

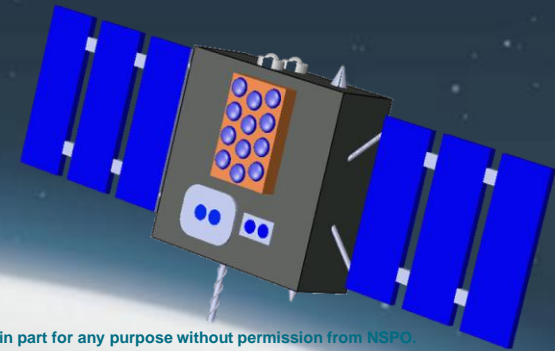
# FORMOSAT-7/COSMIC-2 RADIO OCCULTATION MISSION: FROM RESEARCH TO OPERATIONS

**Presenter: Chen-Joe Fong**  
**National Space Organization (NSPO)**

**29 March 2012**



**NSPO**



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# CO-AUTHORS

- **Chen-Joe Fong, National SPace Organization (NSPO)**
- **Vicky Chu, National SPace Organization (NSPO)**
- **Nick L. Yen, National SPace Organization (NSPO)**
- **Jer Ling, National SPace Organization (NSPO)**
- **Tiger J.-Y. Liu, National SPace Organization (NSPO)**
- **G.-S. Chang, National SPace Organization (NSPO)**



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# OUTLINE

- Radio Occultation (RO) Background
- FORMOSAT-3/COSMIC Mission Status and Achievement
- FORMOSAT-7/COSMIC-2 Mission Overview
- FORMOSAT-7/COSMIC-2 Current Status
- Conclusion



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# BACKGROUND

- **FORMOSAT-3/COSMIC**

- COSMIC = **C**onstellation **O**bserving **S**ystem for **M**eteorology, **I**onosphere, and **C**limate
- 6-microsatellite scientific “**research**” demonstration mission
- Launched in April 2006
- World’s **first** operational GPS-RO mission for:
  - Global Earth weather forecasting
  - Climate monitoring
  - Atmospheric, Ionospheric, and Geodetic research
- Currently providing near-real-time data to **1,781** users in **59** countries (as-of-3/1/2012)
- Reaching end of design life in 2011
  - Performance already beginning to degrade
- **April 2012 will be the 6th Anniversary**



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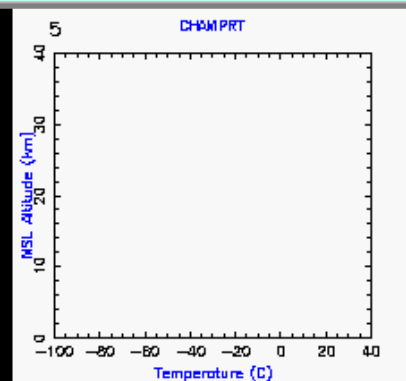


# HOW IT WORKS

$$N = 77.6(P/T) + 3.73 \times 10^5(P_w/T^2) - 40.3 \times 10^6(n_e/f^2)$$

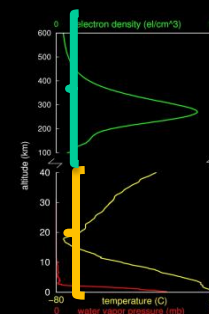
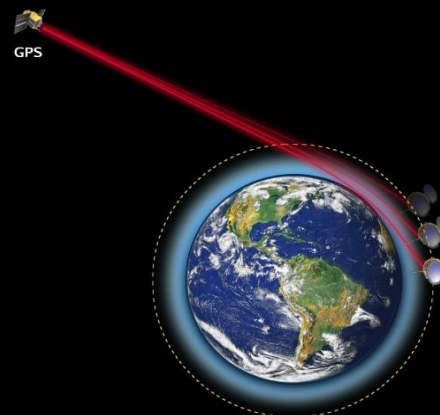
where

The refractivity,  $N$ , is a function of temperature ( $T$  in K), pressure ( $P$  in hPa), water vapor pressure ( $P_w$  in hPa), and electron density ( $n_e$  in number of electrons per  $m^3$ ), and  $f$  is the frequency of the GPS carrier signal in Hz.

