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NANOSATC-BR CUBESAT DEVELOPMENT & CAPACITY BUILDING PROGRAMS: NANOSATC-BR1 & NANOSATC-BR2

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The Brazilian INPE-UFSM NANOSATC-BR Cubesat Development & Capacity Building Programs: NANOSATC-BR1& NANOSATC-BR2, recent progress is presented. This paper is a follow up paper from previous ones that have already been presented at IAA workshops. The 1U CubeSat – NANOSATC-BR1, was launched into a LEO orbit from the Russian Yasny Launch Base by a DNEPR launch vehicle on June 19th, 2014, as the first Brazilian scientific university CubeSat. The NANOSATC-BR2, a 2U CubeSat – is been finalized and its launching is expected for 2015's second semester. These two events marked the beginning of, what we can call now, a Brazilian NANOSATC-BR Program. The NANOSATC-BR 1 & 2 cubesats were planned to operate in space for at least 12 months each. The NANOSATC-BR1 & 2 Ground Stations (GS(INPE-CRS) & GS(INPE-ITA)) with the VHF/UHF band and S-band antennas, are described in specific papers at this IAA-2014. These CubeSats Development & Capacity Building Integrated Programs (CBP) are for space science, engineering and computer sciences and for the development of space technologies using CubeSat satellites. They started with the launching of the first Brazilian Scientific Nanosatellite, the NANOSATC-BR1. The INPE-UFSM's CBP has the involvement of UFSM' undergraduate students and graduate students from: INPE/MCTI, MG/II/UFRGS and ITA/DCTA/CA-MD. These Program and Projects have support from the Brazilian Space Agency (AEB) and CITAR-FINEP Project.

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II. Introduction

The Brazilian INPE-UFSM NANOSATC-BR CubeSat Program consists of a Capacity Building Integrated Program on space science, engineering and computer sciences for the development of space technologies using CubeSat satellites, starting with a first Brazilian Scientific Nanosatellite, the NANOSATC-BR1. The INPE-UFSM's cooperation is basically between the Southern Regional Space Research Center (CRS), from the Brazilian INPE/MCTI, with the Santa Maria Space Science Laboratory - LACESM/CT-UFSM; the Santa Maria Design House (SMDH); and the Graduate Program in Microelectronics from the Federal University of Rio Grande do Sul - UFRGS. The Capacity Building Program was conceived at the CRS, where acts the Program's General Coordinator and Manager, having technical collaboration and management of the Mission's General Coordinator for Engineering and Space Technology at INPE's Headquarter (HQ), in São José dos Campos, São Paulo, with the involvement of undergraduate students from the Federal University of Santa Maria – UFSM and graduate students from INPE/MCTI, ITA/DCTA/CA-MD and UFRGS.

This paper is a follow up paper from previous ones that have already been presented at IAA's International Workshops. It explains the Program institutional arrangement and the technical characteristics of the satellites and their missions.

The INPE-UFSM NANOSATC-BR CubeSat Program and its CubeSats Projects can be synthesized with the following Background & Development Strategy:

The Brazilian INPE-UFSM NANOSATC-BR CubeSat Program has support from The Brazilian Space Agency (AEB).

III. NANOSATC-BR – Capacity Building

The Brazilian INPE-UFSM NANOSATC-BR Cubesat Program, consists of a National Institute for Space Research – INPE and Federal University of Santa Maria – UFSM, Capacity Building Integrated Program on space science, engineering and computing sciences for the development of space technologies through CubeSat satellites, the first Brazilian University Scientific Nanosatellite.

The Capacity Building Program was conceived at the CRS, where acts the NANOSATC-BR1's Mission General Manager and PI, having technical collaboration and management of the Mission's General Coordinator for Engineering and Space Technology at INPE's Headquarter (HQ), in São José dos Campos, São Paulo, with the involvement of High School and Undergraduate students from the Federal University of Santa Maria – UFSM, Part of the NANOSATC-BR team, mainly the students directly involved in the Program can be seeb at Figure 1.

