

**Towards a Science and Technology agenda
for an integrative approach to the Atlantic:
*Climate Change and Energy Systems, Space and Ocean
Sciences, through North-South cooperation***

Azores International Research Center (AIR Center)

A work in progress towards a white paper to be developed by an International Scientific Committee promoted by the Fundação para a Ciência e a Tecnologia (FCT), together with an open international consultation process and a series of research workshops:

Preparatory events:

- Workshop 1, Institute of International Education (IIE), New York City – US, June 10th
- Workshop 2, University of Azores (UAç), Ponta Delgada, Azores – PT, June 27th
- Workshop 3, “Ciência 2016”, Lisbon – PT, July 4th
- Workshop 4, European Space Agency (ESA), Paris – FR, August 29th
- Workshop 5, Parque Tecnológico de São José dos Campos, BR, September 6th
- Workshop 6, Portuguese Permanent Representation to the EU, Brussels – BE, September 19th
- Workshop 7, Maloka, Bogotá, COL, October 5th
- Workshop 8, Brasilia - BR, October, 31st

Forthcoming events, to be confirmed:

United States of America, Morocco, South Africa; November and December 2016

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Preface

A commitment to knowledge towards future transatlantic and north-south cooperation

The preparation of this white paper has been associated with an open and new debate about multilateral cooperation in complex systems engineering and science towards an integrative approach to space, climate change and energy, earth and ocean science in the Atlantic, together with emerging methods of data science. The ultimate goal is to help building the future through an effective commitment to science and knowledge and North-South cooperation.

Our commitment is to foster *networks of opportunity* to help future generations build a better future.

We are entering critical times that require the creation of conditions able to strengthen knowledge-based international cooperation. Lessons learned over the last decades with international partnerships in science, technology and higher education, including those established over the last decade between Portuguese and US universities, among many other intergovernmental scientific ventures, have clearly shown that the future can only be built with more knowledge, more culture and more exchange of ideas.

A new paradigm of structured international research relationships is emerging shaped by a new era of government and industry intervention in association with knowledge. Cross-disciplinary new frontier research should be the result of ambitious initiatives yet to be developed or stimulated from the huge potential of intergovernmental research laboratories and joint ventures. It is under this context that the debate of the potential installation of an *Azores International Research Center (AIR Centre)* is focused on. This debate is centered under two main priorities: i) new data collection for innovative research; and ii) synergies Sea/Space towards new knowledge production and diffusion.

Our ambition is driven by an increased perception by society of the growing evidence for the potential benefits resulting from the human, social and economic appropriation of the results and methods of science. We aim to stimulate the necessary knowledge-driven conditions to build in Azores an intergovernmental research center with strong international cooperation and better use the strategic Atlantic positioning of Azores and Portugal to foster North-South cooperation in science and technology. By promoting new knowledge on climate change and

related issues in the Atlantic, we are fostering conditions to provide the world with more science, more knowledge and more scientific culture. By facilitating the access to space from the unique position of Azores we are promoting access to new frontiers of knowledge, together with the development of new space industries. Also, by promoting new research in the Azores's deep-sea we facilitate the access to a better understanding of living organisms in extreme environments and new energy sources.

The sustainable future of our society requires more knowledge and more scientific culture, ensuring the access to science and education as an inalienable right of all. More science and the systematic democratization of access to knowledge means more equal opportunities, more social mobility and a new stimulus for entrepreneurial activities and well-being.

Manuel Heitor

Minister for Science, Technology and Higher Education, Portugal

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Part I - A vision to explore the North and South Atlantic through an Azores International Research Center

1 The Atlantic

Science is an essential tool for rationally addressing critical societal challenges such as those concerning climate change by intertwining space, ocean and energy systems. The importance of an integrative approach drives the current efforts to establish an International Research Center in the Azores as it offers a unique location in the middle of the Atlantic Ocean, bridging the American, European and African continents, particularly suited to provide unique data on the Ocean and to study its interactions with atmosphere and space.

The Atlantic Ocean comprises about 20% of the Earth's surface. It borders the Americas, Europe, Africa and the Arctic region and is today still understudied in terms of its natural resources, ecosystems dynamics and interdependences with human activities. It is clear that a better understanding of the Atlantic in terms of its response to climate change and for the sustainable management of common resources entails the alignment of research strategies through international cooperation. In this regard, the Azores International Research (AIR) Center enables that cooperation and will provide an ideally located center of excellence and a unique venue to address issues that impact society on a global level.

Climate Change research is one area that will benefit the most from the establishment of an AIR Center since a changing climate is directly associated with a dynamic Ocean and benefits from Space driven observation and monitoring systems. In particular, it is estimated that 90% of the excess energy accumulated in the climate system since 1971 is stored in the Ocean, and that 30% of human-emitted carbon has ended up in the Ocean, causing ocean acidification. Significant heat absorbed by the ocean through spatially and temporally varying atmosphere-ocean energy and momentum exchanges has been redistributed internally and sequestered at depth through complex dynamic mechanisms involving waves, ocean currents, small-scale eddies, and other processes. Biogeochemical tracers transferred to the ocean through air-sea-gas exchanges and, in particular, carbon dioxide and oxygen, have been redistributed in similar ways. That absorbed energy has caused thermal expansion of the oceans, which is responsible for about half of the rise in sea level to date.

Accurately projecting the future path of climate change and monitoring whether current mitigation efforts are reversing unsustainable pathways requires a sustained, globally distributed ocean-observing system, especially at depths where very few observations currently exist, as well as detailed measurement of atmospheric circulation changes, along with the determination of the Earth's net radiative imbalance from space. Seasonal to decadal climate information is needed to improve seasonal predictions, El Niño forecasts, and other climate phenomena manifest that are crucial for agriculture, water management, and disaster risk reduction. Operational climate information (days to months) is needed because sustained ocean observations underpin early warnings for ocean-related coastal hazards, such as storm surges and hurricane predictions, as well as more accurate medium-range weather forecasts that can improve the safety and efficiency of the maritime economy.

We also need to develop better models that clarify human impact on the oceans ecosystems and the basic ecosystem services of coastal protection, food security, and tourism that enable coastal livelihoods and the blue economy. Our knowledge here is still evolving through research and leaps forward when we have sustained ocean observations to validate our theories.

Energy dependency is another great challenge that cannot be disassociated from Climate change. There is a growing need for more efficient, more renewable, more cost-effective Energy systems which can allow the crescent diminish of our dependency from non-renewable fuel energy sources while maintaining energy security, economic growth, and environmental goals.

Space science and technology can play a major role in the Atlantic, and includes the provision of access to space through safe and reliable spaceports, satellite control and data transmission and collection. Satellite data processing opens opportunities for new ventures with economic, environmental and social impact, namely in areas such climate change and sustainable energy systems design, fisheries and aquaculture, maritime safety and security, managing marine resources including the support required for deep-sea mining, as well as characterizing the renewable energy potential in the Atlantic islands and coastal environment. Space is thus critical to address climate change and sustainable energy systems design challenges as well as for ocean exploitation.

Permanent and persisting observation systems are required to observe, monitor and collect reliable data in order to improve local and global models. Such models should improve understanding of the complex earth system, enable the assessment and monitoring of human activities, and inform decision-making in a number of different areas of key importance that lead to human well-being and to sustainable growth of nations. Integrated large-scale environmental observations are absolutely critical for producing an efficient and effective data system in any environment. Therefore, there is a need to develop advanced data and network systems that include space, air, ground, and ocean-integrated instruments allowing sustained data gathering to produce better, more accurate models that serve all the disciplines involved.

Addressing these challenges mandates international cooperation and interdisciplinary collaboration. This white paper proposes an international research center committed to the study of climate change, energy, space, and oceans issues in the Atlantic Ocean as a key enabling infrastructure to successfully tackle these pressing challenges.

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2 Island Research Stations

Island research stations are well placed to enable the advances of frontier research in the 21st century. Darwin's expedition to the Galapagos Islands had a paramount influence on the practice of modern science and highlighted the importance of islands and archipelagos for scientific progress.

For research purposes, an island has the advantage of making available relatively small but complete, and for the most part closed, ecosystems that are perfectly suitable for holistic studies through experiment and observation of natural processes. In other words, they represent natural laboratories enabling and facilitating the design of scientific studies of international relevance. In this sense island research stations are perfect for designing and achieving those direct and precise observations especially required for studying biophysical phenomena, but also for validating concepts, techniques, and methodologies, particularly in remote places or in circumstances of scarcity of reliable platforms.

As an example, Figure 1 illustrates the composition of a global geodetic observing system (GGOS) and all its core sites. Including the AIR Center as one reference point in this global network of geodetic science incorporates both infrastructure and data to support global change research in Earth system sciences. And, when combined with space and ground segments, opens new research areas such as global reference frames (a basis for precision metrology – positioning, and gravimetry), regional coastal hazard assessment (measurement, vulnerability, and science), global sea-level measurement (climate and Earth system science), global essential climate variables, and space weather and signal propagation (ionosphere, troposphere, scintillation, etc.). This combination would be symbiotic with the development of new capabilities and state of the art technologies and a space port for small satellite launching.

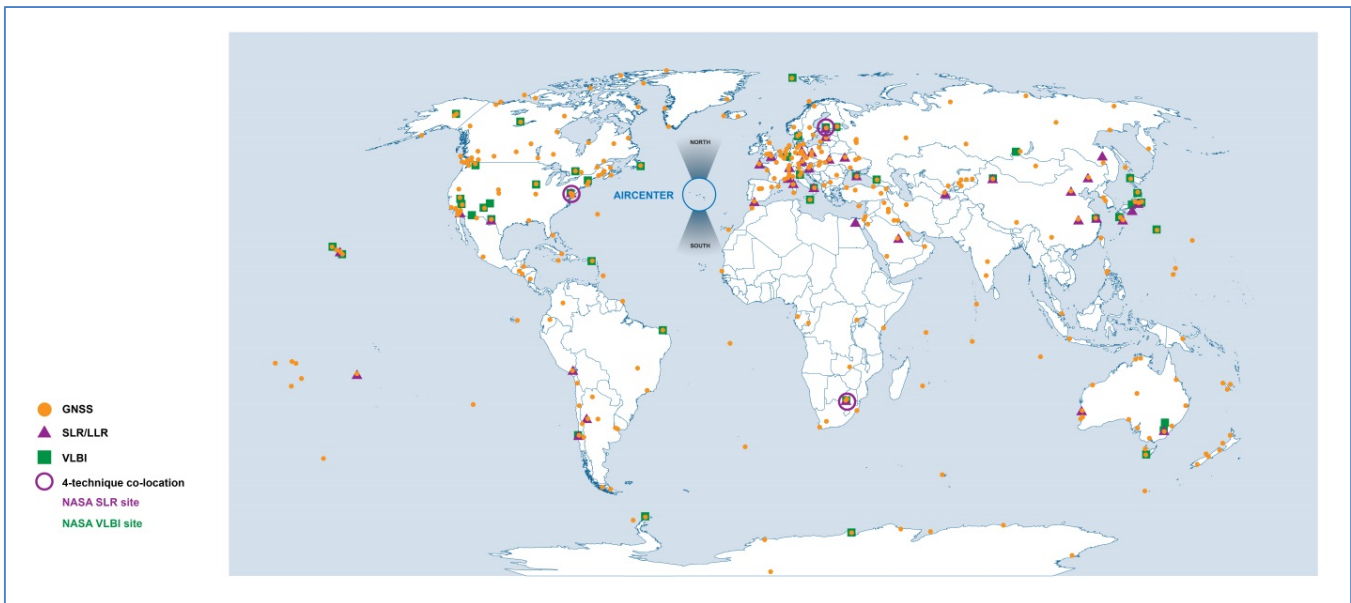


Fig.1 – Illustration of a Global Geodetic Observing System (GGOS) and all its core sites

