# Special Issue on Applied Earth Observation and Remote Sensing in Latin America

THIS Special Issue focused on recent research led by South American researchers and teams. It is a long overdue possibility offered to researchers in this geographical area to share their excellent work with the international community. Accordingly, the response to the call for papers was overwhelming, with more than 60 papers submitted from eight countries.

Eventually, 23 articles were accepted, among which 11 are authored from Brazil, while Argentina and Mexico contribute each with five papers, and Colombia and Ecuador have one article accepted each. Testifying the international breadth of these researches, seven of these contributions have coauthors from outside Latin America: two from Italy, and one from France, Canada, Finland, USA, and Germany.

Before describing the contributions that have been selected for this issue, it is worth recalling briefly the history and current situation of remote sensing activities in the three major countries in the area, which, as mentioned, contribute to the large majority of the works published in the following pages.

## I. Remote Sensing Research in Mexico

The United Mexican States, commonly referred to as Mexico, is a country of about 2 million square meters of area with a population close to 120 million, the sixteenth largest nation in the world. Mexico is crossed by four mountain ranges, two north to south—the extension of the Rocky Mountains—a volcanic belt from east to west, and finally a fourth mountain range in the south west. This is why the majority of Mexican central and northern territories are located at high altitudes. Moreover, the Tropic of Cancer effectively divides the country into temperate and tropical zones. Lands located in the north experience cooler temperatures during winter months, while at the south of the twenty-fourth parallel the temperatures are fairly constant through the year, and vary solely as a function of the elevation. This provides the country with one of the world's most diverse weather systems. Finally, Mexico is one of the eighteenths most diverse countries of the world in terms of biodiversity, with over 200 000 different species.

All these qualities in geography, topography, climate, biodiversity, and other physical characteristics raise a huge variety of challenges for remote sensing researchers, and make geoscience and remote sensing research a very important topic.

In accordance with the information available through the Integrated Information System about Scientific Research, Technological Development and Innovation [1], which is an online report tool developed by the National Council for Science and Technology (Consejo Nacional de Ciencia y Tecnología) [2], the scientific research within Mexico has been increasing in recent years, from the 7000 total publications in indexed journals published by Mexican scientists in 2005, up to more than 14 000 in 2014. Specific research fields considered for this analysis are astrophysics, plants and animals, ecology, agriculture, microbiology, physics, geosciences, mathematics, engineering, pharmacology, immunology, biology, materials, chemistry, molecular biology, neurosciences, computational sciences, social sciences, economy, psychology, medicine, and multidisciplinary areas as a group. As for geosciences, there has been an increment in the publication number from 261 in 2005 to 375 in 2012, a net increase of 44%. Still, absolute and relative numbers quantities are low compared with the other research fields, such as engineering, whose publications increased from 562 in 2005 to 836 in 2012.

The topics in geoscience and remote sensing are a small fraction of total number of publications in indexed journals. During the period 2010–2014, they accounted for less than 1.8% of the total. Instead, their average impact factor (IF) was 5.01, well above the mean of IF for all the topics.

Although Mexico is listed as the 22nd member country in the Organization for Economic Cooperation and Development [3] as for scientific production, with a participation of 0.57% for the period of 2010–2014, the Mexican share of the global scientific production in the field of geoscience and remote sensing in the same period is only 0.85%, while for astrophysics accounted to nearly 2%. Accordingly, it is clear that there is a gap to be filled to increase the scientific production in the former area. The reason for this gap is the lack of Universities and Research Centers in Mexico willing to develop and participate in projects in these topics.

