# Fengyun Meteorological Satellites and Consideration on Calibration Issues


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**National Satellite Meteorological Center, China Meteorological Administration (NSMC/CMA)**



**99th AMS Annual Meeting**
**8 Jan., 2019, Phoenix, USA**

# Outline

- Fengyun Program Overview
- Current Missions and Services
- Latest Progress
- Future Programs
- Consideration on Calibration Issues

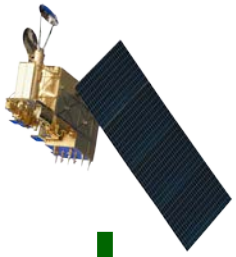
# 1. Fengyun Program Overview

## Chinese FENGYUN Meteorological Satellites

**Polar System**

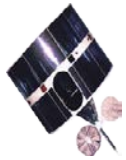
**First Generation**
FY-1 A, B, C, D

**Second Generation**
FY-3 A, B, C, D

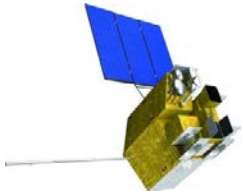


FY-3E, F, G planned until 2025

**Geostationary System**



**First Generation**
FY-2 A, B, C, D,
E, F, G, H



**Second Generation**
FY-4 A

FY-4B, C, D planned until 2025

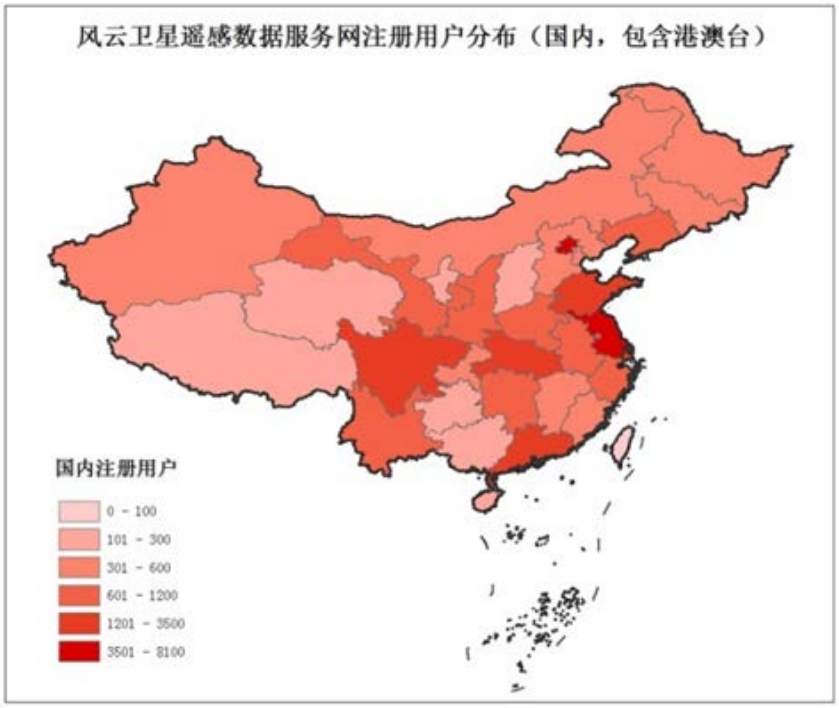
# Launched Satellites

| Since Jan. 1969, China began to develop his own meteorological Satellite | | | | |
|---|---|---|---|---|
| Leo | Launch Data | | Geo | Launch Data |
| FY-1A | Sept. 7, 1988 | | FY-2A | Jun. 10, 1997 |
| FY-1B | Sept. 3, 1990 | | FY-2B | Jun. 25, 2000 |
| FY-1C | May 10, 1999 | | FY-2C | Oct. 18, 2004 |
| FY-1D | May 15, 2002 | | FY-2D | Dec. 8, 2006 |
| FY-3A | May 27, 2008 | | FY-2E | Dec. 23, 2008 |
| FY-3B | Nov. 5, 2010 | | FY-2F | Jan. 13, 2012 |
| FY-3C | Sept. 23, 2013 | | FY-2G | Dec. 31, 2014 |
| FY-3D | Nov. 15, 2017 | | FY-4A | Dec. 11, 2016 |
| | | | FY-2H | Jun. 5, 2018 |

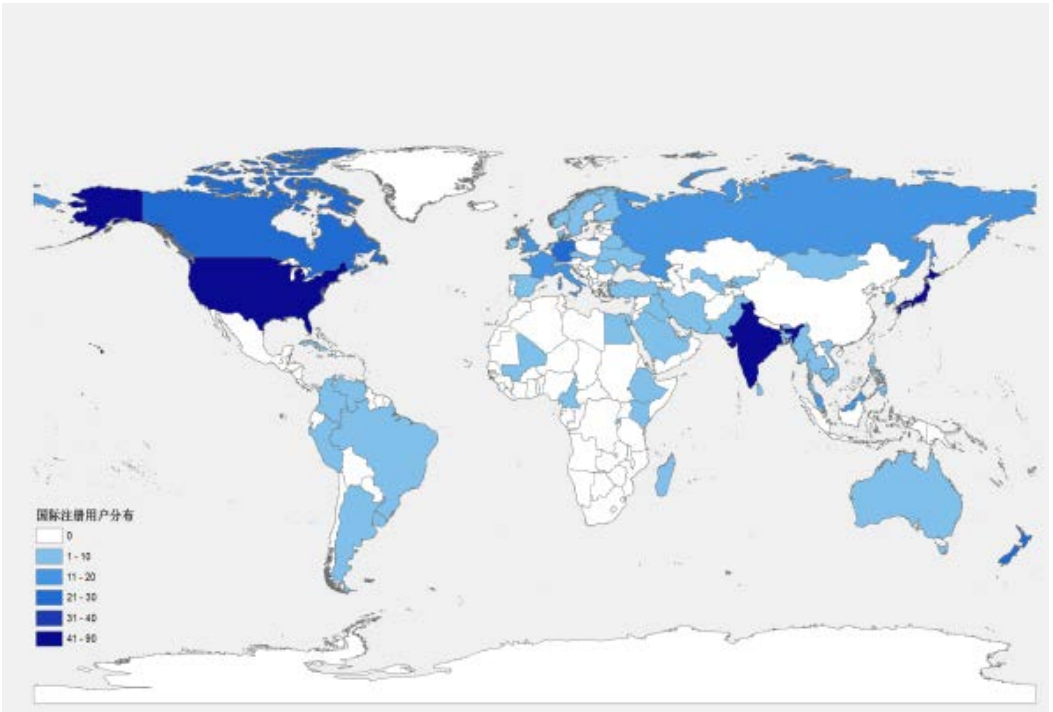
## Overall Development Strategy (4 stages):

**1) 1970 - 1990:** Conducting satellite research and development
**2) 1990 - 2000:** Implementing transition from R&D to operational
**3) 2000 - 2010:** Implementing transition from 1st generation to 2nd generation
**4) 2010 - 2020:** Pursuing accuracy and precision of satellite measurements

## Web-based User Location (Domestic)




## Web-based User Location (International)




Country： > 90

# International User Community

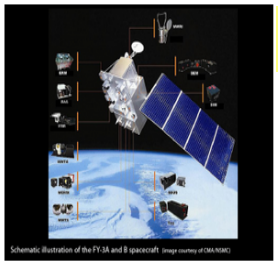
## Global Data

ECMWF About Forecasts Computing Research Learning Log In Search site Go

ECMWF starts using Chinese satellite data

- Who we are
- What we do
- Jobs
- News centre
- Suppliers
- Contact us

**29 September 2014**



Schematic illustration of the FY-3A and B spacecraft (Image courtesy of CMA/NSMC)

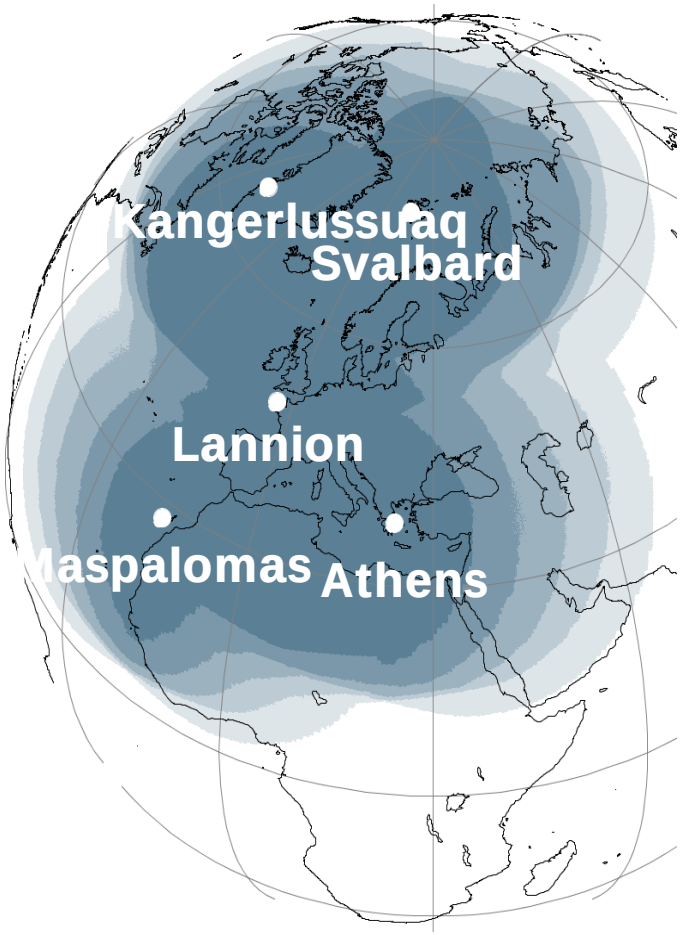
On 24 September 2014, ECMWF actively used Chinese satellite data for the first time in the operational forecasting system. This marks a milestone in ECMWF's fruitful cooperation with the Chinese Meteorological Administration (CMA) and the Chinese Institute of Atmospheric Physics (IAP) in the area of characterisation and use of Chinese satellite data. China is expected to play a leading role in providing meteorological satellite data in the near future, alongside Europe and the US, currently the main providers of satellite sounding data used operationally. Activating the first Chinese satellite data in the ECMWF system is therefore an important step towards a much greater use of Chinese satellite data in the future.

The new data originates from the Microwave Humidity Sounder (MWHS) on-board the Fengyun-3B (FY-3B) satellite. It contributes to an improved analysis of mid- to upper-tropospheric humidity, and adds robustness to the satellite observing system. Although FY-3B is an experimental satellite, the data has been found to be of sufficient quality to further improve ECMWF's atmospheric analysis. Keyi Chen, visiting scientist from IAP, explains: "Our work has shown the data is of reliable quality, and it has an impact comparable to similar European or US satellite instruments that have been used operationally for a long time."

The development is the result of a very constructive partnership with CMA and IAP to characterise Chinese satellite data. During regular visits to ECMWF, Qifeng Lu from CMA has significantly advanced our understanding of the performance of the instruments on the experimental FY-3A and B satellites. This work continues with the analysis of data from the latest Chinese satellite, FY-3C, performed together with CMA, ECMWF, and the UK Met Office. FY-3C is China's first operational meteorological polar-orbiting satellite, and it carries much improved instruments compared to the earlier FY-3A and B satellites. It was launched in September last year and Qifeng Lu is currently

**FY-3C sounding data have been assimilated into CMA GRAPES, ECMWF, UK NWP model operationally.**

## Regional Data




EUMETSAT Advanced Retransmission Service

ECMWF European Centre for Medium-Range Weather Forecasts

15 April 2011

Re: **The Status of Data from China's FY-3 Satellite in ECMWF's Forecasting System**

Dear Sir/Madam,

This brief letter outlines the status of ECMWF work on data from the FY-3A Satellite.

Data from the FY-3 series of meteorological satellites is set to become an increasingly important component of the global satellite observing system, supporting NWP centres worldwide. As part of a CMA-ECMWF co-operation agreement data from the first satellite in the series, FY-3A, was assessed at ECMWF during 2009-2011. Much of this work was carried out by a visiting scientist from China's National Satellite Meteorological Center, actively supported by staff from CMA and ECMWF. These ground-breaking investigations led to significant improvements in the quality of the data from the FY-3A Microwave Temperature Sounder (MWTS) instrument. The data quality for the MWTS instrument is now comparable to that from equivalent US and European meteorological satellites.

Pre-operational testing has shown the FY-3A data delivers measurable positive impact improvements in the ECMWF model, a very stringent test of the data given the global performance of the ECMWF forecast system. This represents a significant milestone for the FY-3A programme and cooperation with ECMWF. Final pre-operational testing of the FY-3A data is underway and ECMWF plans to use the data operationally in early summer 2011. The scientific work is well documented in a series of Technical Memoranda available from the ECMWF website, and in a series of journal articles.

ECMWF are very appreciative of the support provided by CMA and hope this productive collaboration strengthens in order to support the continued success of the FY-3 programme.

Yours faithfully,

Prof. Erland Kallén
Director of Research

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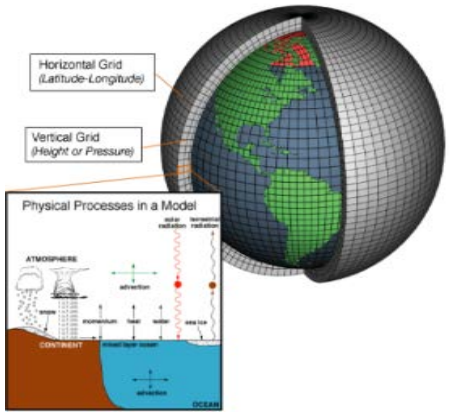



# Cost Function

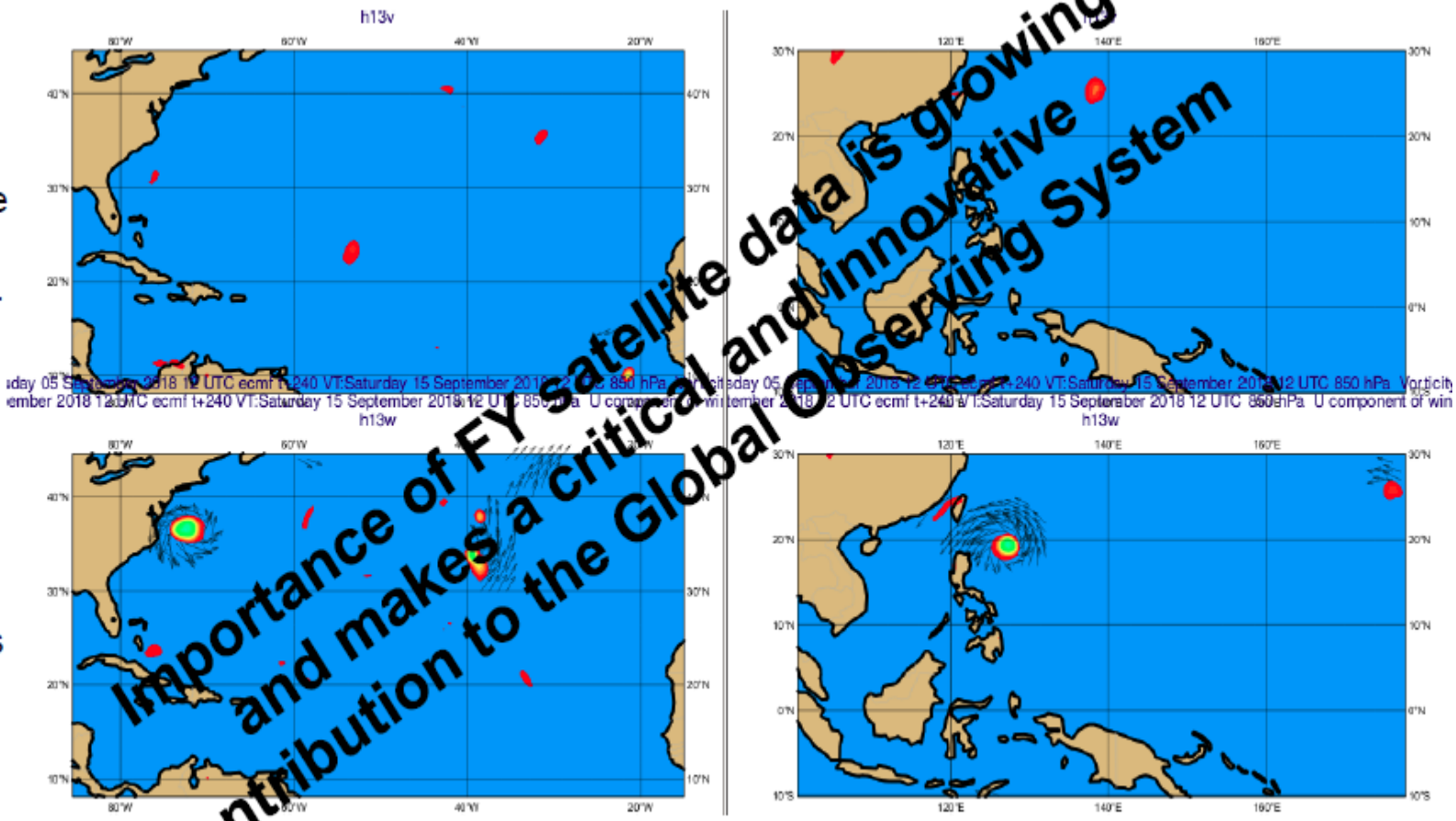
$$J = \frac{1}{2}\left(\mathbf{x}-\mathbf{x}^{b}\right)^{T}\mathbf{B}^{-1}\left(\mathbf{x}-\mathbf{x}^{b}\right)+\frac{1}{2}\left[\mathbf{I}(\mathbf{x})-\mathbf{I}^{o}\right]^{T}(\mathbf{E}+\mathbf{F})^{-1}\left[\mathbf{I}(\mathbf{x})-\mathbf{I}^{o}\right]$$

**The data quality is now comparable to that from equivalent US and European meteorological satellites**

# Conclusion: satellite data is vital for accurate NWP

Take away satellite data – no Hurricane Florence and no typhoon MangKhut.

