From Climate School to GaindeSat1

A Physicist at the Forefront of the Senegalese Space Program

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Context

GAINDESAT-1A, the first Senegalese-built nanosatellite, was launched on August 16, 2024, at 18:56 GMT. SpaceX's Falcon 9 rocket carried GAINDESAT-1A during its Transporter 11 mission, from Vandenberg Space Force Base in California (USA). This technological achievement places the country among the narrow group of African nations with launched satellites. Senegal is the first French-speaking sub-Saharan African country to join this "Ivy league". "This achievement marks a major step towards our technological sovereignty. I want to express my utmost pride and gratitude to everyone who contributed to making this project possible," tweeted our President H.E. Bassirou Diomaye Faye.

Professor Amadou Thierno Gaye, a physicist and former Head of the "Direction Générale de la Recherche et de l'Innovation" (DGRI) in Senegal, is the initiator of the Senegalese space program that led to the SENSAT satellite project. In this interview, we discuss with him his scientific background and institutional responsibilities, and the origins of the Senegalese space program.

Mame-Penda Ba

Professor Gaye, thank you for agreeing to be interviewed in this special issue of the Global Africa journal entitled "Publishing African Research". Let us begin by talking about your scientific background. Your field of expertise includes atmospheric physics, climate science, climate change, climate impact assessments, air quality, hydrology, and Earth observation, among others. Could you tell us about your journey as a physicist and explain why the issues you are working on are important even for a social sciences audience?

Amadou Thierno Gaye

I am a physicist. I was trained in physics and in using mathematics to address and solve problems in Physics. However, I quickly took a different path by pursuing a DEA (equivalent to a master's degree nowadays) in Engineering Sciences, which broadened my perspective by using physics equations and mathematical tools to solve practical problems in various fields such as fluid mechanics, energy, thermodynamics, environment, and more.

As part of my PhD studies, I focused on research in physical climate sciences. I aimed to understand the climate dynamics of our planet, particularly the West African climate, initially with a focus on the atmosphere. However, I quickly realized the complexity of these issues, which prompted me to expand my field of study to various components of the climate system, such as the biosphere, while still examining the interactions between the atmosphere and this component, the ocean, the surface water, and different time scales.

More recently, I became interested in the impact of climate change on various development sectors, such as agriculture, water resources, health, and human settlements. This journey has been both scientific and philosophical. Initially, like many students, I pursued climate physics mainly for career goals, but over time, I came to understand the importance of my work in everyday life. As a Senegalese born in the Sahel and who grew up in different parts of Senegal, I have personally witnessed the climatic realities of the region. During my teenage years, I lived in the city but regularly spent time in the countryside. My generation closely experienced climatic upheavals, particularly high precipitation variability in the Sahel region, marked by a prolonged drought. At that time, we did not realize how long it was going to last; we simply lived through it daily, witnessing the gradual deterioration of crops and the growing consequences on the population's daily lives. The prolonged drought impoverished our relatives in the villages. Thirty years of drought, without understanding the causes of these upheavals as well as lacking effective economic or social responses, have severely affected our countries. This has largely contributed to increasing poverty in countryside and our populations. When I realized the magnitude of these challenges, my passion for the field intensified. I had the opportunity to join the Laboratory of Atmospheric and Ocean Physics (LPAO-SF), a research center founded by Siméon Fongang, a distinguished professor from Cameroon, who named the laboratory after himself. Unfortunately, he passed away too soon, in 2000, at the age of 60. Quite early in my career, I found myself having to take over the laboratory and build what I almost call a climate school in Africa, with its own specificities compared to the major climate laboratories in leading universities in the North. I have rarely left this laboratory since then, except for a few administrative excursions, particularly in the ministry, while remaining active in research. I replaced Professor Fongang with a dual mission: to sustain this laboratory, which trained students from across the sub-region, to accelerate its development to meet the training needs of the young African scientists in the atmospheric science, climate, and oceanography fields. Our goal has always been to conduct research and produce internationally recognized work, published in international journals and read by researchers from all over the world.

I received support from local colleagues and professors from the same generation as the founder of our laboratory, who significantly helped me establish this research institute on atmospheric and climate sciences. My ambition, and our goal, was to provide opportunities for many young Senegalese and Africans to pursue careers in this field, in order to build the human resources we so desperately need. It is true that this need is felt across all research areas, but the deficit in the climate field was starking. At that time, we had meteorologists in Senegal, people capable of making short-

term rain forecasts, but we lacked researchers capable of addressing fundamental questions: Why is it no longer raining? What are the causes of persistent droughts? How can we improve precipitation forecasting? What are the dynamics of the nearby ocean?, etc.

