	11°23' S 15°08' E	01/01/1961	01/12/1966
ANGOLA_001_007_001-ANGOLA_001_007_036	13	Dundo	07°24' S 20°49' E	01/01/1957	01/12/1973
ANGOLA_001_008_001-ANGOLA_001_008_026	14	Henrique de Carvalho	09°40' S 20°23' E	01/01/1961	01/12/1972
ANGOLA_001_009_001-ANGOLA_001_009_036	15	Lobito	12°22' S 13°32' E	01/01/1957	01/12/1973
001-ANGOLA_001_020_042 + ANGOLA_001_022_001-ANG	5	Luanda	08°49' S 13°13' E	01/01/1958	31/12/1973
ANGOLA_001_021_001-ANGOLA_001_021_036	16	Luso	11°47' S 19°55' E	01/01/1957	01/12/1973
ANGOLA_001_023_001-ANGOLA_001_023_036	17	Malange	09°33' S 16°22' E	01/01/1959	01/12/1973
ANGOLA_001_024_001-ANGOLA_001_024_004	18	Malverina (Mozambique?)	22°05' S 31°41' E	01/09/1961	01/12/1961
ANGOLA_001_025_001-ANGOLA_001_025_036	19	Mavinga	15°50' S 20°21' E	01/01/1957	01/12/1973
ANGOLA_001_026_001-ANGOLA_001_026_036	20	Mocamedes	15°12' S 12°09' E	01/01/1957	01/12/1973
ANGOLA_001_027_001-ANGOLA_001_027_004	21	Negage	07°41' S 15°22' E	01/01/1972	01/12/1973
ANGOLA_001_028_001-ANGOLA_001_038_036	6	Nova Lisboa	12°48' S 15°45' E	01/01/1945	01/12/1973
ANGOLA_001_039_001-ANGOLA_001_039_017	1	Pereira d'Eca		01/01/1957	01/12/1961
ANGOLA_001_040_001-ANGOLA_001_040_004	22	Porto Aboim	10°42' S 13°45' E	01/01/1972	01/12/1972
ANGOLA_001_041_001-ANGOLA_001_041_030	23	Rocadas	16°45' S 14°58' E	01/01/1961	01/12/1973
ANGOLA_001_042_001-ANGOLA_001_042_004	4	Silva Porto	12°23' S 16°57' E	01/01/1972	01/12/1972
ANGOLA_001_043_001-ANGOLA_001_043_028 + ANGOLA	3	Serra Pinto	14°39' S 17°42' E	01/01/1957	01/12/1973
ANGOLA_001_044_001-ANGOLA_001_045_007	2	Sa De Bandeira	14°56' S 13°34' E	01/01/1957	01/12/1973

Fig . 8 First part of an inventory for Angola created using images stored in the ACMAD collection. Shown is the id sequence of each station on the ecgate system, the station id (if known), the co-ordinates of the station (if known), and the start and end dates.

variables	time_of_observations	frequency	remarks
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.01	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00.	2xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	07.00, 13.00. 19.00 (sor	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, relative humidity, cloud, rainfall, weather type	09.00,	1xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable

Fig. 9 Second part of an inventory for Angola showing the variables observed at each station, the times the variables were observed, the frequency of the observations and remarks about the quality of the images

Sahel

The following countries were discovered to be in the Sahel files; Senegal, Niger, French Sudan, Haute Volta (Burkina Faso) and Mauritania. The country of Mali was called French Sudan which was its name before independence in 1960. Within the Sahel files there is 80 stations, 8 in Senegal, 11 in Niger, 38 in French Sudan, 10 in Haute Volte and 13 in

Mauritania. One station in Mali called Tessalit made observations 7 times a day, every three hours. The station with the earliest observation is Rufisque in Senegal beginning in June 1893, however it only observed wind and precipitation.

4.4 Quality of the images

The quality of the images was mixed. Most of the images were perfectly clear and legible. However, several images had white specs dotted across the data (Figure 13). It is unclear if this was caused by the process of imaging the data, degradation of the fiche or film, or if they existed on the paper record originally. Unfortunately, as the paper records were destroyed following the process of transferring the data on to film and fiche, we would have to rule out the first two before confirming if the specs existed on the pages originally. A good number of the images also appeared very dark (figure 12) or appeared to have poor focus (figure 11). Figure 10 shows an otherwise high-quality image that's unfortunately has a grey column running down the page blocking many of the observed data. Again, it is unsure if this is due to the quality of the digitisation carried out on the film and fiche, or if this is the result of degradation of the film over the past thirty years.

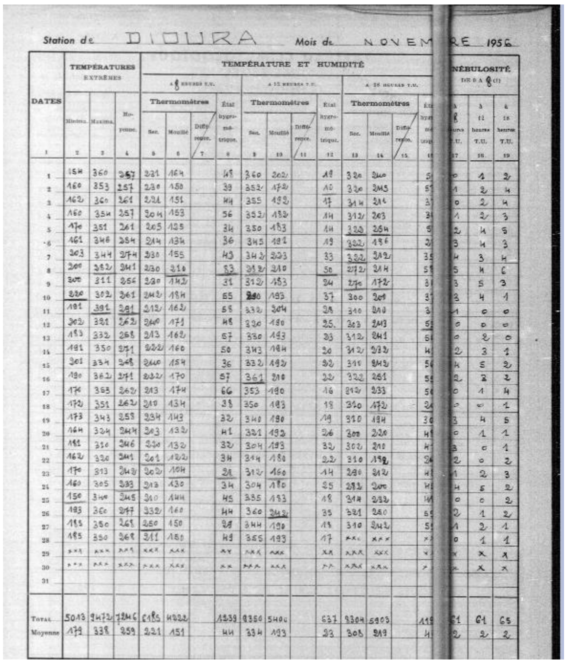


Fig. 10. An image of a form from Dioura, Senegal, with a grey column blocking data

