# Aquarius/SAC-D Mission Overview

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**ABSTRACT**

Aquarius/SAC-D is a cooperative international mission developed between the National Aeronautics and Space Administration (NASA) of United States of America (USA) and the Comisión Nacional de Actividades Espaciales (CONAE) of Argentina. The overall mission objective is to contribute to the understanding of the total Earth system and the consequences of the natural and man-made changes in the environment of the planet. Major themes are: ocean surface salinity, water cycle, climate, natural hazards and cryosphere.

**Keywords:** Aquarius, SAC-D, Remote Sensing, NASA, CONAE, ESSP, Sea Surface Salinity, Ocean Circulation and Climate Interaction, Global Water Cycle, Hydrology

## 1. INTRODUCTION

Aquarius/SAC-D is a cooperative international mission developed between the National Aeronautics and Space Administration (NASA) of United States of America (USA) and the Comisión Nacional de Actividades Espaciales (CONAE) of Argentina, and includes contributions from Agenzia Spaziale Italiana (ASI), Centre National d'Etudes Spatiales (CNES) and the Canadian Space Agency (CSA). Implementation of Aquarius/SAC-D is governed by the international Memorandum of Understanding (MOU) signed between the NASA & CONAE on 2 March, 2004 in Buenos Aires, Argentina.

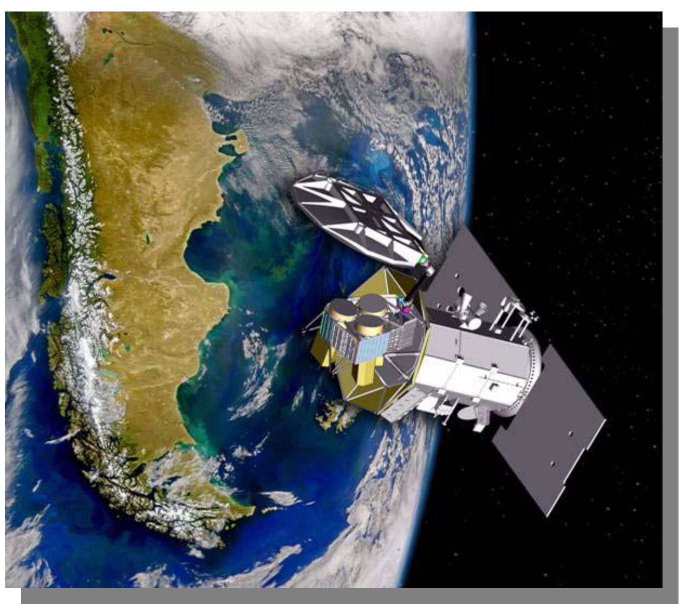

Fig 1: Artist rendition of the Aquarius/SAC-D Observatory

The overall mission objective is to contribute to the understanding of the total Earth system and the consequences of the natural and man-made changes in the environment of the planet. Major themes are: ocean surface salinity, water cycle, climate, natural hazards and cryosphere The Aquarius Mission focuses on understanding of the interactions between the global water cycle, ocean circulation and climate through the measurement of Sea Surface Salinity (SSS), whereas the SAC-D (Satelite de Aplicaciones Centificas - D) science mission focuses on complimentary global climatological measurements, environment and hazards monitoring, and region land and ocean imaging for Latin America and elsewhere. The prime instrument of the mission, Aquarius, provides global measurements of salt concentration at the ocean surface. The data is needed to study ocean circulation and heat capacity of the ocean, which in turn affects Earth's climate and the water cycle.

## 2. SCIENCE MEASUREMENTS

The goals of Aquarius/SAC-D are closely aligned to the goals of NASA's Science Mission Directorate (SMD) program and to the National Space Program of Argentina. The Aquarius science goals are to observe and model the processes that relate salinity variations to climatic changes in the global cycling of water and to understand how these variations influence general ocean circulation. These address NASA's fundamental science goals to understand how the Earth's global water cycle is changing and how climate variations affect ocean circulation. Accurate measurements of SSS, along with sea surface temperature, will determine the sea surface density, which controls the formation of water masses and regulates the 3-dimensional ocean circulation.

Aquarius and the suite of instruments on SAC-D address goals of the Argentine space agency to contribute to the understanding of the total Earth system and the effects of natural and human-induced changes on the global environment. The measurements address the Argentina Space Information Cycle II "Information System devoted to Oceanography, the Coastal Environment, Climate and Hydrology" and Space Information Cycle III "Emergency Management" as set forth in the "National Space Program, Argentina in Space 2004-2015". Among the emergency management issues are natural and man-made events such as forest and pasture fires, floods, volcanic eruptions, and severe weather (tornados, cyclones, hurricanes). Among the applications in Cycle II are studies of the Southern Atlantic Ocean, the Antarctic Sea and in other geographic regions to allow for the seasonal forecast of global phenomena such as El Niño as well as the measurement of related parameters such as soil moisture (support for agricultural and livestock management) and sea and coast surveys for scientific purposes as well as for the support of harbor, transportation and navigation activities.

