

Space and Ground Segment Performance of the FORMOSAT-3/COSMIC Mission: Four Years in Orbit

C.J. Fong, D. Whiteley, E. Yang, K. Cook, V. Chu, B. Schreiner, D. Ector, P. Wilczynski, T.Y. Liu, and N. Yen

Anonymous Referee #1

Received and published: 17 March 2011

Referee general comment:

The paper reviews FORMOSAT-3/COSMIC (F3/C) mission and system performances after 4 years in orbit, trying to put in evidence all the problems arose, their causes and what should be done in the future follow on FORMOSAT-7/COSMIC-2 (F7/C2) operative mission in order to outperform the good results already obtained up to now.

The paper well describes all what happens to F3/C satellites and payloads during the 4 year in orbit and fit quite well with AMT topics. It does not present novel concepts or ideas since it is a review paper, but the description given allow interested readers to well understand what have been main problems occurred. The performances have been analyzed considering several point of views (mission, constellation, spacecraft, Radio Occultation payload, spacecraft batteries, ground station) and given a very honest overview, highlighting also lacks noticed since mission was planned.

The presentation is well structured. As a general comment, authors used too much acronyms inside the text, and sometimes the readability is definitively lost. As a suggestion, in some cases the authors should avoid the acronym, directly using the extended words. Several times the authors refers to “working capabilities” which are not defined for who is not an expert (i.e.: Nadir mode, Nadir-Yaw mode, ...). Finally, there are a lot of references to papers owning to the author, but from their title it is difficult to understand if they are appropriate or not when they are referenced. Moreover some cited papers are not reported in the bibliography list.

Response:

- **Thank you for your comments.**
- **The authors have responded to all of the individual specific**

comments and technical corrections, see responses provided below.

- For acronym issues, see response of the specific comment #20.
- For reference issues, please see response of the specific comment #5, #6 and #38.

Please read carefully before final submission to avoid typos. For a detailed revision, please check the attached **Supplement** pdf file, listed below:

Supplement

Referee specific comments and technical corrections:

1. p. 600, row 5: ...the atmospheric profiles derived by processing Radio Occultation signals are retrieved... instead of the Radio Occultation signals are retrieved

Response:

- Thanks for the suggested modification.
- Modify from "The radio occultation signals are retrieved in near real-time for global weather/climate monitoring, ... " to "The **atmospheric profiles derived by processing** radio occultation signals are retrieved in near real-time for global weather/climate monitoring, ..." (page 600, row 5-6)

2. p. 600, row 12: pls use a more appropriate term instead of transitions

Response:

- Modify the paragraph from "A proposed follow-on mission transitions the program from the current experimental research system to a significantly improved real-time operational system, ..." to "With the proposed follow-on mission, the current experimental research mission will evolve into a significantly improved real-time operational mission, ..." (page 600, row 12-14)

3. p. 600, row 15: 12 satellites and data latency of 45 min are two completely different aspects. Please address better the point

Response:

- Modify the paragraph from "The follow-on mission as planned will consist of 12 satellites with a data latency of 45 min, ..." to "The

follow-on mission as planned will consist of 12 LEO satellites (compared to 6 satellites for current mission) with data latency requirement of 45 minutes (compared to 3 hours for current mission), ..." (page 600, row 14-15)

4. p. 601, row 6: Earth's observation instead of Earth

Response:

- Thanks for the suggested change.
- Modify the paragraph from "... demonstration of GNSS-RO mission to Earth ..." to "... demonstration of GNSS-RO mission to Earth's observation ..." (page 601, row 6)

5. p. 601, row 7-9: Ware, Kursinski, Rius, Hall, Melbourne references are not reported in the References list.

Response:

- Thanks for the correction – it was an oversight.
- Add reference of Ware (1996) to References list as follows:
"Ware, R., Rocken, C., Solheim, F., Exner, M., Schreiner, W., Anthes, R., Feng, D., Herman, B., Gorbunov, M., Sokolovskiy, S., Hardy, K., Kuo, Y., Zou, X., Trenberth, K., Meehan, T., Melbourne, W., and Businger, S.: GPS sounding of the atmosphere from low earth orbit: Preliminary results, Bull. Am. Meteorol. Soc., 77(1), 19-40, 1996." (page 619, row 5)
- Add reference of Kursinski (1996) to References list as follows:
"Kursinski, E. R., Hajj, G. A., Bertiger, W. I., Leroy, S. S., Meehan, T. K., Romans, L. J., Schofield, J. T., McCleese, D. J., Melbourne, W. G., Thornton, C. L., Yunck, T. P., Eyre, J. R. and Nagatani, R. N.: Initial results of radio occultation observations of Earth's atmosphere using the Global Positioning System, Science, 271(5252), 1107-1110, 1996." (page 618, row 28)
- Add reference of Rius (1998) to References list as follows:
"Rius, A., Ruffini, G., and Romeo, A.: Analysis of ionospheric electron-density distribution from GPS/MET occultations, IEEE Trans. Geosci. Remote Sens., 36(2), 383-394, 1998." (page 618, row 31)
- Add reference of Hajj (2000) to References list as follows:
"Hajj, G. A., Lee, L. C., Pi, X., Romans, L. J., Schreiner, W. S., Straus, P. R., and Wang, C.: COSMIC GPS ionospheric sensing and space

weather, Terr. Atmos. and Ocean. Sci., 11(1), 235-272, 2000.” (page 618, row 19)

- **Add reference of Melbourne (2005) to References list as follows:**
“Melbourne, W. G.: Radio Occultation Using Earth Satellites: A Wave Theory Treatment, John Wiley & Sons, Inc., ISBN 0-471-71222-1, 2005.” (page 618, row 31)

6. p. 601, row 9-15: No reference to the GRAS on-board METOP-A mission is given. No reference to ROSA on-board OCEANSAT-2 is given. Please update the list.

