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DATA ARTICLE

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Investigating the potential for students to contribute to climate data rescue: Introducing the Climate Data Rescue Africa project (CliDaR-Africa)

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Abstract

The majority of available climate data in global digital archives consist of data only from the 1940s or 1950s onwards, and many of these series have gaps and/or are available for only a subset of the variables which were actually observed. However, there exist billions of historical weather observations from the 1700s, 1800s, and early 1900s that are still in hard-copy form and are at risk of being lost forever due to deterioration. An assessment of changes in climate extremes in several IPCC regions was not possible in IPCC AR6 WGI owing, in many cases, to the lack of available data. One such region is Africa, where the climate impact research and the ability to predict climate change impacts are hindered by the paucity of access to consistent good-quality historical observational data. The aim of this innovative project was to use classroom-based participatory learning to help transcribe some of the many meteorological observations from Africa that are thus far unavailable to researchers. This project transcribed quickly and effectively station series by enrolling the help of second-year undergraduate students at Maynooth University in Ireland. The newly digitized African data will increase the temporal and spatial coverage of data in this important data-sparse

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region. Students gained new skills while helping the global scientific community unearth new insight into past African climate. The project managed to transcribe 79 months of data at Andapa in Madagascar and 56 months of data for Macenta in Guinea. The digitized data will be openly and freely shared with the scientific and wider community via the Pangaea data repository, the C3S Climate Data Store, and the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI) data centre in the US. The project model has the potential for a broader roll-out to other educational contexts and there is no shortage of data to be rescued. This paper provides details of the project, and all supporting information such as project guidelines and templates to enable other organizations to instigate similar programs.

KEYWORDS
climate data, data rescue, meteorological observations, participatory learning

1 | INTRODUCTION

The majority of current digital climate data holdings consist of data only since the 1940s or 1950s when data were either held in digital form or have been converted via various data rescue programmes and projects (Allan et al., 2011; Brönnimann et al., 2018; Brunet & Jones, 2011; Chimani et al., 2022; Ryan et al., 2018; World Meteorological Organization [WMO], 2016). Many station series have gaps or are available solely for a subset of observed potential variables (Adler et al., 2003; Cram et al., 2015; Noone et al., 2021; Rennie et al., 2014; Schneider et al., 2013). However, there are billions of weather observations from the 18th, 19th and early 20th centuries that are still in hard-copy form and at risk of being lost forever due to deterioration (Brönnimann et al., 2019). An assessment of climate extremes in several regions was impossible in the Intergovernmental Panel on Climate Change (IPCC) AR6 Working Group I (AR6 WGI) owing to lack of data, resulting in no basis for verifying future projections of climate extremes in those regions and hence no means to effectively plan adaptation measures (Seneviratne et al., 2021). Undigitized weather observations, if rescued and openly shared, offer the potential to increase the temporal coverage of existing records and expand the spatial coverage in data-sparse regions where climate change impact studies are crucial.

To this end, there have been many data rescue initiatives that have been conducted by a broad range of contributors including various independently funded climate research projects, citizen science projects and National Meteorological and Hydrological Services (NMHSs) often at considerable expense and person-hours. There are many global consortium efforts to coordinate activities across disparate funding streams. Most noteworthy is the international Atmospheric Circulation Reconstructions over the Earth (ACRE) initiative which has undertaken and facilitated the recovery of historical instrumental surface terrestrial and marine global weather observations (http://www.met-acre.org/).

There are many funded data rescue projects such as the Mediterranean Climate Data Rescue (MEDARE) which was supported by the World Meteorological Organization (WMO), with a focus on developing, consolidating and progressing climate data and metadata rescue activities across the Greater Mediterranean Region (http://www.omm.urv.cat/MEDARE/index.html). The European Union (EU)-funded Recovery of Logbooks and International Marine data project (RECLAIM) continues to locate, image and digitize meteorological and oceanographic observations from historical ships' logbooks from as early as the 17th century (Wilkinson et al., 2011). The WMO-funded I-DARE portal was set up to assist and promote these data rescue initiatives and provides clear expert guidance on climate data rescue and management (https://public.wmo.int/en/resources/meteoworld/international-data-rescue-i-dare-portal). In addition, the Uncertainties in Ensembles of Regional ReAnalyses (UERRA) project digitized data for 127 stations across northern African and European countries from 1877 to 2012 (Ashcroft et al., 2018).

Additionally, the Copernicus Climate Change Service (C3S) service aims to provide access to information for monitoring and predicting climate change, required to support climate change adaptation and mitigation policy development across Europe and globally. C3S is EU-funded and operated by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Union. To deliver the service, C3S has commissioned several service contracts to evaluate, quality control and consolidate and make available climate data information which currently exists in numerous different formats and locations. The C3S service also supports coordination and harmonization of in situ climate data rescue activities around the world (https://insitu.copernicus.eu/news/the-c3s-data-rescue-service). One of these contracts, entitled 'C3S2-311 Lot 1 Collection and Processing of In Situ Observations', (https://climate.copernicus.eu/c3s2311-collection-and-processing-situ-observations) is led by the Irish Climate Analysis and Research UnitS (ICARUS) at Maynooth University, Ireland, and aims to provide access to a comprehensive archive of historical surface observations, with support for data rescue (Noone et al., 2021).

There are also numerous examples of successful volunteer citizen science data rescue projects. For instance, the Data Rescue: Archival and Weather project (DRAW) allowed volunteers to participate in the transcription of historical weather logs from the McGill weather observatory (https://draw.geog.mcgill.ca/en/about/draw). In addition, the WeatherRescue.org project enrolled volunteer citizen scientists to transcribe millions of weather observations taken in the Victorian era from across Europe (Hawkins et al., 2019) via the Zooniverse platform (https://www.zooniverse.org/). The Zooniverse is the world's largest and most popular platform for people-powered research, with more than a million people around the world assisting professional researchers.

Even with all the above approaches, there remains a substantial volume of data still to be rescued. The potential for students to rescue significant volumes of climate data efficiently and effectively is substantial even if each student rescues only a small subset of the records. The possibility of building data rescue into a more holistic geography and science curriculum is substantial and yet largely unexploited to date. There have to date been only limited initiatives to engage with students in formal educational settings to become involved in climate data rescue efforts, despite evidence of the benefits of participatory learning outcomes to educational attainment and skills (Ryan et al., 2018).

Previous work at Maynooth University, Ireland has already developed an interest in student participation in such activities by integrating experiential and participatory learning techniques into undergraduate courses. These have included efforts to rescue Irish daily precipitation records from scanned hard copy sheets in collaboration with Met Éireann (Ryan et al., 2018). This student data rescue project at Maynooth University ran from 2016 to 2018 and digitized over 4000 station years of daily precipitation records for the Island of Ireland. The study evaluated the student experience by way of a survey and the responses were all positive. More than 90% of the students agreed that they gained important insights into the process of data rescue and got an appreciation of the importance of historical data in climate research. Over 90% of the students felt that they made a valuable contribution and 80% of respondents said that they would much prefer to participate in more similar class assignments (Ryan et al., 2018).

Noone et al. (2019) designed the Geo-locate Project and enrolled the assistance of second-year undergraduate students at Maynooth University to help resolve meteorological station location errors in global data holdings. The project began in 2018 and ran for four academic years with students ostensibly resolving over 3500 station location issues. Student surveys provided positive feedback and numerous suggestions as to how student experiences may be improved. Over 94% of students agreed that they had gained important insights into some of the issues with data and over 70% agreed that the assignment was a valuable learning experience. Over 70% of students felt that they had made a worthwhile contribution to an important global project and 85% felt that they gained useful transferrable skills from the assignment.

Aside from Maynooth University, a study by Mateus et al. (2021) enrolled students to digitize and rescue historical Irish temperature data at the National University of Ireland, Galway. The study enrolled the help of 357 university and secondary school students to rescue over 700,000 daily air temperature records from paper format. A project survey revealed that 97% of students felt that climate data are crucial for research and 88% of students felt that they had a positive experience. The survey results also showed that this type of engagement can generate interest in future data rescue activities and may encourage students to pursue a career in science, geography or meteorology (Mateus et al., 2021).