Considering the existing gap, and willing to foster the research in geoscience and remote sensing, the Mexican members of the IEEE Geoscience and Remote Sensing Society (GRSS) worked to be authorized and create a chapter of GRSS [4], an event that took place on October 4th, 2012. The vision of this chapter is to offer the opportunity to foster collaborations among industry, universities, and research centers within the country on topics related to geosciences and remote sensing, under the leadership of a growing group of professionals in both the academic and industrial fields. So far, the membership of this Mexican chapter has been growing, and the chapter counts nowadays 65 members, from different locations and sectors throughout the country. The chapter has already organized several activities. Specifically, the two national conferences organized in 2014 and 2016, were the most successful opportunity to build links with governmental agencies and research groups not related to IEEE but focused on the same topics. The main objective has been the collaboration work between members, the creation of research networks, able to share project proposal and results, and the promotion of the values in which the IEEE is grounded.

By means of a search in the IEEEXplore database [5] with keywords such as “remote,” “sensing,” and “Mexico,” and refining the results to find only publications in journals for the last five years, the results show only 56 papers. However, it was mentioned before that the number of scientific publications for this topic has been increasing every year; hence, this is an important opportunity area that should be addressed.

The collaboration between Mexican academic and public researchers working in the topics of geosciences and remote sensing, and those working in industry, universities and research centers, has been a complicated process due to the physical extension of the country, the lack of communication, and the scarce diffusion of the different performed projects nationwide. However, the creation of groups similar to the Mexican chapter of the GRSS is allowing to improve the entailment through the participation in national and international conferences, joint publication in indexed journals, the creation of research networks throughout the country, and the collaboration in the framework of projects funded by the government by means of federal resources.

## II. Remote Sensing Research in Argentina

Space activity in Argentina has its roots in the “Dirección de Aerotécnica del servicio de estudios y ensayos,” created in 1929, which became Instituto de Investigación Aeronáutica y Espacial. As an evolution, in 1960, the Comisión Nacional de Investigaciones Espaciales (CNIE) was created, within the Argentine Air Forces, with the objective of planning and execution of aerospace research programs in Argentina. Its first secretary was ing. Teófilo Tabanera, a leading figure in the spatial development of this country. CNIE policy aimed at promoting the peaceful use of aerospace, scientific research, technological developments, and their practical applications. Projects were designed for rocket and satellite developments, remote sensing and climate change monitoring, unconventional energy exploration, in addition to those aimed at training human resources through courses, scholarships, and agreements with other international agencies.

Among these themes, CNIE [6] decided to develop a program of evaluation of natural resources covering the reception, processing, and analysis of satellite data for all the country. The large size of Argentina (more than 4 000 000 square km, including Antarctica) and the diversity of geographical and ecological zones make it necessary to have an automatic, fast, and effective means to obtain an inventory of its natural resources, to update its maps, and to foster more and better use of the renewable and nonrenewable available resources. In this framework, in 1976, the central government declared the development of remote sensing as national interest too for natural resource monitoring, and entrusted to the CNIE the implementation of the required actions. This decision led to the creation of the Remote Sensing Center, distributed in three distinct locations to fulfill its mission: a Satellite Reception Ground Station, an Image Processing Station (in the Federal Capital), and a Department of Analysis and Applications (in Vicente Lopez). The principal areas for RS use were agriculture, geology, cartography, and hydrology.

On April 16, 1980, the first receiving satellite (ERS) station was inaugurated, being at that time the second one installed in Latin America after Brazil (1973) [7]. Reception activities were carried out until 1990, when the change in the transmission band caused its end. By 1982, the Meteorological Service started operating a receiving station for NOAA GOESS missions in its facilities in Villa Ortuzar. On January 31, 1985, the SAC (Satellite Scientific) program was declared as one of the priorities by the Ministries of Education, and Defense in a joint resolution.

