OPAC-4 & GRAS-SAF Climate & IROWG-1 Workshop at Graz University, Austria
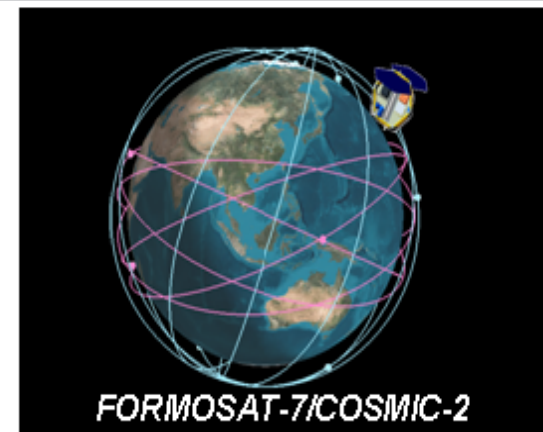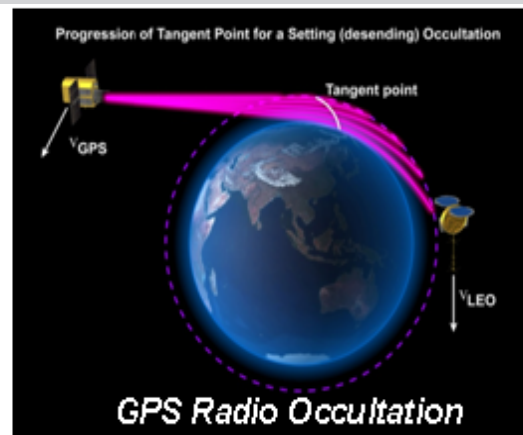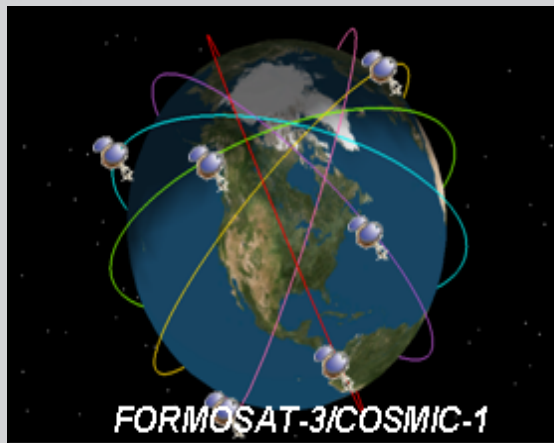
FORMOSAT-7 / COSMIC-2
Joint Plan and Current Progress

Nick Yen

FORMOSAT-3/COSMIC-1

Progression of Tangent Point for a Setting (desending) Occultation

Tangent point

V_{GPS}

V_{LEO}

GPS Radio Occultation

FORMOSAT-7/COSMIC-2

NSPO
NATIONAL SPACE ORGANIZATION

09-10-2010

2010/9/17

Applications Status: 52 countries, 1379 users

U.S.A.	481	Argentina	12	Israel	2
Taiwan	184	Philippine	11	Malaysia	2
India	135	Spain	9	Peru	2
China	95	Iran	6	Puerto Rico	2
Japan	54	New Zealand	6	Finland	2
Korea	34	South Africa	6	Bulgaria	2
Germany	34	Nigeria	6	Czech	2
Canada	33	Denmark	5	Pakistan	1
U.K.	33	Switzerland	5	Bangladesh	1
Russia	29	Turkey	4	Singapore	1
Brazil	26	Chile	4	Bhutan	1
Italy	25	Portugal	4	Costa Rica	1
Indonesia	24	Ukraine	4	Sweden	1
Australia	24	The Netherlands	3	Ireland	1
France	21	Poland	3	Norway	1
Vietnam	17	Thailand	2	Belgium	1
Austria	13	United Arab Emirates	2	Egypt	1
				Senegal	1
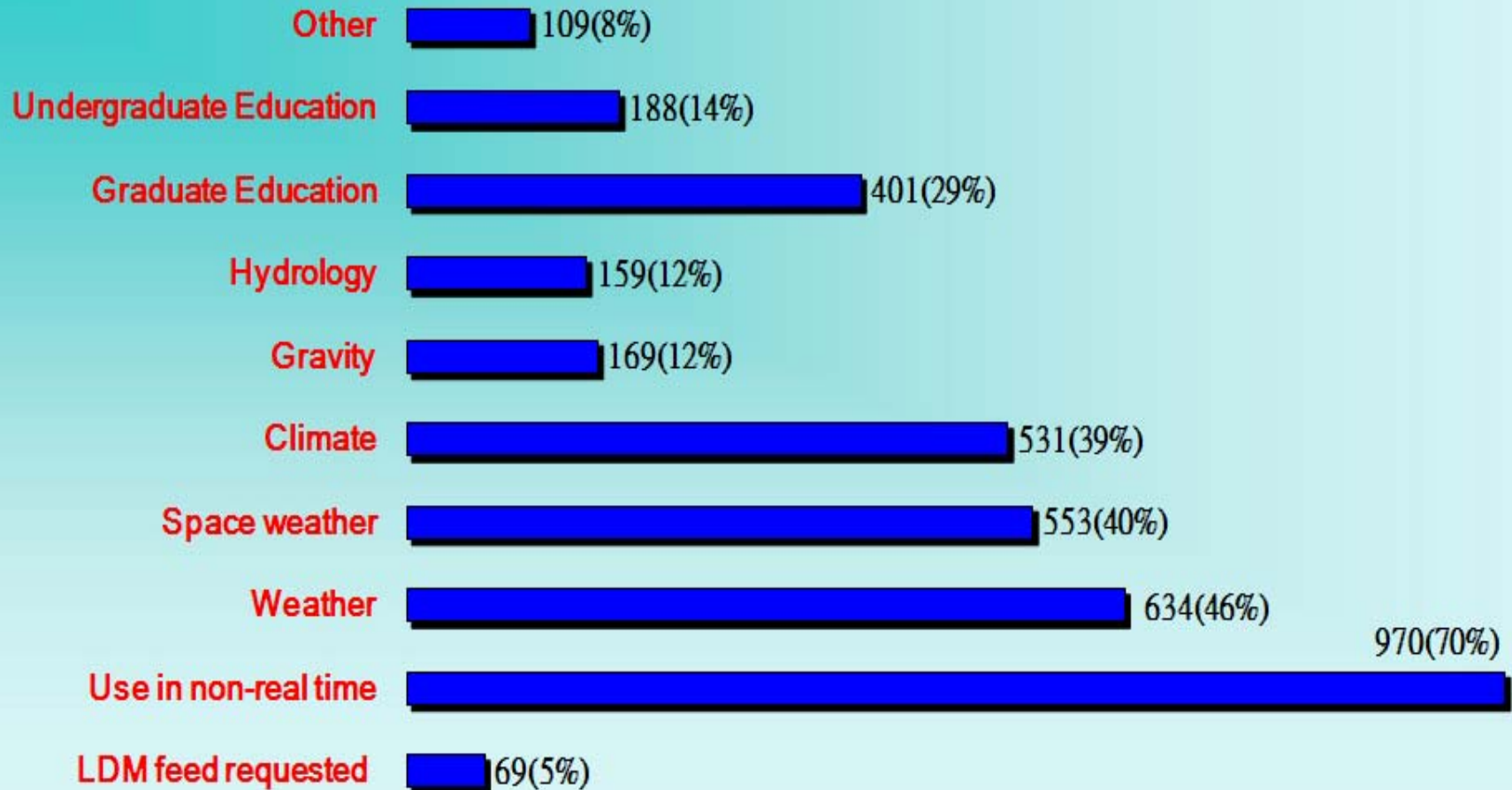
FORMOSAT-3 Satellite Status

➢ **~1200 sets of data profiles are generated per day on average**

➢ **FM3 have been an abnormal condition since July 6**

SC	Bus Status	GOX Status	60d average Data profile (now/peak)	TIP TBB
FM1	Battery Degradation	POD1 Failure	290/350	ON
FM2	One half of Solar Array provides the power	Duty Cycle 60 %	200/320	OFF
FM3	Solar Array drive mechanism problem	POD1 Failure Duty Cycle 36 %	150/300	OFF
FM4	Battery Degradation	POD1 Failure	300/420	OFF
FM5	Battery Degradation	POD1 Failure, POD2 degradation, OCC SNR decrease	160/310	ON
FM6	Battery Degradation	POD1 Failure, OCC SNR decrease	130/300	ON

Existing Radio Occultation Mission and Outlooks

Mission	Launch Time	Mission Life	RO Profiles per Day	Note
GPS/MET	1995/4	2	125	Proof of Concept
CHAMP	2000/11	5	250	Improved receiver, tracking
SAC-C	2000/11	3	300	Improved receiver, open loop tracking test
GRACE	2002/5	5	500	RO data publicly not available
FORMOSAT-3/COSMIC	2006/4	5	2000	World Only Near-real-time Operational Constellation
MetOp-A	2006/10	5	500	Near-real-time operations
TerraSAR-X	2007/6	5	400	IGOR RX & Antennas
OceanSat-2	2009/9	5	500	ROSA RX
TanDEM-X	2010/6	5	400	FORMOSAT-3 RX
KOMPSAT-5	2010	5	300	IGOR+ RX & Antennas
EQUARS	2012 On-hold	3	400	IGOR RX & CHAMP Antennas
MetOp-B	2012	5	600	GRAS RX & Real-time operations
PAZ	2012	5	500	IGOR+ RX
Megha-Tropiques	TBD	5	500	ROSA RX
SAC-D	TBD	5	500	ROSA RX
CICERO	TBD	5	>10,000	Pyxis/TriG RX and Real-Time Ops for GPS-RO & GPS-SR
FORMOSAT-7/COSMIC-2	2014 2016	5	>8,000	Real-Time Ops with TriG RX

FORMOSAT-7/COSMIC-2 Mission v.s. FORMOSAT-3/COSMIC (1/2)