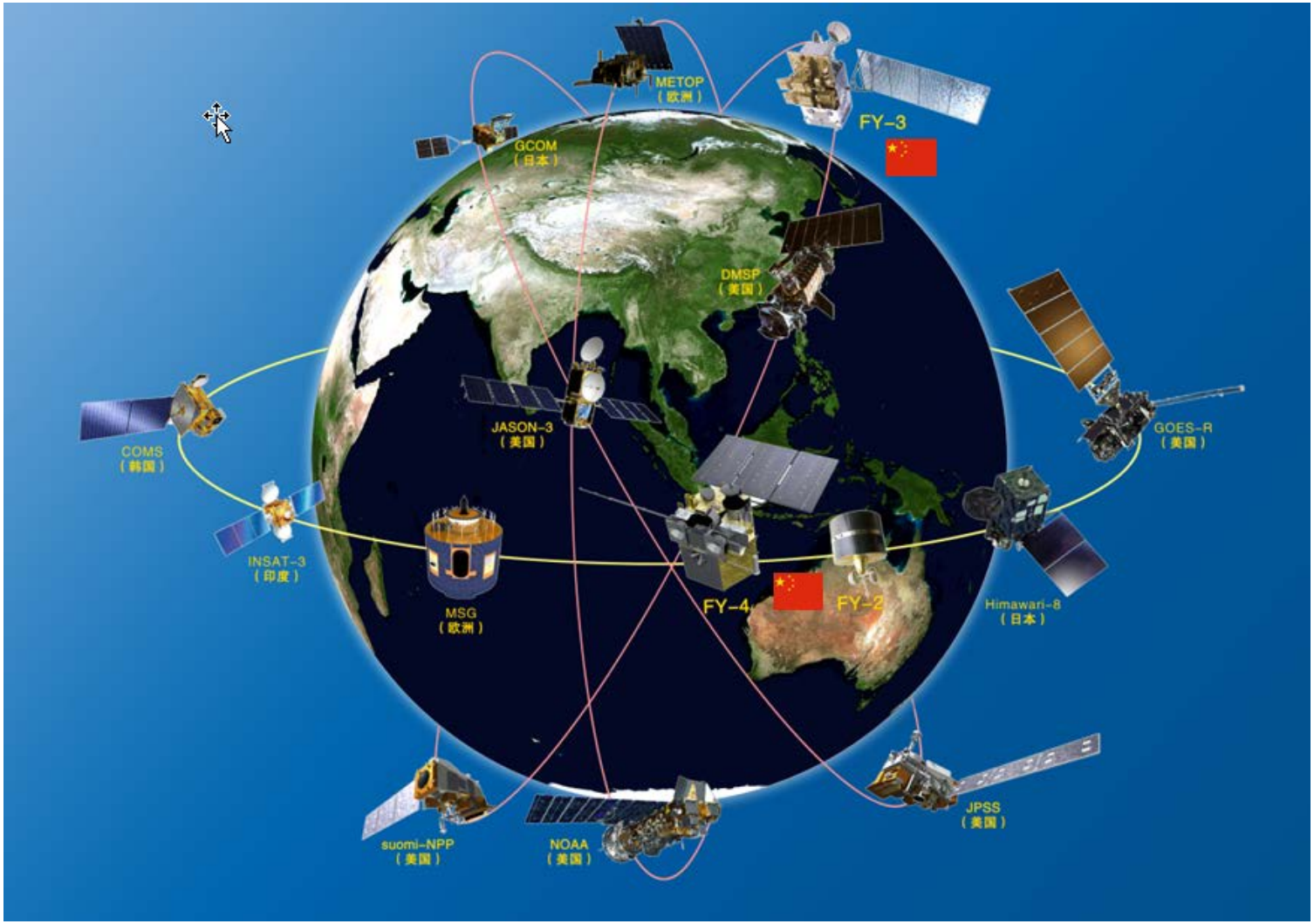
With satellite data they are accurately forecast many days before landfall.




Importance of FY satellite data is growing and makes a critical and innovative contribution to the Global Observing System

# Important Component of WMO Space Program

- reliable and sustained observation in operation
- open data policy to free access

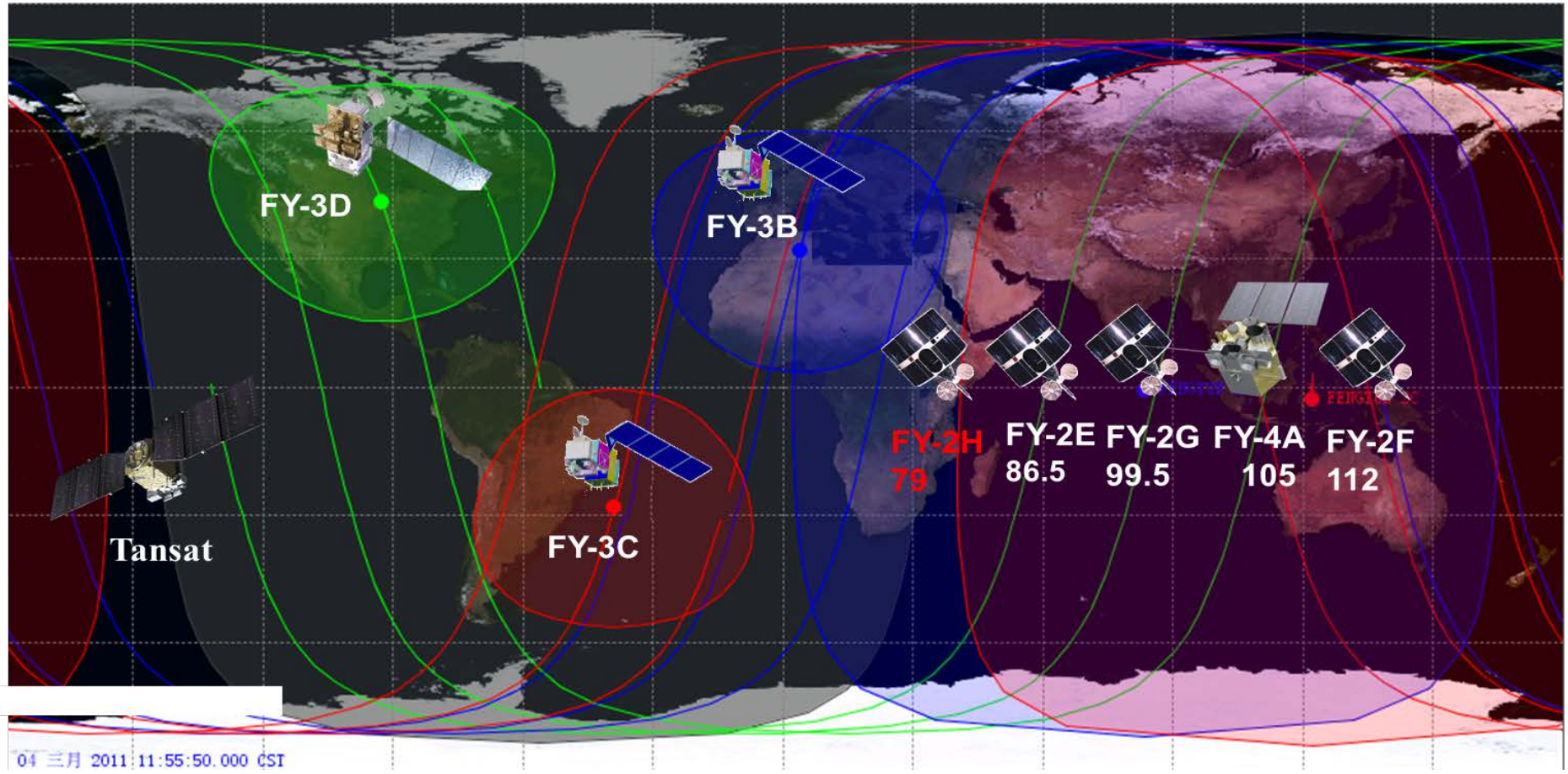


# 2. Current Missions and Services

## Current FengYun Constellation

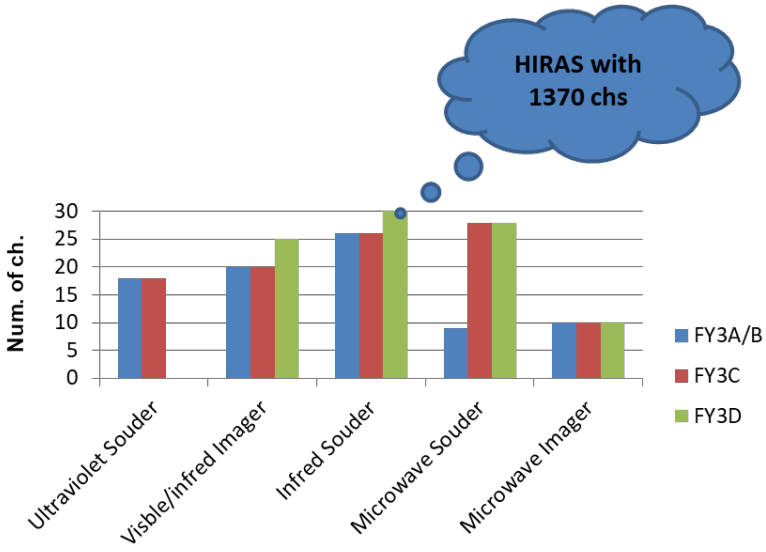
**FengYun Programs:** 8 in orbit, 8 in operation

**Joint programs:** Tansat, GF-4



# Current Instruments for EO

| Satellite | | No. of Instruments | Name in Abbrev. |
|---|---|---|---|
| FY-1 | FY-1 A/B | 2 | 5-channel VIRR |
| | FY-1 C/D | 2 | 10-channel VIRR |
| FY-2 | FY-2 A/B | 1 | 3-channel VISSR |
| | FY-2 C/D/E | 1 | 5-channel VISSR |
| FY-3 | FY-3 A/B | 10 | 10-channel VIRR |
| | | | MERSI |
| | | | IRAS |
| | | | MWTS |
| | | | MWHS |
| | | | MWRI |
| | | | SBUS |
| | | | TOU |
| | | | ERM |
| | | | SIM |
| | FY-3C | 11 | GNOSS |
| | FY-3D | 10 | HIRAS |
| | | | GAS |
| FY-4 | FY-4A | 3 | AGRI |
| | | | GIIRS |
| | | | LMI |




Optical Imager

Atmospheric Sounder

Microwave Imager

Atmospheric Composition Detector

Radiation Budget Monitor

# Fengyun GEO Constellation

## 4 in operation

FY-2E: Full Disk (86.5° E)

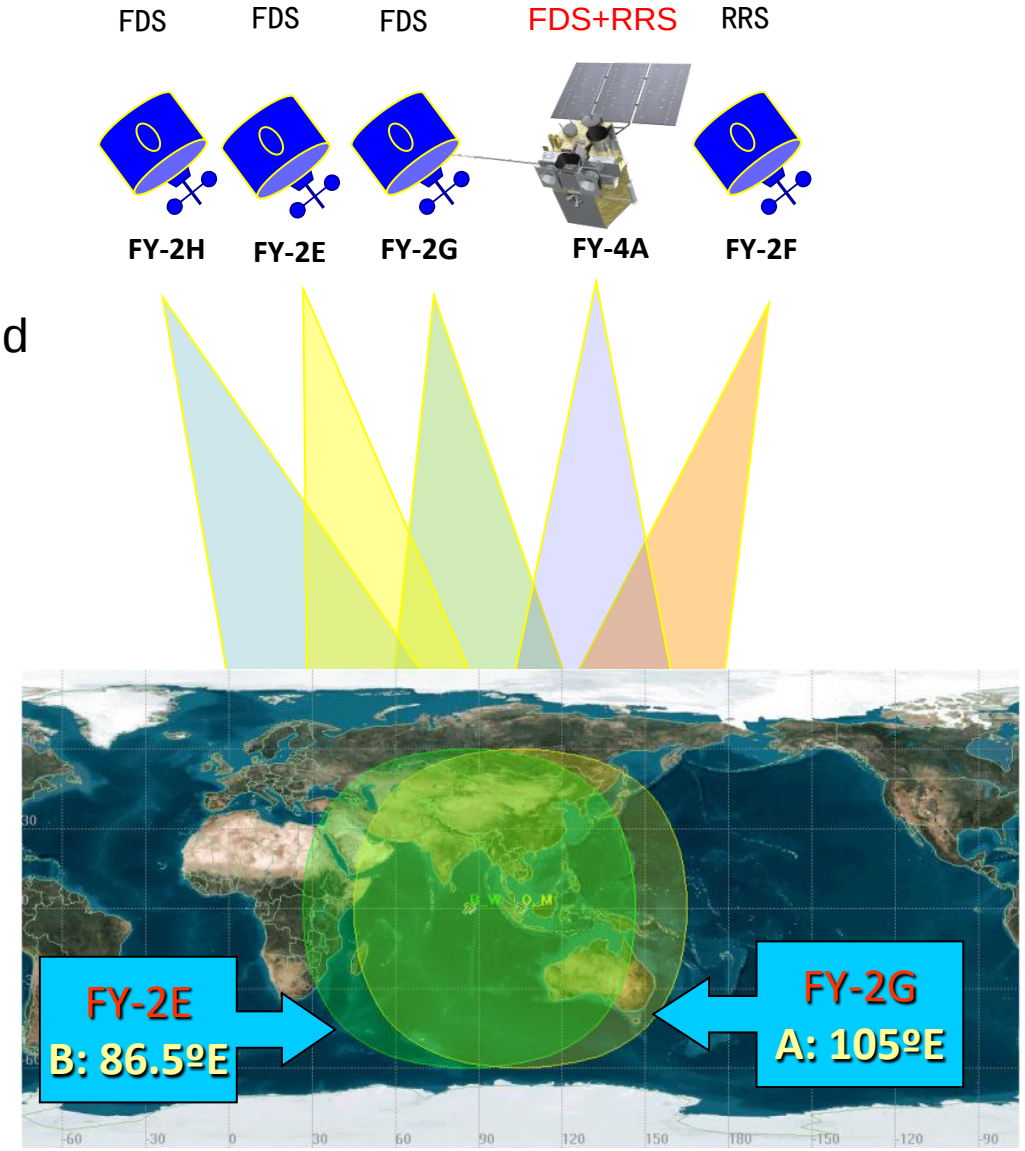
FY-2G: Full Disk (99.5° E)

FY-4A: Full Disk + Regional Rapid (105° E)

FY-2F: Regional (112° E)

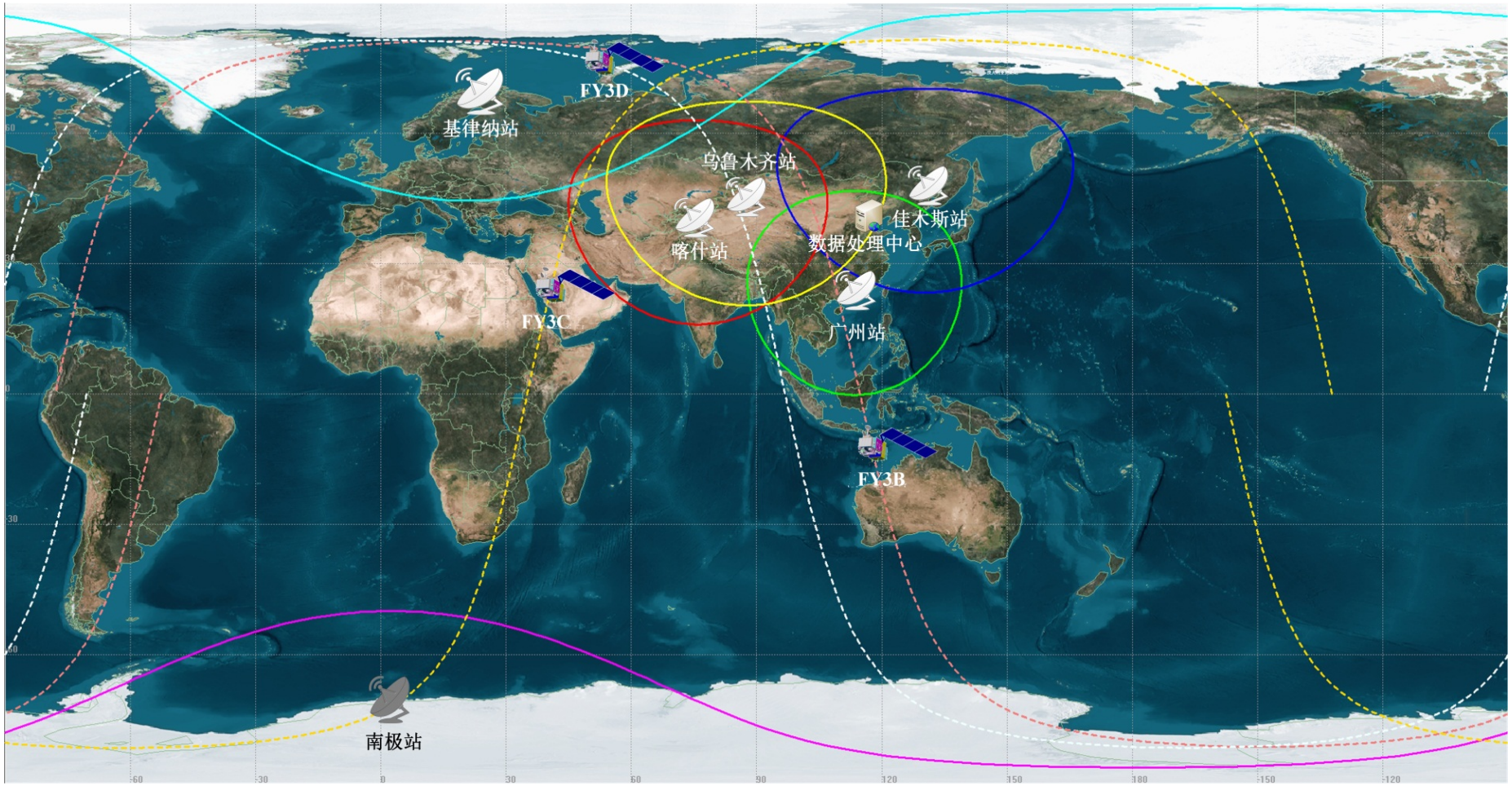
## 1 in orbit test

FY-2H (79° E)