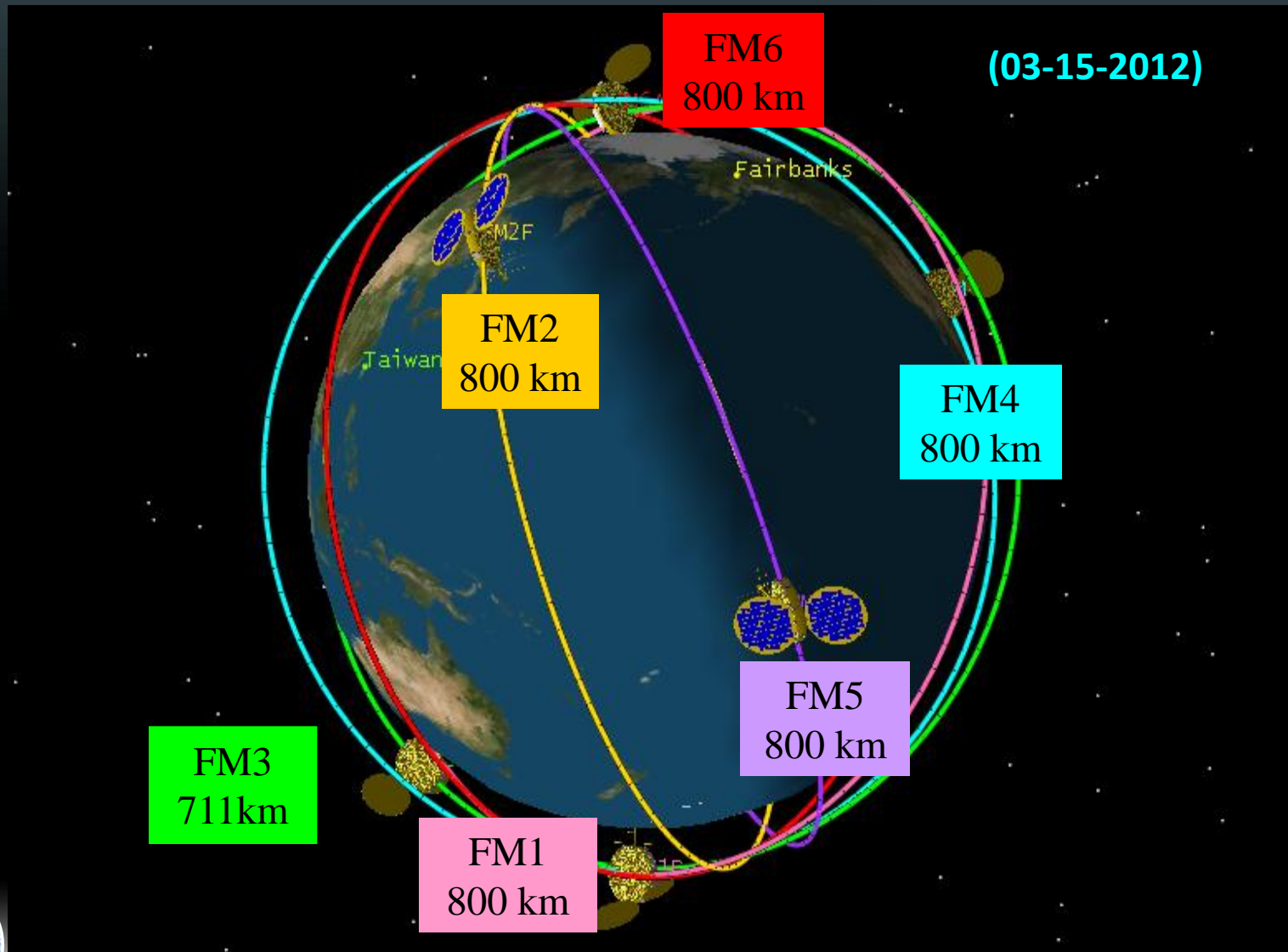


Space weather - electron density profiles

Temperature, moisture profiles in the neutral atmosphere



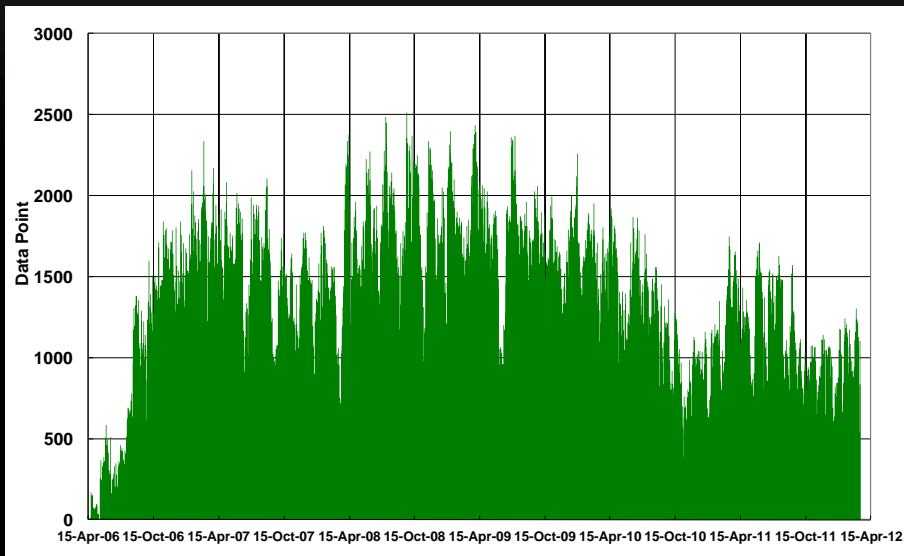
# CURRENT FORMOSAT-3/COSMIC CONSTELLATION



# FORMOSAT-3/COSMIC RADIO OCCULTATION PROFILES

## Atmospheric

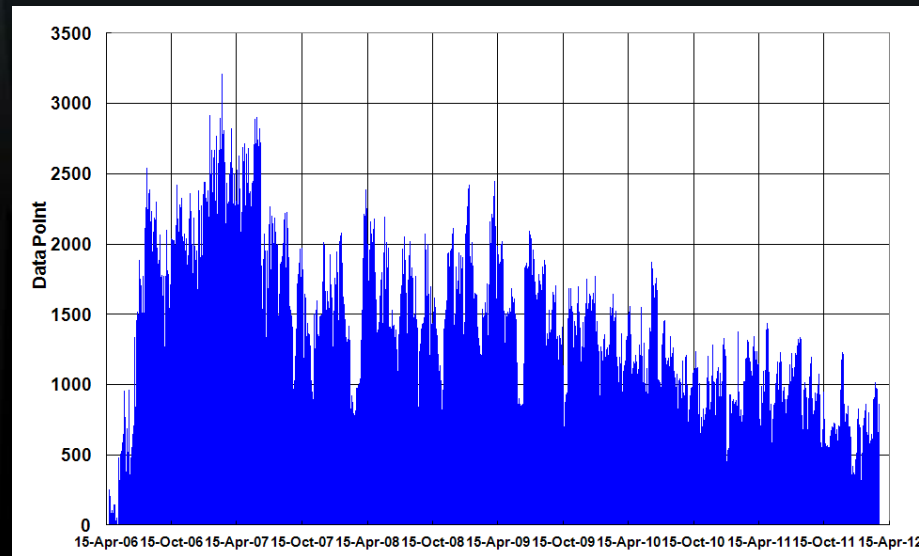
(03-15-2012)



2,913,677 Profiles

## Ionospheric

(03-15-2012)



2,916,771 Profiles



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# Global Data Users Status: 59 countries, 1781 users

