

**The Most Accurate and Stable Space-Borne Thermometers –
FORMOSAT-3/COSMIC Constellation**

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ABSTRACT

The FORMOSAT-3 mission, also known as COSMIC, Constellation Observing System for Meteorology, Ionosphere, and Climate, is the third major project of the FORMOSAT series implemented by the National Space Organization (NSPO) in Taiwan. This is a collaborative effort between NSPO and University Corporation for Atmospheric Research (UCAR) in the US. The six satellites were launched by a single Minotaur launch vehicle on April 15, 2006. The retrieved Radio Occultation (RO) data has been published on line since shortly after the satellite in-orbit check out. Having completed verification and validation, the science community is satisfied with the FORMOSAT-3/COSMIC data and calls it the most accurate, precise, and stable thermometer in space for measuring global and regional climate change.

These fruitful mission results were obtained by continuous efforts of the mission team. The current constellation configuration as of May 2007 is four satellites (FM5, FM2, FM6, and FM4) having been successfully raised to the 800 km mission orbit with the remaining two (FM3 and FM1) operating at the 518 km lower parking orbit. In this paper, we will address the mission status and the technical challenges we have encountered, and how NSPO derived the corrective actions to maintain the scientific instruments operations and enhance the satellite operations. All six spacecrafts have generated a total of more than 2,500 RO data per day, however, only 50%~70% of the RO data received today could be retrieved into useful atmosphere profiles. The retrieved RO data (~ 1,700 + per day on the average as is in May 2007) were introduced into the assimilation processes by many major weather forecast centers and research institutes even in the current constellation configuration. The paper will also describe how to enhance the RO data volume and to reduce the data latency by optimizing the satellite pass scheduling and the ground station coverage. The implementation results will be described in the paper, too.

INTRODUCTION

Since 1991, Taiwan's National Space Organization (NSPO), under the supervision of the country's

National Science Council and National Applied Research Laboratories, has been executing a long-term, multi-spacecraft acquisition program designed to advance Taiwan as a self-sufficient space system developer and integrator. Each consecutive

program has provided NSPO personnel with more insight and experience. FORMOSAT-3 mission, also known as COSMIC (Constellation Observing Systems for Meteorology, Ionosphere, and Climate), the third program in the series; it is a joint endeavor between several agencies and institutions in Taiwan and the United States.

The mission requirements were defined by NSPO and the University Corporation for Atmospheric Research (UCAR) in order to meet the needs of the meteorology and science community. NSPO is the system integrator, while Orbital Sciences Corporation (Orbital) provided the spacecraft bus and the UCAR provided the payload suite of scientific instruments. NSPO engineers fully involved in the areas of system and subsystem design. FM1, the prototype spacecraft, was integrated and tested by both NSPO's and Orbital's engineers in Orbital facility. FM2 through FM6 were fully integrated and tested by NSPO personnel in Taiwan I&T facility. After near four months S/C-to-L/V integration and test efforts between NSPO and Minotaur launch system team at US Air Force Vandenberg base in California, FORMOSAT-3 satellites were successfully launched on April 15, 2006. NSPO conducted the mission operations from satellite operations control center with the supports from Orbital on spacecraft anomaly resolutions and supports from UCAR on the mission enhancement and scientific payload operations.

The mission objective is to deploy a constellation of six satellites to collect atmospheric and ionospheric remote sensing data. The mission goals are to use the near real time global coverage data for atmosphere, ionosphere, climate, and geodesy researches and improvement on weather prediction. Three payload instruments are on board on each FORMOSAT-3 spacecraft; the GPS Occultation eXperiment receiver (GOX), the primary payload, the tri-band beacon and the tiny ionospheric photometer.

As GPS signal pass through the atmosphere, they are delayed and bent. The information of atmospheric pressure, temperature, and water vapor are inferred from the bending angle. In the case of GOX measurements, one occultation event corresponds to one profile of atmospheric sounding. The target of the FORMOSAT-3 constellation is to collect 2500 sounding data everyday uniformly distributed manner globally. The satellites will downlink the occultation measurements to the ground receiving stations every revolution for post data processing to

retrieve the atmospheric data. These data are then further distributed to the weather forecast centers and assimilation into the weather forecast models. The data latency from the occultation events to the weather forecast centers is expected to be within 90 minutes when all six satellites reach the final constellation.

