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The DACCIWA project: Dynamics-aerosol-chemistry-cloud interactions in West Africa

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Abstract

Massive economic and population growth, and urbanization are expected to lead to a tripling of anthropogenic emissions in southern West Africa (SWA) between 2000 and 2030. However, the impacts of this on human health, ecosystems, food security, and the regional climate are largely unknown. An integrated assessment is challenging due to (a) a superposition of regional effects with global climate change, (b) a strong dependence on the variable West African monsoon, (c) incomplete scientific understanding of interactions between emissions, clouds, radiation, precipitation, and regional circulations, and (d) a lack of observations. This article provides an overview of the DACCIWA (Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa) project. DACCIWA will conduct extensive fieldwork in SWA to collect high-quality observations, spanning the entire process chain from surface-based natural and anthropogenic emissions to impacts on health, ecosystems, and climate. Combining the resulting benchmark dataset with a wide range of modeling activities will allow (a) assessment of relevant physical, chemical, and biological processes, (b) improvement of the monitoring of climate and atmospheric composition from space, and (c) development of the next generation of weather and climate models capable of representing coupled cloud-aerosol interactions. The latter will ultimately contribute to reduce uncertainties in climate predictions. DACCIWA collaborates closely with operational centers, international programs, policy-makers, and users to actively guide sustainable future planning for West Africa. It is hoped that some of DACCIWA's scientific findings and technical developments will be applicable to other monsoon regions.

BACKGROUND. Southern West Africa (SWA; see Fig. 1 for a geographical overview) is currently experiencing unprecedented growth in population (2–3% per yr) and in its economy (~5% per yr), with concomitant impacts on land use. The current population of around 340 million is predicted to reach about 800 million by 2050 (United Nations 2012). Much of this population will be urbanized with domestic, industrial, transport, and energy (including oil exploitation) demands leading to increases in atmospheric emissions of chemical compounds and aerosols. Figure 2 shows examples of significant sources of air pollution. Already anthropogenic pollutants are estimated to have tripled in SWA between 1950 and 2000 (Lamarque et al. 2010) with similar, if not larger, increases expected by 2030 (Liousse et al. 2014). These dramatic changes will affect three areas of large socio-economic importance (see the more detailed discussion in Knippertz et al. 2015):

1) Human health on the urban scale: High concentrations of pollutants, particularly fine particles, in existing and evolving cities along the Guinea Coast cause respiratory diseases with potentially large costs to human health and the economic capacity of the local work force. Environmental changes including atmospheric pollution have already significantly increased the cancer burden in West Africa in recent years (Val et al. 2013).
2) Ecosystem health, biodiversity, and agricultural productivity on the regional scale: Anthropogenic pollutants reacting with biogenic emissions can lead to enhanced ozone and acid production outside of urban conglomerations (Marais et al. 2014) with detrimental effects on humans, animals, and plants, both natural and crops. The small-scale farming immediately to the

north (and thus downstream) of the cities along the Guinea Coast is important for food production and would be seriously affected by degraded air quality.

3) Regional Climate: Primary and secondary aerosol particles produced from biogenic and human emissions can change the climate and weather locally through their effects on radiation and clouds, which could modify the regional response to global climate change (Boucher et al. 2013). An illustration of the co-occurrence of clouds and large amounts of aerosol is given in Fig. 3 for a typical situation in spring. Associated effects on temperature, rainfall, and cloudiness can feedback on the land surface, ecosystems, and crops and affect many other important socio-economic factors such as water availability, production systems, physical infrastructure, and energy production, which relies on hydropower in many countries across SWA (e.g. Lake Volta).

To date, the impacts of the projected rapid increases in anthropogenic emissions are largely unknown and present a pressing concern. The new DACCIWA (Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa) project will for the first time provide a comprehensive scientific assessment of these impacts and disseminate results to a range of stakeholders to inform policies for a sustainable development of this heavily populated region. In this way it will build on results from large aerosol-chemistry-cloud programs in other parts of the world such as ACE-2 (Raes et al. 2000), INDOEX (Heymsfield and McFarquhar 2002), and VOCALS (Mechoso et al. 2014). However, the complexity of sources and rapid development in SWA make this a very different situation to, for example, the biomass burning dominated pollution experienced over Amazonia (Roberts et al. 2003) and considerably more complex. This article will provide an overview of the project and the planned research activities and expected outcomes.