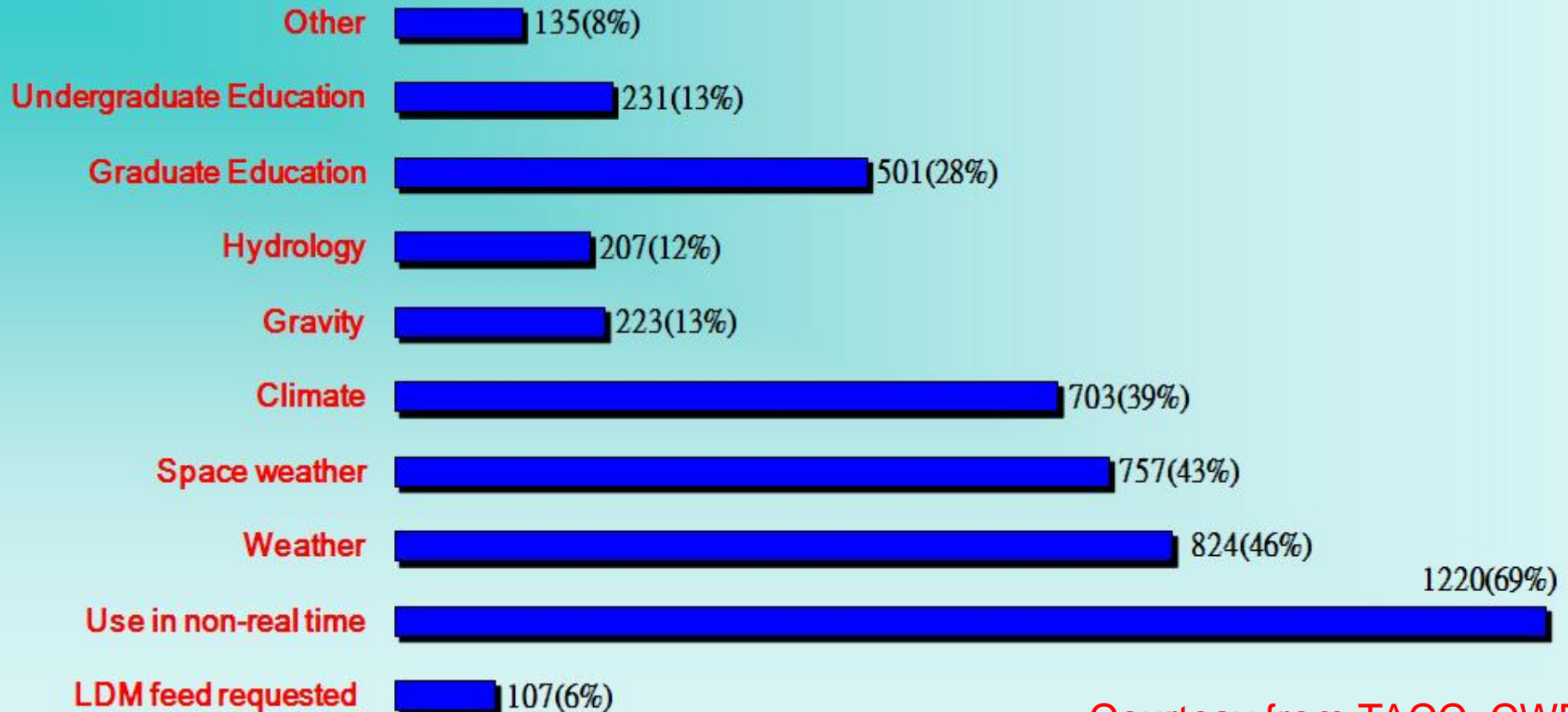
As-of- 3/1/2012

U.S.A.	573	Austria	15	Turkey	4	Hungary	1
Taiwan	278	Philippine	13	Czech	4	Egypt	1
India	188	Spain	11	Bulgaria	3	Senegal	1
China	134	Denmark	10	Israel	3	Bangladesh	1
Japan	68	South Africa	10	Peru	3	Cuba	1
Germany	39	Iran	9	Singapore	3	Tanzania	1
Canada	38	New Zealand	7	Ethiopia	3	Kazakhstan	1
U.K.	43	Nigeria	7	Belgium	2	Kenya	1
Korea	39	Switzerland	6	Puerto Rico	2		
Russia	40	Malaysia	6	United Arab Emirates	2		
Brazil	32	Poland	5	Cyprus	2		
Indonesia	28	Portugal	4	Bhutan	1		
Australia	27	Ukraine	4	Costa Rica	1		
Italy	26	Thailand	4	Sweden	1		
France	26	Chile	4	Ireland	1		
Vietnam	18	Finland	4	Norway	1		
Argentina	16	The Netherlands	4	Pakistan	1		



# RO DATA STATISTICS OF FORMOSAT-3/COSMIC USERS

As is of 2/29/2012



Courtesy from TACC, CWB



# CURRENT FORMOSAT-3/COSMIC SPACECRAFT/PAYLOAD STATUS

	FM1	FM2	FM3	FM4	FM5	FM6
<b>Spacecraft</b>	<ul style="list-style-type: none"> <li>- Battery Degrade (80% Duty Cycle)</li> </ul>	<ul style="list-style-type: none"> <li>- Lost 1 of 2 Solar Arrays Power</li> <li>- Average ~70 % Duty Cycle</li> <li>- Ever lost contact for 43 days in early 2012</li> </ul>	<ul style="list-style-type: none"> <li>- Solar Array Stuck</li> <li>- Battery Fail</li> <li>- Went into coma since June 6 2010</li> <li>- Still able to make contact with very low power (&lt; 30%) occasionally</li> </ul>	<ul style="list-style-type: none"> <li>- Battery Seriously Degraded (has to shut down P/L in eclipse)</li> <li>- Ever lost contact for 14 &amp; 2 days in March 2012</li> </ul>	<ul style="list-style-type: none"> <li>- One Battery Cell failure</li> <li>- Ever Lost Contact Sep 26, 2010 for 50 days</li> </ul>	<ul style="list-style-type: none"> <li>- Battery Degraded (65% duty cycle)</li> <li>- Ever Lost Contact In 2007 for 67 days</li> </ul>
<b>GOX Payload</b>	<ul style="list-style-type: none"> <li>- POD-01 Low SNR</li> </ul>	<ul style="list-style-type: none"> <li>- POD-02 Low SNR</li> </ul>	<ul style="list-style-type: none"> <li>- N/A</li> </ul>	<ul style="list-style-type: none"> <li>- POD-01 Low SNR</li> </ul>	<ul style="list-style-type: none"> <li>- Lost POD-01</li> <li>- OCC-01 Low SNR</li> </ul>	<ul style="list-style-type: none"> <li>- POD-01 Low SNR</li> <li>- OCC-01 Low SNR</li> </ul>

(3-15-2012)



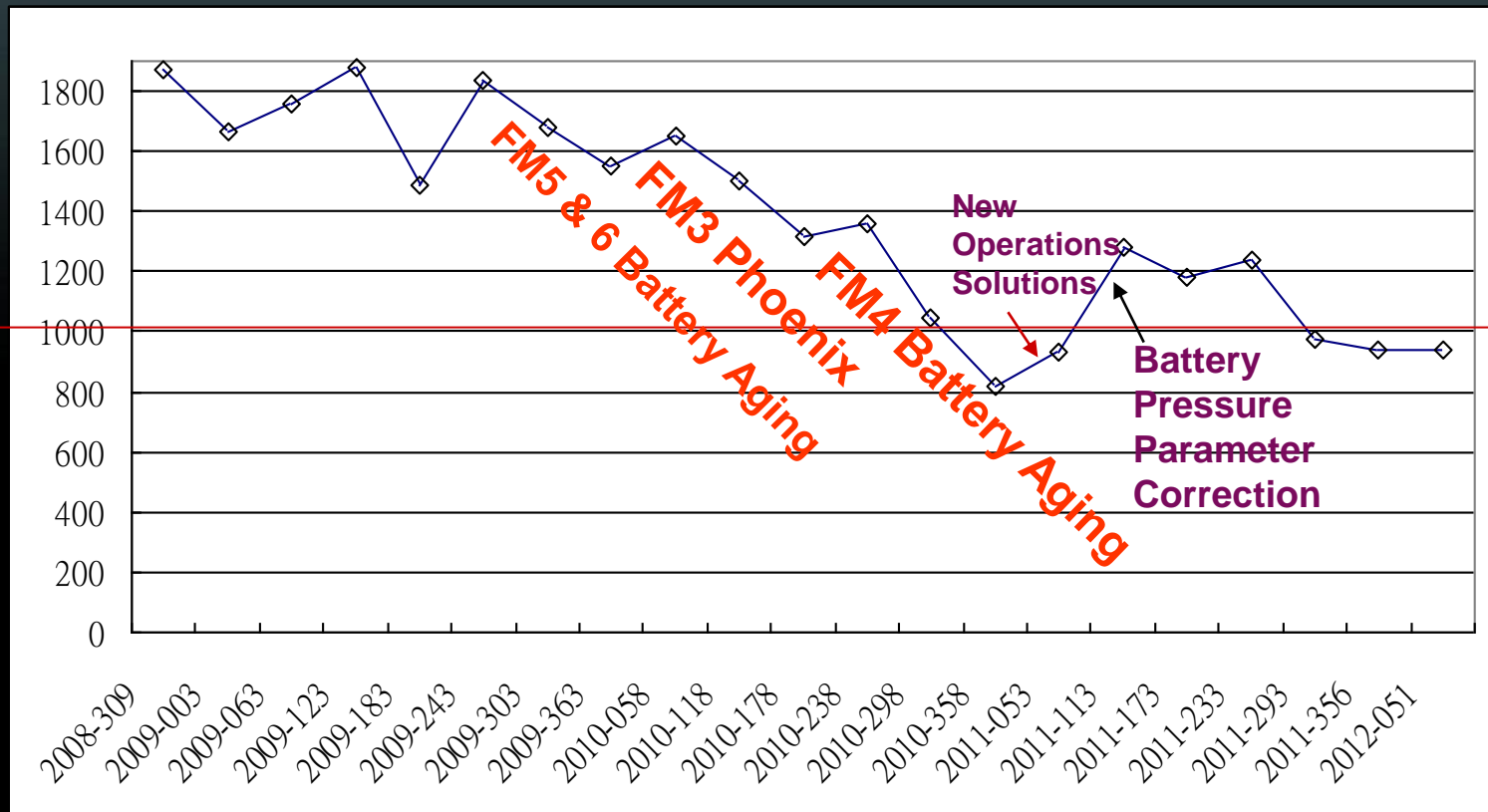
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# FORMOSAT-3 RO STATISTICS (2008.09~2012.02)



- FORMOSAT-3/COSMIC RO numbers went below 1000 in Nov 2010, and now is 1000 per day in average.
- FM1,FM4,FM5,FM6 using new L2C tracking with new firmware, it helps OCC profiles in current S/C condition (up to 30% more sometimes)