Recent studies have shown that young people between the ages of 10 and 24 are experiencing climate anxiety related to the global climate crisis and associated threat of environmental disaster (Galway & Field, 2023; Hickman et al., 2021; Marks et al., 2021; Wu et al., 2020). Many young people feel sad, anxious, angry, powerless, helpless and guilty about climate change (Marks et al., 2021). These young people feel frightened by the future and think that the world's population has failed to take care of the planet with many feeling that governments are inadequately addressing climate change (Hickman et al., 2021). Studies have found that there is a sense of injustice, insecurity and uncertainty around climate change which has seen many young people across the globe become involved by joining protests and demonstrations (Sanson et al., 2018). The same study stated it is vital that young people are engaged with in a supportive and solutions-based way with a focus on constructive, collective actions that could address both climate change and emotional anxiety (Sanson et al., 2018). By getting involved in climate data rescue projects, students would be involved in a real-world climate data project and contribute to the wider scientific community as well as improving our understanding of historical and ongoing climate change. Such projects would provide them with new transferable skills, and better educate them on global climate change issues. In doing so, such projects may also help address some of the climate anxiety felt by young people.

Building on previous work, the C3S2-311 Lot 1 Collection and Processing of In Situ Observations contract team (C3S2-311 team) in collaboration with teaching staff at the Department of Geography at Maynooth University designed the Climate Data Rescue Africa project (CliDaR-Africa project) that enrolled the assistance of the 2022/23 cohort of undergraduate Geography students to digitize some of the many millions of African meteorological observations from an image format. These students were in their second year of a 3-year degree and this project forms part of their mandatory Methods of Geographical Analysis module.

The remaining sections of this paper are structured as follows: Section 2 describes the unique climate data in image format and its origins. Section 3 describes the design of the CliDaR-Africa project. Section 4 presents the outcomes of the CliDaR-Africa project. Section 5 provides details on the results of a student feedback survey. Section 6 presents future plans and Section 7 the final remarks.

2 | DATA FOR DIGITIZING

Important data from the African Centre of Meteorological Applications for Development (ACMAD) collection have been recently rescued from unstable fiche and film media and scanned into digital images by the EU-funded Copernicus Climate Change Service and the Royal Meteorological Institute (RMI) of Belgium. The ACMAD initiative was created in 1985 by the UNECA Conference of Ministers of Economy and Finance to act as the continental weather/climate watch and the excellence centre on the applications of meteorology for development. The ACMAD images were originally rescued from hard copy paper format and transferred to microfiche by the RMI in the late 1980s and early 1990s from National Meteorological Services archives across Africa. Records are available in French or English depending upon the colonial history of the country. Due to the fragility of the microfilms and microfiches, they were all scanned into jpeg images by an ECMWF/C3S-funded project in 2021 as a priority activity to ensure preservation. The scanning produced over 4 million data images across 44 African countries including islands and island nations: Sao Tome and Principe, Cape Verde, Mauritius, Madagascar, Comoros and Seychelles. Table 1 presents a list of the 44 countries and includes the years covered by the data and the number of stations available for each country (note that not all individual stations in each country will span the period of record given). Major efforts are being made by the C3S2-311 team to tackle the huge task of getting some of the unique data in the ACMAD data image collection digitized. To this end, the first step was to ascertain what data exist in globally available archives so that unique data could be identified for digitization. In 2022, the C3S2-311 team collaborated with a Master of Sciences (MSc) student who was studying at ICARUS in Maynooth University, Ireland to produce an initial inventory of the ACMAD collection for his thesis dissertation. The student was successful in this task and was able to produce initial detailed inventories for 44 countries across Africa. The images contain climate observations dating back to the late 1800s with many station data images containing sub-daily and daily observations of temperature, precipitation, pressure, humidity, soil temperature, evaporation, weather phenomenon, wind and cloud as well as hydrological observations.

Greenhouse gases cause ongoing climate change but African countries have historically emitted and continue to emit amongst the lowest amounts of greenhouse gases on a per capita basis (Trisos et al., 2022). However, the same countries are experiencing widespread impacts attributable to human-induced climate change with biodiversity loss, water shortages, reduced food production, loss of lives and livelihoods and reduced economic growth (Nkwi et al., 2023; Sultan et al., 2019; Trisos et al., 2022). The population in African countries is disproportionately employed in climate-exposed sectors with over 60% of the African workforce employed in the agricultural sector, and the crops are completely dependent on rainfall (Sultan et al., 2013; Yobom, 2020; Zougmoré et al., 2016). The rural poor population in Africa is more at-risk from an increase in climate extremes and climate hazards (Mendelsohn & Wang, 2017; Thomson et al., 2011; Trisos et al., 2022; van Mil et al., 2014). Informal urban settlements are growing in African countries and with no basic services, the resident population is highly vulnerable to climate hazards, especially women, children and the elderly (Trisos et al., 2022). Appropriate climate impact research and the ability to predict climate change impacts across large areas of Africa are hindered by the lack of available historical and ongoing observational data (Dinku, 2019; Gebrechorkos et al., 2018). Due to this paucity of data, Africa must rely on global studies, including reanalyses, using data in many cases from outside the region to estimate the climate impacts and risks. Such products may

TABLE 1 List of African countries in the ACMAD collection, years of data coverage across the set of stations as a whole (not all stations will exist for all years) and number of stations per country.

Country	Data years	Station count	Country	Data years	Station count
Angola	1945–1973	23	Mauritius	1832–1994	198
Benin	1893–1994	61	Morocco	1960–1990	14
Botswana	1957–1993	13	Niger	1904–1990	253
Burkina Faso	1902–1990	163	Nigeria	1892–1992	78
Burundi	1922–1989	20	PRC	1897–1990	264
Cameroon	1926–1995	343	Central African Republic	1910–1994	141
Cape Verde	1910–1990	317	Rwanda	1910–1992	250
Chad	1901–1971	28	Sahel Region	1893–1965	80
Comoros	1928–1990	11	Sao Tome and Principe	1880–1994	224
Cote D'Ivoire	1905–1994	21	Senegal	1853–1999	207
Djibouti	1948–1988	4	Seychelles	1897–1995	69
Eritrea	1947–1994	6	Sierra Leone	1930–1992	94
Ethiopia	1952–1990	17	South Africa	1897–1992	375
Gabon	1894–1995	116	Sudan	1939–1992	104
Ghana	1933–1995	118	Swaziland	1897–1989	127
Guinea-Bissau	1940–1990	54	Tanzania	1921–1995	188
Guinea	1897–1994	109	The Gambia	1884–1989	76
Lesotho	1885–1995	128	Togo	1889–1990	16
Madagascar	1901–1989	343	Uganda	1931–1993	4
Malawi	1898–1996	244	DRC	1907–1989	1076
Mali	1897–1991	227	Zambia	1905–1995	114
Mauritania	1904–1984	53	Zimbabwe	1890–1991	107

not be sufficient to determine if African countries exhibit differential vulnerability, exposure or adaptive capacity (Thomson et al., 2011; Trisos et al., 2022).

Hence, when fully digitized, the ACMAD collection will increase the temporal and spatial data coverage for the African region which is highly vulnerable to climate change impacts. The digitized data will allow scientists to gain a better understanding of how climate has changed across African regions. The unique African data can also be assimilated into reanalysis data. Hawkins et al. (2023) demonstrated the importance of transcribing historical climatological observations from paper records for reanalysis, showing how they can improve our understanding of past extreme weather events. For example, Storm Ulysses in February 1903 across the United Kingdom and Ireland. Hawkins et al. assimilated the newly transcribed atmospheric pressure observations into the NOAA-CIRES-DOE 20th Century Reanalysis version 3 system (20CRv3; Compo et al., 2011; Slivinski et al., 2019, 2021). As a consequence, the storm intensity and structure are now more reliably represented in an improved reanalysis of the event, and current risk assessments from severe storms, based on modern period data, may need to be revised (Hawkins et al., 2023).

3 | CLIDAR-AFRICA PROJECT DESIGN

The first step was to identify unique African data that were suitable to be digitized. To achieve this, the inventories of the ACMAD data for each country had to be compared with existing digitized data held in numerous sources collated by the Copernicus C3S2-311 database effort, the International Surface Database, The International Surface Pressure Databank and known current and planned data rescue initiatives. Initial results identified unique data in the ACMAD collection exist for at least: Burkina Faso, Chad, Ghana, Guinea, Lesotho, Madagascar, Republic of Congo, Democratic Republic of Congo and Sierra Leone, with work ongoing and many more unique holdings likely to be identified still.