The measurements to be performed by the Aquarius/SAC-D Mission are:

- Measurement of global Sea Surface Salinity over free ice ocean and soil moisture over Argentina.
- Measurement of the physical parameters of the High Temperature Events (HTE) on the ground, caused by biomass fires and volcanic eruptions.
- Measurement of Sea Surface Temperature (SST).
- Measurement of the temperature and humidity profile of the troposphere and the stratosphere.
- Measurement of rain rates, surface wind speeds, water vapor and cloud liquid water, over the oceans.
- Measurement of sea ice concentration.
- Measurement of lightning, light intensity over urban areas and polar auroras.
- Receive and store meteorological and environmental data generated by the ground based measurement systems for later retransmission to Cordoba Ground Station and distribution to the scientific user community.

In addition, the Aquarius level 1 instrument data will be archived continuously over all earth surfaces and made available for investigations of soil moisture, cryosphere or other applications.

Other Mission objectives are to provide space-based platform to study the behavior of micro-particles and space debris by monitoring events in time and in space, perform debris-cloud analyses and compare results with laboratory tests and simulations and to monitor the space radiation environment and measuring the associate effect on a variety of electronic components. An experiment to measure the atmospheric (troposphere and stratosphere) temperature and humidity profiles using Global Positioning System (GPS) Radio Occultation measurement technique is also on-board. The

Mission will also include a Technological Demonstration Package with the aim to validate technologies for attitude and navigation control which will be used in the spacecraft bus of CONAE´s future missions.

The suite of science instruments, their objectives, high level specification and their providers are summarized in Table 1.

| Instrument | Objectives | Specifications | Resolution | Coverage | Owner |
|---|---|---|---|---|---|
| Aquarius | Understanding ocean circulation, global water cycle and climate interaction. Soil moisture measurements over Argentina | Integrated L-band radiometers (1.413Ghz) and scatterometer (1.26Ghz) | Three beams: 76 x 94, 84 x 120, 96 x 156 km | Global | NASA |
| MWR | Precipitation rate, winds speed, sea ice concentration, water vapour, clouds | 23.8 and 37 GHz<br>H and V pol.<br>Bandwidth: 0.5 and 1 GHz<br>Swath: 390 km | 50 km | Global | CONAE |
| NIRST | Hot spots events, sea surface temperature measurement | 3.8, 10.85 and 11.85 µ<br>Swath: 182 km<br>Tilt: +/-532 km<br>FOV: 15,6° | 350 meters | ETC coverage area, Canada (stored mode) and other targets of opportunity ( about 30/ year) | CONAE |
| HSC | Urban lights, electric storms,<br>Polar regions, snow cover | 450-900 nm<br>swath: 700 km | 200-300 meters | ETC coverage area, Canada<br>(stored mode) and other targets of opportunity ( about 30/ year) | CONAE |
| DCS | Data Collection System | 401.55 Mhz uplink | 2 contacts per day with 200 platforms | Argentina, | CONAE |
| ROSA | Atmospheric properties | GPS Occultation Techniques | Horiz: 300 km<br>Vert: 300 m | Global | ASI |
| Carmen 1 Composed by ICARE and SODAD | I: Effect of cosmic radiation on electronic devices<br>S: distribution of microparticles and space debris | **I**: three fully depleted Si and Si/Li detectors<br>**S**: four SMOS sensors | I: 256 channels S: Sensitivity 0.5 part at 10 km/sec | Global | CNES |
| TDP | Position, velocity and time determination<br>Inertial angular velocity | GPS receiver<br>Inertial reference unit | 20 m, 1 m/sec, 2 m/sec<br>ARW: 8* $10^{-3}$ o/sec/sqrt h | | CONAE |

Table 1. Suite of Experiments on Aquarius/SAC-D Observatory

## 3. MISSION

Over the last decade, the Argentine space agency, CONAE, has successfully developed three consecutive science application satellites in cooperation with NASA. More than 17 university, corporate, government and international institutions are also involved in the Aquarius/SAC-D mission. NASA uses the term **Aquarius** for the mission within its ESSP (Earth System Science Pathfinder) program context. CONAE uses **SAC-D** in reference to its previous successful missions with NASA (namely SAC-A, B & C).