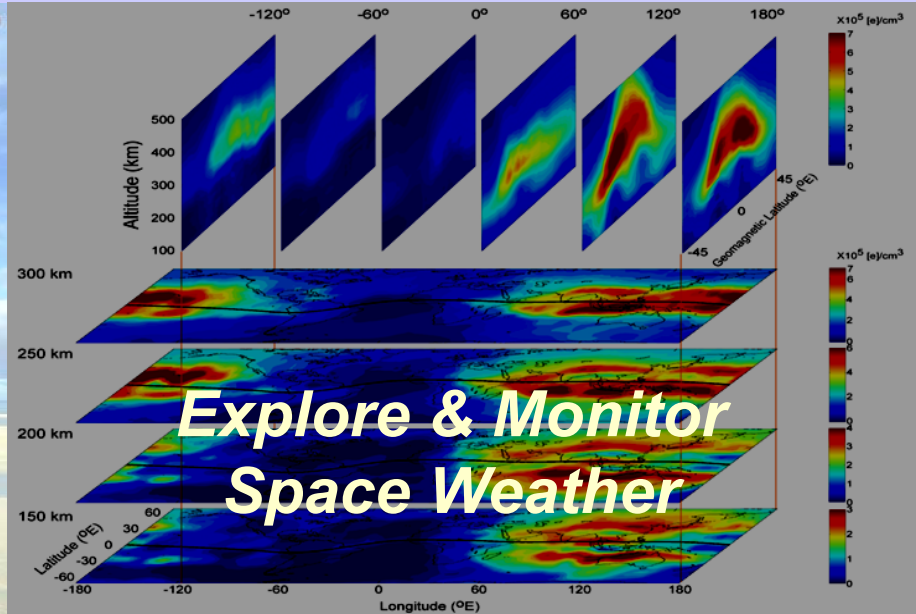|	FORMOSAT-7/COSMIC-2 Mission	FORMOSAT-3/COSMIC Mission
Mission	✓ *Establish an operational mission for near real-time numerical weather prediction* ✓ *8,000 (threshold) profiles per day (the objective is 10,000)*	✓ *Demonstration of near real-time numerical weather prediction* ✓ *1,600~1,800 profiles per day*
Spacecraft	✓ **NSPO will provide 12 satellites for the joint mission and a spare satellite in space depending on the launch vehicle capability.** ✓ **NSPO will integrate new GNSS P/L provided by JPL & perform P/L system Integration & Test at NSPO**	✓ **NSPO define system requirement** ✓ **NSPO & Orbital design spacecraft ; UCAR provide P/L suite** ✓ **EDU and FM1 I&T at Orbital** ✓ **FM2 to FM6 I&T at NSPO**
Mission Payload	✓ *GPS / GALILEO / GLONASS tracking capabilities*	✓ *GPS tracking capability*

FORMOSAT-7/COSMIC-2 Mission v.s. FORMOSAT-3/COSMIC (2/2)

	FORMOSAT-7/COSMIC-2 Mission	FORMOSAT-3/COSMIC Mission
Launch Vehicle	✓ **NOAA will provide 2 dedicated launches into selected orbits and inclinations**	✓ **Use the US Air Force MINOTAUR L/V through UCAR's Acquisition**
Ground	✓ **NOAA's strategy to use U.S., Europe, Asia, and Polar Ground Networks**	✓ **Use USN ground stations for the first 2 years, and then supported by NOAA ground stations for the following 3~5 years**
Operations	✓ **High degree of automated ground system for a minimum of 12-satellite constellation**	✓ **6-satellite constellation operations**
Data Processing	✓ **TACC Upgrade** ✓ **CDAAC Upgrade** ✓ **GPS-ARC II**	✓ **TACC & CDAAC Implementation** ✓ **GPS-ARC Initiation**

2010/9/17

Mission Goals: Societal Impacts

Enhance the Capabilities of Regional and Global Weather Prediction
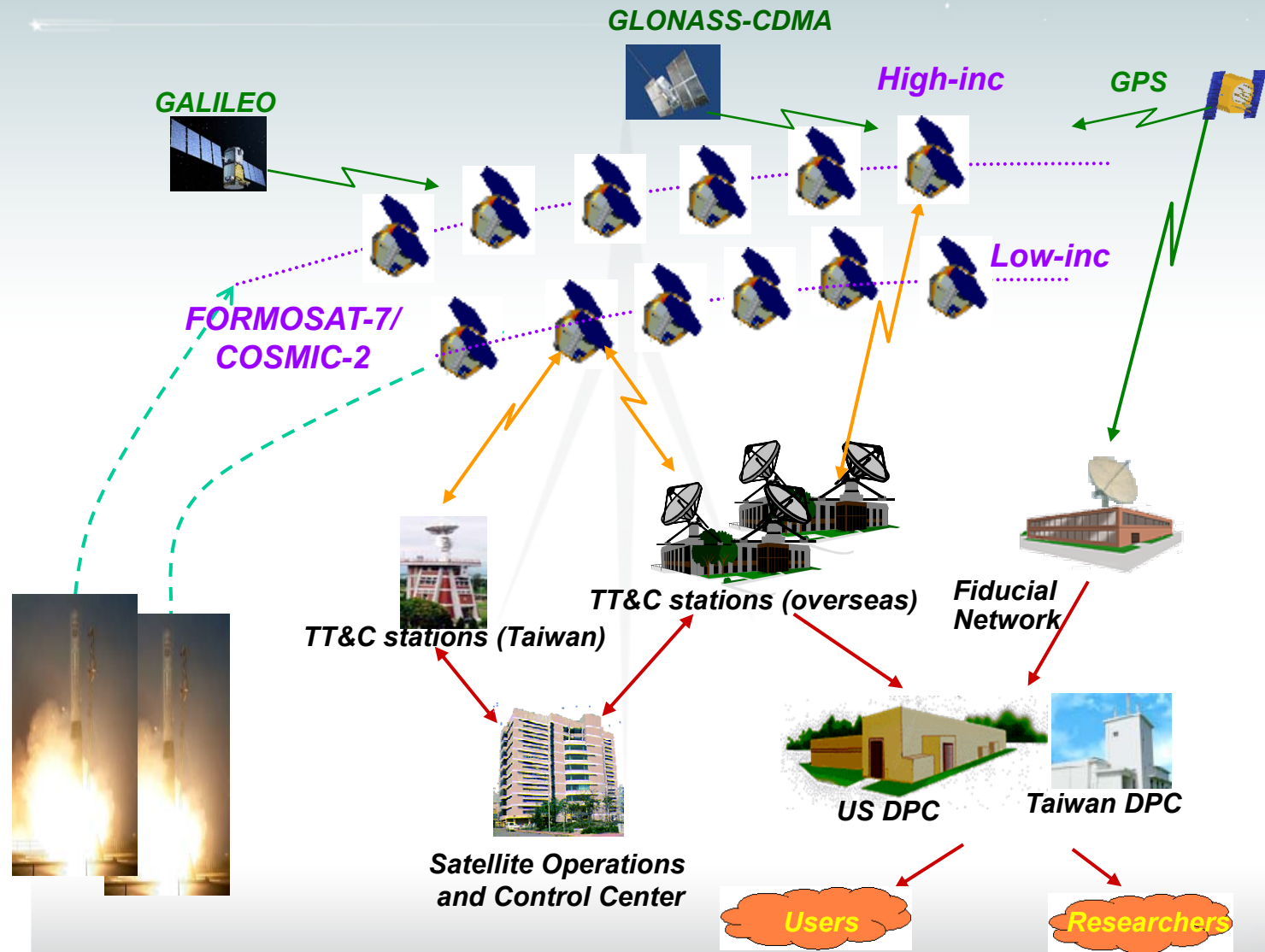
Explore & Monitor Space Weather

Enhance the Capability on Severe Weather Prediction

Monitor Climate Trend

FORMOSAT-7/COSMIC-2 System Architecture

GLONASS-CDMA

GALILEO

High-inc

GPS

FORMOSAT-7/
COSMIC-2

Low-inc

TT&C stations (Taiwan)

TT&C stations (overseas)

Fiducial Network

Satellite Operations and Control Center

US DPC

Taiwan DPC

Users

Researchers

NATIONAL SPACE ORGANIZATION

Mission Baseline

	First Launch	Second Launch
Mission Constellation	6 satellites (inclination ~24 deg, mission altitude ~ 520 km)	6 (or 7) satellites (inclination ~72 deg, mission altitude ~ 800 km)
Mission Payload	Tri-G	Tri-G
Science Payload	■ 2 band beacon ■ Plasma Drift/Fluctuation Sensor Together around 10kg, 22W	Taiwan furnished payload
Launcher	Minotaur IV carrying 6 satellites	Minotaur IV carrying 7 satellites (including 1 spare satellite)
Launch Schedule	2014 Q3	2016 Q3
Communication Architecture	Via ground station	
Mission Duration	10 years [TBR]	

Mission Requirements *(1/3)*

Key Parameter	FORMOSAT-7 / COSMIC-2
1.0 Constellation Requirements	
Number of Satellites	■ 12 plus one spare satellite.
Launch 1	■ 6 satellites. ■ Inclination ~ 24 deg. ■ Mission Orbit ~520 km. ■ Phasing ~ 60 deg apart on right ascension ascending node; ~ 60 deg apart on argument of latitude. ■ Parking orbit ~ 700 km.
Launch 2	■ 6 satellites . ■ Inclination ~ 72 deg. ■ Mission Orbit ~ 800 km. ■ Phasing ~ 30 deg apart on right ascension ascending node; ~ 60 deg apart on argument of latitude. ■ Parking orbit ~ 520 km . ■ Spare satellite located at 600 km .