PROJECT PARTNERS AND COLLABORATIONS. DACCIWA runs from 1 December 2013 until 30 November 2018 and receives a total funding from the European Union of €8.75M. The scope and logistics of the project demand an international and multidisciplinary approach. The consortium is composed of 16 partners from four European and two West African countries and consists of universities, research institutes, and operational weather and climate services (Fig. 4). The project is coordinated by the Karlsruhe Institute of Technology in Germany. DACCIWA builds on a number of past and existing successful projects and networks in West Africa such as the African Monsoon Multidisciplinary Analysis (AMMA; Redelsperger et al. 2006), the Ewiem Nimdie summer schools (Tompkins et al. 2012), and the IGAC (International Global Atmospheric Chemistry) / DEBITS (Deposition of Biogeochemically Important Trace Species) / AFRICA (IDAF) atmospheric chemistry and deposition monitoring network (http://idaf.sedoo.fr), but the focus is now for the first time on the densely populated coastal region of West Africa and on anthropogenic emissions. The expertise covered by the DACCIWA consortium ranges from atmospheric chemistry, aerosol science, air pollution and their implications for human and ecosystem health, to atmospheric dynamics, climate science, cloud microphysics, and radiation. It includes expertise in observations from ground, aircraft, and space as well as modeling and impact research. There are numerous African Partners linked to

DACCIWA through subcontracts and other forms of collaborations, the most important of which are listed in Table 1. In order to develop scientific knowledge and data for wider application by users, policymakers, and operational centers, DACCIWA frequently interacts with an Advisory Board of key representatives from relevant groups (Table 2).

OBJECTIVES & WORKPACKAGES. DACCIWA aims to contribute to ten broad objectives. The first nine are research-focused and cover the whole process and feedback chain from surface-based emissions to aerosols, clouds, precipitation, radiative forcing, and the regional monsoon circulation, taking into account meteorological as well as health, and socio-economic implications in an integrated way. A further objective targets the dissemination of scientific results and data. The objectives are:

O1 Quantify the impact of multiple sources of anthropogenic and natural emissions, and transport and mixing processes on the atmospheric composition over SWA during the wet season.

O2 Assess the impact of surface/lower-tropospheric atmospheric composition, in particular that of pollutants such as small particles and ozone, on human and ecosystem health and agricultural productivity, including possible feedbacks on emissions and surface fluxes.

O3 Quantify the two-way coupling between aerosols and cloud and raindrops, focusing on the distribution and characteristics of cloud condensation nuclei (CCN), their impact on cloud characteristics and the removal of aerosol by precipitation.

O4 Identify controls on the formation, persistence, and dissolution of low-level stratiform clouds, including processes such as advection, radiation, turbulence, latent-heat release, and how these influence aerosol impacts.

O5 Identify meteorological controls on precipitation, focusing on planetary boundary layer (PBL) development, the transition from stratus to convective clouds, entrainment, and forcing from synoptic-scale weather systems.

O6 Quantify the impacts of low- and mid-level clouds (layered and deeper congestus) and aerosols on the radiation and energy budgets with a focus on effects of aerosols on cloud properties.

O7 Evaluate and improve state-of-the-art meteorological, chemistry, and air-quality models as well as satellite retrievals of clouds, precipitation, aerosols, and radiation in close collaboration with operational centers.

O8 Analyze the effect of cloud radiative forcing and precipitation on the West African monsoon (WAM) circulation and water budget including possible feedbacks.

O9 Assess socio-economic implications of future changes in regional anthropogenic emissions, land use, and climate for human and ecosystem health, agricultural productivity, and water.

O10 Effectively disseminate research findings and data to policy-makers, scientists, operational centers, students, and the general public using a graded communication strategy.

To deliver these objectives DACCIWA science is organized into seven scientific Workpackages (WPs) reflecting the main research areas (Fig. 5):

Boundary-Layer Dynamics (WP1), Air Pollution and Health (WP2), Atmospheric Chemistry (WP3), Cloud-Aerosol Interactions (WP4), Radiative Processes (WP5), Precipitation Processes (WP6), and Monsoon Processes (WP7). Finally WP8 covers dissemination, knowledge transfer to non-academic partners, and data management. WPs 9 and 10 are dedicated to scientific and general project management. For more details, see the DACCIWA webpage at www.dacciwa.eu.

