KADI

Report on the Design of a Value Chain from Observations to Climate Services

Deliverable 3.5. HORIZON-INFRA-2021-DEV-01-02

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Executive Summary

The objective of the KADI project is to design an African data and observation Research Infrastructure to develop common actions on climate change by sharing and improving knowledge on climate change and co-designing climate services that meet the needs of African stakeholders based on existing or identified solutions. Several climate services identified in WP1 have been designed as pilot studies to test the concept and co-design approach developed in WP1. The process of design of these pilots has led to the conceptual understanding of the links between RI and climate services, illustrated in Figure 1, that go beyond the "traditional" organisation of science-oriented RI. Based on a compilation of existing network and observational capabilities, WP3 provided a design study of a pan-African Climate observation RI (D3.1) that also accounts for the recommendations from WP1 on key elements of the RI. The aim of Deliverable 3.5 is to illustrate **the value chain from observations to climate services, based on the WP2 pilot studies and the five pan-African topical research infrastructures (RIs)** developed in WP3. **More than a linear chain, the interactions and feedback between the stakeholders, the pilots, and the RIs have been identified and highlighted. When relevant, the links and connections with European and International organisations are also accounted for**. The identification of these links should allow a fluid circulation of the observations, product, information and knowledge from the stakeholders to the climate services and the RI. A crude analysis of the ratio cost/impact is provided keeping in mind that regarding the scarcity of observations and climate services in Africa, any additional observational or digital nodes can only have a high impact.

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1. Introduction

The objective of the KADI project is to design an African data and observation Research Infrastructure to develop common actions on climate change by sharing and improving knowledge on climate change and co-designing climate services that meet the needs of African stakeholders based on existing or identified solutions.

Several climate services identified in WP1 have been designed as pilot studies to test the concept and co-design approach developed in WP1. These pilot climate services address diverse topics tailored to specific regional needs: urban areas, Marine biogeochemistry and Earth System model development. The process of design of these pilots has led to the conceptual understanding of the links between RI and climate services (Figure 1), that go beyond the "traditional" organisation of science-oriented RI.

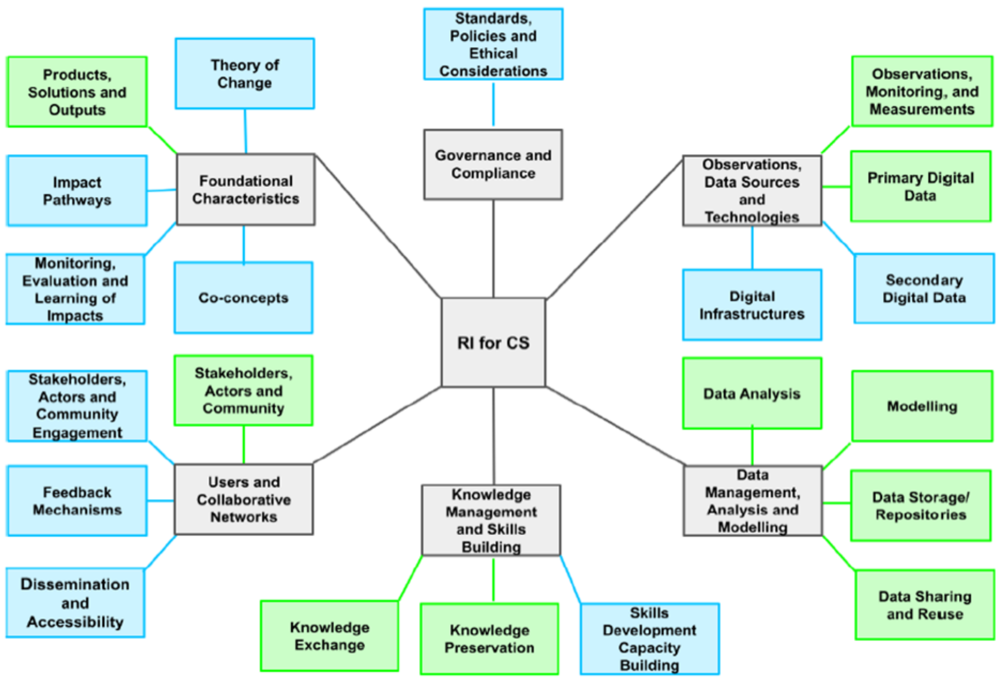

Figure ES1. Key elements of a CS RI. The green boxes indicate those elements that are typical in an RI and the blue boxes indicate those elements that are added through this review.

Figure 1.Key elements of a climate service research infrastructure. The green boxes indicate the elements that are typical in an RI and the blue boxes indicating those elements that are added through the review from WP1

A comprehensive compilation of observational networks was provided in WP 3 (deliverable 3.1) upon which a suite of topical research infrastructures to support climate services in Africa was proposed, considering the existing and required observational and numerical capacities but also recommendation from WP1. These topical RI have been designed for the provision of essential climatic variables, as identified by Lopez-Ballesteros et al. (2018) (except routine meteorological addressed by meteorological or hydrological organizations) including data acquisition and distribution. Despite the consideration of recommendation from WP1, interactions and output with the stakeholders engaged in the KADI project leads to reconsider the hierarchical organization of these topical RI to better reveal the connections between the conceptual elements of the RI but also the elements that should be shared between the RI such as digital infrastructure and the data sharing and re-use but also the knowledge exchange and the communities of stakeholders, actors and involved community.