Response:

- **Modify the paragraph from “... and the twin Global GNSS Radio Occultation Mission for Meteorology, Ionosphere & Climate Gravity Recovery and Climate Experiment (GRACE) missions (in 2002).” To “..., the twin Global GNSS Radio Occultation Mission for Meteorology, Ionosphere & Climate Gravity Recovery and Climate Experiment (GRACE) missions (in 2002), the Europe's meteorology operational satellite series A (MetOp-A) (in 2006) (Luntama et al., 2008), and the Oceansat-2 (in 2009) (Perona et al., 2007).” (page 601, row 9-15)**
- **For MetOp paper, the authors add reference of Luntama (2008) to References list as follows:**
“Luntama, J.-P., Kirchengast, G., Borsche, M., Foelsche, U., Steiner, A., Healy, S., von Engel, A., O'Clerigh, E., Marquardt, C.: Prospects of the EPS GRAS Mission For Operational Atmospheric Applications, Bull. Am. Meteorol. Soc., 89(12), 1863-1875, doi: 10.1175/2008BAMS2399.1, 2008.” (page 618, row 31)
- **For Oceansat-2 , the authors add reference of Perona (2007) to References list as follows:**
“Perona, G., Notarpietro, R., Gabella, M.: GPS radio occultation on-board the OCEANSAT-2 mission: An Indian (ISRO) – Italian (ASI) collaboration, Indian Journal of Radio Space Physics, 36(5), 386-393, 2007.” (page 618, row 31)

7. p. 601, row 19: ...operational exploitation of global... instead of ... operational global...

Response:

- **Modify the paragraph from “... new era for near real-time operational**

global navigation satellite system (GNSS) ...” to “... new era for near real-time operational **exploitation of global navigation satellite system (GNSS) ...” (page 601, row 19-20)**

8. p. 601, row 25-28: the sentence is bad written.

Response:

- **Modify the paragraph from “FS-7/C-2 will incorporate the next generation GNSS-RO receiver, an improved spacecraft design, and a greater ground network for data download as a follow-on constellation mission to FS-3/C (Chu et al., 2008; Fong et al., 2008c, 2009a,b).” to “FS-7/C-2 will incorporate the next generation GNSS-RO receiver, **a new and significantly** improved spacecraft design, and a greater ground **communication** network for data download (Chu et al., 2008; Fong et al., 2008c, 2009a,b).” (page 601, row 25-28)**

9. p. 602, row 1-2: did you intend that FS-7/C-2 will provide the next generation of GNSS-RO data to scientific community? What does next generation of GNSS-RO data users mean?

Response:

- **Yes, the authors’ intention is that FS-7/C-2 will provide the next generation of GNSS-RO data to the scientific community and the global weather centers.**
- **Modify the paragraph from “FS-7/C-2 is intended to provide continuity of GPS-RO data as well as provide the next generation of GNSS-RO data users.” to “FS-7/C-2 is intended to provide continuity of **the** GPS-RO data as well as the next generation of GNSS-RO data **to the scientific community and the global weather centers.**” (page 602, row 1-2)**

10.p. 602, row 3-6: The objectives you described are the actual objectives of FS-3/C. What will be the real innovation of the follow-on mission? The operativity? Please better address this crucial point.

Response:

- **As previously mentioned in page 600, row 12-14, FS-7/C-2 mission is a follow-on FS-3/C mission that transitions the current experimental research mission of FS-3/C into a significantly improved “real-time operational” mission. The data latency requirement has changed from 3 hours (near-real-time) of current FS-3/C mission to 45**

minutes (real-time) of FS-7/C-2 mission. (page 602, row 3-6)

11.p. 602, row 11: pls use a more appropriate term instead of comprised

Response:

- **Modify the paragraph from “The FS-3/C space segment is comprised of six Low-Earth-Orbit (LEO) satellites in a constellation-like formation.” to “The FS-3/C space segment **includes** six Low-Earth-Orbit (LEO) satellites in a constellation-like formation.” (page 602, row 12-13)**

12.p. 602, row 17: pls use a more appropriate sentence instead of “was to have”

Response:

- **Modify the paragraph from “The intended satellite constellation was to have six orbit planes at 800km ...” to “The satellite constellation was **planned** to have six orbit planes at 800km ...”**

13.p. 602-603 row 25-7: It is not clear what are main differences between Local and Remote Tracking Stations.

Response:

- **Both local tracking station and remote tracking station are all ground tracking stations. The main difference between local and remote tracking stations is that the local tracking station is close to where the SOCC located, while the remote tracking station is located significantly far from where the SOCC located. The SOCC is located in Taiwan, so are the two local tracking stations as already mentioned in page 603, row 2-3.**

14.p. 603, row 12-15: Will double differences be used to extract excess-phases? If it is true please specify.