For in-classroom teaching, the C3S2-311 team selected two stations with contrasting climates, but both in data-sparse regions: Andapa, Madagascar in the southern hemisphere; and Macenta, Guinea in the northern hemisphere. For the student climate data digitization project, images for Macenta, 1947–1953 (missing data years 1949 and 1950) and Andapa, 1949–1958 (missing data years 1955 and 1956) were collated and prepared. The C3S2-311 team visually inspected the data images for both countries and found that they had consistent form layouts and mostly were good quality clear images. Figure 1 shows the location of each station and Table 2 provides details of each station in terms of temporal coverage and unique data identified. Although the team identified unique data for Macenta that spans from 1904 to 1993, only images from 1947 onward were in a consistent format and of usable quality in the student project. The same applied to Andapa where, while unique data are available from 1935, only images from 1949 were usable in this project. The C3S2-311 team will revisit the inconsistent forms for each station later and see if the data can be salvaged either by future cohorts or by other means.

The data image sheets for each station consisted of 3 separate sheets for each month of observations, with station name, month and year on each sheet with observations of parameters variously taken at 3 times a day and once-a-day intervals for each climate variable (see example in Figure 2). The first sheet contains precipitation and evaporation observations, the second sheet contains temperature, cloud and humidity observations and the third sheet contains pressure and wind observations. Due to these countries being former French colonies, the text is in French. The sheets also had a total and mean of all values entered at the end of each variable column, which provided useful information for quality checks post digitization.

The C3S2-311 team produced Excel template sheets with a layout of cells that exactly matched up to each of the 3 data image form types (see Figure 3). The C3S2-311 team created two station folders, one for Macenta and one for Andapa, and each folder contained sub-folders with 3 separate data sheet images from 1 month of observations and 3 separate Excel template forms that match the original data sheet images. The folder also contains an Excel spreadsheet called additional_notes.xlsx to record any issues encountered in the process. These station folders were hosted on the Maynooth University online teaching platform for student access.

The class of approximately 150 students was divided into three groups (Groups A, B and C). Each student was tasked with digitizing 2 months of data, 1 month for a station in Madagascar and 1 month for a station in Guinea, that is, six data sheets in total. Each station month was assigned to a student in both Group A and Group B, and in some cases to the smaller Group C, so that all data were

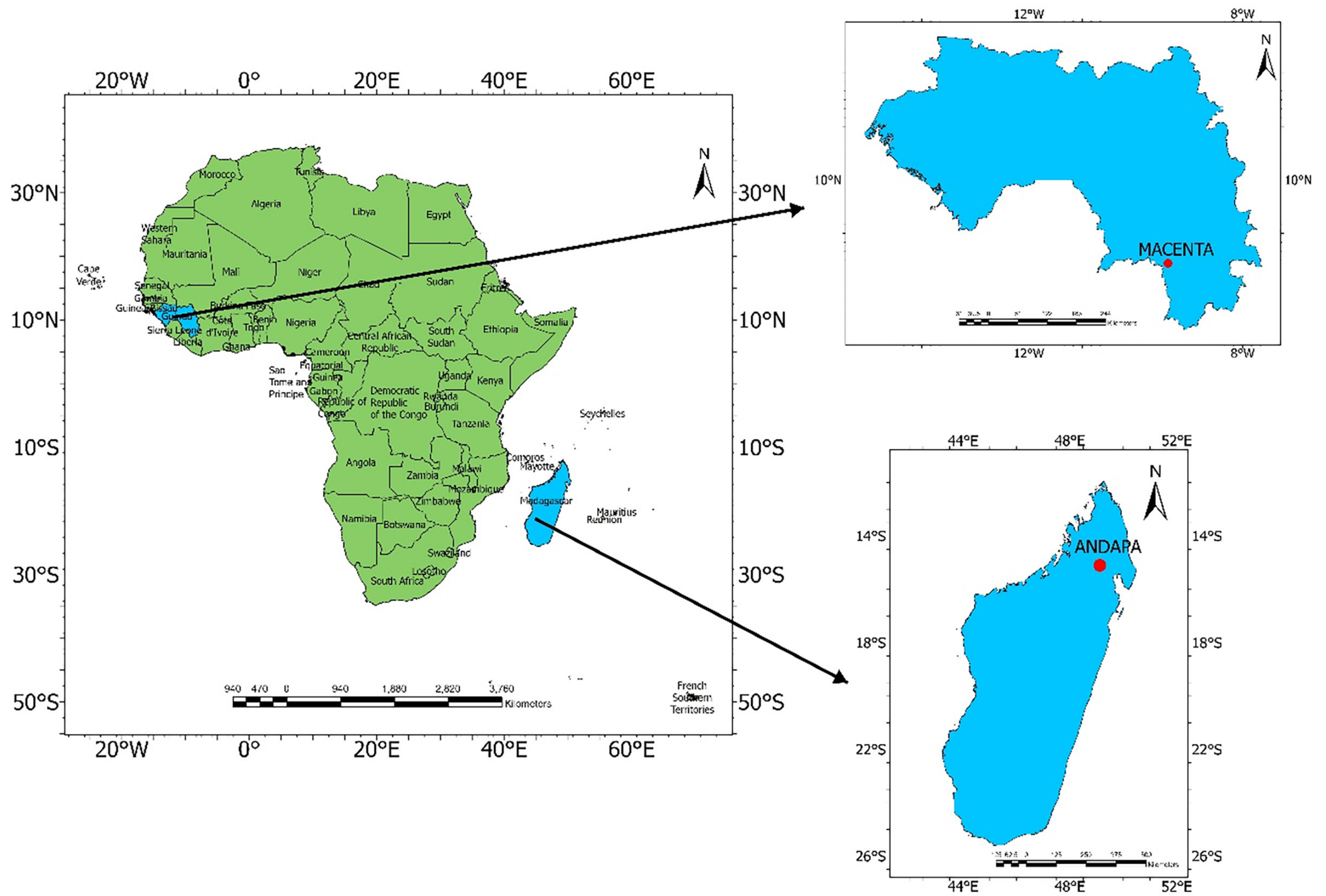


FIGURE 1 Map of Africa showing the location of two countries of focus for the CliDaR-Africa project, Guinea and Madagascar (highlighted blue). Two map inserts show the location of the two chosen stations Macenta and Andapa.

TABLE 2 Details on two stations chosen for the student digitization project.

Station name	Latitude/longitude/ elevation	Unique data identified for digitizing	Prepared unique data for student digitizing project	Total months of data images prepared for digitization
Macenta, Guinea	9.57, −13.61, 554 m	1904–1993	1947–1953 (missing years 1949 & 1950)	60
Andapa, Madagascar	−14.65, 49.617, 474 m	1935–1989	1949–1957 (missing years 1955 & 1956)	79