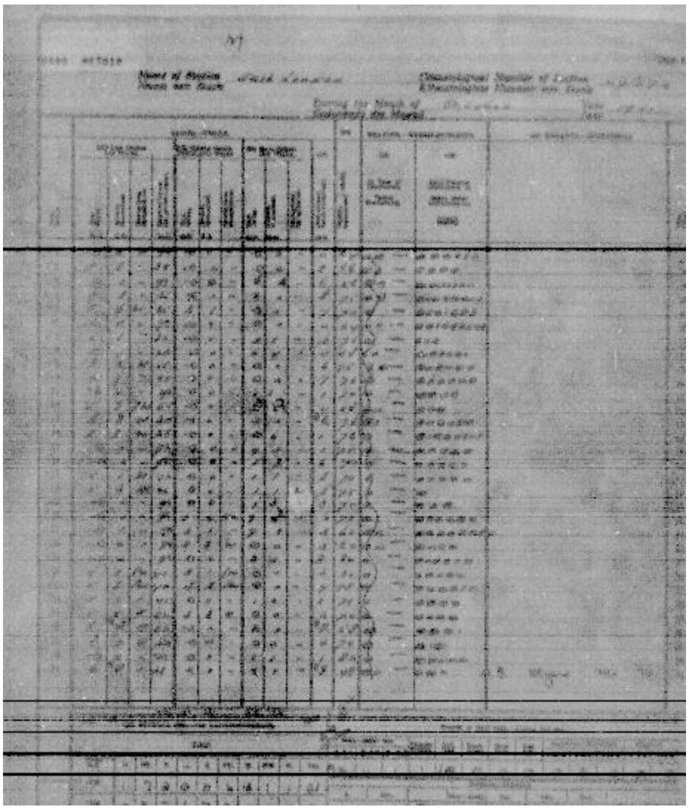


Fig. 11: An image of a form that is out of focus and difficult to read

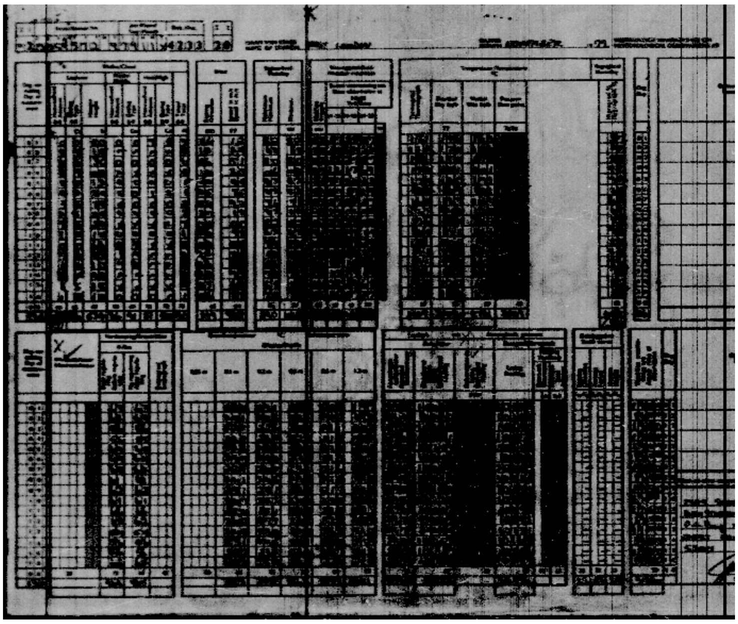


Fig 12. An image of a form that is too dark to read

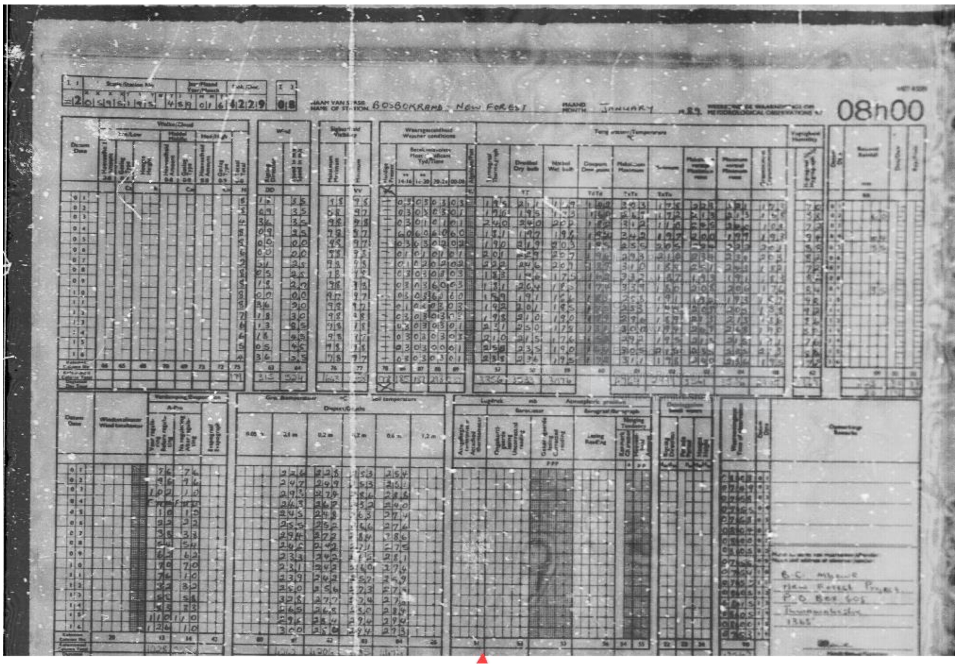

JANUARY
08h00

Fig 13. Example of an image of a form with white specks obstructing data

4.5 Comparison with existing data

Côte d'Ivoire

In the ACMAD collection, there were nineteen stations in Côte d'Ivoire that collected synoptic data. After comparing the date ranges of stations in our inventory with pre-existing inventories from Côte d'Ivoire, it was discovered that there were four new stations in the ACMAD collection not yet inventoried. These stations are Abidjan Aero located in the city of Abidjan in the south-east of the Côte d'Ivoire, Agboville also in the southeast just north of Abidjan, Bingerville a suburb of Abidjan, and Grand Bassam, another coastal suburb of Abidjan. The station in Grand Bassam may also be of particular importance as this has the earliest date of observation beginning in October 1898 and ending in September 1921.

Of the other stations, all but one had new data that did not exist in pre-existing inventories. The station in Korhogo is of particular interest as the synoptic data located in the ACMAD collection adds 68 extra years of new data starting in 1905. The existing data covered the years 1973 to 2021. Korhogo is in the north of the country.

It was also noted that in the existing data there is a station named Yamoussoukro, but in the ACMAD data there are two stations named Yamoussoukro Ville and Yamoussoukro Aero. The dates covered by the two stations from the ACMAD collection cover the years 1978 to 1994. In comparison an inventory from the GHCND had a station called Yamoussoukro covering the years 1978-2017, the HadISD inventory had Yamoussoukro covering the years 1979-2013, while the GSOD inventory had Yamoussoukro covering 1978-2012. The start years matching up may suggest that the stations Yamoussoukro Ville and Yamoussoukro Aero may be the same station named Yamoussoukro in the GHCND, HadISD, and GSOD inventories but this will need to be confirmed.

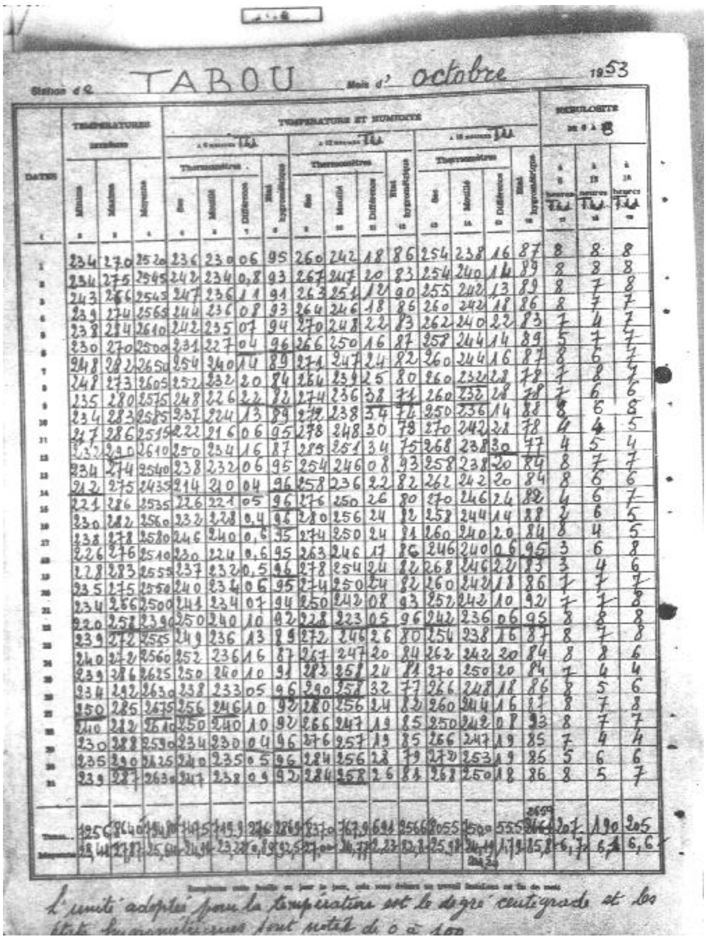


Fig. 14. High quality image of observations from the Tabou weather station.

Images from the stations covering the periods of unique data were also observed to determine their quality and suitability for future digitisation. Due to the large number of images every tenth image was observed. Following this it was determined that every station had high quality images taken of their data and would be suitable for further digitisation. A more in-depth analysis of the images will have to be carried out to confirm this. Figure 14 shows an example of a high-quality image available from the station in Tabou, south-west Côte d'Ivoire.

<u>Lesotho</u>

Lesotho contains 13 stations in the ACMAD collection that observed synoptic data. Following a comparison of our inventory with existing inventories of synoptic stations in Lesotho, it was found that there are 8 new stations in ACMAD that had not being inventoried before. These stations are named Dunelin, Ox-Bow, Glen College, Mapholaneng, Maseru Airport, Mohale-Hoek, Semonkong and Wimburg, An issue was discovered with the stations of Dunelin, Glen College, Ox-Bow and Wimburg as they had no co-ordinates given to identify their location. A search for these locations on Google Maps gave back no results. After inquiring with Dr. Stefan Grab, who has worked on rescuing data in Lesotho, it was confirmed that Ox Bow, Mapholaneng, Maseru Airport, Mohales Hoek, Quachas Nek and Semonkong were in Lesotho while Dunelin and Glen College were in South Africa. The station of Wimburg could not be found however Stefan Grab did confirm that there was a station named Winburg in South Africa and that Wimburg may be a spelling mistake. After inspecting the South African inventory, that I created along with Dr. Noone, the stations of Dunelin, Glen College, and Winburg were found thereby confirming Dr. Grabs suspicions.

Four stations which existed in previous inventories contained unique data. These were Mokhotlong, New Amalfi Station, Waterford and Qach-Asnek. Again, an issue was discovered with the stations in Waterford and New Amalfi as no co-ordinates were given to provide their location in Lesotho. Their names also don't appear when searched for on Google Maps or the Google search engine. After inspecting our South African inventory, the Waterford and New Amalfi stations were found meaning that these too are in South Africa.

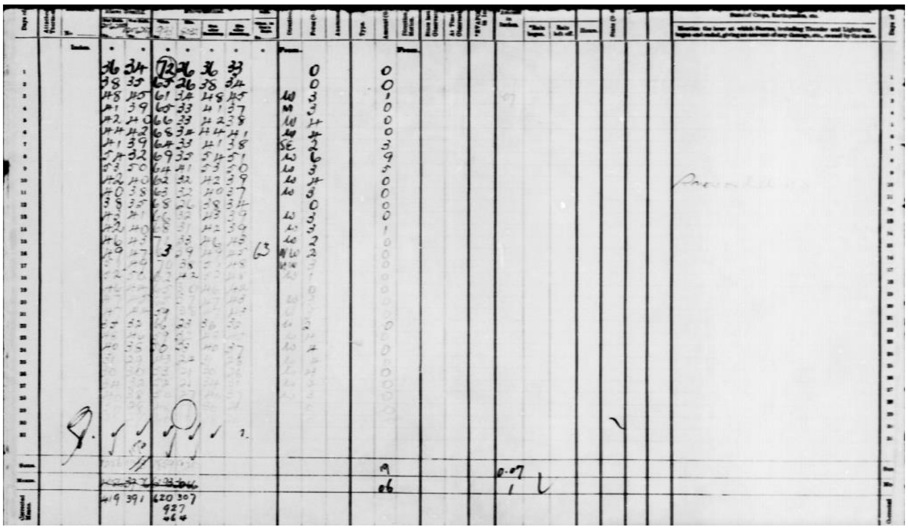


Fig.15. Image of instrumental data recorded at Qachasnek station, Lesotho

Like Côte d'Ivoire, the quality of the images of the unique data is of a really good quality. However, some issues were identified. Figure 12 shows an image of a form taken from the Qachasnek station, Lesotho. While the image is clear and a lot of the data is legible, the data begins to fade further down the page. The form is also missing some headings which may be because of an error during the imaging of the form, or due to damage inflicted on the document.