Response:

- **The mission uses single difference to extract excess-phases.**

15.p. 603, row 24: why did you use “etc.”? This means that other meteo centers can in future operatively exploit the follow-on mission RO data? If it so, better address the point. The last sentence should be written before the list of Meteo Centers...

Response:

- The listed weather centers in the paragraph are those that have made the announcement of using RO data in their numerical weather prediction (NWP) models. In the future the authors expect there will be more international weather centers using the FS-7/C-2 RO data.
- Modify the paragraph from “... French National Meteorological Service (Météo France), and Taiwan’s CWB, etc.” to “... French National Meteorological Service (Météo France), and Taiwan’s CWB.”

16.p. 604, row 5-6: pls use a more appropriate sentence instead of “the spacecraft...as anticipated”

Response:

- After two years of spacecraft mission life, the FS-3/C spacecraft has started to show some hardware degradation, and even worse, some hardware failure. Since the spacecraft design life is five years, the spacecraft is anticipated to have serious hardware failure when approaching its five year design life.
- In order to clarify the difference between mission life and design life, the authors modify previous paragraph from “The constellation was intended to be a two-year experimental mission with a five-year spacecraft design life.” to “The **experimental** constellation was **defined** to have a two-year **spacecraft mission life**, and the spacecraft design life **is five years**.” (page 604, row 4-5)

17.p. 605, row 1-15: please describe better what Fig. 1 shows before starting the description of the performances. Since performances are correlated with beta angle, please introduce here this angle instead of in p 606, row 2-4.

Response:

- Delete the paragraph “The beta angle is defined as the angle between the spacecraft orbit plane and the vector from the sun that determines the percentage of time the spacecraft in low Earth orbit spends in direct sunlight, absorbing solar energy.” as shown in page 606, row 2-4.
- Modify the paragraph from “... performance vs. spacecraft sun beta angle. The GOX payload ...” to “... performance vs. spacecraft sun beta angle. **The beta angle is defined as the angle between the**

spacecraft orbit plane and the vector from the sun that determines the percentage of time the spacecraft in low Earth orbit spends in direct sunlight, absorbing solar energy. The GOX payload ...” (page 605, row 1-2)

18.p. 605, row 24-25: for the four year since... is repeated

Response:

- **Modify the paragraph from “Figure 2 shows the four-year statistics for the number of daily occultation events for (a) atmosphere profiles for the four years since launch and (b) ionosphere profiles of electron density for the four years since launch.” to “Figure 2 shows the four-year statistics for the number of daily occultation events for (a) atmosphere profiles and (b) ionosphere profiles of electron density.” (page 605, row 23-25)**

19.p. 606, row 7: what does “occulting precision orbit determination antenna” mean? In my knowledge, the occultation antenna is different from the antenna necessary for POD purposes, isn’t it?

Response:

- **Although it was called POD antenna, in this mission the POD antenna has two functions (or purposes): one is to provide precision orbit determination, and the other is to perform ionospheric radio occultation processing function. The occultation antenna only performs atmospheric radio occultation processing function.**

20.p. 606, row 9-10: POD1 or POD2. What does 1 or 2 mean. In general, several times you used a number after some system component. A Table showing all these conventions should be added

Response:

- **The authors have put a note under Table 4 to describe what the meaning of POD1 and POD2 are. For different tables, the authors have put a necessary note to describe the acronym shown in that table.**
- **POD1 is Precision Orbit Determination (Antenna) No. 1 and POD2 is Precision Orbit Determination (Antenna) No. 2. There are two POD antennas and two OCC antennas on the spacecraft, POD1 and OCC1 are on the same side of the spacecraft, and POD2 and OCC2 are on**

the other side of the spacecraft. The POD1 and OCC1 antenna required longer cable than POD2 and OCC2 to connect to the GOX mission payload.

- For the acronym comments. The authors here provide an acronym list and will include it at the end of the paper. As follows: (page 619, row 11~)

Appendix Acronyms and Abbreviations

ACE	Attitude Control Electronics
ADCS	Attitude Determination and Control Subsystem
AFWA	Air Force Weather Agency
Ant#	Antenna No. #
ATT	Attitude
BCR	Battery Charge Regulator
C&DH	Command and Data Handling
CDAAC	COSMIC Data Analysis and Archive Center
CHAMP	Challenging Minisatellite Payload
COSMIC	Constellation Observing Systems for Meteorology, Ionosphere, and Climate
Canada Met	Canadian Meteorological Centre
CLASS	Comprehensive Large Array-Data Stewardship System
CSSA	Coarse Sun Sensor Assembly
CSSA#	Coarse Sun Sensor Assembly no. #
CWB	Central Weather Bureau
DC	Direct Current
dMdC	Derivative of Battery Molecular to Charge
DPC	Data Processing Center
DPS	Data Processing System
ECMWF	European Centre for Medium-range Weather Forecast
EPS	Electrical Power Subsystem
ESPC	Environmental Satellite Processing Center
FB	Firmware Build
FC	Flight Computer
FCDAS	Fairbanks Command and Data Acquisition Station
FDC	Failure Detection Correction
FM	Flight Model
FM#	Flight Model no. #