FORMOSAT-3 has the advantage of being able to operate in all weather conditions and is capable of gathering data over vast stretches of oceans and ices where there are few or no sounding balloons. Having produced more than one year worth of data, four satellites have reached their final orbit as of May. The data products from FORMOSAT-3 constellation have been proven to be very competitive with those of traditional sounding measurements and similar space borne RO payloads. The existing weather prediction capability has shown positive improvement with FORMOSAT-3's data. Many major weather data centers have recognized that FORMOSAT-3 is the most accurate and stable space-borne thermometer in the world.

MISSION STATUS

In order to make the data applicable to weather prediction, the mission objectives are to have data distributed as homogenously as possible globally and to have the data feed into weather prediction models as soon as possible. Two key constellation parameters were derived:

- All six satellites will be deployed into six orbital planes with 30-deg separation angle in right ascension ascending node between adjacent orbits.
- The orbit phasing is 52.5 deg in the argument of latitude between adjacent orbits so that ground stations can receive the measurement every revolution for every satellite. This is an important factor to ensure the shortest possible data latency to feed operational weather forecasting centers.

The FORMOSAT-3 final constellation and GPS constellation are shown in Figure 1.

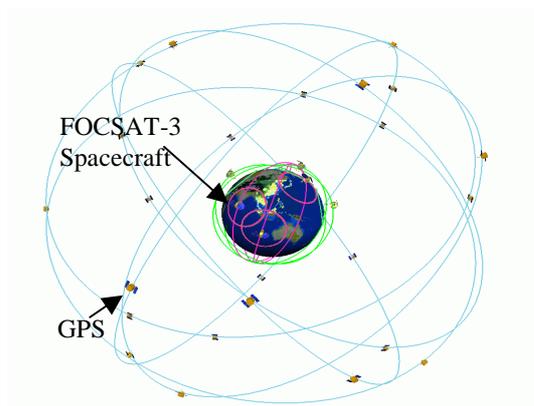


Figure 1 : FORMOSAT-3/COSMIC and GPS Constellation

All six satellites were delivered to the same injection orbit and they are in cluster formation after launch separation. Orbit transfer maneuvers of each spacecraft are required in order to achieve the final constellation at the designated mission orbit. FORMOSAT-3 takes the advantage of the nodal precession to conduct the orbit raising maneuvers at the appropriate times, so that the effect of different altitudes makes orbital planes drifts. The nodal precession is a well-known gravity phenomenon due to the Earth oblateness.

The current constellation status is shown as Figure 2. The dash line is the planned schedule and the dots recorded the execution results of the thrusting. One can see there is a pause period on FM2's thrusting because the team changed the orbital separation from 24 deg to 30 deg.¹ The modification will extend the constellation deployment period. However, the change is blessed by science community because it is found the spacecraft at parking orbit can collect data with the quality better than expected and the scientists' desire is to have more even distributed constellation.

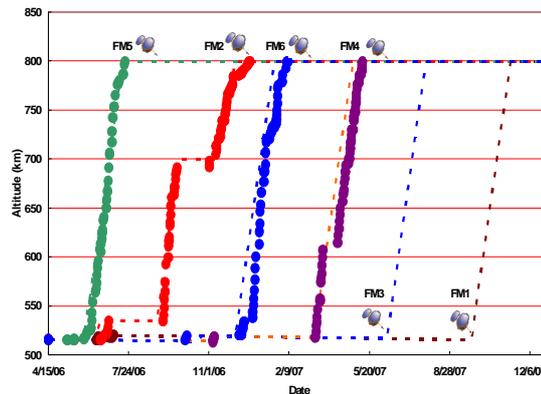


Figure 2: Deployment Timeline

With four satellites at final orbit and two spacecraft at parking orbit, the retrieved average number of soundings is more than 1700 points per day. The statistics since launch are as shown in Figure 3.

