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CLIMATE LINKS: A TERRESTRIAL CLIMATE DATA COLLECTION NETWORK COMPLEMENTING SATELLITE OBSERVATIONS

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The increase in the number of satellites dedicated to studying climate variables and the establishment of international programs such as the Global Earth Observation System of Systems show that space infrastructure plays a key role in understanding the mechanisms and effects of climate change. Although increasing amounts of climate data are being collected from space, there remains a lack of $in - situ$ data collection to correlate and validate the satellite-collected data. The reason for this deficiency is that traditional methods of terrestrial data collection are often expensive and time consuming. This report envisions a comprehensive system of sensory devices for proficient users in the scientific community and non-specialized users in the public to address the above-mentioned shortcomings. The main focus is to establish requirements for a pilot study in Nigeria using stationary data collection devices (the 'GreenBoxes') for the systematic collection of precise and accurate data of ten essential climate variables. This integrated system includes all components required for collection, management, and distribution of the sensory data to appropriate users such as scientists and the general public. This paper presents recommendations for the system architecture and implementation plan, as well as discuses social and political impacts and legal consideration during the pilot project in Nigeria.

Keywords: System of Systems, Climate Change: Nigeria, Law, Policy, Ethics, Business

INTRODUCTION

Many definitions of climate change exist and vary depending on who provides them. According to the United Nations Framework Convention on Climate Change, climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" [1]. For the purposes of this paper this definition is adopted.

The Earth's climate depends on multiple interconnected systems, such as the atmosphere, oceans and land. In order to acquire a good understanding of climate change, the interaction and feedback mechanisms between these systems must be understood [2]. Changes occurring to the Earth's environment are already evident. Some of these changes include rising global sea levels, melting ice sheets and glaciers, increasing average global temperature, changing precipitation patterns and rising intense cyclone activity [3]. Scientists argue that both natural phenomena and human activity cause climate change. Natural factors such as the precession of Earth's axial tilt, variability of solar activity, and cycles of glacial advance and retreat are responsible for variations in Earth's climate history. Human activities, such as clearing rainforests, depleting freshwater resources, burning fossil fuels, and dramatically altering coastal habitats and marine fisheries have all been cited as factors that accelerate climate change. Climate change affects ecosystems and biodiversity, human health and social development, business and economics, and political and technological environments.

Responses to climate change can be divided into two categories: mitigation and monitoring. Monitoring allows for a greater understanding and predictability of climate change by tracking related environmental variables. Mitigation includes actions that attempt to decrease Green House Gas (GHG) concentrations, or to reverse or lessen their impact on the environment. Both methods are important, and if employed in combination can effectively decrease climate change.

Climate monitoring aims to provide a better understanding of climate change. The information gained from climate monitoring may be used to evaluate the current state of Earth's climate and predict future changes; take action against further changes and reverse negative impacts; and propose mitigation strategies and evaluate their effectiveness.

Mitigation refers to human interventions that reduce sources or enhance sinks of atmospheric GHGs. Mitigation is a complex challenge that must take into consideration many factors, for example technical feasibility and global cooperation. Other political, social and economic concerns further complicate this effort.

Another challenge in climate change mitigation is that the effort made by current generations to fight the problem does not reap immediate benefits. For this reason, it is often difficult to convince decision-makers to take action. Monitoring is therefore important so that trends and predictions can gain credibility in order to emphasize the importance of taking action today. However, it is imperative to make the general public more aware of the climate change problem and encourage them to take action to solve this problem for generations to come.

There are various satellites that monitor or mitigate climate change. These satellites are meant to complement or improve upon terrestrial applications, or in some cases provide a service that cannot be achieved any other way. There are approximately 100 civilian Earth Observation (EO) satellites in orbit today that have at least one instrument capable of measuring climate-related variables. Envisat, Odin, EOS-Aura, and GOSAT are examples of EO satellites providing coverage of Essential Climate Variables (ECVs).

The Global Climate Observing System (GCOS), whose responsibility is to coordinate all climate related studies and activities, has identified 44 ECVs to be monitored by both $in-situ$ and remote sensing systems [4]. Of the 44 ECVs, 26 can be measured with EO satellites. There are 326 payloads onboard EO satellites that monitor ECVs, as shown in Figure 1.

The strength of satellite data is high spatial coverage; measurements from a single instrument are available for a large area over a relatively short period of time. However, the main weaknesses identified in satellite measurements are low spatial resolution and infrequent re-visit time [5]. These are important to validate and improve regional climate models. These gaps are being addressed by the use of ground networks, but they in turn lack the high spatial coverage of satellite data. Thus, ground- and space-based climate data complement each other and must be integrated in order to gain full understanding of the climate system and any changes therein.

Low spatial and temporal resolutions are critical in many climate studies and are expected to become the dominant source of error as climate models become more accurate [6]. While it may seem that temporal resolution would not

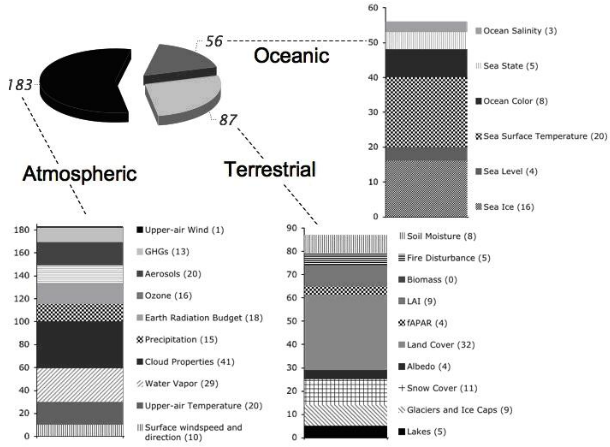

FIG. 1: Distribution of satellite payloads measuring atmospheric, terrestrial, and oceanic ECVs.
Note: One item to note is the number of instruments listed for the measurement of biomass. While it is listed as '0', almost any EO satellite with a multi-spectral optical payload could measure this ECV.

be a critical factor in the evolution of climate models this is not the case. The short variations in weather over a few days plays a critical role in the long-term balances of energy, momentum, and water vapor in atmospheric climate systems [7]. Using a combination of $in-situ$ and satellite data in climate models can make them more robust and accurate, improving both their spatial coverage and resolutions.