FPGA	Field Programmable Gate Array
FS-3	FORMOSAT-3
FS-7/C-2	FORMOSA SATellite mission no.7/ Constellation Observing Systems for Meteorology, Ionosphere, and Climate mission no. 2
FSW	Flight Software
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
GPS/MET	GPS/Meteorology
GOX	GPS Occultation Receiver
GPSR	GPS Receiver
GRACE	Gravity Recovery and Climate Experiment
GTS	Global Telecommunications System
I&T	Integration and Test
IV&V	Independent Verification and Validation
JMA	Japan Meteorological Agency
JPL	Jet Propulsion Laboratory
JSCDA	Joint Center for Satellite Data Assimilation
KSAT	Kongsberg Satellite Services Ground Station
LEO	Low-Earth-Orbit
LOS	Loss of Signal
LTS	Local Tracking Station
MAG	Magnetometer
Météo-France	French National Meteorological Service
MIU	Mission Interface Unit
NARL	National Applied Research Laboratories
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NSC	National Science Council
NSF	National Science Foundation
NSOF	NOAA's Satellite Operations Facility
NSPO	National Space Organization
NWP	Numerical Weather Prediction

OCC#	Occultation No. #
OSC	Orbital Sciences Corporation
PCM	Power Control Module
PL	Payload
POD	Precision Orbit Determination
POD#	Precision Orbit Determination No. #
RF	Radio Frequency
RF#	Radio Frequency No. #
RFI	Radio Frequency Interference
RO	Radio Occultation
RTS	Remote Tracking Station
RWA	Reaction Wheel Assembly
SAA	South Atlantic Anomaly
SAC-C	Satellite de Aplicaciones Cientificas-C
SADA	Solar Array Drive Assembly
S/C	Spacecraft
SFTP	Secure File Transfer Protocol
SNR	Signal-to-Noise Ratio
SOC	State-of-Charge
SOCC	Satellite Operations Control Center
SOH	State-of-Health
SSR	Solid State Recorder
TACC	Taiwan Analysis Center for COSMIC
TBB	Tri-Band Beacon
TBR	To Be Reviewed
TDRSS	Tracking and Data Relay Satellite System
TEC	Total Electron Content
TIP	Tiny Ionospheric Photometer
UCAR	University Corporation for Atmospheric Research
UKMO	United Kingdom Meteorological Office
USA	United States of America
USAF	United States Air Force
USN	United Service Network
VC#	Virtual Channel No. #
VIDI	Velocity, Ion Density and Irregularities
WCDAS	Wallops Command and Data Acquisition Station
ZTD	Zenith Tropospheric Delay

21.p. 606, row 11-13: the sentence is bad written

Response:

- **Modify the paragraph from “In February 2009, the FM6 GOX SNR decreased to where the GOX operating temperature was not over its red high limit that will shut down the GOX power by the autonomous control system.” to “In February 2009, the FM6 GOX SNR decreased, however, the GOX operating temperature was not over its red high limit required to shut down the GOX power autonomously.”**

22.p. 606, row 15: what does flip-flopped mean?

Response:

- **The ‘flip-flop’ means the spacecraft will rotate 180 degrees when the spacecraft sun beta angle is changed to 0 degree every ~57 days. This kind of design will save half of the solar panel structure and so does the generated power. The solar array mechanism could also be reduced from 2 axes into 1 axis.**

23.p. 606, row 19-23: the sentence is bad written. It is not clear what are you describing.

Response:

- **Delete the paragraph “In order to assess the GOX payload instrument performance, all of the other payloads were powered off for the GOX software revision upload, and there are only few events on some spacecraft when the GOX payload instruments were powered off for trouble shooting.” (page 606, row 19-23)**

24.p. 606, row 25: what is the “nadir” mode?

Response:

- **The definition for “Nadir mode” in this mission is one of the attitude control subsystem modes which is similar to the Nadir-Yaw mode except it is focused on reducing nadir pointing error while controlling yaw rate only (neglecting yaw angle).**

25.p. 607, row 16: what is the “nadir-Yaw” mode?

Response:

- **The definition for “Nadir-Yaw mode” in this mission is one of the attitude control subsystem modes to maintain nadir pointing and fixed yaw pointing in the local vertical local horizontal (LVLH)**

attitude.

26.p. 607, row 23: what does “stabilize/safehold/thrust” mode mean?

Response:

- **“Stabilize/Safehold/Thrust mode” in this mission are all belong to the attitude control subsystem modes, and their definition are as follows:**
- **Stablize mode: A mode to recover from tumble by damping rates and align S/C z-axis with geomagnetic field.**
- **Safehold mode: A mode to initialize attitude reference system and transition into normal mode.**
- **Trust mode: A mode to perform orbit-raising.**

27.p. 607, row 25: upexpected or unexpected?

Response:

- **Change from “upexpected” to “unexpected” (page 607, row 25)**

28.p. 607, row 25: deviation instead of diveation.

Response:

- **Change from “diveation” to “deviation” (page 607, row 25)**

29.p. 608, row 1: the acronym TT & C is defined after (row 26).

Response:

- **Change from “a ground TT &C passes.” to “a ground Telemetry Tracking and Control (TT &C) passes.” (page 608, row 1)**
- **Change from “NSPO also provides two Telemetry Tracking and Control (TT &C) ...” to “NSPO also provides two TT &C ...”. (page 608, row 26)**

30.p. 608, row 12: what does variation rate mean? Time variation and rate are synonyms... Is it a technical idiom? Could you specify?