Source: Juan Sanchez, AIR Center workshop in Azores, 2016

In sum:

- Island sites provide a capability for unique Earth and ocean observations (e.g., atmosphere, ocean, terrestrial, biosphere);
- Islands are ideally suited to monitor changes in the ocean forced by natural and human activities at a continental level;
- Islands can be excellent space ports;
- Islands can be superb calibration/validation sites for global satellite missions;
- Islands serve as a base for scientific process studies and a center for maritime information and technology development; and
- Island research stations are an ideal place to build scientific capacity in the marine sector and the development of ocean-related products to support the blue economy.

3 The Azores Archipelago

The Azores Archipelago's privileged location (as depicted in Fig. 2) in the middle of the Atlantic Ocean, with its unique environmental characteristics, biodiversity and accessibility to the different ecosystems, provides an undeniable competitive advantage for studying oceanic attributes and processes, Energy, Climate change and Space.



Fig.2 – Island Research Stations across the world and the Azores archipelago location

The Azores archipelago is located in the northeast Atlantic in the midst of complex ocean currents which transport important water masses impacting climate; moreover, symbiotic datasets among the Azores, Madeira and Portugal can provide flux measurements which single point data sets cannot.

Hereby are highlighted some of its main unique features

- The marine ecosystems and oceanographic conditions associated with the Mid-Atlantic-Ridge confers a unique opportunity for deep-sea research (ecosystem science, biodiversity and geodiversity; economic activities). The Azores Exclusive Economic Zone (EEZ) covers about 1 million km², of which about 99% is deep sea (defined here as below 200 meters depth), with more than 450 seamounts, several known hydrothermal vent fields, deep fracture zones and trenches, deep and isolated

holes and basins, and a considerable extension of the Mid-Atlantic Ridge (MAR) and abyssal areas;

- It sits over the Azores Triple Junction (ATJ) where the North American, Eurasian and African tectonic plates meet over a divergent tectonic system that is of fundamental importance in geology and geophysics, as well as provides an avenue to explore sub-seafloor processes. The chemical and biological processes that are impacted by the geological processes at the Ridge are of potential global significance. Establishment of a long-term observing presence on the Azores would be of great value scientifically;
- The proximity and accessibility to the open ocean and to the diverse ecosystems of the deep sea present unique possibilities in the Azores region for ocean observation systems and research on ocean-atmosphere interaction and other climate change-related issues
- The Azores are located in the path of intense meteorological and oceanographic activity that arises from the collision of warm air and sea water coming from the south, against colder air and colder water that comes from north, in evolution along the Gulf Stream and Polar Front;
- As part of the Meridional Overturning Circulation in the North Atlantic, which has been identified as a highly important but poorly understood aspect of the Earth's climate system, the Azores Current is a topic of significance in physical oceanography;
- The geostrategic position of the Azores is serving space missions through a range of ground segment infrastructures presently operating. This small infrastructure cluster contributes to a new growth paradigm for the upstream and downstream space industry in relation to the "newspace" market (e.g., implementing a European spaceport in the Azores or promote the development of small launchers);
- The archipelago of the Azores offers a set of unique features for studying the transition from prototype to sustainable energy systems. First, it is composed of nine independent energy systems with different dimensions and contexts, which makes the Azores a unique multiple scale system. The systems range from Corvo, a small rural island with 500 inhabitants, to São Miguel, a "services" island with 130,000 inhabitants. Hence, it is possible to test different transition solutions with a diverse set of socio-economic characteristics and sizes in the controlled environment of the archipelago;

- The Azores has a large and diverse set of renewable endogenous energy resources, which enables testing different conversion technologies and as well as posing different integration challenges. Two islands have geothermal resources (São Miguel and Terceira); all islands in general have high wind resources – in fact some wind parks in the islands of Terceira and Pico possess very large capacity factors for onshore wind park (above 30%); some islands possess good solar resources like Santa Maria and Graciosa; some islands present good biomass resources; and finally all islands face the challenge of managing their waste.
- The degree of innovation in the energy systems is fostered by the Regional Government and the local utility (EDA). For many years the island of Flores has utilized an integrated hydro-wind system with a flywheel that enables it to operate a significant number of hours in the winter only on renewables. The island of Graciosa has a very recent project on the integration of batteries and wind and solar. The islands of São Miguel and Terceira will have pump-hydro storage systems to transfer excess renewable electricity production from wind and geothermal from off-peak periods to peak periods; the island of Corvo has a 100% deployment of solar thermal systems for domestic hot water generation that can be used to integrate renewable energy resources like wind. There are also a significant number of programs in other areas, like the promotion of electric vehicles in the islands, which already has some charging stations, to energy efficiency promotion in the dairy industry.
- As islands' systems, the set of socio-economic pressures create an environment that is very prone to develop innovation. The fact that the systems are isolated introduces an additional constraint of robustness in the development of solutions. Further, because the distance to the mainland has a large impact on the cost of importing energy, this facilitates the economics and therefore the business case of most of green technologies.

The unique “living laboratory” characteristics of the Azores, together with the already existing infrastructures in the archipelago, make the Azores a prime location for the proposed international research center that will focus on atmospheric science and climate change, energy systems, space, and ocean interactions. A dimension of particular relevance that emerges from these areas is the monitoring and modeling of natural hazards and the related capacities that have been developed over the years at the University of the Azores.

A better understanding of the Atlantic Ocean and the sustainable management of this common resource require the alignment of research strategies through international cooperation. Interdisciplinary research able to face the ocean challenges and the economic transitions, in particular environmental changes, security conditions, and other human dimensions, almost by definition calls for the design of an international partnership that aims for resilience and leadership for the Atlantic Ocean and related north-south cooperation in the following five thematic areas (Figure 3):

- i. **Atmospheric Science and Climate Change**
- ii. **Energy Systems**
- iii. **Ocean Science and Technology**
- iv. **Data Science**
- v. **Space Science and Technology**

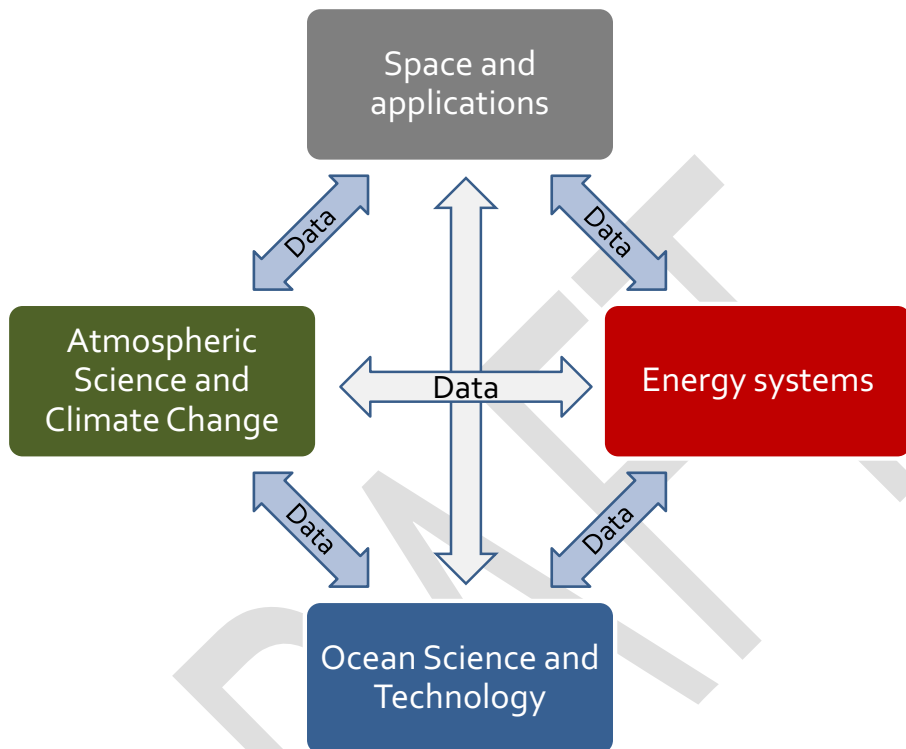


Fig. 3 – Five thematic areas for a research agenda towards an AIR Center

Part II of the document elaborates on these five areas and is organized to highlight the following topics:

- Uniqueness of the Azores
- Key research challenges
- Infrastructures and other potential additional resources

Part II - A research and technological agenda for an Azores International Research Center

4 Atmospheric Science and Climate Change for the Atlantic

4.1 Uniqueness of the Azores

- Azores sits at a geographic confluence of critical geophysical phenomena close to the triple junction of the Eurasian, North American, and African plates. The Azores atmospheric high pressure system constitutes one pole of the North Atlantic Oscillation, a leading climate phenomenon; the Azores Current is an important branch of the Atlantic Ocean's subtropical gyre circulation.
- The local maxima of the subtropical time-averaged wind speed (jet stream) downstream of the Rocky Mountains over the North Atlantic and associated mid-latitude storm tracks play a key role in the annual variation of precipitation and northward fluxes of heat and moisture.
- The richness of marine boundary layer clouds makes the location ideal for maintaining long-term observations of the responses of shallow marine cloud systems to aerosols and greenhouse gases, which are a source of uncertainty in global climate models.
- Situated at the southern demarcation of the North Atlantic storm track, the downwind location from the North American continent, and its impact by continental pollution aerosol, the air circulation properties of the Azores turns it into a uniquely suited place for the monitoring of the influx of pollutants into Europe.
- The orographic diversity of the nine islands makes them ideally suited for cloud studies (e.g., Graciosa) or pollution monitoring (e.g., Pico).
- The proximity of land and deep sea make for an optimal platform to study ocean-atmosphere interactions, as well as deep-sea ecosystems.
- The Azores is a rare platform for ground-based reference measurements for satellite comparisons, with few alternatives in the North Atlantic.

