Policy-relevant findings of the DACCIWA project

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Cite as

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Key Findings

The EU funded project Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa (DACCIWA) produced the most comprehensive observational dataset of the atmosphere over southern West Africa to date. Analysing this dataset in combination with results of numerical modelling has led to the following conclusions:

**Air pollution concentrations and sources**
- Concentrations of small particles frequently exceed World Health Organization limits in southern West African cities.
- Annual concentration of gaseous pollutants do not currently exceed air quality guidelines but short term peaks may.
- Concentrations of small particles are highest in the dry season.
- During the rainy (summer) season, smoke from fires in Central Africa make a substantial contribution to air pollution in southern West Africa.

**Health impacts**
- The high particle concentrations in southern West African cities present substantial risks to public health and intensify common medical problems.
- The pollution impact is strongest in the rainy season and depends on pollution source.
- Domestic fires appear to be the most significant health risk due to extreme concentration levels.
- More aerosol observations, increased access to health statistics and associated socioeconomic data are needed.

**Emissions**
- Standard global estimates of human emissions are significantly underestimated for southern West Africa.
- Emissions of particles and organic gases from vehicles in southern West African cities are higher than those in other locations.
- Burning seemingly similar materials may lead to very different emissions.
- The underestimate in southern West African emissions likely leads to an underappreciation of the impacts of air pollution.

**Pollution impacts on weather and climate**
- A further increase in manmade pollution in southern West Africa will have a small effect on cloud properties due to the already high aerosol burden.
- An increased aerosol amount and/or shift to more water-loving particles will reduce the amount of sunlight reaching the Earth’s surface, impacting on the circulation, clouds and possibly rainfall.
- More research is needed to better quantify the impacts of anthropogenic particles in southern West Africa.

**Long-term outlook**
- Temperatures over West Africa are projected to rise by 1 to over 3°C by 2050 depending on geographical location, emission scenario and model used.
- Even the sign of future changes in rainfall remains highly uncertain.
- Pollution exposure in the future will be influenced by local and remote anthropogenic emissions and altered patterns of transport and dust emissions.

**Observations and models**
- An adequate air quality monitoring system is absent in southern West Africa.
- The meteorological station network is sparse and existing data are not always available for research.
- Satellite observations provide a wealth of information but need more validating.
- Computer models still struggle to realistically represent the complex atmospheric dynamics and chemistry in West Africa.
Implications for policy

**Improve air quality**
- Reduce emissions associated with domestic burning. Alternative fuels and stoves using gas or electricity would help to achieve this (http://cleancookstoves.org).
- Reduce biomass burning locally in West Africa and work with Central African countries to reduce their enormous fire emissions.
- Establish regulations to reduce the sulfur content of fuels and to modernize the fleet of two wheel, four wheel and heavy goods vehicles.
- Work with Sahelian countries to reduce land degradation and thus dust emission.

**Improve emission inventories**
- Improve access to reliable socio-economic data for countries, regions and cities.
- Encourage studies on regionally specific emissions factors for activities such as waste burning, transport and domestic combustion.

**Improve observations**
- Install networks for long-term measurements of air pollutants focusing on cities and suburban areas.
- Sustain and expand networks for observations of meteorological data (e.g. surface stations and weather balloons), including an adequate sampling of the daily cycle.
- Make all these observations accessible to the international research, weather forecasting and climate community.

**Support research and capacity building**
- Fund and support follow-up research activities in Africa and Europe to work on the many open questions left at the end of DACCIWA.
- Support building capacity in weather, climate and air pollution science in Africa.
- Support improvements of computer models and satellite datasets for West Africa.
Introduction

Funded by €8.75M from the European Commission’s Framework 7 programme the Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa (DACCIWA) project investigated the processes controlling air pollution, atmospheric composition, weather and climate over southern West Africa and their influence on health.

The field campaigns

During June–July 2016 extensive measurements were made from three surface meteorological supersites, eleven meteorological balloon launch sites and three research aircraft (Figure 2). In addition, measurements of urban pollution were made from 4 air quality sites between 2015 and 2017.