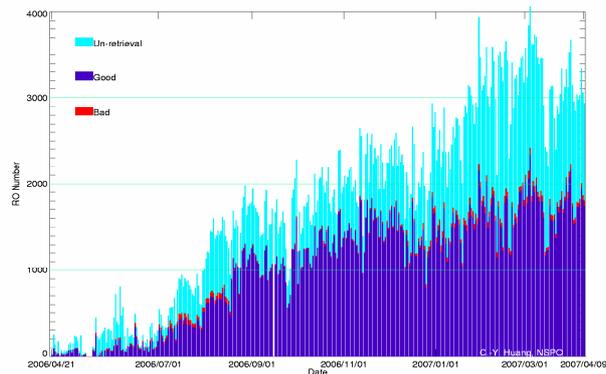


Figure 3: Occultation Number

NSPO has made a lot of efforts to tune the spacecraft and ground operations to improve the spacecraft performance and the operations agility. The efforts will be addressed later. UCAR also has made a significant progress to tune the GOX performance and the post processing in the data processing center to attribute to more and better occultation profiles. The data distribution is more and more world-side as the constellation deployment continues. Figure 4 shows the geographical distribution from FORMOSAT-3 measurement. One dot means one profile of atmospheric measurement. The color represent how deep the retrieval can reach. One can see the distribution is worldwide.

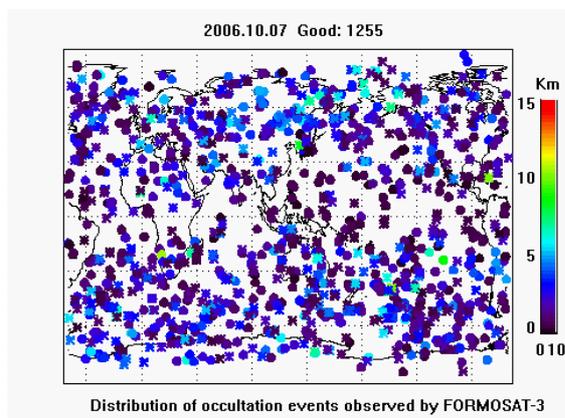


Figure 4: Occultation Distribution

More than 70 % of data has a latency of less than 3 hours as reported by the European Centre for Medium-range Weather Forecast (ECMWF). The ECMWF and the National Centers for Environment Prediction (NCEP) of the United States assimilated the data into the real-time operational forecast systems. The preliminary results have shown the FORMOSAT-3 data improves the predictions of typhoon/hurricane tracks, including when and where they will hit the land.² ECMWF's analysis shows that the FORMOSAT-3 measurements improve the accuracy of their forecast by about 11% in the southern hemisphere at 100 mb.³ NCEP's studies have shown that their forecasts have significantly improved on the score of forecast when the FORMOSAT-3 data is assimilated into the system.³ Central Weather Bureau (CWB) of Taiwan has reported that the contribution of FORMOSAT-3 has advanced their prediction capabilities by 2 years.

Thanks to the findings of UCAR's research group, retiring the phase lock loop technique employed in the previous RO missions such as CHAMP and SAC-C, and employing open loop technique for the first time on FORMOSAT-3, most of the occultation measurements can now penetrate to altitudes as low as 1 km above the earth's surface.⁴ The atmospheric boundary layer measurements from space at altitudes of approximately 2 km are the first observed, providing valuable information on low-level water vapor.

The ability to take ample measurements over the Polar region is providing new insights in the research occurring in that area. It is found the region forecast model over the Antarctica was too cold than actual and the scientists have begun to make the temperature correction based on the addition of data

from FORMOSAT-3 occultation measurements.⁵ The data collected from June to September of 2006 have been used to construct the temperature profile of Antarctica through the stratosphere. Scientists have found the vertex effect of ozone depletion.⁶

The launch of this innovative satellite constellation has brought in a new era of studying the effects of ionospheric space weather. Taking advantage of dense and global three-dimensional observation coverage, a new ionospheric structure and some important atmosphere-ionosphere coupling theories have been observed and proven based on observations made. The newly discovered ionospheric structure, namely the low-latitude ionospheric plasma cave, shows a depleted plasma region underneath the region of strongest plasma concentration.⁷ Observing this new ionospheric structure will improve fundamental understanding of the ionospheric dynamics and will be beneficial to evaluating the ionospheric effects to the space environment and their effects on communications in space. The data provided by FORMOSAT-3 has also uncovered a unique ionospheric structure, which could possibly be associated with tropical rainstorms and proposed to be formed by an atmosphere-ionosphere coupling process. FORMOSAT-3's capability to observe vertical plasma distribution across a twenty-four-hour period, led to the verification of a plausible physical mechanism of this unique ionospheric structure.^{8,9} The influences of the tropical rainstorms and atmospheric weather have been included as considerations for space weather.