Response:

- **Table 5 shows the average variation rate per year of the battery for each spacecraft. This table summarizes and provides the readers an idea of how we identify the degradation rate of the spacecraft battery which is a critical life-limited component. The charts that generated the average variation rate per year values shown in this table are analyzed by using a method called Hilbert-Huang**

Transformation (HHT). And the definition of the parameters shown in the table is listed as follows:

- **Battery SOC Max [Ah] = [the maximum variation value of the battery SOC HHT trend data – the minimum variation value of the battery SOC HHT trend data] / 4 years.** This battery SOC HHT trend data is taken from the maximum value of battery SOC [unit: Amp-Hour] per day database, that is, one value per day.
- **Battery SOC Min [Ah] = [the maximum variation value of the battery SOC HHT trend data – the minimum variation value of the battery SOC HHT trend data] / 4 years.** This battery SOC trend data is taken from the minimum value of battery SOC [unit: Amp-Hour] per day database, that is, one value per day.
- **Battery V mean [V] = [the maximum variation value of the battery voltage HHT trend data – the minimum variation value of the battery voltage HHT trend data] / 4 years.** This battery voltage HHT trend data is taken from the mean value of battery voltage [unit: V] per day database, that is, one value per day.
- **Battery V min [V] = [the maximum variation value of the battery voltage HHT trend data – the minimum variation value of the battery voltage HHT trend data] / 4 years.** This battery voltage HHT trend data is taken from the minimum value of battery voltage [unit: V] per day database, that is, one value per day.
- In this paper, the authors were not able to provide the battery trending data and associated figures due to the paper constraints. Also, there is too much detail to show in this paper to reflect this important issue. This issue is actually worth the authors writing another paper to describe this issue in the future. Recently, we presented our preliminary results in the 5th FORMOSAT-3 Data Users' Workshop held in Taipei, Taiwan on 13~15 April, 2011 with the following information:

Chen-Joe Fong, Tsung-Ping Lee, Yetmen Wang, Amy Liou, and Shan-Kuo (Eddy) Yang, "Applications of Time-Frequency and Hilbert-Huang Transform (HHT) to FORMOSAT-3 Satellite System Key Parameters Trending Data Studies," 5A-03, 5th FORMOSAT-3 Data Users' Workshop held in Taipei, Taiwan on 13~15 April, 2011.

mean?

Response:

- “Time-tagged commands loads” means the command loads are stored in the Spacecraft memory, and the Spacecraft will execute these commands based on the UTC time stamped on each command.
- During the ground station contacts the Spacecraft will be controlled by the Satellite Operation Control Center (SOCC). The SOCC is responsible for scheduling the use of ground receiving stations and preparing commands, command files, data load, & firmware loads to be uplinked to satellites. For selected passes, the SOCC will send the “time-tagged commands loads” to the spacecraft and download back-orbit SOH data for trending analysis. These command files are generated by the SOCC, forwarded to the TT&C station, and transmitted to the intended Spacecraft on an uplinked data stream.

32.p. 609, row 23: what is the Phoenix reset? Please specify

Response:

- Phoenix mode is defined as an off state of the satellite when satellite is out of battery power. The “Phoenix reset” is used to support satellite phoenix mode recovery after the power condition is back to a stable condition. Phoenix reset was recovered by sending a series of configuration commands so that both the satellite and payload could resume normal operation as soon as possible.
- In order to introduce the concept of ‘Phoenix’. Modify the paragraph “... Phoenix resets. Each ...” to “... Phoenix resets. **Phoenix is an off state of the satellite when satellite is out of battery power and is used to support satellite recovery when power condition is back to stable. Each ...**”. (page 609, line 23.)

33.p. 610, row 18: world wide web instead of open internet

Response:

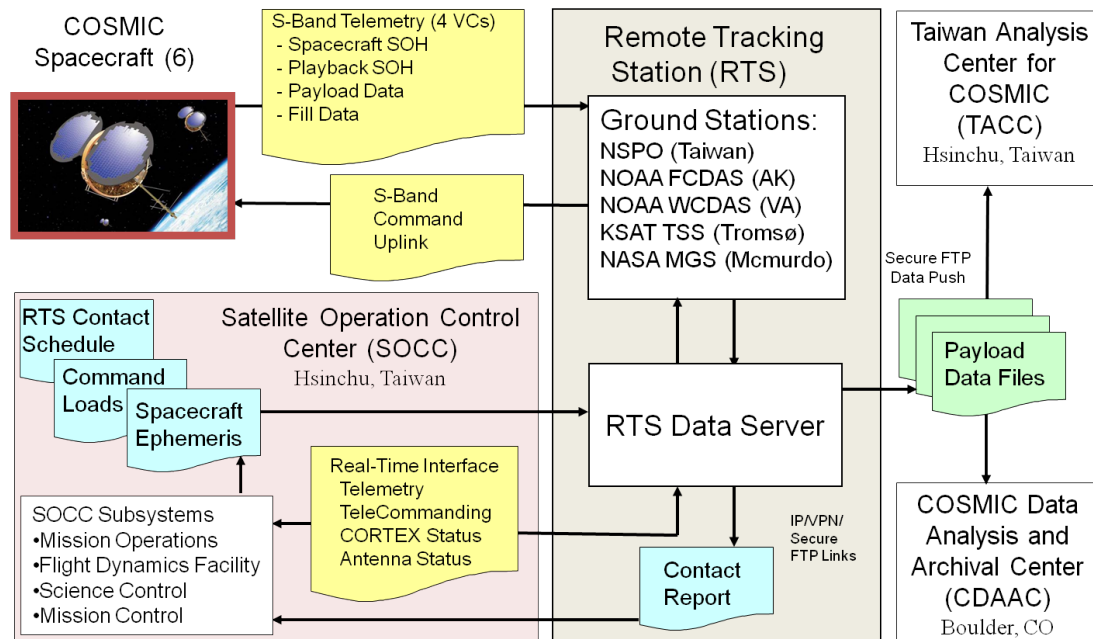
- Modify from “... the open internet via Secure File Transfer Protocol (SFTP)...” to “the world wide web via Secure File Transfer Protocol (SFTP)...” (page 610, row 18)