FIELD CAMPAIGN. The availability of observations is a major limitation to addressing the DACCIWA research objectives listed above. To alleviate this, DACCIWA plans a major field campaign in SWA during June and July 2016, which will include coordinated flights with three research aircraft, and a wide range of surface-based instrumentation (possibly also unmanned aerial vehicles) at Kumasi (Ghana), Savé (Benin), and Ile-Ife (Nigeria) (for locations see Fig. 1). Beginning in June 2014, field preparations and some sodar and other surface-based measurements have already been made at the Ile-Ife site (dry runs). June-July is of particular interest, as it marks the onset of the WAM and is characterized by increased cloudiness (e.g., relative to that shown in Fig. 3) with both deep precipitating clouds and shallow layer-clouds, susceptible to aerosol effects and important for radiation.

The main objective for the aircraft detachment is to build robust statistics of cloud properties as a function of pollution and meteorological conditions. The payload of three aircraft (French SAFIRE ATR42, German DLR Falcon20, UK FAAM BAe146) is required to carry the instrumentation needed to measure chemistry, aerosol, and meteorology in sufficient detail. The flight strategy includes north-south transects between the Gulf of Guinea and ~12°N to sample cloud properties in different chemical landscapes (including different ecosystems) and coast-parallel flights along the latitude of the ground sites (6–7°N) to assess the differences between areas downstream of cities and those with less anthropogenic emissions for similar climatic conditions. The involved operational centers will provide tailored forecast to support flight planning during the campaign.

The main purpose of the ground campaign is to obtain detailed information on the diurnal evolution of the PBL and its relation to cloud cover, type, and properties as well as precipitation. The three ground sites are representative of continental conditions with frequent occurrence of low layer clouds in the morning hours. Kumasi and Ile-Ife are also affected by land-sea breeze convection in June in the afternoon. Having three measuring sites will allow the assessment of local factors such as orography and distance to the coast, and aid in the analysis of synoptic-scale weather systems and variability. The ground campaign will be complemented by an enhancement of radiosoundings from the existing and re-activated AMMA network (Parker et al. 2008) in the area (Fig. 1). More information on payloads, instrumentation, and observational strategy are available on www.dacciwa.eu and will be summarized in an overview article after the campaign.

LONG-TERM MONITORING. The intensive field campaign described in the previous section can only allow a relatively short snapshot on the complex conditions over West Africa. An important aspect of the project is therefore to also improve long-term monitoring and data availability. This will include the set-up / enhancement of networks of surface-based stations around Kumasi (mainly precipitation measurements during 2015–2018) and in Cotonou and Abidjan (air pollution, radiation during 2014–2018) (Fig. 1). The latter will form the basis for updates and extensions to emission inventories and will be accompanied by analyses of urban combustion pollutants, inflammatory risks, and health information from nearby hospitals.

DACCIWA will work closely with West African weather services (Table 1) to digitize data from their operational networks. Figure 1 clearly shows the importance of filling data gaps in the region, particularly in Ghana and Nigeria.

Observations from the short- and long-term DACCIWA field activities (e.g., rainfall, sunphotometer measurements) will be used to validate satellite retrievals of aerosols, cloud, radiation, and precipitation (e.g., products from Spinning Enhanced Visible and Infrared Imager (SEVIRI), Moderate Resolution Imaging Spectroradiometer (MODIS), Visible Infrared Imaging Radiometer Suite (VIIRS), Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), CloudSat, Megha-Tropiques, and Global Precipitation Measurement (GPM)) through detailed analysis of joint distributions of variables and radiation closure studies. This multi-sensor approach will allow characterization of the full cloud-aerosol-precipitation-radiation system and advance understanding of the key physical processes and feedbacks. An effective comparison between the ground- and space-based observations with the aircraft measurements will be achieved through overflying ground sites and coordination with satellite overpasses. Ultimately, this will help to provide improved longer-term remote sensing data for the region. Again, more details are provided at www.dacciwa.eu.

MODELING. DACCIWA plans to conduct coordinated experiments involving a wide range of complementary models with different resolutions and levels of complexity. Realistic model runs will allow a direct comparison to field measurements, while sensitivity experiments will reveal the influence of single model parameters. The range of models used in DACCIWA will include (for more details, see www.dacciwa.eu):

- Large-Eddy Simulations for the PBL and low-cloud development as well as turbulence-chemistry interactions;
- detailed chemistry and air pollution models to assess emissions, air pollution, secondary aerosol formation, and health impacts;
- high-resolution (down to 100m grid-spacing) regional models, some with fully coupled aerosol-cloud interactions to assess the influence of aerosols on cloud evolution and precipitation generation and to quantify systematic biases in less complex or lower-resolution models;
- radiative transfer models to improve process understanding and satellite retrievals;
- regional meteorological models to provide information on rainfall types and seasonal evolution;
- global models to assess effects of cloud-radiative forcing and precipitation on the WAM system including feedbacks and future scenarios.