In 1991, the Argentinian Government decreed the creation of the “Comisión Nacional de Actividades Espaciales” (CONAE), the National Space Agency, as a civil entity reporting directly to the President. Since 1996, CONAE has been governed by the Ministry of Foreign Affairs, and actually by the Ministry of Science. Its activities are developed following the National Space Program. This program stems from the concept that Argentine by its extension, population distribution, natural threats (floods, fires, etc.), economic activities (agriculture, mining, etc.), is a “Space Country,” meaning that Argentine needs space-borne sensors to help planning its socioeconomic development. The key objective of this plan is to build the complete space information cycles in order to optimize the socio-economic development of areas in need throughout the country. The cycles included in the 2004–2015 version of this plan [11] were

1) agricultural, fishing, and forestry production;
2) weather, hydrology, and oceanography;
3) natural as well as human-induced disasters, such fires, floods, volcanic eruptions and earthquakes, tornados, cyclones and hurricanes, landslides, and hydrocarbon leakage;
4) environment and natural resources monitoring;
5) cartography, geology, mining production (including oil and gas prospecting), and territorial planning;
6) health applications related to landscape epidemiology, i.e., to the use of remotely sensed information together with field data in order to set up human disease hazard predictable patterns.

Due to the socio-economic development, two new areas were included in the last years: security and energy. These cycles are driven by the National Space Agency but developed by all the scientific system and exploited by the governmental agencies.

From 1998, four space missions were designed by and within Argentine. The first was the SAC-B (a scientific satellite in 1996. In 1998, a small technological demonstration satellite followed up, operating for almost one year. Then, in 2000, the polar multispectral satellite SAC-C was launched [8], and operated successfully for more than 10 years, taking images of the whole country and the surrounding geographical region for multiple applications. The satellite was designed and built in the country, and mounted instruments developed by CONAE. Finally, CONAE and NASA’s Goddard Space Flight Center and Jet Propulsion Laboratory jointly developed the SAC-D/Aquarius mission [9]. The objective was to realize an Earth observation mission able to obtain new information on climate by measuring sea surface salinity, and a better understanding of ocean circulation and the physical processes of link the water cycle. SAC-D/Aquarius was launched on June 10, 2011, and concluded its operative service on June 8, 2015.

For the near future, Argentina is working in the SAOCOM and SABIA-Mar missions. The main instrument of SAOCOM is a fully polarimetric synthetic aperture radar, operating in L-band. Agency will collaborate in this mission with the SAOCOM-CS system, making possible the first bistatic L-band SAR mission in the space. The principal objective is generating soil moisture maps, useful to agriculture, hydrology, and health applications. The SABIA-Mar mission was instead conceived to provide information and studies of the ocean ecosystem, carbon cycling, marine habitats mapping, coasts and coastal hazards, inland waters, and contribute to fishery activities.

Regarding human resources, it is necessary to mention the role of the SELPER ("Specialists Latin American Society of Remote Sensing and Spatial Information Systems") association. SELPER, since its creation in 1980, has had an important role to promote and support activities related to remote sensing and spatial information systems in Latin America. In particular, the Argentinian chapter of SELPER was started by a pioneering team in Lujan University, and has organized several international and national events related to RS during the last 20 years.

Finally, Infraestructura de Datos Espaciales de la República Argentina (IDERA) an intergovernmental organization aiming at contributing to the generation of the national spatial data infrastructure in the public sector was started in 2007 [10].

Historically, in Argentina the use of remote sensing is centered on natural resource mapping, environmental monitoring, and agriculture applications. Less advanced research has been developed in areas related to new algorithm and software design and machine learning. In this point, it is important to remark the pioneer role of Argentine with respect to the use of RS data in disaster management, in particular, in the International Charter. The International Charter "Space and Major Disasters" is a worldwide collaboration among space agencies, through which satellite-derived information and products are made available to support disaster response. It has been operational since November 2000 and Argentinean professionals have had the responsibility of supporting the generation of remote sensing products in several south-American disaster activation.

With a current remote-sensed-related community involving about 500 professionals, Argentina has profited from the change occurred in the last 10 years, when in several universities appeared postgraduate programs on RS and students started working and producing scientific knowledge in this area. To this aim, it is important to remark the Master program at the national level created by means of an agreement between CONAE and the Cordoba University. Since 2009, it has formed more than 80 new professionals in this area, including nationals from Chile, Paraguay, Peru, Ecuador, Colombia, and Venezuela.

