TAIWAN’S SPACE PROGRAM DEVELOPMENT
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ABSTRACT:
In this paper, we will introduce Taiwan’s space agency, National Space Organization (NSPO), and her plan and development for space programs. NSPO founded in 1991 has successfully operated three satellite programs, FORMOSAT-1, FORMOSAT-2, and FORMOSAT-3. FORMOSAT-1, an experimental satellite carried three science payloads and was expired in 2005. The second satellite FORMOSAT-2 launched in 2005 was an optical remote sensing satellite which mainly supported in natural disasters, government needs, and international cooperation. The third satellite program, FORMOSAT-3 program, consists of 6 microsatellites as a constellation to measure atmospheric and ionospheric weather data and has been operated since 2006. The measured data is open for free use. NSPO has developed the second remote-sensing satellite FORMOSAT-5, a follow-on program of FORMOSAT-2, using the CMOS technique for the remote sensing instrument, this satellite is scheduled to be launched in 2016. The FORMOSAT-7 program is a follow-on program to the successful FORMOSAT-3 program with upgraded performance for spacecraft bus and mission payload. The FORMOSAT-7 program calls for 12 mission specific satellites plus one NSPO-built satellite. Using these satellites, NSPO is committed to providing better quality rapid response services to the international community in the joint efforts fighting against natural disasters. NSPO also welcomes any opportunities for international collaborations for space technology, applications and science research.

1. INTRODUCTION
In 1991, Taiwan established the National Space Program Office to start her space technology development through executing three satellite programs of the first phase of national long-term satellite plan. NSPO is later affiliated to the umbrella of the National Applied Research Laboratories (NARLabs) in 2003, and furthermore renamed to the National Space Organization (NSPO) in 2005. During the past 25 years, major achievements included erection of space infrastructure and facilities, development of indigenous space technology, and operation of multi-satellite and multi-mission.

Satellite shall possess high reliability to ensure that the bus and its components can tolerate special environments during the launch and orbiting phase, and to maintain a long-term normal operation in the space environments. NSPO has her owned satellite Integration & Testing building located in Hsinchu Science-based Park. This satellite I&T building consists assembly of satellite bus with payloads and performing various functions and space environment simulation tests, in order to make certain that the satellite perform its functions in accordance with the specifications. The I&T building finished in 1997 has test equipment for performing electromagnetic compatibility and antenna test, acoustic test, thermal vacuum test, vibration test, mass property measurement, magnetic alignment correction, satellite ground support and has successfully supported all of the NSPO’s satellite programs and some international space programs.

The main function of NSPO ground system is the execution of the overall operating tasks of the FORMOSAT series satellites. The tasks include launch support, satellite bus operation and control, payload operation and control, and the reception, processing and distribution of remote sensing and science data. NSPO Satellite Operations Control Center (SOCC) employs a single ground station software platform to operate multiple satellite missions simultaneously. The SOCC contains a number of subsystems, including Ground Communication Network, Mission Operation Center, Mission Control Center, Science Control Center and Flight Dynamic Facility. Through the communication network, the SOCC monitors and controls two S-band Antenna Stations and an X-band Antenna Station as well as performs data transmission to the IPS and each Science Data Distribution Center of FORMOSAT series satellites.

NSPO has successfully operated three satellite programs, FORMOSAT-1, FORMOSAT-2, and FORMOSAT-3. FORMOSAT-1, an experimental satellite carried three science payloads. The second satellite FORMOSAT-2 was an optical remote sensing satellite mainly used in disaster supports, government needs, and international cooperation. The third satellite FORMOSAT-3 consists of 6 microsatellites as a constellation to measure atmospheric and ionospheric weather data. In recent years, NSPO has developed the second remote-sensing satellite FORMOSAT-5, a follow-on program of FORMOSAT-2 using the CMOS technique for the remote sensing instrument. The FORMOSAT-7 program is a follow-on program to the successful FORMOSAT-3 program with upgraded performance for spacecraft bus and mission payload. The FORMOSAT-7 program calls for 12 mission specific satellites plus one NSPO-built satellite.