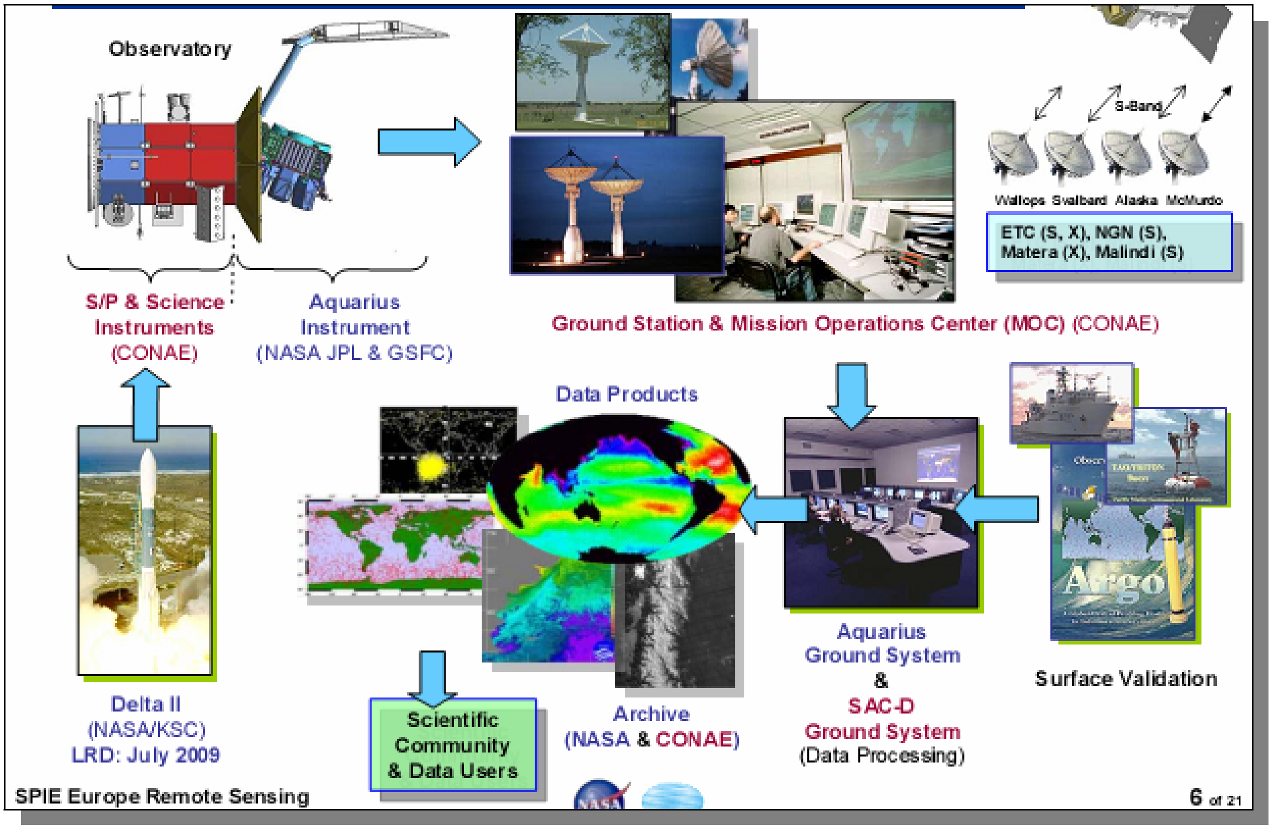


Fig. 2: Mission Overview

For this joint mission, Argentina is providing the SAC-D spacecraft, additional science instruments and the Mission Operations Center (MOC), while NASA provides Aquarius, the salinity measuring instrument, and the Launch Vehicle (LV). The SAC-D portion of the mission is managed by CONAE whereas NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, manages the Aquarius development for NASA's SMD based in Washington, D.C. NASA's Goddard Spaceflight Center (GSFC) in Greenbelt, Maryland, will build the radiometer portion of the Aquarius instrument and will process and generate the Aquarius science data products after launch. The data products will be made available to the science community and archived at the Physical Oceanography Distributed Active Archive Center (PO.DAAC) at JPL. CONAE will also distribute the SAC-D science data products from it's facility in Buenos Aires, Argentina.

The launch (provided by NASA) is from NASA's Western Test Range (WTR) at Vandenberg Air Force Base (VAFB) using a Boeing Delta-II launch vehicle. The observatory will go into a sun-synchronous orbit at an altitude of 657 km, an inclination of 98 degrees and equatorial crossing times of 6 pm (ascending node) Mean Local Time (MLT). The orbit is a 7-day exact repeat orbit. The Aquarius swath (390 km) and orbit have been selected so that complete global sampling is obtained during each 7-day period.

This innovative mission, targeted for launch in 2009, is currently in Implementation phase (detail design, manufacture and test). The Observatory (which consists of the Service Platform (S/P) [a.k.a the spacecraft bus] and the science instruments) will be launched for a five-year mission.