Currently, there is a lack of $in-situ$ climate data available to complement EO satellite climate data. *In-situ* measurements are needed to corroborate space-based measurements, check the validity of satellite sensors and establish adequate baselines [8]. These ground-based sensors need not measure the same ECVs as those measured by EO satellites; Ground-based measurements of variables that are closely related to the ECVs measured from space are also useful[9]. Temporal and spatial correlation between the two methods of observation is needed and the way in which this is done heavily depends on the variables being measured. For example, complementary $in-situ$ and satellite measurements of the ozone must be done in the same day, while those for aerosols are needed within the hour.

In response to the challenges stated above, this paper presents Climate Links, a proposed high-level framework that addresses the following monitoring and mitigations needs:

Monitoring: A need for coordination between terrestrial and space-based data collection.

Mitigation: A need for increased public participation, such that ordinary people feel connected to the problem, and motivated to take action in solving it.

The Climate Links system will be a ground-based sensor network that complements satellite observations. In addition to this, the system will aim at providing a means for communication and collaboration between the space community and $in-situ$ field workers, climate scientists, and the public. The Climate Links system will strive to create a comprehensive $in-situ$ data collection service to improve available satellite data, to raise public awareness of climate change by increasing participation, and to improve public knowledge of the space sector's role in addressing climate change. The overall purpose of the Climate Links system will be to improve human understanding of climate change.

SYSTEM OVERVIEW

The Climate Links system will add value to satellite climate observations by introducing complementary data from a network of $in-situ$ collection devices. Two devices will be employed by Climate Links: sophisticated, deployable, stationary, and professional grade "GreenBoxes" as well as widely distributed "GreenPhones". The"GreenBoxes" will be suitable for use by professoinal scientists while the "GreenPhones" will be used by motivated citizens interested in 'participatory sensing' (*i.e.* the collection of scientific data by any concerned individual regardless of professional qualification). Data collected by all the devices will be managed and processed in order to produce useful information for climate research scientists and public awareness initiatives.

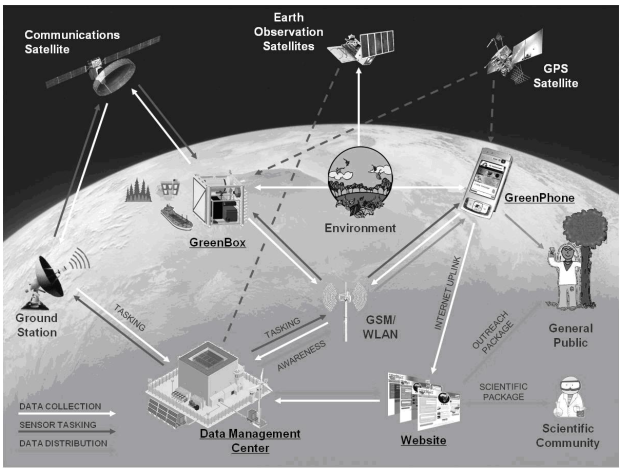

FIG. 2: Climate Links system overview.

The Climate Links system will consist of data collection devices, a data management center, and data product distribution channels. It will be supported by the Global System for Mobile communications (GSM), EO satellites, the Global Navigation Satellite System (GNSS), Satellite Communication (SatCom), Wireless Local Area Networks (WLAN), and the Internet as shown in Figure 2. The acquired raw data will be processed in the data management center and be publicly available through a webpage. The webpage will allow users to upload their data directly from a GreenPhone as well as access basic maps and statistics related to the Climate Links system. Additionally, the public will be able to subscribe to a 'green fact of the day' message via a Short Message Service (SMS). Figure 3 shows the flow of data from the collection devices, through the data center, and finally to completed data products.

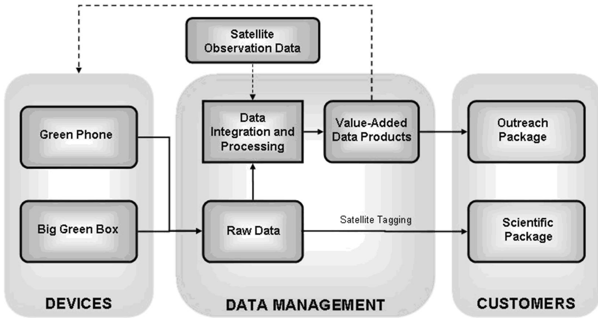

FIG. 3: Climate Links data flow path.

The GreenBox is to be an autonomous package of analytical grade sensors and communications equipment. This device will be geared towards collecting precise, scientifically valuable data and returning information to the data center. Future iterations of the GreenBox could also be placed on different platforms including ships and transport trucks in order to increase geographical coverage. The GreenPhone will utilize miniaturized sensors to collect data at the discretion of the user. This device will be geared towards satisfying the public participatory goals of the system, but will also collect usable scientific data.

Both devices will collect scientifically valuable data and involve a degree of public awareness. Since each device will address these needs to a different extent, the two are seen as complementary components. The data collection will be done by synchronizing ground-based data collection with specific over-flying satellites, or by collecting data to fill gaps between satellite passes. All of the measurements taken by these devices will accumulate within the Climate Links database.

Some basic data reduction would be performed to ensure minimum quality standards, to make certain the data is tagged in time and space, and to ensure that, where appropriate, the relevant EO satellite is identified. The processed data could be used by satellite operators and research scientists to reduce climate data uncertainty and to validate climate models. The data may also be used to produce simplified statistics and information more suitable for public audiences. Such awareness oriented products would be processed by the Climate Links data center, and distributed via the webpage and SMS.