Mission Requirements (2/3)

Key Parameter	FORMOSAT-7 / COSMIC-2
2.0 Mission Duration	
Duration	10 years [TBR]
3.0 Payload	
Mission Payload	Tri-G
US Science Payload	2BB, PD/FS
Taiwan Payload	Guideline (1) RO value added (2) constellation.
4.0 Launcher	
Number of Launches	2
Launcher	Minotour-4 with Falcon-9 as backup.
5.0 System Availability	
System Availability	0.95 [TBR]

Mission Requirements (3/3)

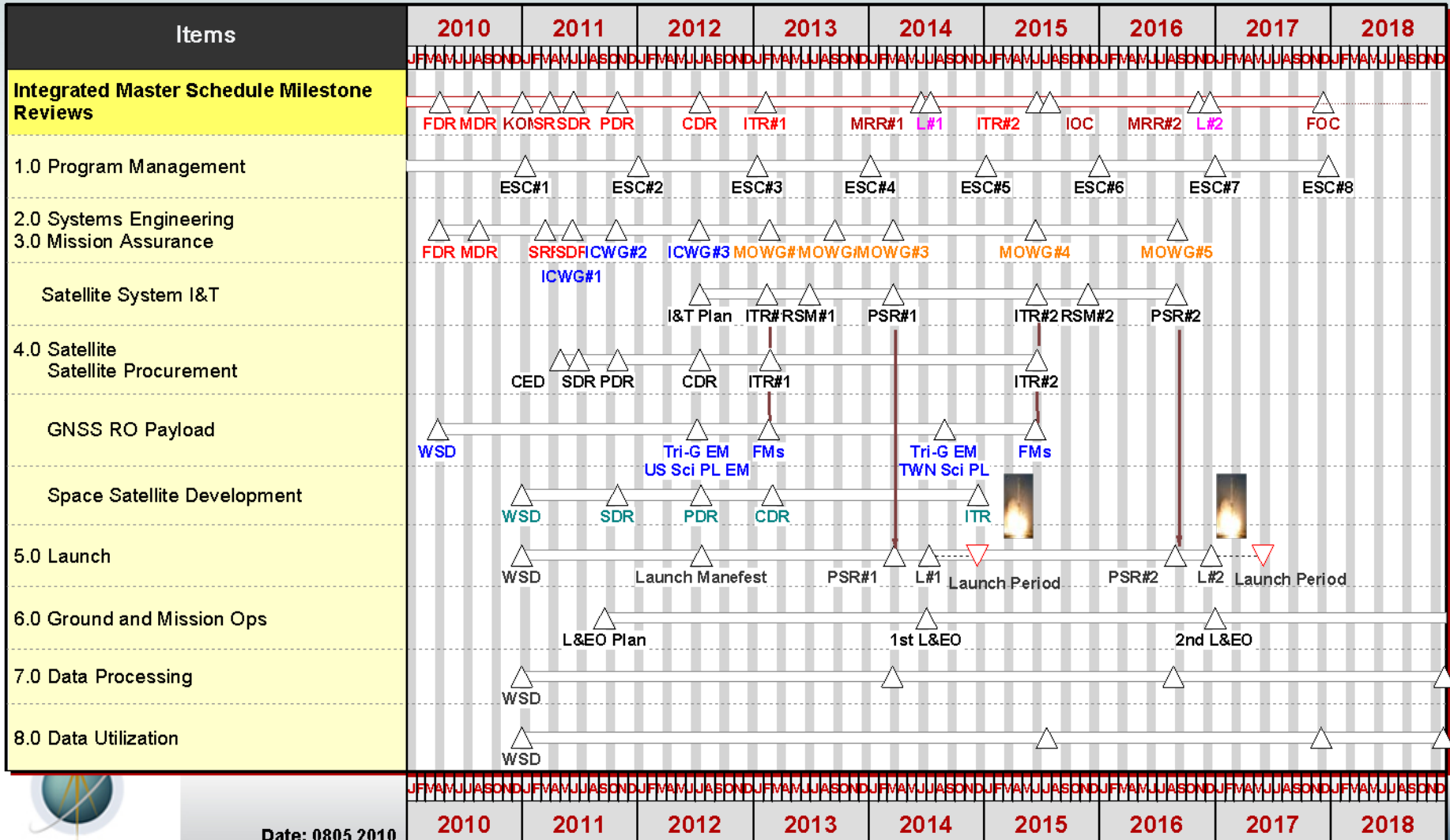| Key Parameter	FORMOSAT-7
6.0 Mission Product Requirement	
Data profiles	*8000 profiles per day for 12-satellite constellation.*
Data latency	*45 minutes on an average.*
7.0 Data Processing Center and Data Distribution Requirement	
8.0 Ground Segment Requirement	
Ground Availability	■ *Commanding capability every orbit for each satellite.* [TBR] ■ *P/L data receiving twice per orbit for each satellite.*
SOCC	■ *Multi-mission and Constellation Operations .*
Ground stations	■ *LTS: TT&C, P/L data receiving, fully remote control.* ■ *RTS: TT&C, P/L data receiving, remote access with trigger control.* ■ *RS: P/L data receiving .*

Mission Collaboration between NSPO and NOAA

Joint Mission
NSPO / NOAA

Mission Systems NSPO / NOAA	Spacecraft System NSPO	Payloads NSPO / NOAA	Launch System NOAA	Ground System NOAA / NSPO	Mission Ops NSPO / NOAA	Data System NSPO / NOAA
Constellation NSPO / NOAA	System Development NSPO	RO Payload NOAA / JPL	Launch #1 NOAA / TBD	SOCC NSPO	L&EO NSPO / NOAA	DPC NOAA
Interface Management NSPO		US Science PL NOAA	Launch #2 NOAA / TBD	LTS NSPO	Constellation Deployment NSPO	TDPC NSPO
Verification NSPO / NOAA		TW Science PL NSPO		RTS NOAA	Normal Ops NSPO	

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NSPO

20100712@NSPO

Mission Deployment Schedule

FORMOSAT-7 / COSMIC-2 Program Integrated Master Schedule (Preliminary)

Date: 0805 2010
FS-7/C-2 Integrated Master Schedule

2010/9/17

RO Data Number Analysis

- *Estimated Occultation Points when all SC complete constellation deployment.*

SC #	GNSS Status	Daily Data # (Raw Data)	75% of raw data
6+6	(24-GPS)	4754	3565
	(30-GPS) + (27-GALILEO)	11307	8480
	(24-GPS) + (27-GALILEO) + (24-GLONASS-CDMA)	14729	11046

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Potential FORMOSAT-7/COSMIC-2 Constellation

- **Constellation of (12+1) satellites**
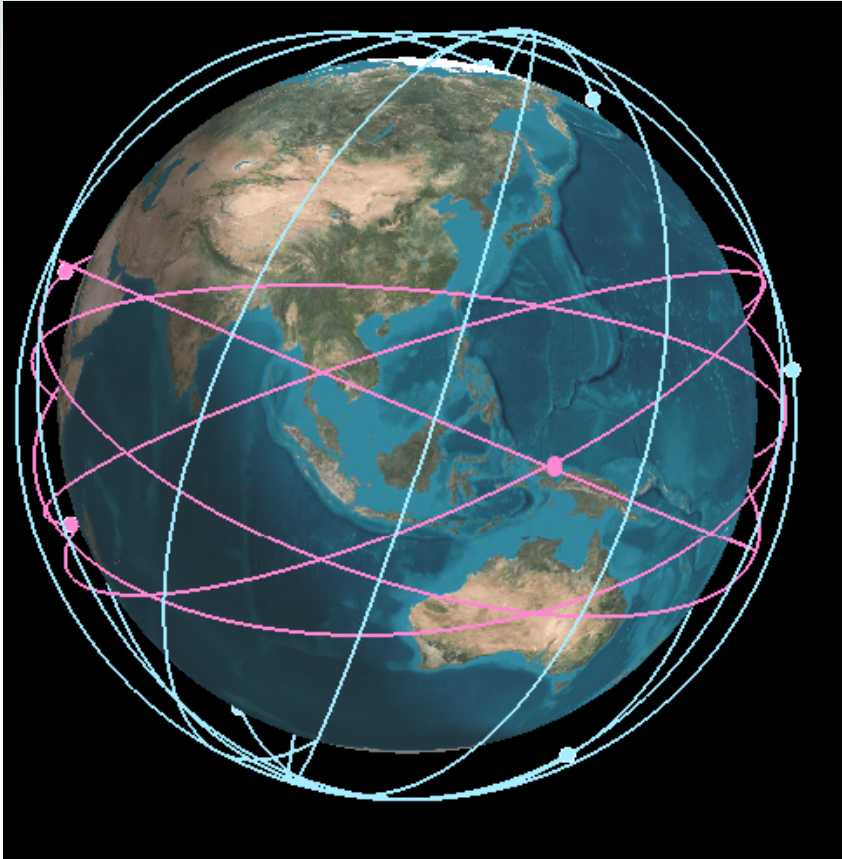
  - **6 satellites to be launched at low inclination (~ 24 deg) and separated by 60 deg when complete cluster constellation deployment.**

  - **6 satellites to be launched at high-inclination-angle (~72 deg) and separated by 30 deg when complete final constellation deployment.**

  - **NSPO built satellite will be placed at a designated orbit**

Constellation Deployment Timeline

Unit:Km (y-axis: 450, 500, 550, 600, 650, 700, 750, 800, 850)