5. Discussion

5.1 Creating the Inventories

Following the completion of the inventories created from the images of the front matter inventories and the images of the forms. From the front matter images the percentage of stations from each country that started observing data before 1940 is particularly interesting as data from this period in African countries is scant. The fact that 59% of stations in Zambia and 64% in Zaire began before this date means that these countries may be of particular focus when it comes to digitising their data in future. Also, as rainfall is the most observed variable across all the stations this backs up previous opinions about how important rainfall is to the people of Sub-Saharan Africa.

In the inventories created using images of their forms, three of the four regions, South Africa, Benin-Dahomey and Sahel, had stations that began observing before 1940. Benin-Dahomey and Senegal (within the Sahel file) had stations going back to the 1890s. There is a great opportunity for these stations to be digitised in future due to their age.

5.2 Discovering Unique Data in other countries

While Lesotho and the Côte d'Ivoire were selected for the detection of unique data contained within the ACMAD collection, there will be a need to do this for every other country inventoried also. This will bring up some challenges as the amount of time and resources that will be required to do this will be large. However, as the identification of unique data in Lesotho and the Côte d'Ivoire has proven, there is new and potentially important information contained in the ACMAD collection waiting to be discovered. This can be added to the data inputted into older inventories. The potential for the discovery of brand-new stations that are waiting to be inventoried for the first time is also quite exciting. A process will have to be carried out to select which countries are the most suitable and the most important to compare with existing inventories. Some countries, particularly those located along the African coastline, while still in need of further work, have had a considerable amount of work carried out inventorying and digitising their instrumental climate data. More inland stations may therefore be prioritised. Contact with other climatologists carrying out digitization projects using the ACMAD collection will also need to be maintained to find out which countries have already had work carried out on their data to prevent duplication of work.

5.3 The Quality of the Images

As was revealed in the results section, some of the images observed to create the inventories were poor. However, as was declared in the methodology section, it was simply not possible to observe every single image from the countries inventoried for this project. There are millions of images of forms contained within the ACMAD collection and this presents a problem for prioritizing future digitisation activities. Prioritizing digitisation involves rating the quality and completeness of each image. There will be several questions to be answered as part of this process such as “is the image complete?” and if part of the form imaged is missing is this down to poor cropping of the image or is this down to damage to the document? There is also a need to identify if the text in the image is legible and if not, why? Creating a list of poor-quality images could allow for the documents to be imaged again to see if the quality improves. Other questions that may need answering are what type of data does the image show (meteorological/hydrological, etc.) and if the data is instantaneous observations, daily summaries, or monthly summaries. Ideally there would be two people observing each image to determine its quality. However, as the ACMAD collection contains millions of images across 43 countries, it will mean that some outside help will be required to complete this process.

5.4 Geo Location

It is recommended to create maps of countries in the collection showing the location of their stations to identify if they may need to have their co-ordinates fixed. As mentioned in the literature review, a similar project was carried out by ICARUS with undergraduate geography students in Maynooth University. There may be an opportunity to carry out a similar assignment in the future again. Like the regions of the world where the co-ordinates of stations were fixed by students, the African countries located in ACMAD suffer from a lack of historical climate data so fixing this issue would be of high importance. It was noticed on some of the forms that some former colonies of the French Empire took their co-ordinates from a point in Paris. The zero-reference line is internationally recognized as the longitude line that passes through the Royal Observatory in Greenwich, England. Creating a map of the stations inventoried from these former French colonies may result in their locations being slightly skewed.

5.5 Citizen Science

As was mentioned earlier in the literature review, citizen science has been used as a method to process the large amount of climate records that require rescuing. While the work carried out as part of this thesis helped complete the creation of inventories for each country in the ACMAD collection, there is still a large amount of work to be completed. As already mentioned in this section, the analysis of other inventories to help identify unique data is one activity that needs to be completed. Also, the identification of suitable stations for future digitization of observed data needs to be carried out. This requires analysing the images from each station to diagnose any damage that exists that makes observing the data difficult or impossible. Some images may also be too dark to observe the data again making it impossible to digitise in the future. Given the location of ICARUS on the campus of Maynooth University and previous experience working with students, this method of citizen science could be used to carry out future work.

5.5.1 University Students

University students have been identified as a group that can contribute towards the data rescue process. Given that thousands of images exist in the ACMAD collection it would be impossible for any one person or small group of people to complete the work in a timely manner given the resources available. ICARUS' location on the campus of Maynooth University, Ireland, means that there is an opportunity to work with undergraduate students to complete the above actions. Doing so can help give students an important insight into processes underpinning research as well as allow scientists gain access to otherwise unobtainable information (Ryan et al., 2018), (Phillips et al., 2018). Studies have found that there is little difference between student and volunteer participants based upon a skill metric (Phillips et al., 2018). Therefore, cooperating with the University to allow students contribute towards identifying suitable stations for future rescue is a suitable way of overcoming the logistical difficulties that the size of the ACMAD collection presents.

As mentioned previously, inventories produced for The Global Land and Marine Observations Database contained weather stations that had incorrect location coordinates. The coordinates of many of the stations recorded as part of this project were included in the inventories. These coordinates should be checked to see if they correspond with the location of the stations on a map. If not, then the process of finding the proper location should be carried out.

5.5.2 Second Level Students

There may be an opportunity to allow secondary school students take part in future work on the ACMAD collection. In Ireland, the final two years of secondary level education is dedicated towards achieving a qualification called the Leaving Certificate. Geography is an optional subject that can be chosen to obtain this qualification. To explain how working on the ACMAD collection can be beneficial to secondary students, a brief explanation of relevant information from the Leaving Certificate geography syllabus is required.

The Leaving Certificate Geography syllabus contains ten aims that each student should aspire to achieve by the end of the course. Working on the ACMAD collection could help students achieve two of these aims. They are:

(i) "To promote an awareness of the spatial, structural, and temporal patterns of environmental phenomena, both physical and human, at a variety of scales, and to realise that these patterns can change with time".

(ii) "To develop a variety of geographical skills which can be applied to the world of work and to many other aspects of life". (Curriculum Online, 2022)

There are also six key skills that the students should learn by the time they complete their course. They are:

(i) Information gathering skills
(ii) Information and communication technology
(iii) Presentation and communication skills
(iv) Investigative skills
(v) Social skills (working in groups, following instructions etc.)
(vi) Evaluation skills (Curriculum Online, 2022)

Again, working on identifying suitable material to be digitised from the ACMAD collection under the supervision of a qualified professional can help the students develop these six key skills. Finally, there are three core units that higher and ordinary level students must complete as part of the geography syllabus. One of these core units is titled “Geographical Investigation and Skills” (Curriculum Online, 2022). Further geographical skills are expected to be developed in this core unit including

(i) Data Collection
(ii) Statistical analysis
(iii) Information technology applications
(iv) The use of documentary sources
(v) Report planning
(vi) Analysis and presentation of results

5.5.3 Transition Year

There is also an option to work with Transition Year students complete further work on the ACMAD collection. In Ireland, Transition Year is an optional year in between the completion of the third year of secondary school (Junior Certificate), and the beginning of the final two years of secondary school (Leaving Certificate). Topics to be studied during this year are different in each school. According to the NCCA (National Council for Curriculum and Assessment) “schools may create new units or adapt a unit that has been developed by another school or organisation” and also that the “school can take into account the possibilities offered by local community interests” (NCCA, 2022). These guidelines open the possibility of creating a unit suitable for Transition Years students where the students can learn the importance of historical climate data, identify unique data for digitisation, and inspect images to detect damage or poor image quality that makes the digitisation of data impossible. As mentioned in previous examples of citizen science, this allows scientists greater access to historical climate data and gives the students a good understanding of climate data collection as well as developing skills in teamwork, analysis, information technology applications, report planning and the presentation of results. This will prepare them for future work for the Leaving Certificate in a variety of subjects.

6. Conclusion

The completion of the work required for this thesis means that there is now an opportunity to prioritize which countries and stations are to be analysed for the identification of unique data and digitisation. The processes carried out for this thesis offers a glimpse into how this can be done.

The quality of the images presented in this paper are but a small percentage of the total amount of images in the collection. A more in-depth analyses will identify which stations have the highest quality images for digitization. The geolocation of the stations will also help improve the accuracy of their addresses as well as provide climate scientists an opportunity to select stations in regions that have a severe lack of data. Finally, the analysis of the types of meteorological data observed by the stations and the length of time periods that the observations took place will further help the data rescuers decide which regions and stations should be focused on first.

The creation of the inventories for countries that had front matter inventories in the ACMAD collection confirmed previous research that rainfall was the most common type of meteorological data that was observed. Given the dependence many Africans have for reliable rainfall to grow crops, this shows how important rainfall is for the livelihood of African populations.

The analysis of stations with synoptic data in the inventories that we created with older inventories from Côte d'Ivoire and Lesotho shows how much unique synoptic data exists in the ACMAD collection. Carrying out the same analysis on stations which observed climatological and rainfall from these countries, as well as in every other country in the collection, is an important process. The unique synoptic data discovered in Lesotho and Côte d'Ivoire highlights the amount of unique data that potentially exists in the rest of the collection.

Finally, the amount of time and resources required to complete these objectives poses a problem. The successful use of students by ICARUS to help in previous projects in return for credits for the undergraduate degree has proven useful for both the students and the climate scientists. There is also an opportunity to inform interested students about the importance of historical climate data and the potential for them to use the knowledge and skills gained in future education and employment.

As the title of this thesis suggests, the work carried out to inventory the countries contained in the ACMAD collection is just the beginning of a journey towards the completion of a much larger digitisation project. Completing the digitisation of the ACMAD collection offers an opportunity to make available rare data from the late nineteenth and early twentieth centuries, a period that we still have much to understand about Sub-Saharan Africa’s climate. The data can be used for research in model-based reanalysis and the re-evaluation of past weather patterns. This research will give us a more accurate picture of how much the climate in Sub-Saharan Africa has changed in the last century. This can help improve decision making as the countries and people of Sub-Saharan Africa attempt to adapt to their changing climate. Various African stakeholders will also be able to provide better climate services such as online applications and consultancies.

