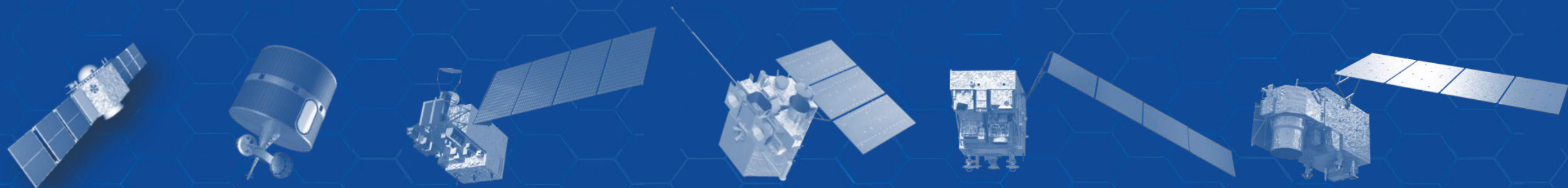


体系创新与发展：风云卫星赋能全球气象早期预警能力

Systematic Innovation and Development: FengYun Satellite Boosts Global Meteorological Early Warning Capability

CHEN Xiaojie Shanghai Institute of Satellite Engineering



AOMSUC-15 2025 FYSUC
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Key Technologies for Systemic Coordinated
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气象灾害及其引发的次生灾害是人类生存发展面临的重大挑战之一！

Meteorological hazards and the triggered secondary disasters constitute one of the major challenges to human survival and development.

持续时间长 地域覆盖广的灾害
Disasters of long duration and
extensive geographic coverage



短时 突发 局地灾害
Short-term, sudden onset, and
localized disasters



2024年，我国气象灾害及其次生灾害引起的直接经济损失2630亿元、受灾5344万人次。

In 2024, China's direct economic loss caused by meteorological disasters and their secondary effects amounted to RMB 263 billion, and 53.44 million people were affected.

2025年，欧洲持续性高温预计将导致GDP减少约0.5%。

In 2025, persistent high temperatures in Europe are expected to reduce GDP by approximately 0.5 percent.

天基遥感助力防灾减灾监测与预警预报！

Space-based remote sensing helps in disaster prevention, surveillance, early warning and forecasting.

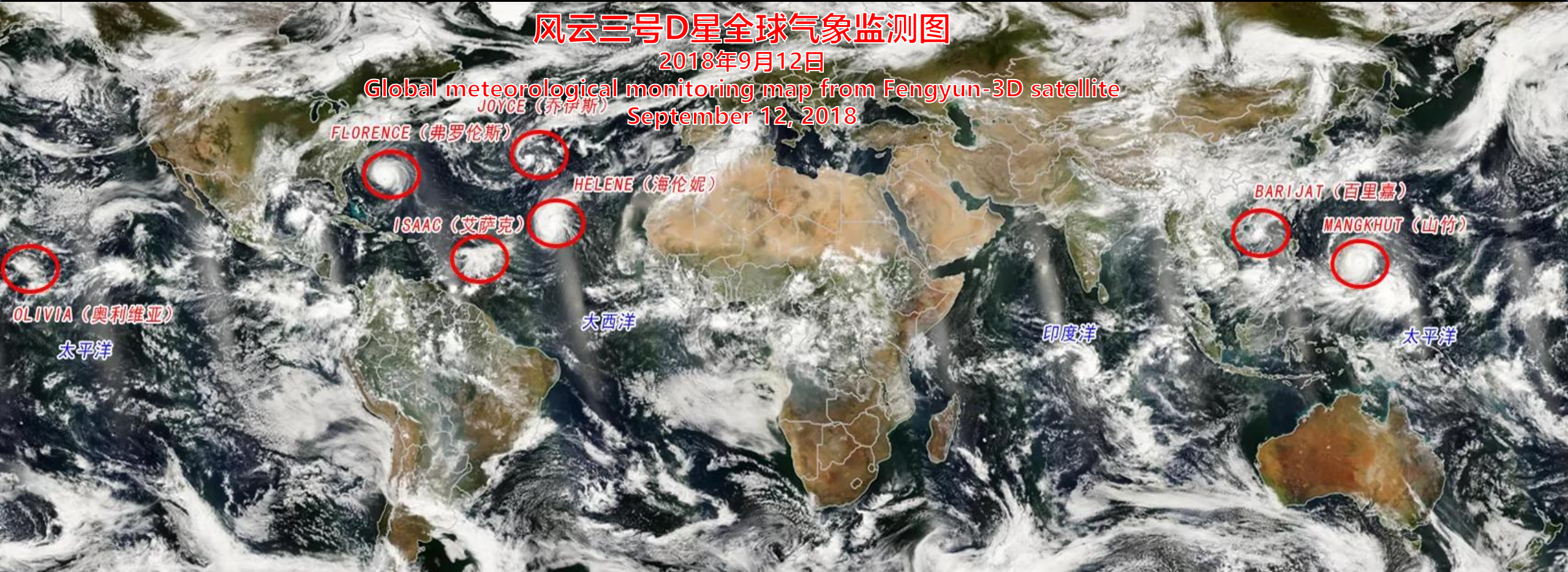
- 日常监测全球覆盖 Monitoring global coverage worldwide
- 中国区域高频监测 High-frequency monitoring of China regions
- 灾害区域加密观测 Intensive observations of the disaster zone

21世纪生成的**602**个台风，其中**185**个登陆我国，均实时监测、无一漏报。
(截止2025年6月)

Among the 602 typhoons generated in the 21st century, 185 of them made landfall in China. All of them were monitored in real time.
(As of June 2025)

天基遥感助力防灾减灾监测与预警预报！

Space-based remote sensing helps in disaster prevention, surveillance, early warning and forecasting.



□ 我国因气象灾害造成经济损失在GDP中的占比:2000年, 约占5%; 2024年, 约占0.2%。
China's economic losses due to meteorological disasters as a proportion of GDP: in 2000, approximately 5%; in 2024, approximately 0.2%.

□ 2024年夏季欧洲的危害造成经济损失约等于欧盟GDP的 0.26%。
In the summer of 2024, disasters in Europe resulted in economic losses amounting to about 0.26% of the European Union's GDP.



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Source: the Internet.

“全球沸腾”时代已经到来！

“The era of ‘global boiling’ has arrived.”

WEATHER

联合国政府间气候变化专门委员会 (IPCC) :

全球平均气温近百年**上升1.5°C**，近50年加快趋势明显。

气候变化造成**短时、突发、局地**气象及次生灾害频率与强度明显增加。

Intergovernmental Panel on Climate Change (IPCC):

The global mean surface temperature has risen by approximately **1.5 °C** over the past century, with a marked acceleration in the last 50 years.