The Climate Links system plans to integrate itself into existing programs such as GCOS. Climate Links will contribute to GCOS by feeding $in-situ$ measurements directly into it in order to reduce uncertainties in satellite climate data and improve the spatial and temporal resolution of the overall GCOS dataset.

SYSTEM IMPLEMENTATION

The architecture outlined previously presents an overview of the entire Climate Links system while this section presents a roll-out plan for parties interested in its implementation. It is recommended that Climate Links be rolled out in 5 phases, which will take the project from conception through full maturity. The milestones for all 5 phases are outlined in Table I. The main highlight of the first phase of the Climate Links rollout plan, as well as this section of this paper, will be the development of a pilot project in Nigeria, which will feature the stationary Greenbox sensory device.

TABLE I: Climate Links Roll-out Plan.

Phase	Milestones
1	1. Formation of organization 2. GreenBox development 3. GreenBox manufacturing 4. Pilot project in Nigeria 5. Cellular phone SMS
2	1. Geographic expansion of GreenBox 2. Additional sensors 3. Mobile GreenBox edition
3	1. Two-way phone application 2. Establish partnership with mobile phone manufacturer 3. Prototype GreenPhone 4. Upgrade data capacity and communication infrastructure
4	1. GreenPhone release to pilot market
5	1. Geographic expansion of GreenPhone market 2. Professional GreenPhone add-on development and release 3. Complete global data availability and release

Phase 1 is anticipated to last 7 years in order to allow adequate time for fundraising, product development and the formation of partnerships that will facilitate later phases of the project. A pilot project will begin 2 years into phase 1, the details of which will be discussed later. At the same time, a project webpage and a SMS service will be developed. The phone service will provide an avenue for public awareness, while the webpage will provide distribution of the data products to scientists and the general public.

The Climate Links business plan is tailored towards a Non-Profit Organization (NPO) incorporated in the United States (US). This model was chosen because NPOs in the US benefit from a wide range of funding options and tax benefits, while avoiding most of the political and consumer market complications associated with other business models. The US was chosen for incorporation because there has been an emergence of climate change initiatives in the country. Furthermore, the US government provides substantial funding for US-based climate change NPOs, and US laws governing establishment of NPOs and tax exemptions are clear, well established and easily accessible [10].

Suitability of Nigeria

Nigeria is the proposed site for the Climate Links pilot project because there is potential for a mutually beneficial relationship: Climate Links can help Nigeria tackle climate change, while Nigeria can provide Climate Links with an ideal platform for its pilot project. As a developing country near the equator, Nigeria is particularly susceptible to the effects of climate change; its 800 km coastline is likely to be affected by sea level rise and almost $2/3$ of its land is prone to drought and desertification. This threatens the large majority of the population who depend on the coastline and arable land for survival.

Nigeria also appears to be open to foreign partnerships regarding climate change. It has recognized the threat of climate change, but also that it lacks the technology, finances, and legal framework to successfully fight the potentially negative impacts on its own [11]. There are many organizations and individuals in Nigeria working to promote climate change action in the country. In fact, the Nigerian Climate Action Network has the specific purpose of bringing these organizations and individuals together to achieve their common goal. The existence of such an organization illustrates how addressing climate change is a key part of Nigeria's strategy for the future. [12].

The leaders of Nigeria are focused on making their country one of the leading economies in the world by revitalizing government investments in science and technology. As Climate Links is a scientifically and technically innovative endeavor, Nigeria should be particularly interested in hosting its pilot project. Nigeria is also in the process of revamping its international reputation, which has historically been tainted by corruption, poverty, and political turmoil. By engaging in climate science in cooperation with international organizations like Climate Links, Nigeria can show its people and the rest of the world that it is taking concrete action.

The proposed pilot project can promote education and encourage more students to continue their studies. Forty-five percent of Nigeria's population is below the age of 15, making the education system a good platform for climate change and space awareness [13]. One way to encourage Nigerian students is to assign GreenBoxes to local schools to provide more hands-on educational experiences. By involving students in real science at an early age, Nigerian students will be encouraged to continue studying and even pursue careers in science and technology sectors, thereby fostering lasting benefits for the entire country [14].

The Nigerian government is also developing partnerships with Cisco, Microsoft, and Intel to expand the country's Information and Communication Technologies infrastructure [14]. The GreenBox pilot project therefore presents an opportunity to increase the technical infrastructure of Nigeria while simultaneously raising awareness about climate change.

Furthermore, Nigeria created its National Space Research and Development Agency (NASRDA) in 1999. Climate Links is consistent with NASRDA's vision, which is to "pursue the development and application of space science and technology for the socio-economic benefit of the nation" [15]. NASRDA also aims to provide better ground- and satellite-based monitoring to enhance its Earth monitoring activities, as well as foster international cooperation in all aspects of space science and technology [16].

It is evident that Nigerians have realized the possible impacts that climate change may have on their country. They are currently taking action to better understanding the problem, as well as prevent any future negative impacts. A partnership with Climate Links will help Nigeria achieve its climate change goals.

THE GREENBOX

The main feature of the pilot project will be the development and implementation of the GreenBox. The GreenBox will be a compilation of sensors that provide the needed $in-situ$ measurements of ECVs to enhance satellite climate data. The instruments proposed are all Commercial-Off-The-Shelf (COTS), as autonomous and maintenance-free as possible, and follow a scheme of modularity to allow more flexibility. Some challenges may arise when deploying the GreenBox in extreme climactic environments, such as Nigeria's high tempertures and humidity. Thus, rugged instruments, special calibration and desiccants may be needed.

The Nigerian pilot project will focus on atmospheric ECVs, resulting in 10 ECVs measured with 8 sensors. These 10 variables are shown in Table II along with the availability of satellite data for each ECV. In particular, the focus of phase 1 of the project will be to monitor the rapid development of airborne gases, which in turn influence climate models.