The fragile nature of the microfilm and microfiche mediums means that there is a real possibility that the data from the stations inventoried in this collection could have been lost forever. Their rescue and future digitization of the data means that there is a real opportunity to gain knowledge about the climate of a continent whose poor meteorological records has meant that reanalysis of the climate in one of the most vulnerable regions on the planet has proven difficult.

7. Appendices

7.1Appendix A: Inventories created from Front Matter Inventories

Gabon

	Station	Start Date	End Date	Type	Type	Type	Type	
2	Abanga	01.11.1959	31.12.1983			R		
3	Akieni	01.02.1957	31.12.1993			R		S=Synoptic Observations
4	Akok	01.08.1992	30.06.1995			R		C=Climatologocal Observations
5	Aloumbe	01.08.1959	30.04.1964			R		R=Rainfall
6	Awua-C/S Bitam	01.01.1993	31.12.1994			R		D=Diverse Observations
7	Ayem	01.11.1959	30.09.1968			R		
8	Bakoumba	01.11.1961	31.05.1995			R		
9	Bakwaka	01.07.1994	31.05.1995			R		
10	Batouala	01.03.1957	31.05.1995			R		
11	Bayadi	01.09.1992	31.10.1992			R		
12	Belvedere	01.01.1995	28.02.1995			R		
13	Bitam	01.05.1946	31.07.1995	S		R	D	
14	Beach	01.08.1946	31.07.1995	S				
15	Booue	01.01.1948	31.12.1983		C	R		
16	Coco Beach	01.02.1953	30.11.1990				D	
17	Cap Esterias	01.08.1947	30.04.1977			R		
18	Cap Lopez	01.10.1956	30.11.1974			R		
19	Centreville	01.07.1993	30.04.1994			R		
20	Comilog Moanda	01.12.1988	31.05.1995			R		
21	Dibwangui	01.03.1964	31.05.1974		C			
22	Djidji	01.02.1957	31.01.1995			R		
23	Donguila	01.10.1992	31.05.1995			R		
24	Doussala	01.10.1992	30.11.1995			R		

Zambia Zimbabwe Lesotho Tanzania Uganda Gabon Guinea Guinea-Bisseau Zaire

Guinea

	Station	Start Date	End Date	Type	Type	Type	Type	Type	
2	Baguinet	01.06.1982	31.12.1987				R		S=Synoptic Observations
3	Balabory	01.08.1972	31.10.1974				R		C=Climatologocal Observations
4	Balaki	01.03.1986	30.11.1986				R		R=Rainfall
5	Banguigny	01.01.1985	31.12.1987				R		D=Diverse Observations
6	Baring	01.01.1989	31.12.1993		C				
7	Benty	01.07.1937	31.12.1987				R		
8	Beyla	01.03.1897	31.12.1991		C		R		
9	Bintimodia	01.05.1982	30.11.1987				R		
10	Bissikrima	01.02.1922	31.03.1970				R		
11	Bodie	01.06.1987	31.12.1987				R		
12	Boffa	01.09.1900	31.12.1993		C		R		
13	Bokaria-Salguida	01.03.1982	30.09.1990		C		R		
14	Boke	01.01.1922	31.12.1993	S			R		
15	Boola	01.10.1987	31.12.1987				R		
16	Bordo	01.01.1989	31.12.1992		C				
17	Camayenne	01.01.1903	31.01.1963				R	D	
18	Conakry	01.08.1897	31.12.1989	S	C			D	
19	Conakry Chemin De Fe	01.01.1903	31.12.1907	S					
20	Conakry-Gbessia Aero	01.01.1945	31.12.1994	S					
21	Conakry Port	01.01.1942	31.12.1992	S	C		R		
22	Coyah	01.10.1934	31.12.1986				R		
23	Dabola	01.03.1922	31.12.1987				R		
24	Dalaba	01.02.1907	31.12.1993	S	C		R		

Zambia Zimbabwe Lesotho Tanzania Uganda Gabon Guinea Guinea-Bisseau Zaire +

Guinea-Bisseau

Station	Start Date	End Date	Type	Type	Type	Type	Type	
Bafata	01.09.1953	31.08.1988	S		H		D	
Bambadinca	01.07.1978	31.07.1989				R		S=Synoptic Observations
Bancacia	01.08.1978	31.10.1980				R		C=Climatologocal Observations
Batio	01.05.1987	31.10.1988				R		R=Rainfall
Bedanda	01.08.1984	30.04.1989				R		D=Diverse Observations
Beli	01.07.1978	30.11.1988			H	R		
Bissau	01.01.1958	31.12.1989	S			R	D	
Bissau Aeropı	01.07.1941	31.12.1989	S					
Bissora	01.01.1956	30.11.1989				R		
Bolama	01.07.1952	31.12.1989				R		
Buba	01.01.1940	31.12.1986		C		R		
Bubaque	01.07.1940	31.01.1975	S	C				
Bula	01.01.1953	31.12.1968				R		
Buruntuma	01.01.1957	31.03.1990				R		
Caboxanque	01.05.1988	30.09.1988				R		
Cacheu	01.01.1953	31.12.1967				R		
Cactne	01.01.1955	31.11.1971	S	C		R		
Cade	01.05.1979	30.11.1986			H	R		
Caio	01.06.1953	31.12.1984	S	C				
Cantchungo	01.01.1975	31.12.1988				R		
Catio	01.01.1946	31.10.1986	S	C		R		
Contubo	01.01.1986	31.12.1986				R		
Dandum	01.06.1978	31.10.1984				R		

Zambia Zimbabwe Lesotho Tanzania Uganda Gabon Guinea Guinea-Bisseau Zaire +

Lesotho

Station	Start Date	End Date	Type	Type	Type	Type	
Arcadia	01.02.1922	31.03.1940			R		
Butha Buthe	01.01.1893	31.08.1989		C	R		
Berlin	01.01.1945	31.07.1959			R		
Bokong	01.10.1932	31.05.1958			R		
Blue Mountain Pass-	01.08.1975	30.09.1995			R		
Brith	01.02.1931	31.12.1944			R		
Caledonspoort	01.12.1965	31.12.1980			R		S=Synoptic Observations
Clarens	01.11.1920	31.12.1980			R		C=Climatologocal Observations
Clifton	01.11.1906	30.09.1926			R		R=Rainfall
Comtemplative Com	01.07.1979	31.12.1995			R		D=Diverse Observations
Botsabelo	01.01.1972	30.11.1995			R		
Drakensberg	01.02.1940	31.05.1943		C			
Dunblane	01.11.1910	30.11.1962			R		
Dunelin	01.11.1905	31.03.1918	S				
Dwarskloop	01.01.1907	31.08.1962			R		
Fort Hartley	01.03.1965	30.11.1995			R		
Fouriesburg	01.01.1929	30.06.1948		C			

Zambia Zimbabwe Lesotho Tanzania Uganda Gabon Guinea Guinea-Bisseau Zaire +

Tanzania

Station	Start Date	End Date	Type	Type	Type	Type	
Alliance	01.02.1972	31.05.1972				D	
Amani	01.01.1958	31.11.1990				D	
Arusha	01.02.1959	31.12.1990	S		R	D	
Arusha Airport	01.01.1961	31.12.1990			R	D	
Arusha Chini	01.07.1968	31.12.1981				D	
Arusha Plant	01.01.1958	31.12.1981				D	
Arusha Tpri	01.01.1966	31.12.1990				D	S=Synoptic Observations
Bagamoyo	01.10.1959	31.05.1960				D	C=Climatologocal Observations
Bahi	01.01.1966	31.12.1990				D	R=Rainfall
Basotu	01.01.1976	31.12.1989				D	D=Diverse Observations
Biharamulo	01.01.1978	31.08.1989				D	
Bihawana	01.09.1987	31.05.1990				D	
Buiko	01.01.1980	31.09.1988				D	
Bukoba	01.08.1927	31.12.1990	S	C	R	D	
Bulongwa	01.01.1982	31.12.1985				D	
Bustani	01.09.1971	31.01.1979				D	
Bwanga	01.01.1970	31.03.1990				D	

Zambia Zimbabwe Lesotho Tanzania Uganda Gabon Guinea Guinea-Bisseau Zaire +

Uganda

Station	Start Date	End Date	Type	Type	Type	Type	
Different Stations	01.01.1951	31.07.1993		C	R	D	
Entebbe	01.01.1936	02.10.1993	S	C	R	D	
Gulu	27.07.1931	31.12.1977	S		R		
Lira	01.01.1936	31.12.1939	S				
							S=Synoptic Observations
							C=Climatologocal Observations
							R=Rainfall
							D=Diverse Observations

Zaire

Station	Start Date	End Date	Type	Type	Type	Type	
Aba	01.10.1920	30.04.1960		C	R		
Abiengama	01.03.1935	30.04.1960		C	R		S=Synoptic Observations
Abimva	31.12.1938	31.05.1948			R		C=Climatologocal Observations
Abumonbazi	01.01.1936	28.02.1942		C	R		R=Rainfall
Adi	01.01.1938	30.11.1957			R		D=Diverse Observations
Adia	01.07.1929	30.04.1953			R		
Adusa	01.07.1953	30.09.1953					
Agameto	01.10.1933	31.06.1959		C	R		
Ageau	01.09.1959	30.04.1960			R		
Aim Adi	01.09.1938	31.12.1939			R		
Aketi	01.04.1932	30.04.1960		C	R	D	
Ala	01.11.1959	30.04.1960		C			
Alimasi	01.02.1957	31.12.1959			R		
Alimba	01.11.1937	31.10.42			R		
Amadi	01.01.1921	30.04.1960			R		
Ambaki	01.01.1949	30.04.1960			R		
Amekupi	01.01.1945	30.09.1949			R		
Ango	01.01.1937	30.06.1959		C	R		
Angodia	01.04.1938	30.04.1960			R		
Angumu	01.08.1952	31.05.1957		C			
Ankoro	01.12.1931	30.04.1960					
AO I	01.01.1938	31.07.1952			R		
Api	01.01.1916	30.06.1932		C	R		

