MICROWAVE REMOTE SENSING: QUANTITATIVE TECHNIQUES AND DEVELOPMENT IN CHINA

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Chinese Academy of Sciences (CAS)

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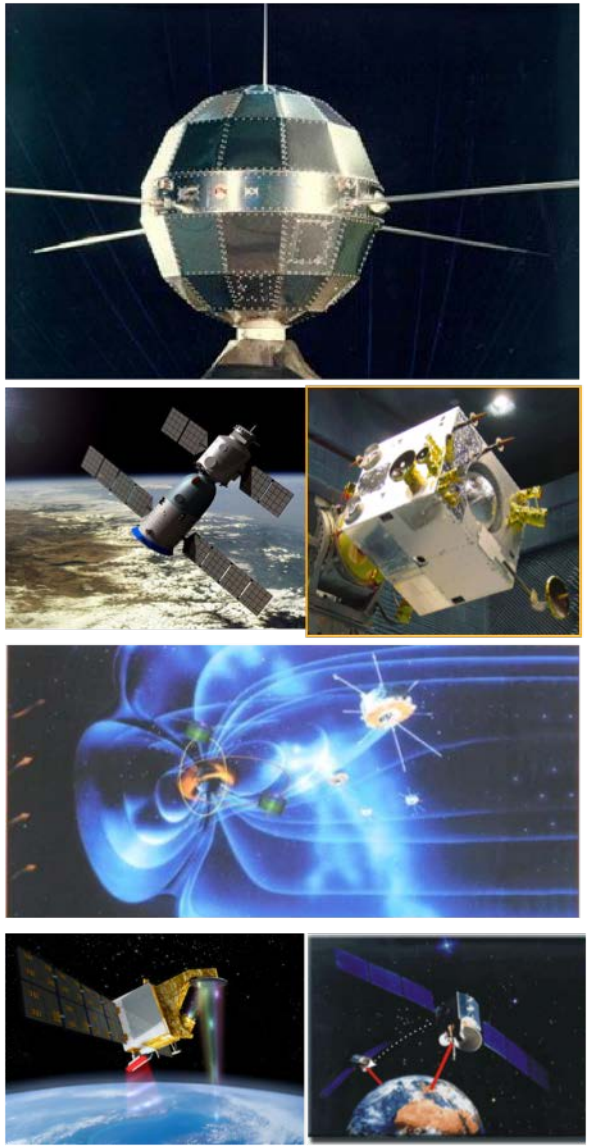
Outline

- Early Developments
- Development for atmospheric and ocean applications
- Development for future missions
- Summary

NSSC

(National Space Science Center, Chinese Academy of Sciences)

- Founded in 1958, initiated 1st satellite project in China (DFH-1, 1970)
- Key role in China's space program:
  - Manned space mission, oceanic/meteorological satellite, lunar exploration
  - Payloads, data processing and scientific applications
  - Space physics & space weather, spacecraft electronics, space environment monitoring and detection & microwave remote sensing
- Planning, management, development and operation of space science satellite programs
  - Space-based astronomy and astrophysics;
  - Solar and space physics;
  - Planetary science;
  - Microgravity science and astrobiology;
  - Earth science from space.

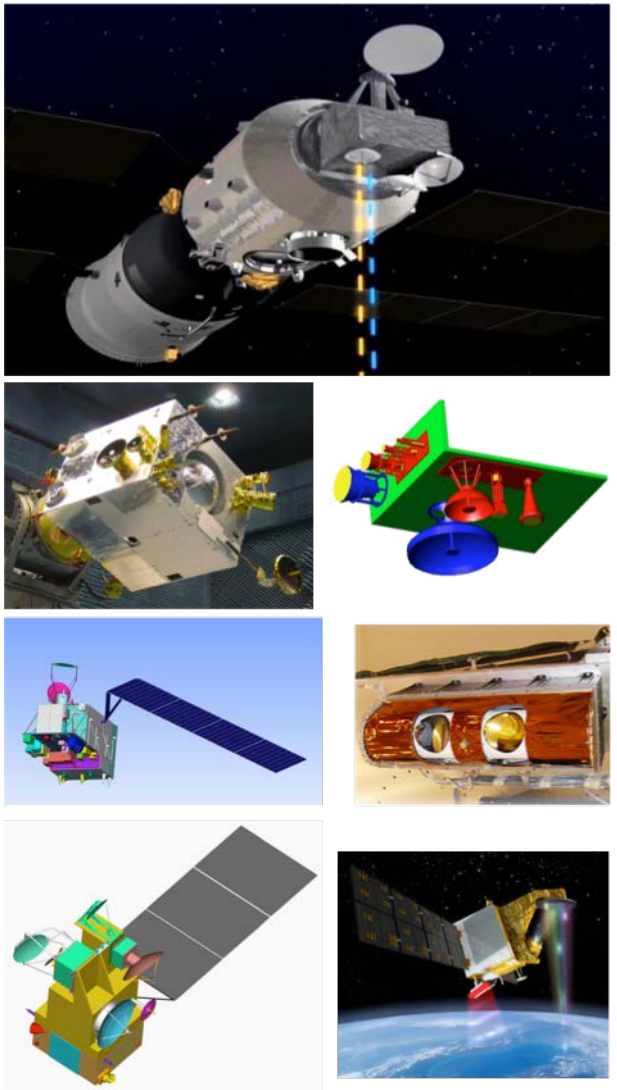


MiRS

(CAS Key Laboratory of Microwave Remote Sensing)