Access to the data from the FORMOSAT-3 spacecraft is free provided to the potential user. All users are required to register at web site tacc.cwb.gov.tw and to accept the data use agreement. To date, there are more than 500 registered users representing more than 40 countries.

SPACECRAFT PERFORMANCE

The overall spacecraft performance of the six FORMOSAT-3 spacecraft is in good healthy conditions to carry the mission.^{10,11} The spacecraft's magnetically controlled attitude control system does experience excursions from the required $\pm 5^\circ$ pointing accuracy in roll, pitch and yaw which impacts sciences data sometimes. 40% power margin on average of each spacecraft is observed based on one-year trend data. There is also no sensible degradation for power system on all six satellites except for FM2 suffering 20% power

shortage when the 40% original margin is taken into account. The thermal control subsystem is behaving nominally across the range of solar beta angles. There was an issue concerning earth sensor temperature rising too high at high beta angles, but was resolved by a ground operations based solution to turn off the secondary payloads during these periods. FM2, FM5, FM6 and FM4 have reached their respective mission orbits, and the remaining propellant masses for these four satellites is approximately 2.0 kg, the equivalent of 30% of full tank capacity.

There are four major anomalies as described below on FORMOSAT-3 constellation:

- (1) The GPS Receiver (GPSR) of FM1, FM3, FM4, and FM6 could not reliably acquire and lock on the signals from the GPS constellation. And GPSR sometimes provides erroneous data causing problems in the attitude processing and the timing system; those data glitches result in the strange behaviors on the spacecraft. The issue was resolved by commanding four known state vectors daily to each corresponding spacecraft from the satellite operations control center. The state vector is obtained using the normal GPS functions of the payload GOX. NSPO picked FM5 and FM2 as the first two spacecraft to be raised from their parking orbit since their GPS receivers were behaving nominally. This allowed the team to perform orbit determination using the data from the spacecraft bus GPS receiver. As for FM4 and FM6, NSPO has modified the thrusting procedure to include GOX operations as part of burn activities.
- (2) There were thermal anomalies related to orbital high beta angles. At high beta angles, the spacecraft is under constant sunlight (no eclipse). It causes that the earth sensor temperature to rise higher than expected. Additionally the battery pressures were rising higher and closer to the specified limit during this time period. To solve the issue, the operations team turns TIP and TBB off when the beta angle is higher than 60 deg. To resolve the battery pressure issue, the power engineers fine-tuned the charge rate to maintain the battery within the normal pressure limit through frequent monitoring and commanding until the modified flight software was delivered by Orbital, which included a new battery over-pressure protection function. This new software was successfully uploaded early

this year and is now maintaining the battery pressures autonomously.

- (3) FM2 has experienced a sudden power shortage. The ground operations team observed that the maximum power capacity of the solar arrays had been reduced by about 50% starting on March 1, 2007. A plan to operate the GOX at a reduced duty cycle was analyzed and executed. FM2 is supporting to operate the GOX at a ~70% duty cycle with the secondary payloads remained off at all times.
- (4) The GOX experienced performance anomaly. The GOX enters into reboot loop sometimes. The root cause is still under investigation. So far, this does not appear to be causing any permanent degradation. The payload team is working on firmware change to make the four antennas of GOX capable of supporting each other. Hopefully, the issue can be resolved by the firmware change.

EFFORTS ON ENHANCEMENT

The success of the FORMOSAT-3 mission depends on abundant provision of data with short latency as described above. In this section, we will address the efforts on increasing GOX data volume and the number of data dumps.

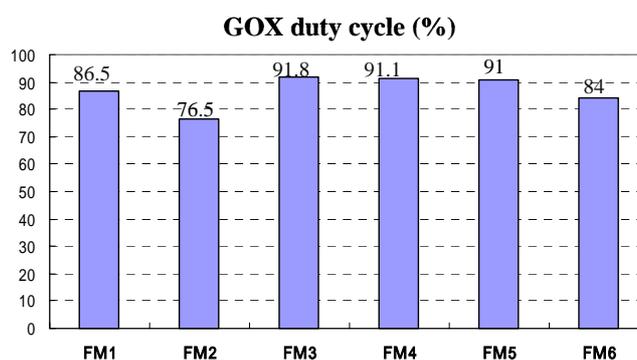


Figure 5: GOX Duty Cycle

The GOX operational duty cycles for each spacecraft as shown in Figure 5, with the average on-time being about 87% for the first year. The engineering team collected statistics on the events that triggered the GOX instrument to be turned off for the remaining 13% of the time and compiled the results shown in Table 1.