The project had partner and collaborator institutions from Benin, Côte d’Ivoire, France, Germany, Ghana, Nigeria, Switzerland, Togo and the United Kingdom.

Over the last 2 years DACCIWA scientists have been analysing data collected over West Africa from field programmes and satellites. This document outlines their initial policy relevant conclusions.
Air pollution concentrations and sources

Air pollution is a key global risk with the World Health Organisation (WHO) estimating 8 million people a year dying prematurely from breathing polluted air. DACCIWA made observations from the ground and from the air, to measure the concentrations and sources of air pollutants.

Concentrations of small particles frequently exceed WHO limits in southern West African cities.

Measurements of small particles suspended in the air (known as PM2.5) were made in the cities of Abidjan and Cotonou [Djossou et al. 2018]. The sites were close to major sources of air pollution: waste burning at a local landfill site, motor vehicles and domestic fires for cooking. All sites show PM2.5 concentrations almost continuously above 10 μg m⁻³ (the WHO annual limit) and regularly above 25 μg m⁻³ (WHO 24 hour limit) (Figure 3). These concentrations are higher than those typical for European cities but are less than those in Asia.

Annual concentration of gaseous pollutants do currently not exceed air quality guidelines but short term peaks may.

Long-term observations do not exist for gaseous pollutants (ozone O₃, nitrogen dioxide NO₂, sulfur dioxide SO₂) in southern West African cities. For DACCIWA bi-monthly surface observations were made during 2015-2017 at the four air quality measurement sites as well as the airborne observations during the summer of 2016. These pollutants did not exceed WHO limits [Bahino et al. 2018]. However, it seems likely that NO₂ exceedance could occur on specific days.

Concentrations of small particles are highest in the dry season.

The highest monthly PM2.5 concentrations are seen in the dry (winter) season (Figure 4). This is due to a combination of enhanced desert dust from the Sahara and smoke from the burning of savannah / agricultural land within southern West Africa on top of the local human pollution. Local wood burning emissions maximize in the rainy (summer) season due to less efficient burning of wet wood. The same seasonality was seen for other pollutants such as NO₂.

During the rainy (summer) season, smoke from fires in Central Africa make a substantial contribution to air pollution in southern West Africa.

Changes in the circulation and rainfall in the wet (summer) season, reduce the impact of desert dust and local agricultural and savannah fires. However, smoke from savannah and agricultural burning in Central Africa can be blown thousands of kilometers to the coast of southern West Africa (Figure 5). Remarkably, in these months 20–40% of the particle mass is produced from these Central African fires and transported into the region.

Air pollution in southern West African cities has a complex mix of sources which changes over the year, but is often above WHO levels with implications for human health.
Health Impacts

High concentrations of aerosols have an adverse impact on health through increased respiratory, cardiac and dermatological illness. A halving of air pollution emissions in Africa could reduce air quality deaths by a third [Lioussé et al., 2014]. DACCIWA focused on the cities of Abidjan and Cotonou and for the first time investigated how the local population is impacted.

The high particle concentrations in southern West African cities present substantial risks to public health and intensify common medical problems.

Using the number of medical visits as a proxy for adverse health outcomes, long term relative risk values were calculated for each municipality in Abidjan. This describes the relationship between long-term exposure to PM2.5 and respiratory, cardiac and dermatological health, as well as emergency room mortality. We estimate the number of visits to the emergency room could be reduced by 3–4% for respiratory or cardiac issues and that up to 4% of emergency room mortalities could be avoided with a reduction of PM2.5 concentrations to the WHO recommended limit of 10 µg m⁻³.

The pollution impact is strongest in the rainy season and depends on pollution source.

Analyses for all three measuring sites in Abidjan show significant correlations between the number of hospital visits and PM2.5 concentrations, primarily during the rainy season. This suggests that humidity may play a significant role in the interaction between particulate matter and health, possibly through helping bring pollutants into the lungs. The associations we see between particulate matter and health outcomes differ for each metropolitan area, suggesting not only the concentration levels, but also the source of PM2.5 should be taken into consideration when addressing air quality impacts on health.