Unit:Week (x-axis: 0, 12, 24, 36, 48, 60, 72, 84, 96, 108, 120, 132, 144, 156, 168, 180, 192, 204, 216)
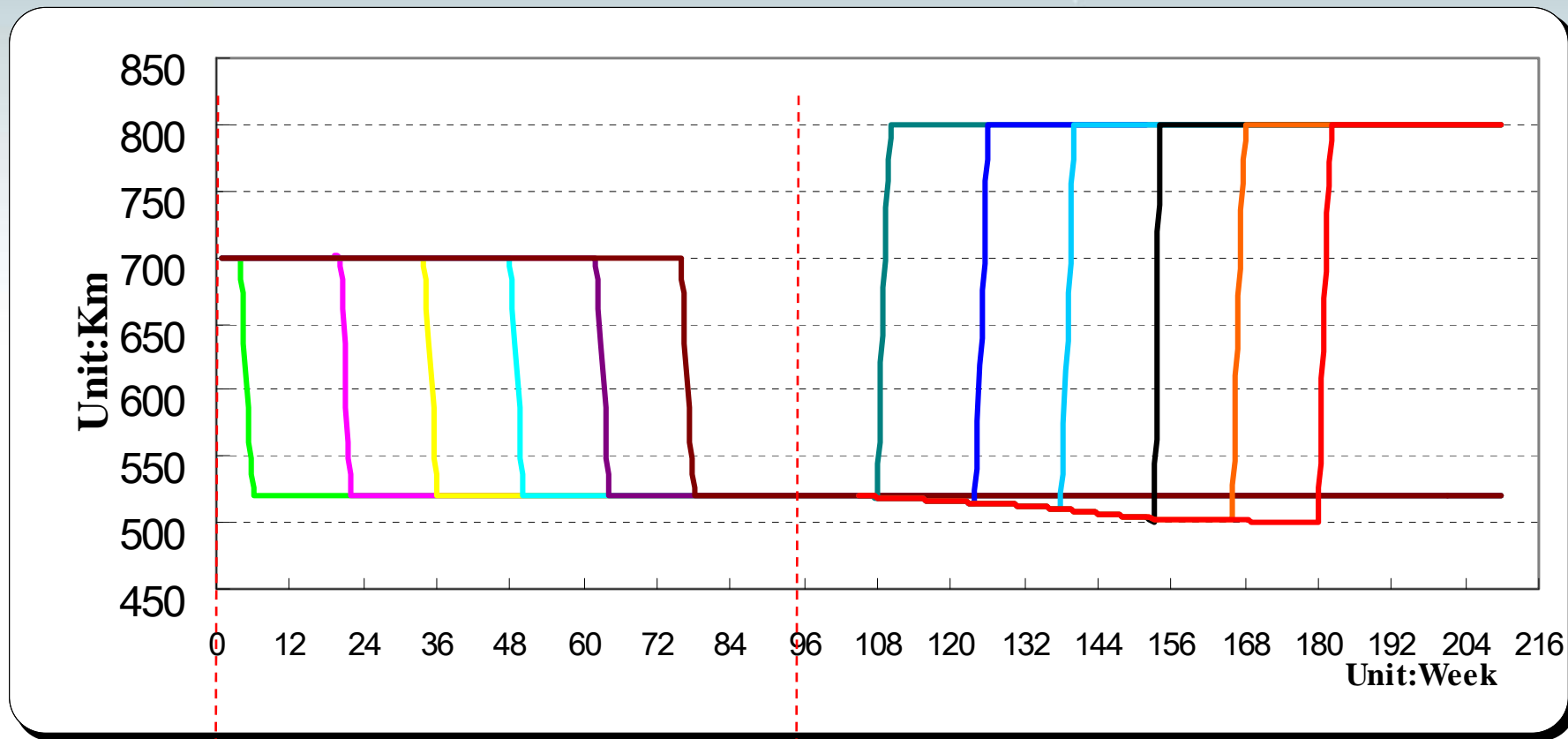
1st Launch
2014/7

Inclination angle	24º
Parking orbit altitude	700 Km
Mission orbit altitude	520 Km
Separation angle	60˚

2nd Launch
2016/7

Inclination angle	72º
Parking orbit altitude	520 Km
Mission orbit altitude	800 Km
Separation angle	30º

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Geographic Coverage

1 S/C, 72° inc, GPS, 24 hrs
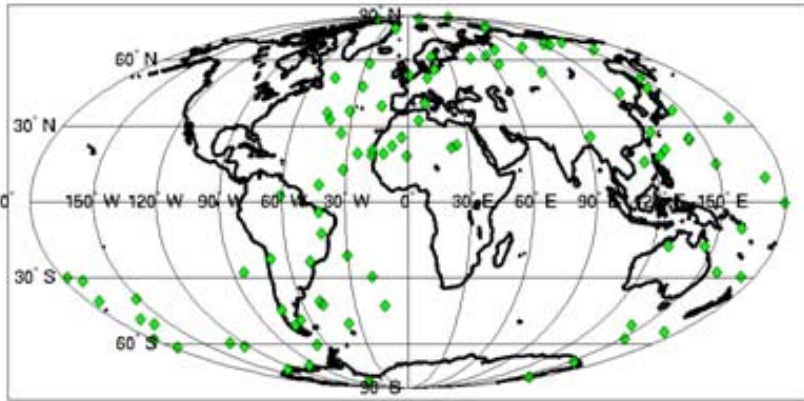
8 S/C, 8 planes, 72° inc, GPS, 24 hrs
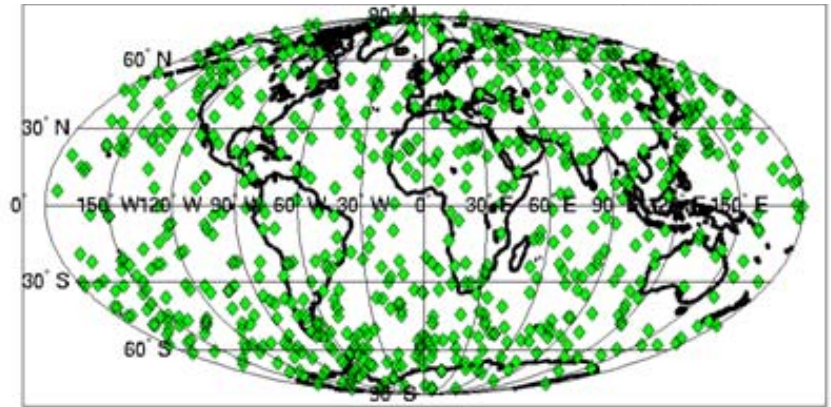
1 S/C, 72° inc, GPS, 4 hrs
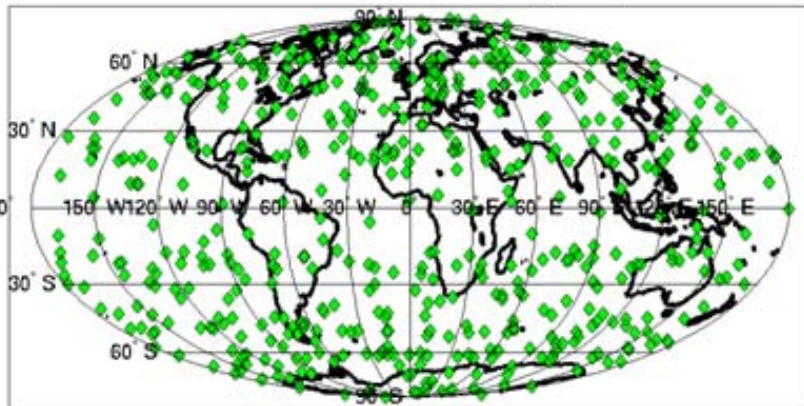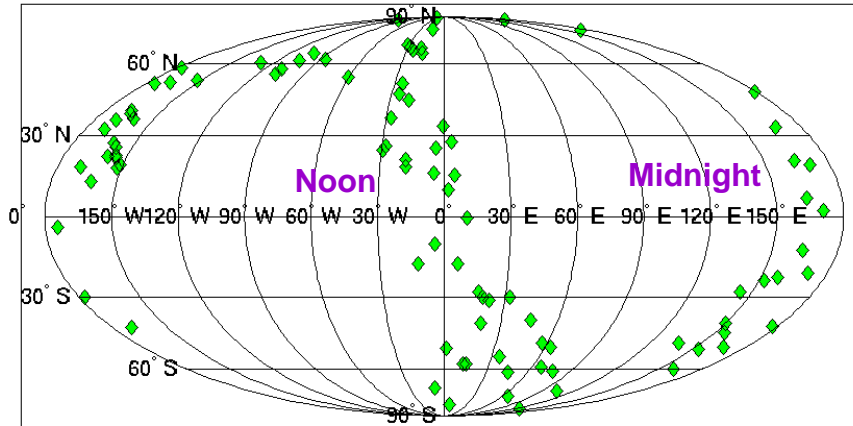
8 S/C, 8 planes, 72° inc, GPS, 24 hrs
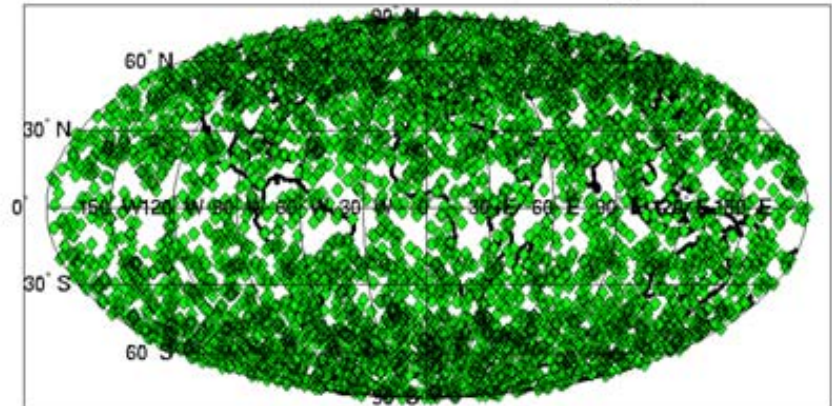
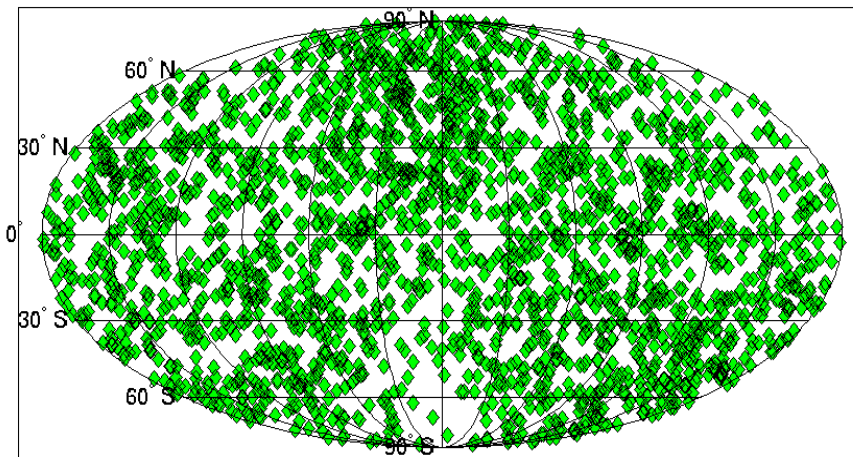*Courtesy of UCAR*