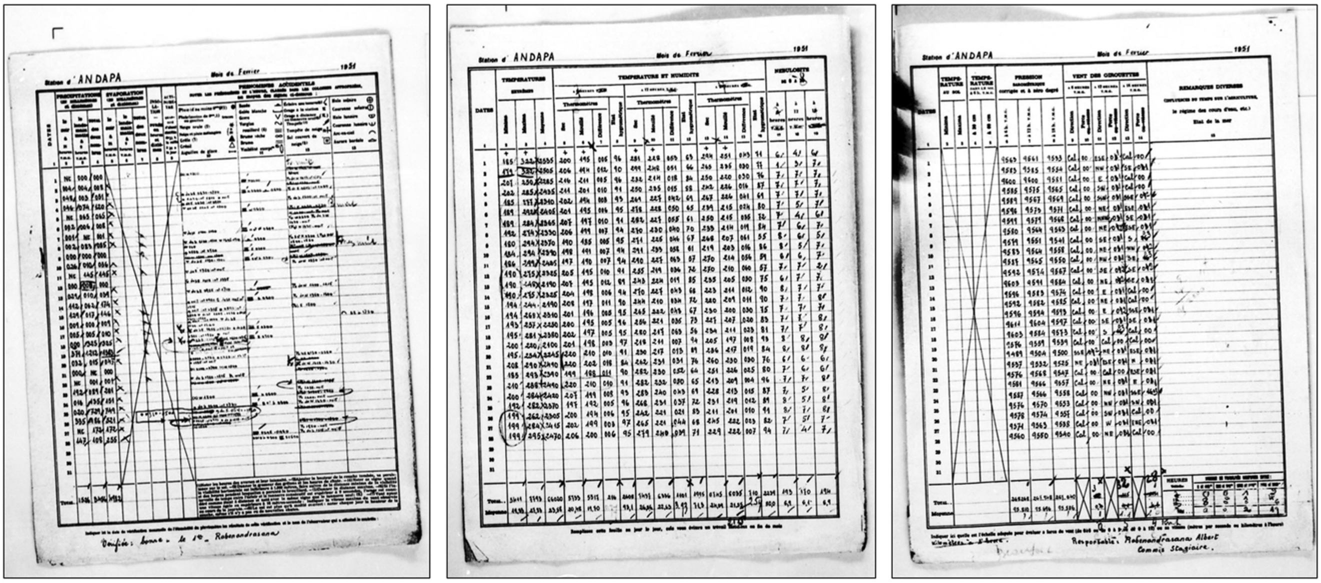
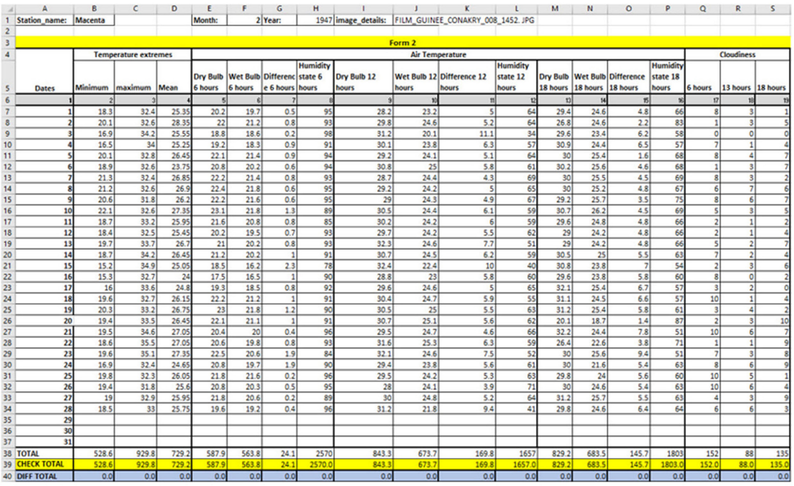


FIGURE 2 Example of the 3 forms for 1 month of data during February 1951 at Andapa, Madagascar. The first sheet on the left contains precipitation and evaporation observations, the middle sheet contains temperature, cloud and humidity observations and the sheet on the right contains pressure and wind observations.

either double- or triple-keyed for quality control purposes. This is in line with the WMO data rescue best practice guidelines (WMO, 2016).

Students had to download their allocated station folders to a local storage drive and open the first image. The students were able to zoom in to see values on the data image sheet more clearly and then they were instructed to open the matching Excel template. When the two Windows Explorer browsers were open, the students could resize them side by side. For traceability and quality control, the students had to add the image details to the template file at the top of the sheet where indicated: for example, FILM_MADAGASCAR_001_1746, and this was found from the data image sheet name. Next, the students had to add the month (by number e.g. July=7) and the year of the observations to the Excel template which could be found on the data image sheet. As the form language was French, we provided a 'French_month_translate' document to avoid any confusion for the students.

Students were then instructed to key in exactly what they saw on the data sheet images to the corresponding cell in the matching Excel template including the total of all entered values which was written at the end of each column. In addition, the formula total checks at the end of each column of values in the Excel template allowed the students to check and make sure that there were no keying mistakes. If the check totals did not match, the student could check all the keyed values for that column again. Once checked and if the totals were still not matching, the student was instructed to make a separate note of the image details and outline the issue in the additional_notes.xlsx for one of the C3S2-311 team to check later. Once all issues were entered in the additional_notes.xlsx, it was saved and renamed by concatenating the student's group, the station name, month, year and additional notes, for example, A_Andapa_12_1947_additional_notes.xlsx. Likewise, once all the values from the image were keyed into the Excel template, the files were saved and renamed by student's group, the station name, month, year and form type number 1, 2 or 3, for example, A_Andapa_12_1947_form1.xlsx. The C3S2-311 team also provided additional support to students such as step-by-step instructions, detailed guidance, online chat rooms, workshops and a frequently asked questions' troubleshooting document that



Station_name:	Macenta			Month:	2	Year:	1947	image_details:	FILM_GUINEE_CONAKRY_008_1452. JPG									
Form 2																		
	Temperature extremes			Air Temperature												Cloudiness		
Dates	Minimum	maximum	Mean	Dry Bulb 6 hours	Wet Bulb 6 hours	Difference 6 hours	Humidity state 6 hours	Dry Bulb 12 hours	Wet Bulb 12 hours	Difference 12 hours	Humidity state 12 hours	Dry Bulb 18 hours	Wet Bulb 18 hours	Difference 18 hours	Humidity state 18 hours	6 hours	13 hours	18 hours
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	18.3	32.4	25.35	20.2	19.7	0.5	95	28.2	23.2	5	64	29.4	24.6	4.8	66	8	3	1
2	20.1	32.6	28.35	22	21.2	0.8	93	29.8	24.6	5.2	64	26.8	24.6	2.2	83	1	3	5
3	16.9	34.2	25.55	18.8	18.6	0.2	98	31.2	20.1	11.1	34	29.6	23.4	6.2	58	0	0	0
4	16.5	34	25.25	19.2	18.3	0.9	91	30.1	23.8	6.3	57	30.9	24.4	6.5	57	7	1	4
5	20.1	32.8	26.45	22.1	21.4	0.9	94	29.2	24.1	5.1	64	30	25.4	1.6	68	8	4	7
6	18.9	32.6	23.75	20.8	20.2	0.6	94	30.8	25	5.8	61	30.2	25.6	4.6	68	1	3	7
7	21.3	32.4	26.85	22.2	21.4	0.8	93	28.7	24.4	4.3	69	30	25.5	4.5	69	8	3	2
8	21.2	32.6	26.9	22.4	21.8	0.6	95	29.2	24.2	5	65	30	25.2	4.8	67	6	7	6
9	20.6	31.8	26.2	22.2	21.6	0.6	95	29	24.3	4.9	67	29.2	25.7	3.5	75	8	6	7
10	22.1	32.6	27.35	23.1	21.8	1.3	89	30.5	24.4	6.1	59	30.7	26.2	4.5	69	5	3	5
11	18.7	33.2	25.95	21.6	20.8	0.8	85	30.2	24.2	6	59	29.6	24.8	4.8	66	2	1	2
12	18.4	32.5	25.45	20.2	19.5	0.7	93	29.7	24.2	5.5	62	29	24.2	4.8	66	2	1	4
13	19.7	33.7	26.7	21	20.2	0.8	93	32.3	24.6	7.7	51	29	24.2	4.8	66	5	2	7
14	18.7	34.2	26.45	21.2	20.2	1	91	30.7	24.5	6.2	59	30.5	25	5.5	63	7	2	4
15	15.2	34.9	25.05	18.5	16.2	2.3	78	32.4	22.4	10	40	30.8	23.8	7	54	2	3	6
16	15.3	32.7	24	17.5	16.5	1	90	28.8	23	5.8	60	29.6	23.8	5.8	60	8	0	2
17	16	33.6	24.8	19.3	18.5	0.8	92	29.6	24.6	5	65	32.1	25.4	6.7	57	3	2	0
18	19.6	32.7	26.15	22.2	21.2	1	91	30.4	24.7	5.9	55	31.1	24.5	6.6	57	10	1	4
19	20.3	33.2	26.75	23	21.8	1.2	90	30.5	25	5.5	63	31.2	25.4	5.8	61	3	4	2
20	19.4	33.5	26.45	22.1	21.1	1	91	30.7	25.1	5.6	62	20.1	18.7	1.4	87	2	3	10
21	19.5	34.6	27.05	20.4	20	0.4	96	29.5	24.7	4.6	66	32.2	24.4	7.8	51	10	6	7
22	18.6	35.5	27.05	20.6	19.8	0.8	93	31.6	25.3	6.3	59	26.4	22.6	3.8	71	1	1	9
23	19.6	35.1	27.35	22.5	20.6	1.9	84	32.1	24.6	7.5	52	30	25.6	9.4	51	7	3	8
24	16.9	32.4	24.65	20.8	19.7	1.9	90	29.4	23.8	5.6	61	30	21.6	5.4	63	8	6	9
25	19.8	32.3	26.05	21.8	21.6	0.2	96	29.5	24.2	5.3	63	29.8	24	5.6	60	10	5	1
26	19.4	31.8	25.6	20.8	20.3	0.5	95	28	24.1	3.9	71	30	24.6	5.4	63	10	6	4
27	19	32.9	25.95	21.8	20.6	0.2	89	30	24.8	5.2	64	31.2	25.7	5.5	63	4	3	9
28	18.5	33	25.75	19.6	19.2	0.4	96	31.2	21.8	9.4	41	29.8	24.6	6.4	64	6	6	3
29																		
30																		
31																		
TOTAL	528.6	929.8	729.2	587.9	563.8	24.1	2570	843.3	673.7	169.8	1657	829.2	683.5	145.7	1803	152	88	135
CHECK TOTAL	528.6	929.8	729.2	587.9	563.8	24.1	2570.0	843.3	673.7	169.8	1657.0	829.2	683.5	145.7	1803.0	152.0	88.0	135.0
DIFF TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