- R & D department of NSSC
- Founded in 1958, as electronics group contributing to the development of China's 1st satellite (DFH-1) in early 1970s.
- NMRS developed the telemetry receiver for DFH-1.
- From 1973, focuses turned to microwave remote sensing technology
- 1984, the 1st laboratory for microwave remote sensing in China
- Significant contributions for China's main space programs with microwaves:
  - Manned space flight
  - Lunar exploration
  - Oceanography
  - Meteorology…

- **Research & development priorities:**
  - Development of microwave remote sensing
    - microwave radiometry,
    - radar altimetry,
    - radar scatterometry
  - Calibration and validation, information techniques and science with microwave remote sensing.
    - Calibration/validation
    - Geophysical parameter retrieval
    - Science applications: earth science and global change
- **Contribution to China's space program with microwave**
  - SZ-4 (unmanned spaceship, 2002): M3RS (ALT+SCAT+RAD)
  - FY-3 (2008,2010,2013): MWHS (90, 118, 150, 183GHz)
  - CE-1/2 (2007,2010): MWS (3.0,7.8, 19.35, 37GHz)
  - HY-2A~D (2011, 2018, 2020, 2021): DFRA (Ku+C ALT), ACMR (tri-freq RAD), SCAT (Ku-RPSCAT)
  - TG-2 (2016): Wide-Swath Radar Altimeter
  - RFSCAT (2018): SCAT (Ku-RFSCAT)



Early Developments

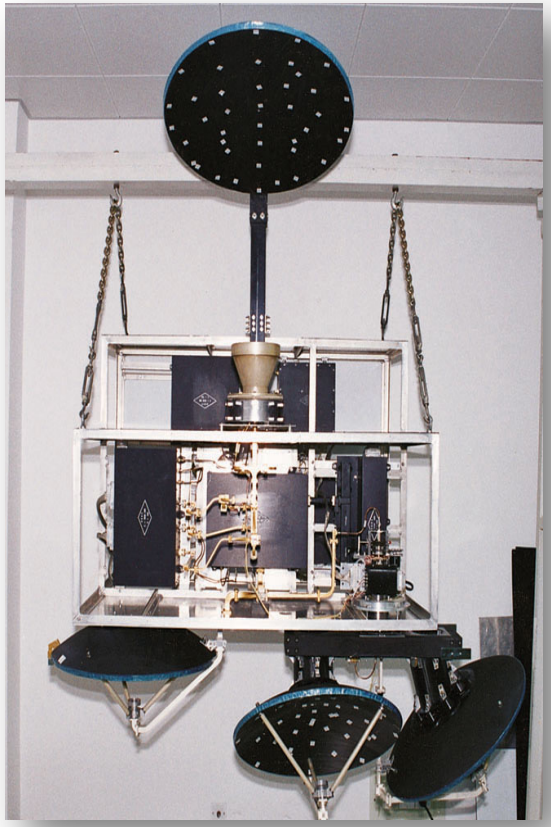
- Research and development of microwave remote sensing in China, started in early 1980's.
- First spaceborne microwave remote sensing mission:
  - Multi-Mode Microwave Remote Sensor (M3RS) : flown on SZ-4 Unmanned Space Flight mission
  - Development started in early 1990's
  - Launched on December 31, 2002

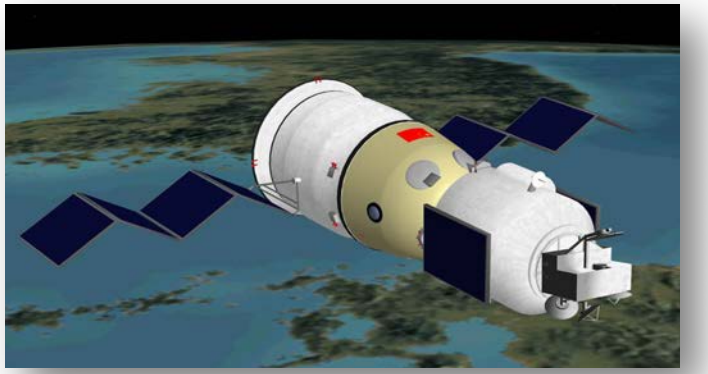
M3RS: Multimode Microwave Remote Sensors on SZ-4 Space mission（2002）

Ku-band (13.9GHz) ALT+SCAT, 5-band Microwave radiometer (6.6-37GHz)