These are the first health research results for Abidjan showing the associations between PM2.5 and emergency room visits for respiratory and cardiac problems (~3% decrease in risk), as well as emergency room mortality (~4% increase in risk) and respiratory visits to outpatient health centres.

Domestic fires appear to be the most significant health risk due to extreme concentration levels.

Due to the extreme concentration levels (see previous section) domestic fires are a huge health risk, while the risks from heavy traffic or waste burning were less extreme. As this study focused more generally on the inhabitants of the neighbourhoods around the DACCIWA measuring sites, rather than specifically on bus drivers, people working in food preparation or at the landfill site, our results may be obscuring the serious risk associated with long periods of time near a significant emission source.

In-vitro experiments with aerosols taken from the four air quality sites show that primary organic matter particles cause the most inflammation. Thus the highest inflammatory impact on people occurs in the wet season at the domestic burning site.

Personal exposure measurements on different groups of the population around these sites showed that the health risk was highest for children in waste burning sites due to heavy metals, whereas for women the risk was highest in the domestic burning site in summer due to organic matter.

Sociological studies have shown significant differences between the occupational status of individuals and their vulnerability to air pollution in the four quality sites.

More aerosol observations, increased access to health statistics and associated socioeconomic data are needed.

This study presents the first results of an epidemiological study on cardiorespiratory impacts of air pollution in the Guinea Coastal region using local measurements. We suspect that a larger, more significant effect would be observed with more detailed data. Both detailed health statistics and continuous, repeated pollutant measurements are necessary to improve epidemiological results and provide a deeper understanding of health impacts on urban, tropical metropolitan areas. Including socioeconomic information may also provide a lever to further understand the data, as not all inhabitants are equally likely to visit a doctor.
Emissions

To produce useful air pollution control strategies, estimates need to be made of the magnitude of the different emission sources. DACCIWA calculated new emissions for Africa, evaluated them against standard international emissions and against local observations.

Standard global estimates of human emissions are significantly underestimated for southern West Africa.

The EDGAR dataset [Crippa et al., 2018] is the global standard for air pollutant emissions. It can be inaccurate, especially in regions which have not been extensively studied. DACCIWA constructed new emissions [Keita et al., 2018] which used Africa specific information. Figure 8 shows a comparison between the mass of key air pollutants emitted over southern West Africa by the EDGAR and DACCIWA inventories, together with an emissions dataset that exploits the DACCIWA observations to optimize the emissions inventory. For many species the EDGAR data underestimate the emissions in the region.

Emissions of particles and organic gases from vehicles in southern West African cities are higher than those in other locations.

DACCIWA made direct measurements of the particles and organic gases emissions from individual vehicles in Côte d’Ivoire [Keita et al., 2018]. They were significantly higher than had been assumed for the region (Figure 9). Old gasoline vehicles are more polluting (factor of a thousand) than new vehicles. Older diesel vehicles were only a factor of five worse. New four-stroke engines have significantly lower emissions than new two-stroke engines.

Burning seemingly similar materials may lead to very different emissions.

Keita et al. [2018] found that the emissions of particles from domestic fires depend strongly on the type of wood burnt. Hevea wood was found to be the largest emitter. The manufacture of charcoal is a big source of particles, and emissions from waste burning are high and offer a risk to health.

The underestimate in southern West African emissions likely leads to an under appreciation of the impacts of air pollution.

As global estimates of the human health impact of pollutants often use the EDGAR emissions, these estimates will likely underestimate the impact of PM2.5 on human health in southern West Africa. This may influence global health choices.
Pollution impacts on weather and climate

A key uncertainty in our assessment of future climate change is how aerosol – tiny particles in the air – interact with the atmosphere, specifically by scattering or absorbing sunlight either themselves or through their influence on cloud properties. DACCIWA has specifically investigated this issue for southern West Africa for the first time.