This paper will detail the plan and development for all NSPO space programs. We will also emphasize the orchestration of various tasks conducted in different institutes in Taiwan in the efforts responding to international nature disasters, monitoring the climate change.
In the First Phase Long Term Space Program of Taiwan, 1991-2004, 3 observation satellite missions in Low Earth Orbit (LEO) had been successfully conducted by NSPO: FORMOSAT-1 (previously known as ROCSAT-1), a scientific satellite; FORMOSAT-2, a high-resolution remote sensing satellite; and FORMOSAT-3/COSMIC, a constellation of 6 meteorological micro-satellites. NSPO has demonstrated in the successful operations of these 8 satellites. In this phase, remote sensing and meteorological type of satellite applications were identified as the main focus that meets national needs.

In the second phase of long term plan, 2004-2018, Formosat-5 and Formosat-7 are being developed as follow-ons to FORMOSAT-2 and FORMOSAT-3, respectively. In this phase, emphasis is focused on developing indigenous capabilities in critical spacecraft component and instrument utilizing Taiwan’s industrial strengths such as micro-electronics and others.

2.1 FORMOSAT-1 Mission

FORMOSAT-1 is a low-earth-orbit scientific experimental satellite. After launched into an altitude of 600 km with 35 degree inclination, it circulates around the earth every 97 minutes, transmitting collected data to Taiwan's receiving stations approximately six times a day. The major mission of FORMOSAT-1 includes three scientific experiments for measuring the effects of ionospheric plasma and electrodynamics, taking the ocean colour image and conducting Ka-band communication experiment. The daily collected payload data are distributed to domestic science groups and to the domestic and international research organizations for scientific experiments.

For the research on characteristics of ionospheric layers, the purpose is to understand the ionospheric layer structure in the space above Taiwan and its surroundings, in order to provide important information that influences wireless communication. Ocean colour research is to provide experimental data in ocean related fields as a basis for practical and theoretical researches in areas ranging from environment, fishery, industrial, commercial areas, and academics. The Ka-band communication experiment is to conduct low and high data rate and rain attenuation communication experiments. FORMOSAT-1 had expired in 2005.

2.2 FORMOSAT-2 Mission

FORMOSAT-2, Taiwan’s first remote sensing satellite, was successfully launched in May of 2004 into the sun-synchronous orbit at altitude of 891 km [1]. FORMOSAT-2 carries two instruments, the Remote Sensing Instrument (RSI) and Imager of Sprites and Upper Atmospheric Lightning (ISUAL) in order to fulfill its remote sensing and scientific missions.

Major payload, a high-resolution electric-optical type RSI has high ground resolution of 2-m panchromatic (PAN, black & white) and 8-m multi-spectral (MS, colour). Images taken by FORMOSAT-2 not only fulfilled Taiwan civilian needs on land utilization, agricultural and forest planning, disaster assessments, and environmental monitoring, but they are also being distributed to international users for specific applications as shown in Figure 2. The science experiments conducted by ISUAL of FORMOSAT-2 is the world’s first long term satellite observation on the lighting phenomenon at the earth's upper atmosphere.

The FORMOSAT-2 circulates the earth on sun-synchronous orbit of 14 revolutions per day. Due to the repetitive characteristic, the daily revisit region ranges 968 km around the ground track, which corresponds to the satellite roll angle of 45 degrees or the ground elevation angle of 36.3 degrees. Some regions near the equator are not covered, but the total area is less than 18% of the global area. For emergency cases, the satellite can be operated at roll angles up to 53.6 degrees to achieve the global coverage.[1]

NSPO announced that FORMOSAT-2 is decommissioning after over 12-year services. FORMOSAT-2 has been
effectively used for earth observations. FORMOSAT-2 has effectively accumulated over 2.5 million images provided to thousands of domestic and international users. With the unique daily revisit capability, FORMOSAT-2 has quick access to disaster areas and can provide continuous monitoring information useful for rescue planning. Taiwan has totally assisted 343 events by providing FORMOSAT-2 images free of charge for humanity relief usage through international organizations including UNOSAT, Sentinel Asia, and International Charter, etc. over its mission life time.

Figure 4. FORMOSAT-2 Footprint

2.3 FORMOSAT-3 Mission

The first international collaboration satellite program between Taiwan and the US is the FORMOSAT-3 (a.k.a. COSMIC in the U.S.) program with joint efforts of NSPO and University Corporation for Atmospheric Research (UCAR) of the US.

This program places six micro-satellites into six different orbits at 700~800 kilometer above the earth ground and utilizes the Radio Occultation (RO) technique to receive the L-band signals from the GPS satellites. [2]

The satellite observation covers the entire global atmosphere and ionosphere, providing over 2,500 global sounding data per day. These data distribute uniformly over the earth's atmosphere. The global climate information collection and analysis can be completed in three hours while the sounding data will be updated every 90 minutes.