Local Time Coverage in 4 hrs

**1 S/C
GPS
4 hrs**

Sun-Fixed Occultations, 1 S/C, Inc 72 deg, GPS, 4 hours

**12 S/C,
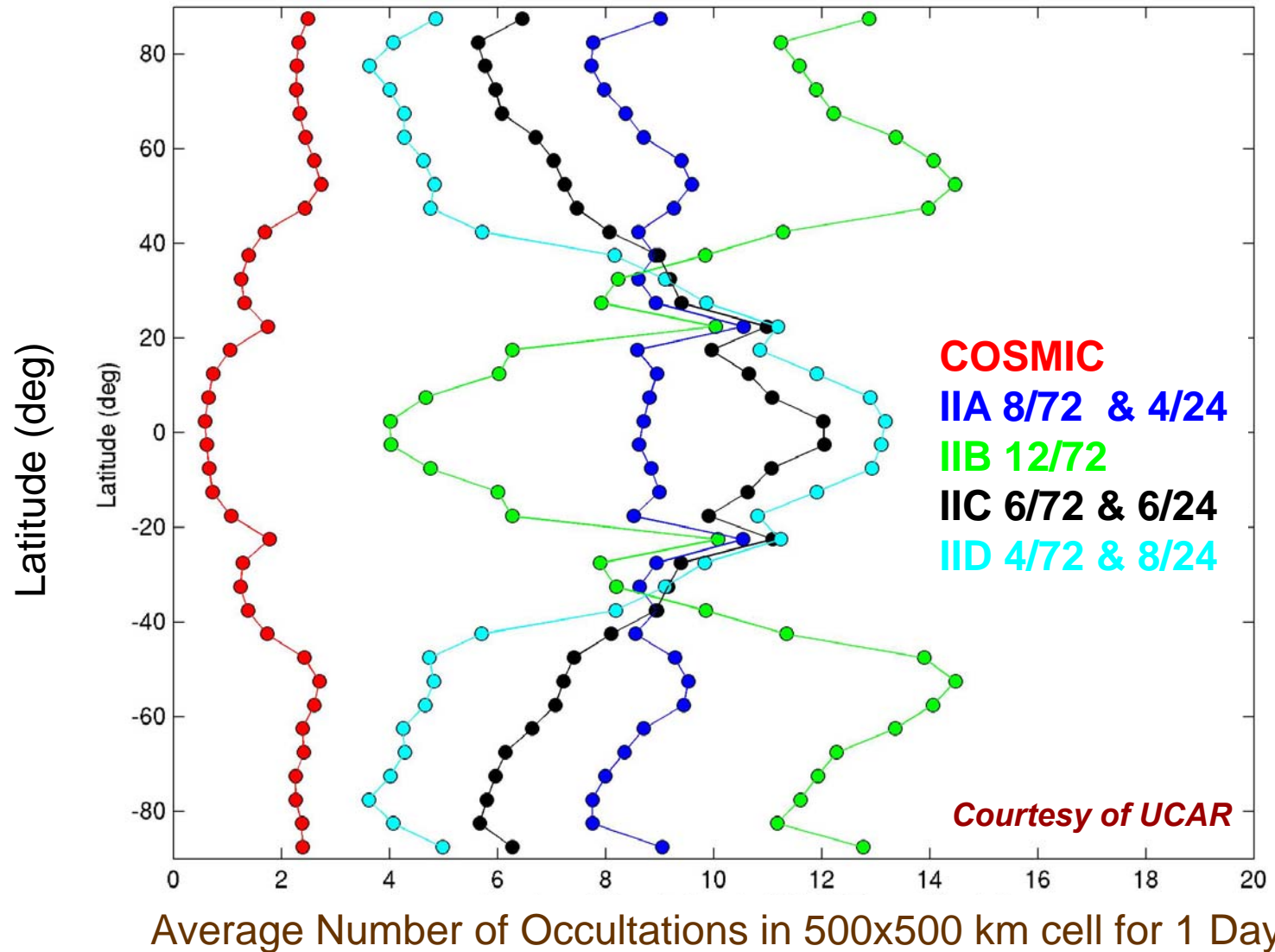GPS+Galileo
4 hrs**
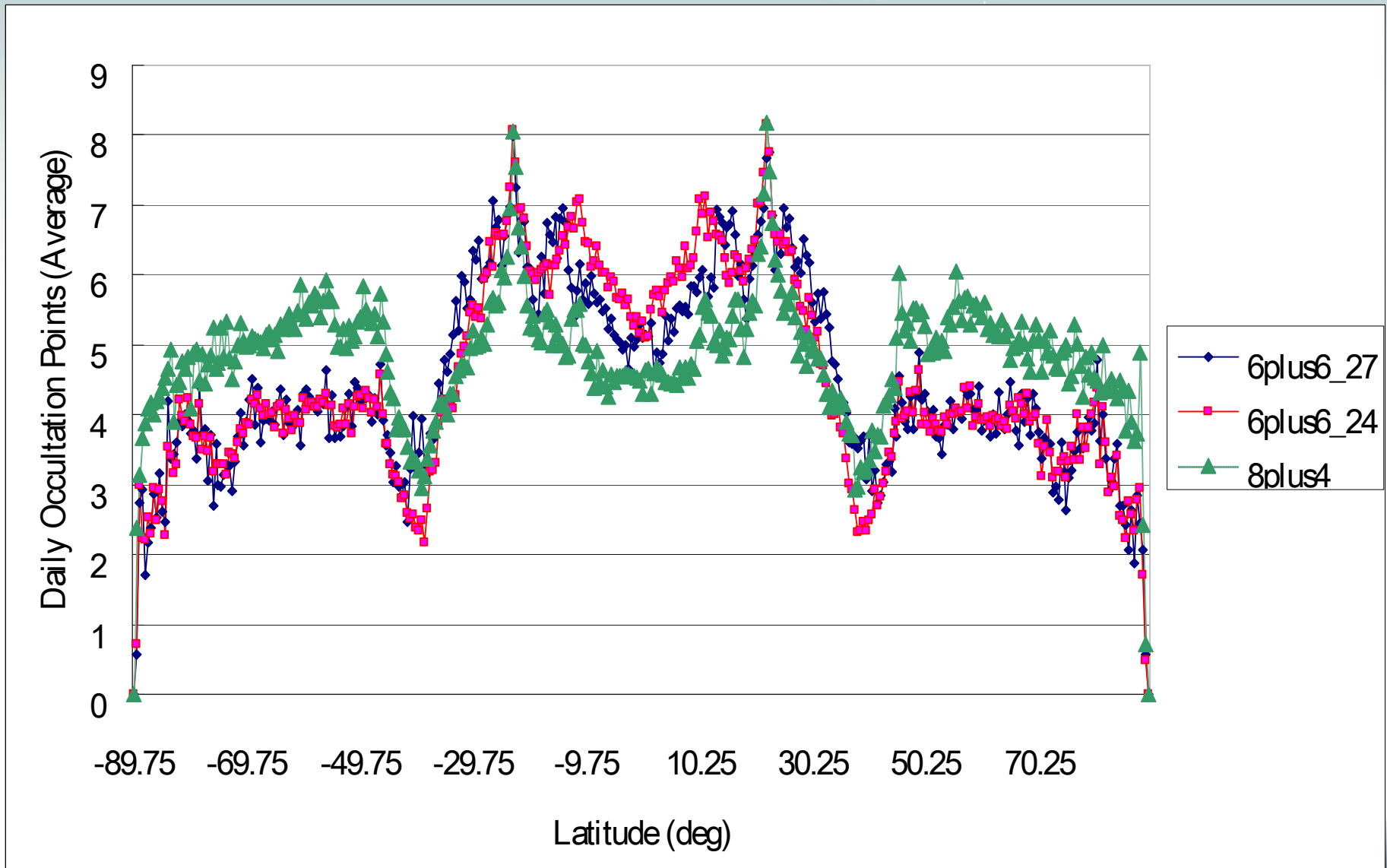
Sun-Fixed Occultations, 8@72, 4@24

Courtesy of UCAR

Multiple vs Single Inclinations

Occultation Density vs Latitude: 14 Day Simulation

COSMIC
IIA 8/72 & 4/24
IIB 12/72
IIC 6/72 & 6/24
IID 4/72 & 8/24

Courtesy of UCAR

Average Number of Occultations in 500x500 km cell for 1 Day

RO Data Distribution *vs. Constellation* (1/2)

Follow-On Spacecraft Bus Highlight

Item	Follow-On Design	FORMOSAT-3	Benefit
System	5-year [TBR] mission life	2-year mission life	- Higher reliability - Longer mission life
Attitude Performance	Roll/Pitch/Yaw: +/-1 deg (3σ)	- Roll/Yaw: +/-5 deg (1σ) - Pitch: +/- 2 deg (1σ)	- Improved attitude performance
Computer Architecture	Centralized Architecture Radiation Harden	Distributed architecture	- Integrated computing capability - Reduced harness & mass

