AFRICA’S CLIMATE
HELPING DECISION-MAKERS
MAKE SENSE OF
CLIMATE INFORMATION
Future Climate for Africa | Africa’s climate: Helping decision-makers make sense of climate information

TOOLS FOR OBSERVING AND MODELLING CLIMATE

AUTHORS
Chris Jack, Piotr Wolski, Izidine Pinto, Victor Indasi

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INTRODUCTION

Atmospheric observations form the bedrock of climate science. We need observations in order to continue advancing our understanding of the climate system. This involves an analysis of the variability at inter-annual and longer time scales, as well as analysis of trends, and the relationships between variables. We also use observations to validate the increasingly complex and sophisticated climate simulation models. Without this, we are unable to continue improving models and increasing the accuracy of climate projections.

However, observing the climate system is incredibly challenging. Spatial scale is a challenge, particularly since two thirds of the atmosphere is over ocean, where we cannot easily place weather stations. Conditions here are continually changing, minute by minute, and hour by hour. We increasingly need to measure temperature, wind speed, and humidity at high altitudes as we search for a better understanding of important features, such as the polar jet streams. Measuring wind speeds at 5km altitude above the southern oceans, for example, creates some unique challenges.

There are two broad types of observations of climate systems. Earth-based (‘in situ’) measurements include data from weather stations, radiosondes, buoys, and similar platforms. Space-based (‘remotely-sensed’) observations include data from satellite platforms.

There are obvious and significant differences between these two types of observations. The in situ observations provide a direct, precise, and relatively continuous measurement of a particular variable, for instance, wind. Those measurements are, however, representative of a very small area. The space-based observations are obtained indirectly, and may not be precise. For instance, measurements of wind over the ocean rely on wind causing ripples on the ocean surface; these are measured by a backscatter of the microwave ‘radar’ signal, which is sent and received by a satellite.

Space-based platforms represent a larger area (typically tens of metres to several kilometres); they may have large spatial coverage, sometimes even global; and they have relatively uniform temporal coverage (e.g. every three hours, or daily).

It is critical to note that space-based observations are also reliant on Earth-based observations to calibrate and check their estimates. Backscatter-based ocean wind estimates,
as described above, are only possible because of accurate Earth – or ship-based wind speed observations against which algorithms can be tested and calibrated.

OBSERVATIONAL PRODUCTS

Both Earth-based and space-based observations are available through an ever increasing array of observational products, from a range of sources. Observational products are typically post-processed versions of the original raw observations. Post-processing is used to convert raw measurements to useful variables, to adjust for known errors or biases in the raw data, as well as to produce types of data that are easier for others to use. Observational products generally fall into three categories:

• Direct Earth-based observed products (weather stations, ship observations, radiosonde, aircraft, etc.).
• Pure space-based and blended space and Earth data products.
• Re-analysis (or blended model/direct observations) products.

Earth-based products

These products include quality control original station observations, as well as products derived from these such as the CRU 3.23 rainfall dataset that use station-based rainfall observations. In the case of the CRU dataset, quality-controlled data from individual stations were added into the process to produce a uniform grid of data points spanning the entire Earth, and covering over 100 years. Such a product can be easily used at any place on Earth in a variety of applications such as trend analyses or hydrological modelling, with an advantage of relative consistency in space and time.

However, datasets such as CRU are still very dependent and vulnerable to raw weather station observations, and the spatial density of those observations. Similar to many parts of the world, the density of land-based station observations is on the decline. Figure 1 shows the average density of observing stations for the southern African region, spanning a century. The latest CRU monthly rainfall dataset clearly shows a rapid decline in the number of stations contributing to the dataset during the last two decades of observations.