It is this observation that pushed me to accelerate the development of human resources with the help of some Senegalese colleagues and experts from all over France, the United States, and Europe to provide opportunities for young African researchers. Many of them are now teaching in our universities or working in major research centers around the world. The goal is for them to continue addressing these issues wherever they are because climate challenges remain ever-relevant, especially in the context of climate change. Now that the entire world is becoming aware of the impacts of human actions on the climate—particularly our continent, which is already highly vulnerable to climate variability and will become even more so—we need to deepen our understanding of these phenomena and evaluate their impact.

Mame-Penda Ba

Indeed, in Senegal and likely throughout the sub-region, LPAO-SF is one of the most recognized laboratories. You managed it for over a decade. Could you explain to us the impact of the research produced, as well as your experience in managing a research laboratory?

Amadou Thierno Gaye

Several factors were involved: luck, a lot of energy, and a lot of work. When Siméon passed away, we all, including myself, thought it would be very difficult to sustain the laboratory. However, I realized that it would require determination because developing climate science was essential. Even today, very few research teams focus on these issues. I should point out that I was just an assistant professor at the time and was still preparing my doctoral thesis. I was therefore not even qualified to lead research. However, I was fortunate to have the support of four individuals: Three French professors (Pierre de Félice, Alain Viltard, and Henri Sauvageot), along with Dr. Jean Citeau, who was the former research director of the IRD. He had retired but was still in Dakar at the time. The first two that i named here were my doctoral advisors at the Laboratory of Dynamic Meteorology at École Polytechnique in Palaiseau. The third was a distinguished physicist at the Midi-Pyrénées Observatory, specialized in radar at Toulouse. These mentors of mine played a crucial role in my career.

During the initial years, these professors assisted us with courses. They were regularly present to teach, while my Senegalese colleagues and I, as an assistant professor, were in charge of the tutorials and practical sessions. This lasted for two or three years until I completed my doctoral thesis. Other colleagues in the laboratory were also undergoing training and, just like me, went on regular stays abroad, primarily to France, before returning to teach. This experience allowed me to step back and reflect on the way the laboratories i visited were functioning, by observing the best practices in labs. These trips also enabled me to establish collaborations and seek funding. What was fundamental for me was not to simply replicate models from northern regional laboratories but to create a research laboratory environment tailored to our resources and objectives.

We wanted to progress at our own pace and according to our own needs. That is why at times, collaborations with northern regional researchers did not always work out. It must be said that some partners come with preconceived notions, thinking they can treat researchers from the Southern region like mere research apprentices. We have always refused this. We sought to develop our own and unique model, with the goal of strengthening research in Senegal while remaining totally open to international partnership, support, and collaboration. Fortunately, we also met excellent researchers, particularly in France, the United States, England, Italy, and Spain, who provided us with valuable and crucial support.

Today, thanks to this collective effort, we have been able to train young researchers who publish their works in leading journals and who are invited to international conferences. However, nothing is to be taken for granted. All of this rests on a fragile and non-institutionalized balance. Maintaining this momentum largely depends on individual efforts and the partnerships we have successfully established.

Our students travel a lot and are often welcomed in labs in the north, as part of co-supervised theses. However, I only remember a very few number of students who actually chose to stay abroad, even when they go to Canada, the United States, or France. These researchers, once they return, tend to make valuable contributions. I think it is essential to train researchers who are both skilled and receptive to best practices, even in conditions that are very different from those in the North, and who know how to apply their skills to specific contexts. Our students do not just learn scientific disciplines such as physics, chemistry, computer science, or scientific computing. They learn other aspects as well. They learn practical skills. They learn to understand the impact of their work on their immediate environment. Here, we encourage them to participate in meetings, to collaborate with ministries, environmental or meteorological agencies, which enhance their experience and skills. They thus understand the importance of their work for their country and pass on their knowledge through teaching as adjunct lecturers and contributing to improving supervision rates in our universities

They influence the quality of teaching and also the quality of operational services in ministries.

In fact, I believe that the quality of certain public services, such as ANACIM, which is one of the best meteorological agencies in West Africa, is partly due to the presence of a laboratory like ours in universites. Without research in universities, you would not find functioning operational services. The international leadership which animates those who run these institutions is also based on their ability to conduct local research. Since 1998, our laboratory has been producing significant studies for the Senegalese National Committee on Climate Change which are used in national reports during the United Nations Framework Convention on Climate Change (UNFCCC), whereas other countries often have to rely on foreign experts.