NSPO NATIONAL SPACE ORGANIZATION

72° Orbit Data Recovery
Current FORMOSAT-3 / COSMIC Network

Tromso

FCDAS
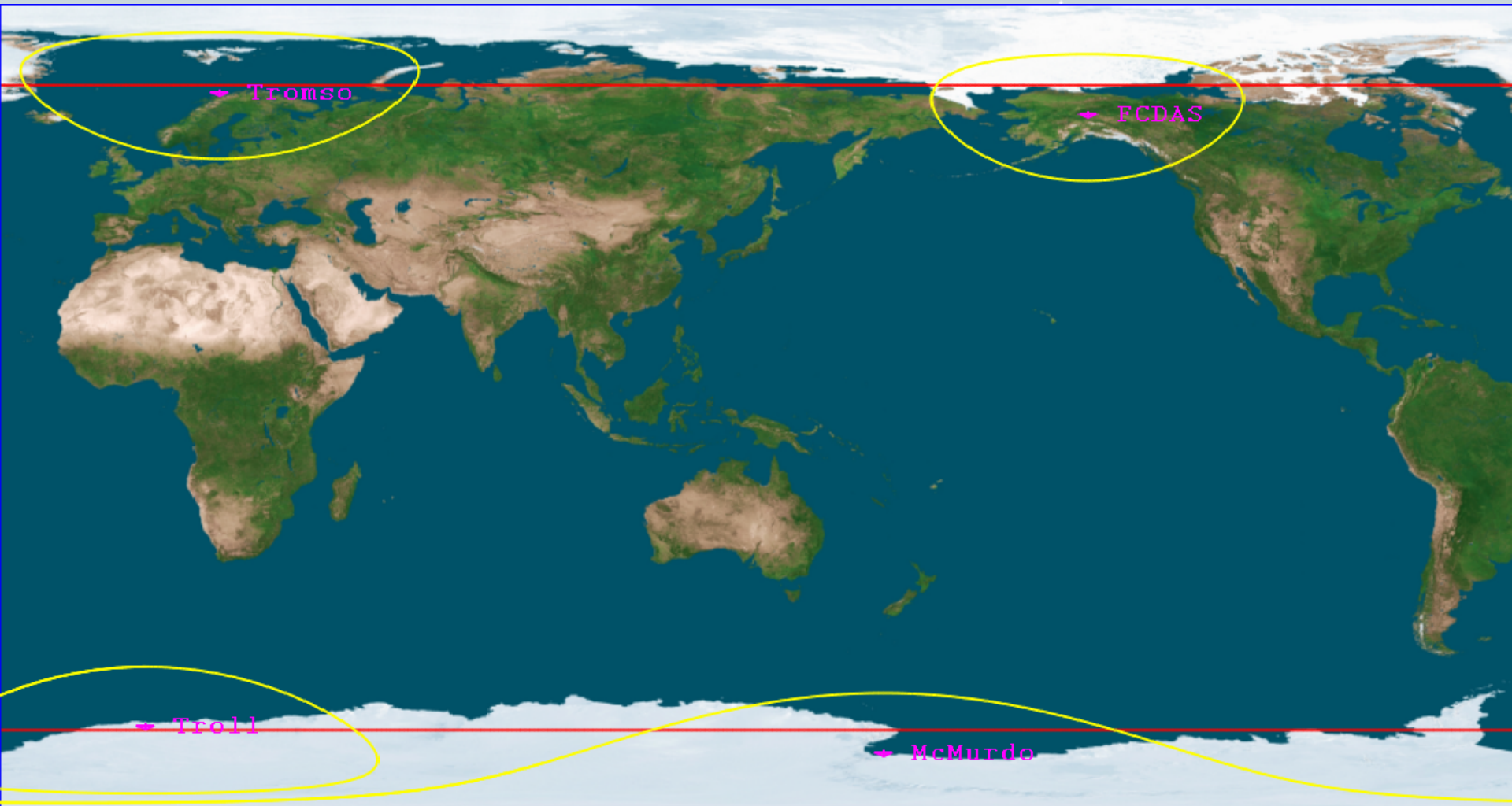
Troll

McMurdo

- *KSAT Tromso*
- *KSAT Troll*

- *NOAA FCDAS*
- *NASA McMurdo*

Courtesy of NOAA

NATIONAL SPACE ORGANIZATION

24° Orbit Data Recovery
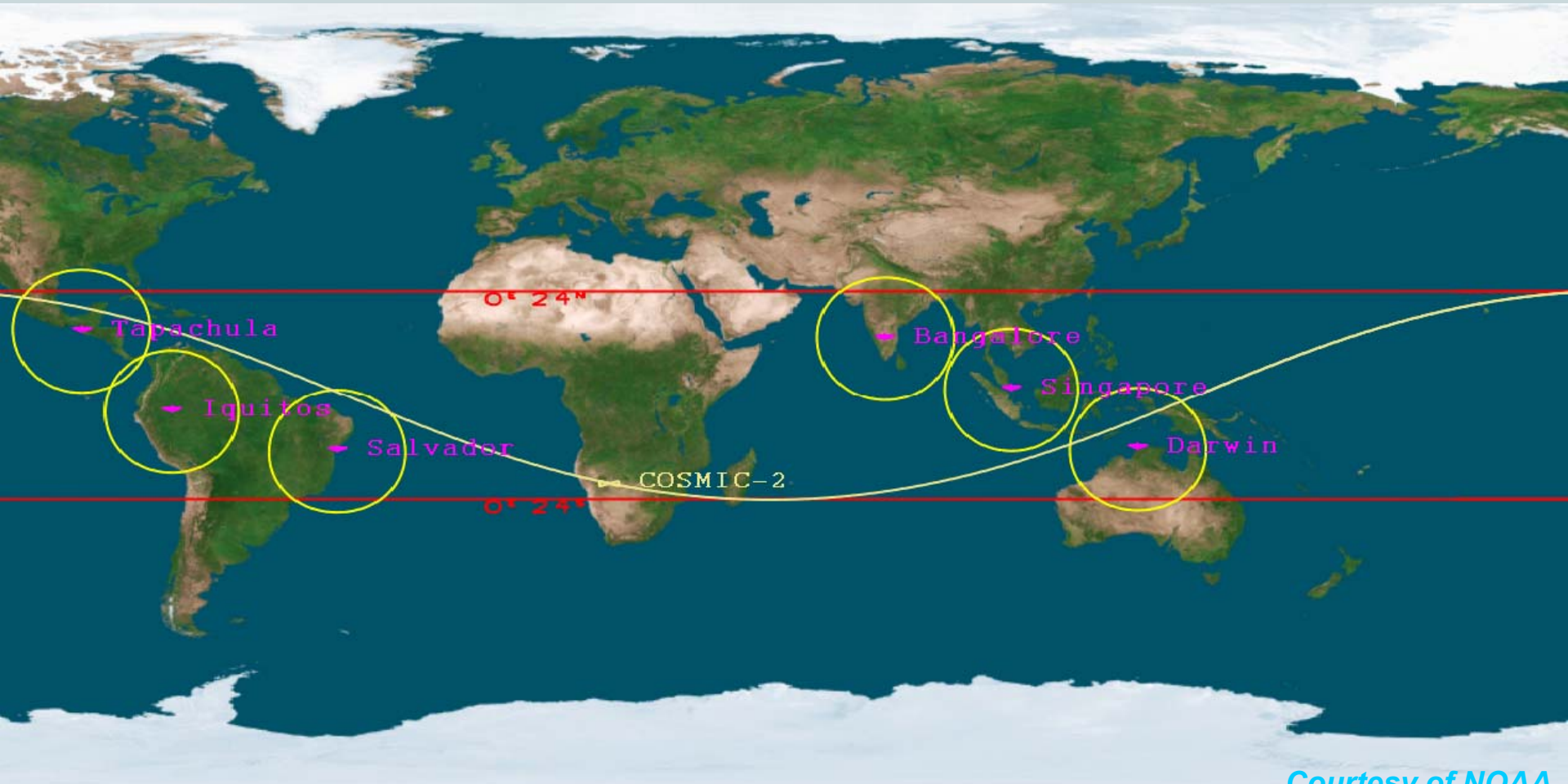## KSAT Service Network
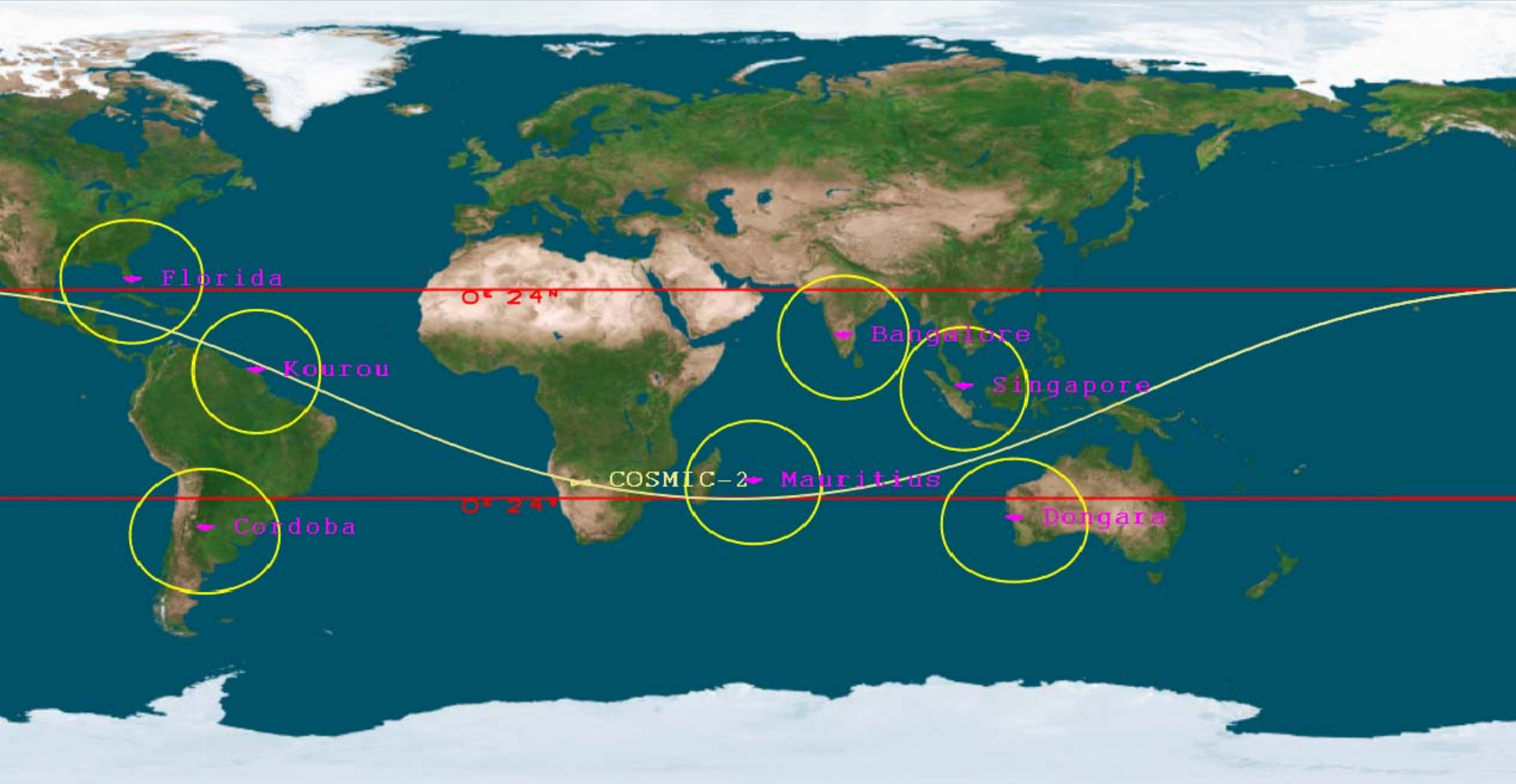
- *Florida, USA*
- *Korou, French Guiana*
- *Cordoba, Argentina*
- *Mauritius*
- *Bangalore, India*
- *Singapore*
- *Dongara, Australia*