Satellite-based products

The second category covers a plethora of products ranging from sea surface temperature readings, to wind and rainfall. Satellite-derived rainfall datasets are particularly interesting because they can be used in numerous applications outside of climate science, for instance in hydrology, water resources, or agriculture. The Tropical Rainfall Measuring Mission (TRMM) rainfall dataset (now discontinued) and its successor, the Global Precipitation Mission (GPM), include three-hourly data with a resolution of a grid that is about 25km by 25km for the area spanning between -60º South and 60º North.

Satellite-based products can include satellite measurements only, or be a blend of satellite and in situ observations. For example, the recently developed Climate Hazards Group InfraRed Precipitation (CHIRP) rainfall dataset is based on processing of data from a number of satellite platforms. A version that uses station observations to adjust the satellite-derived values is called CHIRPS.

1 This is a relatively well-known dataset that was created in the Climatic Research Unit (CRU) of the University of East Anglia in the UK. Since the dataset is periodically updated, various updates differ in code. CRU 3.23 is the most recent update at the time of writing this factsheet.
Re-analysis
A third category is the ‘re-analysis’ products, which are able to merge observed data with climate simulations. Re-analyses use climate models to simulate long periods of historical climate (e.g. 1979–2015) just like a normal climate simulation, except the simulation is continuously being ‘corrected’ by historical observations of temperatures, pressures, and moisture. The process can be seen as a sophisticated interpolation scheme. Different re-analyses use different historical observations and use slightly different approaches to correcting the simulation. Some long climate reconstructions have been done that extend from 1850 through to 2014, and are corrected using long records of historical sea level pressure and sea surface temperatures.

However, there are strong differences between how these re-analyses represent the historical climate conditions, particularly in the tropics where there are few observations and the climate processes involved large exchanges of moisture and energy/heat in extensive rainfall systems. Figure 2 shows the correlation between two of the most common re-analyses, showing strong differences.

The NCAR Climate Data Guide is a valuable resource for searching through the range of observed climate data products available.

Climate scientists specialising in this area of observation and climate modelling, with a special focus on southern Africa (see FRACTAL, below), are compiling a catalogue of observed data products of relevance to the region.

AGREEMENTS AND CONTRADICTIONS IN TRENDS

It is clear that there is a large array of observed climate data products available to scientists. The question that commonly arises is which data product is ‘the best’, or which product should we use. This is a difficult question to answer, and the kind of product we choose is strongly dependent on the case and context in which each is used (where, over what period, and for what purpose).

There are three common types of uses:

- **Climate normals.** When the question revolves around how much it rains in a particular location, or what the average summertime temperature is, then we are interested in climate normals or averages. In this case we are looking for a dataset that has low bias or, in other words, has accurate average values for a particular location or area.

- **Climate trends.** A very common usage is figuring out if the climate in a location or region has changed over time. Again, surface observations are important here, for two reasons. Satellite observations are typically limited to the post-1980s or even later as there are very few satellite data products prior to that. For trend analysis, particularly rainfall trend analysis, statistics require that we look at at least 30 years of data.

- **Climate variability.** Lastly, a very common use is trying to understand the variability or changes in weather from year to year, and from decade to decade. Similar to trend analysis, this requires a dataset with a fairly long set of records, but also requires a dataset that represents natural variability well.

Researchers are putting effort into advancing our understanding of the suite of observed data products available. Some initial results are shown in Figure 3, which illustrates the differences in calculated long term trends across a subset of the available data products.

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2 The NOAA 20th century re-analysis: https://climatedataguide.ucar.edu/climate-data/noaa-20th-century-reanalysis-version-2-and-2c
that includes station-based products (Climatic Research Unit (CRU), Global Precipitation Climatology Project (GPCP), Global Precipitation Climatology Centre (GPCC), University of Delaware (UDEL)), satellite-based products (TRMM, CHIRP, Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), Climate Prediction Center Merged Analysis of Precipitation (CMAP)), and re-analysis products (WATCH-Forcing-Data-ERA-Interim (WFDEI)).