So far, in Argentina, a growing number of professionals in governmental entities use operatively geo-technologies in their daily work (emergencies, agriculture, health, energy, taxes, etc.). This produces an increase on the demand of trained human resources, and in geo-products to be generated. Additionally, the last years show the first appearance of private initiatives related to remote sensing applications in the agriculture area, software development (for educational purposes), as well as the design and operation of small Earth observation satellites.

In this framework, the Argentinean chapter of IEEE Geoscience and Remote Sensing Society was formed in 2015 as a new way to improve collaboration at the national and international level. The chapter has now about 30 members and has already organized events (workshops and schools) in 2015 and 2016, each one attracting more than 100 participants.

## III. Remote Sensing Research in Brazil

Brazilian territory comprises over 14 million square km. Just behind China and Russia, Brazil has the longest border, about 17 000 km shared with all South American countries, with the exceptions of Ecuador and Chile. The country contains rich natural resources of all sorts, including about 30% of the rainforest on Earth, whose preservation matters the entire word. In addition, Brazil is a leading food producer. Such resources need to be studied, monitored, managed, explored, and protected in the best possible way. In order to accomplish these goals, many different techniques in the geosciences and remote sensing area have been exploited.

Imaging technologies of Earth surface were started being used in Brazil by 1893, four years after the end of the Brazilian monarchy. In this year, the first cartographic map of Rio de Janeiro, then Brazil's capital city, was produced using photogrammetric methods [18], [19], [21].

In 1910, Brazil had a diplomatic issue with Argentina regarding the common border. The existing cartographic methods did not provide the required accuracy and the Brazilian government contacted the Austrian Imperial Cartographic Academy for technical assistance to solve the dispute. After some delay caused by the WWI, a mission of the Austrian Academy arrived in 1920 in Rio de Janeiro, and one year later, the first aerial survey was carried out in the Rio de Janeiro [20].

Later on, between 1943 and 1945, flights covering more than half of Brazilian territory were carried out by the US Air Force, yet operating at a coarse scale (1/1 000 000). In the 60s, surveys at finer scales covering most parts of the national territory were executed, again in cooperation with US Air Force.

A further important landmark of remote sensing history in Brazil is the Radam project, whose mission was to cover large areas, mostly in Amazon region, for geology, geomorphology, soil, and vegetation. From 1970 to 1985, about 1.5 million square km were imaged using the most advanced technology available at that time: side looking airborne X-band SAR, with 20 m resolution along with optical sensors. Another project started in 2008, called Amazon Radiography [9] led by Brazilian government in partnership with private companies aimed at the topographic mapping of the Amazon region at 1/100 000 and 1/50 000 scales until 2018 using airborne P-band SAR, able to penetrate the dense vegetation layer that covers most part of the Amazon region.

As for space research, Brazil engaged in this area about three months after Yuri Gagarin became the first human being in orbit. The space race between US and Soviet Union motivated the Brazilian government to create in 1961 a special commission

(COGNAE) whose main mission was to elaborate the so-called Brazilian Space Program. At first, training human resources and developing applications of the space technology took priority over building and launching satellites [8].

The year 1971 witnessed important changes: a Brazilian Commission for Space Activities was created with the mission to reformulate the national space policy, which in turn should be executed by the National Institute of Space Research (INPE). Created in the same year [13], INPE eventually turned out to be a leading institution on space research in Latin America. Two years later Brazil became the third country in the world to receive LANDSAT images through an antenna installed by INPE in the city of Cuiabá.

As the time went on, the Brazilian space program became more ambitious. In 1980, the central government approved the so-called Brazilian Complete Space Program. It involved the construction of a launch complex, the development of satellite launch vehicles and two satellite families (SCD and SSR) entirely designed and built in Brazil.