China's 1st MW Remote Sensing Experiment in Space

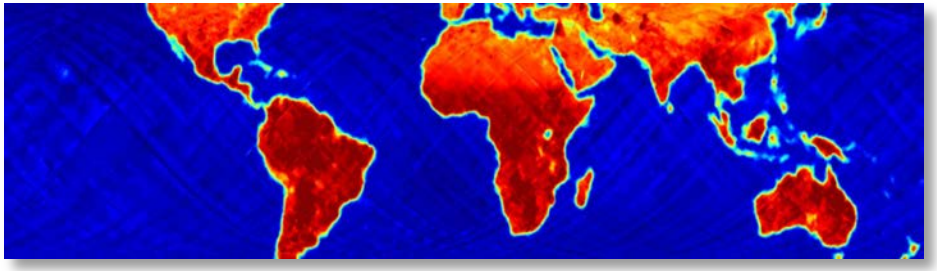
Technology test & verification for oceanography and meteorology microwave sensors



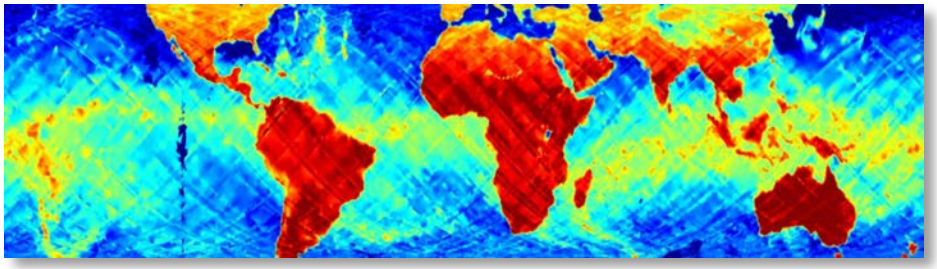


Ocean surface brightness temperature, significant wave height and wind vector

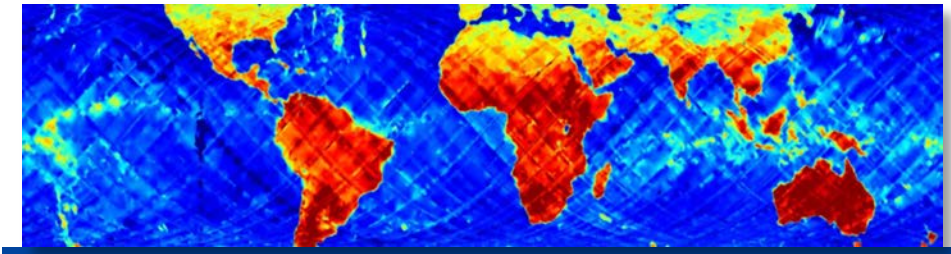
6.6GHz-H Channel

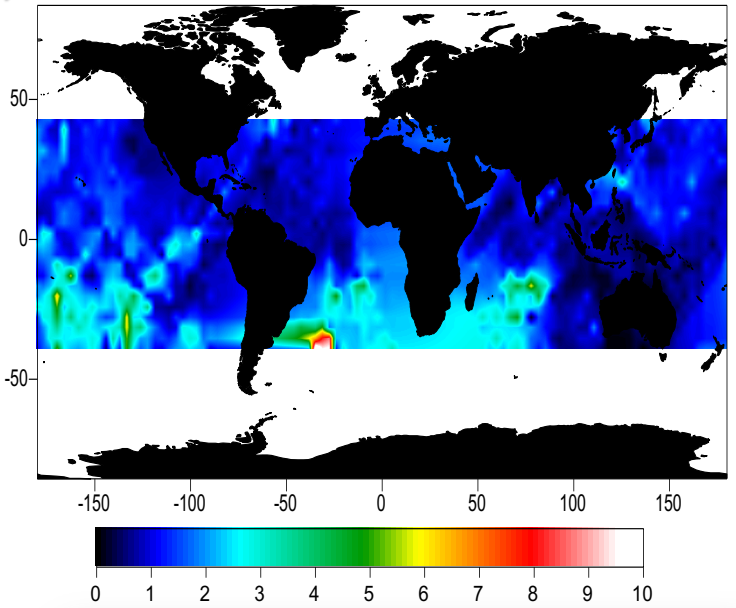


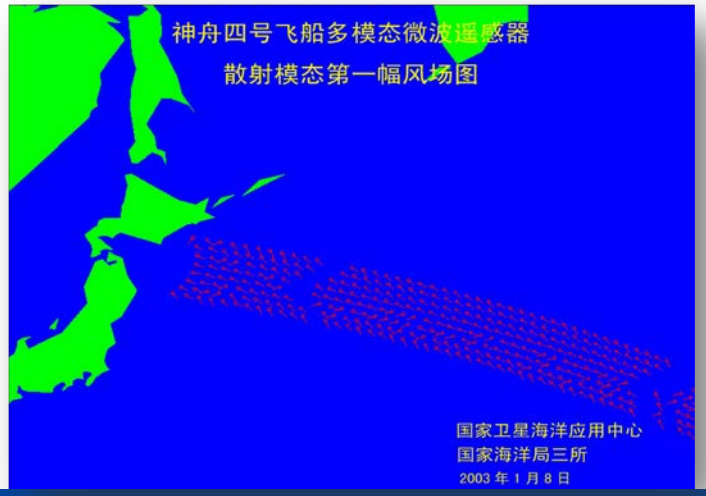
23.7GHz-V Channel



37GHz-V Channel