Here is a concrete example of the impact of research on development and public policies in our region.

Mame-Penda Ba

You have mentioned climate change, which is a crucial issue. However, I would like to relate this to the question of multidisciplinarity and interdisciplinarity approaches. You are a physicist, but very early in your career, you ventured into engineering sciences. Then, computer science and environmental sciences naturally captured your interest. There is also an additional dimension: your attention to living conditions, your connection to the territory, and socio-economic realities. One could almost describe this as an anthropological perspective.

In your opinion, why do you think it is important for a researcher not to be confined to a single discipline, but instead to embrace multidisciplinary approaches?

Amadou Thierno Gaye

It is almost vital. We observe situations and ask ourselves, “How can I provide a solution?” Even if we do not have the financial means to address them directly, we feel the importance of the skills we acquire and the research we conduct for the future of our territory. This becomes an intrinsic motivation. We move forward without expecting any rewards, with no other fuel than the boundless energy we draw from the certainty that what we are doing is for ourselves, for our loved ones, and for our country.

Another key element is experience. Of course, I would not advise a young researcher to dive into this approach without having established some solid foundation first. You must start somewhere. A researcher might begin with physics, another with anthropology, or yet another with medicine, each developing their own expertise. But, at some point, it becomes essential to connect disciplines, especially in our countries where challenges are complex.

Climate change is a good example of this complexity. It affects all sectors: health, with heatwaves and diseases such as malaria or dengue. Faced with climate change and emerging diseases, all countries are wondering what the next major health threat will be. And one doctor alone cannot address this issue. No single discipline is sufficient to understand the implications of climatic change on the economy and society, because these phenomena are complex. It is not just a matter of rising or falling temperatures or increasing or decreasing precipitation. The dynamics are much more complicated. Climate change poses big challenges to agriculture, especially rain-fed agriculture, where a single bad rain can ruin an entire crop. In response, it is not enough to say, "We are going to work on weather or climate forecasts."

Of course, this information is valuable, but there are too many uncertainties in climate models and too few reliable data in our regions. We still need to provide useful information, whether for decision-making or for example to help agricultural services, advise farmers, and develop appropriate policies. However, we cannot present these forecasts as absolute certainties. This is where multidisciplinary approaches are essential. We need to understand society, to know why agricultural practices inherited from ancestors are no longer necessarily optimal in response to climate change. Perhaps we have lost these skills, or maybe conditions have changed so much that they are no longer appropriate. Therefore, we need to create tools to effectively transfer today's scientific skills to users. Climate change also fundamentally affects the economy, as international negotiations aim to steer economic trajectories toward decarbonization. By 2050, most major economies, including China, will mainly operate with low-carbon energies. This represents a significant challenge for our economy. It is a complex issue that cannot be solved by limiting ourselves to energy specialists or policymakers.

This is why interdisciplinarity has become vital. Without this approach, we won't be able to make the necessary and effective progress. It is not just about finding ready-made solutions; we need to learn how to build them together. And now is the right time for this. Everywhere, people are starting to learn this collaborative approach. Of course, our approach has evolved nowadays. We no longer simply ask, "What can we produce for the user?" We have realized that this method doesn't work. We have gone through this stage, and now our goal is to work together with various stakeholders. We often talk about "co-production". In the case of public policies, it means developing them with scientists, in collaboration with policymakers and, of course, the beneficiaries of these policies. Climate change is an excellent example of this process. Once again, we are at a critical juncture, as this phenomenon is already shaping the global economy.

Mame-Penda Ba

Now, I would like to discuss a pivotal moment in your career in 2016, when you were appointed Head of the "Direction Générale de la Recherche et de l'Innovation" (DGRI) Senegal. From this position, your experience and ambitions for Senegalese and African research really had the opportunity to come to fruition. Can you tell us how you used the DGRI position to initiate and engage in discussions about the Senegalese satellite program?

Amadou Thierno Gaye

The satellite program was one of the major focuses for developing science in Senegal, and especially technology geared towards innovation. But before we get into that, allow me to take a step back. I was the Director of the "École Supérieure Polytechnique" (ESP) when I was appointed as the Head of Research in Senegal. I had already started thinking about projects focused on research innovation. I had noticed that there were very few engineering schools in Senegal. At that time, there was a lot of talk about the "Plan Sénégal Émergent" (PSE) and the need to transform the economy and

industrialize the country. However, I could not see how this could be achieved without developing human resources. Looking at India for example, it is clear that the country developed very rapidly by investing in the development of engineering and science education.