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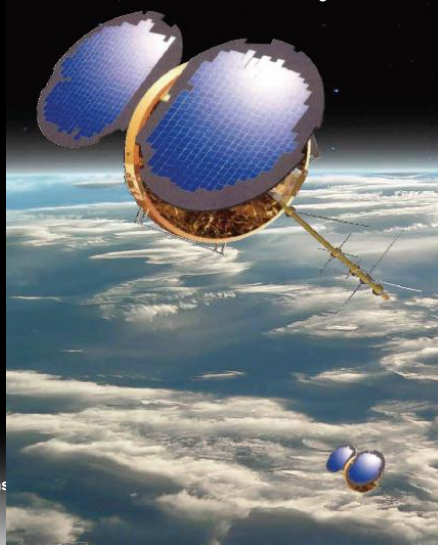
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# FORMOSAT-3/COSMIC

- FORMOSAT-3/COSMIC has been proven to:
  - Increase the accuracy of the predictions of hurricane behavior
  - Significantly improve long-range weather forecasts
  - Monitor climate change with unprecedented accuracy



This document contains

organization (NSF)

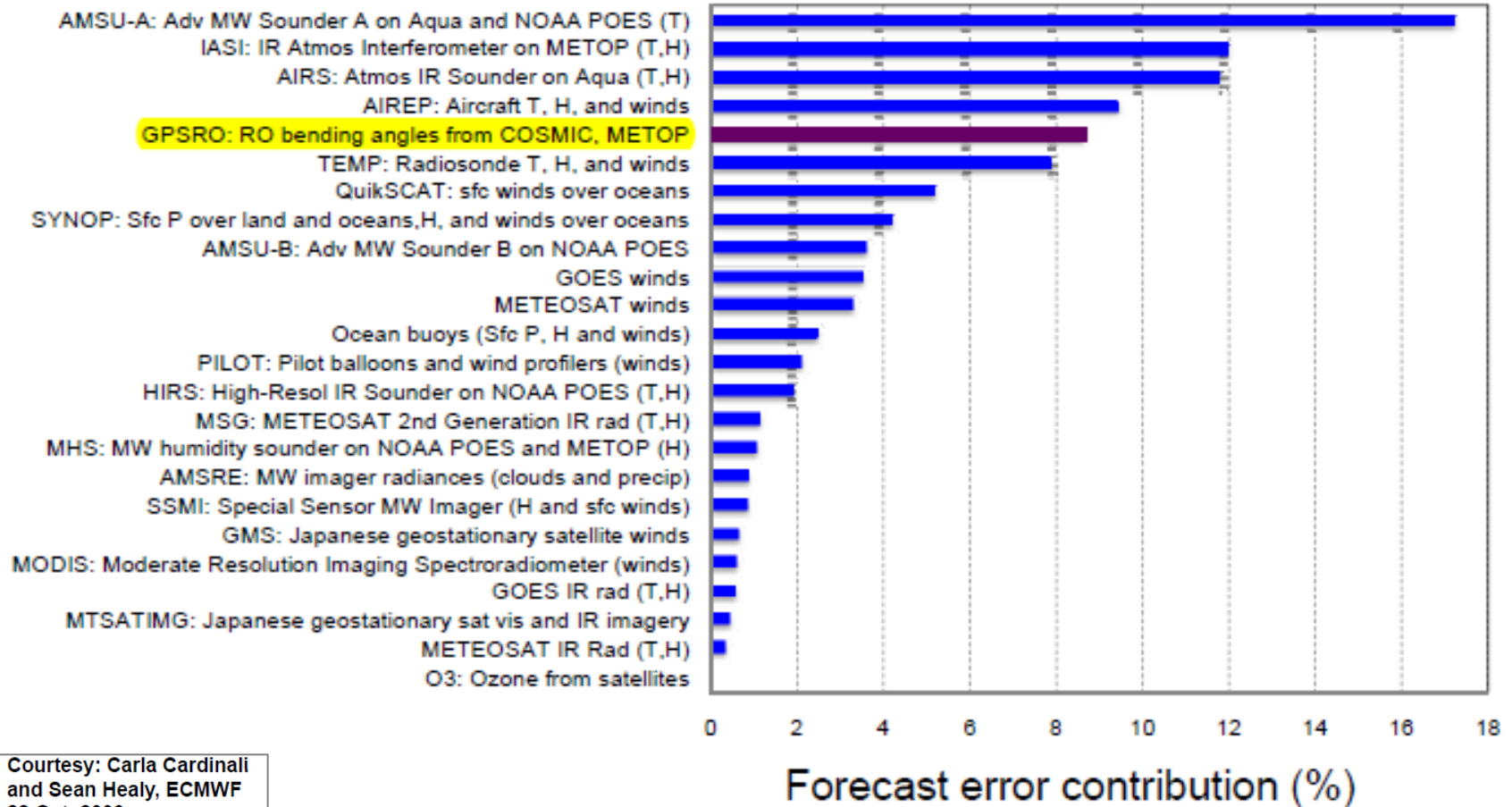


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# EFFECTIVENESS OF GPS RO DATA

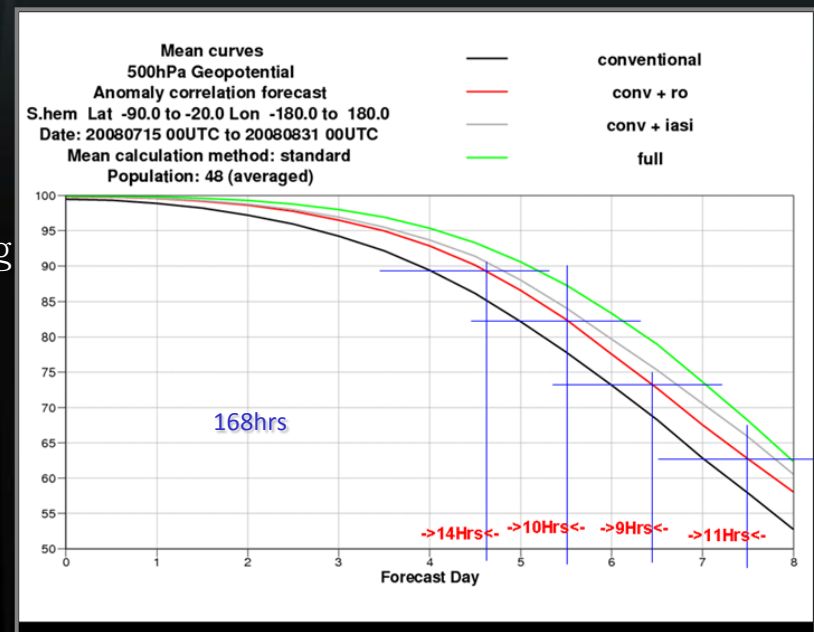
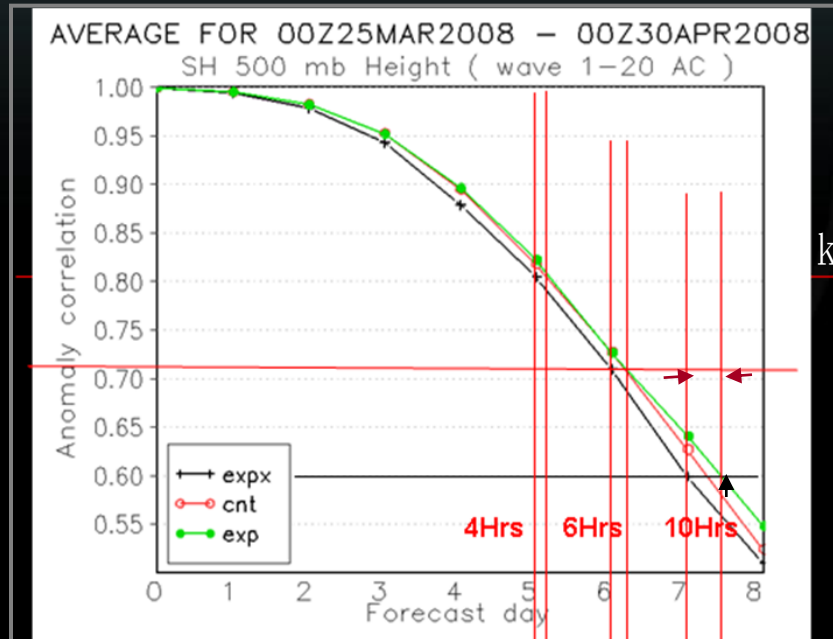
*ECMWF ranked GPS RO data as the 5th place in all atmospheric observation data collected by space- and air-borne sensors in which GPS RO contributed 4.7% data that improved 8.5% of weather prediction error. (Sept.~Dec. 2008)*