TABLE II: Availability of Satellite Data for chosen ECVs.

Variable	Measured by satellite
Carbon Dioxide	Yes
Methane	No
Other GHGs (N_2O, CO)	Yes
Aerosols	Yes
CFCs	Yes
Water Vapor	Yes
Surface Temperature	No
Precipitation	Yes
Ground Atmospheric Pressure	No
Incoming Surface Radiation	No
Wind Speed and Direction	Yes

Choosing a location for each of the GreenBoxes will be challenging, as the site will ideally need to be representative of the surrounding area (within approximately 100 km^2); far from pollution sources, areas of false reflectance, and man-made phenomena that affect the micro climate; far from major roadways and airports; not sheltered by trees, buildings, *etc.*; near terrestrial networks to reduce the cost of a communication; an area with low flooding and lightning probabilities; and a location not prone to theft and vandalism.

GreenBox sensor requirements along with typical scan swaths of EO satellites dictate that the spacing between 2 GreenBoxes should be no larger than 100 km, and spread as evenly as possible across the regions of interest. To cover Nigeria's approximately 924 thousand km^2, 93 boxes are required. They should not be placed in locations where vegetation cover is not uniform over at least 100 m^2 and in regions with elevations that would introduce additional sources of error [17]. Only 90 boxes will be sufficient to cover sites that are of uniform vegetation in Nigeria and their locations are shown in Figure 4.

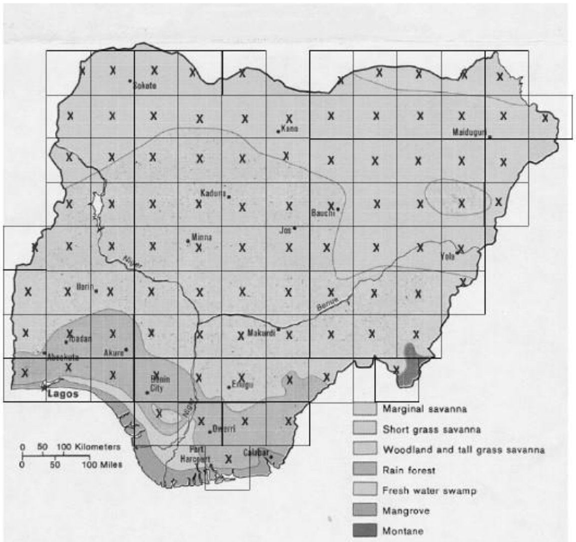

FIG. 4: 100 km × 100 km grid overlaid on vegetation map of Nigeria. GreenBoxes are represented by 'x'.

System Design

The sensors in the GreenBox determine its design for the Nigerian pilot project. A list of the sensors chosen for the GreenBox is shown in Table III. The data collected by these sensors will meet minimum performance requirements for measuring ECVs set out by the World Meteorological Organization. Other subsystems that allow for the functionality of the GreenBox are discussed in turn.

The main structural frame will provide the rigidity to the GreenBox and house the main components. The total dimensions of the GreenBox frame will be 0.94 m (l) × 0.6 m (w) × 0.64 m (h). It will house the computer system for overall system management, integrate all sensor feeds, provide power management and thermal control, and handle data storage and communications. All subsystems should be fully enclosed, with a door for easy access during maintenance, and should be kept at a constant temperature.

A specific program to manage the GreenBox hardware will also be necessary, and this will most likely have to be custom-made software due to the uniqueness of the system. The main task of this software will be to communi-

TABLE III: GreenBox sensor list.

Variables	Sensors	Considerations
Greenhouse Gases	Photovac's Voyager system [18]	Low size, weight, power consumption. Good ruggedness
Water Vapor	Chilled mirror dew-point sensor	No problems when operating in a polluted area
Surface and Solar Radiation	Black and white thermopile junction and infrared pyranometers [19]	Only downwelling
Temperature	Platinum resistance thermometer	Wide range, excellent accuracy, good long-term stability [20]
Atmospheric Pressure	Redundant electronic barometers	Good accuracy and long term stability
Precipitation	Tipping-bucket rain gauge	
Wind Speed and Direction	Hemispherical cup anemometer and wind vane	

cate with the input/output interface box, which connects the computer to all sensors and instrumentation, communications equipment, the power system, and the thermal control system. It should also serve as a fault-monitoring program that reports anomalies in the state of the GreenBox.

The program will be required to collect data from all sensors and perform some pre-processing. The sensors (with the exception of the GHG sensor) will collect data once every second, and the mean value and deviations collected over a minute will be calculated to ensure basic quality of the data points. The Gas Chromatographer (GC) will gather data of all the different gases once per hour.

Aside from the sensors that measure ECVs, the GreenBox should be designed to accommodate secondary instrumentation required to support collection of the climate data. To ensure an accurate and standardized data set, the GreenBox should contain a GNSS receiver to obtain clock signals and should be equipped with three micro-electromechanical accelerometers that will raise alerts when the GreenBox experiences excess vibrations that could cause errors in the collected data.

Housekeeping data will also be collected every minute. Every sensor will provide a status report that, in its simplest form, is a flag indicating whether the sensor is working nominally or not. This should facilitate maintenance, as well as tag any defective measurements. The total estimated size of the data to be recorded every minute is 266 Bytes (B), 236 B for the GC (recorded hourly), and 73 B for the housekeeping data. Therefore the total data accumulated in a day to be stored or transmitted to the data center can be calculated shown below.

$$(266B \cdot 60min \cdot 24h) + (236B \cdot 24h) + (73B \cdot 60min \cdot 24h) + 20\% = 600kB/day.$$

For the Nigerian pilot project, WLAN and LAN will not be used due to lack of availability. From the disposition of the GreenBoxes in the Nigerian territory, it was established that 16 of the GreenBoxes should be able to transmit their data through GSM networks. At 30 kbps, this would take approximately 3 minutes. The remaining 74 GreenBoxes will thus have to rely on SatCom for data transfer, transmitting for 8 minutes per day at approximately 10 kbps.