# Fengyun Polar Constellation

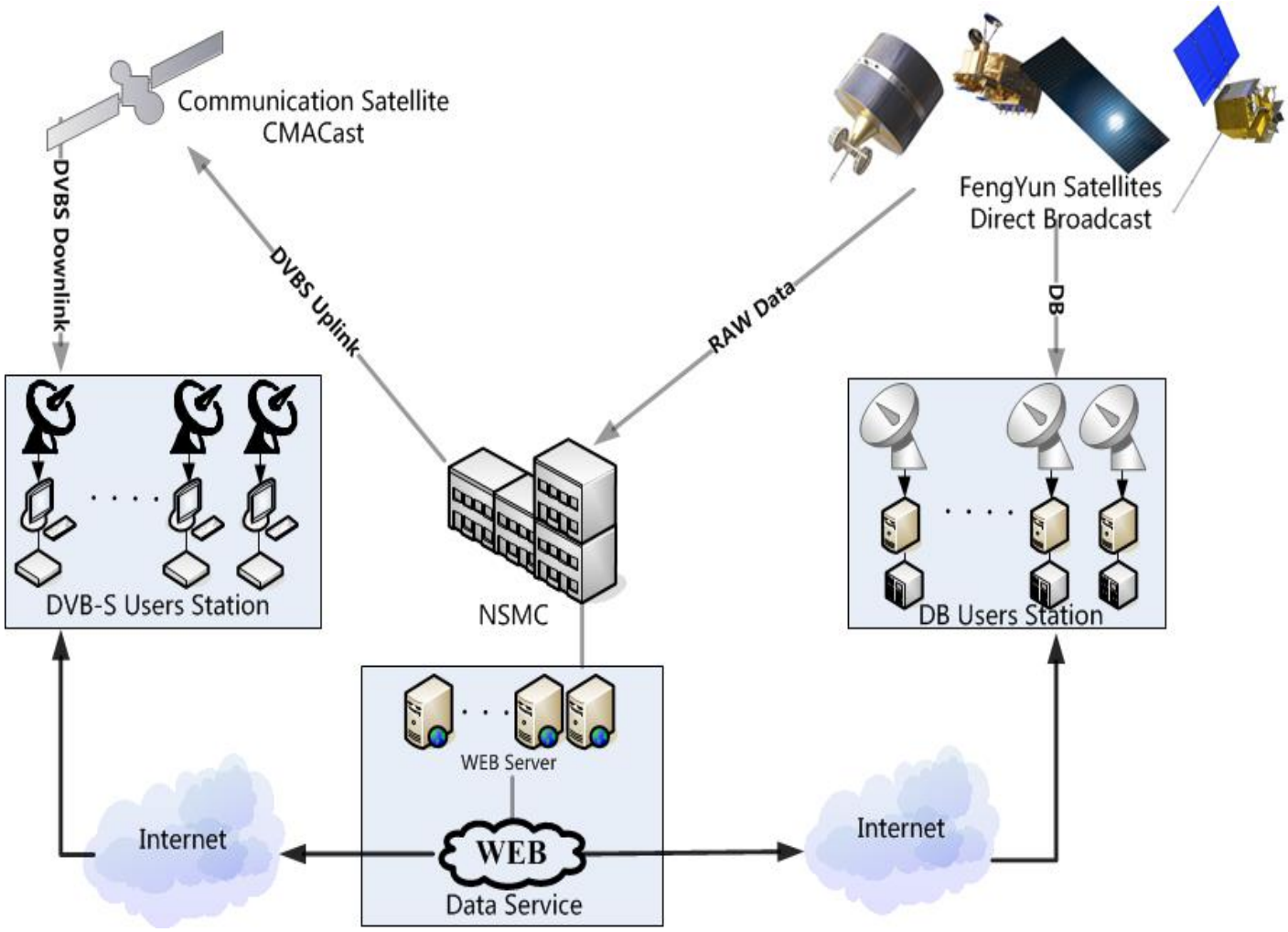
- In Primary l Operation (Global) : FY-3C + FY-3D, global coverage 4 times per day



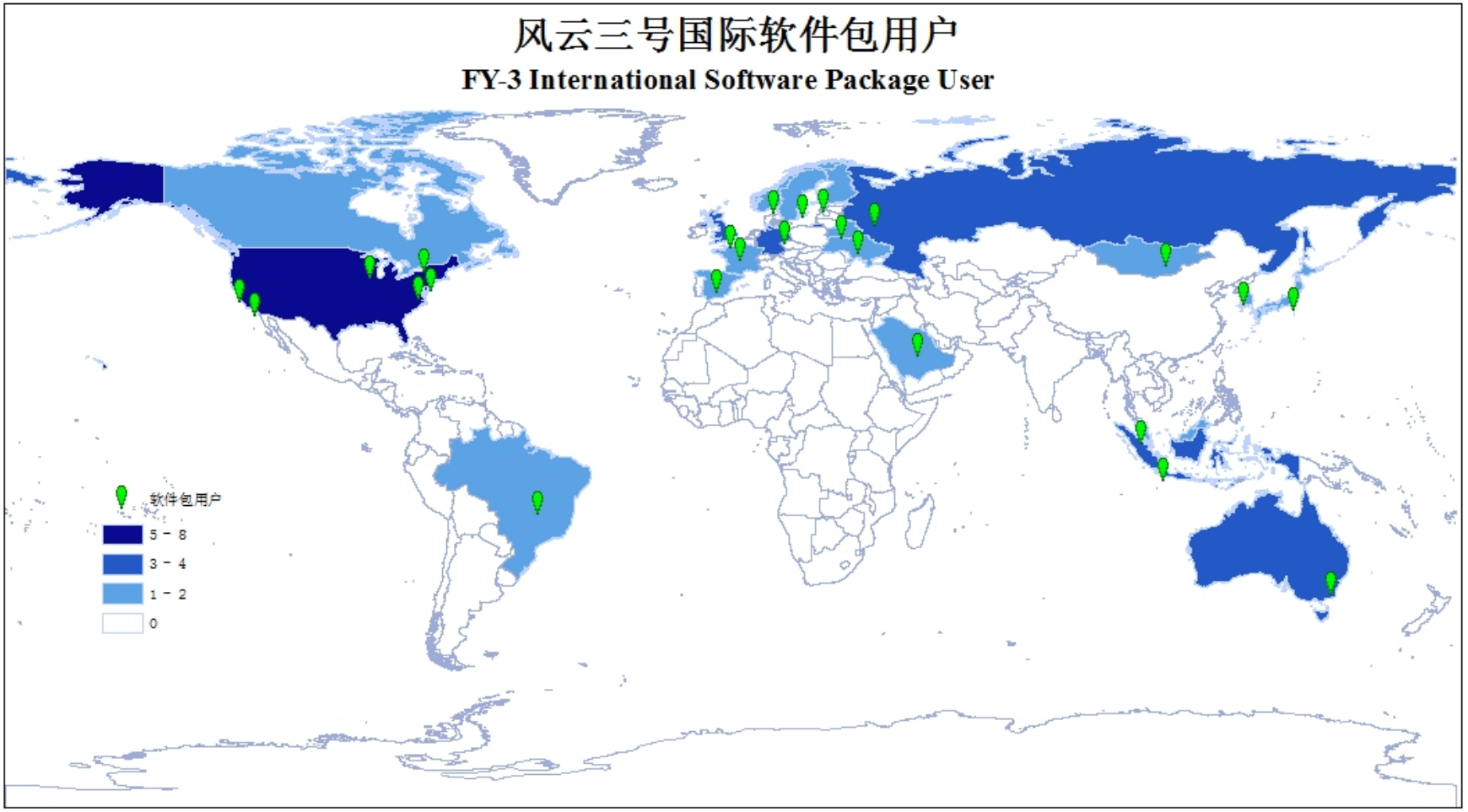

FY-3C LTC 10:30 AM FY-3D LTC 13:40 PM

# FengYun Satellite Data Service

- Real time
  - Direct Broadcast
  - CMACast
- Non-Real Time
  - Website
  - Cloud Service
  - FTP Service
  - Manual Service

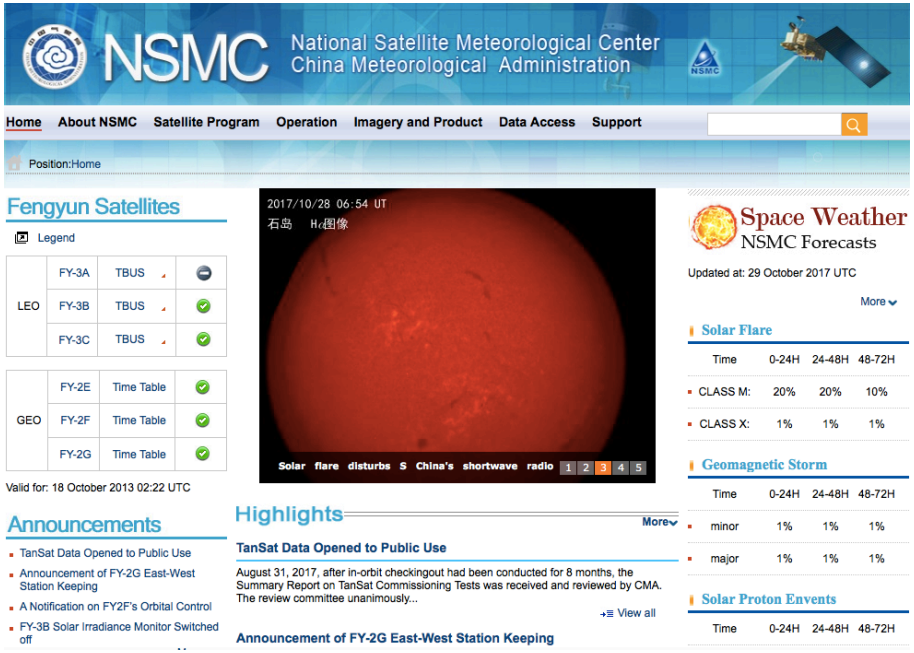


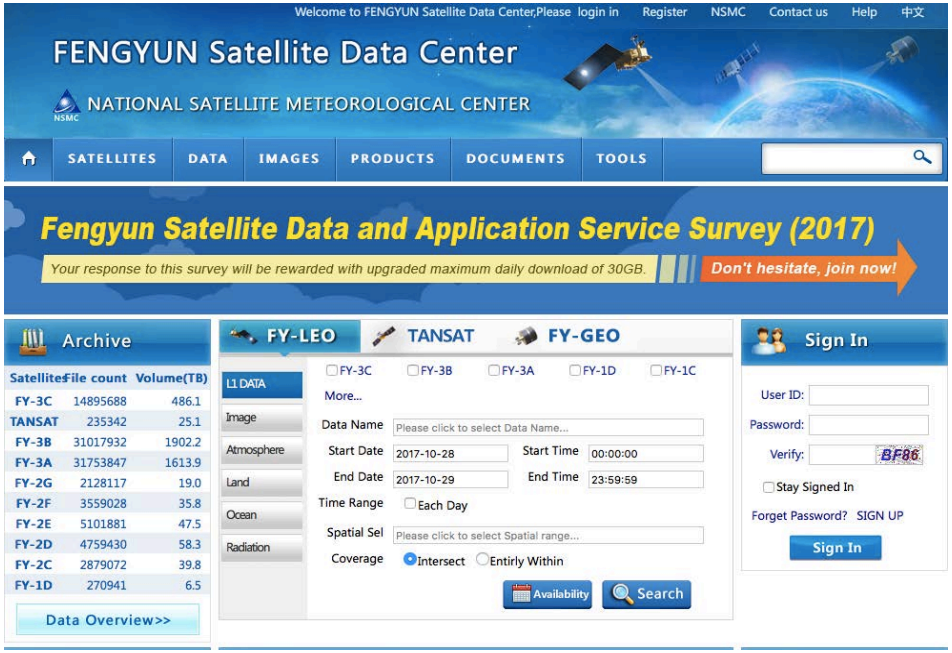
# Fengyun DB Users

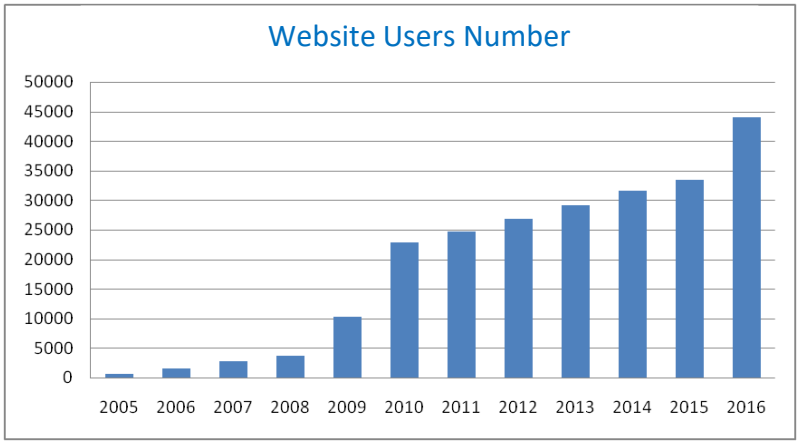



**More than 45 International DB Users**

# Web Portal Service




# Application Tools

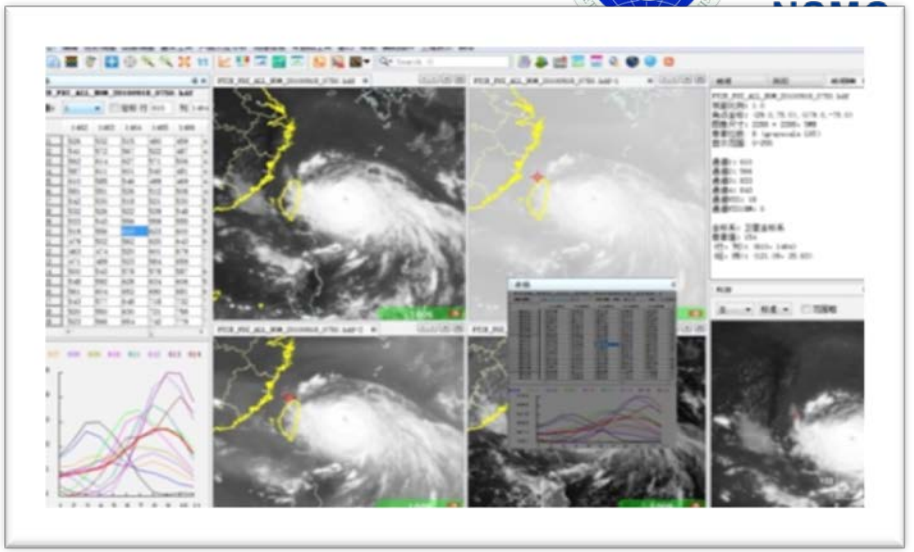
SATs: New Observation Capability

Users: New Applications

Application tools

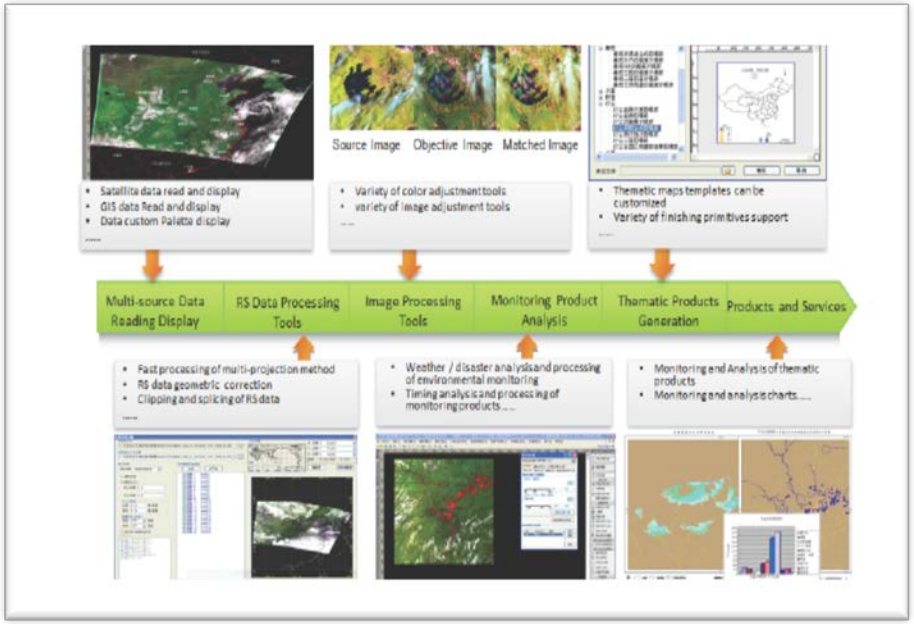
Weather monitoring and analysis
---Geostationary Satellite data (FY-2/FY-4)

Satellite Weather Application Platform
SWAP



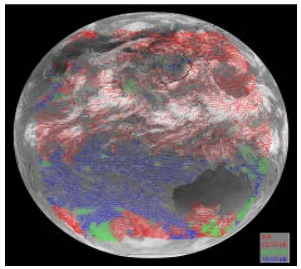
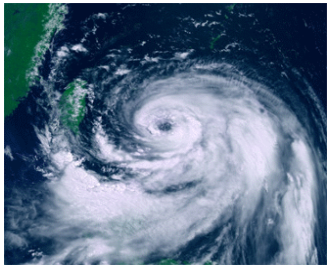
Natural disaster and environment monitoring and analysis
---polar orbiting Satellite data