A further increase in manmade pollution in southern West Africa will have a small effect on cloud properties due to the already high aerosol burden.

Clouds form through condensation of water vapour on particles. Changes in their number and characteristics can thus affect cloud properties and also precipitation. Over southern West Africa, however, the concentration of particles from local emissions and smoke imported from Central Africa (Page 13) is already so high that there are always enough particles and further increases merely change cloud properties. A deterioration in particle pollution will, therefore, have a small effect on rainfall through changes in cloud properties (Figure 10).

An increased aerosol amount and/or shift to more water-loving particles will reduce the amount of sunlight reaching the Earth’s surface, impacting on the circulation, clouds and possibly rainfall.

Aerosols also reduce the amount of sunlight reaching the Earth’s surface. In a humid environment such as southern West Africa during the summer monsoon, aerosol particles can take up water, increasing their dimming effect by 5 to 7 times [Haslett et al., 2018]. Reductions in surface heating of 20 Wm⁻² are seen [Deetz et al., 2018b]. This decreases the temperature contrast between land and sea and so delays the inland progression of the coastal front during the late afternoon and evening by up to 30 km (Figure 11, left) and the daytime development from low layer-clouds to deeper, more patchy clouds by 1–2 hours (Figure 11, right). There are first indications that the dimming leads to a reduction in rainfall, with possible impacts on food production, water availability and hydropower. The reduction of direct sunlight also affects plants and photovoltaic electricity generation. Increasing aerosol emissions and/or a shift to particles that more easily take up water such as sulfates or nitrates will exacerbate these impacts.

More research is needed to better quantify the impacts of anthropogenic particles in southern West Africa.

DACCIWA has demonstrated that interactions between aerosol particles, clouds, precipitation and sunlight over southern West Africa are complex. Several new processes have been discovered such as the coastal front and the relevance of water uptake. Yet, many details are unclear, for example how larger drops falling through the cloud from its top redistribute cloud water and thus change cloud lifetime [Dearden et al., 2018]. High sensitivities and compensating effects, together with variations with distance from the coast and time of day, make a quantitative analysis very challenging. Substantial uncertainties remain due to both limited observational data — even after the DACCIWA field campaigns — and large differences between computer models of different resolution and complexity.
Temperatures over West Africa are projected to rise by 1 to over 3°C by 2050 depending on geographical location, emission scenario and model used. In line with projections for global warming, temperatures in southern West Africa will likely increase considerably from now until the middle of the 21st century. However, the exact size of this increase remains uncertain. DACCIWA has investigated several factors that determine the size of the increase in the summer June–August (Figure 12):

1) **Proximity to the ocean:** The temperature rise along the Guinea Coast will tend to be smaller than farther inland.

2) **Emission of climate gases:** For a low emission scenario (green line in Figure 15), temperature increases are mostly below 2°C across entire northern Africa but could exceed 3°C for high emissions (red, blue and magenta lines in Figure 12).

3) **Ocean:** Different assumptions about sea-surface temperature evolution have a small impact on the magnitude of the warming inland (compare blue and red lines in Figure 12).

4) **Aerosol, vegetation and other factors:** Warming is very sensitive to how vegetation and interactions between aerosol and clouds are represented in a climate model (compare blue and magenta lines in Figure 12).

Even the sign of future changes in rainfall remains highly uncertain. Computer models still struggle to realistically represent the West African monsoon (e.g. Hannak et al. 2017). The last two IPCC multi-model assessments (CMIP3 and CMIP5) both show a rainfall increase along the Guinea Coast until the end of the 21st century but with a very low agreement between different models, even about the sign of the change (Figure 13). This impedes an assessment of the frequency of future droughts and floods. DACCIWA model experiments further confirm large sensitivities, showing that our understanding of future precipitation in the region remains to be poor.