Senegal had just completed its national dialogue on higher education (2014) and had decided to focus on STEM (science, technology, engineering, and mathematics). When Professor Mary Teuw Niane, the Minister of Higher Education, Research, and Innovation (ESRI) back then, offered me a position at the DGRI, I was a little apprehensive. I had started initiatives at ESP to accelerate skills development, particularly by encouraging entrepreneurship. My ambition was for the engineers we trained not to be content with working in our big companies, but to become entrepreneurs themselves. We had even started organizing entrepreneurship competitions for youths, and the results were promising. The idea was to show students that they could start their own businesses and not just limit themselves to working in our big companies where there was just a little bit of research and development (R&D). Indeed, in most big companies in Senegal, processes are often imported, with no real local innovation. My goal was to train engineers and scientists capable of contributing to the creation of local industries, similar to India's approach, by sometimes replicating technologies that have entered the public domain.

When I was offered the General Director position, I had some second thoughts, but I saw it as an opportunity to scale up and expand this vision at the national level. Although several projects, such as those of the "la Cité du Savoir", the supercomputer, and other scientific facilities, had already been initiated before my arrival, my role has been to drive these projects forward, to bring together the different academic and research communities around these initiatives.

We then started to think about how Senegal could capitalize on satellite data usage, which is very abundant globally. We wanted to develop a culture of using satellite data, to facilitate access to these data, and train students in geomatics, a field still underdeveloped in our universities. I was very enthusiastic about this project. We started working on a national space strategy, with the goal of creating an ecosystem for technological innovation in Senegal, from the development of space technologies.

I saw the space sector not only as a technology development project but as a lever to stimulate innovation and industry in the country. This project, by integrating cutting-edge sciences and technologies like artificial intelligence, connected devices, embedded systems, and telecommunications systems, as well as scientific skills such as atmospheric sciences, remote sensing, and data science, could have a significant impact on the Senegalese economy.

Our vision was clear and centered around three main points:

1. Develop a space ecosystem capable of driving an entire innovation and industrialization ecosystem.
2. Emphasize the training of a new generation of engineers specialized in space technologies, the trainers.
3. Establish space infrastructure, as well as governance structures, such as eventually setting up a space agency.

In this framework, I had a discussion about all of this with a French engineer from Airbus, with whom I had collaborated on a project to develop fablab at ESP. He put me in touch with Ariane Group, which was working on nanosatellite manufacturing and integration projects. With Ariane Group, we initially considered setting up a nanosatellite manufacturing center in Senegal, equipped with advanced technologies for pre-launch testing. This led to the signing of agreements between the ministry and several stakeholders, including the French National Centre for Space Studies (CNES) and Ariane Group. Subsequently, starting in July 2019, we reassessed our objectives, and Ariane Group kindly put us in touch with the Space Center of the University of Montpellier (CSUM), composed of academics with whom we felt more comfortable collaborating. We thus developed a cooperation agreement with CSUM Montpellier in 2020, with the goal of launching the first

Senegalese nanosatellite in 2022. I would like to sincerely thank Dr. Laurent Dusseau, Director of CSUM, for his professionalism and honest collaboration at the start of the project. It seems to me that this continued throughout the entire course of the project.

This global agreement aimed to develop skills in three areas: training of engineers and technicians, training of trainers, and finally, launching of a demonstration microsatellite. As a General Director of DGRI, I negotiated this agreement with Montpellier, and established a technical committee of teacher-researchers, from the three engineering schools in Senegal (ESP in Dakar, EPT in Thiès, and IPSL in Saint-Louis). Since I had no expertise in space issues within the DGRI, I called on Dr Gayane Faye, whom I knew well (I was the chair of his thesis committee). For his thesis, he worked on processing data from a radar onboard a satellite to detect surface water resources. He is now the project coordinator but, for a long time, volunteered to support me throughout the process. The technical committee selected the engineers and technicians for the program. Following my departure from DGRI, the technical team around the coordinator remained unchanged, which is rare in Senegal and deserves to be emphasized, as the continuity of the team helped maintain the coherence of the work.