The power consumption of each device was used to calculate its energy consumption during a 24 hour period. This is calculated to be 936 W-h. Taking into account the worst-case effective peak sunlight hours in Nigeria (estimated at 3 hours per day). Three Suntech folding 140 W, 24 V panels are recommended for energy production. The electric charge needed for the battery system was calculated to be 32 A-h therefore four 12 V batteries with 225 A-h capacity are recommended for use for the system. The batteries should be located in the temperature-controlled processing module.

The GreenBox frame is designed to provide easy and safe transportation of the box. The main advantage of the box is that before deployment, all the sensors and structure required for deployment are neatly packaged within the box, making it easy and convenient for stacking multiple units in a shipping truck. In its pre-deployed state, the GreenBox is only a few centimeters wider than the frame dimensions, as all components are secured within the frame with the exception of the folding solar panels that attach to the outside. Figure 5 shows the locations of the components in the predeployed state.

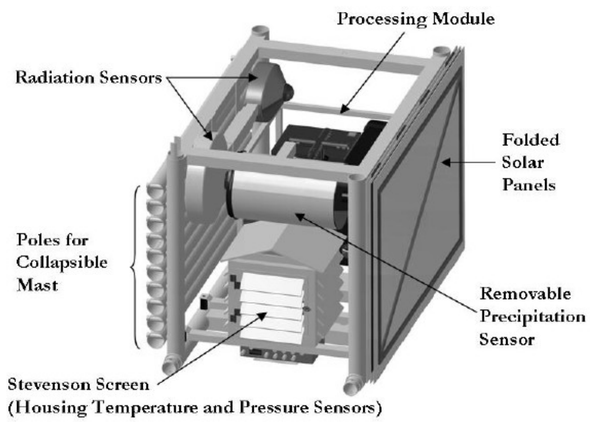

FIG. 5: Predeployed GreenBox.

In deployed configuration, the box will be 2.7 m (l) × 2.4 m (w) × 10 m (h). The mass of the device is estimated to be approximately 84 kg. This excludes the structural stand, the concrete foundation for the stand, cables supporting the wind sensor mast, and the recommended fence erected around each GreenBox. Figure 6 shows the GreenBox in its fully deployed state. Procedures for installing the structural stand of the GreenBox will have to be determined on a case-by-case basis.

The grid of GreenBoxes in Nigeria would most likely con-

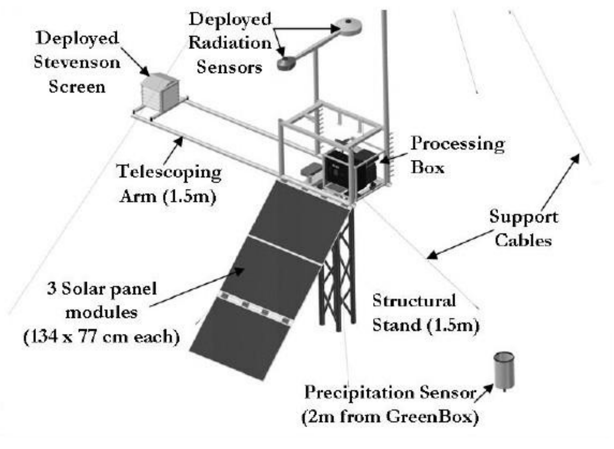

FIG. 6: Deployed GreenBox.

sist of a mixture of these advanced devices, and a few more simplified versions that would only measure 1 or 2 ECVs, such as GHGs.

General maintenance of the GreenBox should be carried out on a monthly basis to coincide with the calibration of sensors. This general maintenance will include solar panel cleaning, battery replacement if necessary, structural inspections, desiccant recharge and cleaning the radiation sensor housing. Due to the relatively low cost of most of the sensors used in the GreenBox and high staff costs, it will often be more efficient and cost-effective to discard faulty or broken sensors and replace them with new ones. Since all the sensors chosen in the GreenBox are COTS sourced, warranty agreements will be a significant factor in the overall cost of the system.

DATA HANDLING

Delivering the Climate Links data products to the users requires a robust data management system to handle the data throughout their life cycle. The data flow path is presented in Figure 7 and these steps are described below in the context of the pilot project for Nigeria.

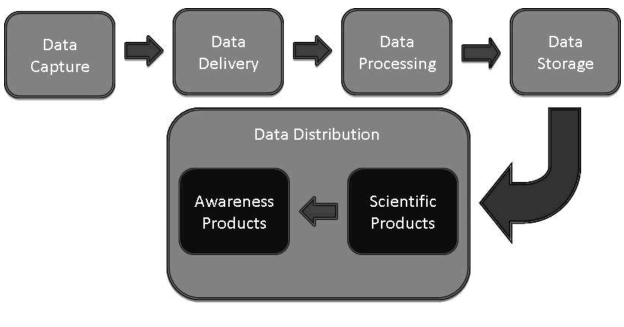

FIG. 7: Data life cycle showing data flow from measurement to product distribution.

Measurements of the surrounding environment will be taken by onboard sensors and coupled with associated data such as time of measurement and sensor health status information. The captured data will then be packaged and made ready to be sent to the data center.

For the delivery of the data from the device to the data center, the GreenBox will follow a Communication Priority Sequence Protocol (CPSP). It will attempt to upload its data through what is typically the least costly option, *i.e.* a WLAN or LAN connection, which is most likely to be available in urban areas. If it is unavailable, the device will attempt to upload through a GSM network. Finally, if GSM is not available, the GreenBox will try to upload via SatCom. Failing this, the data will be stored until a connection is established through one of the mentioned networks. For the pilot project in Nigeria, MTN will be the GSM provider and Thuraya will be the SatCom provider.