Zambia Zimbabwe Lesotho Tanzania Uganda Gabon Guinea Guinea-Bisseau Zaire +

Zambia

	A	B	C	D	E	F	G	H	I	J
1	Station	Start Date	End Date	Type	Type	Type	Type			
2	Abercorn (Mbala)	01.01.1905	30.06.1991	S		R				
3	Broken Hill (Kabwe)	01.01.1938	01.08.1993	S		R				
4	Chasefu Mission	01.10.1926	30/06.1974			R				
5	Chavuma Mission	01.08.1927	30.06.1993			R				
6	Chibote	01.07.1926	30.05.1990			R				
7	Chifwefwe (Mkushi Agri.)	01.11.1933	31.01.1992			R				
8	Chilonga Mission	01.01.1939	30.06.1991			R				S=Synoptic Observations
9	Chilubula	01.01.1939	30.06.1991			R				C=Climatologocal Observation
10	Chimpembe	01.10.1949	30.06.1991			R				R=Rainfall
11	Chingombe Mission	01.10.1925	30.04.1993			R				D=Diverse Observations
12	Chinsali Boma	01.07.1926	31.03.1993			R				
13	Chipata (Fort Jameson)	01.07.1949	31.12.1990	S		R				
14	Chipata Agri.	01.03.1929	30.01.1989			R				
15	Chipata Civic Centre	01.07.1919	31.05.1989			R				
16	Chitokoloki	01.07.1961	30.06.1991			R				
17	Chiyuni	01.07.1955	30.06.1990			R				
18	Choma	01.03.1948	31.12.1990	S						

Zambia Zimbabwe Lesotho Tanzania Uganda Gabon Guinea Guinea-Bisseau Zaire

Zimbabwe

	A	B	C	D	E	F	G	H	I	J
3	Agric Expt Stat	01.07.1903	30.06.1980			R				
4	Agric Salisbury	01.07.1890	30.06.1944			R				
5	Airport Salisbury	01.07.1955	30.06.1990	S		R				
6	Alexander Park	01.07.1965	31.12.1980			R				
7	Allenby Rhodesville	01.07.1925	30.06.1965			R				
8	Angus Ranch	01.08.1921	31.10.1925		C					S=Synoptic Observations
9	Ardbenny	01.07.1915	30.06.1943			R				C=Climatologocal Observations
10	Ascot Road	01.07.1950	30.06.1973			R				R=Rainfall
11	Ashbrittle	01.07.1950	30.06.1980			R				D=Diverse Observations
12	Ashdown Park	01.07.1973	30.06.1979			R				
13	Aspindale Park	01.07.1927	30.06.1980			R				
14	Avondale	01.07.1911	30.06.1927			R				
15	Beatrice	01.03.1931	31.08.1948	S						
16	Beech Cottage	01.07.1925	30.06.1967			R				
17	Beit Bridge	01.10.1933	31.12.1948	S						
18	Belvedere	01.01.1949	30.06.1956	S						
19	Between Rivers Banket	01.07.1931	31.05.1931	S						
20	Bikita	01.07.1931	31.08.1949	S	C					

Zambia Zimbabwe Lesotho Tanzania Uganda Gabon Guinea Guinea-Bisseau Zaire

7.2 Appendix B: Inventories Created from Images of Forms

Angola (I)

1	film_id_sequence	station_id	station_name	address details	start_years	end_years	variables
2	ANGOLA_001_001_001-ANGOLA_001_001_004	8	Ambizete	07°14' S 12°52' E	01/01/1972	31/12/1972	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
3	ANGOLA_001_002_001-ANGOLA_001_002_004	7	Baia dos Tigres	16°36' S 11°43' E	01/01/1972	01/12/1972	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
4	ANGOLA_001_003_001-ANGOLA_001_003_034	9	Cabinda	05°33' S 12°11' E	01/01/1957	01/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
5	ANGOLA_001_004_001-ANGOLA_001_004_004	10	Camaxilo	08°22' S 18°56' E	01/01/1972	01/12/1972	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
6	ANGOLA_001_005_001-ANGOLA_001_005_026	11	Carmona	07°35' S 15°00' E	01/01/1961	01/12/1972	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
7	ANGOLA_001_006_001-ANGOLA_001_006_012	12	Cela	11°23' S 15°08' E	01/01/1961	01/12/1966	temp, pressure, relative humidity, cloud, rainfall, wind, weather type
8	ANGOLA_001_007_001-ANGOLA_001_007_036	13	Dundo	07°24' S 20°49' E	01/01/1957	01/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
9	ANGOLA_001_008_001-ANGOLA_001_008_026	14	Henrique de Carvalho	09°40' S 20°23' E	01/01/1961	01/12/1972	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
10	ANGOLA_001_009_001-ANGOLA_001_009_036	15	Lobito	12°22' S 13°32' E	01/01/1957	01/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
11							
12	001-ANGOLA_001_020_042 + ANGOLA_001_022_001-ANC	5	Luanda	08°49' S 13°13' E	01/01/1958	31/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
13	ANGOLA_001_021_001-ANGOLA_001_021_036	16	Luso	11°47' S 19°55' E	01/01/1957	01/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
14	ANGOLA_001_023_001-ANGOLA_001_023_036	17	Malange	09°33' S 16°22' E	01/01/1959	01/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
15	ANGOLA_001_024_001-ANGOLA_001_024_004	18	Malverina (Mozambique?)	22°05' S 31°41' E	01/09/1961	01/12/1961	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
16	ANGOLA_001_025_001-ANGOLA_001_025_036	19	Mavinga	15°50' S 20°21' E	01/01/1957	01/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
17	ANGOLA_001_026_001-ANGOLA_001_026_036	20	Mocamedes	15°12' S 12°09' E	01/01/1957	01/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
18	ANGOLA_001_027_001-ANGOLA_001_027_004	21	Negage	07°41' S 15°22' E	01/01/1972	01/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
19							
20	ANGOLA_001_028_001-ANGOLA_001_038_036	6	Nova Lisboa	12°48' S 15°45' E	01/01/1945	01/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
21	ANGOLA_001_039_001-ANGOLA_001_039_017	1	Pereira d'Eca		01/01/1957	01/12/1961	temp, relative humidity, cloud, rainfall, weather type
22	ANGOLA_001_040_001-ANGOLA_001_040_004	22	Porto Aboim	10°42' S 13°45' E	01/01/1972	01/12/1972	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
23	ANGOLA_001_041_001-ANGOLA_001_041_030	23	Rocadas	16°45' S 14°58' E	01/01/1961	01/12/1973	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type
24	ANGOLA_001_042_001-ANGOLA_001_042_004	4	Silva Porto	12°23' S 16°57' E	01/01/1972	01/12/1972	temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type

Angola (II)

variables	time_of_observations	frequency	remarks
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.01	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00.	2xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	07.00, 13.00. 19.00 (sor	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, relative humidity, cloud, rainfall, weather type	09.00,	1xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable
temp, pressure, relative humidity, cloud, insolation, rainfall, wind, weather type	09.00, 15.00. 21.00	3xDAILY	data mostly readable

Benin-Dahomey (I)

G	H	I	J
riables	time_of_observations	frequency	remarks
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation	8.00, 12.00, 18.00	3XTIMES	Appears to be located in Guinea, not Benin, data mostly readabl
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation	8.00, 12.00, 18.00	3XTIMES	Appears to be located in Guinea, not Benin, data mostly readabl
eather conditions, wind, atmospheric pressure, temperature, humidity, cloudiness, precipitation, evaporation	7.00, 13.00, 18.00	3XTIMES	Appears to be located in Guinea, not Benin, data mostly readabl
eather conditions, wind, atmospheric pressure, temperature, humidity, cloudiness, precipitation, relative humidity, water vapour pressure, visib	7.00, 12.00, 18.00 + 6.00, 12	3XTIMES	Appears to be located in Guinea, not Benin, data mostly readabl
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, water vapour pressure, dew point	7.00, 12.00, 18.00	3XTIMES	data mostly readable
eather conditions, wind, atmospheric pressure, temperature, humidity, cloudiness, precipitation, evaporation, insolation	6.00, 12.00, 18.00	3XTIMES	data mostly readable
mperature, wind, precipitation, visibility, cloudiness, insolation, atmospheric pressure, relative humidity, water vapour pressure	0.00, 03.00, 06.00, 09.00, 12	7XTIMES	data mostly readable
eather conditions, wind, atmospheric pressure, temperature, humidity, cloudiness, precipitation, evaporation, water vapour pressure, dew poin	7.00, 12.00, 18.00 + 8.00, 12	3XTIMES	data mostly readable
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, water vapour pressure, dew point	7.00, 12.00, 18.00 + 8.00, 12	3XTIMES	data mostly readable
eather conditions, wind, atmospheric pressure, temperature, humidity, cloudiness, precipitation, evaporation	8.00, 12.00, 18.00	3XTIMES	data mostly readable
eather conditions, wind, temperature, cloudiness, precipitation	8.00,	1XTime	poor quality images
eather conditions, temperature, wind, precipitation, visibility, cloudiness, atmospheric pressure, relative humidity, water vapour pressure	7.00, 12.00, 18.00	3XTIMES	data mostly readable
eather conditions, temperature, wind, precipitation, visibility, cloudiness, insolation, evaporation, atmospheric pressure, relative humidity, wate	8.00, 13.00, 18.00 + 8.00, 13	3XTIMES	data mostly readable
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, water vapour pressure, dew point	8.00, 18.00 + 7.00, 12.00, 18	2XTIMES (later 3 XTIMES)	data mostly readable
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, atmospheric pressure	8.00, 13.00, 18.00	3XTIMES	data mostly readable
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, atmospheric pressure	8.00, 13.00, 18.00 + 7.00, 13	3XTIMES	poor quality images
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, water vapour pressure, dew point	7.00, 12.00, 18.00	3XTIMES	data mostly readable