The Capacity Building marks can be noted along the past two years, started in 2006 with just with one undergraduate student, actually, 2013/2014, the project counts on 25 students among High School, Engineering, Computer Sciences and Physics Undergraduate from UFSM.

The major objective of the INPE-UFSM's NANOSATC-BR – CubeSats Development Capacity Building Program, through the NANOSATC-BR1 & NANOSATC-BR2 CubeSats Projects, is to perform a Specialized Human Resource Capacity Building Program through the training of UFSM's undergraduate and former students in their respective areas, mainly: Engineering, Computer Sciences and Physics, through Science, Technological & Innovation Initiation at INPE/MCTI.

Students have an important weight on the Project's technical and scientific branches due their tasks providing subprojects results for each subsystem. The results are consequence of their hard work made in conjunction basically with the UFSM's and INPE's specialists: Engineers, Technologists and Researchers which are the main providers of information.

On the other hand, the Capacity Building Missions aims to Capacity a new generation of scientists, engineers and researches engineering and computing sciences through a CubeSat Program providing hands-on training.

Through the NANOSATC-BR Program it was possible to approximate the Brazilian Space Program to Universities, such as: UFSM, UFRGS, Federal University of Rio Grande do Norte - UFRGN and University of São Paulo - USP. Therefore, the Program provides hands-on training and learning with Aerospace Engineering & Technologies and Space Weather issues. This participation includes training of the students at INPE and at the Brazilian space industries as well, as at universities and space industries abroad (TU - Berlin, University of Wurzburg in Germany; Innovative Solutions In Space - ISIS - Delft in The Netherlands, see Figure 2, and after Delft at The La Sapienza – Università Degli Studi di Roma, TU-

Figure 1: The INPE-UFSM's NANOSATC-BR – CubeSats Development Capacity building. Involvement of UFSM Undergraduate and INPE's Graduate students at LIT/INPE-MCTI. NANOSATC-BR1 hands-on training at LIT/INPE-MCTI - Brazil in 2013/2014.

Roma, in Italy), with funding from the Brazilian Space Agency – AEB and from the new Brazilian Program Science without Borders – SwB.

IV. NANOSATC-BR Missions

The Program already consisting of two CubeSats, the NANOSATC-BR1 and NANOSATC-BR2 and of the possibility of launch of three other CubeSats in the next five years and operates them in space for at least 6 months each. These new missions aim to study and monitor the Geospace and Space Weather and its relationship with the solar cycle and the Earth's atmosphere. This paper main focus

is on the development, launching, mission in space operation and the first scientific results of the NANOSATC-BR1 1U CubeSat Project.

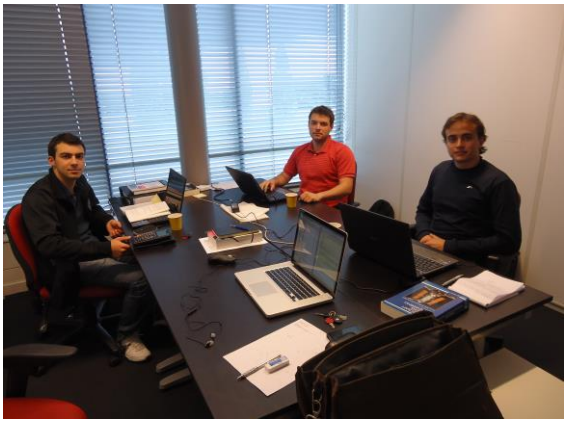

Figure 2: The INPE-UFSM's NANOSATC-BR – CubeSats Development Capacity Building Program training of undergraduate students at space industry abroad from Brazil. From left to right are: Tális Piovesan, Lucas Lourencena Caldas Franke and Fernando Landerdahl Alves in 2013 at ISIS-Delft, in The Netherlands, supported with funding from the Brazilian Program Science without Borders – SwB and from ISIS.

The NANOSATC-BR1 concept was developed to: i) monitor, in real time, the Geospace, the disturbances at the Earth's Magnetosphere over the Brazilian Territory, and ii) the determination of their effects on regions such as the SAMA and the sector of the EEJ, Figure 12 - *i)* - Ref.[4], [5], that is:

- Earth Magnetic Field intensity measurements;
- South American Magnetic Anomaly – SAMA;
- XEN-1210 is a three-axis magnetometer with a resolution of 15nT from the Dutch company XI - Xensor Integration (www.xensor.nl);
- Only one payload circuit board with scientific and technological payloads.