As soon as measurements are delivered to the data center, an initial processing procedure will be required before the data is organized and stored in the database. This procedure is recommended to include rectification, filtering, classification, and validation [21]. Each sensor installed in the GreenBox will attach a health tag to every measurement that it performs. The responsibility of the data center will be to identify and filter out erroneous measurements through the processing procedure. These irregularities may be an indication of abnormal function of one of the sensors and can identify the need for maintenance or replacement. Another method of validating data indirectly is to use the measurements of some sensors to extract information about the health condition of others. For instance, extreme temperature or humidity levels measured may indicate that some of the sensors are working outside their optimal conditions, and therefore not performing properly.

After retrieval and processing, the data will need to be organized and stored systematically. This is an important aspect of database management since it will make the database accessible. Proper and systematic data handling may facilitate future partnerships with data sharing portals such as GCOS, as well as promote the credibility of the system to potential users. Moreover, it is important that the design of the database be flexible enough to easily include data from new sources in later phases of the roll-out plan, or collaborations with other projects. In the case of the pilot project in Nigeria, the annual amount of data to be captured and stored will be approximately 20 GB per year. This quantity can easily be handled by a COTS server. This server can be located in virtually any location with good connectivity to the Internet. For example the server could be located at a university in Nigeria, encouraging collaboration with local researchers and students, who could assist in the maintenance of the server and handling of any problems.

The data collected by the Climate Links system will be distributed through the project's webpage. The webpage is recommended to be an interactive user interface that will distribute information about the Climate Links project, the data gathered by the deployed sensors, and the results from scientific analysis. The webpage will deliver information with the aim of reaching a wide range of audiences, from school aged children to university scholars. The goal of the webpage will be to benefit the scientific community by providing essential correlated data for analysis (scientific product), as well as create awareness for social change (Awareness Product).

The Scientific Product will address the lack of correlation between satellite data and $in-situ$ data measurements of ECVs. Users of this product will include scientific communities, researchers, and possibly EO satellite operators. This product will provide data that has been processed and presented in a commonly practiced and accepted format.

The Awareness Product will address the lack of public knowledge about climate change, previously identified as one of the crucial needs to address climate change. It will present information directly from scientists in order to influence social, educational, public, and governmental changes. The ultimate goal is to bring the problem of climate change to a level that will influence citizen behavior. Proposed users of the public data are the general public, climate enthusiasts, and governmental and environmental agencies.

Since the data will be available free of charge to the scientists, they would be encouraged to share the information deduced from data, and their results and findings could be submitted to the data center through the webpage. These results would then be published on the webpage and act as an input to the awareness product. This method could be implemented to encourage a sense of community between climate scientists and enhance collaboration with the Climate Links project. Most importantly this would allow the general public interested in the field of climate change to be aware of ongoing research.

Intelligent Sensing

The ability of the data center to communicate with the GreenBox will be very important as the boxes can be prompted to perform various tasks that are not routine. The data center will be capable of communicating with the GreenBox through WLAN and LAN, GSM, and SatCom following the CPSP. Through this capability, any software update can be done remotely. Another advantage is that in case of anomalous weather conditions (hazardous), the GreenBox could be commanded to halt measurements as data measured at this time may not be useful.

One goal of the Climate Links system is to add value to satellite climate data by synchronizing its collection with those of $in-situ$ sensors. Synchronization will be accomplished using intelligent sensing. Each GreenBox will be tagged with the names of the EO satellites that include the GreenBox in their ground tracks. The data center will then alert the devices when satellites are overhead so they may take synchronous measurements.

FACILITATING THE PILOT PROJECT

Nigeria is located in West Africa, a region where climate research is in need of improvement [22]. Regional models can more accurately predict, with greater confidence, precipitation from the seasonal monsoons for Nigeria and surrounding countries, thereby providing better understanding of the regional climate. More detailed regional models, with higher spatial resolution of local climate drivers, also improve global climate models. Climate Links' partnership will not only give Nigeria a better understanding of its climate, but also prepare its government and people for the effects of climate change.

GreenBox data could be used to improve weather forecasting as well. The Nigerian Meteorological agency (NIMET) has 37 Automatic Weather Observing System (AWOS) and 55 Manual Weather Observing System (MWOS) stations across the country, with more planned for the future [24]. However, AWOS and MWOS data show discrepancies. One reason for this is that MWOS uses analogue data systems, which can produce standard errors when converted to digital standard. The Climate Links' GreenBoxes will offer better data reliability and authenticity for NIMET as it acquires data in a digital format similar to AWOS; data acquired from the GreenBoxes and AWOS could be used to calibrate the MWOS stations so that its outputs meet acceptable standards. Moreover, the 3 systems working at the same time and in the same location will increase the density of the existing network, creating the redundancy necessary for measuring the ever-changing climate variables at different spatial and temporal scales [24]. Because of this potential for a mutually beneficial relationship between NIMET and Climate Links, it is suggested that a partnership be formed. This cooperation could include placing GreenBoxes at AWOS or MWOS locations, so as to take advantage of the land rights granted to NIMET, and possibly also power and maintenance sharing.

Financing

The proposed NPO will provide much of the Climate Links system at no charge, making responsible management and continuous funding crucial. The components and materials for the GreenBoxes are estimated to cost approximately 44 thousand US Dollars (USD) each. As the NPO will not own a manufacturing plant, integration of the GreenBoxes will be contracted to an external company. Choosing a Nigerian company will reduce shipping costs, as well as benefit the country's economy and technological capabilities. Table IV shows the required resources for the pilot project.

The main sources of funding for NPOs can be categorized into 4 donor markets: individual donations, corporate donations, government grants and foundations and trusts [25]. All 4 donor markets, as well as partnerships in the form of non-monetary support, are considered.

TABLE IV: Pilot project resources.