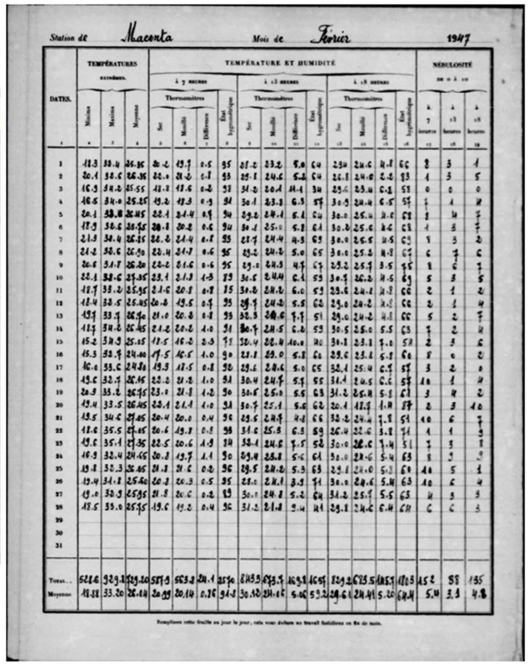


FIGURE 3 An example of the Excel template forms that students use to enter the values from the data image sheet.

provided solutions to potential issues that may arise. This document was consistently updated as any new issue was discovered.

The CliDaR project aligns with the Maynooth Geography Department curriculum and each student was given assignments worth 30% of the overall module grade. As well as transcribing 2 months of data images, the students also had to write a 900-word essay on the climate and climate change of a region in either Madagascar or Guinea. Students had to compare climate change at different scales, assess the vulnerabilities and impacts on the population in that region and evaluate the role of citizen science in helping climate change research to reduce future impacts. Assignment 2 was a group assignment where students had to create and present a 10-minute presentation on the climate of their assigned country. The presentation had to include details on the climate at Andapa/Macenta, the experiences and results of the digitization process, the climate at the assigned contemporary weather station and how climate change will affect the assigned country. Full details on the teaching technical details can be found in the Data S1.

4 | OUTCOMES OF THE CLIDAR-AFRICA PROJECT

The original transcribed data for Andapa and Macenta have been uploaded to the Pangaea data repository and are openly available. All the transcribed data from the CliDaR-Africa project will also be integrated into the C3S2-311 Collection and Processing of In Situ Observations database. The data will be merged or appended to any existing data at these two stations after which a suite of quality control methods will be applied to the observations. The daily observations quality control procedure is documented extensively in Menne et al. (2012) whereas the sub-daily observations quality control tests have been based on the suite of checks from the HadISD (https://www.metoffice.gov.uk/hadobs/hadisd/) global sub-daily station dataset (Dunn et al., 2012; Dunn et al., 2014; Dunn et al., 2022; Durre et al., 2010). Next, the C3S2-311 team will convert the quality-checked data format into a common data model format where it will be made openly and freely available to data users via the Copernicus Climate Data Store (https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-observations-surface-land?tab=overview) and the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI) data centre in the United States (https://www.ncei.noaa.gov/) through GHCNd and the new GHCNh product. Subsequently, all the CliDaR-Africa project sub-daily data will be assimilated into the ECMWF ERA6 reanalysis product.

4.1 | Details of errors identified in the transcribed data forms

The data were double-keyed by students with Group A transcribing one set of images with Group B and a small number of students in Group C transcribing the same set of images. The C3S2-311 team checked a full set of Group A transcribed forms and the matching full set of forms from Group B/Group C combined. The initial quality control involved visually checking each set of forms to check for differences between the stated and calculated monthly totals indicating keying errors. The difference value was generated automatically by the formula deducting the total stated value entered by students from the sum of all values entered against the column.

In general, most data forms from Group A and Group B/C had no issues and passed the initial quality control. The most common issue identified across both groups was keying errors for individual values and in all cases, the C3S2-311 team could correct this error by referring to the original image sheets. Another common issue identified was that some students in both groups did not key the total value from the data image sheet creating a difference error, and this was easily resolved by the C3S2-311 team again by referring back to the original image sheets and adding in the total from the imaged sheet.

Various other, more complex, issues were identified, such as some values in a column being unreadable due to poor image quality. In this case, if there were one or two such values, the keyed values were checked first, and if not readable, the C3S2-311 team entered logical values in the missing cells by trial and error until the total value difference was 0. However, if the value could not be fixed, the cell value was left blank and the issue was noted. Sometimes, a difference was identified whereby the total exists and disagrees with the transcribed values, but when the values in the data image sheet were visually checked, they were found to have been correctly transcribed. In such cases, the observer's total was deemed to be incorrect and adjusted accordingly to match. There were also some minor issues with student data image sheet allocations to the three groups due to final class numbers not matching the number of image sheets prepared. In addition, some students failed to download the correct allocated image sheets resulting in some datasheet images being keyed multiple times and some sheets not being double-keyed, with a small number of other sheets omitted. Consequently, 32 data image sheets had to be transcribed and completed by the C3S2-311 team to produce a full set of keyed data forms for each station. The pilot CliDaR-Africa project managed to transcribe 79 months of data for the station at Andapa, Madagascar and 56 months of data for Macenta, Guinea.

Table 3 shows the metrics of the initial quality control comparison between Group A and Group B/ Group C combined. The results are encouraging and show that most data image sheets were transcribed without any errors by all groups of students.

TABLE 3 Results of the C3S2-311 team's initial quality control of the data image sheets transcribed by the students in Group A and Groups B and C combined.

Station name and form type	Climate variables on sheet	Number of forms transcribed group A	Number of forms errors group A	% of forms with errors group A	Number of forms transcribed group B/C	Number of forms errors group B/C	% of forms with errors group B/C
Andapa, Madagascar-1	Precipitation and Evaporation	61	0	0	89	7	7
Andapa, Madagascar-2	Temperature, humidity and cloudiness	63	13	20	90	11	12
Andapa, Madagascar-3	Pressure, wind direction and wind speed	62	7	11	91	9	10
Macenta, Guinea-1	Precipitation and Evaporation	54	9	16	88	12	13
Macenta, Guinea-2	Temperature, humidity and cloudiness	56	11	19	75	10	13
Macenta, Guinea-3	Pressure, wind direction and wind speed	57	13	22	91	15	16

The results of the analysis for station Andapa show that form 2 had the most errors with 20% of forms (13/63) by Group A and 12% of forms (11/90) by Groups B/C needing corrections. Interestingly, form 2 had 18 columns of data to be transcribed: the most across all forms. It is therefore perhaps unsurprising that this form had the most errors. Only 11% of Group A's form 3 (7/62 forms) for Andapa needed correcting and 0 of form 1. Groups B/C had 7% (7/89) of errors in form 1 and 10% (9/91) of errors in form 3 for Andapa.

Results show that form 3 for Macenta had the most errors with 22% (13/57 forms) for Group A. Groups B/C performed slightly better and only had errors in 16% (15/91 forms) for Macenta Form 3. Group A form 2 for Macenta required corrections in 19% of forms (11/56) and 13% (10/75) for Groups B/C. Group A had 16% (9/54 forms) errors in Form 1 for Macenta, whereas Groups B/C only had 13% (12/88) errors.

The C3S2-311 team noticed that some of the errors made by Group A were also made by Groups B/C. The most common errors across the groups were incorrect totals being entered and incorrect values being keyed due to the poor quality of an image. Overall, the forms for Macenta were of lower image quality and thus proved more problematic than the Andapa forms, with issues such as blurred values, unreadable values, incorrect totals and missing values.