4.2 Key Research Challenges

- *Understanding local climate and climate change impacts*

Small Islands worldwide are highly dependent on their climate and have been identified as one of the major targets of climate change impacts (IPCC WGII TAR, 2001; IPCC AR4, 2007, AR5, 2014). Current and future climate-related drivers of risk for small islands during the 21st

century include sea-level rise, tropical and extra-tropical cyclones activity, increasing air and sea surface temperatures and changing rainfall patterns (high confidence, robust evidence, high agreement). The future risks associated with these drivers include loss of adaptive capacity and ecosystem services critical to lives and livelihoods in small islands.

However, the analysis of present spatial diversity of climate, climate change scenarios and impacts in small islands is a difficult task. Islands with horizontal scales of the order of tens of km are subscale orographic features for most of the Climate Models since the horizontal scales of these models are too coarse to give a detailed representation of the islands' topography.

- ***Understanding the effects of aerosols in the cloud condensation nuclei (CCN) budget***

A quantitative understanding of the effects of aerosols in the cloud condensation nuclei (CCN) budget is currently lacking for some of the processes underlying perturbations of CCN population by aerosols. Remote marine low cloud systems are particularly susceptible to perturbations in CCN associated with anthropogenic emissions because of their relatively low optical thickness and low background CCN concentrations. The CCN population is driven by a range of processes, including generation of sea spray aerosol through breaking waves, entrainment of free tropospheric aerosol, and removal of aerosol particles by drizzle. The indirect effects of aerosols in CCN budget is one of the main research themes at the Eastern North Atlantic (ENA) Atmospheric Radiation Measurement (ARM) site at Graciosa Island (28°W 39°N).

- ***Understanding cloudiness transitions, through the integration of in situ ground based, airborne and satellite data***

Marine low cloud fields display coherent mesoscale organization ("mesoscale cellular convection" or MCC) on horizontal scales of 5 - 100 kilometers. Key processes controlling MCC are currently not well understood. The horizontal scales of MCC present a significant modelling challenge to global change models, as the dominant scales are comparable to the horizontal resolution in the next generation of climate models. There is currently no consensus on how to characterize MCC in observations and in models that are able to resolve the relevant scales.

Ground-based remote sensing techniques, including ENA-ARM's new scanning radar and lidar capabilities, offer new ways to probe mesoscale structure and dynamics. Combining newly available ground-based views with aircraft and broader-scale satellite data will provide insight into the structure and dynamics of MCC and how it impacts cloudiness transitions.

- ***Monitoring the influx of atmospheric pollutants into Europe***

The air pollution observatory station at Pico mountain in Pico Island (PICO-NARE, see section 3.3.1), which is located at 2225 meters above sea level, provides a ground base for free tropospheric measurements on the central North Atlantic region and is suitable for observation of air pollution and boreal fire plumes from North America, occasional African dust, and European air pollutant emissions. On the other hand, simultaneously the ENA-ARM site (Graciosa Island) is downwind of the North American continent and is periodically impacted by continental pollution aerosol.

- ***Integration of the atmospheric and ocean information in global climate models***

The responses of shallow cloud systems to changes in atmospheric greenhouse gases and aerosols are major sources of uncertainty that limits the accuracy of predictions of future climate. Low cloud systems over the remote oceans are a key research challenge because they are poorly represented in climate models. Interactions between cloud microphysical and macrophysical processes play a fundamental role in modulating cloud dynamics and, entrainment and precipitation, which all of which help determine cloud radiative properties that impact global climate. The ENA-ARM site at Graciosa Island provides unprecedented conditions as an International research platform dedicated to the understanding of key processes of ocean atmospheric interactions in a remote marine environment along the boundary between the subtropics and mid-latitudes, and the southern demarcation of the North Atlantic storm track, where great diversity of meteorological conditions can be observed.

- ***Towards developing a regional earth system model for the Atlantic Ocean***

Climate variability over the Atlantic Ocean ranges from seasonal migration of storm tracks to inter annual and decadal-scale North Atlantic oscillations and to long-term climate trends. On weather scales, hurricanes can influence the Gulf Stream and associated oceanic eddies. On paleoclimatic and global warming scales, ice sheet melt from Greenland and glacier melt from nearby continents can affect the thermohaline circulation, which in turn changes climate on time scales from decades to millennia. Understanding and predicting such a wide-range variability from weather to climate scales requires a dedicated regional earth system model

(RESM) for the Atlantic Ocean, coupling the atmosphere, oceans (including waves and ice), land (soil, vegetation, snow, glaciers, ice sheet, and rivers). This RESM must be versatile for various configurations, such as a high-resolution for ocean eddy-resolving simulations or a coarse-resolution capable of long-term integrations. The RESM can include biogeochemical processes in land, the atmosphere and the oceans to study the impacts of coastal eutrophication and ocean acidification.

- ***Towards developing a sophisticated data analysis and modeling capability for the Atlantic Ocean***

Vast data sets from various fields, different satellite platforms, and in situ sources must be synthesized, stored, catalogued, and processed. A data distribution center must be established to support model development, testing, and validation. Data assimilation capabilities must be developed to assimilate atmospheric, oceanic, geophysical, and biogeochemical data into a RESM. This data assimilation effort is critical for effective monitoring and predicting the atmospheric, climatic, oceanic, and geophysical phenomena in the Atlantic Ocean and surrounding continents.

4.3. Infrastructures and other Resources

4.3.1. Existing Infrastructures

The text table below presents existing research infrastructures in the Azores as well as the specific island on which they reside. These should be considered resources when considering the development and implementation of the AIR Center.

Existing Infrastructures	Island
Eastern North Atlantic (ENA) Atmospheric Radiation Measurement (ARM) facility, U.S. Department of Energy & University of Azores	Graciosa
Pico Mountain Air Pollution Observatory - North Atlantic Regional Experiment, University of Azores	Pico
Center for Volcanology and Geological Risk Assessment, University of Azores	São Miguel
Center for Climate, Meteorology and Global Change - Center for Agriculture Research and Technology, University of Azores	Terceira

In addition to institutional resources, the Azores have numerous non-institutional resources that can potentially be utilized in developing and implementing the AIR Center. As indicated below, these potential resources include human as well as intellectual resources. For example, there is a robust cyber-infrastructure that allows accelerating the pace of scientific discovery in climate change research and large scale monitoring, modelling and simulation of Earth phenomena. The proliferation of datasets, modelling tools and the convergence of diverse disciplinary expertise calls for an integrated and efficient approach to data curating, analysis and visualization.

Furthermore, there are existing relationships such as integration into the European and Global Research Infrastructure Landscape, namely, the integration of PICO-NARE in the World Meteorological Organization - Global Atmospheric Watch and integration of existing Infrastructures in Azores for atmosphere science and climate in the European infrastructures of ACTRIS (observation of aerosol, clouds, and trace gases), IAGOS (long-term observations of atmospheric composition, aerosol and cloud particles), ICOS (carbon cycle and greenhouse gas budget and perturbations), and InGOS (improving observation of non-CO₂ greenhouse gases). Even so, additional resources will be required in climate modeling, land surface modeling, observations (from space), computing and data science, and mass data storage to fully operationalize the AIR Center Specialized human resources.

4.3.2. Potential additional resources

Potential resources

A robust cyber-infrastructure that allows accelerating the pace of scientific discovery in climate change research and large scale monitoring, modelling and simulation of Earth phenomena. The proliferation of datasets, modelling tools and the convergence of diverse disciplinary expertise calls for an integrated and efficient approach to data curating, analysis and visualization.

Integration in the European and Global Research Infrastructure Landscape, namely:

- the integration of PICO-NARE in the World Meteorological Organization - Global Atmospheric Watch;
- integration of existing infrastructures in Azores for Atmosphere Science and Climate in the European Infrastructures ACTRIS (Aerosols, Clouds, and Trace gases), IAGOS (In-Service Aircraft for a Global Observing System), ICOS (Integrated non-CO₂Greenhouse GAS Observing System) and InGOS (Integrated non-CO₂Greenhouse GAS Observing System)

Specialized human resources

Long-term sustainability considerations: Industry involvement and international commitment/support.

Laboratory for detailed measurement of over 40 greenhouse gases, at high altitude (over 2000 m) at the Pico Island

5 Energy Systems for the Atlantic

5.1 Uniqueness of the Azores

The world is facing critical challenges to meet growing energy needs while maintaining energy security, economic growth, and environmental goals. The isolation and small-scale of island energy systems offer an even greater challenge for energy planning, since fluctuations in local energy supply and demand dynamics are magnified within a small network, requiring additional accommodations to ensure reliability and key technical performance factors. Because of these additional constraints, island communities make an ideal testbed for evaluating the integration of new energy solutions.

The Azores have several unique characteristics that are particularly valuable for international, collaborative research. For instance:

- The Azores archipelago possesses a diverse set of endogenous energy resources, which across the chain of islands include geothermal, wind, hydro, solar and biomass.
- The geographic isolation and dispersion of the Azores have led to the formation of unique cultural, socioeconomic, and ecological identities for each of the islands, and therefore unique energy system structures, environmental conditions, and requirements when conducting and interpreting analyses.
- The Azores are ideal when establishing international cooperation due to their special circumstances regarding the energy sector, together with other outermost regions (i.e. Guadeloupe, French Guiana, Martinique, Réunion, Saint-Barthélemy, Saint-Martin, Madeira and the Canary Islands) in the context of Article 349 of the Treaty on the Functioning of the European Union.

This unique combination of natural and anthropogenic factors allows the creation of high-level technology centers in the area of renewable energies and complementary technologies (such as the existing one in the Canary Islands) and connecting research and development directed toward enhancing the exchange of knowledge and experiences.

Overall, the Azores are an example of the modern challenges faced by energy systems around the world: a relatively high penetration of renewable resources and modernization of energy grids, the need for efficient storage systems, increased adoption of energy efficiency, increasingly distributed generation, and the electrification of energy systems and sector, particularly in the transportation sector.

5.2 Key Research Challenges

- ***Micro-grid management tool to exploit the use of high penetration of renewable resources, including distributed generation***

The penetration of renewables in the Azores in primary energy represents, in some periods of the year, 40% in electricity generation, mainly coming from geothermal sources, followed by wind, hydroelectric and biomass (residual). In some islands, like Sao Miguel, the renewable penetration is beyond 50% and in Flores for some periods of the year; it has been observed 100% penetration for several hours.