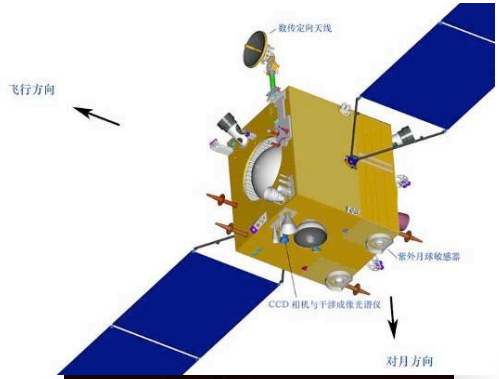


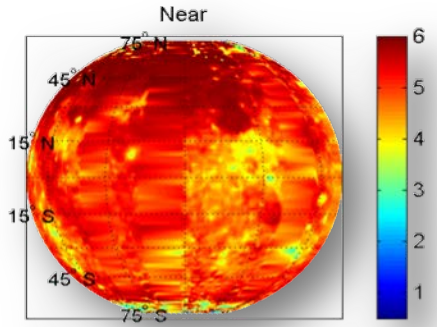
CEMWS: Microwave Sounders for Chang-E 1 & 2 Lunar Satellites（2007，2010）

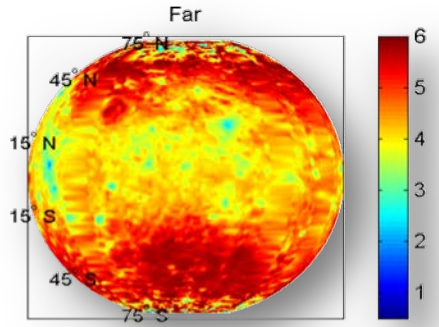
Lunar surface regolith sounding by penetration difference (3.0，7.8，19.35，37GHz)

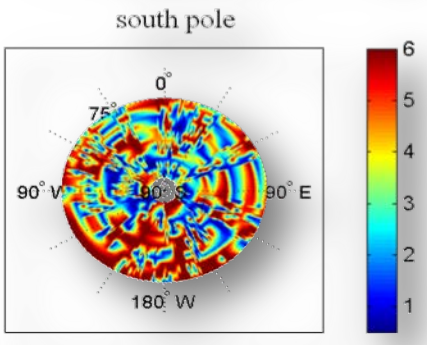
Microwave Moon (MicM):1st global lunar microwave mapping from lunar orbiter; 1st microwave BT mapping of remote side

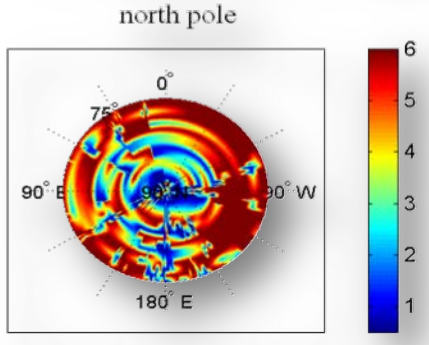
Significant discoveries for polar regions