All DACCIWA observations, including satellite data, will be used for model evaluation in detailed case studies. This work will be complemented by statistical analyses of selected existing model data (reanalysis, climate simulations, research experiments). Scenario experiments will be conducted using emission projections compiled as part of DACCIWA to assess the range of possible future developments and their socio-economic implications. Collaboration with operational centers will encourage the uptake of scientific results into weather forecasting and climate prediction.

Modeling studies will specifically target parameterizations of the PBL, chemistry, moist convection, cloud microphysics, and radiation. Results from and components of parameterizations will be confronted with observational data and sensitivities to explicit *versus* parameterized representations of these processes will be evaluated. The DACCIWA modeling strategy includes the consortium-wide sharing of model output from individual WPs run at institutions with the critical expertise and infrastructure required to carry simulations out efficiently. A standard set of model domains will facilitate this: global, continental (West Africa), regional (flight area), and local (supersites or case-studies from flights) with corresponding standard grid-spacings and initial conditions. This will enable the use of a seamless approach within DACCIWA, understanding how model errors in “fast processes” lead to systematic biases in weather and climate models (e.g., Birch et al. 2014).

CONCLUDING REMARKS. DACCIWA will significantly advance our scientific understanding as well as our capability to monitor and realistically model key interactions between surface-based emissions, atmospheric dynamics and chemistry, clouds, aerosols, and climate over West Africa. This will pave the way to improving future projections and their expected impacts on socio-economic factors such as health, ecosystems, agriculture, water, and energy, which will inform policy-making from the regional to the international level. To bring about progress in these areas DACCIWA will:

1) generate an urgently needed observational benchmark dataset for a region, where the lack of data currently impedes advances in our scientific understanding and a rigorous evaluation of models and satellite retrievals. The campaign data will be added to the AMMA database (Fleury et al. 2011) and will be available to the wider scientific community after a 2-year embargo period and to selected partners on request as regulated by the DACCIWA data protocol. It is hoped that this way DACCIWA can make an important contribution to future attempts to synthesize our understanding of aerosol chemical composition and climate impacts (e.g., Quinn and Bates 2005).

2) contribute to the improvement of operational models through process studies using a multi-scale, multi-complexity ensemble of different state-of-the-art modeling systems, which will be challenged with high-quality observations. DACCIWA works closely with operational centers to ensure the uptake of new scientific findings into model development and improvement of predictions on weather, seasonal, and climate timescales.

3) advance our scientific understanding by exploiting observations and modeling to for the first time characterize and analyze the highly complex atmospheric composition in SWA and its relation to surface-based emissions in great detail. DACCIWA will document the diurnal cycle over SWA in an unprecedented and integrated manner and will build on new advances in cloud-aerosol understanding and modeling, and apply them to a highly complex moist tropical region. DACCIWA will contribute to the scientific understanding, climatology, and modeling of Guinea Coast rainfall systems, advance our understanding of the effects of aerosol and

clouds on the radiation and energy budgets of the atmosphere, and investigate key feedback processes between atmospheric composition and meteorology. DACCIWA will be the first project that extensively studies the role of SWA drivers for the continental-scale monsoon circulation.

4) advance the assessment of socio-economic impacts of these atmospheric processes across SWA. DACCIWA will expand and analyze existing datasets on air pollution and medical data including future projections, further our understanding of regional ozone and PM2.5 levels and assess mitigation strategies, provide a comprehensive assessment of the contribution of short-lived pollutants on regional climate change in SWA, and estimate potential implications on water, energy, and food production. DACCIWA will communicate relevant aspects to policymakers and other relevant stakeholders through dedicated policy briefs.

It is hoped that the improved scientific understanding, as well as observational and modeling tools of chemical/physical processes in West Africa will support and inspire similar research in other monsoon regions around the world.