Courtesy of NOAA

NATIONAL SPACE ORGANIZATION

24° Orbit Data Recovery
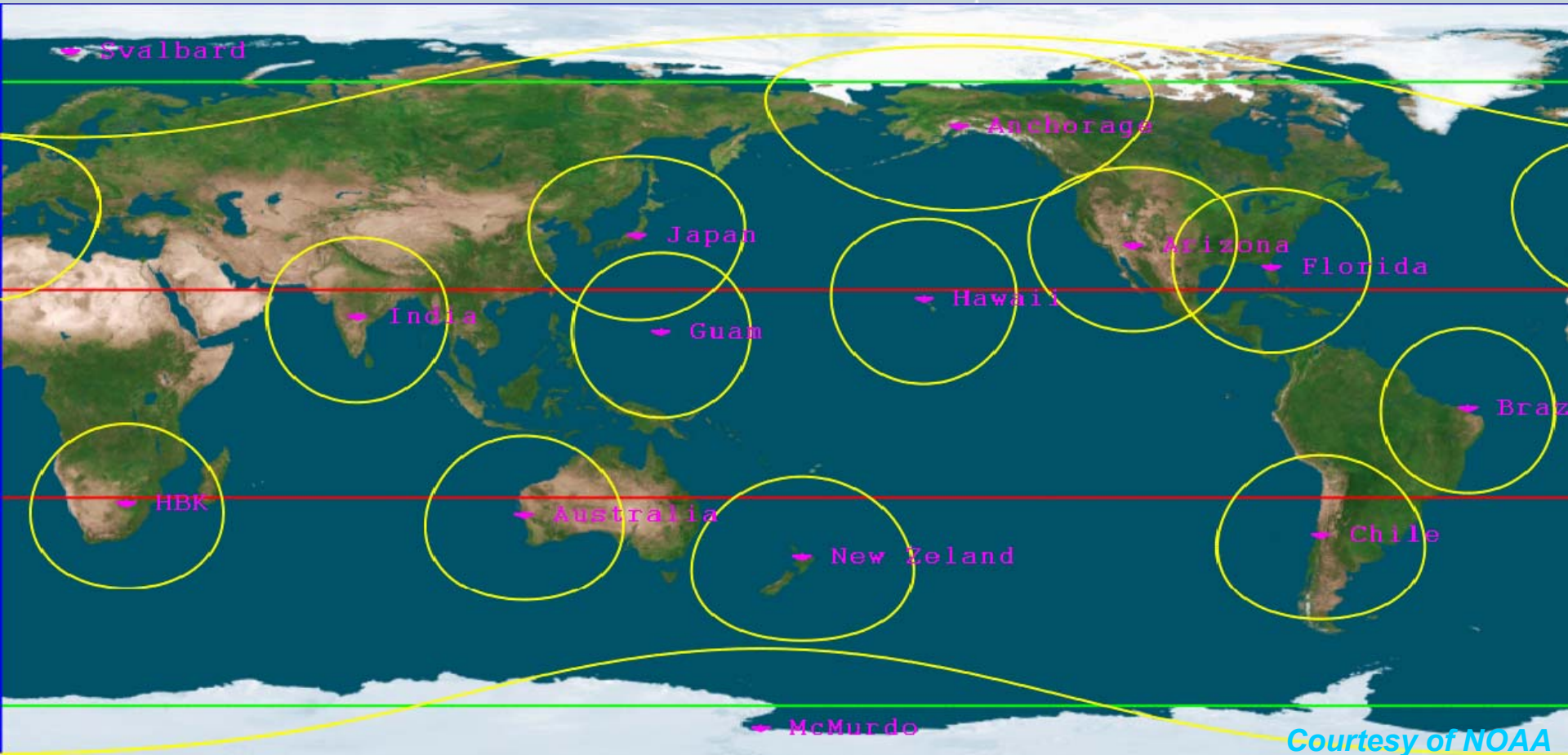## FORMOSAT-7/ COSMIC-2 Candidate Sites

Courtesy of NOAA

- *Tapachula, Mexico*
- *Iquitos, Peru*
- *Salvador, Brazil (INPE)*

- *Bangalore, India (ISRO)*
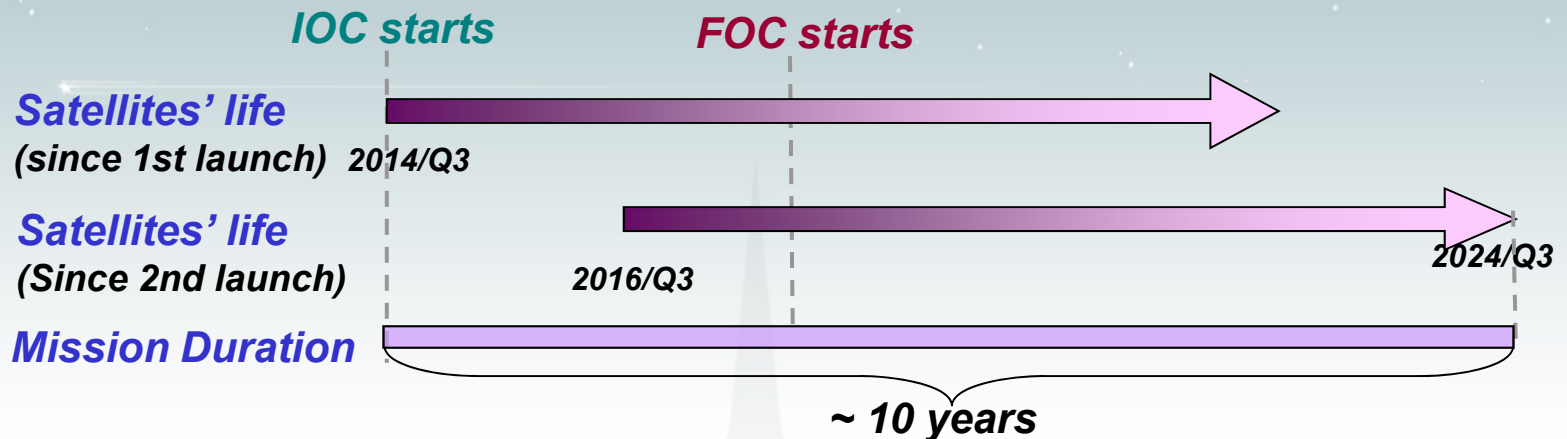- *Singapore*
- *Darwin, Australia (BOM)*

MMGN Receptor Locations

Courtesy of NOAA

- **Hartebeesthoek, South Africa (CSIR)**
- **Shadnagar, India (ISRO)**
- **Geraldton, Australia**
- **Hatoyama, Japan (JAXA)**
- **Tuman Bay, Guam (ATT POP)**

- **Warkworth, New Zealand (NZ Telecom)**
- **McMurdo Station, Antarctica (NSF, 2 receptors)**
- **Paumalu, Oahu, Hawaii (Intelsat)**
- **Anchorage, Alaska (ATT POP)**
- **Mesa, Arizona (ATT POP)**

- **Orlando, Florida (ATT POP)**
- **Santiago, Chile (SSC)**
- **Eusebio, Brazil (INPE)**
- **Madrid, Spain (INTA)**
- **Svalbard (KSAT)**

Mission Duration Analysis

IOC starts **FOC starts**

Satellites' life
(since 1st launch) 2014/Q3

Satellites' life
(Since 2nd launch) 2016/Q3 2024/Q3
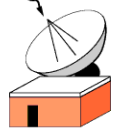
Mission Duration

~ 10 years

- **IOC (Initial Operational Capability):**

  After first launch and when the system begins to provide the data.

- **FOC (Full Operational Capability):**

  When all of the threshold requirements are met or exceed.

- **Mission Duration:**

  Mission begins at first launch and ends when the total number processed data points available from the data processing center degrades below **15% [TBR]** *of the threshold value.*

- *To reach the mission duration of 10 years* **[TBR]** *, the possibility for 2 satellites surviving 8 years after the 2nd launch needs to be higher than 50%.*

COSMIC Operational Processing

TACC

JCSDA

NCEP
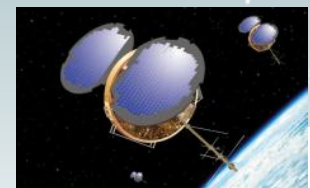
RTSs:
Alaska
Norway
Antarctica/McMurdo

C D A A C

UCAR/Unidata's LDM

WGET

Research Community

N E S D I S

ECMWF

GTS

CWB

Input Data
- *COSMIC data*
- *GPS ground data*
- *GPS NDM Bits*
- *GFS Forecast*
- *IGS/IGU ORB/CLK*
- *Bernese Conf files*

1500-2000 WMO BUFR Files per day with Latency ~ 75-90min

UKMO

JMA

SFTP

AFWA

Canada Met.