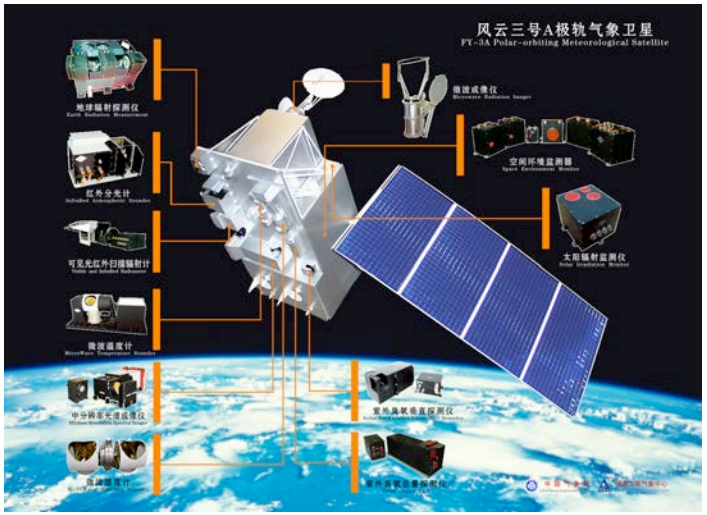




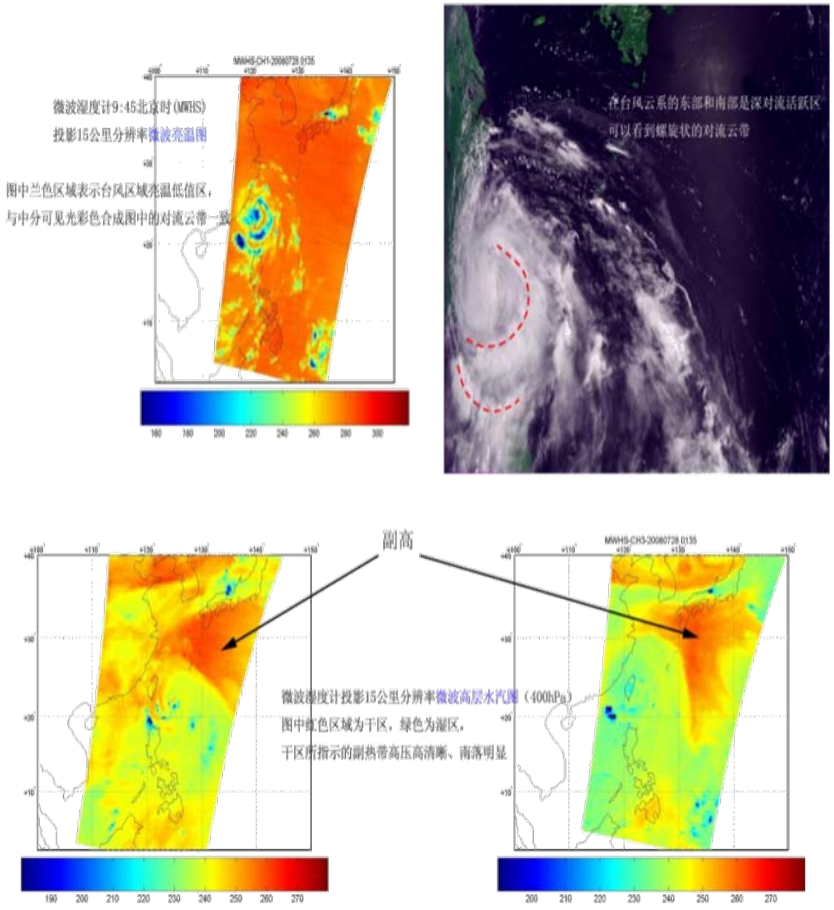


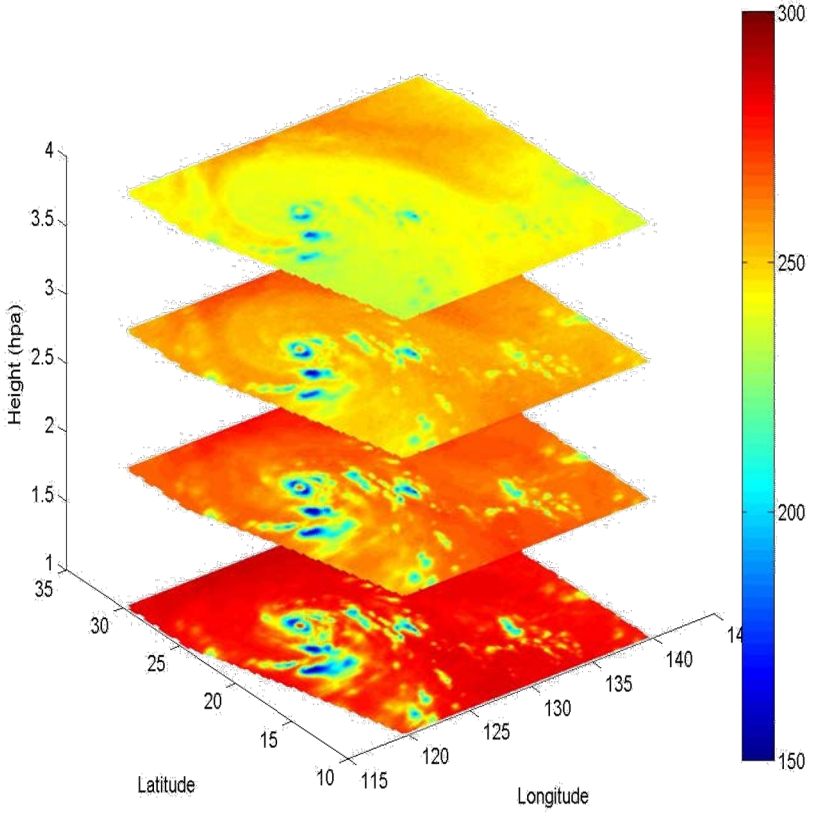
MWHS: Microwave Humidity Sounders on FY-3 Meteorological Satellites（2008，2010，2013, 2016, 2021）

FY-3A & B: 150GHz (H&V-pol),183GHz (3-channels)
FY-3C~：90GHz,118GHz,150GHz,183GHz (15-channels)
1st short MMW space applications in China
1st 118GHz down-looking radiometers in space internationally
Improved vertical resolution and capability for upper troposphere
Data integrated into ECMWF operational system from September 24, 2014