Climate change has caused the frequency and intensity of **short-duration, abrupt, and localized** meteorological and secondary disasters to increase significantly.



2024, Spain, Flash Floods

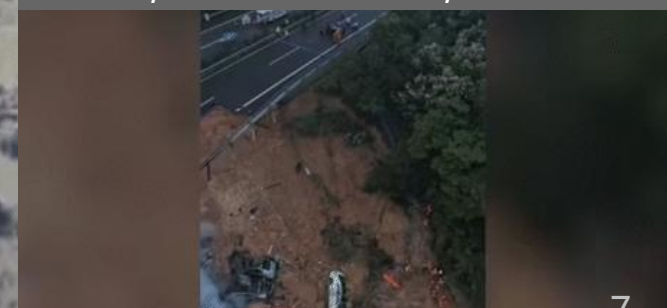


凌晨

2024, Saudi Arabia,
waterlogging



2024, United States, Tornado



2024, Guangdong, Landslide

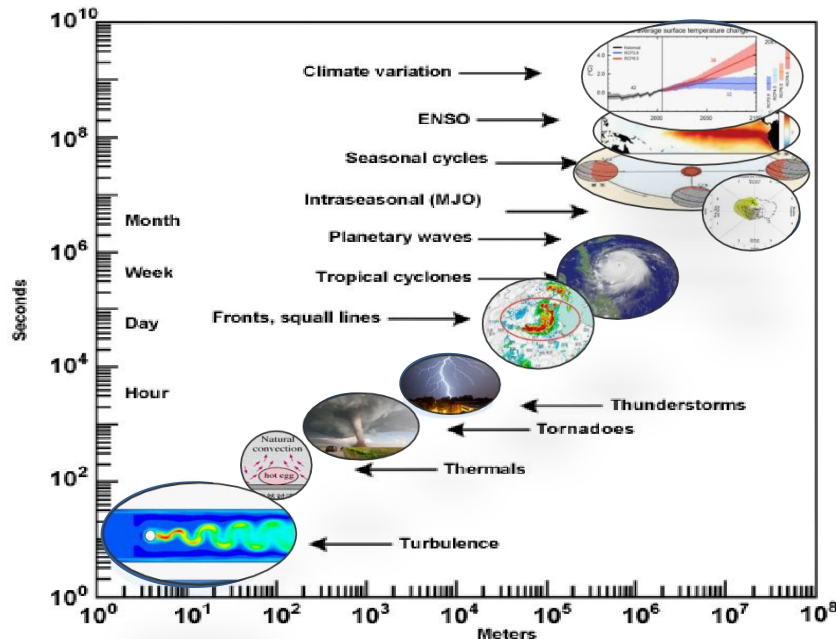
二、未来气象卫星体系观测需求

2. Observation Requirements for Future Meteorological Satellite Systems

2.1 观测愿景目标 Long-term Observational Objective

以世界气象组织制定的WIGOS 2040年愿景规划作为需求牵引，旨在构建一个覆盖地球全圈层、实时响应极端天气的**智慧化观测网络**，实现**体系级高时效响应、端到端低时延早期预警**，支撑气象服务、科研和可持续发展目标。

Guided by the vision of World Meteorological Organization' s WIGOS 2040 Vision, we aim to build an **intelligent**, Earth-system-wide observational network covering all spheres, with real-time response to extreme weather, achieving **system-level, high-timeliness and end-to-end low-latency early-warning**, and supporting meteorological services, scientific research and sustainable-development goals.



Meteorological Services:

- 1) Severe Weather Early Warning **30-minute** advance warning for destructive severe weather events; **10-minute** tornado impact zone forecasting.
- 2) Tropical Cyclone Tracking **5-day typhoon** path forecast accuracy: **±30 km**.
- 3) Extended-Range Forecasting **10-14 day operational weather** prediction capability.

二、未来气象卫星体系观测需求

2. Observation Requirements for Future Meteorological Satellite Systems

2.1 观测愿景目标 Long-term Observational Objective

《气象高质量发展纲要（2022~2035年）》指出：到2035年，气象监测、预报和服务水平大幅提升，以智慧气象为主要特征的气象现代化基本实现。

By 2035, the capabilities in meteorological monitoring, forecasting, and services will be significantly enhanced, achieving a new level of intelligent meteorology.

Meteorological Service Requirements

- ❑ Disaster Prevention and Mitigation
Extreme weather, climate, and hydrological events
- ❑ Meteorological services for coastal areas and megacities
High-precision weather forecasting services
- ❑ Air quality forecasting and monitoring services
- ❑ Sustainable Socioeconomic Development
Agriculture, disaster reduction, water resources, and energy



Meteorological Operational Requirements

- ❑ Weather Domain
Numerical Weather Prediction (NWP)
Nowcasting (0-6 hour forecasts)
- ❑ Climate Domain
Short-term Climate Prediction (Seasonal-to-interannual), Climate System Monitoring
- ❑ Emergency Observation and Tracking Requirements for Sudden Weather Events
- ❑ Full-chain Multi-Parameter Monitoring Requirements for Meteorological Disasters
- ❑ Full Causal-Chain Monitoring Requirements for Space Weather

二、未来气象卫星体系观测需求

2. Observation Requirements for Future Meteorological Satellite Systems

2.2 主要观测需求 key Observational Requirements

2.2.1 早期预警的观测需求 Observational Requirements for Early Warning

①早期预警重点在于“**预警范畴之广**”，需提高面向高影响天气的关键要素探测能力，实现实时、低时延的全球数据交换，赋能灾害预警业务与科学研究。

One of the key focuses of early warning is **the breadth of the warning domain**: improving the capability to detect key elements of high-impact weather, while simultaneously achieving real-time, low-latency global data exchange, thereby empowering disaster-warning operations and scientific research.

■ **多手段精细化观测需求** Requirements for Multi-Method and High-Precision Observation

气象卫星观测覆盖**风、云、雨、温、湿、压**等多种要素及内部结构、时空分布观测。

Meteorological satellite observations shall cover multiple parameters (**wind, clouds, precipitation**, temperature, humidity, **pressure**) along with their internal structures and spatiotemporal distributions.

■ **观测数据的连续性和实时性需求** Requirements for Data Continuity and Real-Time Availability

观测数据实时下传和观测结果实时分发要求高低轨卫星具备**星间互联、数据预处理**等能力。

Real-time downlinking and dissemination of observational data require GEO and LEO satellites to possess **inter-satellite links and onboard preprocessing** capabilities.

■ **观测模式的灵活性和突发性需求** Requirements for Adaptive and Rapid-Response Observation Modes

气象灾害突发性、短时性等特点要求卫星具备**灵活观测、及时响应、自主智能管理和运行**的能力。

The sudden and short-lived nature of meteorological disasters demands satellite capabilities in **agile sensing, prompt response, and autonomous AI-driven operations**.