After launch, CONAE will provide the ground station and telecommunication services through their ground station and Mission Operations Center (MOC) in Cordoba, Argentina and through an agreement with ASI via the Matera GS (Ground Station). Aquarius science telemetry will be separated at the MOC and sent to the Goddard Space Flight Center for processing. The salinity data products will be generated at GSFC and eventually will be sent to the PO.DAAC at JPL for permanent archiving. Salinity maps and relevant ancillary data will be released to the public from GSFC prior to final archiving. CONAE will release their science data to its users from Buenos Aires. Figure 2 above, shows the Mission overview and flow.

## 4. OBSERVATORY

The 8 instruments are integrated on the SAC-D Service Platform (S/P). The S/P is a functionally redundant 3-axis stabilized spacecraft that supports the nadir pointing instruments with maneuvering thrusters supporting S-band up/down link and X-band hi-rate data communication. SAC-D is an evolution of the SAC-C platform built by INVAP (prime contractor for CONAE). SAC-C launched Nov 2000, is still operating after successfully completing 4-year prime mission. The SAC-D S/P has an operational life of 5 years. The 8 instruments and the S/P make up the Aquarius/SAC-D Observatory. Figure 2 shows the instruments on the Observatory. This section describes and presents and overview of each of the science instruments.

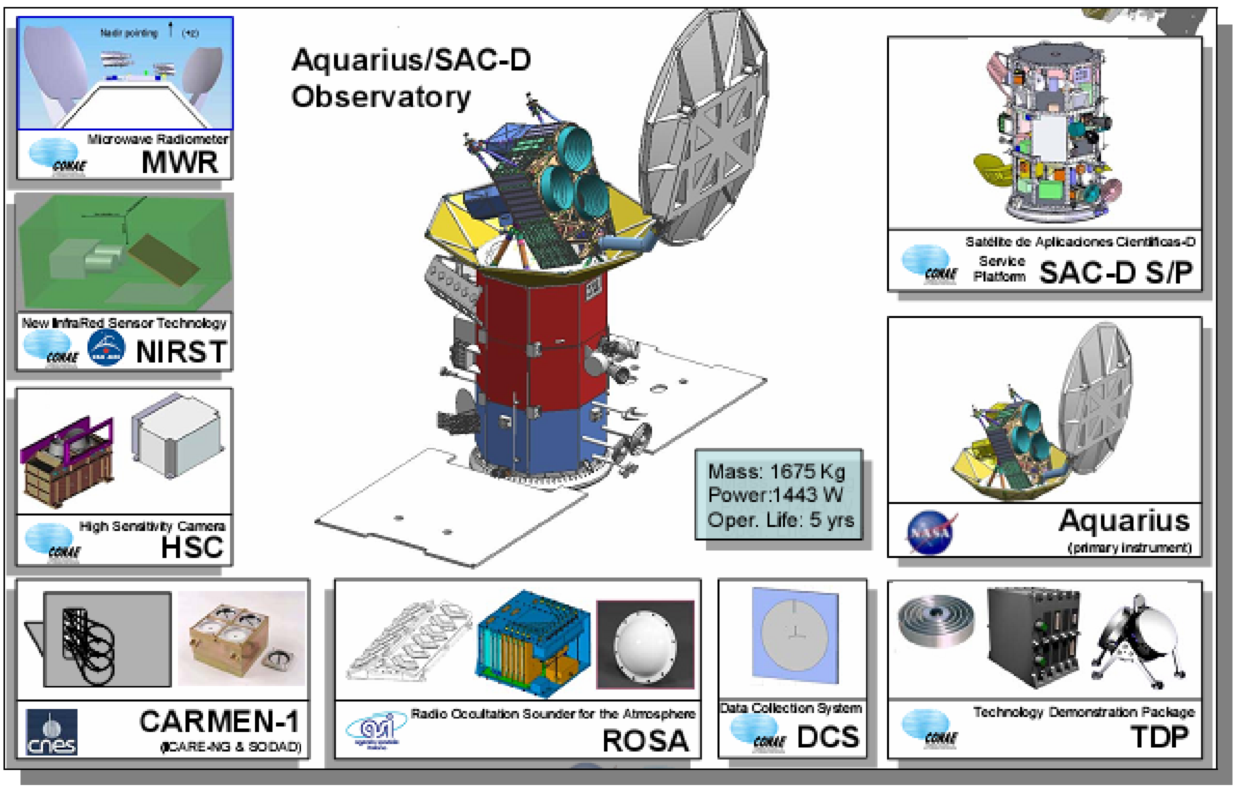


Fig. 2: Aquarius/SAC-D Observatory and Instruments

**Aquarius**

Contributed by NASA, Aquarius will make pioneering space-based measurements of Sea Surface Salinity (SSS) in order to characterize salinity variations and investigate the role of salinity in the ocean circulation, climate variability and change, and the Earth's water cycle.