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FOR FURTHER READING

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Figure captions

FIG. 1: Geographical overview of the DACCIWA study area in southern West Africa highlighted in blue. Black stars mark the three DACCIWA supersites at Kumasi (Ghana), Savé (Benin), and Ile-Ife (Nigeria). Radiosondes will be launched regularly from the supersites and the stations indicated by black crosses, some of which will get re-activated for the DACCIWA field campaign. Red dots mark synoptic weather stations (size proportional to available number of reports in the WMO Global Telecommunication System from 1998–2012). In addition, there will be longer-term measurements of air pollution in Abidjan and Coutonou, and a rainfall meso-network around Kumasi.

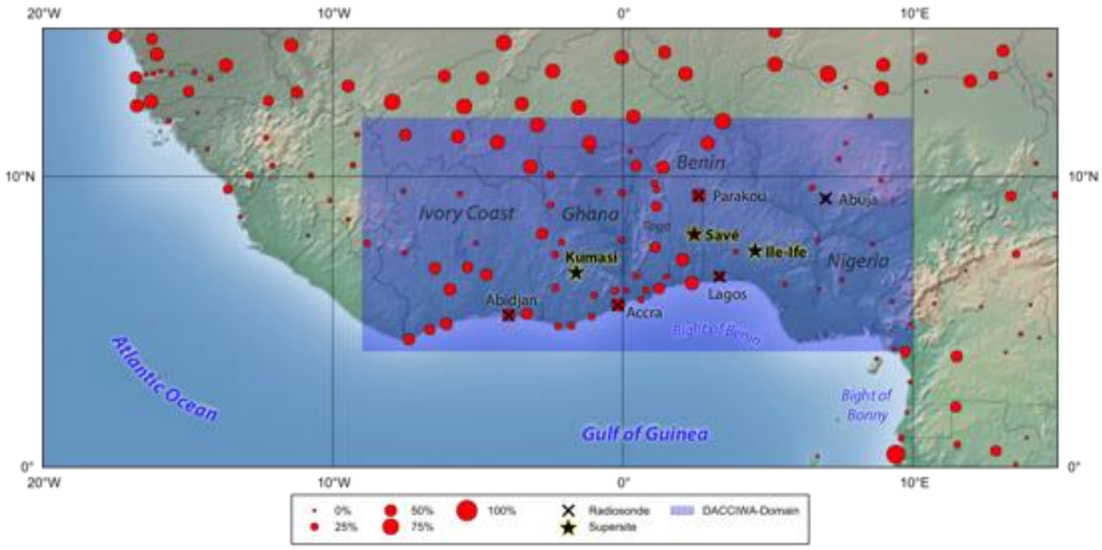
FIG. 2: Examples of contributors to urban and regional air pollution in West Africa. (a) A domestic fire in Abidjan, Ivory Coast (copyright C. Liousse). (b) Two-wheeled taxis (zemidjan in local language) in Cotonou, Benin (copyright: B. Guinot). (c) Emission of hydrocarbons through gas flares from the extensive oil fields in the Niger Delta (Nigeria) from VIIRS (Visible Infrared Imaging Radiometer Suite) nighttime data V2.1 (Elvidge et al. 2013) given in equivalent CO_2 *emission rates in* $g\ s^{-1}$ *for the date of 08 July 2014. "NA" stands for "flare identified but no emission retrieved".*

FIG. 3: Regional air pollution and clouds: MODIS visible image at 1300 UTC on 8 March 2013 over southern West Africa showing a well defined land-sea breeze, small-scale cumulus inland, and enhanced air pollution along the coast, particularly over the coastal cities (MODIS aerosol optical thickness at 0.55 µm wavelength (Levy et al. 2007) overlaid as color shading).

FIG. 4: Overview of DACCIWA EU-funded participants.

FIG. 5: Schematic overview of the DACCIWA Workpackages (WPs). The institution leading each WP is given in brackets (see Fig. 4 for a listing of abbreviations) together with the objective that the WP is the main contributor to (WPs 1–7 only; see list of objectives in text).