In such isolated grids, to grow from 50 to 70% requires the use of storage systems, but increasing the penetration beyond 70% will require the development of a new grid management tool and the enabling technologies to implement it. Thus, a key research challenge is to develop a new set of software to manage the grid operation that must integrate new multiple features: highly accurate demand forecast models depending on weather forecast, and occupation forecast (hotels and plane reservations); renewable energy resource (wind and solar) forecast tools; demand response technologies for industrial systems (mainly large heating and cooling systems), buildings (HVAC systems in hotels and retail) and transportation systems (electric vehicles) and operate in a fully integrated way the operation of all generation power plants (thermal and renewable), the storage systems (hydro pump-storage, batteries) and the distributed generation (mostly small PV power plants for self-consumption).

- ***Integration of multiple efficient and flexible storage systems***

The operation of the grids under such high renewables penetration requires the need for storage system that transfer consumption from off-peak periods to peak periods but also storage systems that can contribute to the voltage and frequency regulation of the grid, improving the overall reliability and robustness of the power networks. This includes traditional storage systems like pump-hydro, batteries and flywheels, already available in Azores, but also the use of electric vehicle charge and discharge and demand response in buildings and industry as flexible storage systems This may also include the use of small scale storage systems integrated at the substation level and the use of distributed storage systems at the residential level to support the distributed generation with PV for self-consumption.

All these storage technologies are commercially available but its full deployment and integration in the networks still requires the development of additional technologies and services.

In addition to serving as a useful testbed for electricity storage from batteries, the Azores can also be used for other storage approaches, such as compressed air energy storage (CAES), pumped hydro, and thermal storage. Proxies for storage, such as flexible desalination and production of hydrogen or methane with excess wind, can be tested in an island setting as a way to balance the grid and provide other value resources as, instance, freshwater and fuels.

- ***Demand response in buildings and large facilities***

Matching the demand of energy at the building level to the availability of renewable energy resources constitutes a major target for the sustainability of an energy system. It requires extensive research in the development of new monitoring, metering, sensing devices and software tools to communicate with intelligent control systems in order to manage energy use while maintaining acceptable environmental conditions within buildings. In particular, it addresses issues on the design of operational control systems to optimize energy use across the urban area, including the scheduling capabilities to enable use of ventilation, lighting, air conditioning to reflect closely the needs of the area while distributing our energy use as optimally as possible.

The full potential of technological excellence are exploited by analyzing in detail specific buildings, which are modeled and instrumented in order to enable the monitoring of human activity as an innovative feature in the formulation of new and advanced energy efficient predictive control strategies that correlate human behavior with the use of energy in the context of dynamic thermal building models.

- ***The electrification of energy systems, in particular in the transportation sector***

The transportation sector is not only one of the largest energy consumers but is the sector where the transition to renewable based technologies is also more challenging. The massive implementation of electric vehicles is definitely a key aspect to achieve the transition. But other technologies are available, mainly the ones associated with the power- to-gas (P2G) paradigm which basically consists of using the excess renewable resources to generate gas fuel, spanning from the traditional electrolysis to generate hydrogen for fuel cell vehicles, but also fuel synthesis. In any case, these technologies need to be coupled with the development of new mobility models, taking advantage of use of information technologies and the shared economy models.

5.3 Infrastructures and other Resources

The Azores have a diverse range of existing infrastructures and systems that will make for valuable research conditions and can be expanded as part of a multi-national collaboration. These are summarized in the in-text table below.

5.3.1 Existing infrastructures

Existing infrastructure	Island
A wave energy pilot plant run by WavEC: OWC Pico Power Plant (www.pico-owc.net)	Pico
High penetration of geothermal and wind energy, with pump storage: "Central Geotérmica do Pico Vermelho" and "Central Geotérmica da Ribeira Grande" in São Miguel; Wind under construction	São Miguel
The "Most" Hydro Flywheels on Flores: "Central Hidroeléctrica da Ribeira Grande" and "Central Hidroeléctrica de Além Fazenda"	Flores
Flores PowerStore Flywheel Project	
Graciosa PowerStore Flywheel Project	Graciosa
System of hybrid power (wind and solar), supported by an innovative battery system, that will enable uninterrupted power supply, to be constructed in Graciosa.	

5.3.2 Potential additional resources

The Azores also have a range of resources that can be leveraged for experimentation and analysis. As set forth below, some of these resources can be integrated for unique solutions.

Potential resources	Island
Geothermal exploration on Terceira: "Central Geotérmica do Pico Alto" planned for 2017	Terceira
Electric Vehicle Deployment Demonstration	
Flexible, efficient and resilient storage systems (i.e. Integration of power grids hardware to be efficient and resilient; grids that are able to cope with the erratic nature of wind and solar power)	All
Renewable energy technologies deployment demonstration in a confined environment	All
Full scale smart grid management of full scale laboratory aiming at 100% renewable energy	Corvo, Flores e Graciosa
Integration of renewable energy with desalination technologies for simultaneously balancing the grid and providing freshwater.	

Potential resources	Island
Integration of renewable energy with hydrogen production (via electrolysis) or methane production (via methanation) for simultaneously balancing the grid and providing domestic fuels.	All
Ocean thermal energy conversion (OTEC), which uses temperature differences between the ocean surface and depths to generate electricity.	All
Osmotic power, which uses salinity gradients between freshwater onshore with saltwater offshore to generate electricity.	All

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6 Ocean Science and Technology for the Atlantic

6.1 Uniqueness of the Azores

- The Azores EEZ covers about 1 million square kilometers of which about 99% is deep sea, with more than 450 seamounts, several known hydrothermal vent fields, deep fracture zones and trenches, deep and isolated holes and basins, and a considerable extension of the MAR and abyssal areas;
- It sits on the Mid-Atlantic Ridge over the Azores Triple Junction (ATJ) where the North American, Eurasian and African tectonic plates meet with an average abyssal plane depth of 3000 meters;
- Moreover, situated at the eastern margin of the Sargasso Sea, the regional oceanography of the Azores is determined by several distinct ocean circulation features, notably the subtropical gyre and the Azores Current;
- A high diversity of open and deep sea ecosystems and habitats are hosted by the ATJ, one of the most interesting and singular areas on the planet and an international reference for testing oceanic scientific instruments and platforms;
- The Azores islands with its steep topography far from anthropogenic sources of nutrients are of particular interest to carry out interdisciplinary studies involving vertical transport;
- Finally, the proximity and accessibility of the open ocean and the different ecosystems of the deep sea render the region a unique and strategic position in the middle of the Atlantic Ocean for maintaining ocean observation systems, conducting research on ocean-atmosphere interaction, and for studying other climate change-related issues.

6.2 Key Research Challenges

- ***Monitoring the large-scale Atlantic subtropical gyre circulation variability and change***

The Azores is situated at the eastern perimeter of the Sargasso Sea, a sea not bounded by land but by one of two large, basin-scale ocean gyres in the North Atlantic, the Subtropical Gyre. It is also influenced by the Azores Current, a rather unique and energetic current that is strongly connected to Mediterranean dense water outflow into the Atlantic Ocean. Because of their critical role in regulating regional (and ultimately global) climate through heat and greenhouse gas uptake, lateral redistribution and vertical sequestration, monitoring these circulation features is an important task of the proposed global ocean and climate observing systems (GCOS and GOOS). On a regional scale, the Azores can play an important role in contributing to the implementation of such observing systems through deployment and

maintenance of required ocean-observing platforms combined with basin-scale analysis and forecasting systems.

- ***Observation and monitoring of seamount, open ocean and deep-sea ecosystems***

The potential to receive, process, and analyze data from complementary satellite, surface, and sub-surface ocean observatories at a mid-Atlantic location, as the Azores, would be a unique contribution to improving knowledge and understanding of the Atlantic Ocean. The circulation in the Atlantic Ocean can be understood as a component of a global-scale turbulent, yet strongly organized system of ocean currents. Local processes at small scales play an important role for lateral and vertical redistribution of water masses and associated nutrients. As such, a multi-scale approach is considered the most suitable to study the Atlantic Ocean circulation, with the global-scale circulation and climate influencing – and being influenced by – regional and local processes. Local-scale manifestations of global change provide the strongest link between science and society. They also provide the most direct ways for verification and validation of scientific projections.

The Azores archipelago constitutes a strategic location for establishing an advanced marine monitoring post in the north Atlantic, possibly complementing other marine monitoring posts in mainland, in the scope of a north Atlantic monitoring grid framework.

This would be particularly relevant for the surveillance of biological communities, as for example looking at changes in species ranges, detection of potential invasive species, links between benthic communities and associated planktonic larvae, monitoring of adults and planktonic larvae of fisheries resources.

A suitable action in this context would be to devise Azores as a pilot site for developing and exploring the application of state of the art biological monitoring tools, such as environmental DNA (eDNA) monitoring, based on new generation DNA sequencing technology.

- ***Building knowledge on the deep ocean biology, resources, environmental services***

It is especially important to increase knowledge of the deep sea ecosystems, which less than 10% has been fully mapped so far. There is an urgent need to invest in areas that are clearly understudied, such as mapping of the seabed and its habitats, understanding the functioning of deep-sea ecosystems, and their resilience and interactions through the development of continuous deep-sea observing systems. Similarly, there is an increasing interest in accessing deep ocean resources beyond the continental shelf. Emerging areas of activity include deep sea mining for rare earth elements and minerals as well as the exploration of the potential economic value of organisms found in extreme environments under the influence of hydrothermal vents.

- ***Conservation of marine biodiversity***

The Azores are the perfect locations to study patterns and processes of oceanic functioning and biodiversity at multiple scales, from bacteria to top predators, relevant to the Atlantic basin (amphi-Atlantic population connectivity) and large scale migrations.

Isolation of populations and limited connectivity and gene flow with mainland and other Macaronesian archipelagos, suggests that the Azores would constitute a key location for biological conservation programs focused on local endemism, or unique genetic variants and gene pools, of multiple marine species from the north Atlantic.

- ***Oceanic governance for a sustainable use of the oceans and blue growth***

To understand and predict the effects and impacts of climate change and human reactions it is first necessary to understand environmental dynamics and natural variability. The Azores MAR region profits from long-term observations made either at seamounts (Condor) or hydrothermal vent fields (EMSO-Azores observatory), two habitats very likely to be directly and indirectly impacted by human activities. A continuous and improved study and monitoring of these habitats is critical as is the development of new capacities for open-ocean monitoring and will promote best practices for the many baseline and environmental impact assessment studies that cannot obtain long-term observations.

- ***To foster marine technology development***

From a technical point of view, there is a need to further develop systems, sensors, robots and deep-sea observatories, as well as systems for capturing and maintaining deep sea organisms. The Azores provide perfect locations as a testbed for these instruments. Their oceanic harbors and proximity of the deep sea extreme environments afford scientists with opportunities to explore a unique part of the world ocean.