二、未来气象卫星体系观测需求

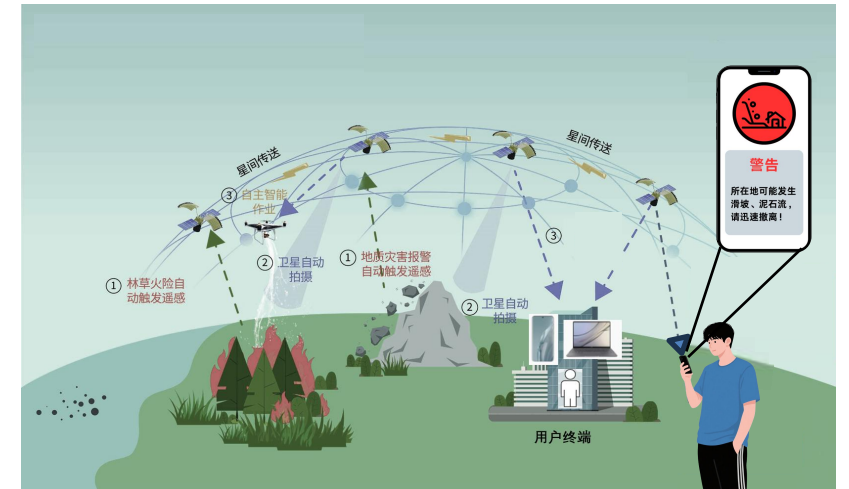
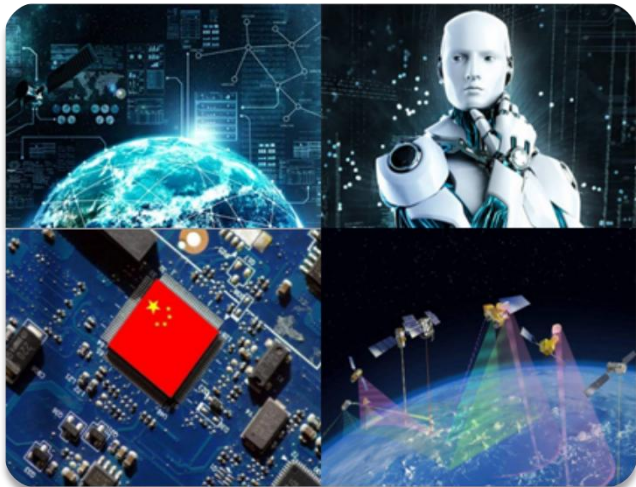
2. Observation Requirements for Future Meteorological Satellite Systems

2.2 主要观测需求 key observational requirements

2.2.3 早期预警的智慧化要求 Intelligentization Requirements for Early Warning

③早期预警重点在于“**预警能力之强**”，人工智能、大数据等多项前沿技术的在轨成功试验，为未来先进卫星发展**网络化、智能化**的应用奠定基础，将实现“天-地-终端”的多节点贯通，形成“**信息触手可及、服务随信而至**”预警服务能力。

The successful **in-orbit testing of cutting-edge technologies** such as artificial intelligence and big data has laid the foundation for the future development of **networked and intelligent applications** in advanced satellites. This will enable multi-node connectivity across "**space-ground-terminal**" systems, forming an **early warning service capability** that ensures "information is readily accessible and services arrive with the signal."



二、未来气象卫星系统观测需求

2. Observation Requirements for Future Meteorological Satellite Systems

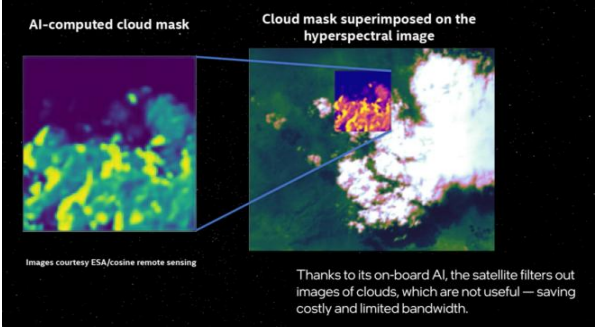
2.3 新技术助推早期预警目标实现 New technologies drive the realization of early-warning objectives

2.3.1 星上智能处理 Onboard Intelligent Processing

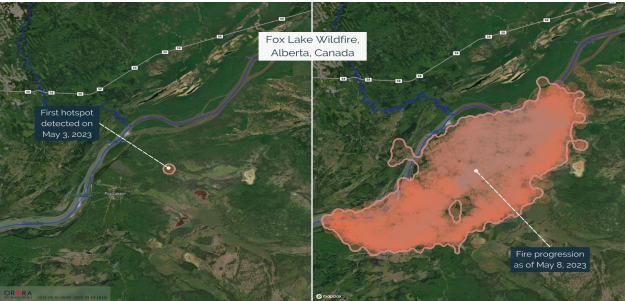
多个国家及机构通过搭载星上智能处理模型，测试了天基数据处理与**火灾识别**等多场景应用。

By deploying on-board intelligent processing models, multiple countries and organizations have tested **in-orbit data processing** and applications across scenarios including **wildfire detection**.

Satellite	Country	Launch Date	Function
EO-1	United States	2000.11.21	identification of regions of interest
BIRD	France	2001.10.22	Hot-spot detection
Pleiades-HR	France	1A: 2011.12.17 1B: 2012.12.02	Radiometric correction, geometric correction, image compression
PhiSat-2	ESA	2024.08.16	Map generation, ship detection, fire recognition
WildFireSat	Canada & Germany	First satellite 2024.10; full constellation by 2029	Real-time tracking of wildfires
Space Compass	Japan	Planned launch 2026	On-orbit ship identification, data compression



PhiSat在轨云判/In-orbit cloud discrimination



WildFireSat星座火灾识别结果
/constellation-based fire detection

二、未来气象卫星体系观测需求

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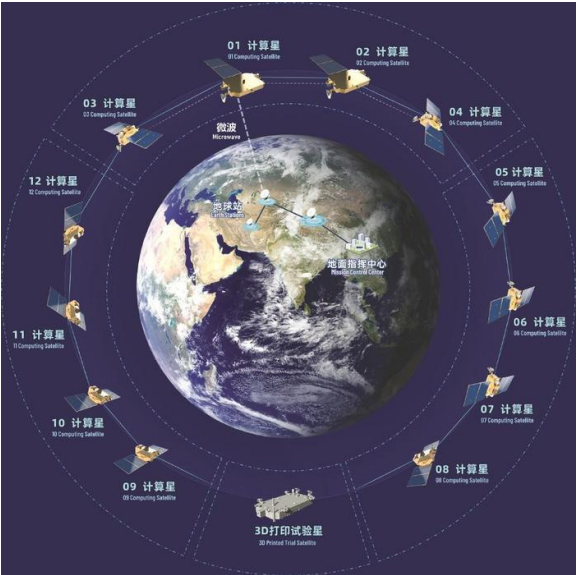
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2.3.1 星上智能处理 Onboard Intelligent Processing

星上智能处理发展迅速，星上自主任务规划、目标检测等技术蓬勃发展。多星协同与组网能力逐步形成，面向大模型的在轨初级计算与推理能力正在建立。

On-board intelligent processing continues to advance, with steady gains in autonomous mission planning and target detection. The capability for multi-satellite coordination and networking is gradually taking shape, with preliminary in-orbit computing and reasoning abilities now available for large models.