The engineers completed their training in France, delving into space technologies, but they already had solid skills. Their final graduation project led to the manufacturing of the Senegalese first nanosatellite. Each team member had a specific and essential role: project manager, assembly supervisor, launch coordinator, etc. The ten trained engineers, along with the technicians, are now capable of working in any space agency or space project worldwide. Regarding the training of trainers, colleagues had to regularly travel to Montpellier for training, with the goal of eventually offering these same courses at Senegalese engineering schools. I think this part wasn't fully accomplished. The third part of the project involves developing a local industry. A ground station was set up to receive data from the satellite, and trained teams were ready to utilize it. However, it is also essential to train communities capable of processing these data, especially teachers and students in the relevant fields at our universities.

Although a nanosatellite alone cannot solve all of Senegal's challenges, it represents an important step in developing an ecosystem. It is necessary to train more people and develop training programs rather than always depending on Montpellier.

In the more or less long term, Senegal will need to consider developing larger satellites, especially for crucial applications in telecommunications, Earth observation, agriculture, livestock, and environment management, as well as defense. This will require researchers, engineers, and dedicated master's programs. I am not in favor of purchasing turnkey technologies without first developing the required skills.

Mame-Penda Ba

Where did the funding for this project come from? Why is it crucial for the state to continue funding such initiatives, with significant and long-term investment?

Amadou Thierno Gaye

All the investment for this project came from the Senegalese government. However, as it was an academic project it did not require a lot of funds. I mentioned another different, and more ambitious project, which aimed at establishing a microsatellite manufacturing center in Senegal. This would have been much more expensive, and we would not have had the trained personnel immediately available to carry it out. This is often the issue: we need to avoid poor investments, like buying a Rolls Royce without having a driver capable of driving it. We have learned what not to do.

The strategy adopted here was focused on training and technology transfer. Indeed, we do not yet have the required facilities in Senegal, but it will not be a waste if the country invests in this field today. What we need is effective and rational funding, directed towards specific research objectives, with well-defined strategies and backed up by international collaborations. It is also important not

to impose too many constraints, as innovation can come from anywhere. What matters is to have clear objectives, to organize our efforts well, and to focus on investments in research development. This primarily involves the training of human resources. We cannot advance research without it. We therefore need sustained, coherent funding for training in the long term, as well as national research programs.

Mame-Penda Ba

Regarding endogenous funding for African research, you tell us that we do not need billions to achieve great things, as long as we plan our actions well and use available resources effectively. However, the issue is that these resources remain extraordinarily limited. You have been at the DGRI and are well aware that the budget for your department and that of the DGES (General Directorate of Higher Education) are extremely unequal. Yet, if we want to inspire new generations of researchers, better represent certain disciplines, promote interdisciplinarity, encourage vocations, eliminate the asymmetries between northern and southern regional researchers as well as decolonize science, it requires more than goodwill and vision; we need resources. How, then, can we urge the Senegalese government to adhere to the long-standing African Union recommendation of allocating at least 1% of GDP to science and technology? Do you still find this recommendation relevant?

Amadou Thierno Gaye

Above all, I think that the 1% figure is symbolic. Of course, it is not enough to achieve the goals on an African scale, but it was a significant first step forward. It is essential to bring this issue back to the table and encourage each state to strive to achieve this goal, as it represents the bare minimum. I sometimes use absurd scenarios to illustrate the impact that a well-funded laboratory or university can have on socio-economic development. Many people are aware of this, but we don't always fully grasp it.

Let us take a simple example: if we had not trained telecommunications engineers, there would not have been Sonatel. Without Sonatel, there would not be the money transfers that generate billions on a daily basis, not to mention the ability to deliver online courses during the COVID pandemic, among many other things. Progress, like innovation, comes with a cost. Knowledge and human resources circulate asymmetrically around the world, creating further disparities not only economically but also in talent distribution.

It is a vicious cycle that needs to be broken, and to do so, it is essential to have clear strategies, to know what we want, and to create a supportive environment for research. This requires a minimum of resources, but these resources must be spent efficiently. It is not about executing one-off actions such as purchasing high-performance facilities or embarking on prestige operations. What is needed are long-term strategies, and a willingness to invest progressively but steadily in knowledge production and research.

Finally, it is crucial to govern these efforts effectively. Nowadays, the few human resources we have often work for the northern regional research inadvertently deepening this asymmetry without even realizing it.

To read more about Professor Gaye:

http://ecoledessavoirs.blogs.rfi.fr/article/2010/03/19/amadou-thierno-gaye-ou-comment-la-physique-de-latmosphere-peut-c.html