The NANOSATC-BR1 Technological Mission is to carry a FPGA and two integrated circuits (IC´s) designed by the Santa Maria Design House (SMDH) and the Graduate Program in Microelectronics from the Federal University of Rio Grande do Sul - UFRGS, that were developed for space use due to their radiation resistance that were using different techniques: design and fault tolerance (software). These are the first circuits designed in Brazil for space applications that are flying in a Brazilian satellite.

The NANOSATC-BR1 Technological Payloads have the flowing technical parameter:

- **The SMDH - IC - HR-DRVTestChip-I - Driver "on/off",** Figure 3**:**

- The **HR-DRVTestChip-I** turn payloads on and off as received commands from the ground.
- Demand presented by INPE Space Electronic Division.
- To be used for INPE Multimission Platform – PMM (not available at CBERS).
- Radiation hardening by design:
  - Design by Santa Maria Design House - SMDH, at UFSM
  - Use of own library
- Prototypes manufactured in Germany.
- The development of this IC - **HR-DRVTestChip-I**, was financed by **CITAR-FINEP Project,** Agreement 01.12.0224.00 between **FINEP** and **CTI-Renato Archer.**

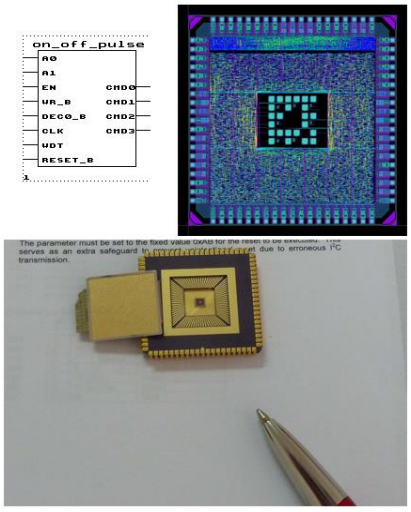

Figure 3: The SMDH - IC - HR-DRVTestChip-I - Driver "on/off", technological payload.

- **The UFRGS - FPGA - Programmed Algorithm for Fault Tolerance:**
  - Radiation resistance FPGA – industrial.
  - Field Programmable Gate Array - ProASIC3 A3PE1500-PQ208 FPGA
  - FPGA Developed by The University Federal of Rio Grande do Sul – UFRGS, in Porto Alegre, RS, Brazil; Informatics Institute - Microelectronics Group.
  - Second method for radiation hardening.
  - FPGA Tested in SJC, at IEAv/DCTA for TID with success.
  - The development of this FPGA, was financed by **CITAR-FINEP Project,** Agreement 01.12.0224.00 between **FINEP** and **CTI-Renato Archer.**

- **The NANOSATC-BR1's Engineering Model Platform (EM), the Flight Model Platform (FM) and Payload Circuit Board Manufacturing,** Figure 4**:**
  - Payload Circuit Board design and prototype was coordinated by The UFRGS.
  - Includes magnetometer, science mission PL, FPGA and driver.
  - Includes BoB – platform internal communication board.
  - Board final manufacturing by ISIS (Platform interfaces, BoB, etc.).

Figure 4: The NANOSATC-BR1's Payload Circuit Board and Engineering Model Platform (EM), the Flight Model Platform (FM).

V. NANOSATC-BR1 - Current Situation

The first Brazilian CubeSat scientific satellite, the NANOSATC-BR1, is a 10x10x11.3 cm. cube, weighing 0,965 kg. It has name and up and down frequencies link determined by The International Amateur Radio Union – IARU, in 2011.

The NANOSATC-BR1's Engineering Model Platform (EM), the Flight Model Platform (FM), the Ground Support Equipment and the Ground Station for the INPE-UFSM's NANOSATC-BR1 mission and equipment were provided, integrated and tested by ISIS from Delft, The Netherlands.