Table 1: GOX Power Down Statistics

Events	Occurrence Percentage
Attitude excursions	35.6%
Orbit transfer maneuvers (planned)	27.5%
Processor reboot	17.5%
Tumbling	7.5%
Power shortage (FM2 only)	5.6%
Charge anomaly	3.8%
Others	2.5%

The top three causes are attitude excursions, orbit transfer maneuvers, and on-board processor reboots. The engineering team has implemented an automated trigger function in the control center to command the GOX on once it detects it has been off, and the attitude and power of spacecraft have met the criteria for operating it. In addition to the trigger function, the auto recovery script for frequent anomaly has been developed and executed by the ground operations team, which restores the spacecraft configuration in the event of a reset or other kinds of similar anomalies. Based on the trending data over the past year, the implementation of these two prompt recovery scripts can yield a 6% gain in data. Meanwhile, engineers are still working on understanding the root cause of these anomalies, which may be due to a software bug.

The science team has made tremendous contribution on enhancements, too. UCAR's scientists reported that there were data-wrapping problem such that stored data that could not be retrieved. They also noticed that sometimes the science data was noisy. NSPO and UCAR worked together to come out a script to dump the data to the air to avoid the wrapping issue and to separate the spacecraft data dump from the science data dump to reduce the noise. In the meantime, the GOX firmware has been progressively updated from version 4.2, 4.2.1 to version 4.3 to improve open loop tracking, to optimize data management, and to fix bugs, etc.. The azimuth window of GOX has been opened to 70 deg. The IO machine and web server has been continuously monitored and the bugs have been fixed.

In order to promote the data application, the pass scheduling needs to be tailored specifically for the FORMOSAT-3 in the various constellation deployment phases. An auto script was developed

in-house to meet the needs for optimizing the resource management. The script starts from a report containing the ground antenna operations information including Acquisition Of Signal (AOS) time, Loss Of Signal (LOS) time, maximum elevation angle, and azimuth angle for all spacecrafts and all ground stations. The first run of the pass selection is to simply pick up the passes by a priority pattern inputed by the scheduler. The constraints for the pass scheduling are (1) one satellite per pass and (2) 5-minute for ground tracking antenna to turn around. In the other words, any given ground station can only take subsequent passes if the AOS of the second pass is 5 minutes later than the LOS of the previous selected pass. After the first run of selection, the script will use the selected pass to determine the priority pattern, which is the time order of the previous run. The pass select logics are as summarized in Figure 6.

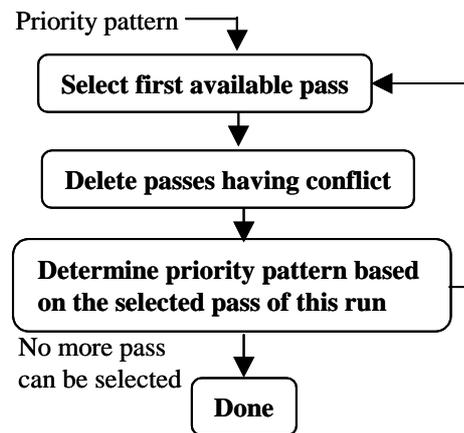


Figure 6: Pass Selection Logics

Since thrusting maneuvers require more than half of working days, another script was generated to accommodate the scheduling when there are burn activities. The satellite, which is performing the orbit raising maneuver takes the first 4 consecutive passes starting from a specific time of a day. The selection for the subsequent passes follows the logics described before. One can find there was a data jump in Figure 3 around the end of July 2006, which is when NSPO started to apply the pass scheduling scripts.

Currently, FORMOSAT-3 constellation is using ground stations located at Kiruna (KIR) and Fairbanks (FBK) for data dumps. The ultimate goal is to have 84 dumps per day. The first action for the team was to optimize the data dump and to do the orbit phasing. The team not only adjusted the

phasing for those spacecraft at final altitude, we also performed burns to make the phasing at the argument of latitude for those spacecraft at the parking orbit. When the analysis was performed, there were three spacecraft in final altitude and three spacecraft at parking altitude, the number of scheduled passes per day was 42~48. Then the team performed an analysis to understand what else can increase the number of data dumps. The first case study was to add more ground stations. Refer to Table 2 for the enhancement if McMurdo and Chung-Li (CHL) are added to the system to downlink science data.