The mission will provide a missing measurement required to address the overarching science question such as "How is the Earth changing and what are the consequences for life on Earth?" The Aquarius SSS measurements will address science questions about Earth's System Variability and Trends. It will try to find answers for changes that are seen in global precipitation, evaporation, and the cycling of water. It will address Earth System Responses and Feedback Processes and promote understanding of how climate variations are coupled to changes in global ocean circulation. This space-based ocean surface salinity measurement will greatly enhance the existing knowledge of ocean surface salinity that has been previously derived from the compendium of ship and buoy observations. The current spatial sampling has been sparse, irregular and largely confined to shipping lanes and the summer season.

The Aquarius instrument designed for the measurement of salinity from space, consists of an integrated instrument consisting of 3 radiometers at 1.413 GHz (L-band) and a scatterometer operating at 1.26 GHz. The instrument operates in a pushbroom fashion with a ground swath of 390 km. The radiometer is the primary instrument for measuring sea surface salinity and the scatterometer is being carried to provide a correction for surface roughness, the largest unknown in the retrieval algorithm. The radiometers will measure the surface brightness temperature, which is a product of the surface emissivity and physical temperature of the seawater. The surface emissivity is a function of the dielectric constant of seawater that is related to salinity and temperature. The scatterometer will measure the surface backscattering cross-section, which is required to provide coincident information of sea surface roughness, a critical correction for the SSS retrieval. Ancillary measurements of surface temperature and other geophysical corrections will be obtained from other operational observing systems and models.

During its 3 year mission life, the Aquarius instrument will be operated continuously to provide global measurements over the ocean, ice and land surfaces (except during spacecraft maneuvers as necessary). Sea surface data will be processed to estimate SSS over the world ocean. Sensor data over ice and land surfaces will be archived and made available to the research community for further investigations. Development of the Aquarius instrument package is a partnership within NASA of the Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL). GSFC is responsible for the radiometer and ground science data processing system, while JPL is responsible for the scatterometer, instrument integration and test and pre-launch mission management.

**Microwave Radiometer (MWR)**

The CONAE developed MWR will measure rain rates, surface wind speed, water vapor and cloud liquid water over the oceans and sea ice concentration in order to provide important geophysical parameters to contribute to climate and hydrological forecasting for the La Plata basin, Patagonia and the Antarctica, where most of the world ice is found. The MWR measurement geometry is designed to overlap Aquarius and contribute complementary science data for the SSS determination. The radiometer consists of two polarimetric receivers at 23.8 and 36.5 Ghz, with antennas arranged in pushbroom configuration. Each frequency is supported by a dedicated structural subsystem, consisting of a reflector, eight feed horns and two radiometers providing a swath width of 390 km, a resolution of 50 km and a sensitivity of 0.5K, covering the same footprint as the Aquarius instrument.

**New IR Sensor Technology (NIRST)**

Jointly developed by CONAE and the Canadian Space Agency (CSA), the NIRST instrument will determine High Temperature Events (HTE) on the ground (fires and volcanic events), will measure their physical parameters (released energy, temperature, hot spots location, etc) and also Sea Surface Temperatures (SST) off the coast of South America and other targeted opportunities. It has one band in the MIR, 4 μ, and two in the TIR, 11 and 12 μ. In the three cases the bandwidth is of 1 μ. The thermal range is of 300-1200K with a NEDT < 2 K.

The baseline design of NIRST is based on micro-bolometer technology developed by the Institute National d'Optique from Canada, (INO). Two tri-linear arrays of 512 x 3 each, one for MIR and the other for TIR, will measure brightness temperature with uncooled bolometric sensors. The swath is of 182 km with an accessible swath of +/- 532 km.

**High Sensitivity Camera (HSC)**

The HSC panchromatic camera, developed by CONAE, will be used for studying lightning, auroras, urban light intensities, fire detection and snow coverage. Its swath is of 700 km and the ground projected IFOV is 200-300 meters. Its sensitivity is such that a 2 kW ground source will produce a signal of 10 % of saturation value. The camera is based in TDI CCD technology. A similar camera is already on board of SAC-C satellite, obtaining images since its launch in November 2000.

**System Data Collection System (DCS)**

The Argentine manufactured Environmental Data Receiving and Transmitting system is designed to receive meteorological and environmental data generated by ground based measurement systems for later retransmission to the Cordoba Ground Station and to users via the Internet. The ground platforms, at least 200, will have sensors of meteorological and environmental parameters. Similar equipment is in orbit on SAC-C launched in November 2000.

**Technological Demonstration Package (TDP)**

The technology demonstration package, the TDP, is composed by two units: The Inertial Reference Unit (IRU), which provides spacecraft triaxial inertial angular velocity; and the GPS Receiver (GPSR) which provides spacecraft position, linear velocity, time and pulse per second (PPS). These units are developed in Argentina by CONAE and will be the baseline sensors for future CONAE missions.