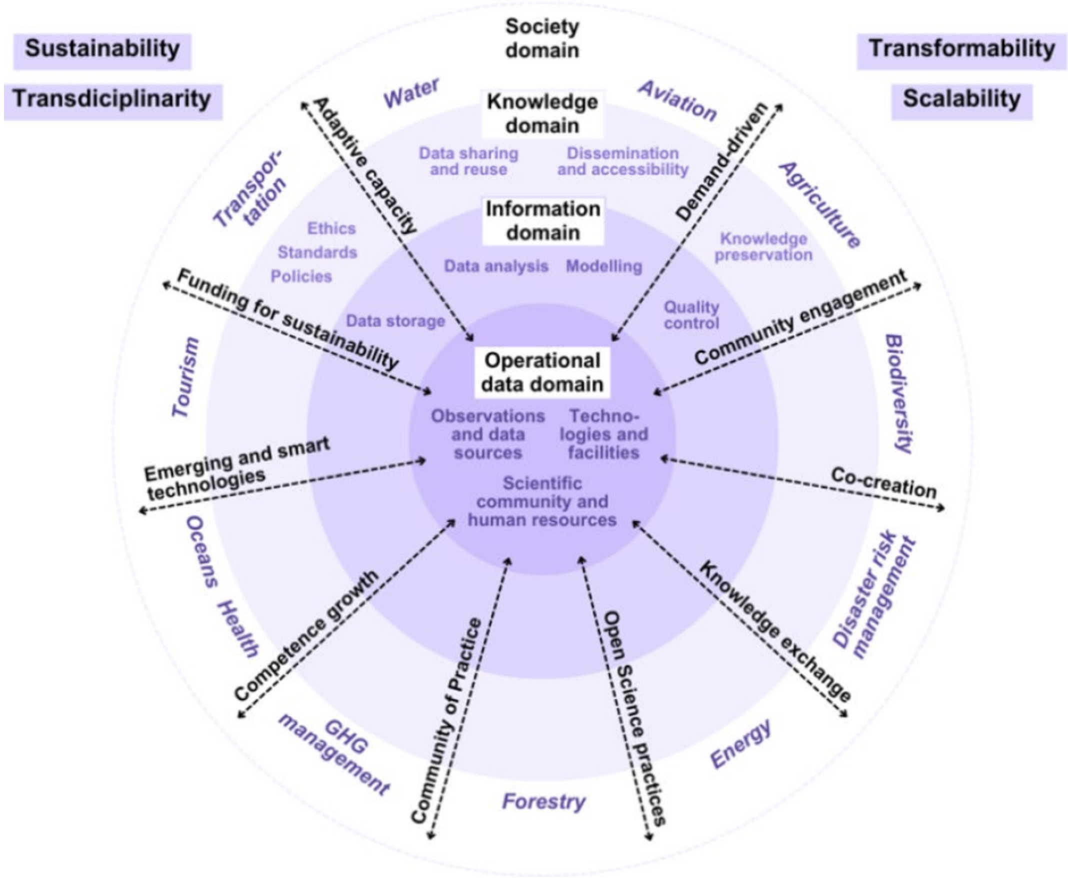

Figure 2. Illustration of the interconnectedness of the key research infrastructure elements and of the evolution of the RI impacts towards the society (figure 21 from KADI deliverable 3.1)

Building on this analysis, the objective of this deliverable is to design a **value chain from observations to climate services. The design will be established by pairing the pilots developed in WP2** and **the pan-African topical RI** designed in WP3. This value chain is not **a linear chain but includes interactions and feedback between the stakeholders, the pilots, and the RIs.** When relevant, the links and connections with European and International organisations are also accounted for**. Whatever the topic, a production chain from observations to products must also be designed.**

2. From observations to climate services and research infrastructure

The production chain for the climate services products would follow a general process flowing from the in-field instrumentation or other observations, through to the servers that host and archive the raw data, and the various steps in cleaning and processing the data that might be required to produce a dataset that is reliable and able to be used for product development.

The initial data is collected in the field, utilising instrumentation of methodologies that are appropriate to the Research Infrastructure in question. Many of the heavily instrumented infrastructures will have an electronic data acquisition system attached to the sensors that will conduct an initial processing of the raw signal to a measurement value, utilising incorporated calibration factors and selected time averaging. These raw data are typically stored on the device and in many instances are transferred to an external server for archiving, further processing, and use. If this is not done automatically, technicians would download the data directly from the logger and manually upload it to the server with specific controls to guaranty the continuity of the data provision. These data are archived as raw data (Level 0).

The second step is that the data that has been uploaded to the server will undergo basic processing and cleaning. This would typically involve the correction of the time steps in the data series, the screening and flagging of values that are outside of the sensor measurement range and the identification and flagging of poor quality values that might not meet the assumptions that are required for the method or other similar issues. This version of the dataset (Level 1) is archived separately and made available for further processing or corrections.

The third step is where the processing of the data is finalised and an approved dataset is produced. This stage typically includes corrections or adjustments made based on offsets from calibrations, the gap filling of missing data, utilising techniques that may be appropriate for the dataset and the calculation of additional derived parameters from the dataset. This version should also be archived separately and represents the most reliable dataset that carries the greatest confidence and may be the most appropriate for further distribution and the production of any required data products.