The C3S2-311 team compiled one full set of initially quality-checked transcribed forms for each station. Figure 4 presents 5 plots showing the daily observations at station Andapa, Madagascar for minimum temperature, maximum temperature, mean temperatures, precipitation, station level pressure and wind speed over the period 1949–1958 with missing data years in 1955–1956. Figure 5 presents six plots showing the daily observations at station Macenta in Guinea for minimum temperature, maximum temperature, mean temperatures, precipitation, station-level pressure and wind speed over the period 1947–1953 with missing data years in 1949–1950. Note that station-level pressure and wind speed daily values derive from the arithmetic average of the original recorded sub-daily values for visualization purposes, all other variables are original daily recorded values. In addition,

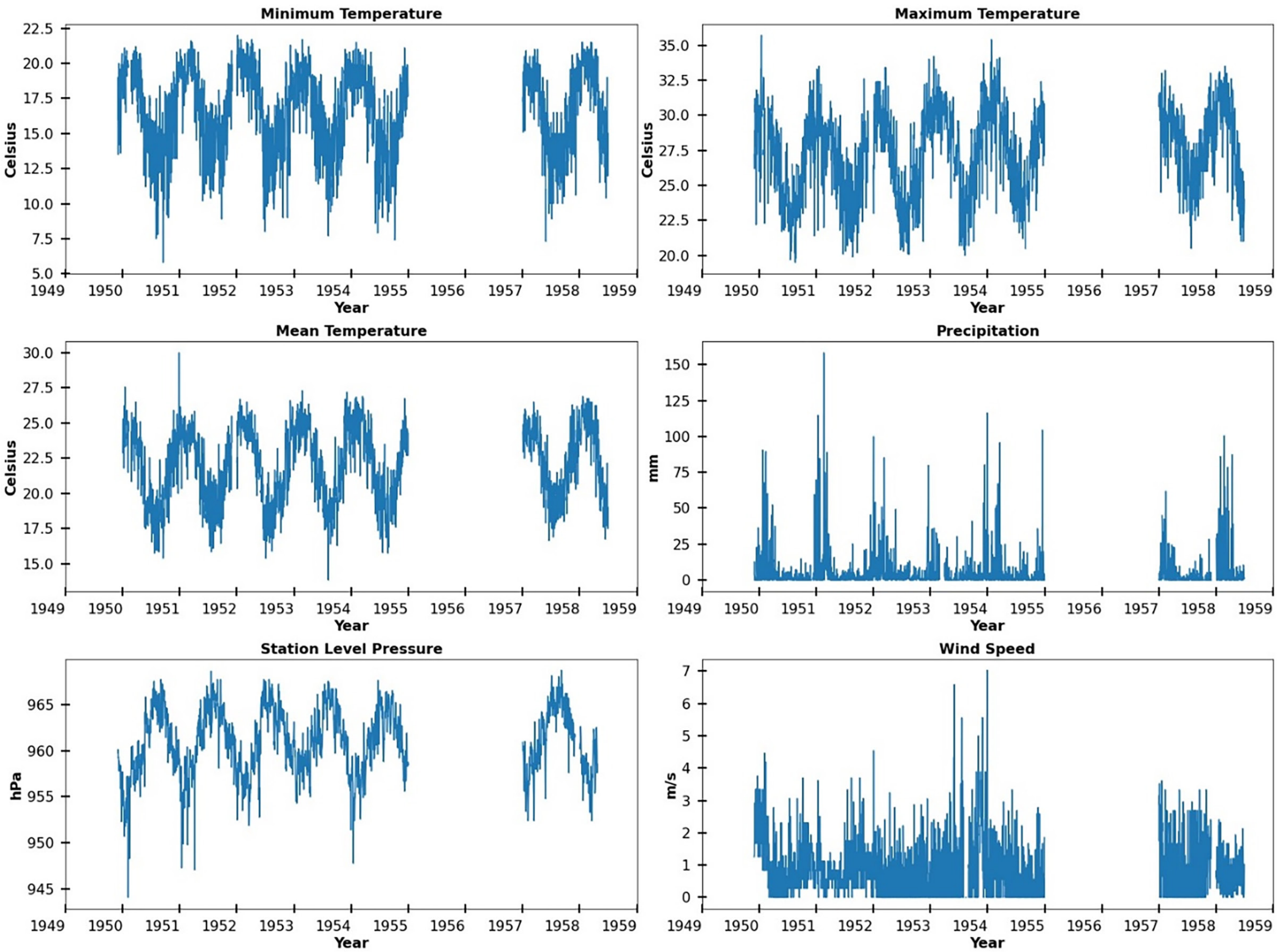


FIGURE 4 Six variables at station Andapa, Madagascar 1949–1958 (missing years 1955–1956) digitized by students. Temperature and precipitation variables are original daily values and station level pressure and wind speed derive from the arithmetic average of the sub-daily values.

the wind speed observations at both stations were originally recorded in either Beaufort-scale or kilometres per hour. For this paper all original wind observations have been converted to the WMO-recommended International System of Units (SI) for a wind velocity of metres per second (m/s). The equation used to convert the Beaufort-scale wind speed observations to metres per second is as follows: $W = 0.836B^{3/2}$ where W is the wind speed in m/s and B is the value on the Beaufort-scale (Icelandic Met Office, 2008). This equation calculates the appropriate median values for that Beaufort number and is approximated to the nearest integer. The equation used to convert the kilometres per hour wind observations to m/s is as follows: 1 km/h = 0.277778 m/s (Icelandic Met Office, 2008).

Andapa has a tropical wet and dry or savannah climate (Köppen-Geiger classification: Aw = Tropical savannah, wet climate) with two main seasons, a hot and wet period from November to April and a dry season from May to October. Macenta has a tropical monsoon climate (Köppen-Geiger classification: Am = tropical monsoon climate) with a dry season from January to March and a heavy monsoon season for the rest of the year and no cold season. The rescued data at both stations generally make sense in terms of seasonality and all the highest and lowest values for each variable have been visually inspected by checking the original image sheets and verified as entered correctly. All the highest and lowest recorded observed values for each variable are available in the Data S1 of the paper. As stated previously, more quantitative quality control checks will be conducted by the C3S2-311 team downstream of this project in the processing chain including additional intra- and inter-station series checks.

The C3S2-311 team found that currently there appears to be only daily temperature and precipitation existing digitized data for Andapa, Madagascar. However, the data are not consistent and contain a large amount of missing data. In fact, Randriamarolaza et al. (2022) had to exclude Andapa from their study due to the incompleteness of the data. The data digitized by the CliDaR-Africa project will contribute towards filling in some of these data gaps in the existing daily temperature and precipitation data at Andapa. In addition, there are some existing digitized sub-daily data at