34.p. 610, row 18-25: From Fig 4 it is clear that someone will make available Ephemeris and Schedule (for operations? It is not clear what Schedule

mean). Who? As far as the data coming from ground fiducial network are concerned, here nothing is said. The overall aspects that guarantee the data latency expected should be addressed better here. A better detailed description of Fig. 4 should be given here.

Response:

- **Insert the following paragraph between the first and second paragraph: “FS-3/C command uplink and telemetry downlink activities are coordinated by the NSPO SOCC with the Remote Tracking Stations (RTS). Once upcoming FS-3/C passes have been deconflicted with other ground station activities, SOCC generates spacecraft ephemeris, spacecraft command uploads and ground schedules and distributes the files to the ground stations. All contacts with the spacecraft are established and conducted autonomously via schedules executed at the SOCC and the RTS, with the exception of any real-time commanding conducted by Mission Control personnel at SOCC. During the pass, the spacecraft and ground system are autonomously monitored by SOCC as the data stored on the spacecraft is downlinked to the ground. After the spacecraft contact has ended, all connections are autonomously terminated and the RTS Data server forwards the Contact Report to the SOCC as well as the Payload Data Files to the Data Centers for processing.”**
- **Replace Figure 4 with the following:**



35.p. 610, row 24: the time related to the spacecraft loss of signal is intended as the time when the satellite-ground connection cannot be established because of ground station is not yet in view from the spacecraft download antenna? Please specify.

Response:

- **Loss of Signal (LOS)** is standard term used to identify the end of a spacecraft contact. The time specified in row 24 is the amount of time it takes the data captured at the ground station to transfer to the data processing center after the ground station has lost signal with the spacecraft at the scheduled end of the contact.
- Modify last sentence (rows 23&24) to read “Statistics show that mission data arrives at CDAAC for processing within 15 minutes after spacecraft loss of signal (LOS, end of scheduled spacecraft contact with the ground station) 97% of the time.”

36.p. 611, row 20-24: what does 16000 ho mean? Acronyms CERTO and GTS are not defined.

Response:

- **CERTO** means “Coherent Electromagnetic Radio Tomography.” CERTO is another name of TBB in other mission. And **GTS** means “Global Telecommunications System”

- **Modify the paragraph from “...ground-based CERTO/TBB observations.” to “...ground-based TBB observations.” (page 611, row 22)**
- **Modify the paragraph from “... processed and delivered (via GTS) to operational centers...” to “... processed and delivered **via Global Telecommunications System (GTS)** to operational centers...”**

37.p. 613, row 1: is it correct that spacecraft state of health is directly related to the payload performance? I think that vice versa is better.

Response:

- **The spacecraft state of health is directly correlated to the payload performance instead of related.**
- **Modify the paragraph from “The spacecraft state of health is directly related to the payload performance.” to “The spacecraft state of health is directly **correlated** to the payload performance.” (page 613, row 1)**

References:

38.Liou et al. (row 28, pag. 618) is never cited in the paper.

Response:

- **Modify the paragraph from “... Kuo et al., 2000, 2004, 2008).” to “... Kuo et al., 2000, 2004, 2008; Liou et., 2007).” (page 601, row 18)**

39.Tab. 1: What does “Low Beta Operating” means? Please add a description in the caption or in the paper paragraph where you describe Tab. 1.

Response:

- **“Low Beta Operating” means operating the payload instrument while the spacecraft is flying at the low sun beta angle period.**
- **Modify from “C&DH=Command and Data Handling” to
“C&DH=Command and Data Handling
Low Beta = low sun beta angle” (page 620, bottom line of Table 1)**

40.Tab. 1: You use S/C or SC to define SpaceCraft number? Please use always the same acronym.