From the third level dataset, the data products are produced and are published to the appropriate community in a format that facilitates its uptake and use. These data products can be produced in the frame of a Research Infrastructure or specifically designed for a climate service. This production requires numerical and technical infrastructure to manage the storage and perform the computations.

In a region where resources are limited, sharing the hardware and the numerical protocols of the production chains is the most relevant approach to optimize the use of the data and the products.

3. Connections between pilot climate services and research infrastructure

Each of the pilots developed in the frame of the KADI project can be thematically connected to one or more of the 5 pan-African Research Infrastructures that have been identified and designed in WP3 to support climate services in Africa (Figure 3). Because of the overlap in the scientific questions and the methodological development between the pilots, the climate service needs and the RI products, we have been able to identify products of the pilot climate services responding to the needs of stakeholder that requires input from the associated RI. Conversely, some of these products represents significant inputs for the RI and can also rely on inputs from stakeholders. The identification of these connections allows an optimized and consistent use of the observation data and the products at the different levels of organization and should allow a fluid circulation of the information between these levels. When relevant, we also identified the connection with international and regional organisations or networks that could benefit from the knowledge brought by the identified products and increase their visibility and their use.

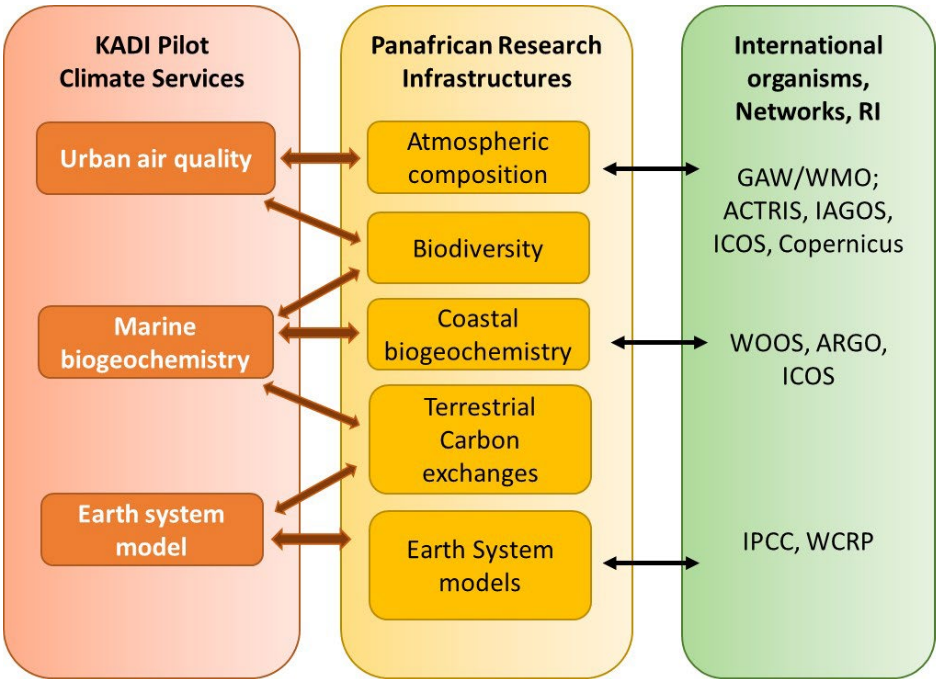

Figure 3. Connection between the pilot climate services, the designed pan African RI and the international levels.

3.1 Air Quality pilot and Atmospheric composition RI

African cities tend to develop very fast with urban intrusions toward the countryside and urban intensification is not always controlled. Most of the cities are exposed to the same climate risks (floods, heat waves, water and air pollution, and others) but with differences in the management of these risks related to political and cultural differences. The three pilot cities (Abidjan, Nairobi, Dar Es Salaam) experience air quality issues that have been approached by different tools. The Abidjan City pilot was dedicated to the development of an Air Quality monitoring and alert network to manage particulate matter pollution episodes, using reference instruments and low-cost sensors. The objective is also to identify the sources of pollution to help decision making to define emission reduction strategies. The Nairobi city pilot was focused on heat waves, but the Kenyan meteorological department initiated a process of air quality monitoring based on low-cost sensors but is lacking reference instruments. Based on the experience on the geo-mapping of flood risks using information for local people, an original mapping approach has been developed in Dar es Salaam based on inquiries to determine the areas in the city where local people consider air pollution a major issue. Specific areas have been highlighted by this approach, demonstrating its potential to guide the strategic deployment of atmospheric pollutant sensors.

Urban areas concentrate specific sources of atmospheric pollutants (traffic, residential and industrial emissions) but air quality in cities is also impacted by remote sources of pollution. As an example, Africa is among the largest sources of biomass burning aerosol and of mineral dust emitted from the African deserts and semi-arid areas. In this context, City pilots on air quality need inputs from the observations, products and services provided by the Atmospheric Composition RI and conversely the City pilots can inform the RI about urban emissions of GHG and short-lived gaseous species and aerosols and their trends of evolution due to local policies of emission reductions.

The African atmospheric composition RI (d3.1) is designed consistently with the focal points addressed by the Global Atmosphere Watch Programme (Schultz et al. 2015) focused on GHG, ozone, aerosols, reactive gases, total atmospheric deposition and solar ultraviolet radiation. Relying on existing networks the RI should establish a coordinated community where internally consistent processes and procedures (standardised operating procedures, traceable calibration processes) are followed to ensure compatibility in the network. Air quality city pilots would benefit from these processes and procedures to deploy standardized measurements and to calibrate low cost sensor networks to make observations comparable in space and time.