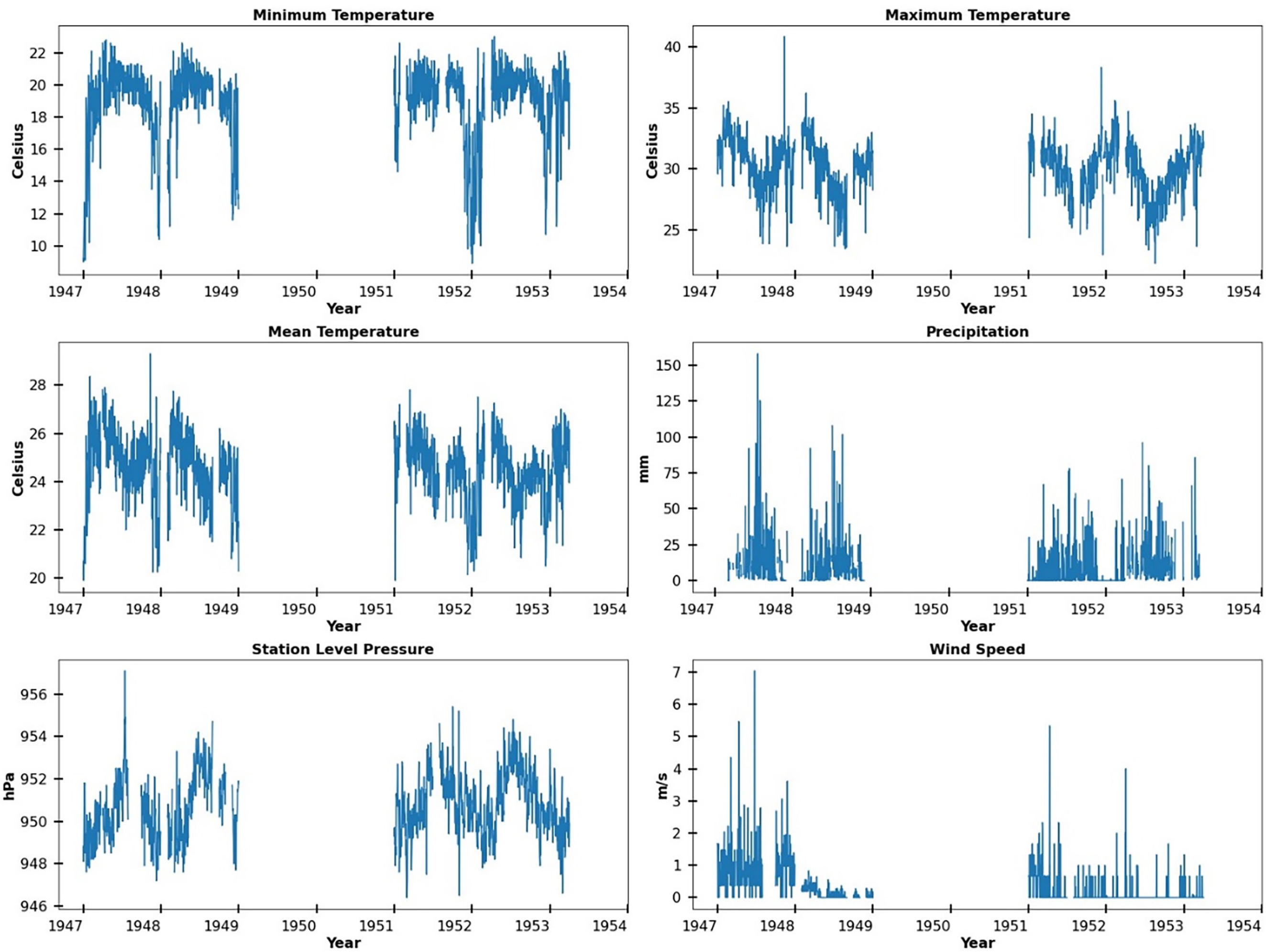


FIGURE 5 Six variables at station Macenta, Guinea 1947–1953 (missing years 1949–1950). Temperature and precipitation variables are original daily values and station level pressure and wind speed derive from the arithmetic average from the original sub-daily values.

Andapa from 1973 to 2017 but it is temporally inconsistent, hence the CliDaR-Africa project will add new historical sub-daily observations of humidity, cloud, pressure, wind and evaporation at Andapa. Future CliDaR-Africa projects will focus on digitizing the remaining images at Andapa to attempt to create a consistent dataset from 1935.

Macenta, Guinea currently has some existing digitized daily temperature and precipitation data from 1945 to 1995 but the station has sporadic large amounts of missing data. There are some existing digitized sub-daily pressure data for Macenta (1949–1955), but this also contains some missing data. The CliDaR-Africa project digitized data for Macenta can be used to fill some of the gaps in the existing daily temperature and precipitation data, as well as in filling the sub-daily pressure data. Additionally, the CliDaR-Africa project has extended the pressure data observations at Macenta by another 2 years back to 1947. Furthermore, the CliDaR-Africa project has added new historical sub-daily observations for humidity, cloud, wind and evaporation at Macenta. Future CliDaR-Africa projects will focus on digitizing the remaining images at Macenta and strive to create a consistent dataset of all variables from 1904.

5 | STUDENT FEEDBACK

It was important that we developed a project that provides a positive experience for students. The students were fully informed that the survey results and their suggestions would be used to assist in improving teaching and improving the project in the future. It was also stressed that all responses are completely anonymous and no personally identifying data would be gathered. By participating in the survey, the students gave their consent to use the results for any reasonable purpose. The following section will present some examples of the survey questions and will provide the details of the student responses for each question. There were 152 responses to each question in the survey. The full results of the survey are provided in the Data S1 of this paper.

Question 1 asked for responses from students to 11 statements, measured on a five-point Likert scale; strongly agree, agree, neither agree nor disagree, disagree or strongly disagree. The results are presented in Figure 6.

The results of question 1 are generally very positive with 8 of the 11 statements receiving greater than 65% of positive responses (combined results for agree and strongly agree), two out of 11 statements received 45% and 49% respectively of positive responses and one statement received 38% of positive responses. In contrast six out of the 11 responses received 5% or less of negative responses (combined results for disagree and strongly disagree) with the remaining five statements showing that they received a range between 11% and 31% of negative responses.

For question 2 students were asked to score seven items from 1 to 10 indicating how important the item provided was in enabling them to successfully complete the assignment (1 is not important and 10 is very important). The results (Figure 7) show that students felt the teaching team had provided sufficient supports and clear guidelines. Overall, each score was higher than 7.5 out of 10 indicating very positive responses, with 'in-class support' scoring 9 out of 10 justifying the inclusion of an entire two-hour session of direct support.

The next three open-ended questions allowed students to provide feedback on the project. The responses presented here have been categorized into overall common themes. We present each of these questions and the main common themes compiled from all the responses:

5.1 | Question 3 please indicate three aspects of this assignment that worked well

Theme 1. Students were happy with the support given, particularly the help received in class and the online assistance.

Theme 2. Students were happy that they learned how to use some new skills especially tools in Microsoft Excel.

Theme 3. The uniqueness of the assignment was a common theme. Responses included that it 'was a different type of assignment', that it was a 'very interesting research project' and 'a nice change to essays'.

5.2 | Question 4 please indicate three aspects of this assignment that could be improved

Theme 1. Students felt that clearer images would work better next time.

Theme 2. Students felt the time required to complete the sheets and the accompanying essay was too short.

Theme 3. Students felt that they needed more assistance working with Microsoft Excel.

5.3 | Question 5 please add any other thoughts/comments you have about the project (good or bad) below

Theme 1. Students understood the importance of digitization and its benefits to the wider scientific community.