Benin-Dahomey (II)

G	H	I	J
riables	time_of_observations	frequency	remarks
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation	8.00, 12.00, 18.00	3XTIMES	Appears to be located in Guinea, not Benin, data mostly readabl
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation	8.00, 12.00, 18.00	3XTIMES	Appears to be located in Guinea, not Benin, data mostly readabl
eather conditions, wind, atmospheric pressure, temperature, humidity, cloudiness, precipitation, evaporation	7.00, 13.00, 18.00	3XTIMES	Appears to be located in Guinea, not Benin, data mostly readabl
eather conditions, wind, atmospheric pressure, temperature, humidity, cloudiness, precipitation, relative humidity, water vapour pressure, visib	7.00, 12.00, 18.00 + 6.00, 12	3XTIMES	Appears to be located in Guinea, not Benin, data mostly readabl
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, water vapour pressure, dew point	7.00, 12.00, 18.00	3XTIMES	data mostly readable
eather conditions, wind, atmospheric pressure, temperature, humidity, cloudiness, precipitation, evaporation, insolation	6.00, 12.00, 18.00	3XTIMES	data mostly readable
mperature, wind, precipitation, visibility, cloudiness, insolation, atmospheric pressure, relative humidity, water vapour pressure	0.00, 03.00, 06.00, 09.00, 12	7XTIMES	data mostly readable
eather conditions, wind, atmospheric pressure, temperature, humidity, cloudiness, precipitation, evaporation, water vapour pressure, dew poin	7.00, 12.00, 18.00 + 8.00, 12	3XTIMES	data mostly readable
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, water vapour pressure, dew point	7.00, 12.00, 18.00 + 8.00, 12	3XTIMES	data mostly readable
eather conditions, wind, atmospheric pressure, temperature, humidity, cloudiness, precipitation, evaporation	8.00, 12.00, 18.00	3XTIMES	data mostly readable
eather conditions, wind, temperature, cloudiness, precipitation	8.00,	1XTime	poor quality images
eather conditions, temperature, wind, precipitation, visibility, cloudiness, atmospheric pressure, relative humidity, water vapour pressure	7.00, 12.00, 18.00	3XTIMES	data mostly readable
eather conditions, temperature, wind, precipitation, visibility, cloudiness, insolation, evaporation, atmospheric pressure, relative humidity, wate	8.00, 13.00, 18.00 + 8.00, 13	3XTIMES	data mostly readable
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, water vapour pressure, dew point	8.00, 18.00 + 7.00, 12.00, 18	2XTIMES (later 3 XTIMES)	data mostly readable
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, atmospheric pressure	8.00, 13.00, 18.00	3XTIMES	data mostly readable
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, atmospheric pressure	8.00, 13.00, 18.00 + 7.00, 13	3XTIMES	poor quality images
eather conditions, wind, temperature, humidity, cloudiness, precipitation, evaporation, water vapour pressure, dew point	7.00, 12.00, 18.00	3XTIMES	data mostly readable

Sahel

	A	B	C	D	E	F	G	H	I	J
1	film_id_sequence	station_id	station_name	address deta	start_years	end_years	variables	time_of_ol	frequency	remarks
2	SAHEL_001_001-SAHEL_001_505 + SAHEL_002_017-SAHEL_002_		Dakar		01/03/1916	01/12/1940	atmospheric p	8.00, 13.00	3XDAILY	located in Senegal, data mostly readable
3	SAHEL_001_997-SAHEL_001_1020 + SAHEL_002_1045-SAHEL_00		Kolo		01/07/1952	01/12/1952	precipitation,	7.00, 12.00	3XDAILY	located in Niger, data mostly readable
4	SAHEL_001_1021-SAHEL_001_1028 + SAHEL_002_1069-SAHEL_(		Niamey		01/12/1939	01/12/1939	atmospheric p	8.00, 13.00	3XDAILY	located in Niger, data mostly readable
5	SAHEL_001_1029-SAHEL_001_1040 + SAHEL_002_1077-SAHEL_(		Niamey Bas		01/01/1947	01/12/1947	wind, tempera	8.00, 18.00	2XDAILY	loacetd in Niger, data mostly readable
6	SAHEL_001_1041-SAHEL_001_1100 + SAHEL_002_1089-SAHEL_(		Dioura	14°49' N 05°	01/06/1955	01/05/1960	precipitation,	8.00, 13.00	3XDAILY	located in French Sudan (Mail), data mostly readable
7	SAHEL_001_1101-SAHEL_001_1180 + SAHEL_002_1149-SAHEL_(		Dounfing	12° 41' N 08°	01/05/1953	01/12/1954	precipitation,	8.00, 13.00	3XDAILY	located in French Sudan (Mail), data mostly readable
8	SAHEL_001_1181-SAHEL_001_1304 + SAHEL_002_1229-SAHEL_(		Gao	16° 41' N 00°	01/01/1936	01/12/1947	precipitation,	8.00, 13.00	6XDAILY	located in French Sudan (Mail), data mostly readable
9	SAHEL_001_1305-SAHEL_001_1429 + SAHEL_002_1353-SAHEL_(		Kabara		01/07/1939	01/12/1948	atmospheric p	8.00, 13.00	3XDAILY	located in French Sudan (Mail), data mostly readable
10	SAHEL_001_1430-SAHEL_001_1685+ SAHEL_002_1478-SAHEL_0		Faladie	13° 11' N 08°	01/01/1948	01/04/1953	precipitation,	8.00, 13.00	3XDAILY	located in French Sudan (Mail), data mostly readable
11	SAHEL_001_506-SAHEL_001_513+ SAHEL_002_554-SAHEL_002_		Dakar-Ouakam	14° 40' N 17°	01/01/1923	01/05/1948	wind, weather	8.00, 13.00	3XDAILY	located in Senegal, data mostly readable
12	SAHEL_001_514-SAHEL_001_525 + SAHEL_002_562-SAHEL_SAHI		Bilma	18° 41' N 12°	01/01/1947	01/03/1947	wind, weather	8.00, 13.00	3XDAILY	located in Niger, data mostly readable
13	SAHEL_001_526-SAHEL_001_597 +SAHEL_002_574-SAHEL_002_		Dosso	13° 00' N 03°	01/01/1947	01/06/1948	wind, weather	8.00, 13.00	3XDAILY	located in Niger, data mostly readable
14	SAHEL_001_598-SAHEL_001_996 + SAHEL_002_646-SAHEL_002		Kelle	14° 17' N 10°	01/01/1948	01/12/1956	wind, evapora	7.00, 12.00	3XDAILY	located in Niger, data mostly readable
15	SAHEL_002_001-SAHEL_002_012		Boulel		01/02/1955	01/04/1958	wind, weather	8.00, 13.00	3XDAILY	located in Senegal, data mostly readable
16	SAHEL_002_1345-SAHEL_002_1348 + SAHEL_006_307-SAHEL_00		Kombosi	15° 20' N 10°	01/12/1947	01/12/1947	wind, weather	8.00, 13.00	3XDAILY	located in Mali, data mostly readable
17	SAHEL_002_558-SAHEL_002_561 + SAHEL_010_824-SAHEL_010_		Agadez		01/05/1948	01/05/1948	wind, weather	8.00, 13.00	3XDAILY	located in Niger, data mostly readable
18	SAHEL_002_013-SAHEL_002_016		Dakar Hann	14° 43' N 17°	01/05/1958	01/05/1958	wind, weather	8.00, 13.00	3XDAILY	located in Mali, data mostly readable
19	SAHEL_003_001-SAHEL_003_030+SAHEL_004_439-SAHEL_004_5		Fada N'Gourma	12° 04' N 00°	01/01/1939	01/12/1954	wind, evapora	8.00, 13.00	3XDAILY	located in Haute Volte (Burkina Faso), Poor Quality Images