The scarcity of in situ measurements in African make satellite products extremely valuable to provide a regional and temporal insight on atmospheric composition, with an increasing spatial resolution that allows to provide relevant information in urban areas. Conversely, satellite products must be calibrated and validated against in situ measurements corresponding to a large range of composition, in terms of concentration levels and in terms of chemical species or pollutants. But the majority of satellite observations are validated using surface observations from industrialised countries, where in situ observations are more prevalent. As an example, AERONET sunphotometers deployed in Africa combined with in situ measurements of aerosol concentrations and optical properties are widely used to validate satellite aerosol retrievals in situation where biomass burning aerosols and desert dust prevail. AOD is a measure of light extinction by atmospheric aerosols, enabling AOD to be a predictor of ambient fine particulate concentrations (PM2.5). Estimates of PM2.5 concentrations from satellite data can be used to identify air pollution hotspots, health effects studies and air pollution trends. However, very few measurements are available in African cities to validate the satellite data estimates. Data generated through an expanded ground-based observations network would improve validation of remote sensing data.

Beside air quality, atmospheric pollutants also influence the composition of the precipitation and contribute to the regional budget of species that are key for the development of ecosystems (nitrogen, iron, et cetera) or that can alter these ecosystems (nitrogen, O_3, acidic species).

From these general statements, we describe in the table below needs from stakeholders that can be met using inputs from the Atmospheric composition RI but also the input from the Air Quality city pilots, built to answer the needs of stakeholders.

Table 1. Abidjan City Pilot

Needs from stakeholders	Climate Service Product	Input from the RI to the CS	Input from Stakeholders to the CS or the RI	Input from the CS to the RI	Connection with international organisations or other RIs
Quantifying Air pollution in African cities	- In situ measurements of the main pollutants cities (Particulate matter and reactive gases : O_3, NO_2, NH_3, ..) in several locations in cities	- Standard protocols for atmospheric pollutant measurements (Particulate matter and reactive gases : O_3, NO_2, NH_3, ..) - Times series of aerosol and reactive gases : continuous and near real time high precision concentrations of GHG, aerosol and reactive gases (like ICOS, ACTRIS, IAGOS atmospheric Data) measured across a network representing the main airsheds in the African Continent		- In situ measurements of GHG, aerosols and reactive gases in urban areas	European RI : ICOS, ACTRIS, IAGOS International networks, AERONET
Mapping Air pollution in African cities	- Daily maps of air quality combining measurements and air quality modelling to evaluate population exposure	- Protocols for low cost sensors calibration or correction		- Strategy for the deployment of low-cost sensors	African Air quality networks

Needs from stakeholders	Climate Service Product	Input from the RI to the CS	Input from Stakeholders to the CS or the RI	Input from the CS to the RI	Connection with international organisations or other RIs
Identification of the primary and secondary pollutant sources	-Modelling of urban air quality	- Regional emission inventories for anthropogenic and natural emissions - Regional observation (satellite) and modelling of atmospheric composition ((useful for SLCF, GHG budgets and C cycle)	- High resolution emission inventories of aerosols, GHG and reactive gases in urban areas - Inquiries on the location of polluted areas, on the intensity of the pollution		
Co-Construction of mitigation strategies with local population	- Maps of most intensively polluted areas based on population enquiries			- Qualitative information on urban air pollution and impact of remediation strategies	
Improvement of Air Quality in African cities to protect the population from air pollution	- Identification of the major sources of primary and secondary pollutants and of the expected change in emissions	- Regional anthropogenic emission inventories by activity sectors - Inverse modelling of anthropogenic emissions (GHG and reactive gases) based on in situ and satellite observations to constrain the continental emission budget	Up-dated high- resolution emission inventories linked with the implementation of mitigation and reduction of pollutants emission		ICOS, IAGOS, ACTRIS, AERONET African Air Quality Network

Needs from stakeholders	Climate Service Product	Input from the RI to the CS	Input from Stakeholders to the CS or the RI	Input from the CS to the RI	Connection with international organisations or other RIs
Evaluation of the mitigation politics	- Evaluation of the impact of reduction of emission policies on the concentrations of pollutants	- Trends in aerosol and reactive gases based on long-term time series of GHG, aerosol and reactive gases across a network representing the main airsheds in the African Continent		Map of the perception of improved (or deteriorating) air quality by population based on inquiries	
Mitigation of poor air quality impacts at the regional scale	Estimation of the contribution of natural and non-urban emissions to the Air quality at the regional scale	- Background levels from rural/remote stations (INDAAF network, Mount Mugogo Observatory, Rwanda and others) - Fire and biomass burning emissions(COV, NOx, SOA): Maps of vegetation cover and characteristics of influence Compilation of dust emission source areas and interannual changes in intensity and extent	Improved emission inventories of regional sources of atmospheric pollutants		ICOS, IAGOS, ACTRIS, AERONET African Air Quality Network
Early warning system to support the management of population exposure	Real-time measurements of pollutants in urban areas	Real time dust and biomass burning aerosol warnings using Satellite products and forecast models			