The NANOSATC-BR1 Project's Engineering Model (EM), Figure 4, and Flight Model (FM) platforms, to provide the project requirements and support the payload, were delivered by ISIS at LIT/INPE-MCTI, in São José dos Campos, SP, in 2012.

The accommodation of the payloads in the circuit board: Magnetometer, ICs and FPGA, has been solved in cooperation between INPE, ISIS, UFRGS and SMDH-UFSM, Figure 4.

The NANOSATC-BR1's Ground Station Network (GS) is already installed and in operations: GS(INPE-CRS), at CRS/INPE-MCTI, Santa Maria, RS, and GS(INPE-ITA) at ITA/DCTA-MD, in São José dos Campos, SP, in Brazil, Figure 5.

Figure 5: The NANOSATC-BR1's Ground Station Network (GS) is already installed and in operations: on left - GS(INPE-CRS) at CRS/INPE-MCTI, in Santa Maria, RS, and *on right* - GS(INPE-ITA) at ITA/DCTA-MD, in São José dos Campos, SP, in Brazil.

NANOSATC-BR Ground Stations Network: GS(INPE-CRS) & GS(INPE-ITA) has the following characteristics and parameters Tables 1 & 2:

- Purchased from ISL-ISIS in the same international bids of the platforms
  - same supplier – ISL-ISIS for the two NANOSATC-BR Program's ground stations;
  - **THE FIRST & PRINCIPAL STATION - GS(INPE-CRS)** - installed at INPE' SOUTHERN REGIONAL SPACE RESEARCH CENTER at UFSM campus, see Table 1: The GS(INPE-CRS) features;
  - **THE SECOND - GS(INPE-ITA)** arrived in december 2012 - installed at the Brazilian Air Force Institute of Technology – ITA, in São José dos Campos, SP, Brazil, see Table 2: The GS(INPE-ITA) features.

Both stations GS(INPE-CRS) & GS(INPE-ITA) are compatible with on board NANOSATC-BR1 & 2 systems and with the GENSO (GLOBAL EDUCATIONAL NETWORK FOR SATELLITE OPERATIONS) and it was based on the DELFI-C3 Project ground station.

The GS were projected to track LEO (LOW EARTH ORBIT) SATELLITES.

- Both stations were included in the Brazilian winning proposal for QB50, from: Fluminense Federal Institute – IFF, LSITEC/USP-ON/MCTI-UNB Projects.

GS (INPE-CRS) Santa Maria, RS	
PARAMETER	VALUE
Frequency range VHF	144-146MHz
Frequency range UHF	430-450MHz
Frequency range S-band (receive only)	2400-2402MHz
Modulation type	SSB (USB and LSB)
	AM
	FM
	CW
Modulation rates	1200-9600db
Demodulation data rates	1200-9600db
AC voltage	230V
AC frequency	45-65Hz
Uplink Capabilities	1200db AFSK
	9600db G3RUH FSK
Downlink Capabilities	1200db AFSK
	1200db BPSK
	9600db G3RUH FSK
VHF antenna gain	10.2dBdc LHCP / RHCP
UHF antenna gain	14.1dBdc LHCP / RHCP
S-band antenna gain	21.4dB RHCP
VHF Noise Figure	4.2dB
UHF Noise Figure	4.2dB
S-band converter Noise Figure	0.9dB typical

Table 1: The GS(INPE-CRS) features
Source: Specs – From ISIS ISIS GSkit Radio Specifications Manual

GS (INPE-ITA) São José dos Campos, SP	
PARAMETER	VALUE
Suply voltge	110 V AC (50-60Hz) 220 V AC (50-60Hz)
Suply current	Max 7.0 A (110 V) Max 3.5 A (220 V)
Temperature range	25°C
Relative humidity	0-90% Non condensing
Weight	94kg (VHF+UHF) 98kg (including S-band)
TX Frequency range	144-146MHz (VHF)
	435-438MHz (UHF)
Maximum output power	50dBm (VHF) 50dBm (UHF)
Uplink modulation	AFSK
Uplink datarate	1200 bps