Figures



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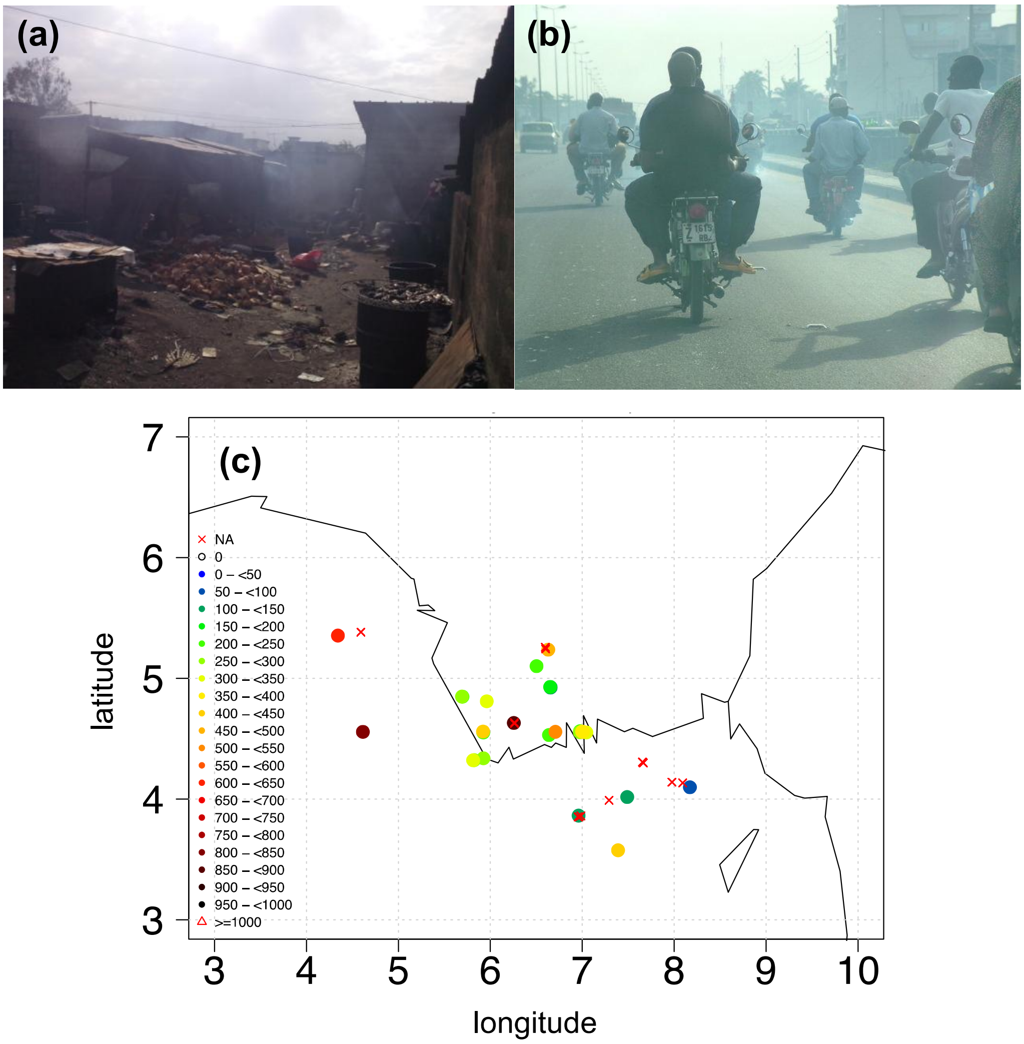