Needs from stakeholders	Climate Service Product	Input from the RI to the CS	Input from Stakeholders to the CS or the RI	Input from the CS to the RI	Connection with international organisations or other RIs
		In situ monitoring of PM concentrations in arid and semi-arid regions			
Management of negative impacts from acidic precipitation	Atmospheric Deposition of reactive nitrogen, acidic compounds and O_3	- Data from INDAAF network (Africa; http://indaaf.obs-mip.fr) and WMO initiative: Measurement-Model Fusion for Global Total atmospheric Deposition (GAW report n°269) to provide regional estimates of the atmospheric deposition of N, S and other biologically active compounds - Estimate of amount of fertilisation or eutrophication potential from deposition (from observation and advanced modelling products) - Estimation of the damages due to O_3 deposition on crops and vegetation			OSCAR WMO data base Global deposition networks part of WMO (NADP, CASNET, EANET, CAPMON, EMEP, INDAAF

Needs from stakeholders	Climate Service Product	Input from the RI to the CS	Input from Stakeholders to the CS or the RI	Input from the CS to the RI	Connection with international organisations or other RIs
Calibration/Validation of satellite products in African urban environments	Maps of GHG and reactive gases concentrations and of aerosol surface concentration and composition			Calibrated satellite product for gases and aerosols	International, European and national space agencies (NASA, ESA, ..)

3.2 Marine Biochemistry pilot and ocean biogeochemistry and biodiversity RI

While the Land – Ocean Continuum from rivers to coastal marine ecosystems plays a crucial role in the global carbon cycle where individual elements serve as important sinks or sources of GHGs, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The air–sea fluxes of GHGs from or to coastal ecosystems is much less constrained than the atmospheric CO_2 sink and required specific observations. However, Africa does not have a sustainable coastal carbon observatory but only observations unevenly distributed regionally and focused on local research questions. There is a critical lack of data to test and constrain models, to establish quantified trends and variability and to assess the effectiveness of policy interventions. This is necessary for African countries to develop effective mitigation measures.

The marine biogeochemistry pilot designed a strategy of long-term observation deployment based on the analysis of existing observations in the main bioregions (Large Marine Ecosystems, LME) of importance in the coastal waters around Africa. Observations are performed by national organisms over 5 of the 8 identified LEM, mainly concentrated on the Agulhas and Benguela Currents LMEs. The pilot advocates for an approach based on the creation of national nodes given the complexity of coastal processes and the specificity and of the individual systems. Such nodes can be built on existing observatories such as the Algoa Bay Sentinel Site (ABSS), operated by SAEON since 2008 and that have benefits from significant up-grades during the KADI project and at St Helena Bay (West Coast of South Africa) Theses nodes are representatives of the LME of the Agulhas Bioregion and the Namaqua Bioregion, and these contrasting sites would create different blue carbon, GHG and ocean acidification results from these two of the LME's.

The objective of the national nodes is to provide long-term measurements consistently with the requirements of the RI for coastal biogeochemistry and following the same or equivalent standardized procedures. The measurements should be the dissolved organic carbon and carbon isotopes from water to determine carbon efflux in the monitoring sites, measurements of pH, and pCO_2 determine ocean acidification and measurements of phytoplankton and zooplankton diversity to evaluate ocean production.

For the Algoa Bay and St Helena Bay nodes, the strategy is to deploy a network of real-time MetOcean moorings to deliver the first real-time mooring observations of pCO_2 (surface water and air) and pH (surface water) in Africa. Essential Ocean Variables can be monitored on an hourly basis, including Salinity, temperature, pH, oxygen, Chl-a, turbidity, nitrate, current direction & strength, waves, swell, climate (weather station on buoy), pCO_2 (in the water and on the buoy using a modified VeGAS system) and acoustic tracking of tagged species. These stations should be labelled as ICOS Marine Stations and contribute to the global database and would serve as example for the deployment of additional monitoring nodes. An additional output of the pilot is the lessons learnt from the development of moorings in-house in Africa that will be communicated to the KADI stakeholders as a possible option for roll-out additional national nodes in other African countries.

The RI for coastal biogeochemistry will be composed of the national nodes deployed to document the main African LME and will benefits from the sharing of knowledge on the development and implementation of instrumentation and on the free access to FAIR data. The connection between the needs expressed by stakeholders for the development of this marine biogeochemistry pilot and the coinciding RI is illustrated in the following table.

Table 2. Marine Biogeochemistry Pilot

Needs from stakeholders	Climate Service Product	Input from the RI to the CS	Input from Stakeholders to the CS or the RI	Input to from the CS to the RI	Connection with international organisms or other RI
Inventory of the flux of CO_2 and other greenhouse gases to the atmosphere from the Land Ocean Aquatic Continuum	Spatially and temporally integrated maps, and regional estimates quantifying the exchange of greenhouse gases from the estuarine and shallow coastal systems to the atmosphere	The RI maintains and develops a network of observation platforms in estuarine and shallow coastal systems covering the major coastal ecosystems in Africa. These measurements of greenhouse gas exchange feed into open data platforms	The direct measurements will support the development of Earth system modelling components and the validation of Earth system model outputs to drive model development and improvement	Model outputs will be used to motivate for and drive the expansion and improvement of the observation networks	ICOS Oceans, GOOS, SOCONET, G3W
Quantification of the burial of carbon in coastal vegetated systems	Spatially and temporally integrated maps, and regional estimates quantifying the amount of carbon sequestered in sediments of the estuarine and shallow coastal systems	The RI maintains and develops a network of observation platforms in estuarine and shallow coastal systems covering the major coastal ecosystems in Africa. These measurements of Carbon sequestration and carbon pools in estuarine and coastal sediments are archived in globally	The direct measurements will support the development of Earth system modelling components and the validation of Earth system model outputs to drive model development and improvement	Model outputs will be used to motivate for and drive the expansion and improvement of the observation networks	International Atomic Energy Agency (IAEA), Intergovernmental Oceanographic Commission (IOC)