Uplink protocol	AX.25
RX Frequency range	144-146MHz (VHF) 435-438MHz (UHF) 2.2-2.5GHz (S-band)
Overal Noise Figure (cable length 10m)	1.6dB(VHF) 2dB (UHF) 0.9dB (S-band)
Maximum Input Signal	-20dBm
Downlink modulation	Raised-Cosine BPSK
Downlink datarate	1.2-9.6 kbps (VHF and UHF) 14.4-115.2 kbps (S-band)
Downlink protocol	AX.25

Table 2: The GS(INPE-ITA) features
Source: Specs – From ISIS ISIS GSkit Radio Specifications Manual

The NANOSATC-BR1 GS (INPE – CRS) Tracking Telemetry is presented in Figure 6.

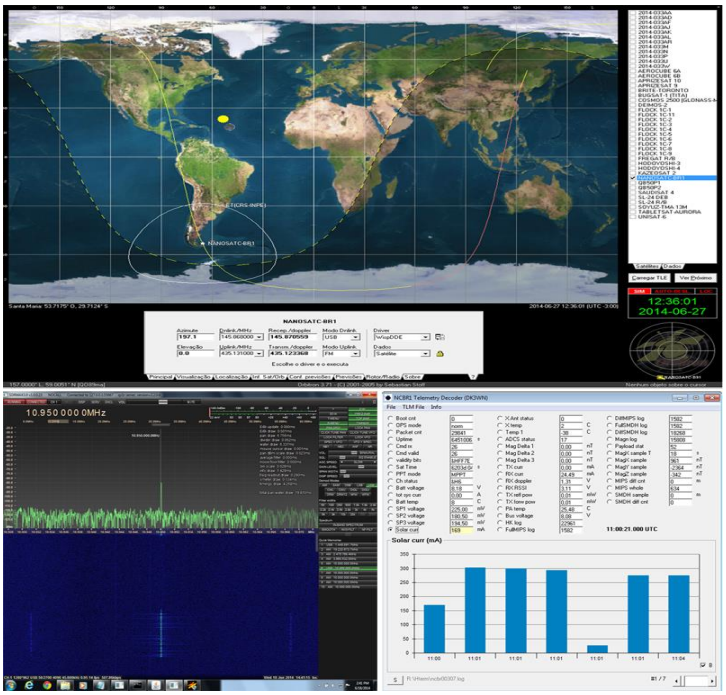

Figure 6: ORBITRON data (top Figure). Morse Code Beacon (left bottom Figure). GS (CRS/INPE) telemetry (right bottom Figure.

The NANOSATC-BR1 was planned to be launched in the first semester of 2013, probably in April, first with the Chinese Long March space vehicle. However, because of the very heavy Brazilian bureaucracy AEB could not conclude, in 2012 fiscal year, the formal budget support for the NANOSATC-BR1, through LSITEC,

for an international bid to select and contract an international Launcher Company. As consequence, all the official Brazilian AEB - LSITEC bureaucracy was done in the second semester of 2013, expecting at that time to contract a probably launch in the first semester of 2014. The wiener of the LSITEC international bid was ISL-ISIS from Delft, The Netherlands. Likewise other CubeSat projects, the NANOSATC-BR1 was launched as a tertiary payload by ISIS in the event ISILAUNCH 07, Figures 7, 8, 9, 10. The NANOSATC-BR1's final tests, shipment NANOSATC-BR1 GS (INPE – CRS) – Tracking Telemetry and the launching by a DNEPR at Yasny Launching Base, Donbarovsky Region, Russia, had the following time table:

- Final tests at LIT/INPE – 19 to 28 March, 2014.
- Shipment to ISL/ISIS - Delft – First week of April 2014.
- Final health check in ISL/ISIS, Delft – April/May, 2014.
- Shipment to Yasny Launching Base, Russia – May 2014.
- Launching by DNEPR at Yasny Launching Base, Donbarovsky Region, Russia
  - June 19th, 2014 – Launch time (T): 19:11:11 UTC –
  - Local time at Yasny: 01:11.