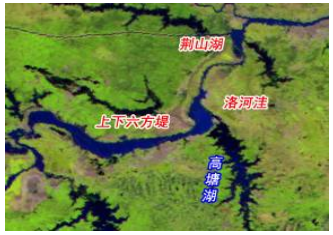
Satellite Monitoring Application Remote sensing Toolkit
SMART

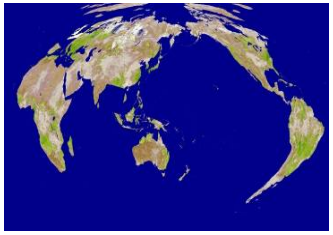
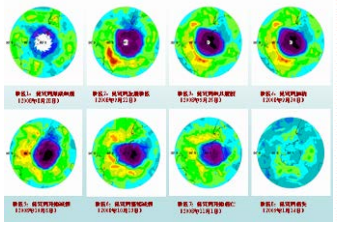
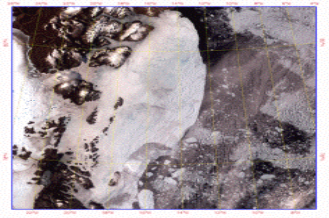


# Application Area

- **Weather Monitoring and Analysis**
  - Tropical Cyclone Monitoring
  - Heavy Rain Monitoring
  - Dust Storm Monitoring
  - Fog Monitoring
- **Natural Disaster Monitoring**
  - Flood Monitoring
  - Fire Monitoring
  - Snow Monitoring
  - Drought Monitoring
- **Environment Monitoring**
  - Vegetation Growth
  - Water Body Change
  - Blue Green Alga Monitoring
  - Sea Ice Monitoring
  - Sea Sedimentation
  - Heat Island Monitoring
  - Atmospheric Composition
- **Global Monitoring**

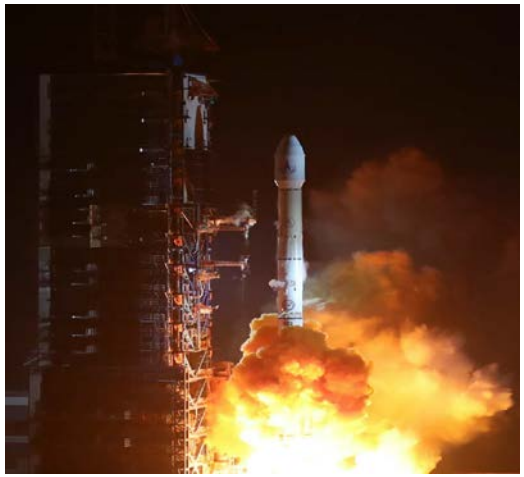




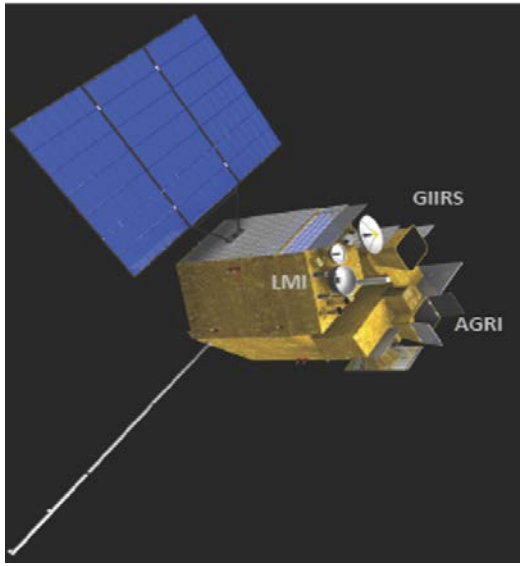
# 3. Latest Progress

## Latest progress on CMA satellite programes

1. FY-4A
   - The first GEO. meteorological satellite of new generation
   - Launched on Dec.11, 2016
   - Official operation on May 1, 2018
2. FY-2H
   - The last one of FY-2 series
   - Launched on June 5, 2018
   - To support IOC and serve for the belt & road countries
3. FY-3D
   - A new operational afternoon orbit LEO. satellite, will co-work with FY-3C in morning orbit.
   - Launched on Nov. 15, 2017.
   - On-orbit commission test completion on Aug. 6, 2018

# FY-4A: Launched on 11 Dec, 2016

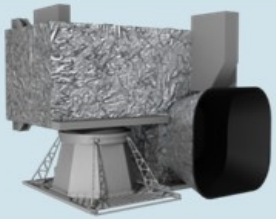
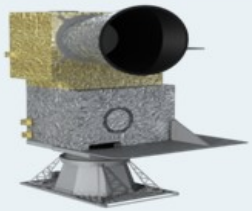




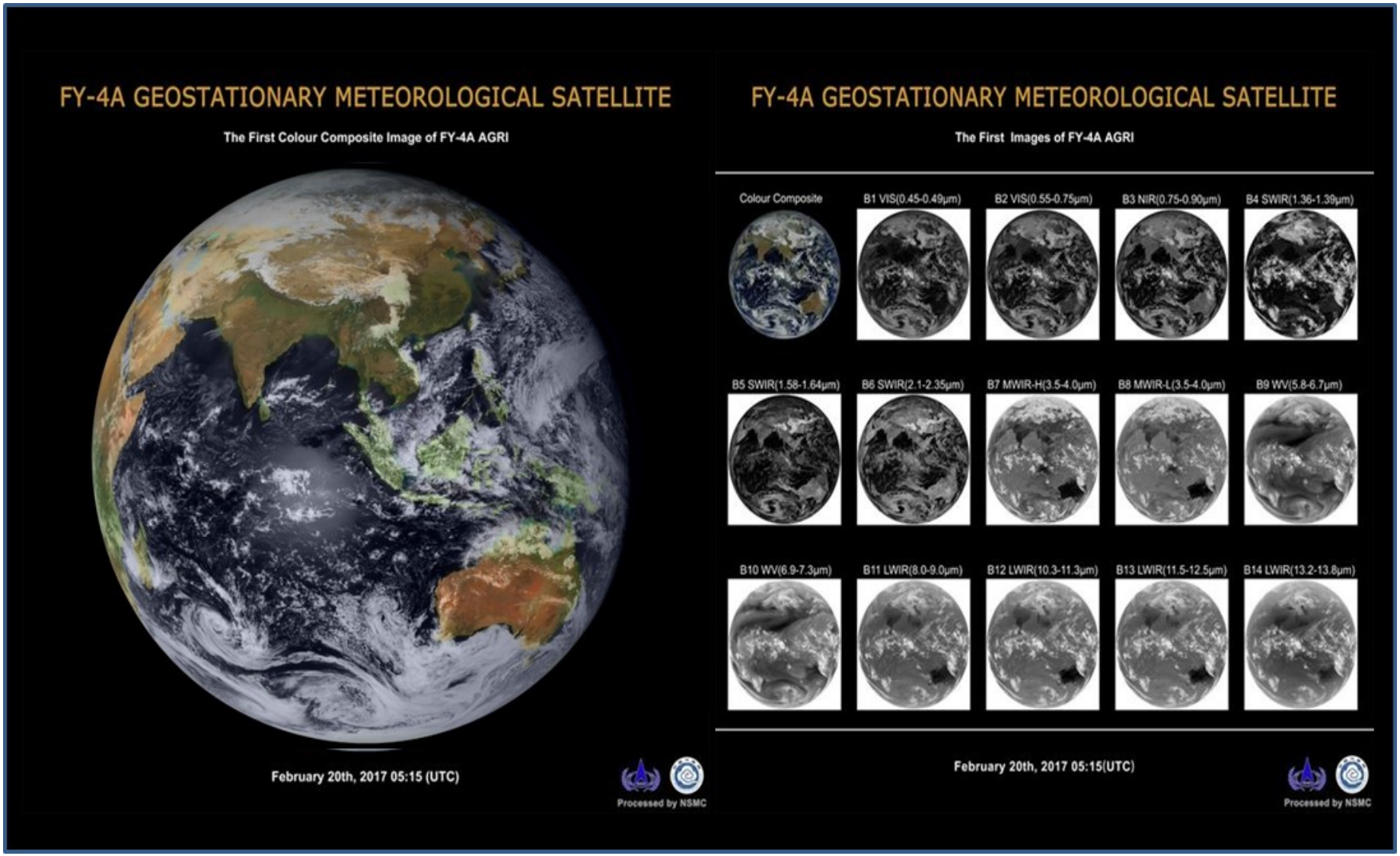

**FY-4 is the CMA new generation meteorological geo-satellite series, expected to support various weather-related services, including weather forecasting, disaster prevention and reduction, and monitoring and warning of space weather.**

Spacecraft:

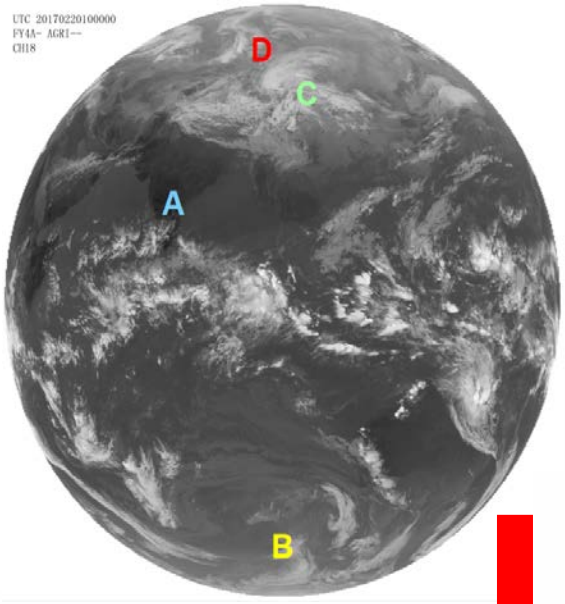
1. Launch Weight: approx 5300kg
2. Stabilization: Three-axis
3. Attitude accuracy: 3″
4. Bus: 1553B+Spacewire
5. Raw data transmission : X band
6. Output power: >= 3200W
7. Design life: over 7 years

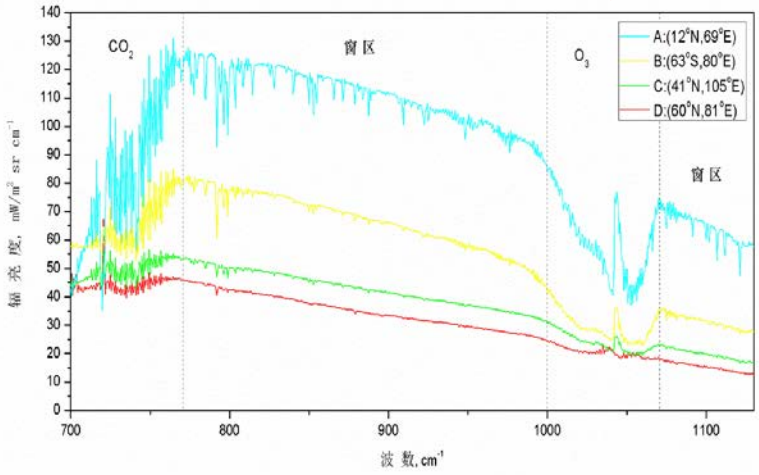
| Instrument | | Purposes |
|---|---|---|
|  | ***AGRI: Advanced Geosynchronous Radiation Imager*** | 14 -channel Earth images |
|  | ***GIIRS : Geostationary Interferometric InfraRed Sounder*** | Clear-sky atmospheric temperature and humidity profiles |
|  | ***LMI : Lightning Mapping Imager*** | Lightning distribution map in China area |
|  | ***SEP: Space Environment Package*** | Space electric and magnetic environment information |

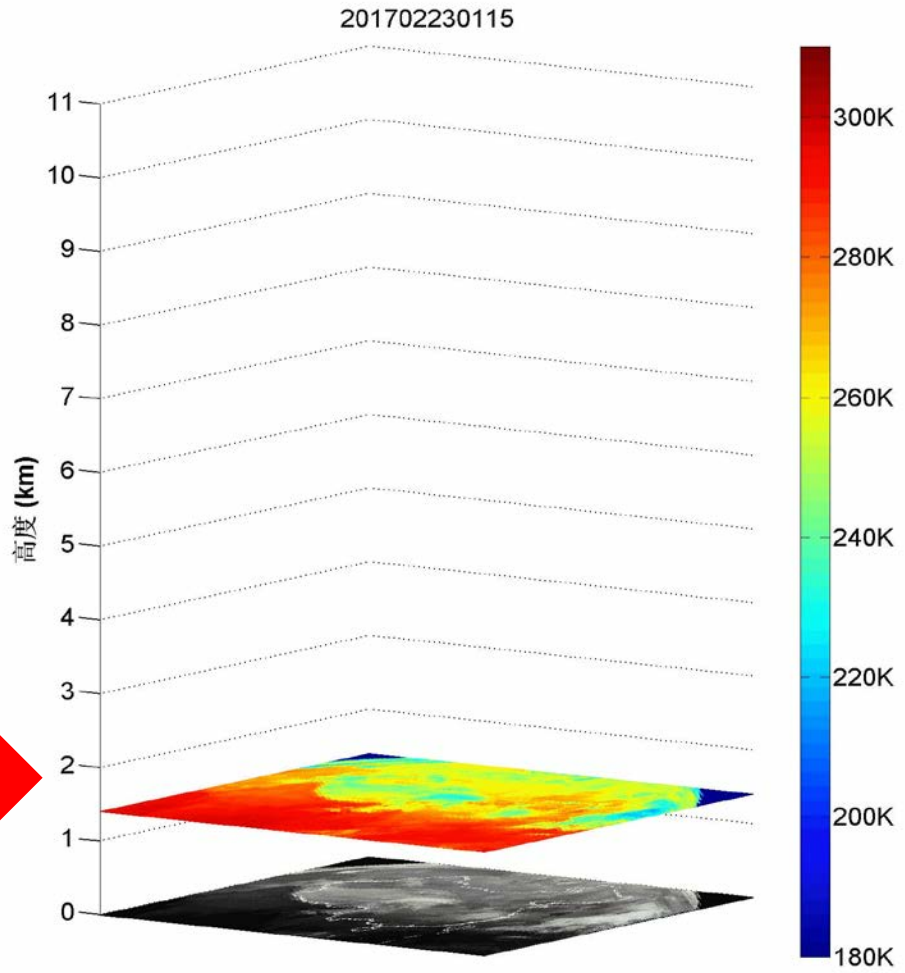
# AGRI: Advance Geo. Radiation Imager



# GIIRS:
# First Geo. Interferometric Infrared Sounder



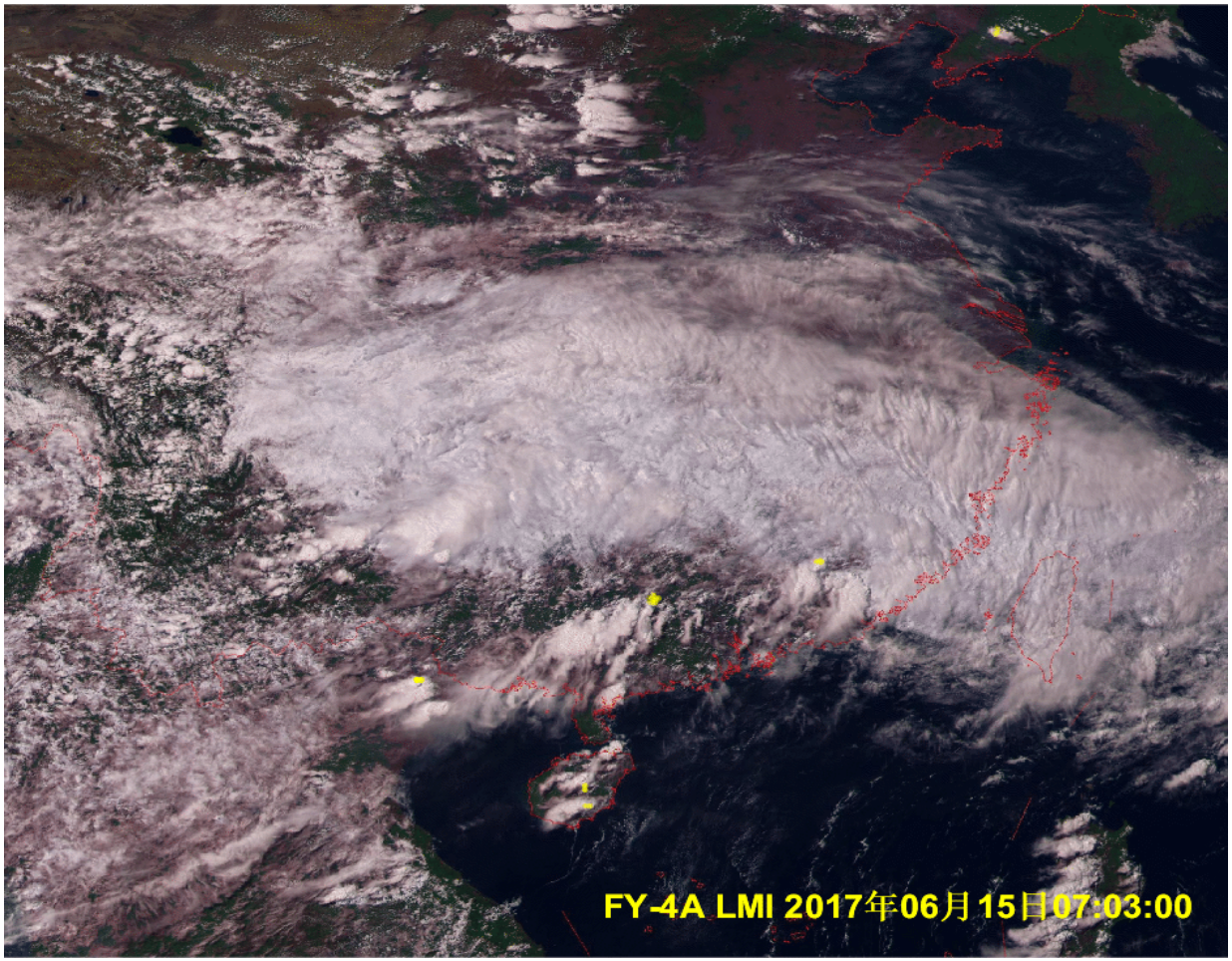



# LMI: Lightning Mapping Imager

**Acquire lightning distribution maps over specific region**

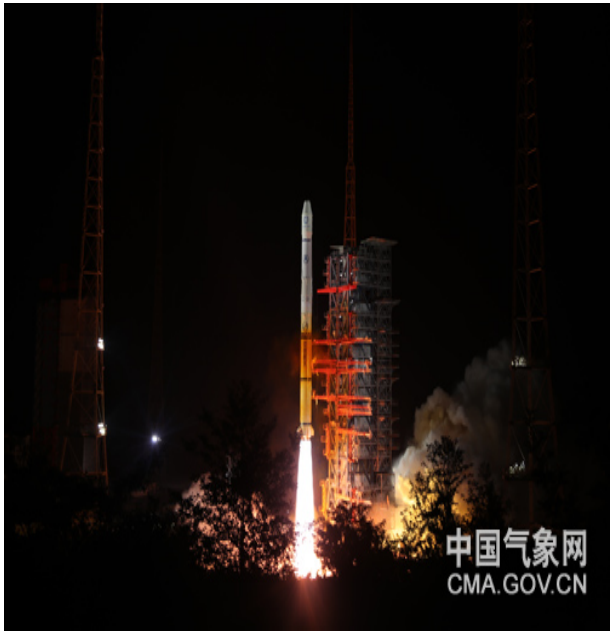
| | |
|---|---|
| Spatial resolution | about 7.8Km at SSP |
| Sensor size | 400×300 ×2 |
| Wave-length at center | 777.4nm |
| Band-width | 1nm±0.1nm |
| Detection efficiency | >90% |
| False-alarm ratio | <10% |
| Dynamic range | >100 |
| SNR | >6 |
| Frequency of frames | 2ms |
| Quantization | 12 bits |
| Measurement Error | 10% |