Table 2: Dump Number vs. Ground Stations

Stations	Dumps/day 3 SC at final orbit	Dumps/day Final constellation
FBK+KIR	42~48	51~54
FBK+KIR +McMurdo	58~64	67~69
FBK+KIR +McMurdo+CHL	64~74	74~76

Another case study was to adjust the operations of the ground antenna angle from 0-deg to 0-deg elevation angle to a higher value. Table 3 shows the enhancement if 7-deg elevation angle is applied.

Table 3: Dump Number vs. Ground Antenna Operations Angles

Stations	Dumps/day 3 SC at final orbit	Dumps/day Final constellation
FBK+KIR (0deg)	42~48	51~54
FBK+KIR (7deg)	43~48	81~86

The operations team now operates the antenna from a 10-deg to 10-deg elevation angle since February. Currently, we have 66~72 passes per day.

COOPERATION WITH ORBITAL AND UCAR

NSPO and UCAR together to define the mission. NSPO served as the system integrator and executed a spacecraft subcontract with Orbital. To execute this program, Orbital worked closely with the U.S. Department of State to develop a Technology Assistance Agreement (TAA) and Technology

Transfer Control Plan (TTCP) that would reasonably regulate the amount of U.S. technology exported. The Defense Technical Services Administration monitored the execution of the program to verify compliance and to provide assistance where needed.

One of NSPO's primary objectives was more direct involvement in the development phase, which included the design of the spacecraft and the integration and test of an engineering development unit. Orbital therefore co-located the NSPO engineers with Orbital program personnel at its Dulles, Virginia, campus. A key challenge to configuring this office space was establishing a work environment that would integrate both teams, promote communications, and provide access to the facilities required, while still following the rules of the TAA.

Once the infrastructure was in place, the team got to work. Each subsystem lead from Orbital was paired with a subsystem lead from NSPO. Since the spacecraft design was based on a heritage bus, the original intent was to have Orbital provide guidance and instruction in the development and operation of the system and each subsystem. However, this task quickly evolved into a cooperative effort with the NSPO engineers not only learning how the system worked, but also making significant contributions to the development of the system, particularly with respect to the mission-specific aspects of the design. This cooperation was especially strong within the systems team, and it helped the development to proceed smoothly on a tight schedule.

That same cooperation carried over into the integration and test of the first flight model (FM1), which also occurred at Orbital's Dulles, Virginia, facility. Still co-located, the NSPO engineering team participated in the development of integration and test procedures, and NSPO technicians worked closely with Orbital's technicians in the fabrication of FM1. Then during the FM1 system test phase, Orbital and NSPO engineers worked side-by-side in performing the test procedures and analyzing the data. It is worth noting that the entire development phase, as well as production and test of FM1, was successfully accomplished by an international team while still meeting all of the requirements of the TAA.

While the team in the U.S. was integrating and testing FM1, the NSPO team in Taiwan was preparing for integration and test of the remaining five spacecraft (FM2 - FM6). Once FM1 was

completed, Orbital shipped production kits to Taiwan, where NSPO took the lead in producing FM2 - FM6 at its facility in Hsin-Chu, Taiwan. During this phase of the project, Orbital engineers provided support to the NSPO production team, answering questions and conducting a parallel troubleshooting effort when problems arose. Meanwhile, NSPO conducted several mission operations simulation and invited Orbital and UCAR to participate part of them. This program configuration was effectively a role reversal from the development phase, and it extended through launch and early orbit operations.

All six spacecraft were successfully launched in April 2006 and have been providing on-orbit service for over a year. The NSPO team is leading the mission operations task with support from Orbital and UCAR. Together, the team reviews the performance of each spacecraft on a regular basis and analyzes conditions surrounding events and anomalies.

In addition, NSPO and UCAR have bi-weekly science operations teleconference to discuss the science data quality, the GOX firmware upload, the implementation of the various campaigns, the adjustment plan, and the enhancement tests as mentioned above.