Needs from stakeholders	Climate Service Product	Input from the RI to the CS	Input from Stakeholders to the CS or the RI	Input to from the CS to the RI	Connection with international organisms or other RI
		accessible data archives, such as the Coastal Carbon Network (Smitsonian)			
Quantification of rates and impacts of ocean acidification	Spatially and temporally integrated maps, and regional estimates quantifying the amount of air-sea flux and ocean acidification in coastal and shelf seas.	The RI maintains and develops a network of discreet and continuous observation platforms covering the major coastal ecosystems in Africa. These measurements of air-sea flux and OA are archived in globally accessible data archives.	The direct measurements will support the development of Earth system modelling components and the validation of Earth system model outputs to drive model development and improvement	Model outputs will be used to motivate for and drive the expansion and improvement of the observation networks	SOCONET, G3W GOA-ON, IOC, GOOS, IPCC

3.3 Support for an African Earth System Model Pilot/ Earth System Modelling RI and Terrestrial Carbon exchange RI

Earth system models are global climate models that represents not only the interactions between different compartments (Surface, Oceans, Atmosphere) but also with biogeochemical processes and in particular the processes related to the carbon cycle.

Several ESM have been developed internationally (NCAR, USA; MPI, Germany, UK Met office, UK; IPSL, France, CCAM-CABLE, Australia, and others). These models are very complex tools that require careful testing and validation. The CCAM-CABLE model has been tested and developed extensively for application in South Africa over two decades (e.g., Engelbrecht et al., 2019). The development of an African Earth system model is justified by (1) the necessity to involve African scientist in the global community of climate and ESM models and (2) the necessity to evaluate specifically the ESM in the African context in order to use them with a relevant confidence level to manage the risks associated to climate change and develop adaptation strategies for Africa. This illustrates the need to develop an ESM specific representation of the processes acting on the African continent that determine the African climate and carbon cycle and to be able to test and verify these representations (Figure 4).

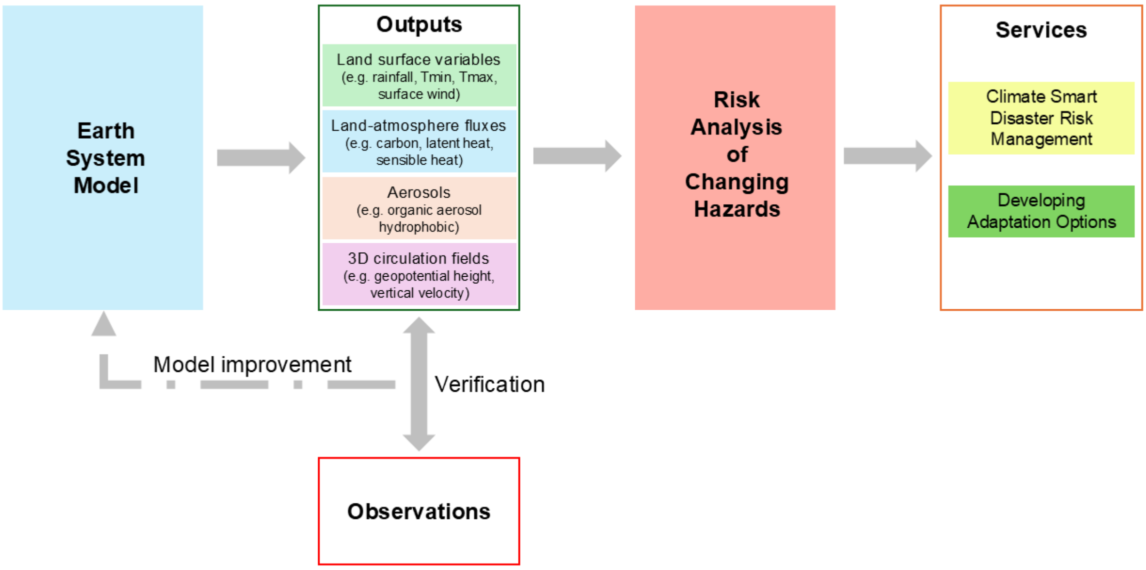

Figure 4. Loops and connections to the RIs and the observation and community data

This is why the pilot "support for an African Earth System model" focused on the evaluation of the CCAM-CABLE model, adapted to South Africa in terms of simulation of the exchanges with the continental surface. This work was based on the fluxes measured by the Eddy-covariance method (water vapour, latent and sensible heat, CO_2 fluxes) at six EFTEON sites typical of different ecosystems (bushland (Nama-Karoo, Fynbos), grassland, savannah, forest). Seasonal cycles of the monthly fluxes have been compared and analysed regarding the diurnal cycles. The model was found to remarkably reproduce the land-atmosphere fluxes for the different ecosystems and environments. This work is stepping forward the improvement of land-surface parametrization that will allow a better estimation of the land-surface fluxes attributed to Africa and a potential contribution to the EMS involved in the forthcoming CMIP exercises.