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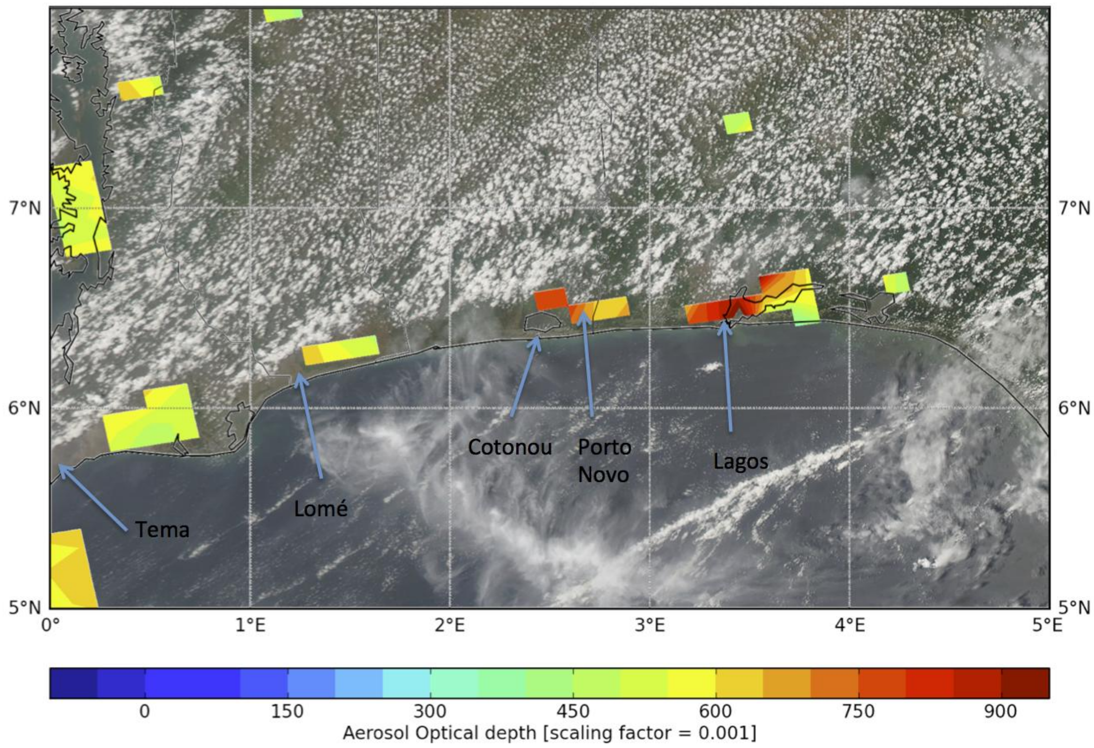

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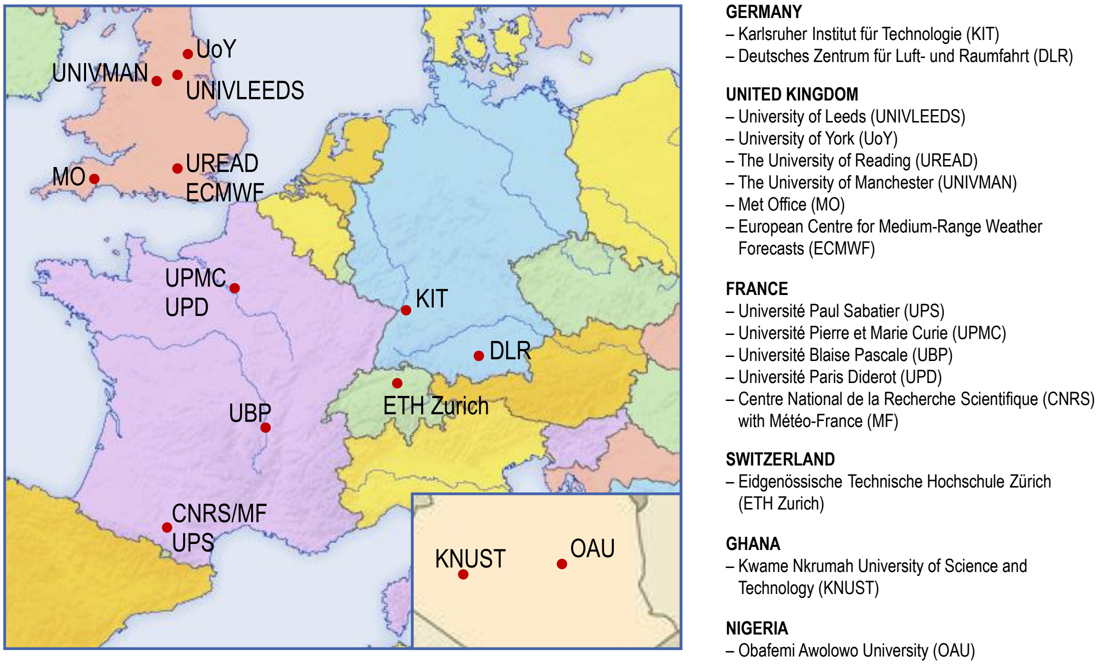