Satellite	Organization	Launch Date	Function
Dongfang Huiyan Gaofen 01	Zhejiang Lab	2024.02.03	Image parsing
"ZhiJia X2" On-board satellite	Zhejiang Lab	2024.09	On-orbit remote-sensing influence processing
"Tianzhi 2C"	Chinese Academy of Sciences	2024.11.11	Autonomous mission planning
Aman-Intelligent-Computing Satellite	Zhejiang Lab	2024.11.11	On-orbit real-time observation and data processing
Siwei Gaogjing 3 02	CASC 8th Institute & China Siwei	2025.03.15	On-orbit autonomous rapid image processing
Cosmic X-ray Polarimetry 03 and 04 series Cubesats	Guangxi University	2025.05.14	rapidly capture gamma-ray bursts and automatically perform target analysis and classification
Three-Body Computing Constellation" first batch of 12 satellites	Guoxing Aerospace & Zhejiang Lab	2025.05.14	Massive-complex-data real-time on-orbit analysis and processing



之江实验室：计算星座首发星座规划图
Three-Body Computing Constellation

二、未来气象卫星体系观测需求

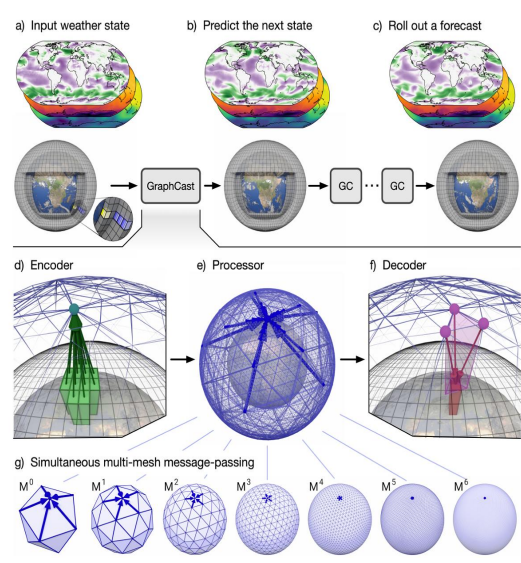
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2.3 新技术助推早期预警目标实现 New technologies drive the realization of early-warning objectives

2.3.2 气象大模型 Meteorological Large Models

中国气象局和多家气象机构相继推出基于人工智能的气象大模型，这些技术成果在气象防灾减灾方面的天基应用正在实践。

CMA and several meteorological agencies have successively launched large AI-based weather models. The application of these technological achievements **in space-based** meteorological disaster prevention and mitigation **is also worth exploring**.



GraphCast

Model Name	Function	Input Parameters
FuXi Meteorological Large Model	Weather forecasting, typhoon track prediction, subseasonal climate forecasting	Wind speed, temperature, precipitation, radar reflectivity, lightning density
PanGu Meteorological Large Model	Global meteorological element forecasting, typhoon track prediction	
Wind Space Weather Large Model	Real-time monitoring of extreme space weather events	
WindClear Large Model	Global medium-range weather forecasting	
WindLightning Large Model	Precise forecasting of severe convective short-duration weather disasters	
WindOrder Large Model	Long-time-series climate trend simulation and analysis	
FuYao Large Model	Intelligent identification and risk evaluation of highly-influential weather	
RainMaster Large Model	High-resolution precipitation forecasting capability construction	

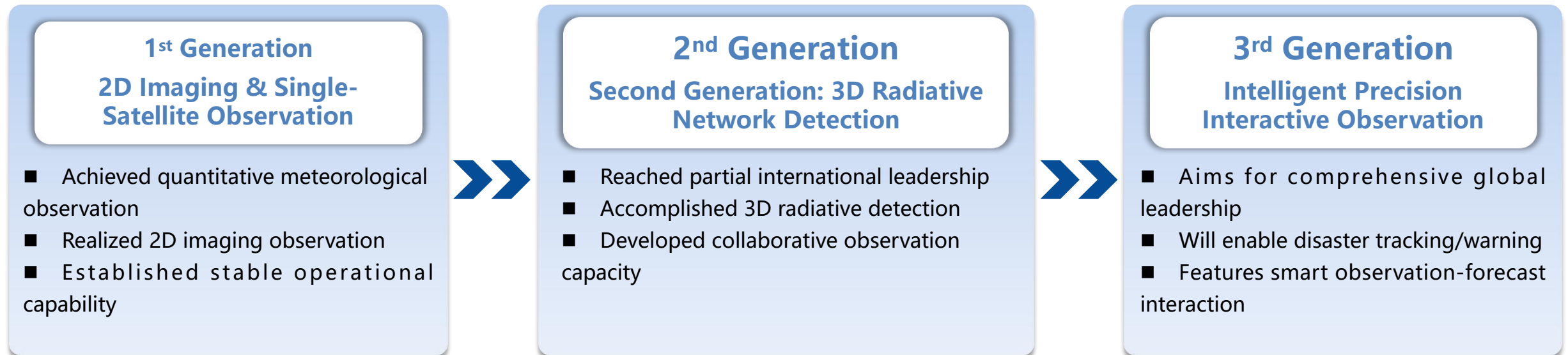
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2. Observation Requirements for Future Meteorological Satellite Systems

2.4 风云卫星发展趋势 Development Trends of FengYun Satellites

围绕气象高质量发展需求，已开展星上网络化与智能化等关键技术验证，系统推进**智慧、精准、互动**观测能力布局，第三代风云卫星亟需全面突破**智慧精准互动**观测。

To meet high-quality forecasting needs, in-orbit tests of FengYun networking and AI are underway and a systematic build-out of **intelligent, precise, interactive** observation is also in progress. The third generation of FengYun satellites will achieve **more breakthroughs**.