In 1988, the China–Brazil Earth Resources Satellites (CBERS) cooperation agreement was signed to develop and place two remote sensing satellites in orbit, CBERS-1 and CBERS-2, which were launched in 1999 and 2003, respectively. The success of this initiative motivated the extension of the agreement in 2002 to develop two new satellites, CBERS-3 and CBERS-4, which were launched in 2013 and 2014, respectively. An additional agreement taken in 2004 allowed for the construction of a third satellite, the CBERS-2B (similar to CBERS-2) that was successfully put in orbit in 2007.

Beyond the CBERS family, a number of space missions are scheduled for next four years in the so-called National Program of Space Activities (PNAE) of the Brazilian Space Agency, as illustrated in Figure X. For further details of each satellite of PNAE, we refer the reader to [6].

Data acquired by air-borne and space-borne sensors have been increasingly used in Brazil along those years for many applications, including environmental resources monitoring, agribusiness, disaster management, and defense, etc.

Two application fields deserve special mention. The first one relates to the preservation of the Amazon forest. INPE has been conducting a monitoring program for more than 26 years that comprises two main systems. The first one is PRODES [11], which became operational in 1988. The PRODES methodology relies predominantly on LANDSAT imagery, although, CBERS images and images provided by other satellites have occasionally been used. Since 2003, the deforestation maps provided by PRODES are freely accessible in the internet [14]. The system is able to detect deforestation spots larger than 6.25 ha, but depends on proper climatic conditions during the dry season. In consequence, PRODES delivers a deforestation report just once a year.

To partially overcome this limitation, the second system called (near) real-time deforestation detection (DETER) was started in 1998. Employing MODIS imagery and almost daily revisit, DETER enables an early deforestation warning [12], however, only in areas between 25 and 100 ha. An extension of DETER, called DETER-B, is currently being developed. It aims at detecting deforestation in the early stages of the degradation process in areas smaller than 25 ha. It employs the advanced wide field sensor of Resourcesat-2 satellite and the wide field imager (WFI) of CBERS 4. The new system allows for up to 56 m spatial resolution and 5 days revisit time [10]. The program also includes the QUEIMADAS system to detect burnt scars using low-resolution imagery. The fourth system is DEGRAD, whose goal is to detect moderate degradation relying also on LADSAT and CBERS data.

Another important remote sensing application's field in Brazil is agriculture. The agribusiness is regarded as the most important sector of Brazil's economy. It accounts for 23% of the GDP, 46% of total exports and employs about 37% of country's labor force [15]. From 1995 to 2014, the area devoted to the agribusiness in Brazil increased 37%, whereas the production more than 170%. This remarkable increase in agricultural and livestock productivity must be mostly credited to the work of the Brazilian Agricultural Research Corporation (EMBRAPA), a public enterprise under the aegis of the Brazilian Ministry of Agriculture "focused on generating knowledge and technology for Brazilian agriculture" [17]. Founded in 1973, EMBRAPA became the largest agricultural R&D agency in Latin America in terms of staff number and expenditures. In the main ongoing EBRAPA projects on climate change and precision agriculture, remote sensing has become a key technological tool to obtaining, processing, and analyzing field data. In the recent years, EMBRAPA has strongly invested in the UAV technology for quick and cost-effective diagnostics as yield estimate, nutritional assessment, detection of pests and diseases, weather forecast, and assessment of plants water requirement in site-specific.

Although the government policies underwent changes over the years, one priority remained nearly constant: training human resources to drive innovation and entrepreneurship. Initially, the education in geosciences was mostly restricted to military academies. In 1969, a graduate course on remote sensing in INPE and two years later a course on geodetic sciences in the Federal University of Paraná were created, which provided human resources for a number of emerging private companies. Today, in Brazil, there are 55 graduate courses on geosciences spread over the country. Brazil's participation in the international scientific production in terms of papers published in indexed journals rose from 1% in 1990 to 2.5% in 2013 and keeps on growing at a rate above the world average [7]. In the last three years, the geoscience Brazilian community published in average 2000 papers per year in international and in local scientific journals. About 10% of them come from the area that comprises remote sensing, geodetic science, and cartography.