**Radio Occultation Sounder for Atmosphere (ROSA)**

Contributed by Agenzia Spaziale Italiana (ASI), the ROSA instrument will measure the atmospheric (troposphere and stratosphere) temperature and humidity profiles using GPS Radio Occultation measurement technique. ASI's top priority is in Earth Observation (E-O). ASI will contribute to the understanding of the Global Climate Change using this GPS Radio Occultation Experiment. A very large number of global occultation observations are needed to successfully perform this experiment. This requires many ROSA like instruments on several earth observing missions. ASI is considering embarking ROSA on several E-O Missions and is in touch with space agencies from the following Agencies (CONAE-Argentina; FSA-Russia; CSA-Canada; ESA-EU; JAXA-Japan and ISRO-India)

The receiver in the ROSA instrument will measure the bending angle between the direction of the undisturbed radio signal and the apparent incoming direction of the signal which is related to the refractive index of the atmosphere, which depends of the temperature and humidity of the atmosphere. The relative motion between the GPS and the Low Earth Orbit (LEO) satellite will provide the vertical sounding of the atmosphere. This technique is self-calibrating and provides temperature profiles with a vertical resolution of less than 1 km and accuracy less than 1 km. The measurements will be applied to develop models of Meteorology/Climatology, to study Space Weather and Solid Earth Physics.

**CARMEN-1 (ICARE-NG / SODAD)**

The CARMEN-1 instrument is comprised of 2 instruments, ICARE-NG (Influence of Space Radiation on Advanced Components – New Generation) and SODAD (Système orbital pour la détection active des débris). ICARE-NG is designed to measure the effect of high energy radiation environment on electronic components. It will measure electrons, protons and heavy ions fluxes in the energy ranges responsible for component effects and is a radiation monitoring instrument (in situ measurements of electron, proton and ion fluxes) while SODAD is an orbital debris/micrometeorite detector. ICARE was first flown on the CONAE SAC-C mission of CONAE, launched Nov. 21, 2000. These instruments will be provided by Centre National d'Etudes Spatiales (CNES), France.

Since ICARE has been successfully operated on board SAC-C, a large amount of environment and component effects data has been gathered and processed in detail. Work is still in progress to correlate the proton flux increases, for different energy ranges, with the Single Events Upsets (SEU) rate variations.

SODAD is designed to study μ-particles and debris (monitoring in time and in space events). The objectives are to perform "clouds" analysis; compare results with laboratory tests and numerical simulations; understand kinetics of space damage and to evaluate orbit population and its evolution.

# 5. PROJECT IMPLEMENTATION

**Project Structure and Organization**

To handle this challenging and complex Mission, the two Projects, Aquarius and SAC-D, have agreed together to work under a mutually agreeable agreement (an agency-to-agency NASA-CONAE Memorandum Of Understanding (MOU)) and establish, for the entire life-cycle of the Mission, a joint set of requirements, policies and documents that define the basis of formulation, implementation and operation – The Aquarius/SAC-D Project Implementation Plan (PIP). This document is jointly written as required in the NASA-CONAE MOU, signed 2 March 2004. Similar Letter of Agreements (LOAs) and MOU's have been established by CONAE with ASI, CNES, AEB and CSA. The organization of the two Project Offices is shown in Figure 3.