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Key Technologies for Systemic Coordinated Observation of the Fengyun Satellite Constellation

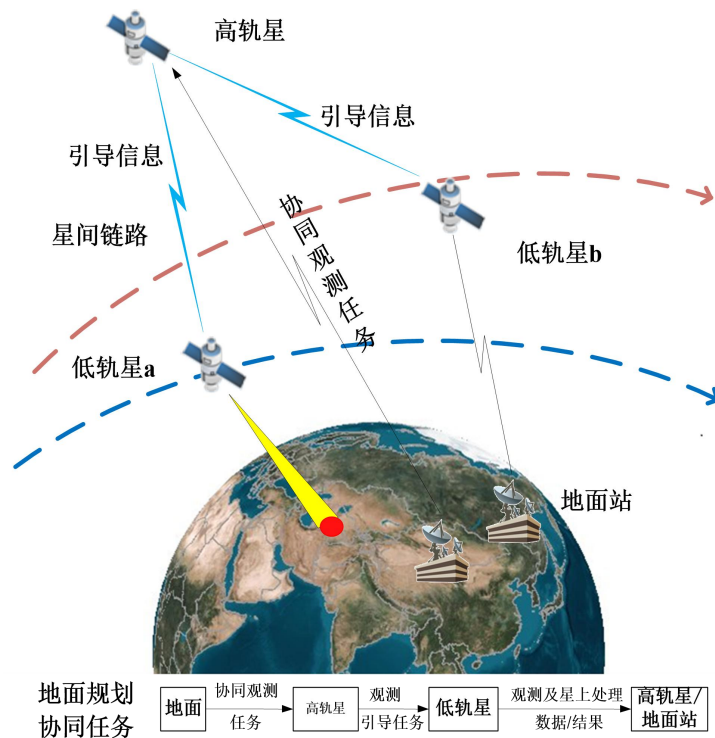
三、体系化风云卫星协同观测关键技术

3. Key Technologies for Systemic Coordinated Observation of the Fengyun Satellite Constellation

3.1 协同观测构想 Collaborative Observation Conception

新一代风云气象卫星体系在用户需求和科技进步的双轮驱动下，将构建更好服务气象防灾减灾的观测和服务能力。

The new generation Fengyun meteorological satellite system, driven by both user demands and technological advancements, will establish enhanced observation and service capabilities to better support meteorological disaster prevention and mitigation.



■ 高轨：天基枢纽

GEO satellites serve as space-based hub

■ 低轨：天基节点

LEO satellites serve as space-based nodes

■ 地面：体系中心

Ground stations serve as the system center

三、体系化风云卫星协同观测关键技术

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3.1 协同观测构想 Collaborative Observation Conception

瞄准要素协同、时空协同、仪器协同、卫星协同、数据协同等目标，实现气象卫星互联互通、智慧协同观测。

Aimed at achieving **element coordination, spatio-temporal coordination, instrument coordination, satellite coordination, and data coordination**, to realize meteorological satellite interconnectivity and intelligent collaborative observation.



Temporal-spatial coordination of detection elements, multi-system coordination, and end-to-end coordination



Remote sensing instrument channel configuration and payload configuration collaborative complementarity



GEO/LEO, general/special-purpose, and large/medium/small satellite collaborative observation



Onboard autonomous operation and intelligent processing, space-ground integrated smart collaboration and services

三、体系化风云卫星协同观测关键技术

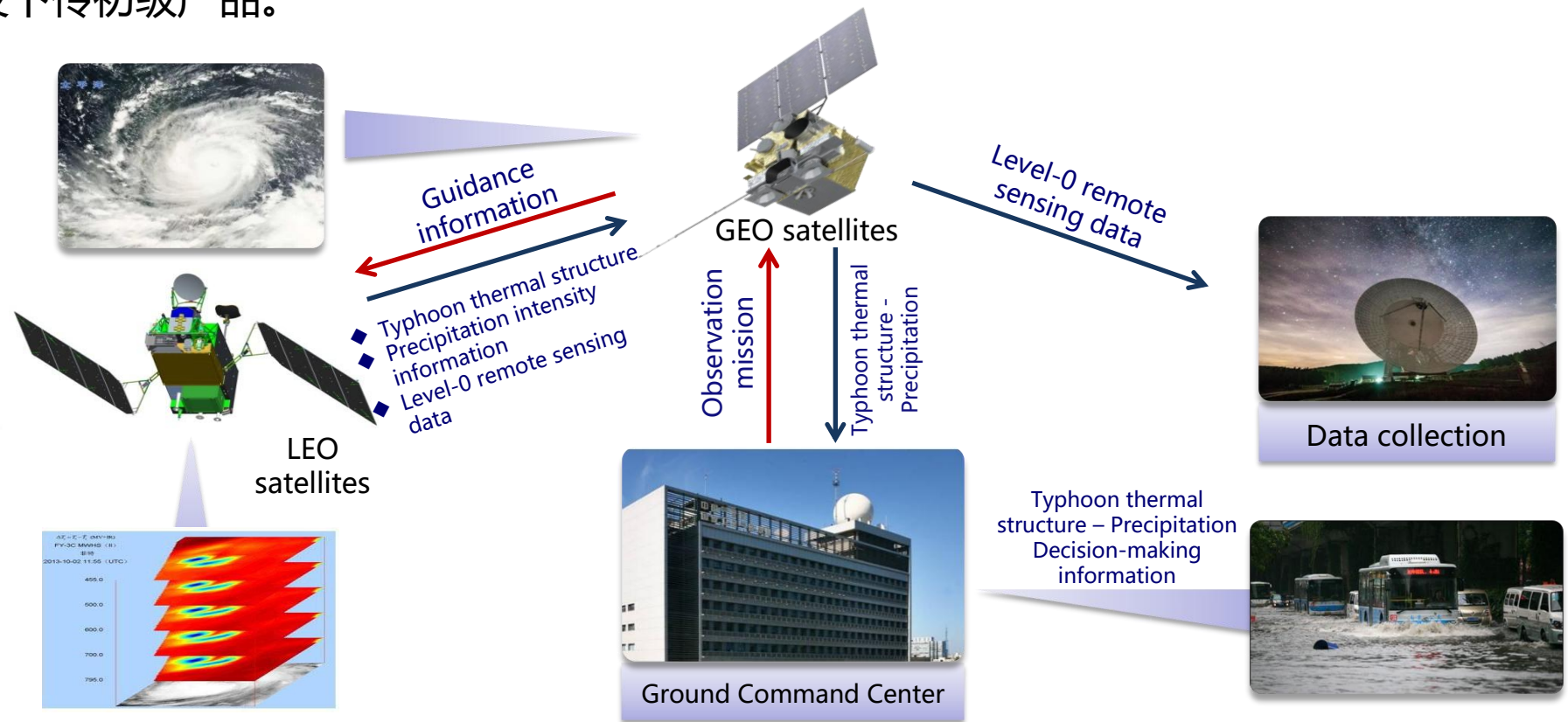
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3.2 协同观测应用场景 Collaborative Observation Application Scenarios

■ 高效率灾害应急响应协同观测体系 High-efficiency coordinated disaster emergency response observation system

针对台风、强降水等应急灾害事件，高轨卫星**动态实时监测**、**自主规划任务**，引导低轨卫星机动观测、回传数据，高轨卫星**在轨融合处理**，分发下传初级产品。

For typhoon, heavy precipitation, and other emergency disaster events, GEO satellites perform **dynamic real-time monitoring and autonomous task planning**, guide LEO satellites to conduct maneuverable observations and downlink data, execute **onboard fusion processing**, and distribute primary products.