The ISC KOSMOTRAS DNEPR cluster mission 2014 certificate of launch accomplishment is presented in Figure 11.

Figure 7: ISLAUNCH 07 - NANOSATC-BR1 – Launching. Source: ISL07 Orbital Injection Parameters 01-05-2014, Front Page, Pag. 1.

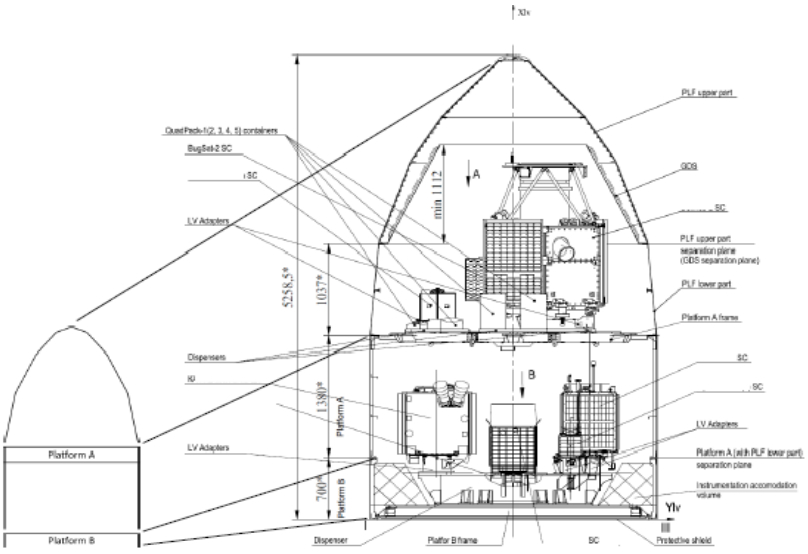

Figure 8: NANOSATC-BR1 – LAUNCHING in a DNEPR Vehicle - Configuration at platform A.
Source: ISL07 Orbital Injection Parameters 01-05-2014, Figure 2-1:SHM lay-out, Pag. 6.

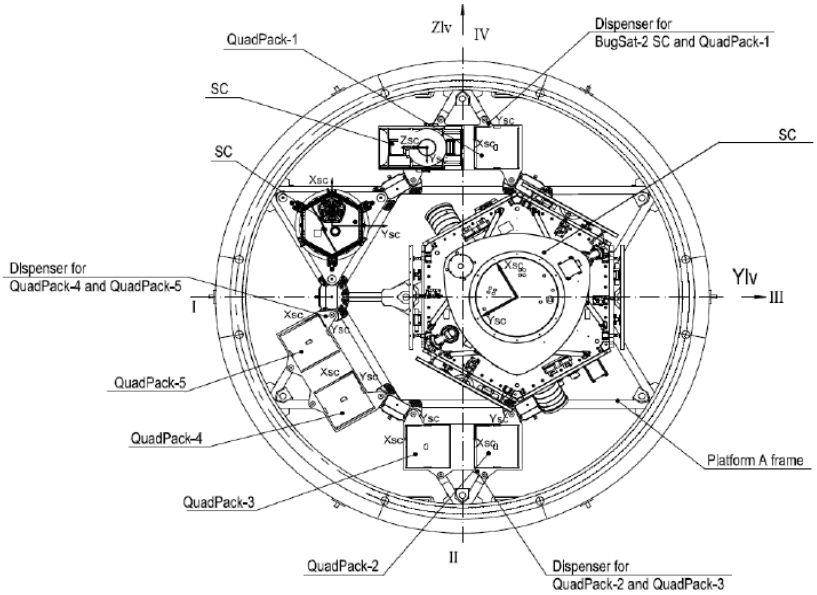

Figure 9: DNPR Platform A lay-out - NANOSATC-BR1 at QuadPack-1.
Source: ISL07 Orbital Injection Parameters 01-05-2014, Figure 2-2: Plataforma A lay-out, Pag. 7.