Courtesy: Carla Cardinali  
and Sean Healy, ECMWF  
22 Oct. 2009



# 6 % Prediction Accuracy Improvement on Global Prediction Model by Assimilating FORMOSAT-3/COSMIC RO Data (Courtesy of L. Cucurull of NOAA)

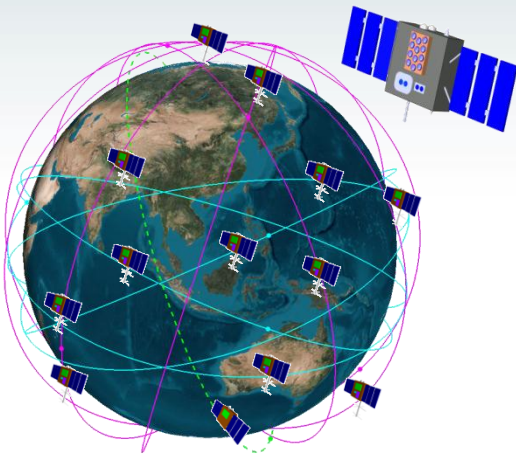


- ◆ COSMIC provides significant improvement in Weather forecast skill
  - 8 hours improvement at Forecast Day 4 and
  - >15 hours improvement during Forecast Day 7
- ◆ Particularly significant improvement over the oceans and in Southern Hemisphere
  - Analysis – COSMIC satellite loss causes significant forecast skill loss



# FORMOSAT-7/COSMIC-2 MISSION

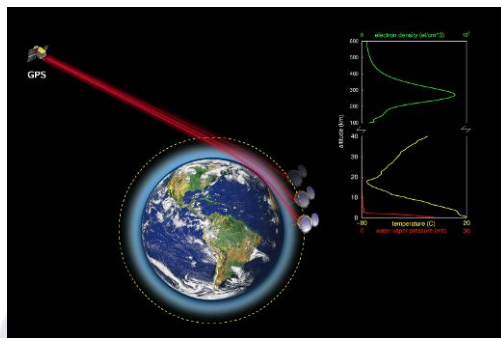
Mission: To deploy an operational constellation system of 12 satellites to perform GNSSRO atmospheric and ionospheric soundings for weather forecasting and space weather monitoring.



- Acquire the international cooperation
- Build-up indigenous spacecraft technology
- Enhance domestic data processing capability
- Promote GNSSRO data utilization and application

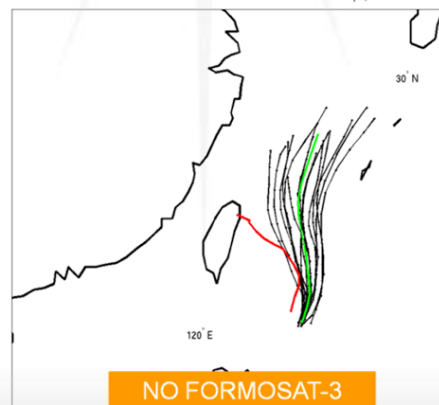


**FORMOSAT-7 / COSMIC-2**  
(To be launched in 2015 & 2018)

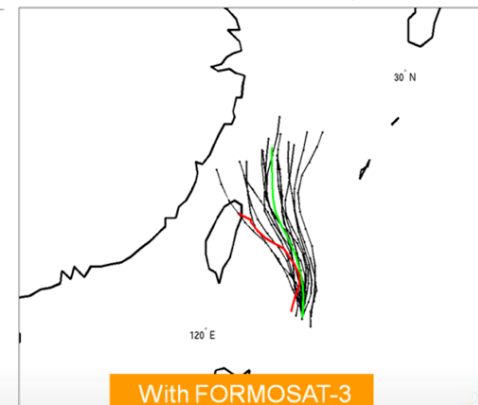


GNSS Radio Occultation

Ensemble forecasts from 00UTC 11 Sept, CTL



Ensemble forecasts from 00UTC 11 Sept, CTL



Legend: Red: Observed track, Black: Ensemble members, Green: Ensemble mean

Potential Improvement of Typhoon Track Predication



# INTERNATIONAL COLLABORATION



NSPO



NSC



UCAR



AEROSPACE



Jet Propulsion Laboratory  
California Institute of Technology



Broadreach



KONGSBERG



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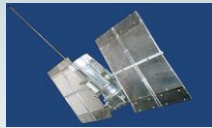
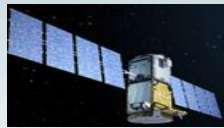
# MISSION BASELINES

<b>FORMOSAT-7</b>	<b>First Launch</b>	<b>Second Launch</b>
<b>Mission Objectives</b>	To be achieved after Full Operational Capability: <ul style="list-style-type: none"> <li>• 8,000 atmospheric sounding profiles per day</li> <li>• 45-min data latency (TBR)</li> </ul>	
<b>Constellation</b>	6 SC to low-inclination-angle orbit (mission altitude ~520 km)	<ul style="list-style-type: none"> <li>• (5+1) or (6+1) SC to high-inclination-angle orbit (mission altitude ~800 km)</li> <li>• 7 satellites to be allocated for mission design purpose</li> </ul>
<b>GNSS RO Payload</b>	TriG	TriG
<b>Scientific Payload</b>	US furnished VIDI and RF Beacon Instrument	Taiwan furnished <b>TBD</b>
<b>Launch Vehicle</b>	<b>EELV-like LV (rideshare)</b>	<b>Minotaur IV series</b> or Falcon 9
<b>Launch Schedule (as a goal)</b>	<b>No earlier than 2015 Q4</b>	<b>2018 Q2-Q3</b>
<b>Communication Architecture</b>	Via ground station	



# FORMOSAT-7/COSMIC-2 SYSTEM ARCHITECTURE

GALILEO or GLONASS-FDMA



GPS



High-inc

Low-inc

NSPO Built S/C

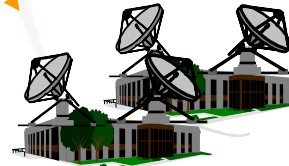
FORMOSAT-7/  
COSMIC-2



TT&C stations (Taiwan)



TT&C stations (overseas)