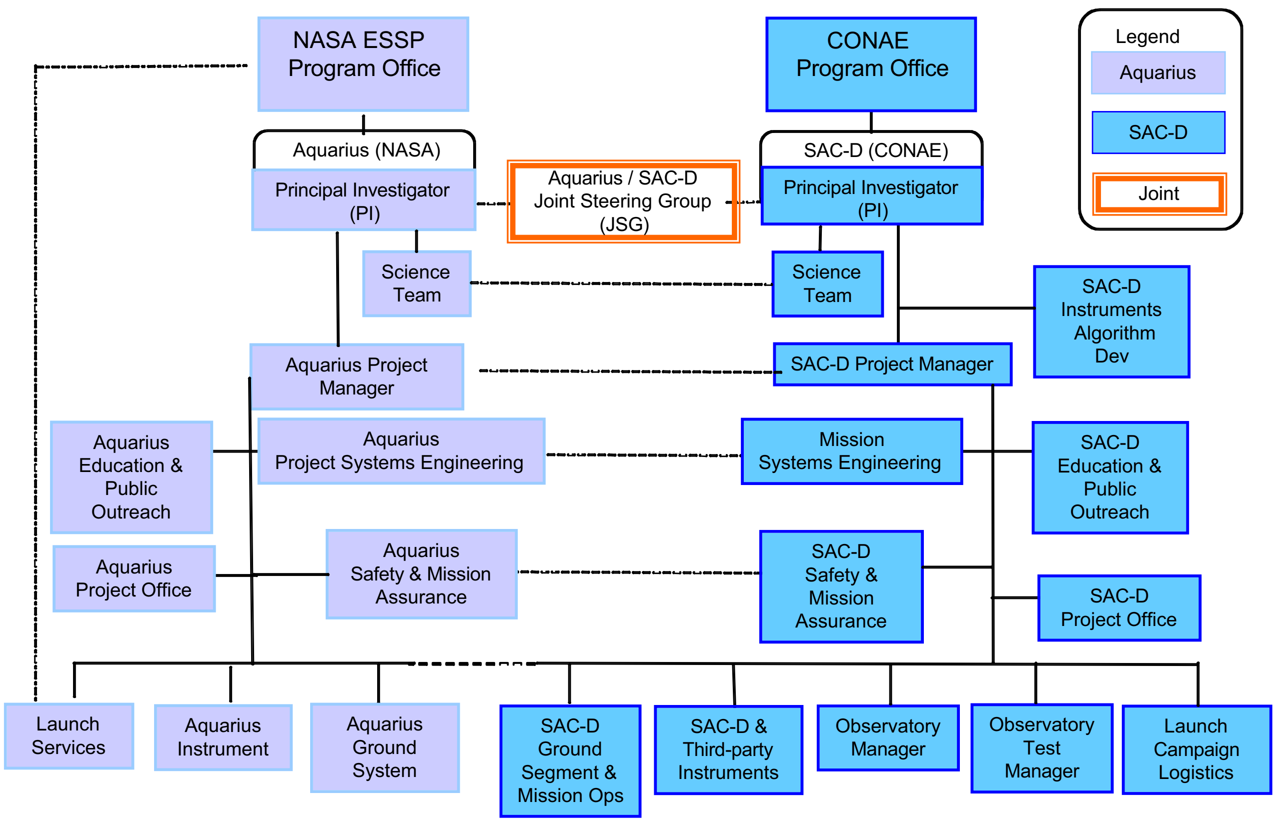


Fig. 3. The Aquarius/SAC-D Project Organization

The Science Investigators or Principal Investigators (PIs) lead the science investigations from their own respective agencies and report to their respective Program Offices. Each PI is responsible for the scientific integrity of the mission and achieving mission success. The PIs delegate day-to-day project implementation authority to the Project Managers (PMs). Figure 4 shows the key implementation centers of the Aquarius and SAC-D Projects.