Science & Archive

Meteo France
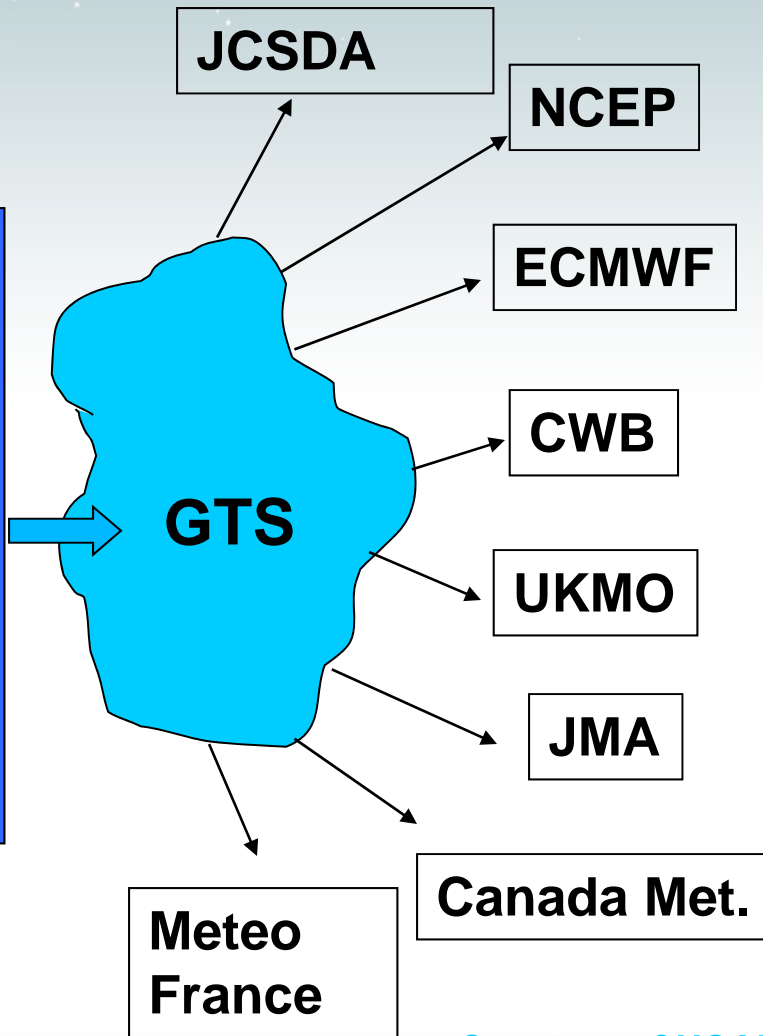
Courtesy of UCAR

CDAAC reliability estimated > 99.5%, Latency ~ 75-90 min

TriG GNSSRO Payload

- ***TriG***
  - *Mass – 6 kg*
  - *Power – 50 Watts*
  - *Volume – 30 X 30 X 20 cm*
  - *Antenna inputs - 8*
- ***GNSS Realtime Nav Processor***
  - *Acquires and tracks GNSS signals*
  - *Sets Real Time Clock*
  - *Generates Position, Velocity and Time*
  - *Outputs time-tagged phase/range/snr*
  - *Sends nav data to Science Processor*
- ***Science Processor***
  - *Schedules Iono/Atmo Occ Profiles*
  - *Extracts 1ms phase/range/amp*
  - *Formats observables*

TriG Instrument

L1/E1, L2, L5/E5a RFDCs (4-12)	GNSS Realtime NAV Processor
Reconfigurable Digital Processor	SCIENCE PROCESSOR
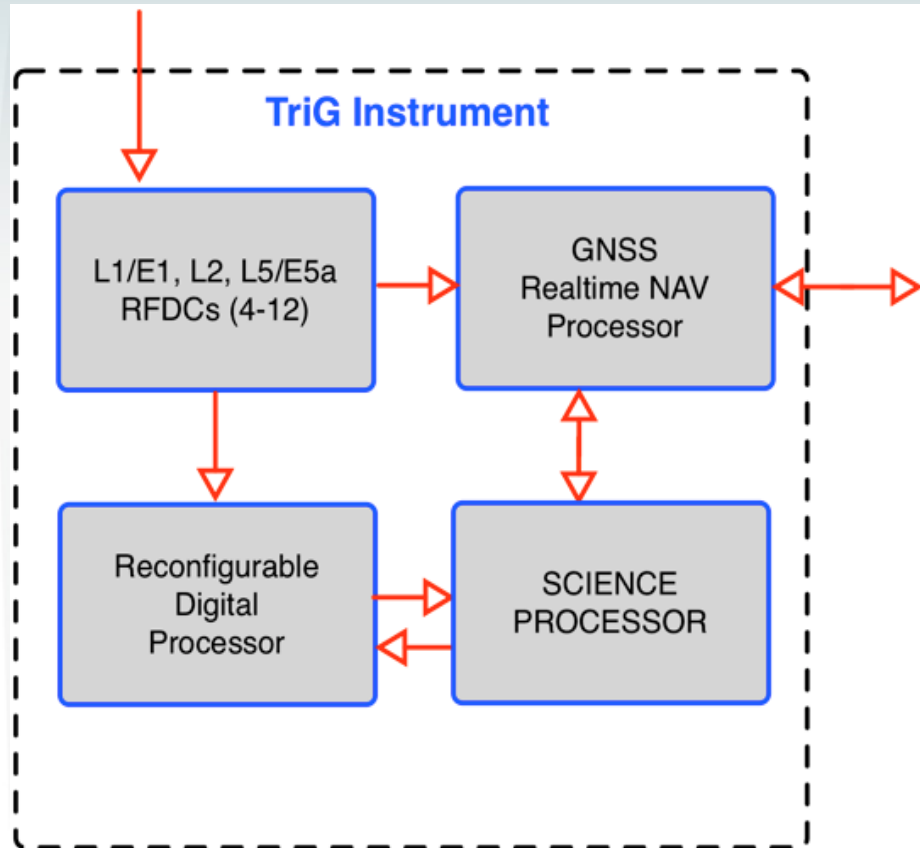
Courtesy of NOAA

Space Weather Sensor Options for COSMIC-2
(Initial US Government List)

Sensor	Observations	Priority
Radio Beacon	**VHF/UHF/L-band scintillation**	**#1**
In-Situ Plasma Sensor	**Plasma fluctuations/electron density & temperature**	**#2**
Ion Velocity Meter	**Vector plasma drift velocity/ion density, temperature & composition**	**#2**
Neutral Wind Meter	**Vector neutral winds**	**#3**
Nadir UV Photometer	**O^+ recombination nightglow**	**#4**

- **Modifications since COSMIC-2 FDR – Maintain COSMIC simplicity**
  - *Neutral wind meter removed because it drives too low an altitude (~400 km)*
  - *Nadir UV photometer removed to reduce sensor count*
  - *Remaining in-situ sensors combined to provide single interface to s/c*
  - *Radio beacon baseline changed to two (TBD) frequencies*

Courtesy of NOAA

FORMOSAT-7 / COSMIC-2 Current Status

- ☐ *FORMOSAT-3 continues to degrade into 2011 (end of life).*

- ☐ *Data gap expected by 2014-2015 due to loss of satellites.*

- ☐ *The U.S. President's budget supports first of 2 launches of COSMIC 2 constellation by mid 2014.*

- ☐ *The U.S. and Taiwan signed the collaboration AIT / TECRO Agreement to proceed to the FORMOSAT-3/ COSMIC follow-on mission, i.e. FORMOSAT-7 / COSMIC-2 mission.*

- ☐ *Based on the agreement, NSPO / NOAA Partnership to build and launch a 12 satellite constellation*

  - ◆ *NSPO to provide: 12 spacecraft buses and the integration of payloads into spacecraft, and Mission Control Center*

  - ◆ *NOAA to provide: 12 GNSSRO Payloads, 2 launches, tracking stations, payload data processing*

  - ◆ *First launch planned for mid 2014 – 2nd launch 2016 (TBD)*

  - ◆ *System will provide 8000+ worldwide atmospheric and 10-12,000 ionospheric soundings per day*

2010/9/17

FORMOSAT-7 / COSMIC-2 Near Term Activities

- ☐ *NOAA/NSPO completed Feasibility Design Review (FDR) in May.*

- ☐ *NASA TriG Payload Kickoff at JPL in June.*

- ☐ *NOAA/NSPO completed Mission Design Review (MDR) in August.*

- ☐ *Level 1 Requirements Document for the joint mission has been signed by NESDIS / Weather Service and is in the process being signed by Taiwan funding authority.*

- ☐ *NSPO has begun the Spacecraft development since early this year.*

- ☐ *US government partnership decisions – Green light - MOU in work*

- ☐ *NASA TriG PDR will be held in October.*

- ☐ *NOAA budget plan will support the FY 2011 COSMIC-2 activities.*

- ☐ *NSPO is in process to submit the FORMOSAT-7 Program Plan that includes the work share portion of the joint mission to NARL and NSC for formal program and the required budget approval.*

- ☐ *NOAA/NSPO will conduct the System Requirement Review in the first quarter next year.*

2010/9/17

Enter Your Organization on
the FORMOSAT-7 / COSMIC-2 Partnership List

Upcoming Workshops

Title	*Time*	*Place*
IWSCFF 2010 *International Workshop on Satellite Constellation and Formation Flying* *(http://iwscff2010.nspo.org.tw/IWSCFF2010/index.html)*	*Nov 1-3, 2010*	*Taipei, Taiwan*
FORMOSAT-3 / COSMIC Data Users' Workshop & the Commencement of FORMOSAT-7 / COSMIC-2 Program	*April 13 ~15, 2011*	*Taiwan*

Thank You !