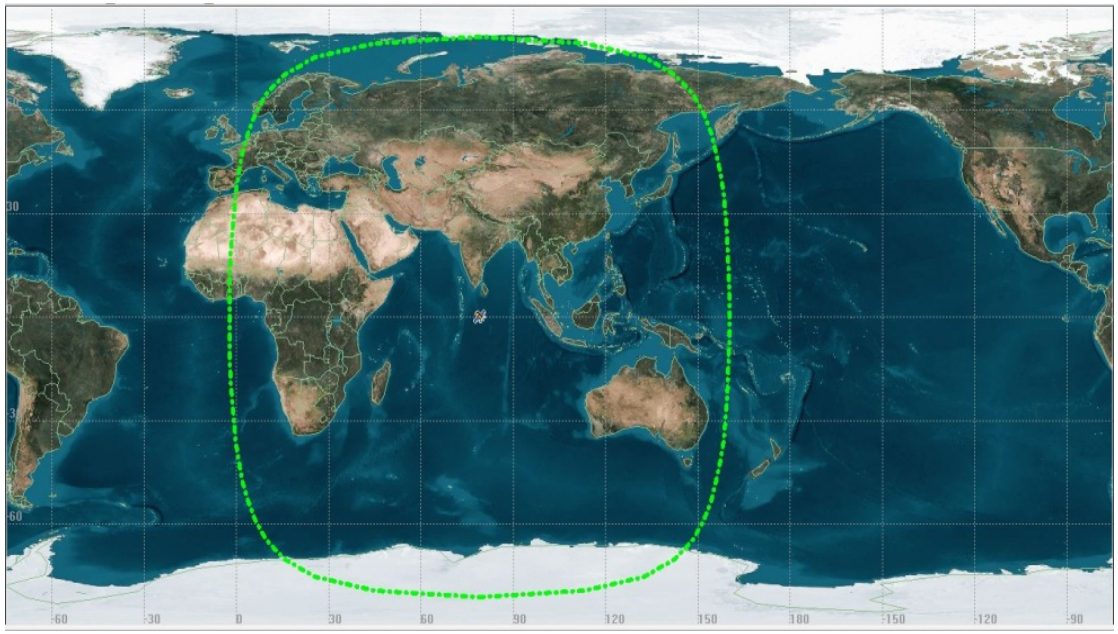


# FY-2H: Launched on 5 Jun, 2018

## FY-2H： To better support IOC and serve the Belt & Road countries

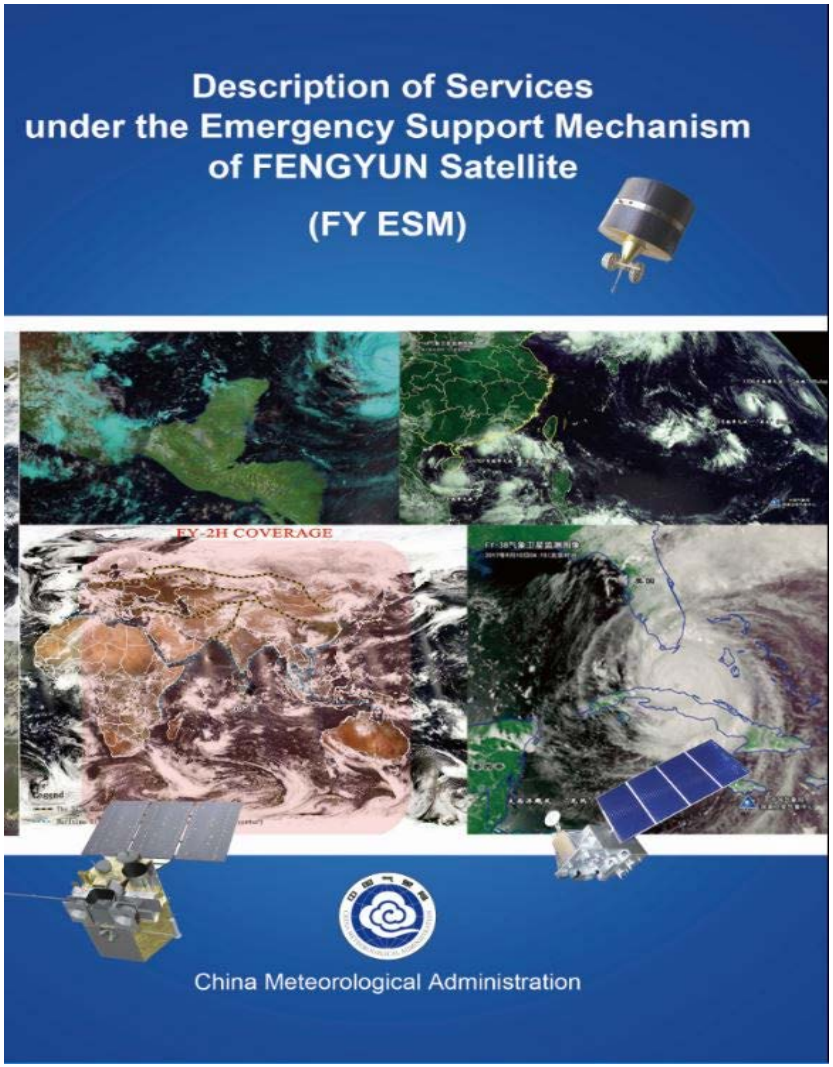
- Launched on June 5, 2018
- positioned at 79° E and operational *by September, 2018*



# CMA Announced "Emergency Support Mechanism for International Users of Fengyun Meteorological Satellites in Disaster Prevention and Mitigation" on April 24, 2018

- Once the request is approved, CMA will command the on-duty FY satellite for frequent and targeted observations per 5-6 minutes over affected areas.
- The images and products will be transmitted to the requesting applicant through CMACast, internet and direct satellite broadcast reception.



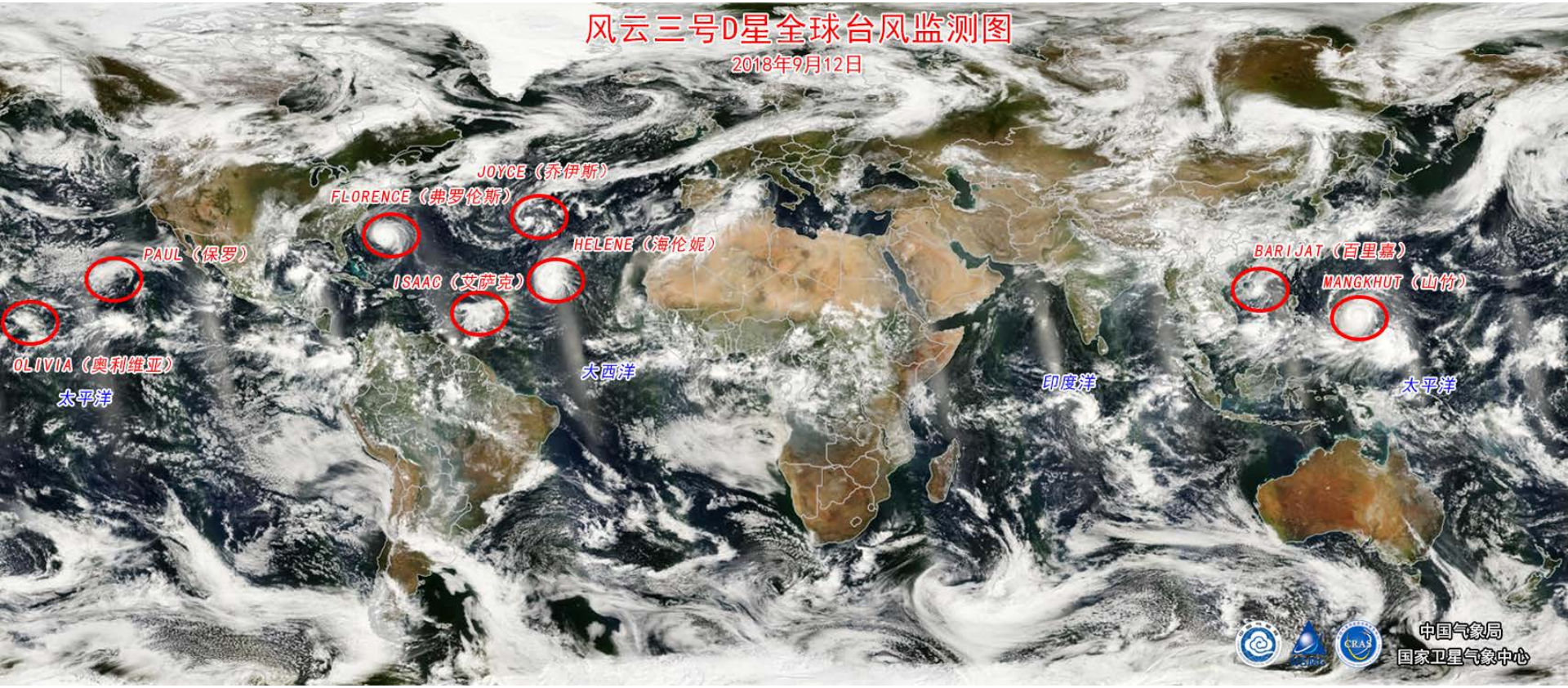
# FY-3D: Launched on 15 Nov, 2017


| Parameters | Satellite Specification |
|---|---|
| Orbit type | Near-polar sun-synchronous orbit |
| Orbital altitude | 836 Km |
| Orbital inclination | 98.75° |
| Precision orbit | Semi-major axis deviation: $\|\Delta a\| \leq 5$Km |
| | Orbital inclination deviation: $\|\Delta i\| \leq 0.1°$ |
| | Orbital eccentricity $\leq 0.003$ |
| Repeat cycle | 5.5d (Design range is in 4-10 d) |
| Eccentricity | ≤0.0025 |
| Local time drift at ascending node | 15 min within 4 yrs |
| Launch window | local time at ascending node: 13:40 – 14:00 |
| Design lifetime | 5 yrs for design, 4 yrs for assessment |

- 4 new instruments (HIRAS, GAS, WAI, IPM)
- 1 important improved instruments (MERSI-2)
- 5 successive Instruments


| Payload Name | Channel Numbers with Spectral Coverage |
|---|---|
| MEdium Resolution Spectral Imager (MERSI-2) | 25 (0.413 – 12 μm) |
| Hyperspectral InfraRed Atmospheric Sounder (HIRAS) | 1370 (3.92 – 15.38 μm) |
| MicroWave Radiation Imager (MWRI) | 10 (10.65 – 89 GHz) |
| MicroWave Temperature Sounder (MWTS-2) | 13 (50.3 – 57.29 GHz) |
| MicroWave Humidity Sounder (MWHS-2) | 15 (89.0 – 183.31 GHz) |
| GNSS Occultation Sounder (GNOS) | 29 (--) |
| Greenhouse-gases Absorption Spectrometer (GAS) | 5540 (0.75 – 2.38 μm) |
| Wide angle Aurora Imager (WAI) | 1 (140 – 180 nm) |
| Ionospheric PhotoMeter (IPM) | 3 (130 – 180 nm) |
| Space Environment Monitor (SEM) | 25 (--) |

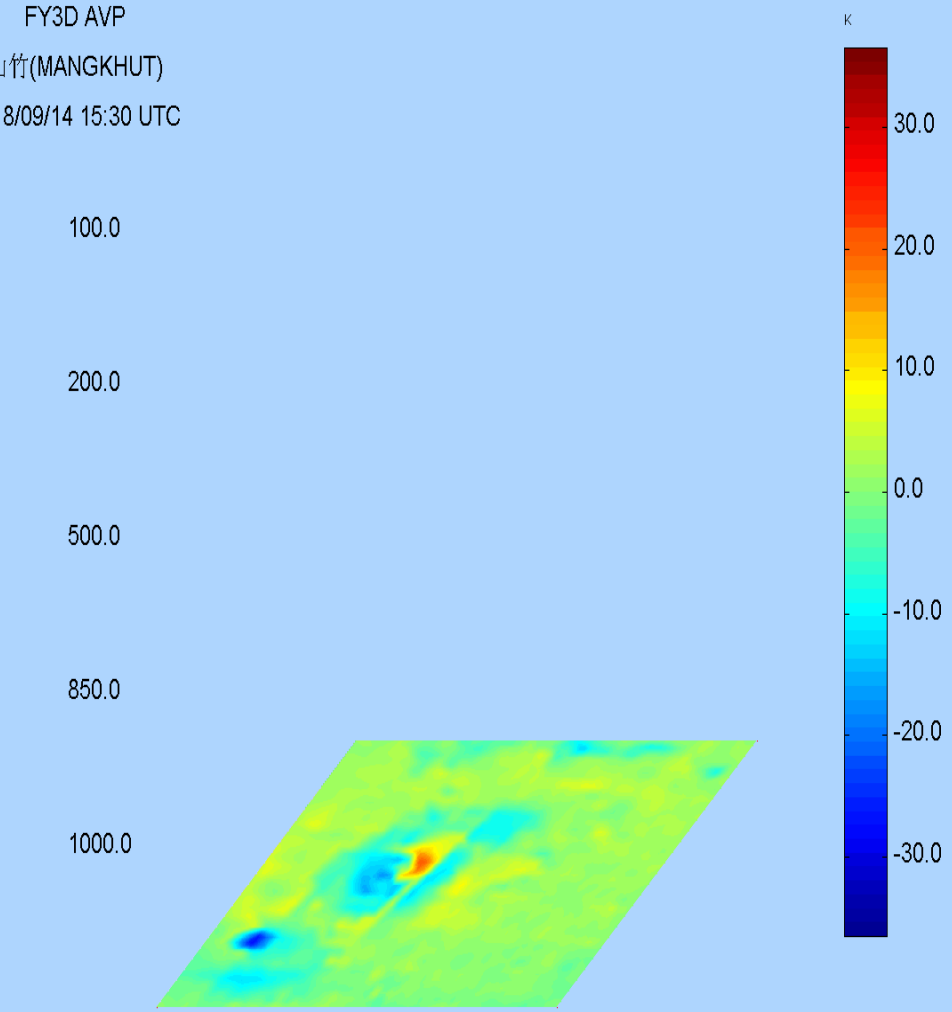
- Performance are improved significantly for the key characteristics, such as S/N, calibration accuracy, etc.