Fiducial  
Network



US DPC



Taiwan DPC



Satellite Operations  
and Control Center



Users

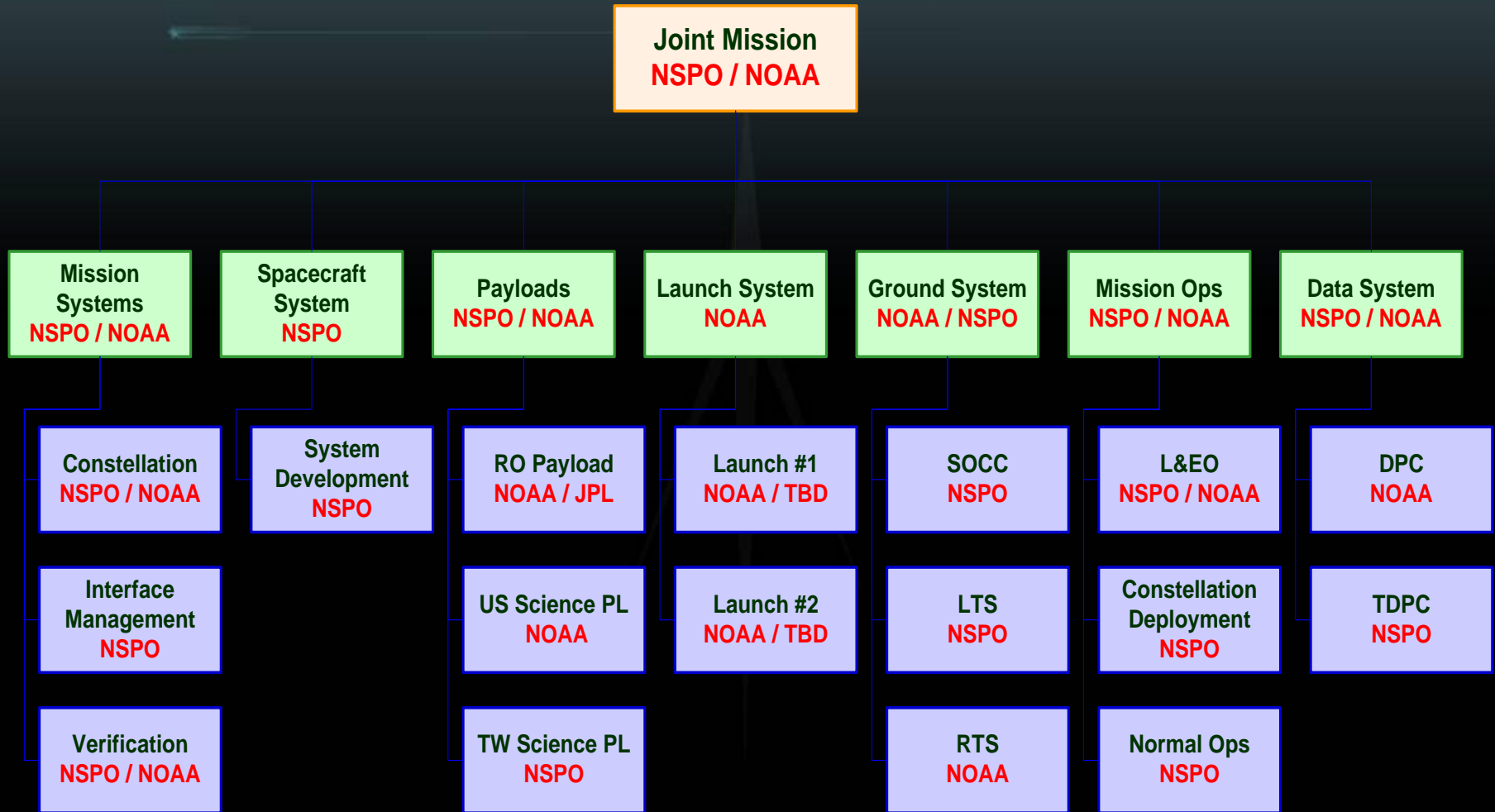
Researchers



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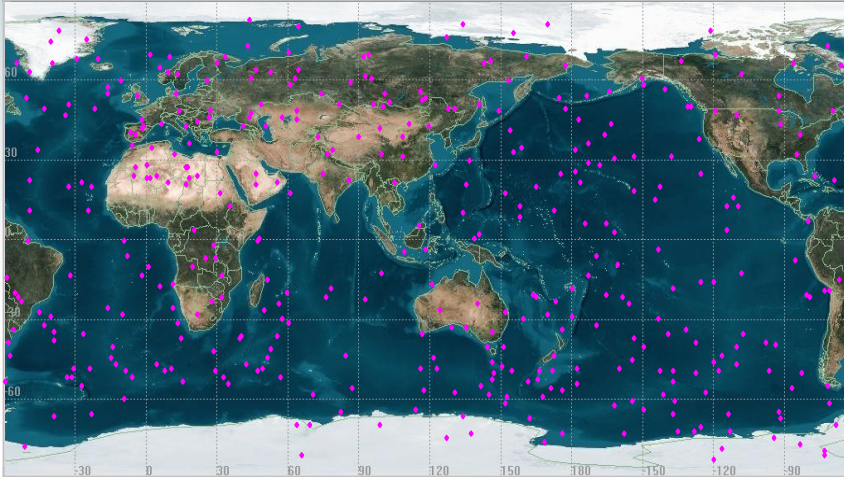
# JOINT MISSION FRAMEWORK BETWEEN NSPO AND NOAA



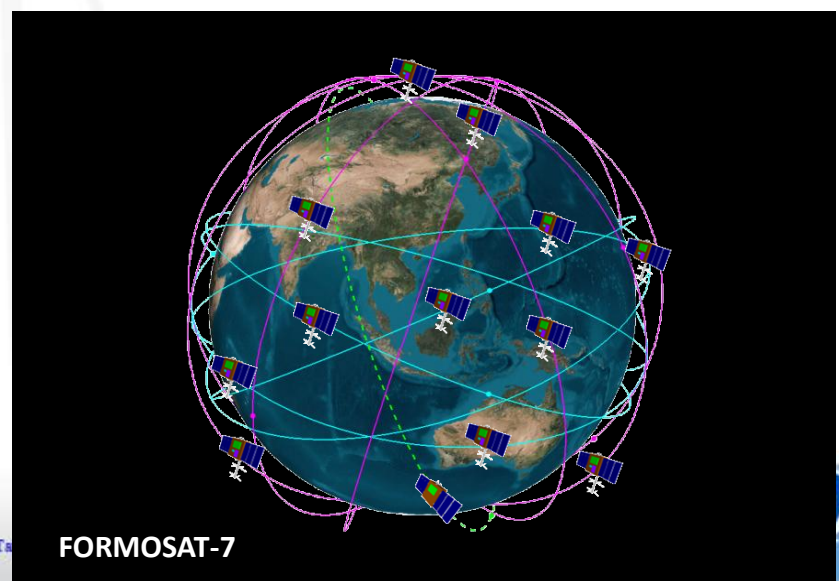
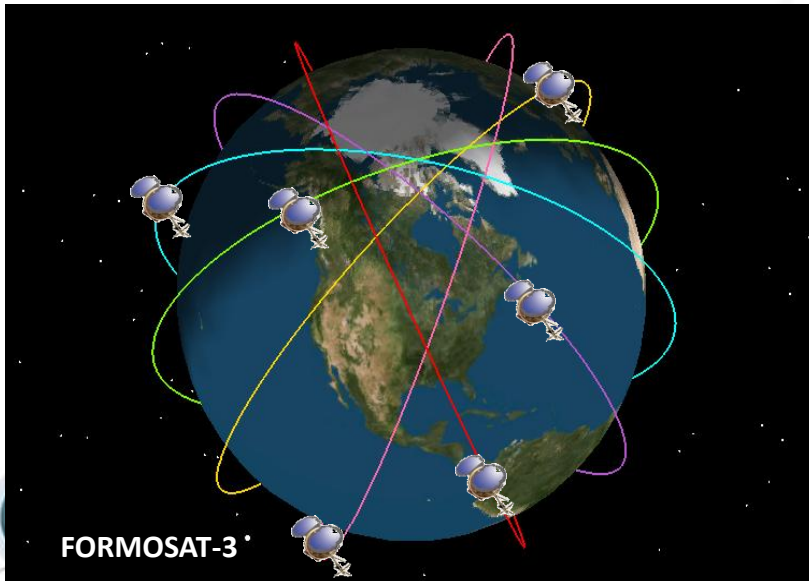
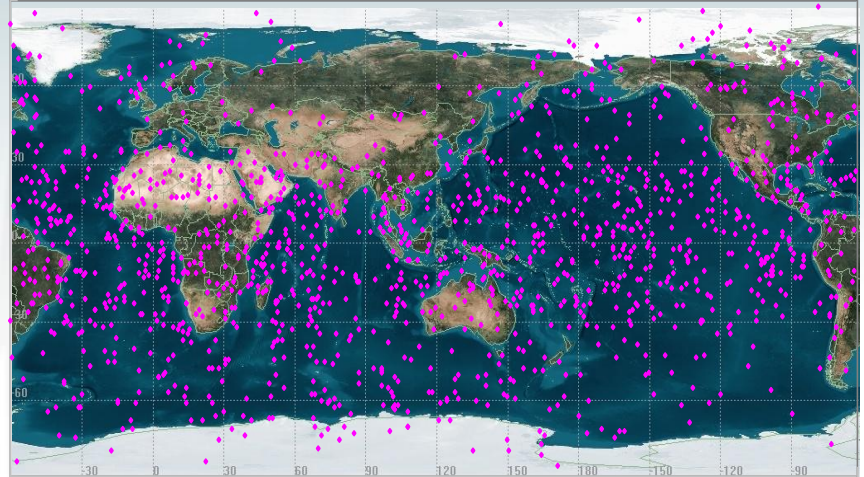