Table 3. Earth System Modelling Pilot

Needs from stakeholders	Climate Service Product	Input from the RI to the CS	Input from Stakeholders to the CS or the RI	Input to from the CS to the RI	Connection with international organisms or other RI
Quantifying and understanding the net CO_2 flux to identify terrestrial CO_2 sources and sinks	Method for comparing measured and simulated surface fluxes Evaluation of the modelled surface exchange fluxes	Measurements of net ecosystem exchange, latent heat and sensible heat using the EC technique in different ecosystems		Identifying gaps in the measurements (missing critical sites or ecosystems)	ICOS
Understanding the behaviour, vulnerability and resilience of ecosystems in relation to climate change and anthropogenic impacts such as land-use change and agricultural expansion.	Regularly updated and spatially resolved modelled estimates of carbon exchange between the land surface and the atmosphere, identifying and quantifying the exchange of CO2 and other greenhouse gases between the terrestrial surface and the atmosphere	Results from several ESM with different land-surface parameterizations		Specific evaluation over the African continent	CMIP

Data Products linked to the targeted RI

Since the previous SEACRIFOG project provided strong insights on the requirements for Research infrastructures for Greenhouse gases observations, these observations appear as less visible in the KADI project. However, many of the products that are not of use for the pilots are of invaluable use for climate studies in Africa. They are directly related to the Terrestrial Carbon exchange RI and to the RI for coastal biogeochemistry

Biogeochemistry: Fluxnet Data releases

Raw Data Products (Eddy Covariance Measurements)

- Ambient CO_2 concentrations (ppm)
- CO_2 density (umol mol^{-1})
- 3D wind velocities (m s^{-1})
- Pressure (Pa)
- Temperature (°C)

Ecosystem Flux Data (processed)

- Net Ecosystem Exchange (NEE)
- Gross Primary Productivity(GPP)
- Ecosystem Respiration (Autotrophic Respiration and Heterotrophic Respiration)

Spatial and Temporal Aggregates

- Daily, monthly and annual fluxes of water, carbon and methane
- Regional patterns aggregated across ecosystems or biomes to identify spatial trends in the exchange of water, carbon and methane

Ecosystem Carbon Budgets

- Annual carbon budgets (Total carbon uptake and release at the ecosystem scale)
- Carbon Use Efficiency (Ratio of GPP to total ecosystem carbon release)
- Net Biome Productivity (Carbon balance of a biome considering disturbance such as fires, deforestation)
- Carbon fluxes: Net ecosystem productivity (NPP) and Gross Primary Productivity (GPP), fluxes from land use change

  Ecosystem Scale Processes/Parameters

- Canopy conductance and transpiration
- Energy fluxes; latent, sensible and ground heat flux
- Range of biometeorological variables such as solar radiation balance, meteorology, rainfall, wind, atmospheric pressure, soil moisture and temperature

- Methane concentrations and localised emissions tracking

In addition to the products derived from the observations, the creation of visualizations for diverse audiences will facilitate information dissemination and general climate literacy, for example:

- Greenhouse gas inventories for regional and national reporting
- Carbon footprint analysis to assess land use impacts and mitigation strategies
- Risk assessment maps identifying areas at risk of becoming carbon sources, for example Global Forest Watch: https://www.globalforestwatch.org
- Land management decision tools for sustainable forestry and agriculture based on carbon flux dynamics, for example COMET-Planner: http://comet-planner.com
- Renewable energy planning, for example, Global Solar Atlas, https://globalsolaratlas.info, and Wind Atlas for South Africa (WASA): http://wasaproject.info/
- Conservation planning which links carbon storage with biodiversity: The Nature Conservancy Resilient Land Mapping Tool: https://www.maps.tnc.org/resilientland/#/explore
- Validation of RS product outputs, e.g., (Floyd Vukosi Khosa et al. 2020; Maluleke et al. 2024)
- Earth system model validation, e.g., (Floyd V. Khosa et al. 2019)

●Integration with emerging technologies: Artificial intelligence (AI)/machine learning (ML) (AI/ML) applications for flux data, including processing, gap-filling, and prediction. Microsoft AI for Earth: https://www.microsoft.com/en-us/ai/ai-for-earth

5. Impact and Integration

In the previous sections, we illustrated how climate services, and in particular the pilots developed in the frame of the KADI project, can be connected to the designed topical RI and allows to better answer the needs of the stakeholder. Having identified these connections makes it possible to anticipate and build the required digital infrastructure and the relevant networks to set up and manage the flow of data and information that is needed to go from basic observations to products. In many cases, we also identified products or knowledge that the stakeholders can provide to the climate services and of interest for the associated RI, illustrating the two-ways exchanges that can be established and the co-benefit that can be obtained.

In a context of limited funding regarding the needs in observations and infrastructure, optimizing the use of open access data and products, information and knowledge produced by the climate services and the RI is imperative. The establishment of links with international organisations or network should allow to benefit from standards to make the observations from Africa comparable and usable at the international level and thus contribute to international science on climate change.