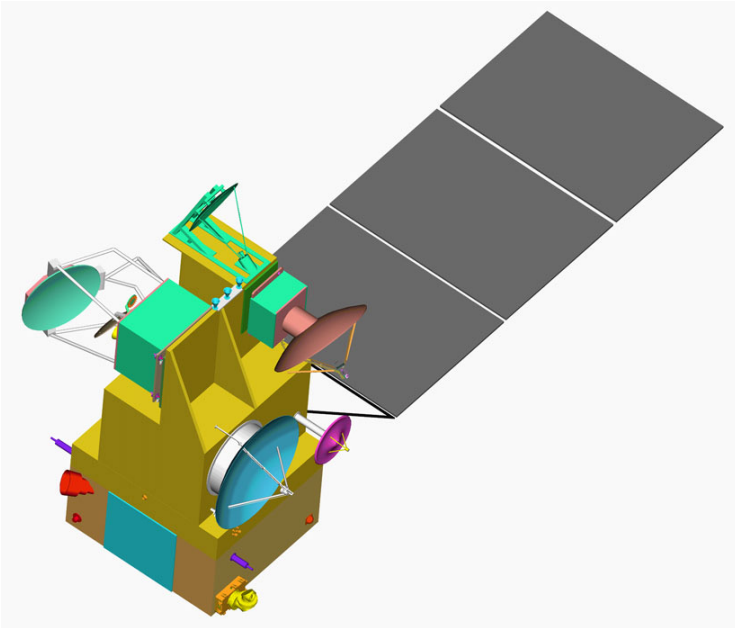
1st Typhoon vapor vertical structure by FY-3A MWHS (Funghuang, July 2008, 15km resolution)





HY-2 Oceanic satellite

DFRA: dual frequency radar altimeter：Ku (13.58GHz) & C (5.25GHz)
ACMR: atmospheric correction microwave radiometer: 18.7，23.8，37GHz
SCAT: radar scatterometer: Ku-band (RF switch network & receiver)
Instrument performance better than Jason-1/2, data quality equivalent to Jason-1/2 and Envisat



Payloads/Instruments

- DFRA: Dual-frequency (Ku, C) radar altimeter and a 3-channel calibration radiometer;
- SCAT: Scanning radar scatterometer (Ku-band, 13.256GHz);
- MWRI: Multiple-channel microwave imager (6.6-37GHz)
- ACMR: Tri-frequency nadir looking microwave radiometer (19.35/23.8/37GHz)

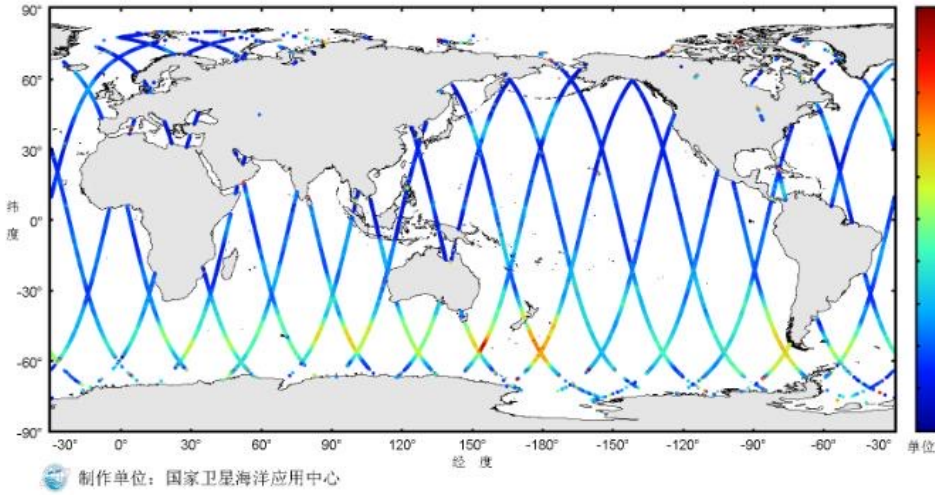
Payloads/Instruments

- DFRA: Dual-frequency (Ku, C) radar altimeter and a 3-channel calibration radiometer;
- SCAT: Scanning radar scatterometer (Ku-band, 13.256GHz);
- ACMR: Tri-frequency nadir looking microwave radiometer (19.35/23.8/37GHz)

HY-2A products (1 orbit)

海洋二号卫星雷达高度计有效波高

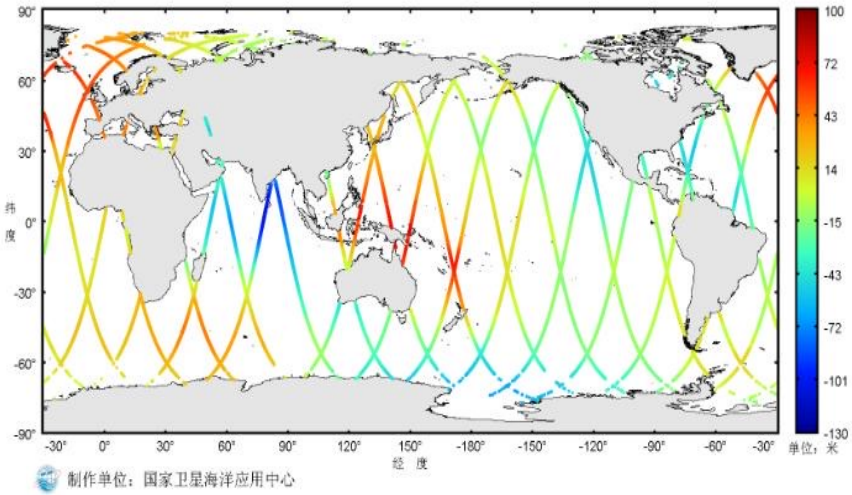
(2015年06月28日23时19分—2015年06月29日23时37分)