# 3-HOURS RADIO OCCULTATION DATA COVERAGE

FORMOSAT-3 Occultation – 3 Hrs Coverage



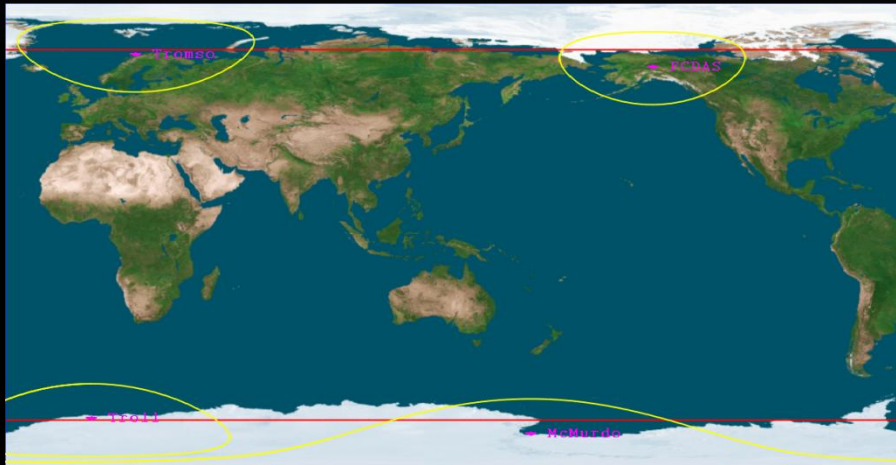
FORMOSAT-7 Occultation – 3 Hrs Coverage



# FORMOSAT-7/COSMIC-2 GROUND COMMUNICATION NETWORKS TO ACHIEVE 45 MINUTES DATA LATENCY

## 72° Orbit Data Recovery

Current FORMOSAT-3 / COSMIC Network

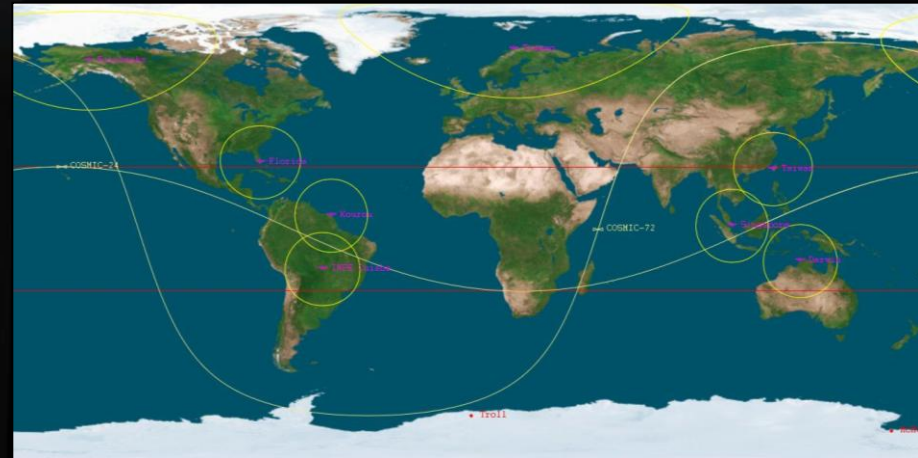


- KSAT Tromso
- KSAT Troll

- NOAA FCDAS
- NASA McMurdo

## 24° Orbit Data Recovery

FORMOSAT-7/ COSMIC-2 Candidate Sites



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# FORMOSAT-7/COSMIC-2 STATUS

- NSPO is working on Version 2 (V2) Spacecraft Bus RFP.
- V2 is to make 6 Spacecraft Buses as the required equipment and 6 Spacecraft Buses as the optional equipment instead of acquiring 12 Spacecraft Buses at one time.
- V2 RFI has been posted on NARL website on January 19, 2012.
- Plan to release of V2 RFP in April, 2012
- Planned to select one eligible Bidder and award the Contract by July 2012.