三、体系化风云卫星协同观测关键技术

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3.3 体系协同观测关键技术 Key Technologies for Systematic Collaborative Observation

面向未来需求，需突破星间激光互联、星上智能处理及多源数据融合广播分发等技术。

To meet future demands, breakthroughs are required in technologies such as inter-satellite laser communication, on-board intelligent processing, and multi-source data fusion broadcasting.

星间激光建链互联 技术

Inter-satellite
laser link
establishment
and
interconnection
technology

高性能星上处理系 统

On-board
processing
hardware design

星上智能处理及多 源数据融合广播分 发技术

Onboard
Intelligent
Processing &
Fusion, Broadcast,
and Distribution
of Multi-source
Data

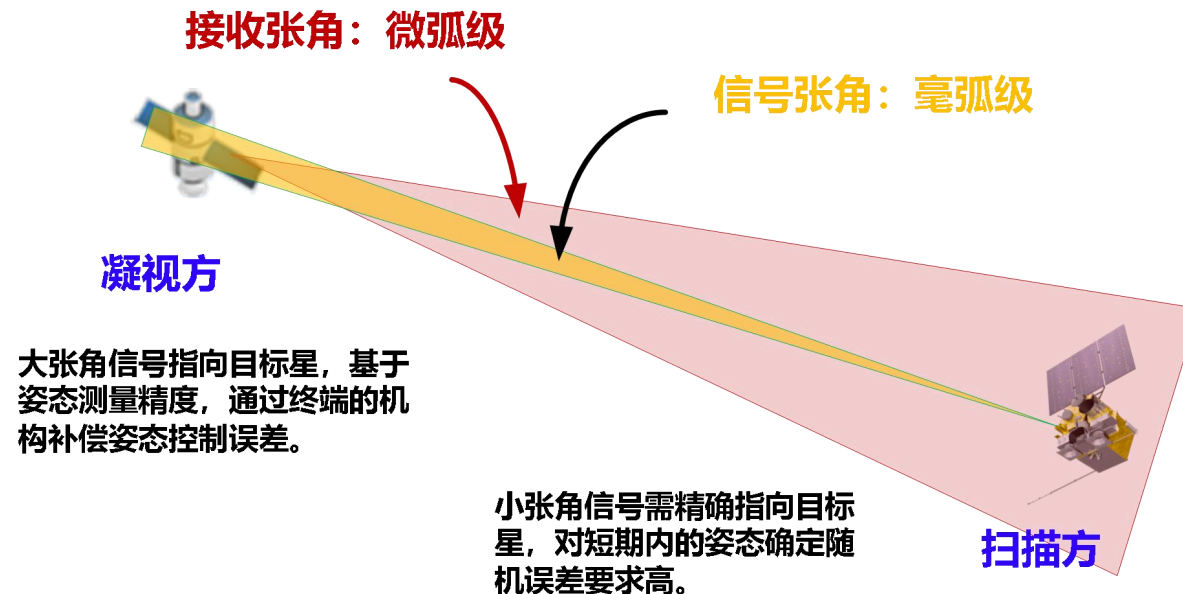
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3.3.1 星间激光建链互联技术 Inter-satellite Laser Link Establishment and Interconnection Technology

采用**凝视+扫描**的捕获方式，完成高低轨星间**快速建链**、**可靠稳定跟踪**和通信，实现高低轨卫星**快速、可靠、稳定建链**，为风云卫星体系协同建立技术基础。

Using a **gaze+scan** capture method, rapid inter-satellite link establishment and reliable stable tracking between GEO and LEO satellites are achieved, enabling **fast, reliable and stable link** building between GEO and LEO satellites, thereby laying a solid foundation for the FY satellite system collaboration.



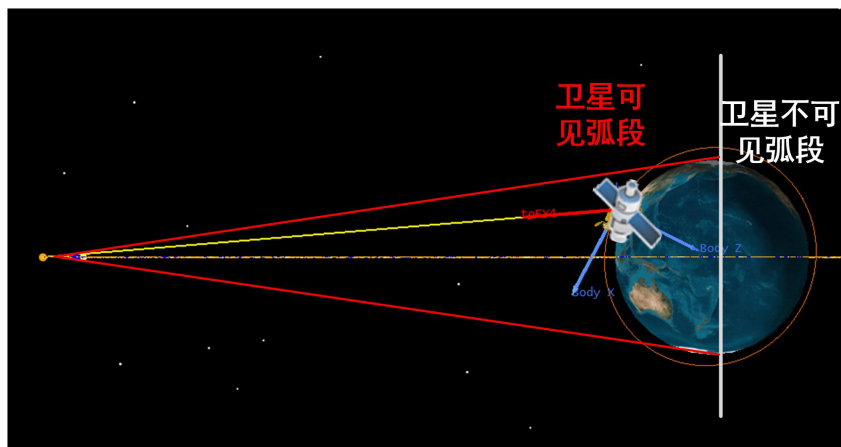
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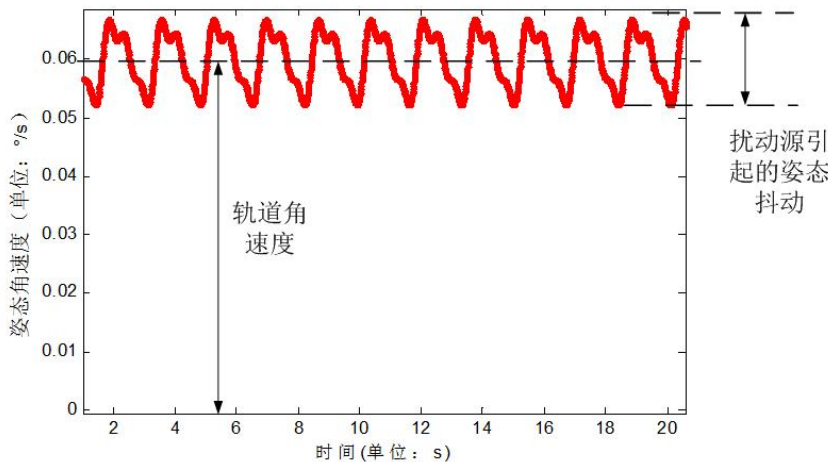
3.3.1 星间激光建链互联技术 Inter-satellite Laser Link Establishment and Interconnection Technology