It is really a challenge to operate a satellite without the complete flight control software source code that was not able to deliver to NSPO due to the technology transfer limitation imposed by the US Government. For FORMOSAT-3, this has been compensated by NSPO's involvement in design, development, and I&T. Although FORMOSAT-3 has encountered various anomalies, as described above, there has always been an operational solution to overcome the situation.

PROSPECT

Since FORMOSAT-3 has provided atmospheric data steadily for one year and it has been proven as the most accurate and stable space-borne thermometers, it is time to start thinking about the Follow On (FO) mission. Based on the lessons learned, there are two approaches to further increase the data volume and data latency. The first approach is to increase the number of satellites, but it will not be discussed in this paper because its advantage can be calculated easily from the number of satellites. The second approach is to make the GPS receiver to be capable of processing signals from GLONASS and Galileo.

Table 4 lists the constellation parameters of GPS, GLONASS, and Galileo. If the receiver can process the data from both GPS and GLONASS, the occultation number can be increased by a factor of 1.8. If Galileo is also considered, the occultation number can be increased by a factor of 2.9.

Table 4: Constellation Parameters of GPS, GLONASS, and Galileo.

	# of satellite	Altitude (km)	Inclination (deg)	Orbit planes	Satellite number per plane
GPS	24	20200	55	6	4
GLONASS	21	19140	64.8	3	7
Galileo	27	23222	56	3	9

Altitude of constellation is not a driving factor for occultation since the implementer can install the antenna based on the chosen altitude. However, inclination angle and the number of orbit planes do have direct impacts on the occultation distribution in terms of latitude. For easy illustration, the parameters of FORMOSAT-3 are used as the baseline except for inclination angle. The total occultation number per satellite per day is about 420. The occultation number with inclination angle of 0-deg, 24-deg, 48-deg, 72-deg, 98.6-deg (sun synchronous) of an 800-km altitude orbit is simulated and the results are shown in Figure 6. From Figure 6, one can see the low inclination orbit can collect more data at low latitude and high inclination orbit can have more data at high latitude.

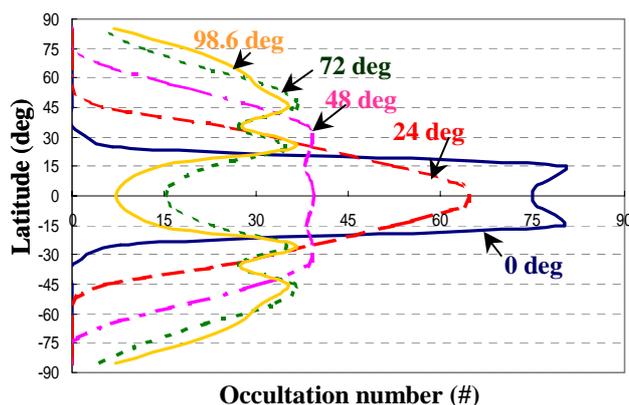


Figure 6: Occultation Number/Satellite/Day for Different Inclination Angles

In fact, the area of low latitude is larger than that of high latitude in terms of per degree latitude. So we need to evaluate the distribution in terms of area. In

Figure 7, the number is the total area divided by the total occultation number from the northern and southern hemispheres. In other words, the smaller is the number, the denser is occultation distributed. FORMOSAT-3's inclination angle is 72 degrees, the occultation distribution is sparser at low latitudes.

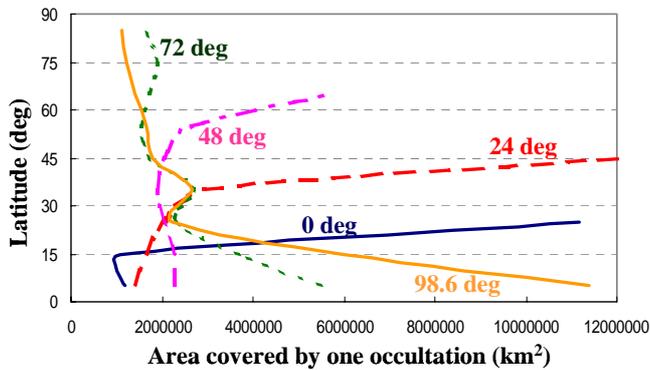


Figure 7: The Area Covered by One Occultation for One Satellite in One Day

For analysis, a constellation of combining inclination angles of 24 deg and 72 deg is adapted for FO mission. In such condition, we can have more homogeneous distribution of occultation. Figure 8 shows the occultation distribution of FORMOSAT-3 mission and the proposed FO mission. For easy comparison, the FO still has 6 low-earth-orbit satellites in total but with three satellites at 24-deg inclination angle orbit and the other three satellites at 72-deg inclination angle orbit. One can find the occultation distribution is more homogeneous with FO. Figure 8 also shows the occultation distribution if FO equipped with GNSS receiver. GNSS means a receiver can receive signals from GPS, GLONASS, and Galileo.