风云三号D星全球台风监测图
2018年9月12日
JOYCE（乔伊斯）
FLORENCE（弗罗伦斯）
HELENE（海伦妮）
PAUL（保罗）
ISAAC（艾萨克）
BARIJAT（百里嘉）
MANGKHUT（山竹）
OLIVIA（奥利维亚）
太平洋
大西洋
印度洋
太平洋
中国气象局
国家卫星气象中心

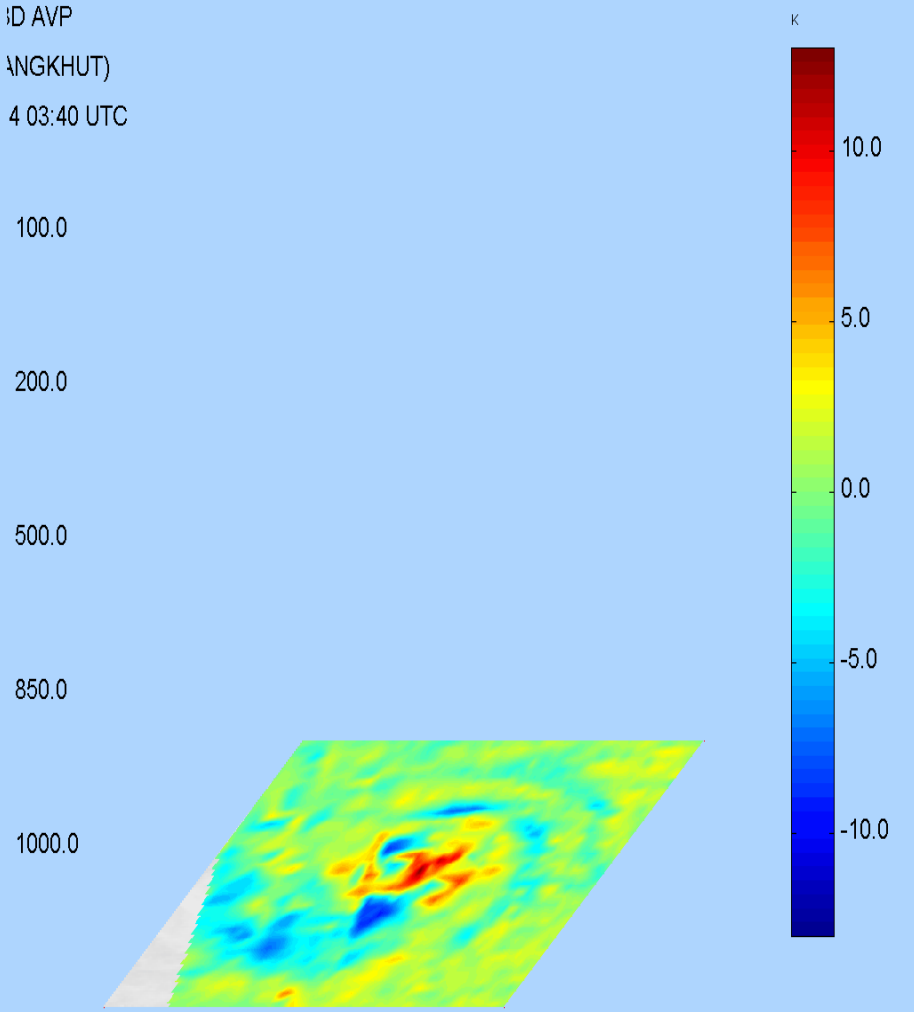
True Color Image in Caribbean Sea from MERSI II with 250m

# Temperature Profile from HIRAS-MWTS-WMHS

9月14日23:30

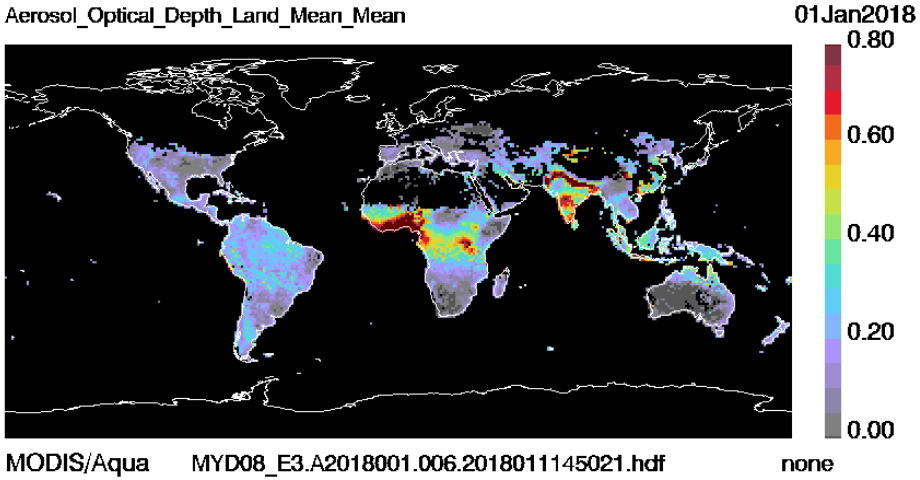


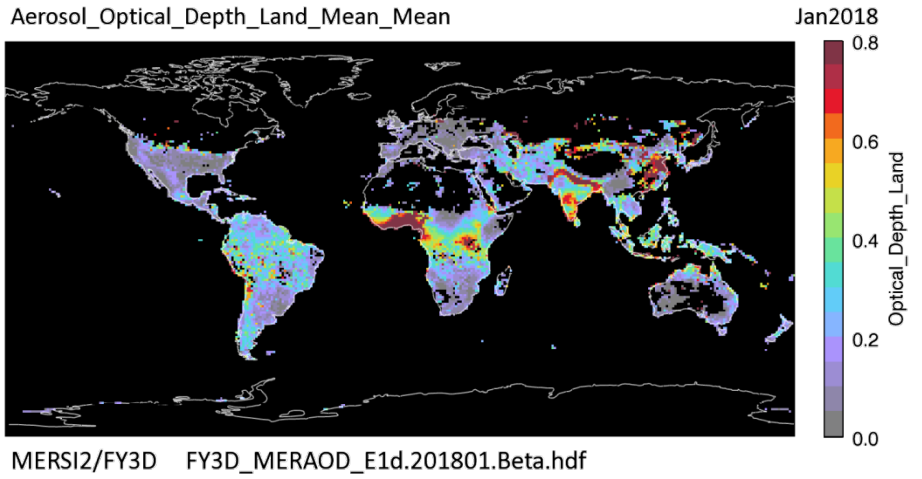

9月14日11:40




Typhoon Mangkhut (1822) 2 hour before landing

# Global 8-day-mean product : MERSI II and MODIS land aerosols

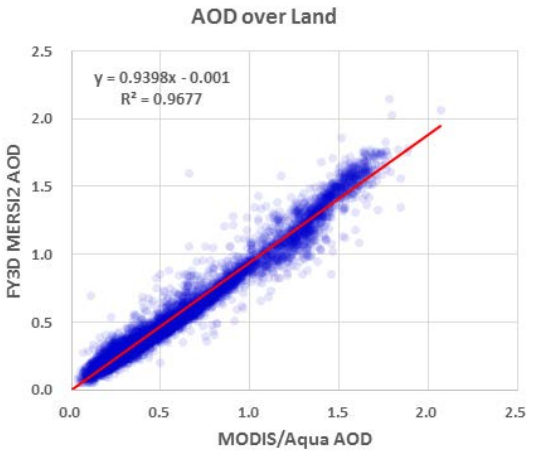


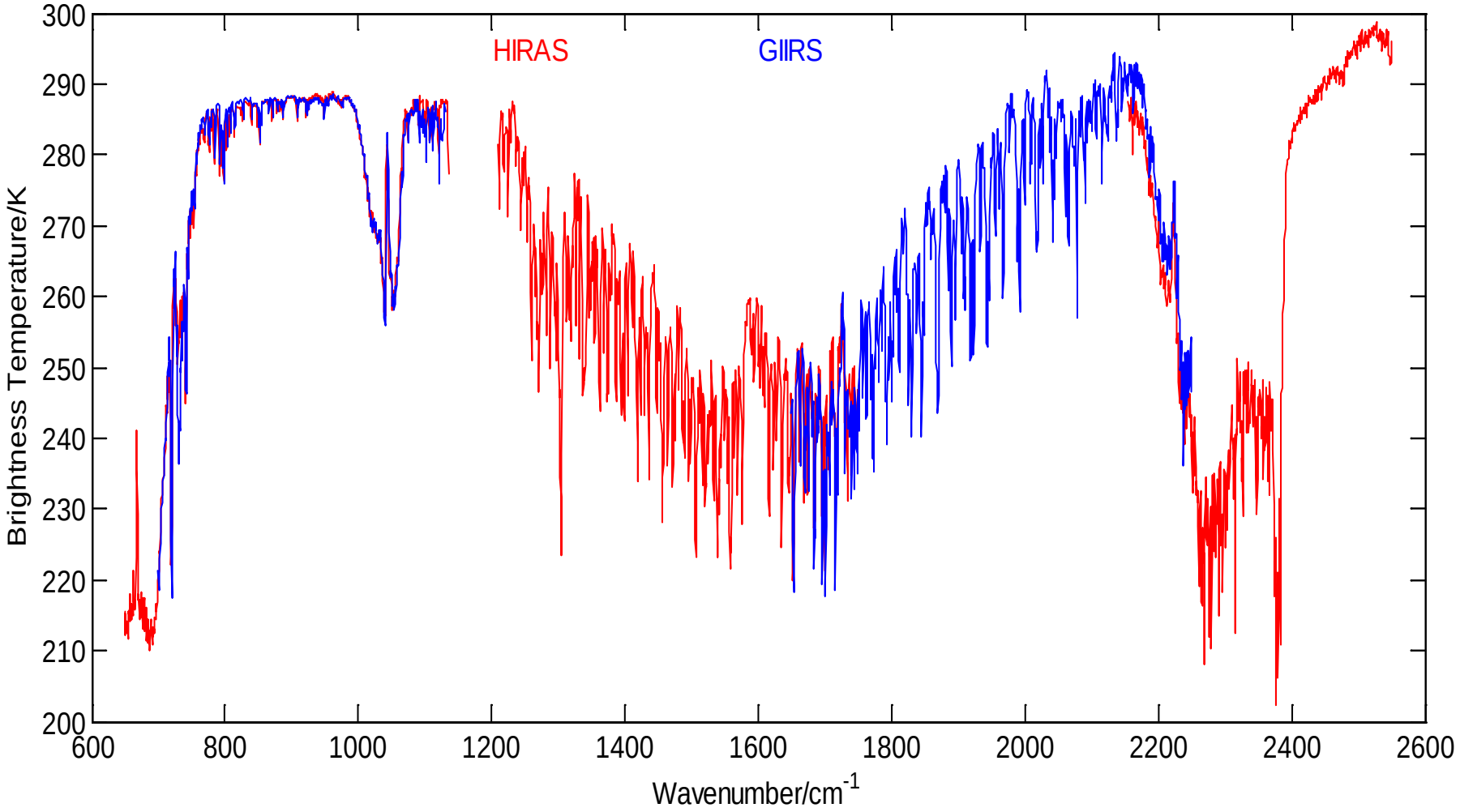




MODIS/Aqua

MERSI2/FY3D

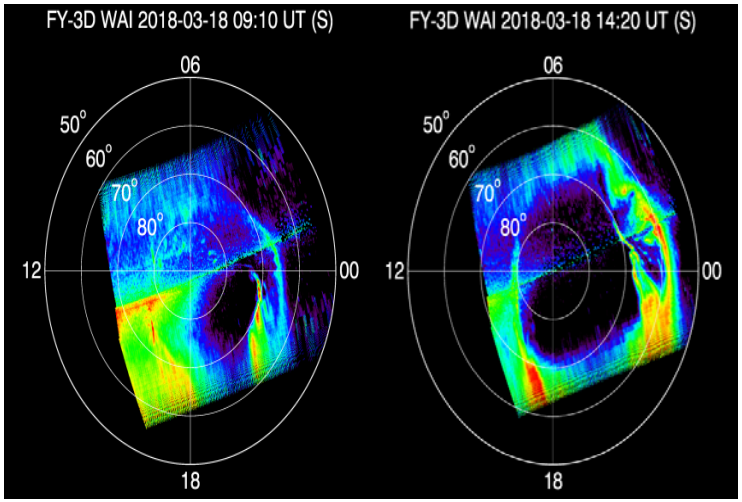
Good consistency in global distribution and AOD of pollution sources.





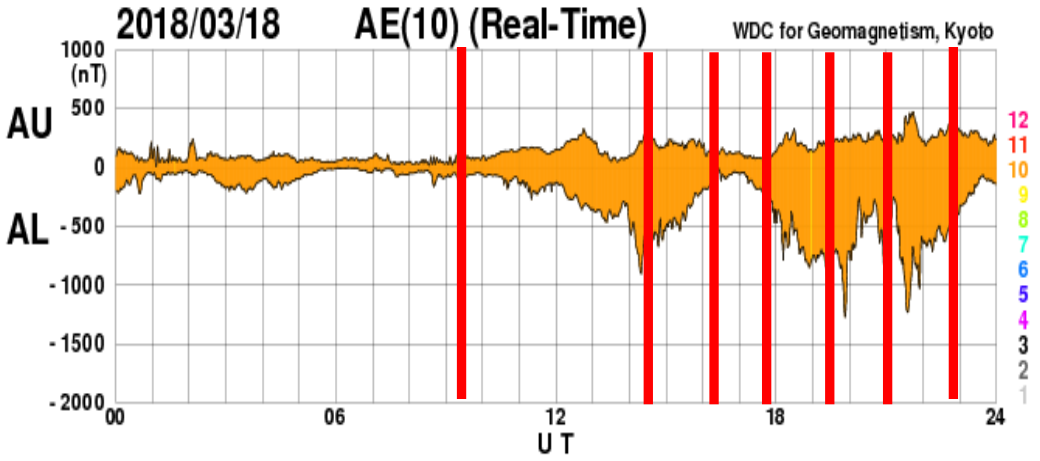

**Spatiotemporally matched hyperspectral BT spectra from both FY-4A/GIIRS (blue solid line) and FY-3D/HIRAS (red solid line)**