风云卫星激光通信体系特征：距离遥远且频繁建链断链、异轨之间相对运动快、平台运动干扰强、热变形变化剧烈，需解决轨道精密递推、机构精确控制、热变形精准校正等一系列难题。

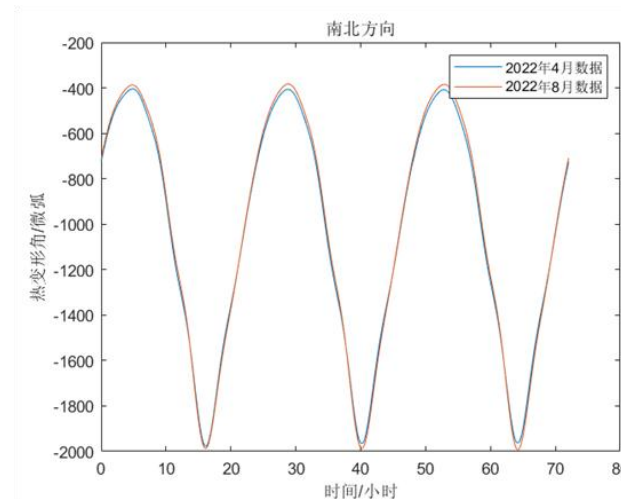
The laser-communication system of the FengYun Meteorological Satellite Constellation is characterised by long link distances and frequent link establishment and disruption, rapid relative motion between disparate orbits, strong platform motion disturbances, and dramatic thermal deformation changes. It must address a series of challenges including precise orbital propagation, accurate mechanism control, and precise thermal deformation calibration.



异轨卫星相对位置变化
changes in relative positioning of
satellites in dissimilar orbits



平台姿态运动
platform attitude motion



轨道周期热变形变化规律
orbital-period thermal variation patterns

三、体系化风云卫星协同观测关键技术

3. Key Technologies for Systemic Coordinated Observation of the Fengyun Satellite Constellation

3.3.1 星间激光建链互联技术 Inter-satellite Laser Link Establishment and Interconnection Technology

在地面构建**高低轨建链系统**，根据在轨真实高低轨建链场景，完成了高低轨建链试验。试验中模拟了**轨道运动、平台姿态变化、热变形**等因素对高低轨建链的影响。

On the ground a **GEO/LEO link building system** was constructed; based on real in-orbit GEO/LEO orbit link building scenarios, a GEO/LEO orbit link building test was completed. During the test the influences of **orbital motion, platform attitude variation and thermal deformation** were simulated.



星间互联现场
Inter-satellite networking

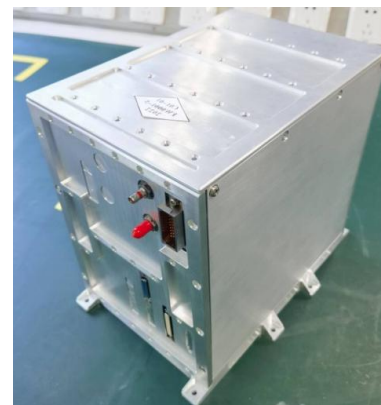
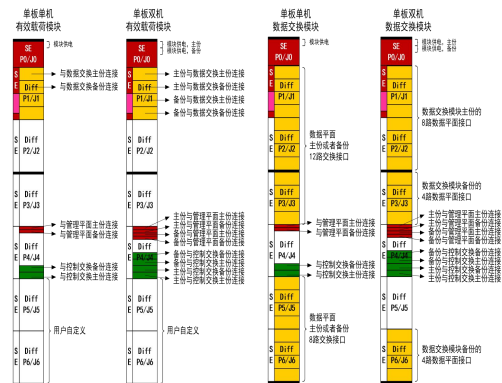


微振动试验
micro-vibration test



3. Key Technologies for Systemic Coordinated Observation of the Fengyun Satellite Constellation

通过提升**星上硬件性能、优化计算架构**，依托“通用计算+专用AI加速”的混合架构构建星上超级计算能力，满足星上处理、任务规划等智能任务模型的部署与运行需求。



YB FT-M6678H R C
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YULONG
810A
ORBITA
2010

AGX Xavier (GPU模组)-

三、体系化风云卫星协同观测关键技术

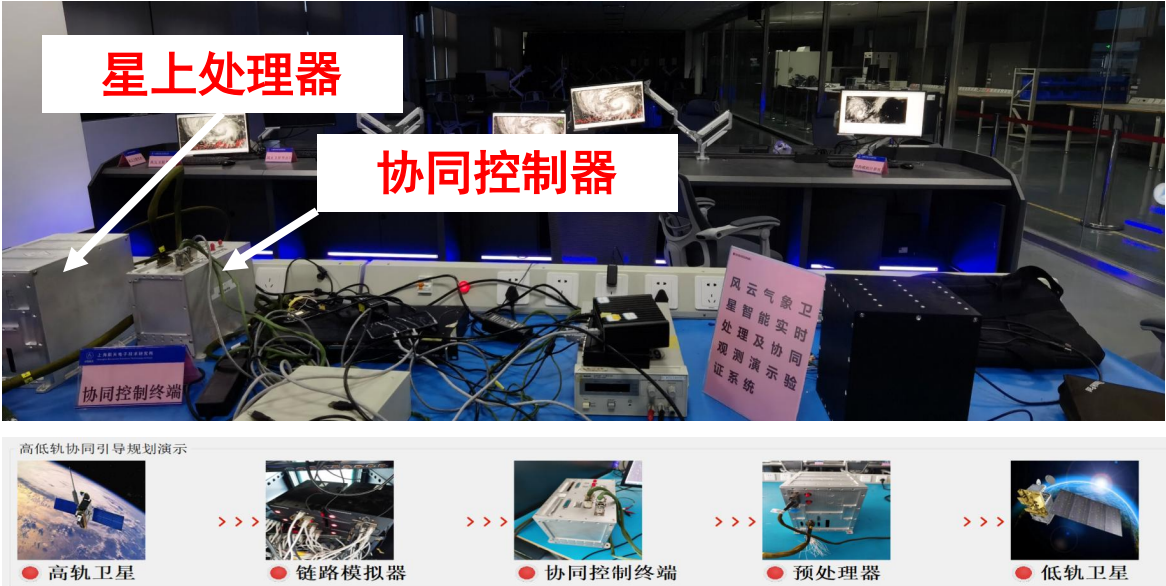
3. Key Technologies for Systemic Coordinated Observation of the Fengyun Satellite Constellation

3.3.2 高性能星上处理系统 Onboard Processing Hardware Design

开展星上处理器系统级仿真验证，完成高低轨协同观测的演示验证并覆盖**协同链路仿真**。

System-level simulation and verification of the on-board processor are conducted, completing a demonstration of GEO and LEO collaborative observation and including **end-to-end simulation of the collaborative links**.