- ***Water availability***

Study how island ecosystems integrate new technologies and systems that may lead to future perspectives related to the water availability complex issues.

Unmanned vehicles now are valuable tools for research especially for sampling small scale ocean processes and the biological environments and their diversity over extents which match their speed and endurance. Intelligent and autonomous sampling of ocean properties such as the usual temperature, depth, conductivity (salinity) and O₂ around the island can provide fine scale oceanographic data. UUV's can also infer currents with ADCP's (acoustic Doppler current profiler) as well as particulates of low concentrations. Side scan sonars and high frequency

multibeam echo sounders can provide very high resolution images of the bottom which can be repeatably mapped for changes induced by volcanic activity. Biologic sampling for phytoplankton activity. Flow cytometers for cellular identification are now being deployed on UUV's which opens many opportunities in biological oceanography. Since this can be very dynamic, simultaneous mapping could be powerful for creating images of the biologic activity.

6.3 Infrastructures and other resources

6.3.1 Existing Infrastructures

There are numerous infrastructure-related resources available in the Azores that can be applied in the context of the AIR Center. For example, there is a critical mass of skilled human resources that work in the Department of Oceanography and Fisheries (DOP) based in Faial. There is Oceanic harbor of Horta and the Deep Sea Laboratory and Hydrothermal Vent Observatory for studying deep-sea animals from hydrothermal vents.

In addition, there is an experimental laboratory to research scenarios of climate change on deep-sea organisms, a pressurized vessel with 20 liters' capacity that can simulate depth to 4000 meters to conduct studies on the effect of scenarios under pressure, and multi-instrumented permanent deep-sea observatories such as EMSO. Finally, there is the Condor Observatory located in the first seamount marine reserve for scientific purposes and a deep-sea array of acoustic receivers for tracking and monitoring of marine animals.

Existing infrastructures

High skilled critical mass in terms of human resources working in the Department of Oceanography and Fisheries (DOP) based in Faial

Oceanic harbor of Horta

Deep Sea Lab facility to study deep sea animals from hydrothermal vents

Experimental laboratory to research scenarios of climate change on deep sea organisms

Pressurized vessel with 20 liters' capacity that can simulate depth to 4000 meters to conduct studies on the effect of scenarios under pressure.

Multi-instrumented permanent deep sea observatories – EMSO

Hydrothermal vent observatory

Condor observatory located in the first seamount marine reserve for scientific purposes

Deep sea array of acoustic receivers for the tracking and monitoring of marine animals

6.3.2 Potential additional resources

Similarly, there are numerous existing potential resources such as skilled workers and specialized equipment. Other resources include land-based facilities (e.g., laboratories, experimentation stations, and monitoring stations) and remote platforms (e.g., vessels, satellites, drifting floats, autonomous underwater vehicles, gliders, underwater robots, receiving devices (and sources) for passive (and/or active) ocean acoustic tomography/thermometry, cabled seabed observatories, instrumented marine mammals. Finally, there are deep-sea and open-ocean long-term fixed point observatories for such targeted contributions as the European Union Horizon 2020 project *AtlantOS* (Optimizing and Enhancing the Integrated Atlantic Ocean Observing Systems).

Potential resources

Land based facilities : laboratories, experimental stations and monitoring stations

Remote platforms: vessels, satellites and underwater robots

Deep sea and open ocean long term fixed point observatories

Equipment: sensors, vehicles and sensors that can operate below 200m

Secure and reinforce high skilled critical mass of researchers through international collaboration

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7 Data Science for the Atlantic

7.1. Uniqueness of the Azores

The Azores offer a unique set of challenges and opportunities to contribute to the design of sustainable energy systems and for the exploitation of large sets of data originating from different levels and sources of research.

7.2 Key Research Challenges

- *Integrating at scale, data collection, curation, and storage with advanced computing and analysis*

Regarding the development of an innovative electronic science environment, it is possible to implement a specific cyber-infrastructure deemed essential to the success of AIR: a Research Cloud dedicated to the AIR Center, and a portal, iAtlantic, which would be designed and deployed to integrate a comprehensive set of tools and technologies linking the science and engineering relevant to the Azores and the North Atlantic. The vision for iAtlantic is that it will become a widely used and indispensable site of reference for the international research community, policy makers, and the public in general.

An Azores Maritime Cloud can support all the thematic areas of the AIR Center as a technological platform and data hub responsible for providing:

- A portal, iAtlantic for web access to hosted applications providing data and services for science and engineering applications including a directory for search and browse;
- Real-time data collection from several , existing and to be developed, maritime sensors and information sources (land, sea, air and space);
- Data correlation and fusion through advanced computational models;
- Data storage and retrieval capabilities enabled by big data distributed databases;
- Open interfaces allowing the research and commercial stakeholders build their own services on top of collected data, core cloud services and third parties hosted services;
- Rapid prototyping environment providing core functionalities such as imagery processing, machine learning and business intelligence;
- Application and services hosting;
- Reliable electronic information exchange between Maritime stakeholders (*including connection to national and international data exchange networks*)

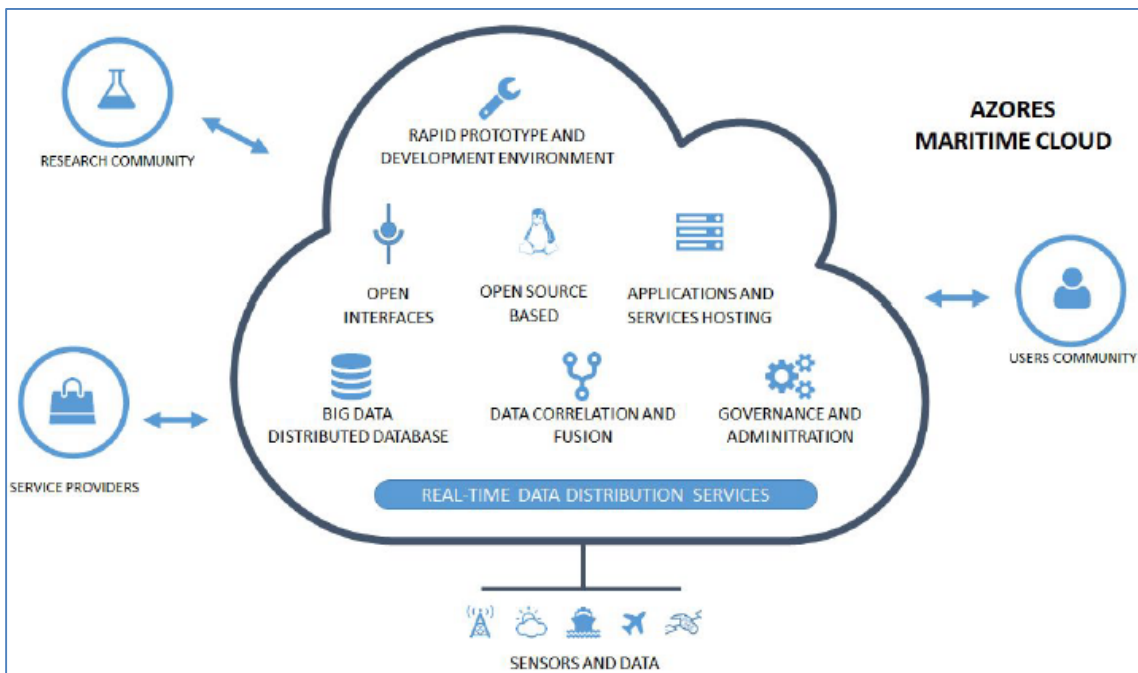


Fig.4 – High-level architecture representation for an Azores Maritime Cloud

The Figure 4 above can be efficiently set-up based on existing assets to support maritime related operations such as data collection from several maritime sensors (land, sea, air and space), data fusion through advanced computational models, storage and dissemination.

7.3 Infrastructures and other Resources

7.3.1 Potential additional resources

The research community engaged in climate change research and large scale monitoring, modeling and simulation of earth phenomena is keenly aware of the need for a robust cyber-infrastructure in order to accelerate the pace of scientific discovery. In particular, the proliferation of datasets, modeling tools and the convergence of diverse disciplinary expertise calls for an integrated and efficient approach to collecting, curating, analyzing and visualizing data.

The ultimate goal and objective of a robust cyber-infrastructure is to support the mission of the Azores International Research Center and to provide enabling tools to researchers in order to maximize their ability to navigate across data sets, computational models, and a variety of disciplines. Ideally, the tools should be components accessible and of demonstrated value to policy makers and to non-experts in the general public.

8 Space Science and Technology for the Atlantic

8.1 Uniqueness of the Azores

Access to space has been ranked among the main priorities of many nations with all the challenges that this entails. Portugal has been consolidating its space sector for sixteen years since it joined the European Space Agency (ESA). Portugal's space industry is almost a 100% exporter of its technologies, products and services to both the European and international space markets.

Certain space activities are founded on developing capabilities for launching and operating satellites, and receiving and processing the observations of the Earth that are collected by satellites. The overall program objectives take advantage of the unique Azorean North Atlantic geostrategic position (EU territory in Schengen area, close to Continental Europe, extensive ocean coverage—more than 1500 kilometers in any direction). The Azores location provides critical advantages for the space industry for implementing a demonstration platform for launching satellites (large, medium, mini-nano) and processing satellite data in close interaction with entities located there as well as monitoring the ocean from air, sea, and subsea vehicles.

- *Space "ecosystem" in the Azores:*

Santa Maria has a regional space capability that has excellent potential for expansion into a significant regional space research hub. The current capabilities include:

- European Space Agency (ESA) Tracking Station: The Santa Maria S-band station, also known as (Hill of Flowers), is one of the first Estrack stations with launcher tracking capability. Currently, it is used to receive real-time telemetry from launches originating from ESA's spaceport in Kourou, French Guiana. This station monitors launching vehicles such as the Ariane 5 and the new generation of small launchers such as Vega and Soyuz.
- Galileo Sensor Station (GSS): This sensor station is part of a worldwide network of stations monitoring signal quality, clock timings, and positioning of the Galileo satellites orbiting Earth. The station also hosts a reference beacon used for assessing Galileo's search and rescue system. For scientific research activity, the facility can receive the signals from the US GPS and the Russian GLONASS satellites. The combined GSS, GPS and GLONASS data, acquired from signals from a more than 80-satellite configuration, provide a basis for determining regional atmospheric temperature and water vapour measurements to support both regional scientific investigations and global weather prediction services (e.g., ECMWF weather predictions). The unique geographical location

of the AIR Center provides an important regional data set for assimilation into operational weather models.