The GPS-RO data has been demonstrated to be valuable to the long-term climate change research, interactive ionosphere monitoring, global space weather forecast, and earth gravity research.

Figure 5. FORMOSAT-3/COSMIC

2.4 FORMOSAT-5 Mission

As a successor to FORMOSAT-2, FORMOSAT-5 is Taiwan’s first indigenous remote sensing satellite which will be operated in a sun-synchronous orbit at 720 km of altitude and offers a temporal frequency of two days revisit. [3]

NSPO is taking a bold step to be responsible for the complete system development of FORMOSAT-5. The basic characteristics of FORMOSAT-5 with mission life 5 years are similar to FORMOSAT-2. Due to the strict export license limitation on key technologies and the accumulated experience & knowledge from FORMOSAT-1, 2, & 3, several key components for FORMOSAT-5 spacecraft bus include Power Control and Distribution Unit (PCDU), Command and Data Management Unit (CDMU), and Flight Software (FSW) are developed by NSPO.

FORMOSAT-5 is the first self-reliant remote sensing satellite designed and fabricated in Taiwan. It carries an optical payload and a science payload which are 100% developed in Taiwan to execute remote sensing mission and perform science research, respectively. The main payload Remote Sensing Instrument (RSI) is equipped with an innovative five-band multi-SOC CMOS sensor shown in Figure 6 that provides 2-m resolution panchromatic and 4-m resolution multi-spectral imagery.

Figure 6. CMOS linear sensor

The science payload of FORMOSAT-5 called Advanced Ionospheric Probe (AIP) is provided by Institute of Space Science, National Central University (NCU). The AIP is an all-in-one plasma sensor to measure ionospheric plasma concentrations, velocities, and temperatures over a wide range of spatial scales. The transient and long-term variations of ionospheric plasma can be monitored as seismic precursors associated with earthquakes. Table 1 details the comparison of key satellite system parameters of FORMOSAT-2 and FORMOSAT-5 missions.

Table 1. Key Parameters of FORMOSAT-2 vs. -5

<table>
<thead>
<tr>
<th>Key Parameter</th>
<th>FORMOSAT-2</th>
<th>FORMOSAT-5</th>
</tr>
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<tbody>
<tr>
<td>Orbit</td>
<td>SSO @ 891 km/99.10°</td>
<td>SSO @ 720 km/98.28°</td>
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<tr>
<td>Revisit Period</td>
<td>1 day</td>
<td>2 days</td>
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<tr>
<td>Mission Life</td>
<td>5 years</td>
<td>5 years</td>
</tr>
<tr>
<td>GSD</td>
<td>PAN (2 m) / MS (8 m)</td>
<td>PAN (2 m) / MS (4 m)</td>
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<tr>
<td>Swath</td>
<td>24 km</td>
<td>24 km</td>
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<tr>
<td>Spectral Bands</td>
<td>1PAN + 4MS</td>
<td>1PAN + 4MS</td>
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<tr>
<td>RSI Image</td>
<td>CCD</td>
<td>CMOS Image Sensor</td>
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<tr>
<td>Sensor</td>
<td>RSI duty Cycle</td>
<td>Satellite Weight</td>
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</tr>
<tr>
<td></td>
<td>8%</td>
<td>760 kg</td>
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<tr>
<td></td>
<td>8%</td>
<td>525 kg</td>
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</table>

Figure 7 shows the mission orbit of FORMOSAT-5, presenting a 2-day revisit period with a 45 degrees normal field of regard.

Compared to FORMOSAT-2 Image Processing System (IPS), IPS development for FORMOSAT-5 has some advanced features. In the FORMOSAT-2, the key technology and on-board compression algorithm was not available due to satellite procured from abroad. NSPO adopts fully self-reliant development approach for FORMOSAT-5. Now, in addition to the Taiwan made FORMOSAT-5 satellite, NSPO also masters the de-compression, de-ciphering and de-package techniques. Therefore, NSPO decided to adopt self-reliant development approach for FORMOSAT-5 Data Ingestion Subsystem (DIS). The upgraded IPS is designed to be an integrated operational environment which can support both FORMOSAT-2 and FORMOSAT-5 image processing. Moreover, FORMOSAT-5 has the capability of asynchronous imaging and the Planning & Scheduling Subsystem (PSS) in IPS is developed to be able to calculate the satellite attitude variations when satellite takes image along a planned ground track.