任务需求	需求特点	硬件设配	在轨软故障率	软件开发
载荷预处理	可靠监控、管理	FPGA (反熔丝)	低	Verilog、VHDL
目标检测	高速并行计算	FPGA (SRAM)	高	Verilog、VHDL
参数反演	低算力高可靠计算	CPU	低	C/C++、Ada、汇编
任务管理	深度学习、神经网络	NPU	高	Python
在轨更新与重构	高算力浮点和定点运算	DSP	最高	C/C++
数据存储与压缩	大容量存储、坏块管理	FLASH SSD MRAM	中 (产生坏区)	
地面开发验证	通用计算	PC、服务器		Matlab、Python



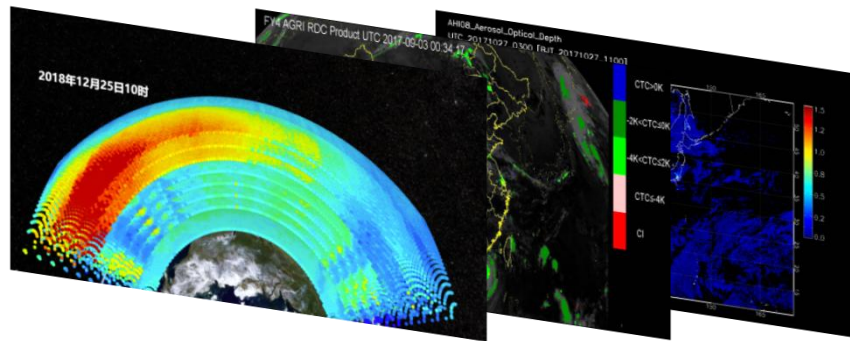
三、体系化风云卫星协同观测关键技术

3. Key Technologies for Systemic Coordinated Observation of the Fengyun Satellite Constellation

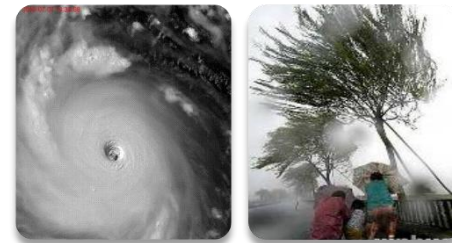
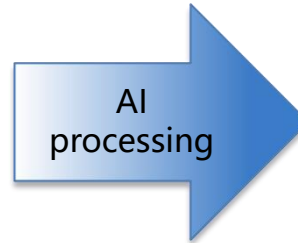
3.3.3 星上智能处理及多源数据融合广播分发技术 Onboard Intelligent Processing & Fusion, Broadcast, and Distribution of Multi-source Data

通过星地大模型、数据联动实现气象产品在轨智能处理、低延迟终端广播推送等技术，实现**卫星到终端**（如手机）的气象信息实时广播、传递、分发，大幅提升气象数据和产品服务体验。

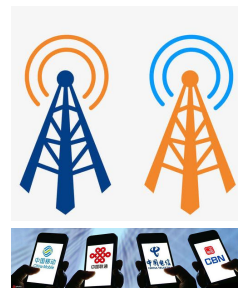
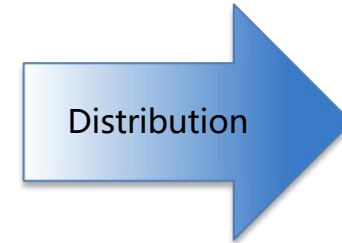
Through the integration of space-ground large models, data collaboration, onboard intelligent processing of meteorological products, and low-latency terminal broadcast push technologies. This system achieves real-time broadcasting, transmission, and distribution of meteorological information from satellites to end-user devices (e.g., smart phones). This innovation significantly enhances the service experience of meteorological data and products.



Satellite observation data



Weather event



End-user service

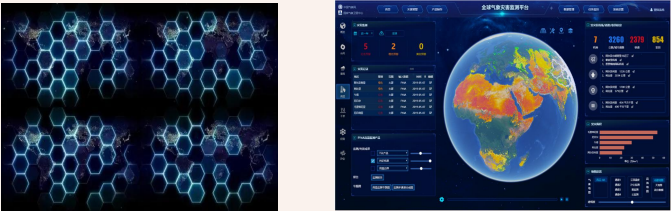
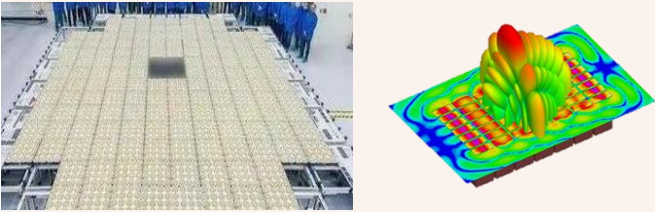
三、体系化风云卫星协同观测关键技术

3. Key Technologies for Systemic Coordinated Observation of the Fengyun Satellite Constellation

3.3.3 星上智能处理及多源数据融合广播分发技术 Onboard Intelligent Processing & Fusion, Broadcast, and Distribution of Multi-source Data

体系化实时观测数据通过星上智能处理快速生成精细化预警产品，直接推送至地面终端，显著缩短预警时效，提升极端天气的“监测-预警-响应”全链条效能。

The system-level real-time observational data undergoes onboard intelligent processing to rapidly generate fine-scale warning products, which are directly pushed to ground terminals, significantly reducing warning latency and enhancing the full-chain “monitor-warn-respond” effectiveness for extreme weather.

Information chain	Physical-space system architecture layer	Satellite layer	Ground terminal layer
Technical key points	- Earth-satellite link path and time-frequency dynamic Optimization - Adaptive transmission technology - Autonomous access and scheduling technology 	- Low-noise array antenna transmission and reception technology - Satellite-ground 5G NTN protocol - Beam and frequency intelligent management and control technology 	- High integration, low power consumption chip - RF signal loss compensation technology 
Development recommendations	- Mobile phones directly connecting to satellites — wireless spectrum allocation - Service monitoring and regulation	- Innovation in satellite transceiver antenna technology - Establishment of standard communication protocol systems	- Unification of terminal communication standards - Reduction of direct-connect mobile phone costs

Conclusion

Systemic collaborative observation by the Fengyun meteorological satellite constellation is an essential requirement for the “high-quality development” .

Building an intelligent collaborative observation system for the Fengyun satellites constitutes a feasible pathway to addressing extreme weather.

- strengthening the timeliness of disaster early warning
- shortening disaster response cycles
- and reducing early warning gaps



Thanks!