- Copernicus Collaborative Station: The Sentinels, a fleet of ESA satellites, are delivering a wealth of data and imagery that are central to Europe's Copernicus program. The Sentinel-1 (first in the series) carries an advanced radar instrument to provide an all-weather, day-and-night supply of imagery of the Earth's surface. An ongoing project is concerned with implementing an SMA (Santa Maria Azores) ground station for receiving, processing, and archiving Sentinel data. The direct data reception enables rapid response services that can support early warning hazard and response activities and include maritime storm monitoring and response, early detection of oil spills/discharges, illegal fishing activities in oceanic areas, earthquake assessment and tsunami warning, and so forth. The AIR Center capability will provide a unique opportunity for interacting with each of the six Sentinel missions. The opportunity for developing unique geophysical or oceanographic products for mission data product validation, along with the use of the data from these missions for scientific and application studies, will lead to a rich suite of scientifically important data products.
- Earth Observation (EO) station: The applications potential for ASIRS can be increased through the EO station, which receives RADARSAT 2 data. These data support several operational and pre-operational services, namely CleanSeaNet¹ (daily operations to supply the European Maritime Safety Agency – EMSA – with near-real time data on maritime pollution service). The data from RADARSAT is applied to support safe marine application and improved weather forecasting. It also contributes to international hurricane monitoring and provides all weather-wind-speed and direction to improve hurricane predictions. The data products possible from analysis of the C-band radar data for RADARSAT are candidates for commercial exploitation through a new business activity.
- Project RAEGE (Atlantic Network of Geodynamical and Space stations): This project consists of a network of four geodetic fundamental stations as part of the development needed to establish a Very Long Baseline Interferometry (VLBI) Geodetic Observing system (VGOS). The applications of these stations are the monitoring of the Earth system (shape, gravity, and rotational motion) and global change research and would be a proposed part of the Global Geodetic Observing System station.

¹ CleanSeaNet – European satellite-based oil spill and vessel detection service. It offers assistance to participating states for the following activities (identifying and tracing oil pollution on the sea surface, monitoring accidental pollution during emergencies, contributing to the identification of polluters)

- The NAV Portugal Air Traffic Control Center (named Oceanic FIR): This is a flight information center east of the North Atlantic (between 18 and 45° N) for approach control for the Lisbon, Porto, Faro, Funchal, and Porto Santo airports and a modern communications center for effective long distance coverage (using an HF system). This facility would be important as a staging area for the use of unmanned aircraft to conduct regional sea surface measurements for both scientific and hazard monitoring activities.

8.2 Opportunities for international collaboration

- *Establishment of an Atlantic Spaceport for low cost access to Space including launchers for mega constellations and small satellites in the Azores*

“New Space” and the related democratization of the access to space has become a research and development-intensive sector open to many players, with significant opportunities for science-based innovation and “new space industries” in a wide range of applications. With the development of a number of non-governmental firms that are developing satellite launch vehicles, there is a competing need for launch sites, or space ports, to accommodate this need. The need will see a major expansion with the maturation of the nanosat and microsat bus and instrument capabilities. The need for global coverage by these satellites emphasizes the need for a polar launch capability, which because of its unique geographical location would be a very appropriate role for the AIR Center. The extensive runway capability would provide capability for both take off and return-to-earth for horizontal launch vehicles. Consequently, a future Spaceport in the Azores for mega constellations and small satellites will provide many new opportunities, as, for example:

- It will create a pull effect for new companies working on new propulsion systems, small launcher development, ground segment for space, lower cost launches, and satellite validation and calibration, among other themes;
- It can serve as a launch and landing facility for an orbital space plane (long runways (+3 kilometers long). Example: Lages airfield was a backup landing site for the U.S. space shuttle;
- It will provide a comprehensive launch capability for nano/micro satellites (payload development, testing and integration services; satellite platform production, integration, testing; constellation networking and operation services; data reception, storage, analysis and dissemination;;
- It will facilitate series production of satellites and subsystems;

- Spacecraft design and testing and the development of novel technology and experiments for the International Space Station (ISS) will be possible;
 - It can serve as a data-hub for data processing for EO satellites in close interaction with on-site observation capabilities with aircraft, unmanned aerial vehicles (UAVs), ships, and remotely operated vehicles/autonomous underwater vehicles (AUV);
 - It can serve as a research hub for conception and development of human spaceflight demonstration projects — development and improvement of materials and manufacturing processes for the purpose of space exploration (protection of spaceships, astronaut protection, protection against corrosion and wear, exposure to extreme conditions) and science- specific experiments that utilize the orbiting spacecraft environment.
- *Establishment of an Atlantic Surveillance Center based in the Azores to leverage the scientific leadership in the Atlantic (North and South)*

This center would cover the following activities:

- Monitoring piracy, illegal and narco activities in Gulf of Guinea & Africa west coast;
 - Supporting search and rescue (SAR) Atlantic activities;
 - Supporting scientific missions and new economic endeavors concerning the Portuguese extended continental shelf;
 - Conducting research and testing for UAVs for maritime applications, including a staging and deployment site for regional campaigns.
- *Establishment of a North Atlantic station integrated in NASA Space Geodesy project for Global Geodetic Observing System (GGOS)*

The Group on Earth Observations (GEO) has detailed an assessment of the requirements for geodetic earth observations to satisfy nine societal benefit areas (SBA). Paramount among these are the requirements for establishing and maintaining the Terrestrial Reference Frame (TRF) and describing its essential role in fulfilling the mission objectives of current, past, and future satellite missions such as ENVISAT, CryoSAT-2, Jason 1, and 3, ICESat 1 and 2, which observe sea and ice surfaces and gravity-mapping missions such as GRACE and GRACE FO, which observe the mass transport involved in the water cycle. These observations provide the ability to detect, monitor, and predict global change signals, if the observations are properly referenced in a consistent reference frame. Synthetic Aperture Radar (SAR) missions provide measurements of land surface displacements that help to detect active volcanoes and earthquakes, unstable slopes, and subsidence due to groundwater withdrawal. Full utilization

of the potential of these observations for research and application will require that an acceptable TRF exists.

In response to this need, the international community is collaborating in the implementation of a set of globally distributed tracking stations to establish the Global Geodetic Observation System (GGOS), whose responsibility will be to determine and maintain the Terrestrial Reference System. At a minimum, each GGOS will have the next generation Satellite Laser Ranging System, VLBI radar, Global Positioning System, and DORIS Doppler tracking system. The unique geographic location of the AIR Center makes it a very desirable location for a GGOS. In addition to the contributions to the definition of the TRF, the data collected at the site would support a number of related studies in solid earth science (tectonics and earth rotation), oceanography (sea level change) and atmospheric science (atmospheric temperature and water vapor from GPS occultation measurements) and support real time hazard-monitoring activities.

The implementation would be a candidate for international collaboration through participation in both European and NASA contributions to the implementation of GGOS. The unique geographic location of the AIR Center makes it an important site for inclusion.

- *Implementation of an upgrade program for the existing ground segment stations and infrastructure to support Space missions*

AIR Center activities would include development and implementation of a larger antenna of 15.5 meters in the ESA tracking station infrastructure, development of a new infrastructure to accommodate activities for the Space Surveillance and Tracking (SST) program and NATO's Future Surveillance Control Project/AGS.

- *Establishment of an ESA/NASA/Azores Launchpad Technology Incubation facility*

This facility would be characterized as a "start-up campus" for NewSpace companies that are "high-risk, high-reward" from an investment view point.

- *Installation of an operational network/platform for an efficient "Azores ocean monitoring and environmental management"*

Basic characteristics of the Azores waters, such as seasonal temperature variability, mean anomaly fields, and biological activity need to be precisely measured to better understand the impact of climate change in the North Atlantic. Past, current, and future satellite remote sensing data have been successfully processed to produce daily-to-monthly composites of these parameters on both regional and global scales. In addition to being decisive

information for studies of regional and global climate change – weather and climate monitoring and forecasting, time-series of SST (sea surface temperature) composites, SSH (sea surface height) and most recently SSS (sea surface salinity) – this information is applicable to a number of application areas such as providing support for the analysis of mesoscale variability at the scale of ocean basins affecting fishing activities in the Azores area and ocean current and wave height as an aid in maritime ship routing. Synthesis of these diverse observational data streams into a unifying modeling, analysis, and prediction framework centered in the Azores would provide a powerful way to enhance the value of these data.

The data reception capability discussed in the previous sections allows a near real time reception of the satellite data. By establishing the capability to produce the application topics in near real time, the means for responding to both anthropogenic and natural hazards could be developed. In addition, the near real time products would provide a basis for commercial exploitation of the data that can be developed and could be one basis for the small business startup envisioned in previous discussions.

The real-time data activity would be a candidate for collaboration with both US (NASA and NOAA) and European activities, such as a consortium that formed the European Gravity Service for Improved Emergency Management. The EGSIEM is a multi-institutional effort to improve response time for regional emergencies. The effort is funded by through the EO-1 Space Call of the Horizon 2020 Framework Program for Research and Innovation for 2015-2017 . The AIR Center capabilities would be important in similar regional remote sense-data applications.

- *Establish a center to assess/improve the efficiency of the renewable energy resources in the Azores*

The integration of in-situ data into models providing more precise and reliable regional predictions will help to improve decisions leading to an effective management of energy resources. Due to the unique conditions of the Azores, different renewable systems can be integrated and the AIR Center can serve as the seed for a deployable system that can be replicated in other similar areas.

- *Establish the capabilities and resources to ensure innovative geo-information services based on EO data for adoption and enhancement of the EU Atlantic Strategy (in particular EU Horizon 2020 project "AtlantOS") and its action plan and of the Portuguese National Ocean Strategy*

Promote a transversal initiative with applicability in many areas related to coastal and ocean management that will allow Portugal to meet the challenges for the promotion, growth, and competitiveness of the maritime economy, in particular, the important changes to the political and strategic framework at both the European and worldwide level. This objective is

consistent with the activities discussed in the applications of the Sentinel program, the RADARSAT data acquisition, and the NewSpace discussion above as well as both research and application programs implemented by NASA and NOAA.

- *Installation of a ground facility incorporating high resolution radars*

The AIR center could manage a ground facility with high resolution radars for the monitoring of active and obsolete satellites (space junk/debris). This facility could be a “mirror site” for example of the Haystack radar of MIT Lincoln Laboratory imaging at W band for NORAD (North American Radar Air Defense). The availability of high resolution images of virtually everything in orbit could be managed as a service.

- *Installation of a reception satellite station in Natal (Brazil) and Azores*

Through the AIR Center a new cooperative intergovernmental agenda for satellite data collection could be installed in both countries, whereas a very large and comprehensive Near Real Time (NRT) satellite coverage of the North and South tropical and sub-tropical Atlantic and Eastern Mediterranean regions could be envisaged.