It clearly shows that there is significant disagreement between the trends calculated using different datasets, which should raise a red flag for anyone trying to understand historical climate trends using this data. What can also be seen is that some data products show similar trends. This is often because they draw on similar underlying source data such as station observations, or the same satellite sensor data. The end goal of this work is to be able to provide a framework to assist researchers in identifying the suitable single or set of data products to use in a particular use case.

CONSEQUENCES FOR CLIMATE SCIENCE AND DECISION-MAKING

Figure 3 highlights the potentially large differences in results that we can obtain by using different datasets. For example, if we were interested in the historical trend in rainfall over western Zambia, in the important Kafue Flats region, and we selected the CMAP dataset because it has good spatial coverage, we might conclude that the region has been experiencing a steady reduction in rainfall over the past decades. However, selecting the commonly used GPCC dataset we might conclude the opposite.

This could have important consequences for research as we attempt to understand local responses in river flows with changing rainfall, or it could have large implications in policy and strategic development if the conclusions inform strategic planning for the region. It is therefore critical that observed data products are well understood before the conclusions we draw from them are used for further research or decision-making. A team of climate scientists and practitioners from South Africa and Europe are collaborating in order to contribute substantively to this process through the observed data selection framework.
**FCFA’S FRACTAL PROJECT**

**Project objectives**
One of the chief scientific challenges for understanding southern Africa’s climate is that different models give contradictory scenarios for climate trends in the next five to 40 years. FRACTAL’s team will advance scientific knowledge about regional climate responses to human activities and work with decision-makers to integrate this scientific knowledge into climate-sensitive decisions at the city-regional scale (particularly decisions relating to water, energy and food with a lifetime of five to 40 years).

Through scientific research, FRACTAL will contribute to improved understanding of climate processes that drive the African climate system’s natural variability and response to global change. By bringing together scientists and people who use climate information for decision-making, the project will enhance understanding of the role of such information. FRACTAL will distil relevant climate information that is informed by and tailored to urban decision-making and risk management. The team’s activities will understanding of how scientists from different disciplines can work effectively together. See www.futureclimateafrica.org/project/fractal/

**The institutions involved in FRACTAL are:**
- University of Cape Town
- Met Office (UK)
- Stockholm Environment Institute
- START
- ICLEI–Local Governments for Sustainability
- Swedish Meteorological and Hydrological Institute/ Sveriges Meteorologiska och Hydrologiska Institut
- Red Cross Red Crescent Climate Centre
- University of Oxford
- Aurecon
- Council for Scientific and Industrial Research
- US National Atmospheric and Space Administration
- Lawrence Berkeley National Laboratory
- European Commission Joint Research Centre
- City of Cape Town
- City of eThekwini
Figure 1
Plot of average station density – stations per 0.5deg x 0.5 deg (~50km by 50km) grid cell, for the southern African region (south of 10°S) from 1900 to 2014 for the CRU TS 3.23 rainfall dataset. Value of 0.3 corresponds to approximately 3 stations per 25,000km².

Figure 2
Maps of consistency for the day to day sequence of the daily time series of ERA-40 and NCEP–NCAR, two common datasets, showing the geopotential height (Z), temperature (T), and specific humidity (Q) in the upper and lower parts of the atmosphere respectively (top – 500 hPa; and bottom – 850 hPa), as revealed by the Pearson correlation coefficient. Colour darkening from yellow to black indicates increasing dissimilarity between the two datasets.3

Assessment of climate trends in various observational products. The panels illustrate rainfall trend (expressed in mm/decade) over the period 1979–2010 except for CHIRPS 0.05deg, CHIRPS 0.25deg & FEWS_ARC (1984) and TRMM (1998). Areas where the trend is positive (i.e. there is an increase in rainfall over that period) are shown in green, and areas where the trend is negative are shown in brown. Note that various products have different spatial resolution (finer or coarser ‘pixels’). Where trends are similar (e.g. panels 2, 3 and 4 in the middle row, and the one in the bottom-right corner), products are based on the same or similar raw dataset.

Maps: produced by the authors.