With the lessons learned from working with international partners, the FORMOSAT IPS has been extensively automated and streamlined with a goal to shorten the time between request and delivery in an efficient manner. The IPS completed all system tests by the end of 2014, and will work on calibration & improvement of the system.

In order to make the operation efficient and effective for supporting disasters, a value-chain to produce satellite image is coordinated by synergizing the NSPO IPS and other domestic institutions-CSRSR of NCU, the GIS center of FCU, and the NCHC. The value-chain with coordinated tasks ranged from receiving emergency observation requests, scheduling and tasking of satellite operation, downlink to ground stations, images processing including data injection, ortho-rectification, to delivery of image products to the users.

FORMOSAT-5 has completed the satellite system level assembly-integration-testing activities in the first quarter of 2016. The launch campaign is targeted in 2016 as the major payload of SpaceX’s Falcon 9 from Vandenberg, California in the United States.

2.5 FORMOSAT-7 Mission

The FORMOSAT-7 (COSMIC-2 in U.S.) is an international collaborative space program between Taiwan and the U.S. In this collaborative program, the designated representative for Taiwan is NSPO and the designated representative for the U.S. is NOAA (National Oceanic and Atmospheric Administration). The FORMOSAT-7 program is a follow-on program to the successful FORMOSAT-3 program with upgraded performance for spacecraft bus and mission payload.[4]

The FORMOSAT-7 program calls for 12 mission specific satellites plus one NSPO-built satellite. The 12-satellites are planned to be launched and deployed in two clusters of 6-satellites into the designated low and high inclination orbits in 2017 and 2018, respectively. The NSPO-Built satellite that is planned to be launched in the second cluster will enhance the utility of the FORMOSAT-7 constellation and will serve as the space qualification platform for the self-reliant key components for the future standard bus of this class.

Each FORMOSAT-7 satellite is equipped with a Radio Occultation (RO) receiver, called TGRS, that receives the GNSS signal from GPS, GLONASS, or GALLIELO satellites. The received radio occultation data is then transmitted down to the ground to retrieve and process into useful atmospheric and ionospheric weather data such as temperature, pressure, water vapour content, electron density, etc. The FORMOSAT-7 constellation can provide 8000 atmospheric soundings per day, data which will contribute to weather forecasts and climate observations.

The first 6-satellites are designed for observing the lower inclination planes to cover the equatorial regions between 50° south and 50° north latitudes. FORMOSAT-7 RO data provides the needed effective weather data to CWB, and post data analysis indicated that the typhoon track prediction accuracy can be dramatically improved.
3. NSPO’S SATELLITES SUPPORTS TO INTERNATIONAL DISASTERS

In the emergency period immediately after the occurrence of a disaster, it is difficult to obtain accurate and timely information from devastated area for a decision-maker to evaluate and manage the disaster. Therefore, better temporal resolution satellite images from different satellites are highly desirable for the response and recovery in an emergency.

FORMOSAT-2 satellite is a satellite with daily revisit and global coverage features because it possesses capabilities of daily repeat, high altitude, and large field of regard. Since 2006, Taiwan has been providing free satellite images from FORMOSAT-2 for humanitarian supports through international organizations including International Charter Space & Major Disasters, UNOOSA/UN-SPIDER (United Nations Office for Outer Space Affairs/ Space-based Information for Disaster Management and Emergency Response), UNITAR/UNOSAT (United Nations Institute for Training and Research/ Operational Satellite Applications Programme) and Planet Action Initiative (since 2008). FORMOSAT-2 was a great and reliable resource for United Nations disaster response work and played an important role in mapping impacts of disasters in Mozambique, the Philippines, Moldova, Uganda, Uruguay, Mauritania, Nepal, Tajikistan, Somalia, and many other locations. [5]- [7]

In 2010, FORMOSAT-2 joined the Sentinel Asia, and since then joined with other nation’s or international organizations’ efforts and contributed to fighting against natural disasters. The events supported include South Asia Tsunami (2004), Sichuan Earthquake (2008), Great East Japan Earthquake (2011), Haiyen typhoon (2014), and Nepal Earthquake (2015). Until 2015, FORMOSAT-2 has supported more than 57 countries in 236 events of major disaster reliefs.