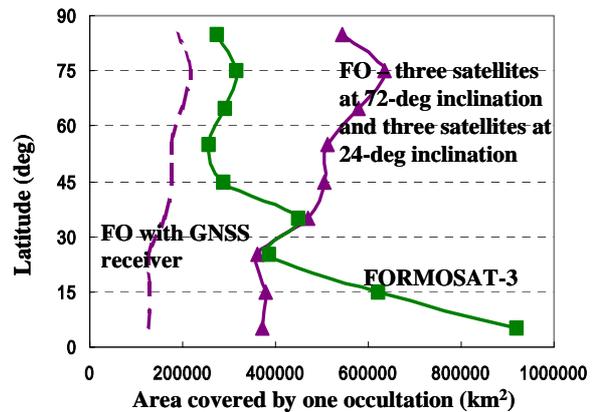


Figure 8: The Area Covered by One Occultation

Another parameter to be discussed in this paper is the number of orbit planes. After deducting the time consumed in early orbit check out, FORMOSAT-3 spends about 18 months for constellation deployment. During the period of thrusting burns, the data volume is reduced due to limited data collected from the thrusting spacecraft and more ground passes are scheduled to support the thrusting activities. Therefore, the proposal for FO is to put three satellites in the same orbit plane so that we can adjust the argument of latitude only. The deployment period can be shortened to within 2 months and the thrusting period can be reduced by a factor of 0.2. One may question why FORMOSAT-3 needs to take such time period for orbit plane separation. The answer is the spread of orbit plane can collect the globally distributed soundings sooner. Figure 9 tells us the coverage for FORMOSAT-3 vs. FO. For one revolution, the FORMOSAT-3 constellation can cover ~25 % of earth surface area and for 14 revolutions (about one day) FORMOSAT-3 can cover ~ 92% of area. The definition of the coverage is the percentage of the grid. One grid is an area with 10 deg latitude by 10 deg longitude. If the occultation occurs at the same grid, it is regarded as one grid occultation. Concerning the coverage, 6 orbit planes is always better than 2 orbit planes. That is why FORMOSAT-3 constellation is contemporarily unique. Since the benefits of the RO technique have been proven in many features, there are some projects booming after FORMOSAT-3 mission. As the FO proceeds its way, the United States, Europe, and India are also developing the next generation. The concern of separated orbit planes will go way.

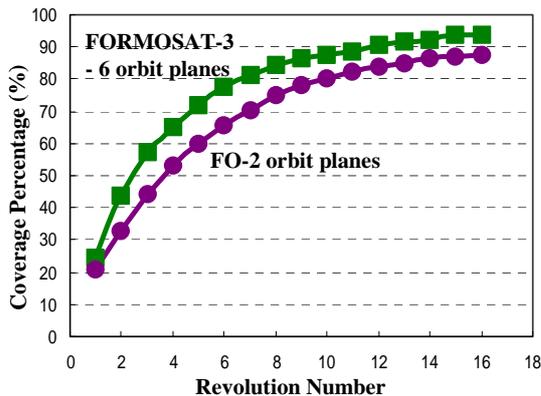


Figure 9: The Sounding Data Coverage Through Revolution

CONCLUSION

Through steadily maintain spacecraft in good health and continuous enhancement to FORMOSAT-3/COSMIC, the provision of atmospheric profiles in terms of data volume and data latency have been proven having great benefits for weather forecast and atmospheric/ionospheric research. NSPO has gained a lot of unique practical experiences and lessons learned by going through the mission definition, system design, system integration & test, launch integration & operations and mission operations through cooperating with international agencies. A follow-on program is promoted to continue the meaningful mission, which will bring the evolutionary view to realize and predict the weather and climate of the planet Earth.

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