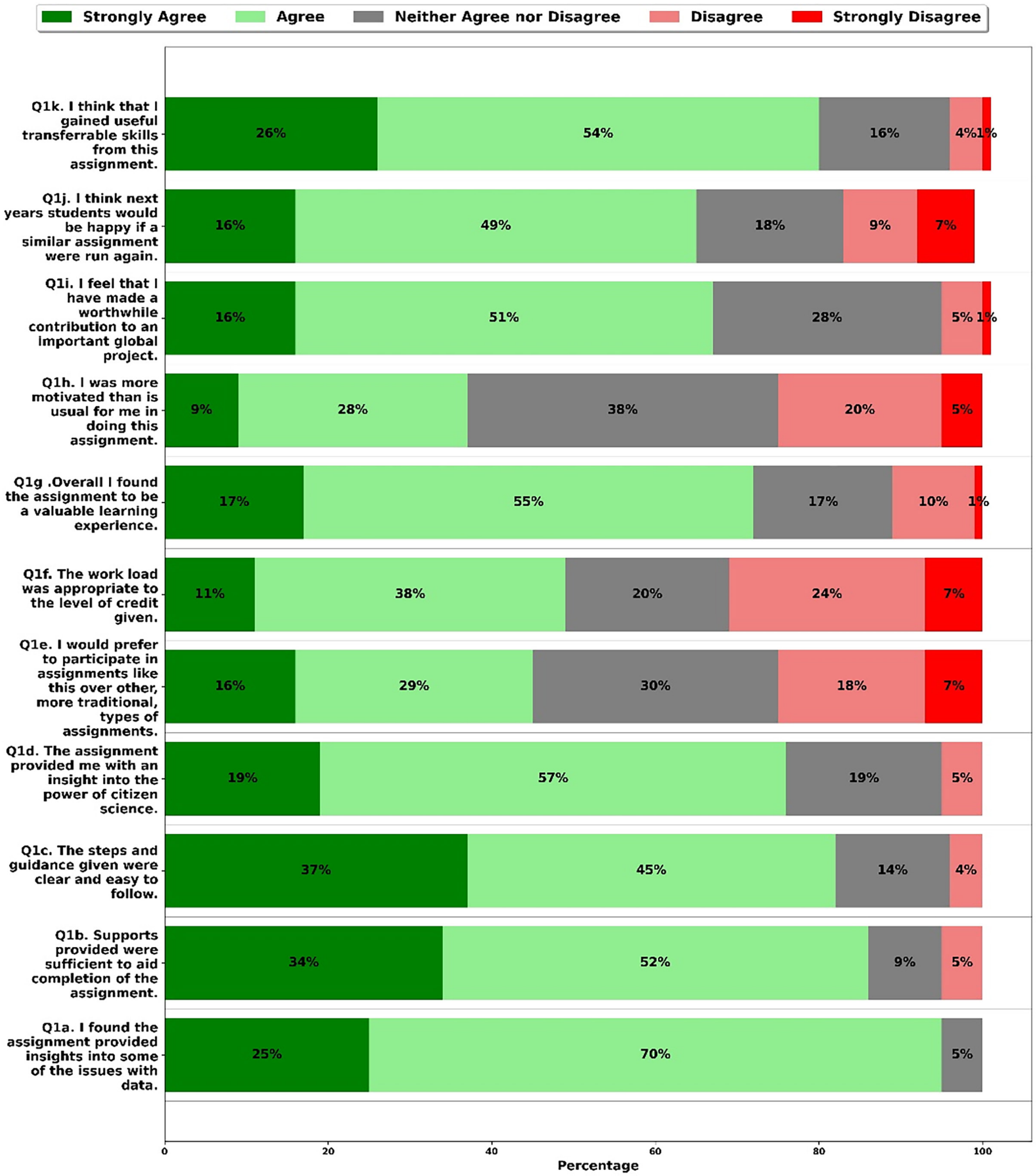


FIGURE 6 Percentage of responses to the 11 statements (1a to 1k) of question 1 of the student survey. The plot bars the percentage of responses to each statement divided by categories; strongly agree = dark green, agree = light green, neither agree nor disagree = grey, disagree = light red and strongly disagree = dark red.

Theme 2. Many students took issue with the overall workload of the project and the time allocated to complete it.

Theme 3. Students found the project interesting and enjoyable.

6 | FUTURE PLANS

Given the success of the initial CliDaR-Africa project, the project will continue to be run in the 2nd year Geography skills module for students at Maynooth

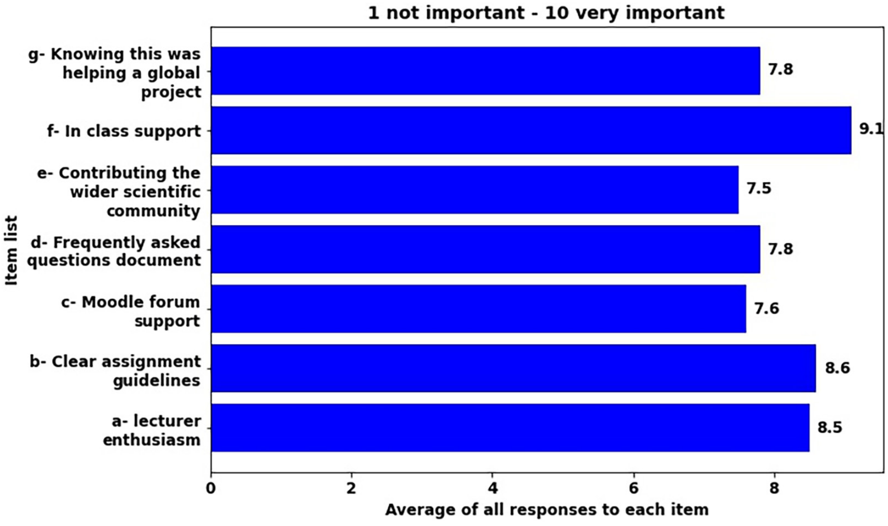


FIGURE 7 Results of student feedback survey question 2 as an average of all the student responses to each item. For each of the items listed, the students gave a score from 1 to 10, indicating how important it was in enabling them to successfully complete the assignment. 1 is not important and 10 is very important.

University. The C3S2-311 team will adapt the project going forward based on the student feedback and lessons learned. For example, one of the main points highlighted by students in the feedback survey was that they felt the workload was too much for the time allocated to complete the transcribing and assignments. The C3S2-311 team will work with the Maynooth geography teaching team to ensure that the project is adapted in the future so that students have adequate time to complete all the tasks required. In addition, lessons were learned from the pilot project, and issues were identified with students downloading the incorrect folders which resulted in some data not being double-keyed. Hence, to ensure that the images are allocated correctly in the future, the folders containing the images for transcribing and templates will include the student university identifier in the zipped folder name, for example, ambodifotatra_1_67135099.zip. These zipped folders will be uploaded to the Maynooth online teaching platform where each student can identify their folder and download it.

It is important to recognize that the project has barely scratched the surface of the challenge of digitizing the billions of images in the ACMAD collection. To that end, the CliDaR-Africa project is being made freely available for other educational institutions to incorporate into their curricula. Using personal contacts and peers other universities have been contacted to ascertain if they can adopt the CliDAR-Africa project model and develop similar projects with their students. Subsequently, several universities have already expressed an interest in rolling out similar CliDaR-Africa projects with their students. The team will also be contacting the Science Education Resource Centre (SERC) at Carleton College in Northfield, Minnesota, US with a view to them showcasing the CliDar-Africa project and assisting us to engage with the wider education community (https://serc.carleton.edu/serc/about/index.html).

The C3S2-311 team is also planning within the next year to contact universities located in the ACMAD data African countries via the Irish Department of Foreign Affairs to see if it is feasible for their students to help transcribe some ACMAD data for their own country. The C3S2-311 team will also liaise with Maynooth University Research and Development and International offices to capitalize on existing links to African Universities.

The C3S2-311 team has also been actively investigating whether the CliDAR-Africa project can be adapted so that secondary-level school students can become involved in digitizing some of the important African meteorological observations. So far, the team has received a positive response from several local secondary schools. Even if the expectations of digitization per student are necessarily lower, the potential for secondary students to rescue large volumes of climate data efficiently and effectively is significant given the substantial number of students.

The pilot project also identified issues with poor quality images which hindered students in the data rescue process. Therefore, it is critical to consider carefully the image quality and filter out unreadable images. To this end, the C3S2-311 team is also currently developing a citizen science project using the Zooniverse platform (https://www.zooniverse.org/). The citizen science project is being developed so that contributors could pre-screen quality check some of the millions of ACMAD data sheet images identifying good quality readable images for transcribing in the future. This citizen science project would save the team many personnel hours and considerably speed up the digitizing of the ACMAD data sheets.

7 | FINAL REMARKS

This paper introduces the CliDaR-Africa project and has shown the potential for students to efficiently and effectively digitize a relatively large amount of climate data from data image sheets. The second-year undergraduate Geography students at Maynooth University successfully transcribed over 6 years of climate observations at Andapa in Madagascar and over 5 years of climate observations at Macenta in Guinea. The newly digitized African data for Madagascar and Guinea will increase the existing temporal and spatial coverage of data in this important data-sparse region, where climate change impact studies are crucial. The data will allow the wider scientific community to conduct more robust climate extremes assessments. The data will also provide a basis for verifying future projections, allowing for more appropriate adaptation plans to be implemented. The results of the student feedback survey are positive, with most students stating that they gained useful new and transferrable skills and felt like they were contributing to an important real-world project. Overall, the students felt that the materials, supports and guidance given were sufficient to help them complete the project. The C3S2-311 team will take on board students' comments and suggestions (positive and negative) to adapt the project to ensure students gain optimal educational outcomes. We encourage other organizations to investigate the potential for university students to engage in similar projects and open CliDaR-Africa to interested parties. If you wish to get involved in digitizing some of the ACMAD data, we encourage you to contact the corresponding author. We will share all current CliDaR project resources and we will provide the ACMAD data images along with Excel templates. Finally, students are intensely aware of the challenge of climate change that will confront them for the rest of their lives, yet at the same time frustrated at a lack of ability to do anything about it. We contend that projects like CliDAR-Africa allow students to be part of and contribute to a real-world global climate project, learn new skills, and gain a better understanding of climate change. This may help address issues around climate anxiety as well as improving climate literacy. When, in the future, the students see, for example, the global temperature curve, they can rightly claim to have made a small contribution to this piece of scientific knowledge.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

OPEN RESEARCH BADGES

This article has been awarded Open Data Badge for making publicly available the digitally-shareable data necessary to reproduce the reported results. Data is available at [https://doi.org/10.1594/PANGAEA.964649].

DATA AVAILABILITY STATEMENT

The data for this paper is accessible from Pangaea data repository (https://doi.org/10.1594/PANGAEA.964649) and will be included in the Copernicus C3S2 311 Lot 1 Global Land and Marine Observations Database (https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-observations-surface-land?tab=overview) and served openly and freely through the C3S Climate Data Store (https://cds.climate.copernicus.eu/\#!/home).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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