The much frequenter sever weathers formation due to the rapid global environment change has been raised as one of the most critical matters among the global atmospheric and earth scientists. The unique feature of radio occultation technique can overcome the conventional difficulties to retrieve the data from the oceans and polar regions with abundant quantity in near-real time that are very useful to improve the weather forecast accuracy, climate change observation, and global warming researches. These RO data of FORMOSAT-3 have been continuously provided to more than 3,000 registered users in 83 countries. European Center for Middle-Range Weather Forecast (ECMWF) reported that the FORMOSAT-3 RO data accounted only 2–3 % among the total data used in the weather forecast assimilation in 2012 has contributed to a 10% forecast error reduction that is a significant increased from 8.5% as studied in 2008. [8]

FORMOSAT-3 RO data was ranked #5 among the most significant contribution weather observation programs in the world. Other than Central Weather Bureau in Taiwan, many major weather forecast centers and agencies in the world, such as Canada, United States, United Kingdom, Japan, Australia, Korea, many nations in European Union, have incorporated the RO data in their weather forecast assimilation system. It’s unprecedented that FORMOSAT-3 constellation RO can attract the global attentions and incorporated into the weather forecast systems within a short period of time.

A case study by Taiwan Typhoon and Flood Research Institute (TTFRI) of the NARLabs utilized 23 typhoons in 2012 indicated that the RO data can improve 10% in typhoon track accuracy for 24-hours advanced forecast. Taiwan scientist team also used the RO data to successfully establish the first near-real time and 3-dimensional (3-D) global ionospheric observation network and forecast assimilation model in the world. The 3-D ionospheric forecast assimilation model is useful for accuracy improvement and correction in communication, positioning, navigation.

The FORMOSAT-3 constellation system retrieved ~ 2,400 RO profiles per day at the initial operation period since its launch in April 2006. Over near 10-year operations, other than one satellite was declared decommissioned due to the unrecoverable power failure, the other five satellites are currently exhibiting intermittent outages caused by the power system failure and the decaying performance due to the aging of many
key components in each satellite. Never the less, the FORMOSAT-3 constellation is currently contributing at 650–850 RO profiles daily. The FORMOSAT-3 RO Constellation has been proven to have significant societal impacts to increase the accuracy of the predictions of hurricane / typhoon behavior, improve the long-range weather forecasts, and monitor the climate change with unprecedented accuracy.

4. SUMMARY

Taiwan is frequently struck by natural disasters such as typhoon, flood, earthquake, landslides and others. As a small country with limited resources, its space agency-the NSPO developed Earth observations and weather satellite missions to monitor the nation’s environments. The FORMOSAT-2 images have been used and contributed to disaster responses.

In order to make the operation efficient and effective, a value-chain to produce satellite image is coordinated by synergizing the NSPO IPS and other domestic institutions-CSRSR of NCU, the GIS Center of FCU, and the NCHC. The value-chain with coordinated tasks ranged from receiving emergency observation requests, scheduling and tasking of satellite operation, downlink to ground stations, images processing including data injection, ortho-rectification, to delivery of image products to the users. The achievements supporting the domestic operations had been extended to international community such as International Disaster Charter, UNSPIDER, UNOSAT, and especially Sentinel Asia. [7]

Based on the operational experiences of FORMOSAT-2, NSPO image processing system (IPS) has been extensively automated and streamlined with a goal to shorten the time between request and delivery in an efficient manner. The integrated team has developed an Application Interface for mobile access to its system platform that provides functions of search in archive catalogue, request of data services, mission planning, inquiry of services status, and image download. This automated system enables timely image acquisition and substantially increases the value of image product. These developments will be used to demonstrate its effectiveness in FORMOSAT-5 program. It is expected to provide more efficient support to international cooperation in disaster mitigation.

The FORMOSAT-3 constellation system retrieved ~ 2,400 RO profiles per day at the initial operation period. Over near 10-year operations, the FORMOSAT-3 constellation is currently contributing at 650–850 RO profiles daily. The FORMOSAT-3 RO Constellation has been proven to have significant societal impacts to increase the accuracy of the predictions of hurricane / typhoon behaviour, improve the long-range weather forecasts, and monitor the climate change with unprecedented accuracy.

Currently, the NSPO has completed all development of the FORMOSAT-5 and FORMOSAT-7 which are follow-on satellites of FORMOSAT-2 and FORMOSAT-3, respectively. With this experience in FORMOSAT-2 and 3, and continuing improvements, the NSPO is committed to providing better quality rapid response services to the international community in the joint efforts fighting against natural disasters.

REFERENCES