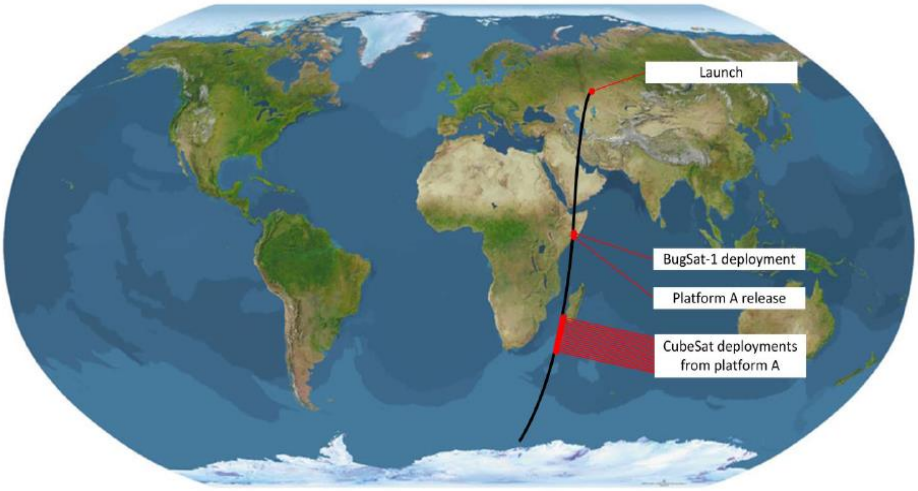

Figure 10: NANOSATC-BR1 – Launching - DNEPR deployment method
Source: ISL07 Orbital Injection Parameters 01-05-2014, Figure 4-1: Impression of ISL07 orbital deployment scheme, Pag. 12.

Figure 11: DNEPR cluster mission 2014 - ISC KOSMOTRAS certificate of launch accomplishment.

The NANOSATC-BR1 Scientific Mission Payload first results

A pre-scientific analysis of the observed data and collected by the Scientific Mission Payload, the magnetometer XEN-1210 in operation aboard the NCBR1,

made by Research Team of NANOSATC-BR1 Project, under the leadership of Dr. Marlos Rockenbach da Silva, the CRS/INPE-MCTI, in Santa Maria, RS, shows an excellent correlation of observed data and collected by the satellite this CubeSat compared with theoretical figures for the intensity of Geomagnetic Field for the same altitude with the theoretical modeling of IGRF-IAGA/IUGG. Figure 12 right hand side, shows a map of the total intensity of the Geomagnetic field at 614km of altitude over South America, domain of the Magnetic Anomaly region of South America - AMAS, showing that the spatial variation of the total intensity of the Geomagnetic field varies between 24.000nT the edge and 17,000 nT at the center in the AMAS, signalized by a black star in the Figure 12. The nanosatellites Earth Tracking and Control Station, ET (INPE-CRS), in Santa Maria - RS, is lying near the center of AMAS. The red line in Figure 12 indicates the approximate orbit NANOSATC-BR1 on August 17, 2014, from 10:57h to 11:07h. During this period, the scientific nanosatellite moves from South Pole towards the geographic North Pole.