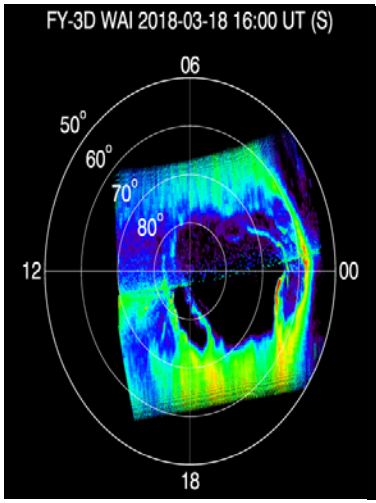
# Aurora in the North Polar from WAI

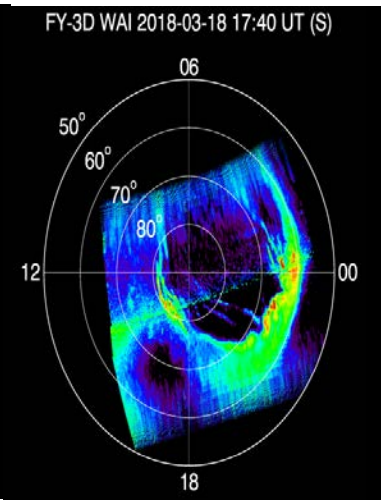


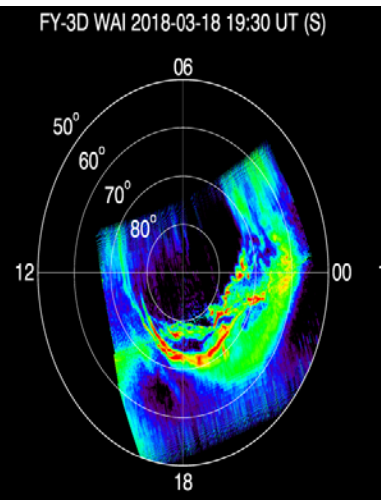


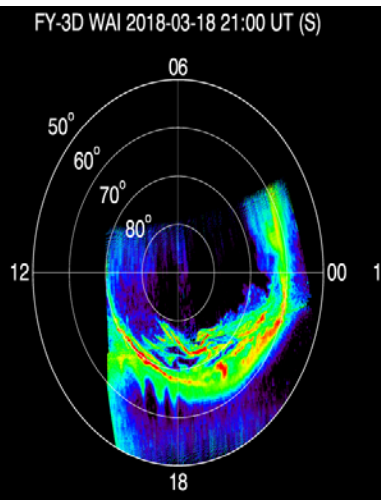


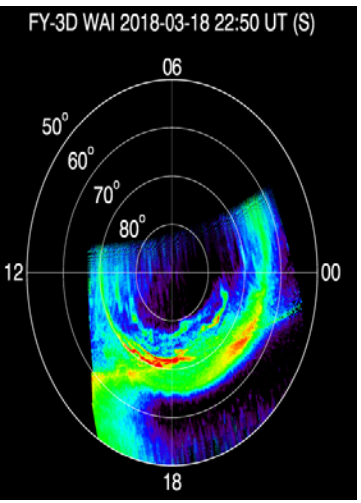


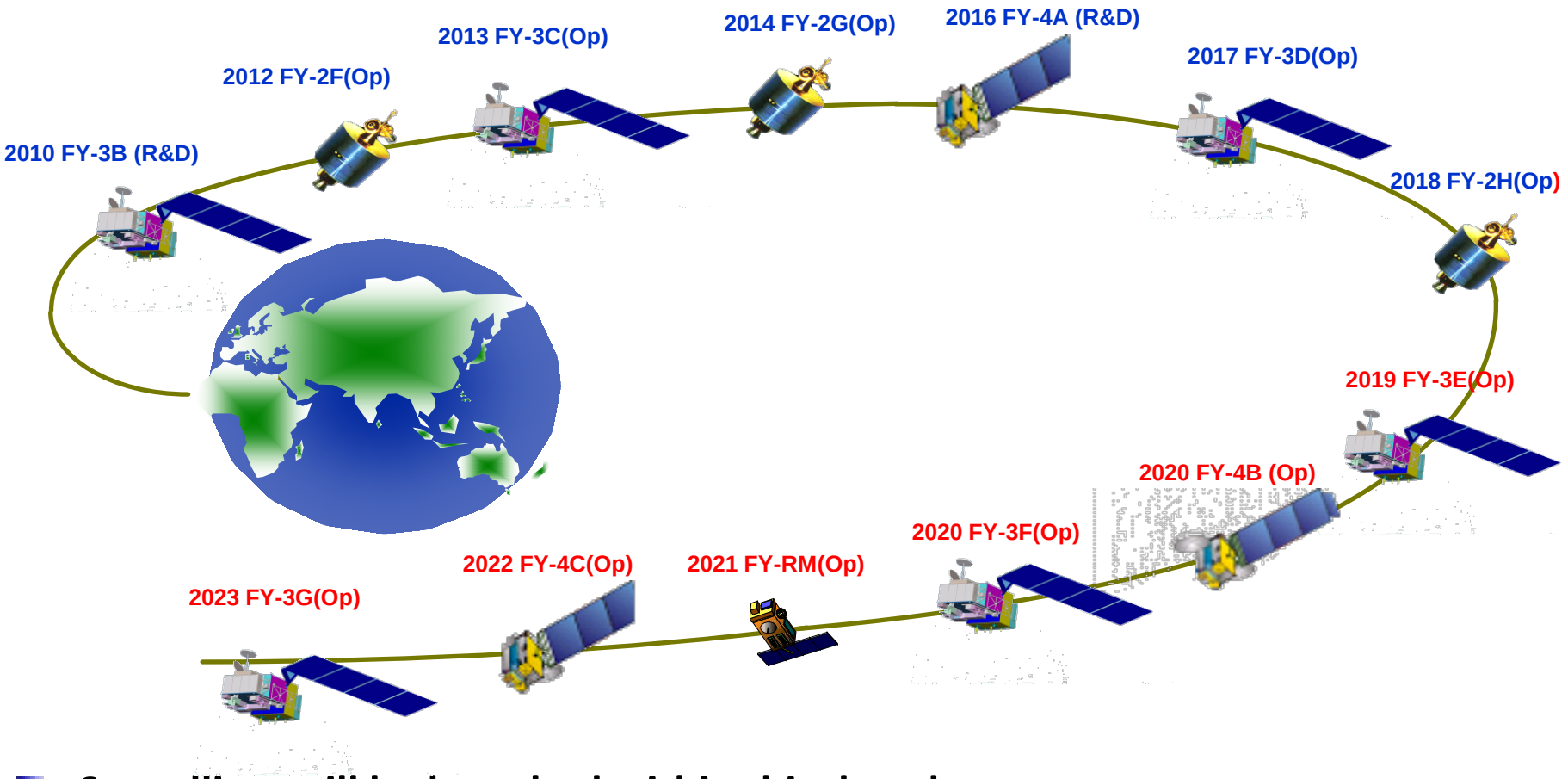



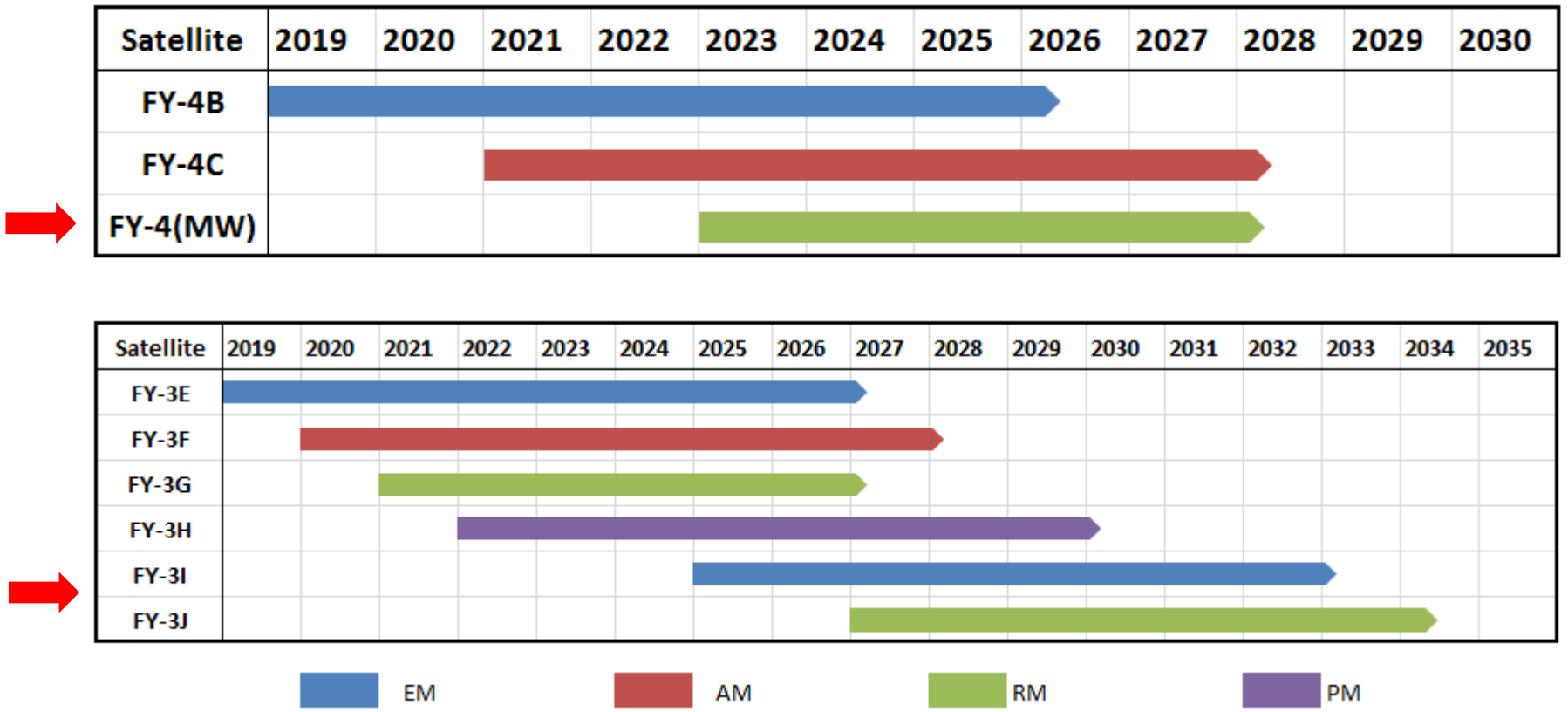
# 4. Future Programs

## National Program for Fengyun Meteorological Satellite from 2011-2020

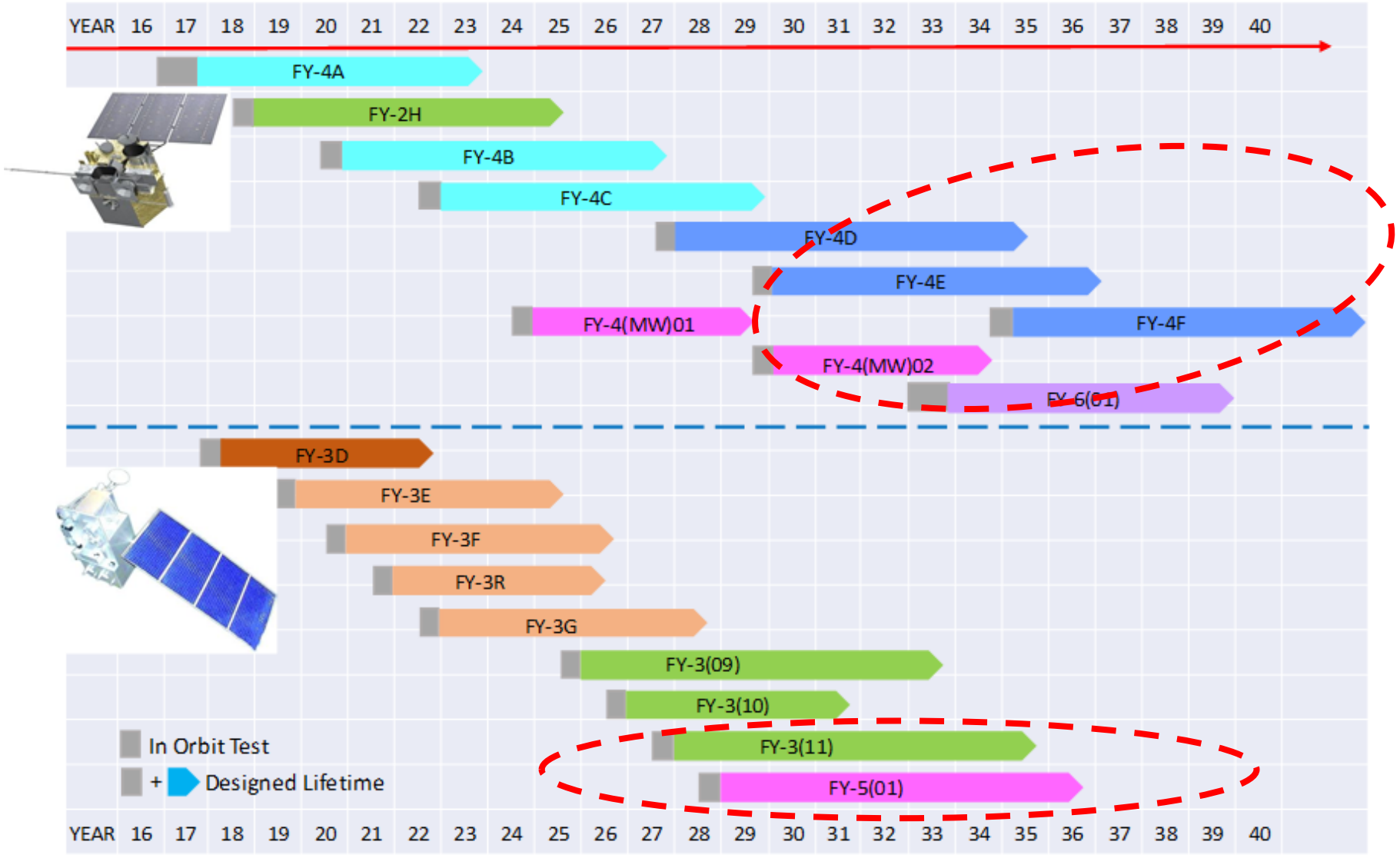



- 6 satellites will be launched within this decade

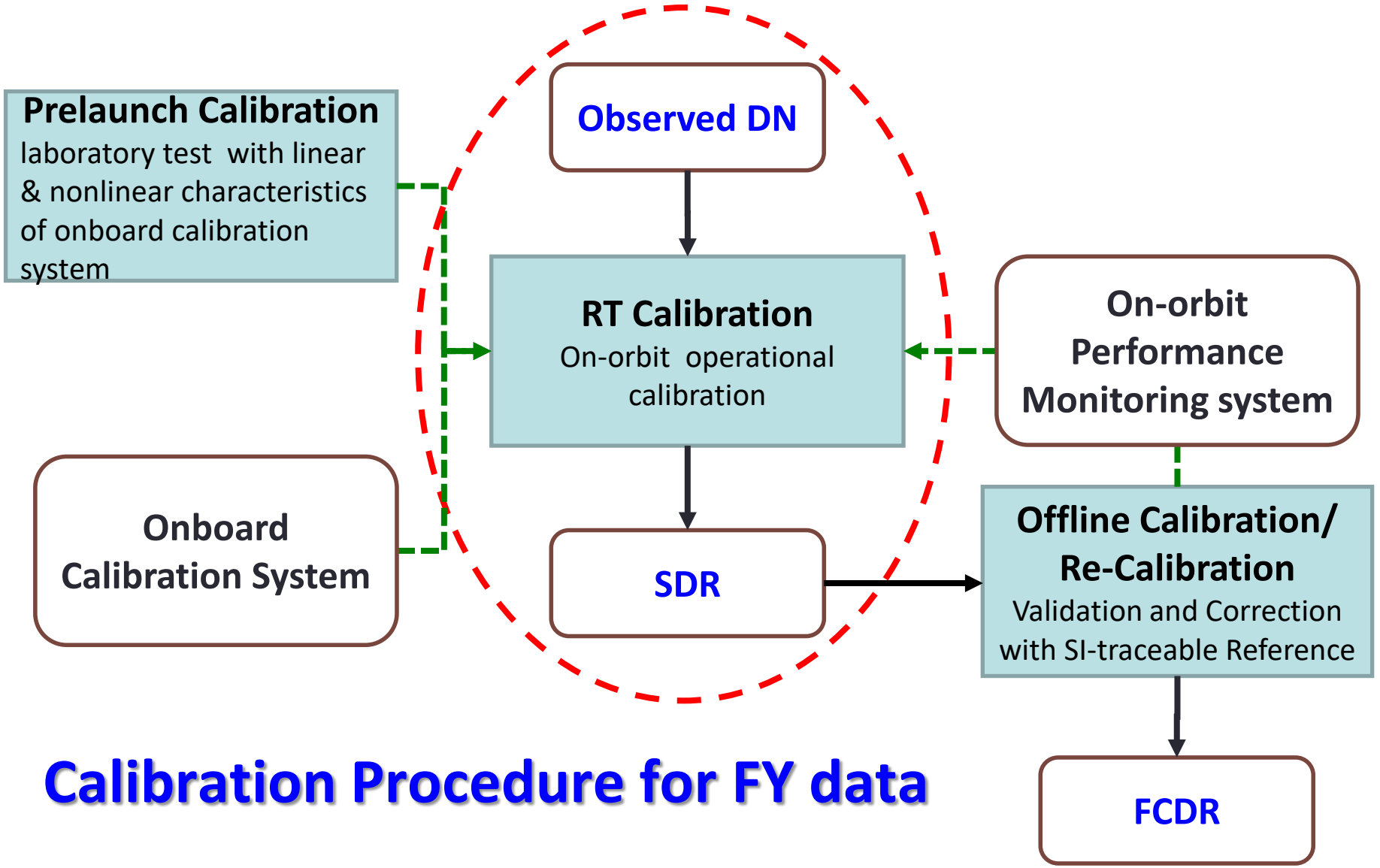
# National Space Infrastructure Program for Meteorological Satellites (from 2020 to 2025) approved by the State Council