**Pollution exposure in the future will be influenced by local and remote anthropogenic emissions and altered patterns of transport and dust emissions.**

Increased population and economic development over the next decades will likely lead to increased emissions of man-made aerosol and gaseous pollutants. At the same time, a changing climate will influence how much desert dust and biomass burning smoke is produced and transported into the region, while changes in rainfall will change the lifetime of these particles. Thus predicting the overall human exposure to pollutants is challenging. DACCIWA modelling results indicate that a potential increase in anthropogenic aerosol concentrations may be partly compensated by a decrease in dust concentrations during winter, while summer changes are more locally controlled (Figure 14). Evaluations of multiple modelling systems with different local emission scenarios will be needed to enhance confidence in future air pollution projections over the region.

**Long-term outlook**

The future state of the atmosphere over southern West Africa is critically important for human health, food production and the economy. Local changes need to be considered within the context of a globally changing climate. DACCIWA has used computer models to investigate which factors are relevant for future developments.
A lack of observations of meteorology and air pollution in Africa holds back understanding.

Observations and models

High quality and accessible meteorological and air quality data are largely missing in Africa. This slows advances in weather forecasting, impedes solution to air pollution and leads to uncertainty in climate change prediction. DACCIWA has collected a plethora of data, made it freely available, and pinpointed deficiencies in how computer models represent the West African monsoon.

An adequate air quality monitoring system is absent in southern West Africa.

Historically, the long-term, publically accessible, monitoring of air pollutants has been the basis of assessing air quality and producing efficient solutions. The lack of this data means that our understanding air quality in southern West Africa remains poor. Local, daily measurements of primary pollutants such as NOx, SO2, O3, and particles are needed. Potentially other chemicals such as polyaromatic hydrocarbons and heavy metals may play a disproportionately important role in West Africa (as they did historically in Europe). They should be monitored to assess their impact which is currently unknown.

The meteorological station network is sparse and existing data are not always available for research.

Meteorological observations have economic benefits that far exceed the expenses of their collection (http://www.wmo.int/pages/prog/apm/gwpw/documents/wmo_1153_en.pdf). They are critical for producing accurate weather forecasts, to establish efficient early warning systems, and to monitor climate change. Africa is notorious for its poor coverage of available data (Figure 15). DACCIWA established short term, state-of-the-art meteorological networks and made the data freely available for research. It has also demonstrated how better data can advance our understanding of the West African monsoon system which will ultimately lead to improved weather forecasts.

Making the case of an improved, open-access meteorological observing system in Africa to policymakers and wider society should be seen as a priority. Clearly, African National Weather Services need support to monitor weather and climate, and also to establish data centres that could also provide access to the currently unavailable historical data.

Satellite observations provide a wealth of information but need more validating.

Satellite observations can help supplement this lack of surface observations but there are limitations on their use. Real-time monitoring of rainfall is one of the grand challenges due to the immense socio-economic value of precipitation. Data from a dense rain gauge network around Kumasi set up by DACCIWA, show that satellite-based rainfall estimation have large errors and poorly sample extreme rainfall events (Figure 16). Although satellite observations of air pollutant concentration are available at increasing resolutions, they are still unable to capture spatial or temporal variations suitable for health. They can, however, provide useful regional climatologies for assessing model performance.

To capitalize on satellite-sensed parameters, ground truth for calibration is essential. The lack of observations in the region makes this difficult.

Computer models still struggle to realistically represent the complex atmospheric dynamics and chemistry in West Africa.

Computer models still struggle to realistically simulate the weather, climate and air pollution of West Africa. Even high-resolution, state-of-the-art weather forecasting models cannot reproduce the observed south–north distribution of rainfall and sensitivities to model resolution are immense (Figure 17). Generally, the quality of daily weather forecasts in southern West Africa is low [Vogel et al, 2018] and the credibility of future changes in rainfall is limited (see Figure 13).

DACCIWA has shown that one issue is the poor representation of the extensive and persistent low-level clouds. These clouds are important in regulating the amount of solar radiation reaching the surface and the rainfall [Kniffka et al. 2018]. In addition, DACCIWA research has shown that including aerosols improves seasonal forecasts for Africa [Benedetti and Vitarte, 2018].


Other publications used in this report