The strength of Brazilian geosciences community can also be observed in many regular national scientific meetings. Particularly impressive is the Brazilian Symposium of Remote Sensing held since 1978, congregating typically more than 1000 attendees every second year. Driven by the big government projects, the market grew remarkably in the 70s and 80s. After a period of retraction in 90s, it blossomed again in the 2000s. In 2008, the geoscience market in Brazil grew by about 20% in relation to the previous year reaching a turnover of approximately 200 million US dollar [16]. However, in consequence of the 2008–2009 global financial crises and due to disastrous policies to face it, the country economy shrunk between 2014 and 2016 more than 7%, affecting the local industry as well as investments in education, research, and technology. Notwithstanding the current difficulties, Brazil keeps on being an immense field of challenges and opportunities for geoscience and remote sensing.

Within this framework, the Brazil GRR chapter was established in April 2015. Having about 30 members, it is probably the largest GRSS chapter in terms of geographic area, from South to North about 3800 km. It has organized meetings for young professionals, workshops and, in partnership with ISPRS, summer schools.

## IV. Papers in This Issue

Testifying the large variety of the interests and developments of the remote sensing community in Latin America, widely described in the previous pages, but also the vast number of different ecosystems that shape the continent, the topics of the 23 papers published in this special issue range from innovative computational infrastructures for segmentation algorithms, applications to atmosphere and air quality, phytoplankton blooms, plant species identification, analysis of live fuel moisture content, effects of moisture and geometry on the return of L-band SAR data, forest monitoring, time series analysis for deforestation assessment, cover changes, and long-term variability of reservoirs characteristics.

It is very well known that microwaves are well suited for cloud-covered regions, as the topical areas. The importance of this technology is also clearly reflected in the number of contributions based on the use of SAR data. Seven manuscripts deal with different aspects of this technology, ranging from technical works focused on speckle noise filtering of SAR and Polarimetric SAR data to more applicative contributions based on land cover classification. In the latter case, all the contributions are clearly related to forest monitoring, and particularly, to the monitoring of the Amazonian forest. Also, one of these contributions is focused on the fusion of SAR data together with passive microwave radar for soil moisture estimation, in line with the Argentinian SAOCOM mission.

Forest monitoring or soil moisture estimation is not restricted to the use of SAR data. Other contributions consider these applications from the perspective of optical data, and for instance they address moisture estimation for fire prediction on forests or they use multitemporal data for the analysis of different ecosystems.

As it happens all around the world, the Latin American continent is affected by somehow specific problems. For this reason, it is worth to mention that one of the contributions is particularly focused on the analysis of seismic events and another one considers the application of remote sensing data to the assessment of Chikungunya, Dengue, and Zika diseases. Additionally, one of the contributions considers the analysis of the air, results of which could be also of interest in other parts of the World.

The Latin American continent is surrounded by oceans and seas, and this is also reflected in the contributions submitted to this special issue as two of them are focused on the use of MODIS data for chlorophyll monitoring.

The competences of the Latin American scientists are not restricted to applications as it comes out from the submitted works. On the more technical side, some of the contributions are focused on specific aspects of the systems, as for instance, calibration, and others tackle with the problem of data modeling and characterization or deal with noise filtering to improve data quality.

The richness and depth of these contributions compose a panorama of the quality and broadness of the research and practice of remote sensing in Latin America, and as it can be observed, it is in line with the contributions of scientist of other parts of the world.

We expect to continue seeing more contributions from these countries, but also from the rest of Latin American countries, and especially more collaborative initiatives among all of them. In this direction, a perfect vehicle to support all these activities is the GRSS chapters. As detailed before in this text, Mexico, Argentina, and Brazil have created already these chapters. In addition, this year, the Chilean chapter has also seen the light, led by Dr. Carlos Cárdenas, from the Universidad de Magallanes in Chile.

Therefore, we would like to close this introduction by encouraging all the Latin American researchers and scientist who are interested to work together and promote communities in the remote sensing area to start thinking about organizing a GRSS chapter in their countries.

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