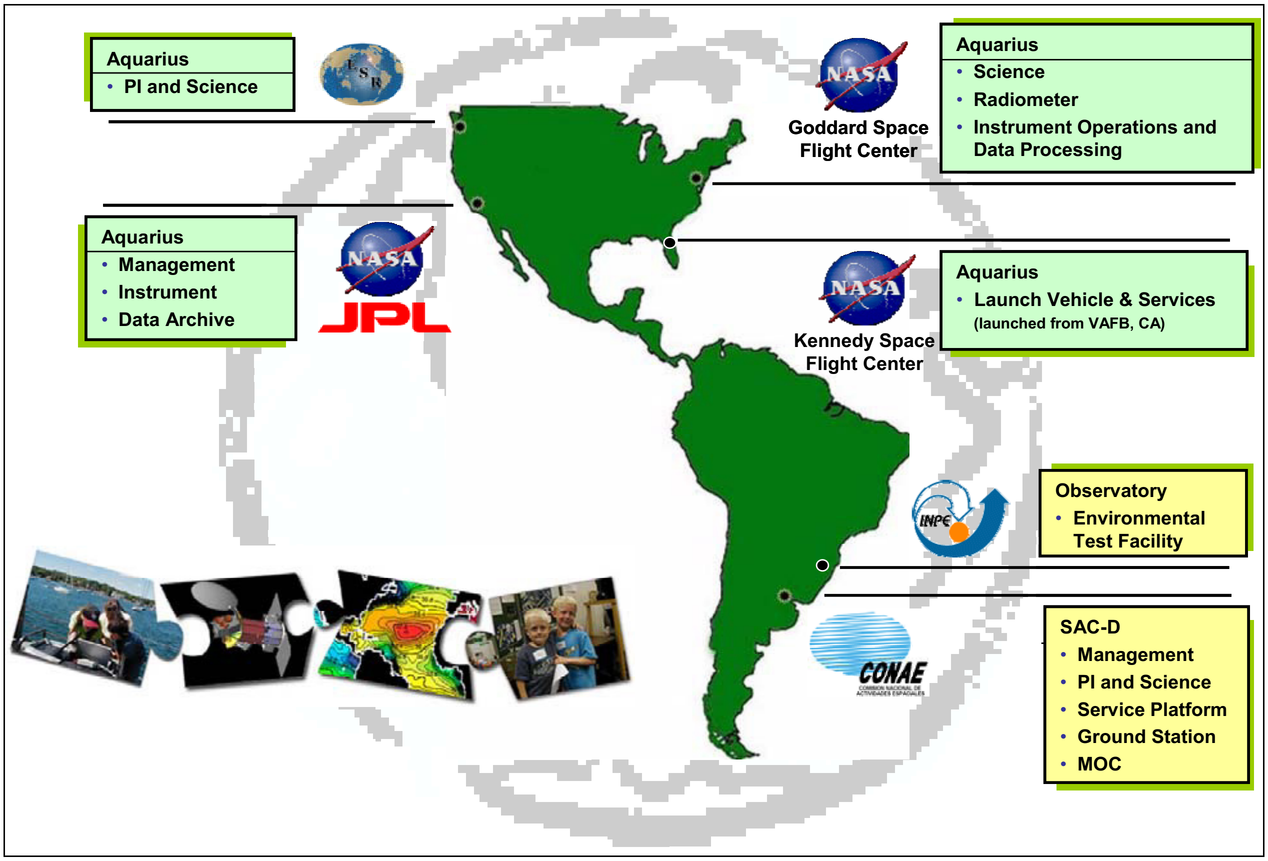


Fig. 4. Key Centers for Implementation

The PMs oversee and have authority over the day-to-day management of the projects, including Project Systems Engineering, Safety and Mission Assurance (SMA), and Instrument, Service Platform and Ground System development. The PMs represent the PI in all implementation aspects of the mission. The PM maintains oversight of project activities, ensures timely detection and correction of problems and risks, and analyzes and assesses cost and work progress against plans and schedule. The established NASA & CONAE partner roles and responsibilities are shown in Table 2.

A NASA/CONAE Joint Steering Group (JSG) has been established that governs the U.S. and Argentine contributions to the Aquarius/SAC-D Mission (as defined in the NASA-CONAE MOU). The JSG provides overall guidance to the Project and decides any matters that affect the mission launch schedule, Level 1 Mission Requirements, or other implementation issues not resolved by the respective PM.

| Aquarius Project | SAC-D Project |
|---|---|
| NASA (JPL, GSFC & KSC) | CONAE |
| • Radiometer & Scatterometer<br>• Aquarius Instrument & Instrument I&T<br>• Ground Support Equipment (GSE)<br>• Aquarius Instrument Shipment to Argentina<br>• Observatory Insight & Interface Assessment<br>• Launch Vehicle (LV) and Services (via KSC-NASA)<br>• Aquarius Mission Science & Algorithms<br>• Aquarius Ground System and Science Data Processing<br>• Aquarius Data Archive<br>• NASA Ground Stations for launch, maneuvers and anomaly support<br>• Reviews & Documents | • Service Platform<br>• Science Instruments & Management of 3rd Party Instruments<br>• Observatory<br>• Observatory I&T including Environment Testing in Brazil & shipment to US LV facility<br>• Ground Support Equipment (GSE)<br>• Observatory to LV Interface<br>• Mission Operations Control Center (MOCC)<br>• SAC-D Science Data Processing<br>• Data Acquisition Services (CRFS)<br>• SAC-D Data Archiving and Distribution Service (CDADS)<br>• Reviews & Documents |

Table 2. Partnership roles and responsibilities

**Development, I&T and Launch**

Currently the two Projects are in Implementation Phase. NASA (JPL, GSFC & KSC), CONAE, and Investigaciones Aplicadas (INVAP), the prime contractor for CONAE, are establishing the detail designs, planning for fabrication, and assembly and testing of their respective elements based on their responsible deliverables. Once the Aquarius Instrument is completed in mid 2008, the Aquarius Project will ship the flight-qualified instrument and its associated Ground Support Equipment (GSE) to CONAE in Argentina for integration. The Aquarius, CONAE and the 3rd party instruments will be integrated on the SAC-D S/P at the INVAP facility in Bariloche, Argentina. Upon completion of Observatory integration, the Aquarius/SAC-D Observatory will then be transported to the INPE/LIT (Instituto Nacional de Pesquisas Espaciais / Laboratório de Integração e Testes) facility in Sao Jose dos Campos, Brazil for Observatory level environmental testing. Upon completion of the environmental campaign, the Observatory will be shipped by air-transport to Vandenberg Air Force Base (VAFB) for integration to the launch vehicle and finally launch in July 2009. After launch, the Observatory will perform a 45 day In-Orbit Checkout (IOC). Completing the IOC phase will start routine science operations for 5 years.

## 6. SUMMARY

CONAE and NASA have conceived the Aquarius/ SAC-D Mission consistently with the objectives of CONAE´s National Space Program and NASA´s Earth Science Enterprise Strategic Plan.

Starting in 2009, Aquarius/ SAC-D will provide monthly maps of global SSS over a period of at least three years allowing the study of the global sea surface salinity field and its influence on ocean circulation, climate change and the global water cycle. Additionally, data provided by the Aquarius/ SAC-D mission will potentially provide information about the precipitation, evaporation, soil moisture, atmospheric water vapor, sea surface wind velocity, sea ice extend and other important geophysical parameters.