# FengYun Vision for Meteorological Satellites Program in 2035



# 5. Consideration on Calibration Issues

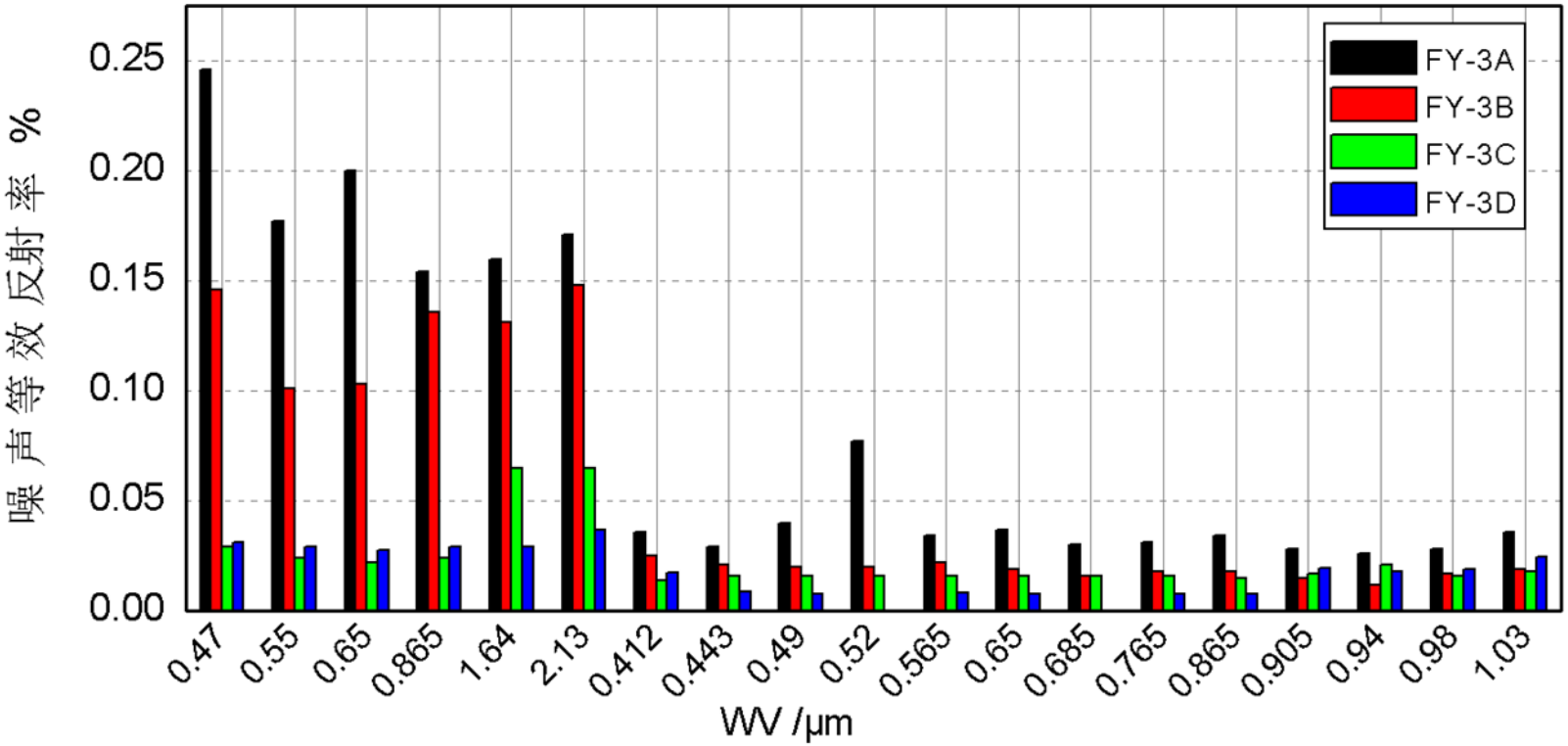



## Calibration Procedure for FY data

# Status of Onboard Calibrator

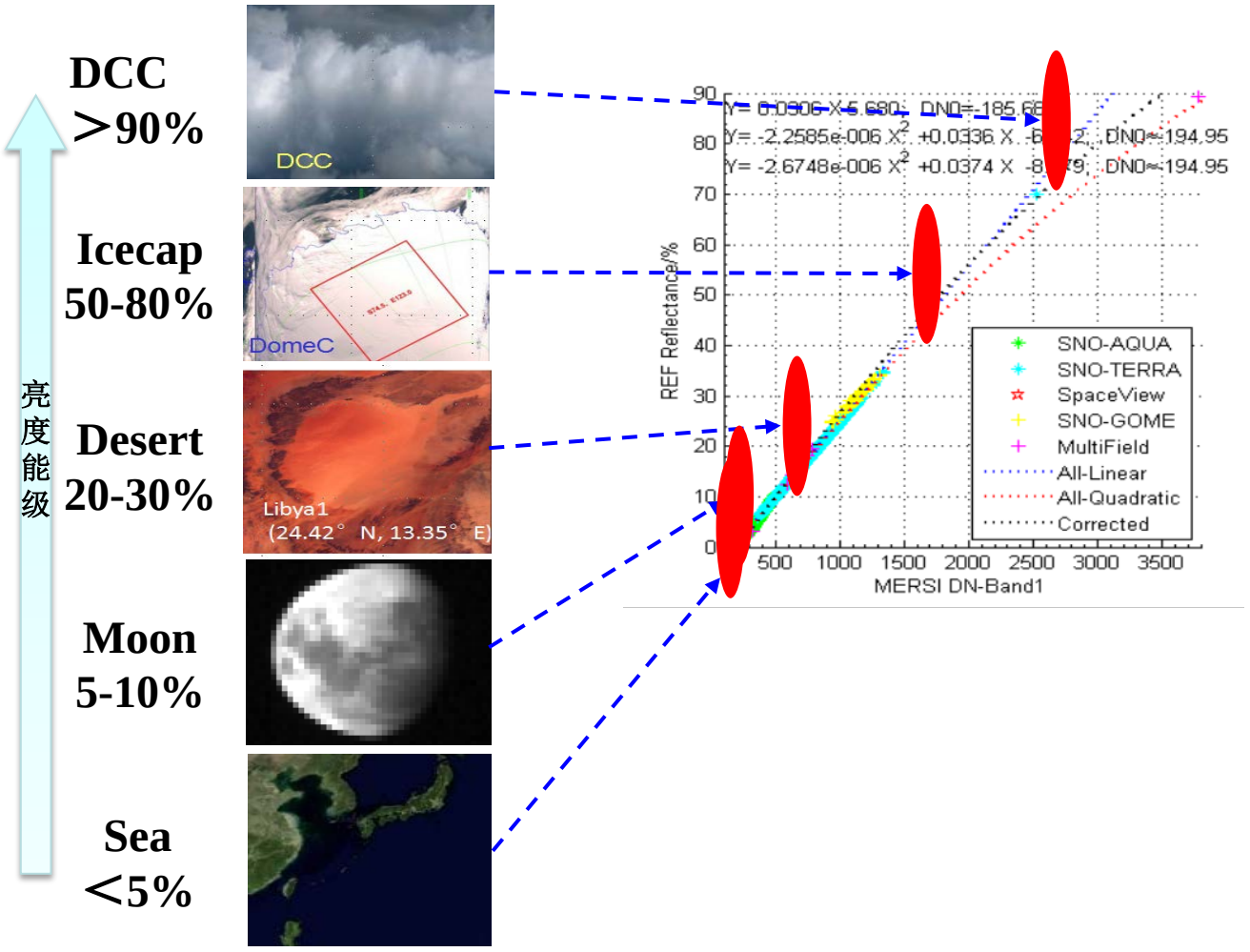
| Spectrum | On board Calibration System | Instrument | Accuracy of RT Calibration |
|---|---|---|---|
| UV | • Solar + diffuser<br>• mercury lamp | TOU/FY-3<br>SBUS/FY-3 | 5% ～ 10% |
| SRB | VOC | MERSI/FY-3 | • can't work<br>• Field Calibration per year, 7%<br>• Lunar Calibration since FY-3C, 3% ～ 5% |
| | halogen tungsten lamp | ERM/FY-3 | ? |
| | absolute radiometers | SIM/FY-3 | ? |
| TEB | blackbody | VISSR/FY-2<br>VIRR/FY-3<br>MERSI/FY-3<br>IRAS/FY-3 | 0.5 ～ 1K |
| | blackbody | ERM/FY-3 | 0.5K ～ 1K |
| WM | blackbody | MWTS/FY-3<br>MWHS/FY-3<br>MWRI/FY-3 | 1K ～ 2K |

# S/N Performance



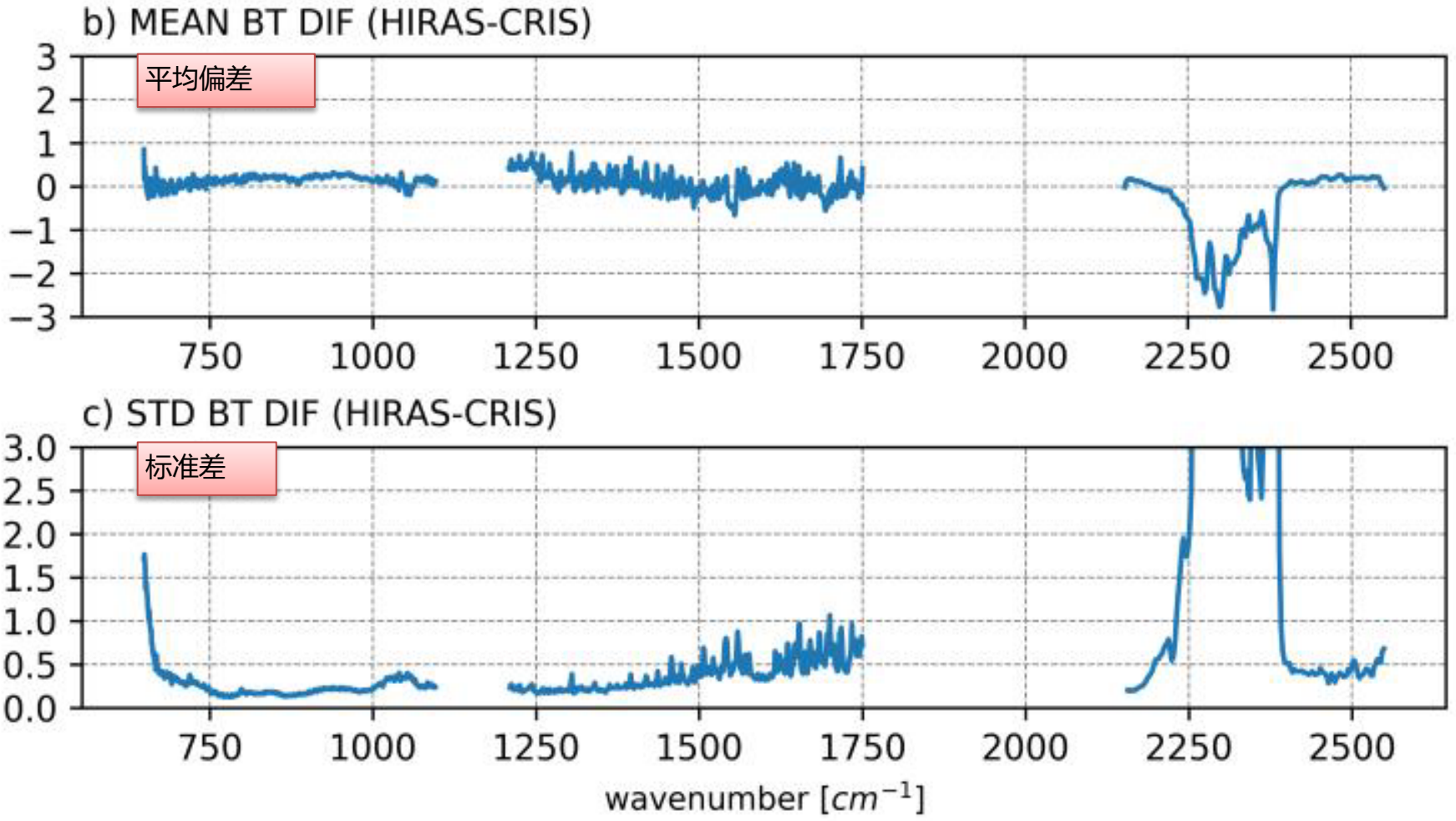

**MERSI onboard FY-3A/B/C/D**

# Nonlinear Performance Validation

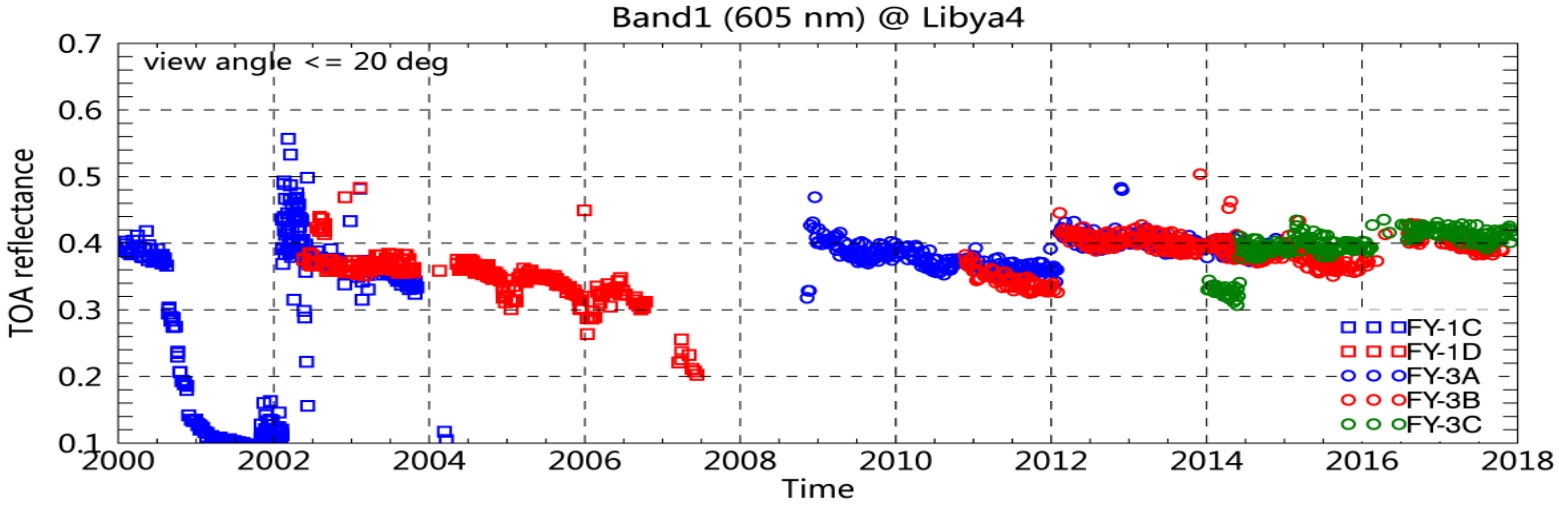


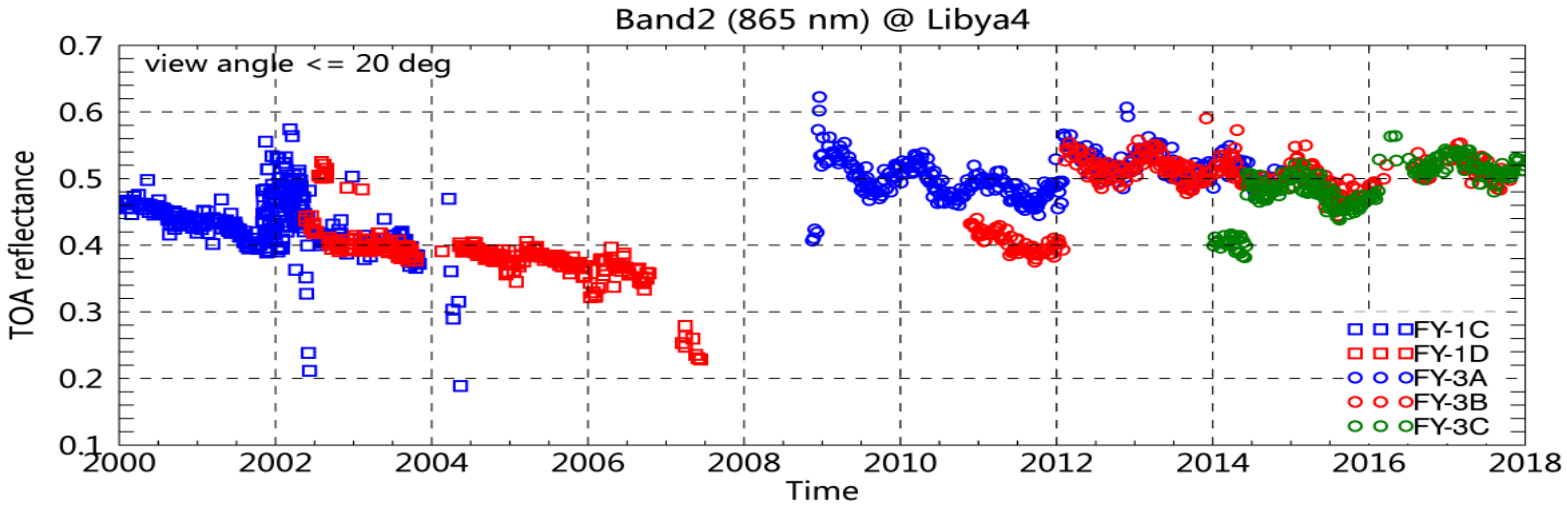
# Calibration Performance from HIRAS

**HIRAS** with the reference of **CrIS** (2018.04.25-2018.05.15)



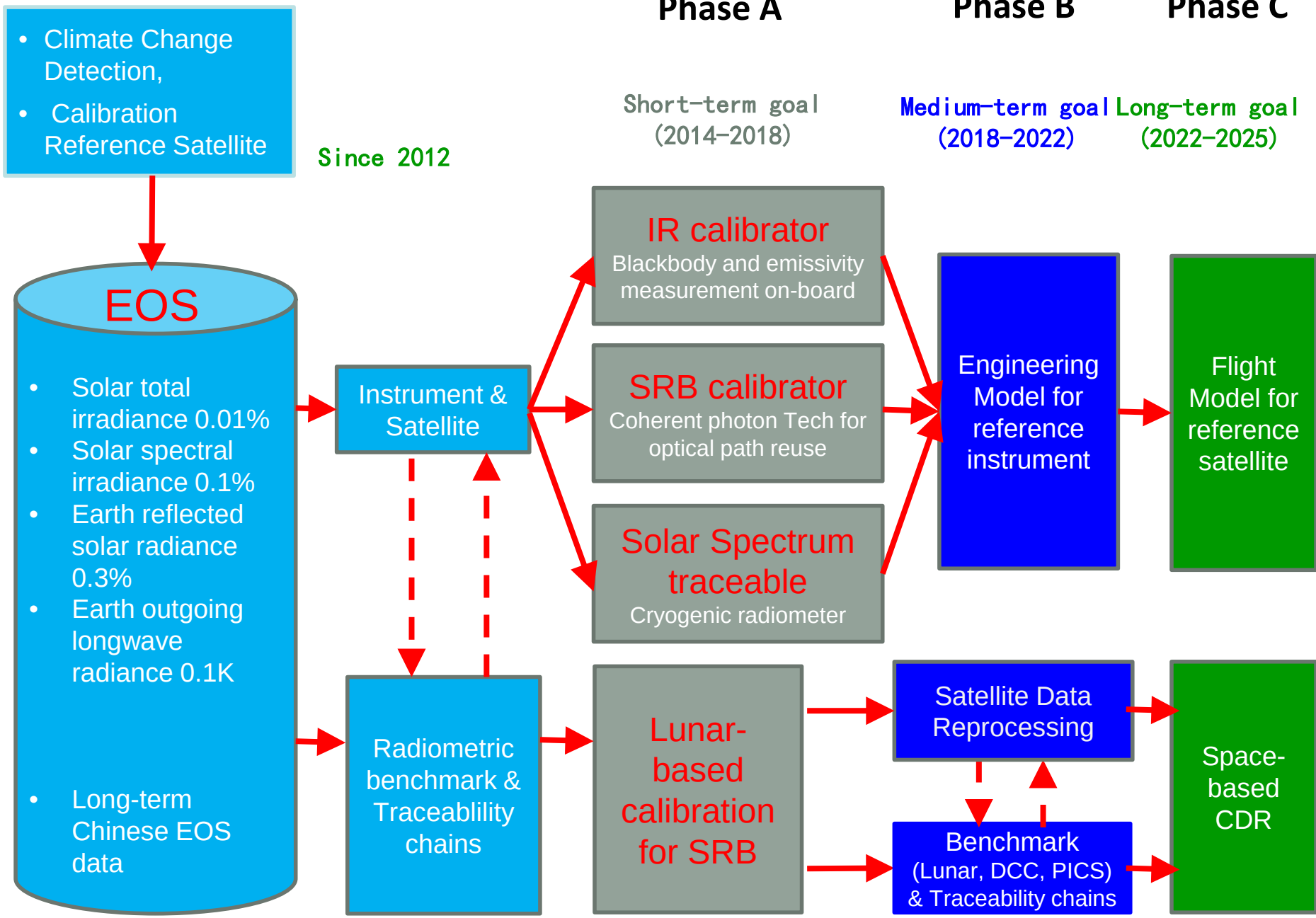
# FCDR Performance and Recalibration




**VIRR recalibrated by Libya4**

# Projects on Space-based Radiometric Benchmark in China



# Conclusion

- With the open data policy, reliable and sustained satellite, good data accuracy, FY series have be one important components of global observation system.
- Current FY-3 series are expected to work until 2035 with Early Morning orbit, Morning orbit, and Afternoon orbit and Rainfall mission.
- Current FY-4 series are expected to work until 2040 with FY-4 East (133E) and FY-4 West (79E).
- Future FY-5 and FY-6 are expected to provide service since 2030 and 2035 respectively.
- Calibration is the fundamental issue for high level products and quantitative applications. The 4 years' project has been founded to generate FCDR by recalibrating 30's FY archive data. Chinese Radiometric Benchmark Satellite has also programed.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For Better
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