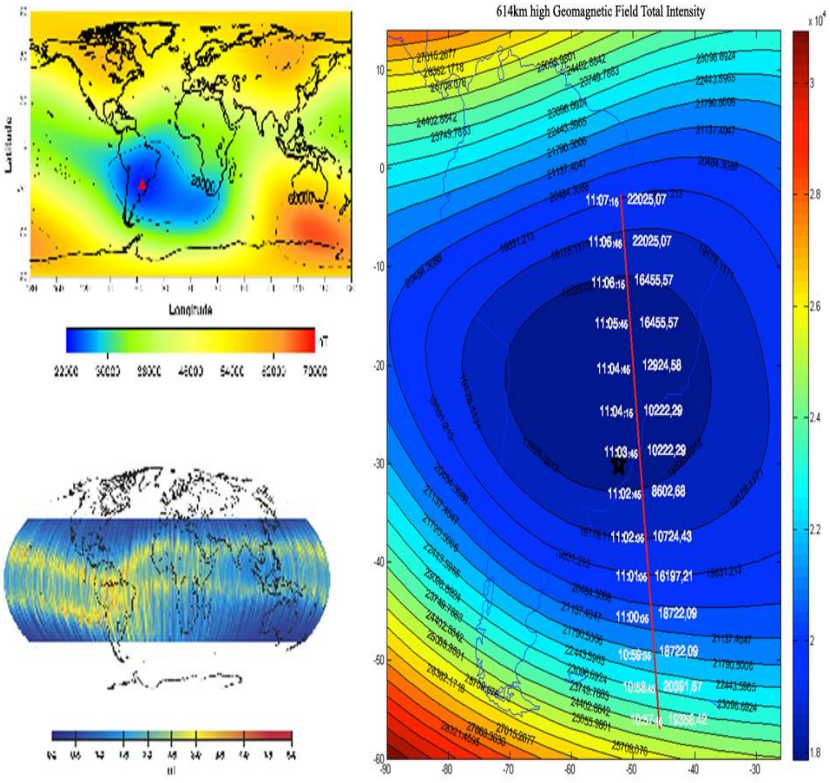

Figure 12: SAMA Geomagnetic Field total Intensity (top left) and EEJ (bottom left) - Ref.[4], [5]. Results from NANOSATC-BR1 Scientific Mission Payload measurements of the SAMA region (right).

VI. NANOSATC-BR2 - CURRENT SITUATION

Through the NANOSATC-BR Program a second nanosat is already being developed by the Partnership INPE-UFSM, it is named NANOSATC-BR2, which is a 2U CubeSat, (10x10x22.6 cm), permitting a more ambitious mission than the NANOSATC-BR1, with three major objectives: academic/capacity building, scientific and technological. The scientific mission is to monitor the Earth's Ionosphere and Magnetic Field. The Ionosphere composition disturbances in the SAMA region over Brazil have severe effects on satellite telecommunications and in the precise location with services such as GPS. The payload equipments for the scientific mission will be a Langmuir probe and a fluxgate magnetometer, XEN-1210. This equipment is available in a larger size and is being miniaturized for CubeSats. The NANOSATC-BR2 platform was developed to satisfy the payload equipment's requirements.

The NANOSATC-BR2 Project's Engineering Model (EM), and Flight Model (FM) platforms, to provide the project requirements and support the payload, was delivered by ISIS, in January 2013, and are at LIT/INPE-MCTI, in São José dos Campos, SP, Brazil.

The accommodation of the payloads for the CubeSat 2U, in the circuit board of NANOSATC-BR2: Magnetometer, ICs and FPGA, has been solved in cooperation between INPE, ISIS, UFRGS and SMDH-UFSM.

The NANOSATC-BR2's Ground Station (GS) was installed and is in operation at the Aeronautic Institute of Technology - ITA/DCTA/CA-MD, in São José dos Campos, SP, Brazil, in a broad agreement/cooperation signed between INPE/MCTI and ITA/DCTA/CA-MD.

The launch of NANOSATC-BR2 is planned to be launched in the second semester of 2015. Likewise NANOSATC-BR1 and other CubeSat projects, the NANOSATC-BR2 will be launched as a tertiary payload. The launch opportunities as well as the Launch Vehicle are under discussion.

VII. Conclusions

The Brazilian INPE-UFSM NANOSATC-BR Cubesat Program with small satellites, already proved to be an excellent tool for developing a new generation of scientists, engineers and researches engineering and computing sciences with Aerospace Technologies in Brazil, since it is been provided to young Brazilian people contact with low cost and fast developments on Space Technology.

The NANOSATC-BR1 & NANOSATC-BR2 Projects are already contributing in order to aggregate human resource, technology and scientific capability to the Brazilian institutions, such as UFSM, UFRGS, ITA, USP, SMDH, INPE, involving them directly to the Brazilian Space Program - PNAE.

Additionally, it is also expected an increase in the Brazilian Space Agency support and more investments from the Brazilian Government for the development of Space Technology and for new universities initiatives, in Brazil, such as the Brazilian INPE-UFSM NANOSATC-BR Cubesat Program, with its CubeSats the NANOSATC-BR1 & NANOSATC-BR2 Projects.

VIII. Acknowledgements

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