Human	Physical	Financial	Intangible
Board of directors	Office space (USA)	15 million USD (Phase 1)	Partnerships
Managers	Office space (Nigeria)		Branding
Fundraisers	Data center		
Technical personnel			
Field Personnel			

Individuals are a major source of donations for many NPOs, with some claiming they account for as much as 81% of their total income [25]. However, it is increasingly difficult to obtain these funds due to the increasing number of NPOs, slowing growth rate in individual donations, and current economic recession. Since donation amounts depend on the nature of the cause, climate change organizations benefit from their philanthropic appeal. Donor recognition is also an important concept for long-term projects, so developing a loyal donor base will be vital for sustainability [26].

Historically, corporate donations have been largely underutilized. In the US, corporate donations typically amount to less than 1% of a company's pre-tax income, even though up to 5% may be donated under US law [25]. The Climate Links project will need to take full advantage of this untapped resource in light of the increasing trend of 'corporate responsibility'. Moreover, corporate donations do not need to be limited to monetary funds as there is great value in alternative forms of support, such as offering products and services at reduced rates.

Government agencies may prove to be the largest source of funding for this project since many countries, including the US and Nigeria, invest heavily in scientific and environmental development. For example, the Natural Science Foundation provides grants for many projects focused on climate change. The Environmental Protection Agency is another US government agency awarding grants to environmental projects. For example, its Environmental Education Grants program supports projects that "enhance the public's awareness, knowledge, and skills to help people make informed decisions that affect environmental quality" [27].

Nigerian grants may come from various sectors, including the Federal Ministry of Education, Federal Ministry of Science and Technology, Federal Ministry of Information and Communications, and the Federal Ministry of Environment, Housing and Urban Development. Nigeria has also been working closely with UNESCO to develop a Nigerian National Science Foundation, similar to that of the US. At the moment, the proposed Foundation is only a draft bill that is to be considered by the Nigerian Parliament [28]. However, assuming it is established within reasonable time, it could be a primary source of Nigerian funding for the Climate Links pilot project.

Foundations and trusts exist to manage funds from various sources for a specific cause. One possible source of funding for Climate Links from this sector is the Earthwatch Institute (EI), an international NPO that raises approximately 15 million USD per year from various individuals, corporations, institutes, and governments around the world. As one of the world's largest private funds for scientific research, it places a high priority on projects that benefit the global scientific community, specifically including those for long-term climate change monitoring [29].

Given the continually growing number of projects addressing climate change, partnerships with existing initiatives may prove to be a considerable source of non-monetary support. One candidate is the previously mentioned EI. As an active promoter of public involvement in understanding and mitigating the impacts of climate change, a partnership between EI and Climate Links would be ideal; its interests are aligned with those of this project, and EI has already established climate change contacts and research centers around the world [29]. Partnerships may also provide alternative forms of support as corporations seek to improve their corporate responsibility. For example, Cisco partners with Non-Governmental Organizations and NPOs as part of their corporate social responsibility program, providing their services for the benefit of humanity [30].

Legal and Ethical Considerations

In order for Climate Links to be able to carry out the pilot project in Nigeria, some important national and international legal and ethical issues need to be considered and resolved. Nigerian law requires that, before obtaining a place of business or an address for service, all foreign corporations register within the Nigerian system [31]. Thus, Climate Links must be registered as an NPO in Nigeria before its start of operations. This will allow Climate Links to apply for funding in Nigeria, as well as grant individual liability coverage for its Nigerian counterparts.

To manage potential data distribution liability issues, data provided to scientists will come with a disclaimer. Data disclaimers are common and used by organizations when supplying professional data. This affords a certain amount of legal protection as such guidelines may be considered best practices. By having such disclaimers as part of the terms and conditions that users must agree to, the Climate Links project will be protected from potential litigation as a result of data dissemination.

Technology transfer refers to the diffusion of technologies and technological cooperation between and within countries [32]. Legal issues surrounding technology transfer include: intellectual property rights; unwillingness of developed countries to divulge environmental information; national security; and government policies (tariffs, trade barriers, etc.). To address climate change in Nigeria there is a need for technological innovation and rapid technology transfer. The Climate Links system will need to verify that all technology transfers follow Nigerian and US laws.

In terms of data collection in sensitive areas, freedom of information could be both a legal and ethical issue. Nigeria depends heavily on its natural resources, such as oil, and the amount of GHGs in the atmosphere near processing plants may be confidential information. Under these circumstances, the climate data would not be accessible and the locations of the GreenBoxes would be adjusted accordingly. This raises an ethical question of how to balance the importance of environmental research and protection with the country's economic imperatives.

FUTURE CONSIDERATIONS

So far the discussion has revolved around the Nigerian pilot project. To implement the complete Climate Links system, a 5-phase roll-out plan was described earlier. After establishing the necessary infrastructure and knowledge, the remaining 4 phases will be implemented very easily. This section will briefly explain the evolution of the GreenBox and the introduction of the GreenPhone through the remaining phases. The expansion and evolution noted here are imperative to achieve the ultimate goal of Climate Links which is to achieve a world wide network of $in-situ$ sensory devices that encourage public participation.

Development of the GreenBox

The roll-out plan presented recommends global expansion of the GreenBox once the pilot project is complete. The recommended roll-out strategy beyond the Nigerian pilot project will begin in the equatorial regions of the world where there is a lack of useful climate data being collected [33]. Initial deployment in equatorial regions will expand to mid-latitudes and finally toward the poles.

The GreenBox presented is designed to work within Nigerian weather parameters. As expansion to other areas begins, slight modifications will have to be made based on geographical weather requirements. The modular design of the GreenBox, with all sensors and components removable and replaceable, allows for suitable modifications depending on the weather conditions.

The first major modification to the phase 1 GreenBox, after making it suitable for different weather patterns, will be to make it smaller. By making a smaller version of the GreenBox, it will have the option of being mounted on, or integrated into, vehicles. The increased mobility will allow for each box to gather data over a larger geographic area. Satellite data could then be verified in more locations thereby minimizing any location biases and maximizing the geographically varied data validation.