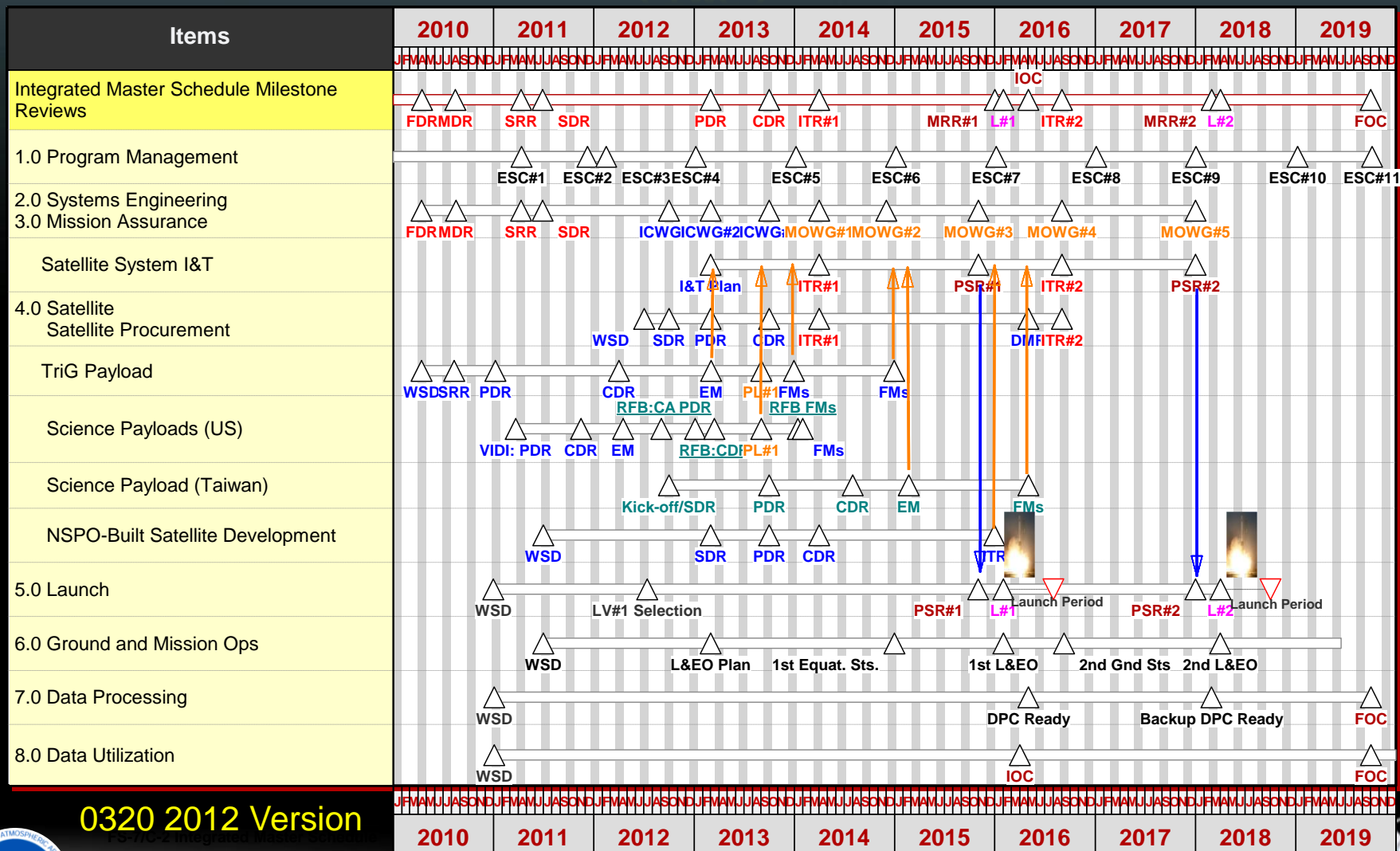
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# FORMOSAT-7/COSMIC-2 INTEGRATED MASTER SCHEDULE (IMS)



0320 2012 Version

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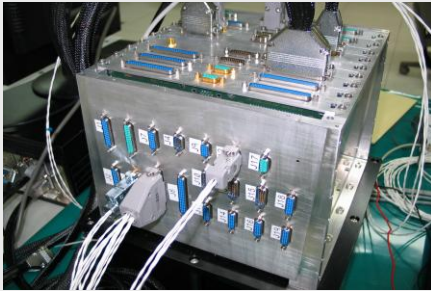
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# NSPO-BUILT 13<sup>TH</sup> SATELLITE KEY COMPONENTS

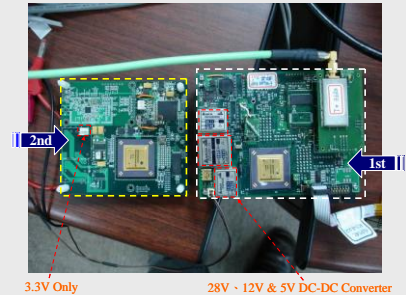
## On-Board Computer

- ✓ Prototype Design
- ✓ Detail Spec. Definition



## GPS Bus Receiver

- ✓ Radiation and TVC Test 式
- ✓ FM Circuit Design



## PCDU

- ✓ Prototype Design
- ✓ Detail Spec. Definition



## 13<sup>th</sup> Satellite

- ✓ System Electrical Configuration
- ✓ Satellite System Specification

## Optical Fiber Gyro

- ✓ Complete 1-Axis OFG
- ✓ 3-Axes Prototyping



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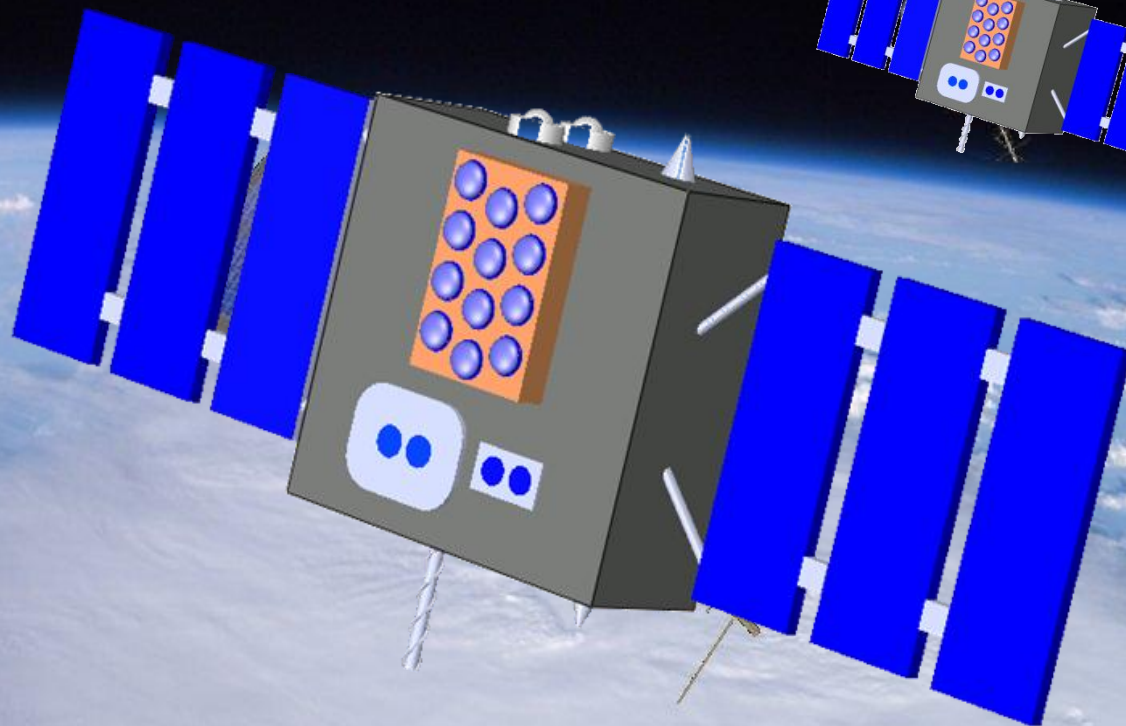
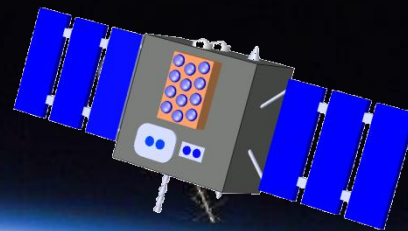


# CONCLUSIONS

- ❑ Research contribution of FORMOSAT-3 mission to weather prediction is considered to be “significant” by the Taiwan CWB and U.S. NOAA’s National Weather Service (NWS), and represents an immense benefit to worldwide forecasting capability.
- ❑ FORMOSAT-3/COSMIC has begun to degrade in 2011, the data gap expected by 2013-2015 due to lost of satellites will result in a significant diminution of performance of the NOAA and CWB’s NWP models.
- ❑ The U.S. (NOAA is the designated representative) and Taiwan (NSPO is the designated representative) have proceed to FORMOSAT-7/COSMIC-2 mission, a FORMOSAT-3/ COSMIC follow-on Radio Occultation mission.
- ❑ It is certain that the implementation and realization of FORMOSAT-7/COSMIC-2 operation mission will continue to fulfill this important mission and further increase weather forecast capabilities.







**THANK YOU !**