制作单位：国家卫星海洋应用中心

海洋二号卫星雷达高度计海面高度

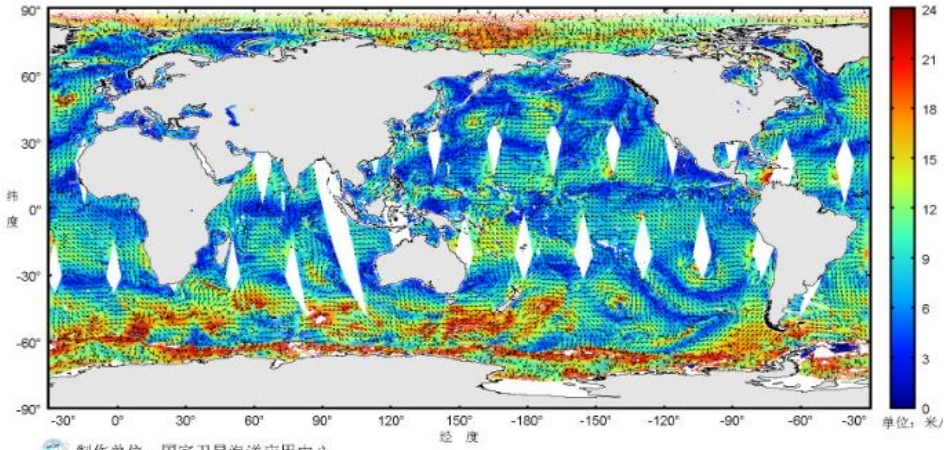
(2015年06月27日23时49分—2015年06月28日23时09分)



制作单位：国家卫星海洋应用中心

海洋二号卫星微波散射计海面风场

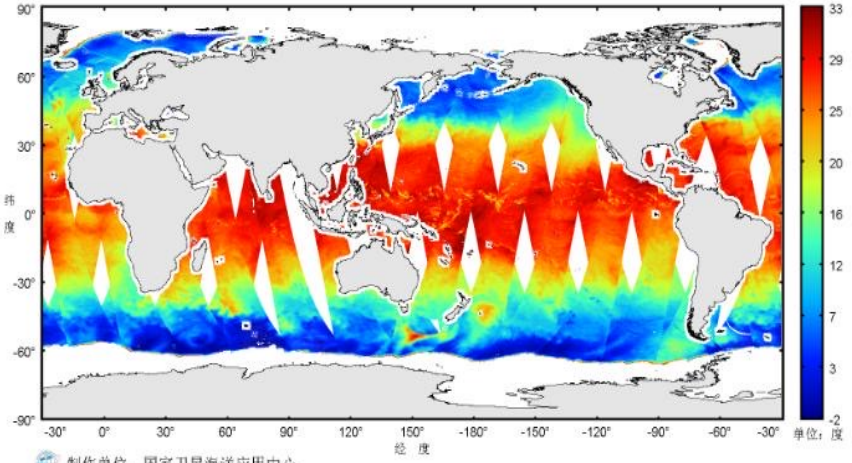
(2015年06月29日00时12分—2015年06月29日22时20分)