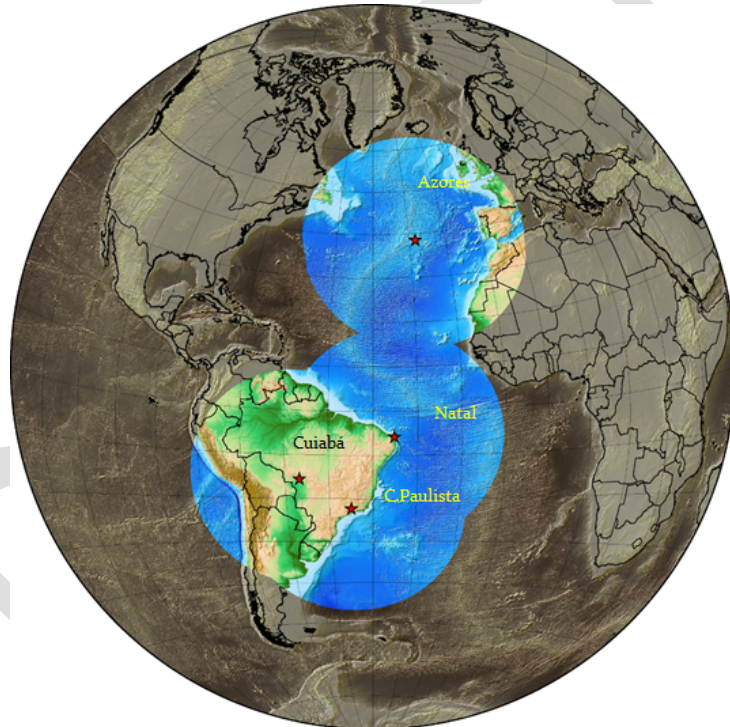


Fig.5 – Illustration of possible Portugal-Brazil cooperative agenda for satellite data collection

8.3 Infrastructures and other Resources

8.3.1 Existing infrastructures

There are several space-related agencies in the Azores that can support the space theme in the AIR Center, especially on Santa Maria. These include the European Space Agency (ESA) Tracking Station, the Galileo Sensor Station, the Copernicus Collaborative Earth Observation (EO) Station, the Atlantic Network of Geodynamical and Space Stations, and the NAV Portugal Air Traffic Control Center. Collectively they constitute a support infrastructure for AIR Center space activities.

Existing infrastructures	Island
European Space Agency (ESA) Tracking Station	Santa Maria
Galileo Sensor Station	
Copernicus Collaborative station	
Earth Observation (EO) station	
Atlantic Network of Geodynamical and Space stations	
NAV Portugal Air Traffic Control Center	

8.3.2 Open Portugal's Space sector to international players and "New Space Industries"

The Fundação para a Ciência e Tecnologia (FCT) manages policies and activities related to the Portuguese space program, including activities through ESA. One of the pillars of the FCT mission is to monitor the participation of Portuguese academia and industry in European and international space programs while providing recommendations relevant to the implementation of a national scientific and technological space initiative. The main Portuguese academic and industrial organizations that comprise the national space sector are represented in Figure 6.



Fig. 6 – Main industrial and academic Portuguese Space sector

8.3.3. Potential additional resources

In addition to the existing space-related infrastructure, there are resources that could be potentially complementary throughout the Azores archipelago. For instance, an Atlantic spaceport for low cost access to space and a NASA space geodesy project location for the Global Geodetic Observing System could be situated on the islands of Terceira or Santa Maria. Likewise, Santa Maria could host an Atlantic surveillance center, a space surveillance and tracking program, or a high data rate direct broadcast reception facility, and any of the islands could serve as the location of an ESA/NASA/Azores launchpad technology incubation facility.

Potential Resources	Island
Atlantic Spaceport for low cost access to Space	Terceira or Santa Maria
Atlantic Surveillance Center	Santa Maria
NASA Space Geodesy project for Global Geodetic Observing System	Terceira or Santa Maria
Space Surveillance and Tracking programme	Santa Maria
ESA/NASA/Azores Launchpad Technology Incubation facility	All

Part III – Promoting International North-South cooperation for knowledge, research and business across the Atlantic

9 Towards an Intergovernmental Organization, fostering North-South cooperation

As an integrative and distributed research platform, the AIR Center can provide a shared and international environment to support and foster new climate, earth, space, and marine research activities benefiting decision makers, public users, universities and industry as well contribute to retain highly skilled human resources and contribute to regional growth.

In particular, the AIR Center may provide a unique opportunity to drive multilateral cooperation in complex systems engineering and science through an integrative approach to climate and energy, earth, space, and ocean research and development in the Atlantic Ocean.

The Center, through a flexible international governance model with international statute and international legal status (i.e., emulating the CERN experience in Geneva or that of INL in Braga, Portugal, among others), would provide a solid legal context to overcome potential national constraints as well as providing an appropriate regulatory framework to efficiently and effectively address operational issues such as staff regulations, financial contributions and definition of the several scientific programs.

Potential advantages to building an intergovernmental research station in the Azores includes the following:

- It can offer a global-scale research site, capable of attracting scientists and technicians from around the world and can stimulate different forms of collaboration with other countries as well as public or private entities in a wide range of areas associated with research and education or commercial applications.
- It can be exempted from direct and indirect taxes for its official buildings and movable goods and from customs duties for importations part of its official use.
- Member states delegations can have diplomatic status.

10 Towards developing new North-South Atlantic Research Agenda

10.1 Expanding and complementing AtlantOs towards new horizons in North-South Atlantic Cooperation

The AtlantOS project (Optimizing and Enhancing the Integrated Atlantic Ocean Observing System; 2015-2019) has been recently promoted under the EU H2020 program with the overarching goal to integrate existing ocean observing activities to a more sustainable, more efficient, and fit-for-purpose integrated Atlantic Ocean Observing System in terms of the “Framework of Ocean Observing” (FOO). It contributes to achieving the aims of the Galway Statement on Atlantic Ocean Cooperation signed in 2013 by the EU, Canada and the US, launching an Atlantic Ocean Research Alliance to enhance collaboration to better understand the Atlantic Ocean and sustainably manage and use its resources. The AtlantOS project, running from April 2015 to June 2019, joins the efforts of 57 European and 5 non-European partners (research institutes, universities, marine service providers, multi-institutional organizations).

The AIR Center is aimed to expand, complement and extend the AtlantOS initiative through a new multi- and inter-disciplinary approach to research. It will act in terms of an international organization that will foster new horizons for Atlantic research through multilateral cooperation and will promote a network of research centers and technology-based businesses in north and south Atlantic. It should take advantage of a new cooperative agenda to be established between Europe, USA and Canada with South Atlantic countries contributing for the expansion of the Galway Declaration to the South Atlantic.

10.2 Opportunity for a new Research Infrastructures of pan-European interest

The AIR Center is envisaged as a major hub of an international network of Atlantic research centers, which needs to consider with particular attention the landscape of European-scale Research Infrastructures (ERIs), namely those that are part of the ESFRI Roadmap, as well as the transnational Projects for new ERIs currently funded by Horizon 2020 (or FP7).

The landscape of existing RIs, is illustrated in Figure 7.

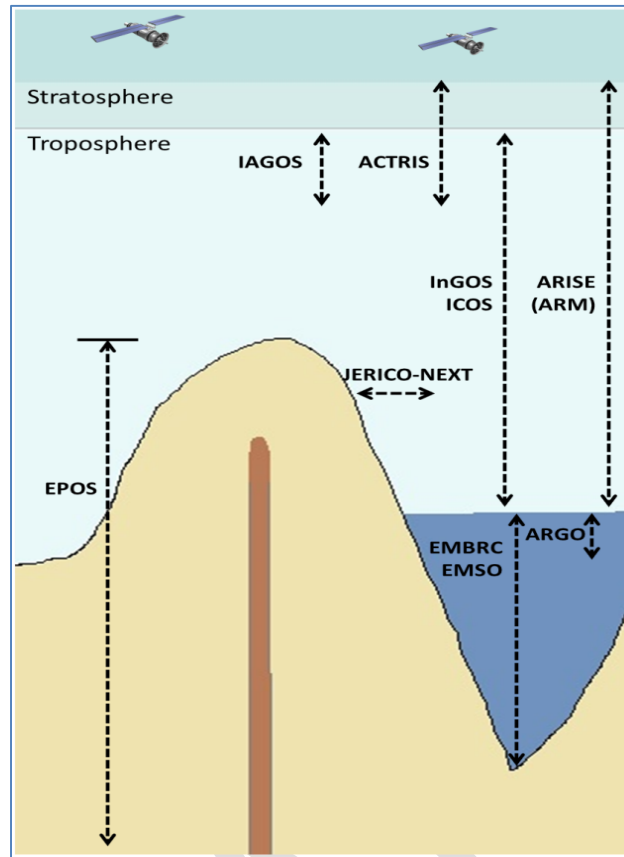


Fig.7 - Illustration of the existing European Infrastructures² within the AIR Center thematic areas

This landscape illustrates a comprehensive coverage of specific topics in dedicated research infrastructures, and allows the identification of gaps that may be filled by new research infrastructure networks, such as:

- I. Research infrastructure on Sustainable Energy Systems;
- II. North-South Atlantic Interdisciplinary Research Infrastructure.

These potential initiatives are described in the next paragraphs.

^{2 2} **EMBRC** – European Marine Biological Resource Centre: a distributed research infrastructure that aims to provide a strategic delivery mechanism for excellent and large-scale marine science in Europe.

EMSO – European Multidisciplinary Seafloor and water column Observatory: main scientific objective of long-term monitoring, mainly in real-time, of environmental processes related to the interaction between the geosphere, biosphere, and hydrosphere, **ACTRIS** – Aerosols, Clouds, and Trace gases Research Infrastructure Network: Atlantic circulation of Aerosols and trace gases; study shallow marine clouds

IAGOS – IAGOS is a new European Research Infrastructure conducting long-term observations of atmospheric composition, aerosol and cloud particles on a global scale from commercial aircraft of internationally operating airlines

InGOS – InGOS is an EU FP7 funded Integrating Activity (IA) project targeted at improving and extending the European observation capacity for non-CO2 greenhouse gases.

ICOS – The Integrated Carbon Observing System (ICOS) is a pan-European Research Infrastructure which provides harmonized and high precision scientific data on Carbon Cycle and Greenhouse Gas budget and perturbations.

ARISE –The aim of ARISE is to provide observations and models for future assimilation of data by operational weather forecasting models in the perspective of improving weather forecasting to monthly or seasonal timescales.

JERICO-Next – The vision of JERICO-Next is to improve and innovate the cooperation in coastal observatories in Europe by implementing the coastal part of a European Ocean Observing System, to cooperate with other European initiatives

EPOS – European Plate Observing System: The activities of the European Plate Observing System span a wide range of themes related to Solid Earth Science, such as Near-Fault and Geomagnetic Observations, Seismology, Geological Modeling, Volcanology, GNSS and Satellite data, among others.