The GreenBox will need to be modified in order to allow it to function on mobile platforms. From the phase 1 GreenBox, a smaller and more aerodynamic device would be developed. This will first require the development of sensors that can operate accurately while in motion. Sensor miniaturization will also be important to minimize both the weight and power consumption. These mobile boxes could utilize a power source provided by the platform, as opposed to the phase 1 edition's solar panels.

The individual platforms heavily influence the GreenBox design and must also be taken into account. For example, the GreenBox that will be placed on a ship would need to consider conditions such as high humidity and the presence of salt-water. Because the GreenBox will be in motion under significantly different circumstances, speed and vibration frequencies will become design requirements. It must also be remembered that all climatic conditions could be experienced by a moving platform traversing large distances.

Increased device mobility and global system expansion enhances support for satellite observations while creating the necessary infrastructure for public involvement. Future changes to the GreenBox design will enhance the overall capabilities of the Climate Links system by increasing satellite verification capabilities and global coverage. A more global system could also utilize more satellites and increase the added-value to satellite data already in use.

Development of the GreenPhone

The Climate Links project will take a unique approach to climate change by including the public in climate monitoring in order to increase awareness and to begin to change destructive behavior patterns. The development of the GreenPhone as a participatory sensing device will be critical to the culmination of the Climate Links system. The GreenPhone will be able to promote awareness and responsibility, as it is a good medium to provide the public with up-to-date information regarding the climate. The GreenPhone will utilize cutting edge technology that will also be attractive to the 'high-tech' demographic.

The GreenPhone roll-out must allow for the maturity of technology and data management. Since public participation is a main goal of the Climate Links project, a key feature of the GreenPhone application will be to prompt the user for data collection when a satellite passes overhead. This enables collection of data synchronously with a satellite pass and helps inform the public about the role of EO satellites and space in climate monitoring. All data will be collected by the data center and processed for quality control. Finally, the webpage interface will make this data available for climate enthusiasts.

The GreenPhone will be made available in the later phases of the roll-out plan, once the infrastructure and operations for the GreenBox are well understood. Since phones with embedded sensors are under development now, the GreenPhone will most likely be developed in partnership with existing mobile phone companies. The GreenPhone will aim to actively involve the public in climate change studies, at minimal cost and without having complicated training procedures.

When designed in detail, the hardware and software application for the GreenPhone should meet modern industry standards in terms of user interface, reliability, and programming language. There will also be particular needs such as increased autonomy, memory and power usage, and graphic interfaces. Mobile phone manufacturers are beginning to develop environmental sensors; Nokia has begun promotion of its Eco Sensor concept [34], while Intel is working with researchers at Carnegie Mellon University to develop sensors [35].

World expansion of the Climate Links initiative will include stationary devices, devices installed on moving vehicles, and potentially millions of GreenPhones. All these devices will be collecting and transmitting large amounts of data. There would also be an increase in the communications necessary to manage the entire network of devices. At this stage, a dedicated data center may be required to retrieve, process, and store the large amounts of data. The CPSP for a public mobile device would be identical to those outlined for the GreenBox. The only exception being that public device users will not have access to SatCom, as the public device is meant to be small in size.

CONCLUSIONS

Long term climate modeling remains a challenge due to high uncertainty resulting in the models, making it difficult for decision makers to utilize predictions. Earth observation satellites are beginning to play a more critical role in climate modeling, with new missions such as JAXA's GOSAT, designed specifically to study the fluctuation of carbon dioxide emissions. Observing the Earth from space allows for a global perspective which provides an overall situational awareness of atmospheric compounds. However, at the ground level, the GHG concentration is constantly changing so satellites are limited by temporal resolution because they only capture a snapshot of the area.

The Climate Links initial proposal is to create a grid of autonomous, $in - situ$ surface level climate stations called GreenBoxes. The objective is to install a grid of these GreenBoxes to enhance the ECV data already collected by satellites through synchronous data collection. The basic GreenBox would be equipped with a rugged set of sensors designed to measure fundamental GHGs (CO_2, N_2O, CO, CH_4) and CFCs, whereas fully featured GreenBoxes would also include a full set of weather parameters. Phase 1 of this project focuses on the case of Nigeria: an emerging equatorial country that has the ideal political and geographical characteristics for a 5-year study to test and validate the Climate Links system before future expansion to other areas.

Aside from enhanced climate modelling, part of the solution to climate change is the increased public awareness on how the issue affects everyday life. In phase 1 of the Climate Links system, interested mobile phone users would be able to receive text messages updating them on the progress of Climate Links and with climate information relevant to their area. As the GreenBox technology and integration matures, and miniaturized environmental sensors become more reliable, the Climate Links project will introduce a new mobile device, the GreenPhone, which is capable of measurement of select ECVs. With the Climate Links data infrastructure in place, the addition of the GreenPhone will open the door to participatory citizen science. GreenBoxes and GreenPhones will have the ability to be prompted by the Climate Links system to take a ground based measurement when an EO satellite is passing over head.

While many people may be concerned about climate change, the problem is so vast and abstract that individuals may not feel they can make a difference [36]. The GreenPhone can empower them to make a direct contribution to climate change data collection, and people will see that 'ordinary' individuals can get involved in climate change mitigation. Furthermore, companies and organizations could adopt a GreenBox to contribute to climate research by supporting the collection of important climate data. Finally, the Climate Links system highlights the role space systems play in monitoring climate change and will also be a way for citizens to feel connected to the space industry's contributions.

The Climate Links long term vision is a world with a seamless network of GreenBoxes continuously monitoring ECVs in order to enhance information obtained from EO satellites. They would be simple, reliable and rugged enough to be used by professionals or amateurs. Moreover, there are potentially millions of GreenPhone users that will be able to measure and exchange valuable GHG information. The Climate Links system would manage the flow of data, and would provide climate modelling professionals with precious raw data that enables them to make more accurate climate predictions far into the future.

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