Response:

- **Thanks for the suggested change.**

- Use S/C instead of SC to define “Spacecraft” in this paper.
- Change “SC” to “S/C” in Table 1. (page 620, row 3)
- Change “SC” to “S/C” in Table 4. (page 623, row 3)
- Change “SC downtime events will ...” to “S/C downtime events will ...” in Table 8 (page 629, row 12)
- Change “errors that cause SC” to “errors that cause S/C” in Table 8 (page 629, row 16)
- Change “SC lost valuable telemetry” to “ S/C lost valuable telemetry” in Table 8 (page 629, row 21)
- Change “the C&DH (and SC) can” to “the C&DH (and S/C) can” in Table 8 (page 629, row 33)

41. Tab. 2: What does “Operation solution” mean?

Response:

- “Operation Solution” means trouble shooting the on-orbit spacecraft problem by using the ground operation solution other than changing the source code of the spacecraft flight software or the payload firmware build (FB).
- Detailed operation solution for some major spacecraft anomalies and technical difficulties could be found from the following paper by some of our co-authors:
E. Yang, V. Chu, V. Chang, A. Hsiao, V. Huang, T. Tsai, C.-J. Fong, and R. Lo, “Operations solutions to spacecraft anomalies and technical difficulties,” presented at the FORMOSAT-3/COSMIC Workshop—Early Results and IOP Campaign, Taipei, Taiwan, Nov. 28–Dec. 1, 2006.

42. Tab. 2 and Tab. 4: here you made a lot of reference to PODn, ANTn, RFn, OCCn. See my comment for p. 606, row 9-10

Response:

- Please see the authors’ response to comment #20.

43. Tab. 3: some statistics should be added (i.e. atmo/iono profile per day)

Response:

- The table 3 has been updated to incorporate the atmo/iono profile per day and operation duration.
- Change the table 3 to the following table:

Atmosphere	FM1	FM2	FM3	FM4	FM5	FM6	Total
Operation Duration	1,397	1,282	1,173	1,424	1,401	1,302	1,442
Atmosphere Profiles Per Day	285.07	229.48	242.94	333.37	248.73	242.96	1468.06
Total Atmosphere Profiles	398,245	294,198	284,970	474,713	348,475	316,335	2,116,936
Ionosphere	FM1	FM2	FM3	FM4	FM5	FM6	Total
Operation Duration	1,293	1,284	1,173	1,423	1,286	1,300	1,442
Ionosphere Profiles Per Day	284.65	275.74	292.71	394.54	241.03	253.17	1571.4
Total Ionosphere Profiles	368,049	354,054	343,353	561,426	309,966	329,116	2,265,964

44. Tab. 5: see my comment for p. 608, row 12

Response:

- **Please see the authors' response to comment #30. And also the response to comment #45.**

45. Tab. 5: what does the number defined by the SOC (State of Charge, unit: Amp-Hour) mean?

Response:

- **Please also see the authors' response to comment #30.**
- **Battery SOC Max [Ah] = [the maximum variation value of the battery SOC HHT trend data – the minimum variation value of the battery SOC HHT trend data] / 4 years. This battery SOC HHT trend data is taken from the maximum value of battery SOC [unit: Amp-Hour] per day database, that is, one value per day.**
- **Battery SOC Min [Ah] = [the maximum variation value of the battery SOC HHT trend data – the minimum variation value of the battery SOC HHT trend data] / 4 years. This battery SOC trend data is taken from the minimum value of battery SOC [unit: Amp-Hour] per day database, that is, one value per day.**
- **Battery V mean [V] = [the maximum variation value of the battery voltage HHT trend data – the minimum variation value of the battery**

voltage HHT trend data] / 4 years. This battery voltage HHT trend data is taken from the mean value of battery voltage [unit: V] per day database, that is, one value per day.

46. Tab. 7, p. 626: IInd row, IIIrd column: RO observed occultations number instead of RO number

Response:

- **Change “RO number” to “RO observed occultations number” (page 626, row 33)**

47. Tab. 7, p. 627: Ist row, IInd column: the sentence in the second bullet is bad written

Response:

- **Change “- GOX instrument, POD cable link, and the POD antenna are assembled into the spacecraft without sufficient system level ground testing.” to “- **After GOX payload instrument, POD antenna cable link, and the POD antenna are assembled into the spacecraft, there is no sufficient system level ground testing during system level I&T.**”**

48. Tab 8: please describe in the caption what “single string design strategy” is.

Response:

- **“Single String Design Strategy” means there is no redundant key component in the design, so that when key components fail, the system could still survive and operate by switching to the redundant unit.**
- **The rationale of the “Single String Design Strategy” vs “Redundancy Design Approach” for this mission is as follows:
The spacecraft reliability was achieved by using a constellation system perspective to design the spacecraft. This makes the FORMOSAT-3/COSMIC spacecraft a single-string spacecraft design that can tolerate a large fault on a spacecraft while the constellation system (redundancy in system) is still capable of delivering good science data. The design of FORMOSAT-3 could afford to lose one (or more) spacecraft and still deliver a significant amount of science data.**

49. Tab 8, p.628, IInd row, IVth column: Second bullet: implement and implementation... please avoid the repetition.

Response:

- **Modify the paragraph from “- Continue to apply system level FDC and implement the necessary redundancy implementation in the spacecraft as well as in the constellation for the sufficient operational service availability in the follow-on mission” to “- Continue to apply system level FDC and implement the necessary redundancy **design** in the spacecraft as well as in the constellation for the sufficient operational service availability in the follow-on mission”**

50. Tab 8, p.629, IInd row, all columns: all sentences are very bad written. Please check.

Response:

- **Modify the following table from**

Computers Resets / Reboots	FS-3/C adapted the discrete computers architecture: Attitude Control Electronics (ACE), Battery Control Regulator (BCR), and Flight Computer (FC) FS-3/C uses single string design strategy that none of the discrete computers has any built-in redundancy or external back-up unit for contingency	262 out of 304 events are computer resets/reboots as-of-4-1-2010 Most of the time and geo-locations the spacecraft anomalies occurred are closely correlated to the space radiation environment. Single event effects (SEEs) in the South Atlantic anomaly region and the polar region are identified as the most probable root cause. SC recovered automatically following system level Failure Detection and Correction (FDC) strategies. Use High reliable Processor/FPGA Use system FDC	The SEE anomalies made SC lost valuable telemetry and payload data. A design with nonvolatile memory is recommended to secure critical S/C housekeeping and payload data for future missions. A higher level red-tolerant or rad-hardening design should be considered in the future The FDC design makes the C&DH (and SC) can recover from anomalies automatically. A similar function should be implemented in the future
---	---	--	---

		strategies.	
To:			
Computers Resets / Reboots	<p>FS-3/C uses single string design strategy that none of the computers has redundancy design.</p> <p>The occurrence frequency of the Single Event Upset (SEU) is not defined clearly in the requirement document.</p> <p>The SEU anomalies made the spacecraft lost valuable telemetry and payload data.</p>	<p>Totally 262 out of 304 events are computer resets/reboots as-of-4-1-2010.</p> <p>Most of the time and geo-locations the spacecraft anomalies occurred are correlated to the space radiation environment.</p> <p>Root cause are due to the occurrence of Single event upset (SEU) event in the South Atlantic Anomaly (SAA) and the polar regions.</p> <p>The spacecraft will be recovered automatically following system level Failure Detection and Correction (FDC) strategies.</p>	<p>Spacecraft design with nonvolatile memory is recommended to secure lost of critical spacecraft housekeeping and payload data for the future mission.</p> <p>Higher level red-tolerant or radiation-hardening design should be considered in the future</p> <p>Similar FDC function should be also implemented in the future mission.</p>

51. Fig. 1: This is one of the most important figures, but there are too many informations shown together. Please describe all the details in the paper, as I already suggested in my comment for p. 605, row 1-15. Subplots are too small. Could you improve the overall quality?

Response:

Fig.1 is readable if you enlarge the pdf file. The authors will provide the high quality figures of Fig. 1 for journal printing.

Fig. 1 is one of the most important figure, so the authors spend 22 rows (from page 604, row 27~28, and page 605, row 1~20) of paragraphs to detail describe the meaning of Fig.1. Table 2 summarize the results of Fig.1 description.

- **Incorporate comment #17's response. The authors modify the one paragraph description to the following:**
"Figure 1 shows the spacecraft system performance observed over the past four years (since launch) for mission payload GOX duty

cycle on, and spacecraft ADCS (Attitude Determination and Control Subsystem) attitude performance vs. spacecraft sun beta angle. **The beta angle is defined as the angle between the spacecraft orbit plane and the vector from the sun that determines the percentage of time the spacecraft in low Earth orbit spends in direct sunlight, absorbing solar energy.** The GOX payload should be on during normal operation period except during the constellation deployment phase.

In Fig. 1, it is observed that all spacecraft continue to operate with the GOX duty cycle on at high percentage rates even as the spacecraft bus and payload start to show degradation. FM1 has provided good payload performance, however it shows worse attitude performance than the other spacecraft. FM2 started to show reduced duty-cycle GOX on operations due to a battery charging efficiency-decreased phenomena that was experienced after the satellite was recovered from lost communication in June 2009. FM3 encountered the solar array drive mechanism malfunctions starting in August 2007 when it reached a 711 km orbit. FM3 has been kept at that altitude and the GOX payload has been operating at low duty cycle since then. FM4 performed very well during the four year operational period, but its battery has shown significant degradation. FM5 has provided good spacecraft performance, however its GOX payload shows low SNR problems, causing good data to be hard to generate even when the GOX is on. FM6 has a similar GOX low SNR problem. FM6 experienced loss of communication in September 2007 for 67 days. The satellite resumed contact and recovered on its own after a computer master reset event occurred over the South Atlantic Anomaly (SAA) region. Due to a battery aging issue, four out of the six spacecraft have begun to encounter a battery degradation problem. FM4 and FM6 are worse than the other four spacecraft. The major on-orbit performance highlights for all spacecraft are summarized in Table 2.”

52. Fig. 5: What does Mission OPS mean? What does DPC mean?

Response:

- **“Mission OPS” means “Mission Operations”.**

- **DPC means “Data Processing Center”**

53. Fig. 6: w-inc means Low-inc? The text box is covered by figure.

Response:

- **“w-inc” means “Low-inc.” means Low-inclination” The text box is blocked and covered by figure.**
- **The authors will provide an updated figure 6.**

54. Fig. 7: please describe better this figure. What does the yellow circle show? The projection of Ground based antenna’s coverage from LEO? What does the two red lines mean

Response:

- **The yellow circles are the 10 degree elevation coverage circle of the potential ground stations, when LEO satellite passes within this yellow circle, then satellite could be acquired by the ground station located in the circle center.**
- **As shown “24N” in the figure, the upper red line is 24 degree northern latitude, and “24S” shown in the figure, the lower red line is the 24 degree southern latitude. These two lines are the upper and lower bound of the low-inclination satellite trajectories of the launch #1.**

55. The authors would also make the following changes:

- **Change “Satellite Operation Control Center (SOCC)” to “SOCC” (page 608, row 21)**