EURO-ARGO – active coordination and strengthening of the European contribution to the international Argo program .

10.2.1. Research Infrastructure on Sustainable Energy Systems

The "ESFRI 2016 landscape analysis" identifies the need for a new Centre of Excellence for energy-related topics, working closely with associated experimental and industrial groups, is expected to have a multiscale integrating character and this motivates this proposal that contribute filling this gap along with databases and research platforms.

The AIR center provides significant opportunities starting from access to a comprehensive set of renewable energies (i.e.: wind, hydro, geothermal, complex and diversified storage systems), satellite measurements for sustainable energy systems and a 15m antenna to be installed in the Azores, that will collect large flows of relevant data from different satellites.

The main goal would be to develop an array of satellite based techniques that will provide spatial and time resolved information on renewable energy resources, namely solar and wind and combine this information with energy systems modeling models that could provide a globally applicable method to design sustainable energy solutions. The research infrastructure will include different sets of local measurements and sensors that will enable the calibration of the satellite based data sets.

10.2.2. North-South Atlantic Interdisciplinary Research Infrastructure

The development of a new interdisciplinary research infrastructure could be considered in order to extend the capabilities of research centers around Europe and North Atlantic Nations to the South Atlantic in addressing the synergies between **Energy, Climate Change and Ocean and Space Sciences**.

This research infrastructure will act as a catalyst for research and innovation in multiple domains ranging from Renewable Energies, to the interactions of the Ocean with the Atmosphere & Climate, the impacts of Global Changes on the open Ocean and the deep Sea, including their biodiversity, as well as blue biotechnologies, etc..

A new infrastructure based at the AIR Center, given the central geographical position of the Azores in the Atlantic, would be a complementary capability to the already existing European RIs in the domains of Atmosphere Science, Climate Change, Ocean Science, and Energy (especially Renewable Energies). This new Global RI would focus on disciplines that combine more than one of these scientific areas, or else the application of enhanced Earth Observation (EO) systems to those areas. Some examples would be:

- Ocean-Atmosphere interactions and Climate (species that provide natural carbon sequestration, model and simulations of Air and Ocean currents);
- Study the Atlantic Meridional Overturning Circulation (AMOC);
- Offshore wind farms, and tidal / wave energy systems;
- Ocean thermal energy (study of gulf stream);
- Study the effect of climate change in hydropower, energy demand;
- Develop and implement weather models and the algorithms that convert weather predictions into power forecasts;
- Research satellites for targeted Climate applications/ studies;
- GNSS measurements of atmospheric properties over the North Atlantic;
- Pollutants circulation over the Atlantic and their impact on Climate;
- Other renewable Energies (on-shore wind, geothermal);
- Inland Carbon sequestraton.

The Air Center would take advantage of the existing Infrastructures in the different Azores Islands, and of the coast of Azores, for the multiple thematic areas involved and would be expected to provide a Global context by having among its Members European partners (Ireland, UK, France, Spain, etc.) as well as other Atlantic Countries such as the USA, Canada, Brazil, South Africa and Cape Verde, among others, as represented in Figure 8.

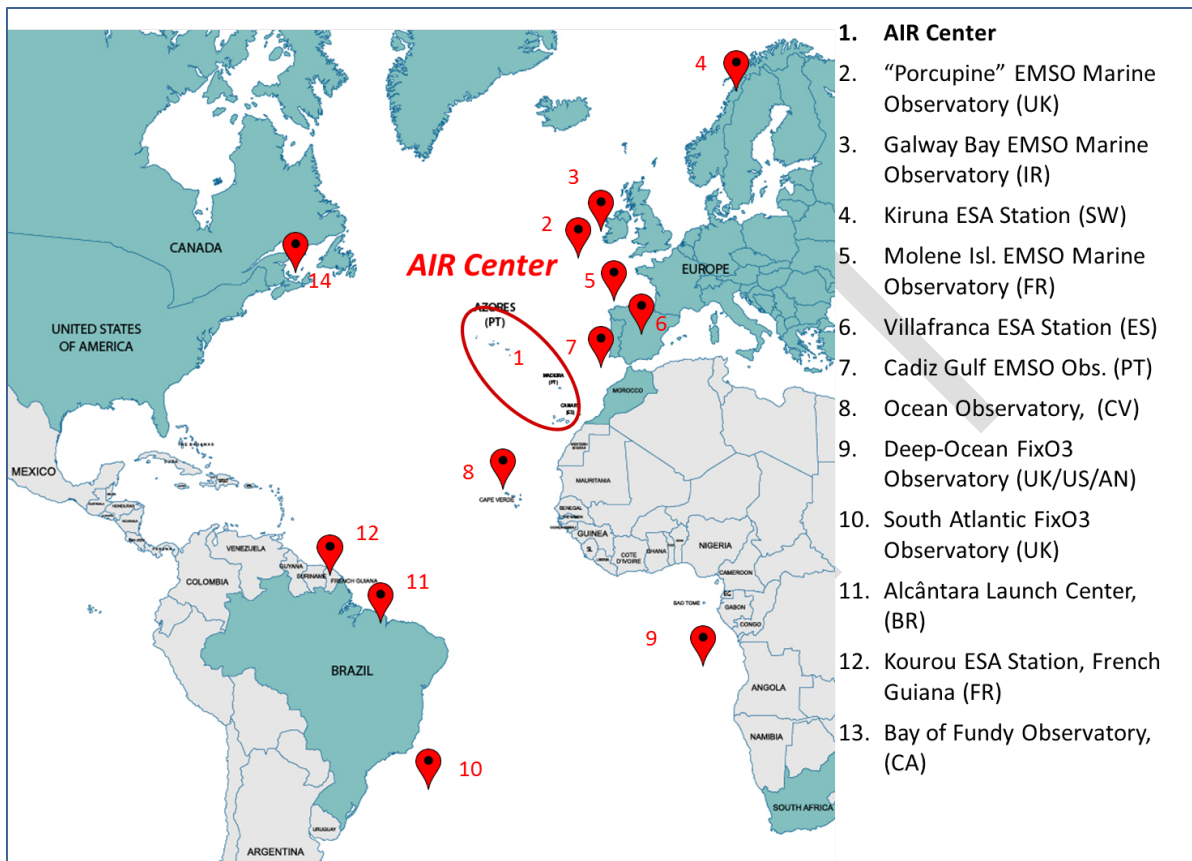


Fig.8 - Illustration of research stations identified as potential partners in the new Atlantic North-South research infrastructure

10.3 Pathways towards new North-South Atlantic Research Infrastructures

The research infrastructures discussed in the previous section will provide enhanced opportunities with the participation of south Atlantic countries, such as Morocco, Cape Verde, Brazil or South Africa, by including different research stations (Figure 8).

In particular, the workshop held in Brazil already allowed the identification of the following synergies:

	Synergies with Brazil		
Atmospheric Science	Cloud formation mechanisms identification and modelling	Monitoring of the atmospheric transport of pollutants emitted in the South American and South African continents	
Climate Change	Biogeochemical variability at the tropics and CO ₂ flows quantification	Global climate change models development and calibration	Climate change scenarios analysis: Project PNUD and Project PROBIO
Energy Systems	Data sets to model and design sustainable energy systems: Project SONDA; Project SWERA	Wind forecasting: Project PREVENTO	Public disclosure of renewable energy availability data
Ocean Science and Technology	Ocean and ocean atmosphere interaction monitoring programs	Satellite based Oceanography	Atlantic Carbon Experiment
Space Science and Technology	Satellite launch and operation	Satellite data collection and processing	Interoperability between different computational systems

Table 1: Synergies with Brazil

Further to the table above, the development of a cooperative agenda between the AIR Center and INPE for capacity building of young undergraduate and graduate students is an imperative for a long-term perspective of scientific and technological aspirations of tackling global issues in areas of space and oceans.

11 Knowledge for Space – Space for Knowledge: an opportunity for cooperation

The AIR Center agenda will include and foster an education and knowledge agenda aimed to promote “knowledge for space” and its integration with ocean, earth and climate education in a fully holistic approach, but it will also extend traditional education and science awareness programs to consider new horizons of space technologies to foster the access to education for all. This will be achieved by involving telecom operators, broadcast services and space providers in a “space for knowledge” network.

Although “star wars” program days are gone, in today’s world space activities are still very much perceived by the general public as a dispute for outer space conquests of “Rocket” scientists. The majority of the world’s population is unaware of the importance of space activities in our daily lives.

This is important in today’s societies because space science involves a series of disciplines that provide new insights on the Universe (physics; astronomy), allows perceiving earth dynamics which helps in the prediction and preparation for emerging threats; foster new advancements in satellites and robotic engineering, as well as in related technology allowing the exploration of outer space and find new materials and new knowledge of the Universe.

It is under this context that several major initiatives have been launched worldwide in the last decades to foster education for space in an effort to bridging the knowledge gap between people and space science. For example, in 2002 UNESCO launched a Space Education programme following recommendations from the 1999 World Conference on Science and the Third United Nations Conference on the Peaceful Uses of Outer Space. It is aimed to enhance space subjects and disciplines in schools and university curricula, the improvement of teaching methodologies to raise awareness about the importance of space and space related activities to human development. Three disciplines are mainly addressed:

- Astronomy;
- Aeronautic engineering, satellite design, robotic engineering;
- Space technology applications;

To carry out these objectives UNESCO develops space education workshops and other initiatives that show the importance of the peaceful uses of outer space and the part played

by space uses and technology in protecting, monitoring, documenting, and sharing our common heritage, both cultural and natural.

In a related action, ESA launched the ESERO initiative (European Space Education Resource Office) with several nations, including several activities to help teachers to introduce space in the classroom and raise awareness in schools of the importance of space science and technology. Among other initiatives, it has provided teacher-training courses, with special emphasis to primary level education and the reinforcement of the communication between the scientific community, enterprises and schools.

By using space as an engaging multidisciplinary challenge, these initiatives are contributing to promote the interest and mobilization of younger generations for science and technology.

The importance of an integrative approach in science drives the current efforts to establish an International Research Center in the Azores, bridging the American, European and African continents, particularly suited to provide unique data on the ocean and to study its interactions with atmosphere and space.

Through the initiative "Knowledge for Space – Space for Knowledge", the AIR Center will aim to expand and complement existing activities at UNESCO, ESA, NASA and other major players worldwide to raise awareness for the sciences among all children, but also to deliver new educational and cultural contents in developing countries through space technologies. Specific activities will be aimed to promote the diffusion of endogenous knowledge of local cultural and natural heritages and contributing for educating more children everywhere, anytime.

A sustainable future requires more knowledge and more scientific culture, ensuring the access to science and education as an inalienable right of all.

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