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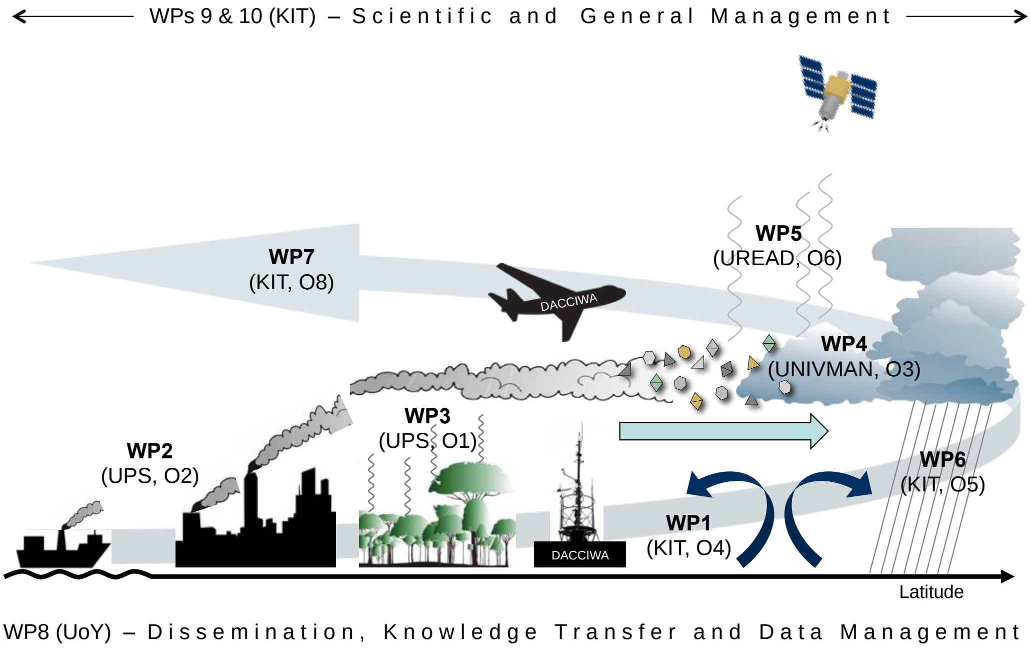

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Tables

Table 1: West African collaborators of DACCIWA.

Name	Country	Type of organization
Université Abomey Calavi (UAC)	Benin	University
The Federal University of Technology, Akure (FUTA)	Nigeria	
Université Félix Houphouët-Boigny	Ivory Coast	
Direction Nationale de la Météorologie (DNM)	Benin	National weather service
Ghana Meteorological Agency (GMET)	Ghana	
Nigerian Meteorological Agency (NIMET)	Nigeria	
Direction de la Météorologie Nationale	Ivory Coast	
Ministère de l’Environnement et de la Protection de la Nature (MEPN)	Benin	Ministry
Ministry of Higher Education and Scientific Research	Ivory Coast	
Ministry of Environment, Health and Sustainable Development	Ivory Coast	
Institute Nationale de Recherche Agricole du Bénin (INRAB)	Benin	Research center
Pasteur Institute	Ivory Coast	
Centre Suisse de Recherches Scientifiques en Côte d'Ivoire	Ivory Coast	
African Center of Meteorological Application for Development (ACMAD)	international	Pan-West African organization
The West African Science Service Center on Climate Change and Adapted Land Use (WASCAL.ORG)	international	
AMMA-Africa Network (AMMANET)	international	
L'Agence pour la Sécurité de la Navigation aérienne en Afrique et à Madagascar (ASECNA)	international	

Table 2: Members of the DACCIWA Advisory Board.

Name	Affiliation	Role
Laurent Sedogo	The West African Science Service Center on Climate Change and Adapted Land Use (WASCAL.ORG)	Research, data collection, and PhD education in West Africa
Ernest Afiesiemama	Nigerian Meteorological Agency (NIMET)	West African national weather service
Georges Kouadio	Ministry of Environment, Health and Sustainable Development, Ivory Coast	West African government
Benjamin Lamptey	African Center of Meteorological Application for Development (ACMAD)	Meteorological research and regional weather forecasting in West Africa
Serge Janicot	Institut de Recherche pour le Développement	Co-Chair of the International Scientific Steering Committee of AMMA (African Monsoon Multidisciplinary Analysis)
Leo Donner	Geophysical Fluid Dynamics Laboratory, GFDL	Climate modeling and model development
Christina Hsu	National Aeronautics and Space Administration, NASA	Space-borne remote sensing
Ulrike Lohmann	Swiss Federal Institute of Technology in Zurich (ETHZ)	Impact of Biogenic versus Anthropogenic emissions on Clouds and Climate: towards a Holistic UnderStanding (BACCHUS)*
Markus Rex	Alfred Wegener Institute, Potsdam	Stratospheric and upper tropospheric processes for better climate predictions (StratoClim)*

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