South Africa

	A	B	C	D	E	F	G	H	I	J	K	L
1	film_id_sequenc	station_id		other_det	start_years	end_years	variables	time_of_observation	frequency	remarks		
2	FILM_SOUTH_AF	595/95	Acorn Hoek		01/01/1941	31/12/1948	weather conditions, t	08.00	1xDAILY	data readable		
3	FILM_SOUTH_AF	595/95	Acorn hoek		01/12/1941	31/01/1948	temp,rainfall, wet bu	08.00 08.30 14.00 20.	3xDAILY	data readable		
4	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1981	31/12/1983	cloud, wind, weather	08.00 14.00	2xDAILY	data readable but some blurre		
5	FILM_SOUTH_AF	35/334	Addo-AGR		01/12/1981	31/01/1983	cloud, wind, weather	08.00 14.00 20.00	3xDAILY	data readable		
6	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1984	31/12/1984	wind, weather condit	08.00 14.00	2xDAILY	data readable		
7	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1984	31/12/1984	cloud, wind, weather	08.00 14.00	2xDAILY	data readable but some blurre		
8	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1985	31/12/1985	wind, weather condit	08.00 14.00	2xDAILY	data readable		
9	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1985	31/12/1985	cloud, wind, weather	14.00 18.00	2xDAILY	mostly blurred images		
10	SOUTH_AFRICA_	035/334	Addo-AGR		01/01/1986	01/12/1988	cloud, wind, visibility,	08.00, 14.00	2XDAILY	poor quality images		
11	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1986	31/12/1986	wind, weather condit	08.00 14.00 20.00	3xDAILY	data readable		
12	FILM_SOUTH_AF	35/334	Addo-AGR		01/01/1987	31/12/1987	wind, weather condit	08.00 14.00	2xDAILY	data readable		
13	SOUTH_AFRICA_	003/020	Addo-AGR		01/01/1988	01/12/1988	cloud, wind, visibility,	08.00, 14.00, 20.00	3XDAILY	data mostly readable		
14	FILM_SOUTH_AF	035/334	Addo-AGR		01/01/1988	31/12/1988	wind, weather condit	08.00 14.00	2xDAILY	data readable		
15	FILM_SOUTH_AF	246/613	Aggeneys		01/01/1981	31/12/1983	weather conditions, t	08.00	1xDAILY	data readable but some blurre		
16	FILM_SOUTH_AF	246/613	Aggeneys		01/12/1981	31/01/1983	weather conditions, t	08.00	1xDAILY	data readable		
17	FILM_SOUTH_AF	765/599	Alaska	louis Trich	01/01/1931	31/01/1946	cloud, wind, weather	08.30	1xDAILY	data readable but some blurre		
18	FILM_SOUTH_AF	274/34	Alexanderbaai		01/01/1985	31/12/1985	wind, weather condit	08.00 14.00 20.00	3xDAILY	data readable		
19	FILM_SOUTH_AF	274/34	Alexanderbaai		01/01/1985	31/12/1985	cloud, wind, weather	08.00 14.00 20.00	3xDAILY	mostly blurred images		
20	FILM_SOUTH_AF	274/34	Alexanderbaai		01/01/1986	31/12/1986	wind, weather condit	08.00 14.00 20.00	3xDAILY	data readable		
21	SOUTH_AFRICA_	274/034	Alexanderbaai		01/01/1986	01/12/1987	cloud, visibility, weath	08.00, 14.00, 20.00	3XDAILY	data mostly readable		
22	FILM_SOUTH_AF	274/34	Alexanderbaai		01/01/1987	31/12/1987	wind, weather condit	08.00 14.00 20.00	3xDAILY	data readable		
23	SOUTH_AFRICA_	589/594	Alma		01/07/1985	01/12/1989	cloud, visibility, weath	08.00, 14.00	2XDAILY	data mostly readable		
24	FILM_SOUTH_AF	589/183	Alma Die Laaste Wat		01/07/1985	31/12/1985	wind, weather condit	08.00 14.00	2xDAILY	data readable		

References

Aich, V., Liersch, S., Vetter, T., Fournet, S., Andersson, J.C.M., Calmanti, S., van Weert, F.H.A., Hattermann, F.F., Paton, E.N., 2016, Flood projections within the Niger River Basin under future land use and climate change, *Science of The Total Environment*, 562, pp. 666-677, https://doi.org/10.1016/j.scitotenv.2016.04.021.

Abdoulaye, A.O., Lu, H.;Zhu, Y., Hamoud, Y.A., 2021, Future Irrigation Water Requirements of the Main Crops Cultivated in the Niger River Basin. *Atmosphere*, 12, 439, https://doi.org/10.3390/atmos12040439

Ahokpossi Y., 2018, Analysis of the rainfall variability and change in the Republic of Benin (West Africa), *Hydrological Sciences Journal*, 63, 15-16, pp.2097-2123, https://doi.org/10.1080/02626667.2018.1554286

Brönnimann, S., Allan, R., Ashcroft, L., Baer, S., Barriendos, M., Brázdil, R., Brugnara, Y., Brunet, M., Brunetti, M., Chimani, B., Cornes, R., Domínguez-Castro, F., Filipiak, J., Founda, D., Herrera, R.G., Gergis, J., Grab, S., Hannak, L., Huhtamaa, H., Jacobsen, K.S., Jones, P., Jourdain, S., Kiss, A., Lin, K.E., Lorrey, A., Lundstad, E., Luterbacher, J., Mauelshagen, F., Maugeri, M., Maughan, N., Moberg, A., Neukom, R., Nicholson, S., Noone, S., Nordli, Ø., Ólafsdóttir, K.B., Pearce, P.R., Pfister, L., Pribyl, K., Przybylak, R., Pudmenzky, C., Rasol, D., Reichenbach, D., Řezníčková, L., Rodrigo, F.S., Rohr, C., Skrynyk, O., Slonosky, V., Thorne, P., Valente, M.A., Vaquero, J.M., Westcottt, N.E., Williamson, F. & Wyszyński, P., 2019, Unlocking pre-1850 Instrumental Meteorological Records: A Global Inventory, *Bulletin of the American Meteorological Society*, 100, 12, pp. ES389-ES413, https://doi.org/10.1175/BAMS-D-19-0040.1

Brunet, M., Gilabert A., Jones, P., Efthymiadis D., 2014, A historical surface climate dataset from station observationsin Mediterranean North Africa and Middle East areas, *Geoscience Data Journal*, 1, pp. 121–128, https://doi.org/10.1002/gdj3.12

Chagnaud, G., Panthou, G., Vischel, T., Lebel, T., 2022, A synthetic view of rainfall intensification in the West African Sahel, *Environmental Research Letters*, 17, 4, pp. 044005, https://doi-org.may.idm.oclc.org/10.1088/1748-9326/ac4a9c

Compo, G.P., Whitaker, J.S., Sardeshmukh, P.D., Matsui, N., Allan, R.J., Yin, X., Gleason, B.E., Vose, R.S., Rutledge, G., Bessemoulin, P., Brönnimann, S., Brunet, M., Crouthamel, R.I., Grant, A.N., Groisman, P.Y., Jones, P.D., Kruk, M.C., Kruger, A.C., Marshall, G.J., Maugeri, M., Mok, H.Y., Nordli, Ø., Ross, T.F., Trigo, R.M., Wang, X.L., Woodruff, S.D. and Worley, S.J., 2011, The Twentieth Century Reanalysis Project. *Quarterly Journal of the Royal Meteorological Society*, 137, pp.1-28, https://doi-org.may.idm.oclc.org/10.1002/qj.776

Copernicus, (2022), *About C3S*, Available from https://cds.climate.copernicus.eu/about-c3s, [accessed 24 July 2022].

Cram, T.A., Compo, G.P., Yin, X., Allan, R.J., McColl, C., Vose, R.S., Whitaker, J.S., Matsui, N., Ashcroft, L., Auchmann, R., Bessemoulin, P., Brandsma, T., Brohan, P., Brunet, M., Comeaux, J., Crouthamel, R., Gleason, B.E., Jr, Groisman, P.Y., Hersbach, H., Jones, P.D., Jónsson, T., Jourdain, S., Kelly, G., Knapp, K.R., Kruger, A., Kubota, H., Lentini, G., Lorrey, A., Lott, N., Lubker, S.J., Luterbacher, J., Marshall, G.J., Maugeri, M., Mock, C.J., Mok, H.Y., Nordli, Ø., Rodwell, M.J., Ross, T.F., Schuster, D., Srnec, L., Valente, M.A., Vizi, Z., Wang, X.L., Westcott, N., Woollen, J.S. and Worley, S.J., 2015, The International Surface Pressure Databank version 2, *Geoscience Data Journal*, 2, pp.31-46, https://doi.org/10.1002/gdj3.25

Curriculum Online, (2022), *Geography-Leaving Certificate Syllabus*, Available from https://curriculumonline.ie/getmedia/9da21be1-3f99-4f50-88ee-ba7ce6638e1a/SCSEC17_Geography_syllabus_eng.pdf, [accessed 8 July 2022].

Curtin, P.D. 1960, The Archives of Tropical Africa: A Reconnaissance, *Journal of African History*, 1, 1, pp. 129-147, http://www.jstor.org/stable/179711

Dritsas, L. & Haig, J., 2013;2014;, An archive of identity: the Central African Archives and Southern Rhodesian history, *Archival Science*, 14, 1, pp.35-54,

Endfield, G. H., & Nash, D. J., 2002, Drought, desiccation and discourse: Missionary correspondence and nineteenth-century climate change in central southern Africa. *The Geographical Journal*, 168, pp. 33-47,

Fischer, E., Knutti, R., 2016, Observed heavy precipitation increase confirms theory and early models, *Nature Climate Change*, 6, pp. 986–991, https://doi-org.may.idm.oclc.org/10.1038/nclimate3110

Fowler, H. J., S. Blenkinsop, and C. Tebaldi, 2007: Linking climate change modelling to impacts studies: Recent advances in downscaling techniques for hydrological modelling. *International Journal of Climatology*, 27, pp.1547–1578, https://doi-org.may.idm.oclc.org/10.1002/joc.1556

Gatti G, Bianchi C.N., Parravicini V., Rovere A., Peirano A., Montefal-cone M., et al. (2015) Ecological Change, Sliding Baselines and the Importance of Historical Data: Lessons from Combining Observational and Quantitative Data on a Temperate Reef Over 70 Years. *PLoS* ONE, 10(2), https://doi.org/10.1371/journal.pone.0123268

Gebrechorkos, S.H., Hülsmann, S., Bernhofer, C., 2020, Analysis of climate variability and droughts in East Africa using high-resolution climate data products, *Global and Planetary Change*, 186, 2020, https://doi.org/10.1016/j.gloplacha.2020.103130.

Grab, S. & Zumthurm, T., 2020, “Everything is scorched by the burning sun"; missionary perspectives and experiences of 19th- and early 20th-century droughts in semi-arid central Namibia", *Climate of the past*, 16, 2, pp. 679-697.

IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

J., Lo, M., 2001, Historical and human dimensions of climate variability and water resource constraint in the Senegal River Valley, Climate Research, 19, pp. 133-147.

Kasper, F., Helmschrot, J., Mhanda, A., Butale, M., de Clercq, W., Kanyanga, J. K., Neto, F. O. S., Kruger, S., Castro Matsheka, M., Muche, G., Hillmann, T., Josenhans, K., Posada, R., Riede, J., Seely, M., Ribeiro, C., Kenabatho, P., Vogt, R., and Jürgens, N., 2015, The SASSCAL contribution to climate observation, climate data management and data rescue in Southern Africa, *Advances in Science Research*, 12, pp. 171–177, https://doi.org/10.5194/asr-12-171-2015

Kaspar, F., Tinz, B., Mächel, H., and Gates, L., 2015, Data rescue of national and international meteorological observations at Deutscher Wetterdienst, *Advances in Science Research*., 12, 57–61, https://doi.org/10.5194/asr-12-57-2015

Kaspar F., Andersson A., Ziese M., Hollmann R., 2022, Contributions to the Improvement of Climate Data Availability and Quality for Sub-Saharan Africa, *Frontiers in Climate*, 3, https://doi.org/10.3389/fclim.2021.815043

Lorrey, A., Pearce, P.R., Allan, R., Wilkinson, C., Wooley, J.M., Judd, E., Mackay, S., Rawhat, S., Slivinski, L., Wilkinson, S., Hawkins, E., Quesnel, P., Compo, G.P., 2022, Meteorological data rescue: Citizen science lessons learned from Southern Weather Discovery, *Patterns*, 3, 6, p.100495, https://doi.org/10.1016/j.patter.2022.100495

Mateus, C., Potito, A. & Curley, M., 2021, Engaging secondary school students in climate data rescue through service-learning partnerships. Weather, 76, 4, pp. 113-118, https://doi-org.may.idm.oclc.org/10.1002/wea.3841

Murphy, C., Broderick, C., Burt, T. P., Curley, M., Duffy, C., Hall, J., Harrigan, S., Matthews, T. K. R., Macdonald, N., McCarthy, G., McCarthy, M. P., Mullan, D., Noone, S., Osborn, T. J., Ryan, C., Sweeney, J., Thorne, P. W., Walsh, S., and Wilby, R. L., 2018, A 305-year continuous monthly rainfall series for the island of Ireland (1711–2016), *Climate of the Past*, 14, pp.413–440, https://doi.org/10.5194/cp-14-413-2018

Nash, D.J. and Endfield, G.H., 2002, A 19th century climate chronology for the Kalahari region of central southern Africa derived from missionary correspondence, *International Journal of Climatology*, 22, pp.821-841, https://doi-org.may.idm.oclc.org/10.1002/joc.753

Nash, D.J. & Grab, S.W. 2009; 2010; A sky of brass and burning winds”: documentary evidence of rainfall variability in the Kingdom of Lesotho, Southern Africa, 1824–1900, *Climatic Change*, 101, 3-4, pp. 617-653.

Nash, D. J., Pribyl, K., Klein, J., Neukom, R., Endfield, G. H., Adamson, G. C., . . . Kniveton, D. R., 2016, Seasonal rainfall variability in southeast Africa during the nineteenth century reconstructed from documentary sources. *Climatic Change*, 134, 4, pp.605-619. https://doi.org/10.1007/s10584-015-1550-8

National Council for Curriculum and Assessment, (2022), *Transition Year*, Available from https://ncca.ie/en/senior-cycle/programmes-and-key-skills/transition-year/#:~:text=The%20Transition%20Year%20(TY)%20is,Certificate%20and%20Leaving%20Certificate%20programmes, [accessed 8 July 2022].

Ng, S. & Cowling, B.J., 2014, "Association between temperature, humidity and ebolavirus disease outbreaks in Africa, 1976 to 2014", *Euro surveillance: bulletin européen sur les maladies transmissibles*, vol. 19, no. 35, pp. 20892.

Nicholson, S. E., 2001, A semi-quantitative, regional precipitation data set for studying African climates of the nineteenth century, part I. overview of the data set, *Climatic Change*, 50, 3, pp.317-353, https://doi.org/10.1023/A:1010674724320

Nicholson, S. E., A. K. Dezfuli, and D. Klotter, 2012b: A two-century precipitation dataset for the continent of Africa. *Bulletin of the American Meteorology Society*, 93, 1219–1231, https://doi.org/10.1175/BAMS-D-11-00212.1

Noone, S., Brody, A., Brown, S., Cantwell, N., Coleman, M., Sarsfield Collins, L., Darcy, C., Dee, D., Donegan, S., Fealy, R., Flattery, P., McGovern, R., Menkman, C., Murphy, M., Phillips, C., Roche, M., and Thorne, P., 2019, Geo-locate project: a novel approach to resolving meteorological station location issues with the assistance of undergraduate students, *Geoscience Communication*, 2, pp.157–171, https://doi.org/10.5194/gc-2-157-2019

Noone S, Atkinson C, Berry DI, et al., 2020, Progress towards a holistic land and marine surface meteorological database and a call for additional contributions. *Geoscience Data Journal*, 8, pp.134–120. https://doi.org/10.1002/gdj3.109

Ryan, C., 2021, Ireland's pre-1940 daily precipitation data: data rescue, quality assurance and analysis of extremes, PhD thesis, National University of Ireland, Maynooth.

Panthou, G., Lebel, T., Vischel, T., Quantin, G., Sane, Y., Ba, A., Ndiaye, O., Diongue-Niang, A., Diopkane M., 2018, Rainfall intensification in tropical semi-arid regions: the Sahelian case, *Environmental Research Letters*, 13, 6, pp.064013, https://doi-org.may.idm.oclc.org/10.1088/1748-9326/aac334

Park, E.G., Burr, G., Slonosky, V., Sieber, R., Podolsky, L., 2018, Data rescue archive weather (DRAW): Preserving the complexity of historical climate data, *Journal of Documentation*, 74, 4.

Picas, J, Grab, S, Allan, R., 2019, A 19th century daily surface pressure series for the Southwestern Cape region of South Africa: 1834–1899. *International Journal of Climatology*, 39, pp.1404-1414, https://doi-org.may.idm.oclc.org/10.1002/joc.5890

Phillips, C., Walsh, D., O'Regan, K., Strong, K., Hennon, C., Knapp, K., Murphy, C., Thorne, P. W., Assessing Citizen Science Participation Skill for Altruism or University Course Credit: A Case Study Analysis Using Cyclone Center, *Citizen Science: Theory and Practice*, 3, 6, https://doi.org/10.5334/cstp.111

Phillips, T. B., Ballard, H. L., Lewenstein, B. V., Bonney, R. (2019). Engagement in science through citizen science: Moving beyond data collection. *Science Education*, 103, 3, 665–690, https://doi.org/10.1002/sce.21501

Ryan, C., Duffy, C., Broderick, C., Thorne, P. W., Curley, M., Walsh, S., Daly, C., Treanor, M., and Murphy, C., 2018, Integrating data rescue into the classroom, *Bulletin of the American Meteorological Society*, 99, pp.1757–1764, https://doi.org/10.1175/BAMS-D-17-0147.1

Senabre Hidalgo, E., Perelló, J., Becker, F., Bonhoure, I., Legris, M., Cigarini, A., 2021, Participation and Co-creation in Citizen Science. In: , *et al.* The Science of Citizen Science. Springer, Cham. https://doi.org/10.1007/978-3-030-58278-4_11

Shah H.R., Martinez L.R.., 2016, Current Approaches in Implementing Citizen Science in the Classroom. *Journal of Microbiology & Biology Education*, 17(1), pp.17-22, https://doi.org/10.1128/jmbe.v17i1.1032

Shirk, J., Ballard, H., Wilderman, C., Phillips, T., Wiggins, A., Jordan, R., et al., 2012, Public participation in scientific research: A framework for deliberate design. *Ecology and Society*, 17(2), 29, https://doi.org/10.5751/ES-04705-170229

Skrynyk, O, Luterbacher, J, Allan, R, et al., 2021, Ukrainian early (pre-1850) historical weather observations. *Geoscience Data Journal*, 2021; 8: pp.55– 73. https://doi.org/10.1002/gdj3.108

Sieber, R., Slonosky, V., 2020, Building a Traceable and Sustainable Historical Climate Database: Interdisciplinarity and DRAW, Patterns, 1(1).

Sorgho, R., Jungmann, M., Souares, A., Danquah, I., Sauerborn, R., 2021, Climate Change, Health Risks, and Vulnerabilities in Burkina Faso: A Qualitative Study on the Perceptions of National Policymakers, *International Journal of Environmental Research and Public Health*, 18, 9, pp 4972. https://doi.org/10.3390/ijerph18094972

Thorne, P. W., Allan, R. J., Ashcroft, L., Brohan, P., Dunn, R. J. H., Menne, M. J., . . . Worley, S. J., Toward an Integrated Set of Surface Meteorological Observations for Climate Science and Applications." *Bulletin of the American Meteorological Society*, 98, 12, (2017), pp.2689–2702,

Trew BT, Maclean IMD., 2021, Vulnerability of global biodiversity hotspots to climate change, *Global Ecology Biogeography*, 2021, 30, pp.768–783. https://doi.org/10.1111/geb.13272

Wang, T., Hamann, A., Spittlehouse, D., Murdock, T., 2012, High-Resolution Spatial Climate Data for Western North America, *Journal of Applied Meteorology and Climatology*, 51, pp. 16-29

World Meteorological Organization (WMO) (2017), "DATA rescue", available at: www.wmo.int/pages/prog/hwrp/datarescue.php (accessed June 9, 2022).