The objective of the deliverable was to provide an analysis of the ratio cost/impact of products of the climate services. Regarding the scarcity of the observations across the continent, any additional observation or service will have an impact, with greater value if it addresses underrepresented regions or ecosystems.

For GHG monitoring stations an estimation of the reduction of the uncertainty on the carbon budget as a function of the measurement sites was performed with an incremental optimization of the geographical deployment accounting for the type of emission zones and the targeted species (CO_2, N_2O, CH_4) (Nickless et al., 2020). More than an estimation of the number of stations required to reach an acceptable level of uncertainty, they proposed a ranking of the station for the different species. For CO_2 and N_2O the best ranking was for sites located in central Africa such as Democratic Republic of Congo, Angola, Cameroon; Chad and Sudan. For CH_4 the same sites have high ranking with a few sites in southern Africa (South Africa). The multi-species optimal network design solutions recommended sites concentrated between 10N and 25S. A network of twelve stations could provide a reduction of the uncertainty of 47.8% for CO_2, 34.3% for CH_4, and 32.5% for N_2O. Satellite observations were found to be a relevant complement to in situ observations but it requires some calibration/validation of the satellite products in African environments and range of concentrations For a set of about 50 stations the uncertainty reduction does not exceed 60% since a higher reduction require additional constrains and measurements.

This approach can hardly be extended to short lived-species whose concentration fields and emissions fluxes are much more diverse and discontinuous. However, the distribution of the stations for the optimized multi-species GHG network allows coverage of a range of ecosystems that corresponds to well identified sources of aerosols (biomass burning, primary and secondary biogenic aerosol; mineral dust) and reactive gases (biogenic organic compounds, NO/NO_2). Regarding air quality, very few countries have national air quality networks and very few African towns are equipped with air quality monitoring systems. South Africa has amongst the most developed and standardized national air quality network with more than 130 measurement stations among which 70 are providing near real time measurements. The network is mainly composed of governmental instrumentation but also use data from private stations. In the recent years, many low cost air quality sensor networks have emerged globally, but also in Africa. The most developed network is the AirQo network, developed by Makerere University (Uganda) in 2015, winner of the Google AI impact challenge in 2019 and winner of the WMO Award in 2020. The network aimed to deploy low cost air quality sensors (Binos air Quality sensor) adapted to the African context (High level of pollution and dust, high temperature). Eight African cities are equipped with more than 250 low cost sensors and a calibration procedure is applied based on machine learning and comparison with referenced instruments. AirQo also promotes communities of practice to connect people, data, and practical solutions that support clean air efforts across the African continent (Africa Clean Air Network). This network exemplifies a low-cost, high-impact initiative action developed in connection with academic partners and local, national and international stakeholders. Over the African continent in 2025, 83 towns are hosting more that 1 million of people. The continent already counts several megacities (> 10 millions of people) (Cairo, Egypt; Kinshasa, Democratic Republic of Congo; Lagos; Nigeria; Luanda, Angola), and several others should reach this status in the coming years (Dar es Salaam, Tanzania; Khartoum, Sudan; Johannesburg, South Africa; Abidjan Ivory Coast, Nairobi, Kenya). Such a concentration of population implies large emission of atmospheric pollutants and a large amount of people exposed to poor air quality. Air quality networks, combining reference instruments and low-cost sensors, should be developed in priority in these cities.

Concerning the costal biogeochemistry, the pilot developed in Algoa Bay and St Helena Bay allows researchers to document 2 of the main bioregions of importance in the coastal waters of Africa. Only five of the eight identified bioregions are hosting in situ measurements. Specific efforts should be made to upgrade the 5 sites at the same level of equipment than the two pilot sites and to deploy measurements in the three non-monitored bioregions.

6. Conclusion and recommendations

This deliverable demonstrates that building a value chain from observations to climate services in Africa requires more than a linear process. By connecting the pilots developed in WP2 with the pan-African topical research infrastructures (RIs) designed in WP3, the project highlights a framework of interactions and feedback loops among stakeholders, data providers, service developers, and international partners. This approach strengthens the flow of observations, products, and knowledge while ensuring that African-specific needs are met and aligned with global standards. The analysis shows that, despite limited observational resources, even incremental improvements in observational coverage and data sharing can yield significant impacts for both scientific advancement and societal resilience.

From these analysis we propose the following recommendations:

1. Strengthen connections between African and global infrastructures: Reinforce ties between African initiatives and global frameworks such as WMO's Global Atmospheric Watch and European RIs (ICOS, ACTRIS, IAGOS) to ensure harmonization, comparability, and greater international visibility of African contributions.

2. Promote interoperability and data sharing: Establish common standards for data management and service delivery to ensure FAIR principles (Findable, Accessible, Interoperable, Reusable) and open access across national, regional, and international levels.

3. Support capacity building and local innovation: Invest in training programs, technical infrastructure, and the development of African-based solutions, such as affordable sensor technologies, to ensure local ownership and long-term sustainability of the value chain

4. Foster stakeholder engagement and feedback loops: Build structured mechanisms for dialogue between climate service providers, end-users, and research communities to increase the usability and societal relevance of climate services.

5. Encourage multi-level partnerships: Expand collaboration between national, pan-African, European, and international organizations to leverage resources and maximize the impact of observation and climate service initiatives.

6. Ensure sustainability: Develop robust financing strategies and governance models that ensure continuity beyond project lifetimes and strengthen long-term African leadership in climate observation and service provision.