制作单位：国家卫星海洋应用中心

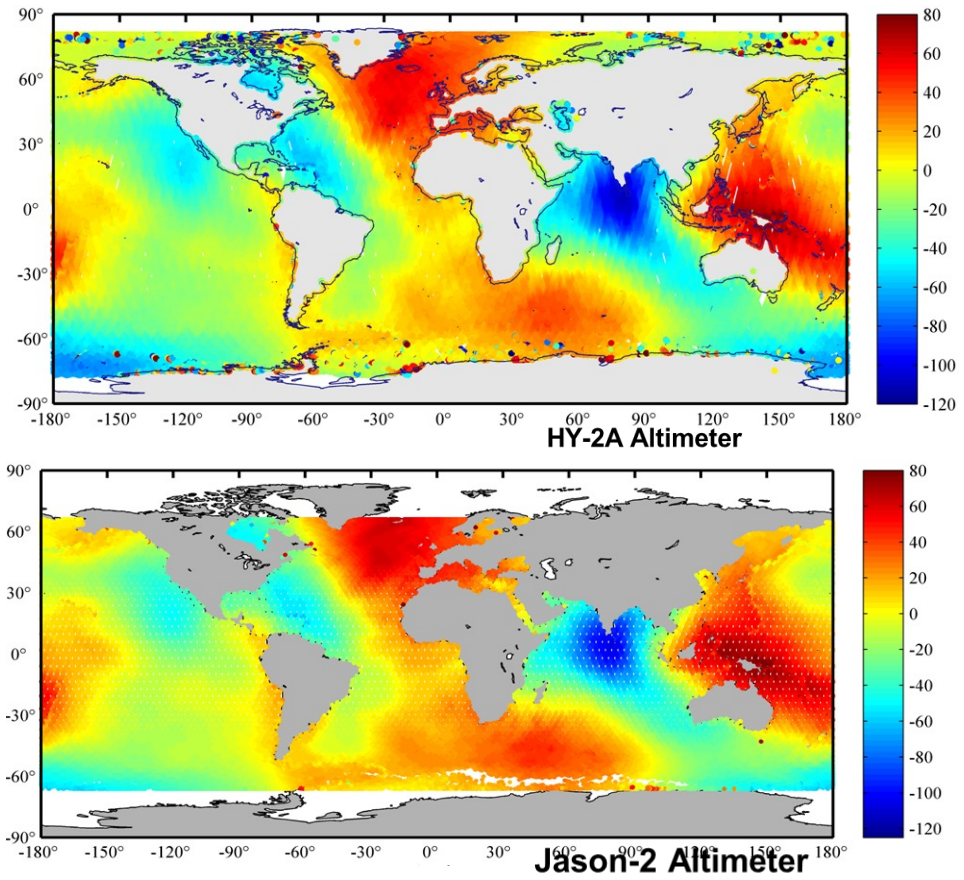
海洋二号卫星扫描微波辐射计原始分辨率海面温度

(2015年06月29日00时08分—2015年06月29日22时20分)



制作单位：国家卫星海洋应用中心

HY-2A SSL assessment



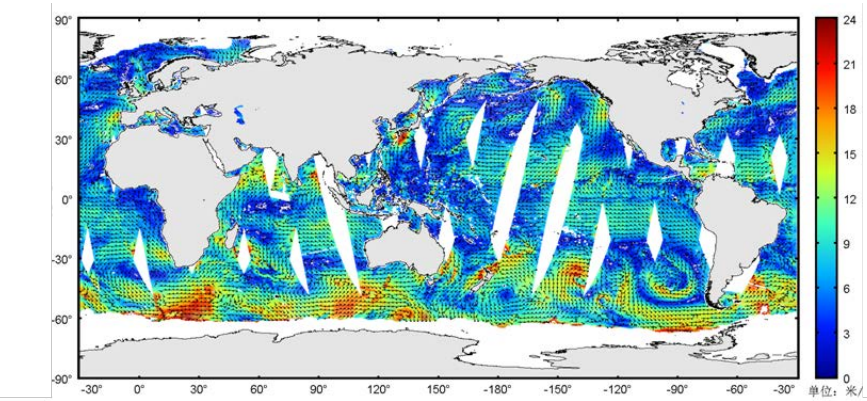
The Sea Surface Height(SSH) distribution retrieve from altimeter between HY-2A and JASON-2 satellite（Unit: m）

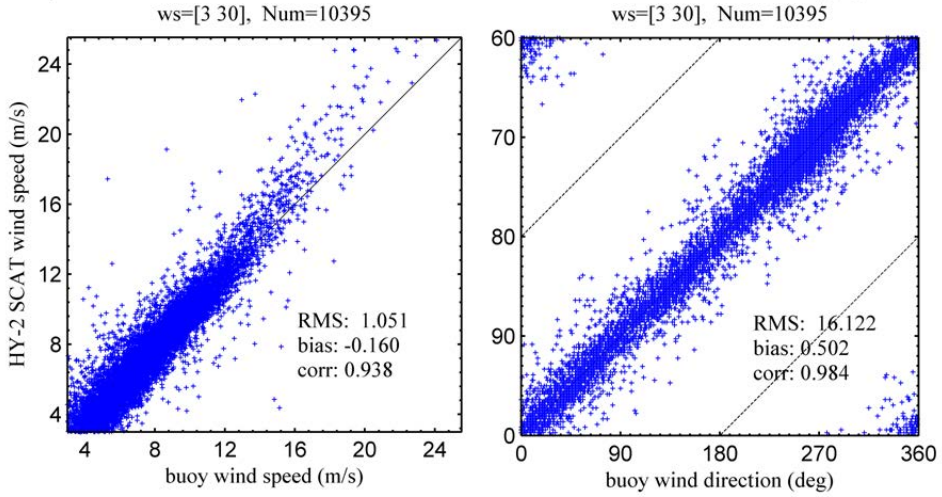
CNES assessment:

The SSH products of HY-2A have been successfully ingested in the **DUACS** test systems and multi-altimeter maps for a few months now. The **quality is stable and very good**.

The HY-2A results on IGDRs products are very good and close to the one from JASON-2.

HY-2A OSVW assessment



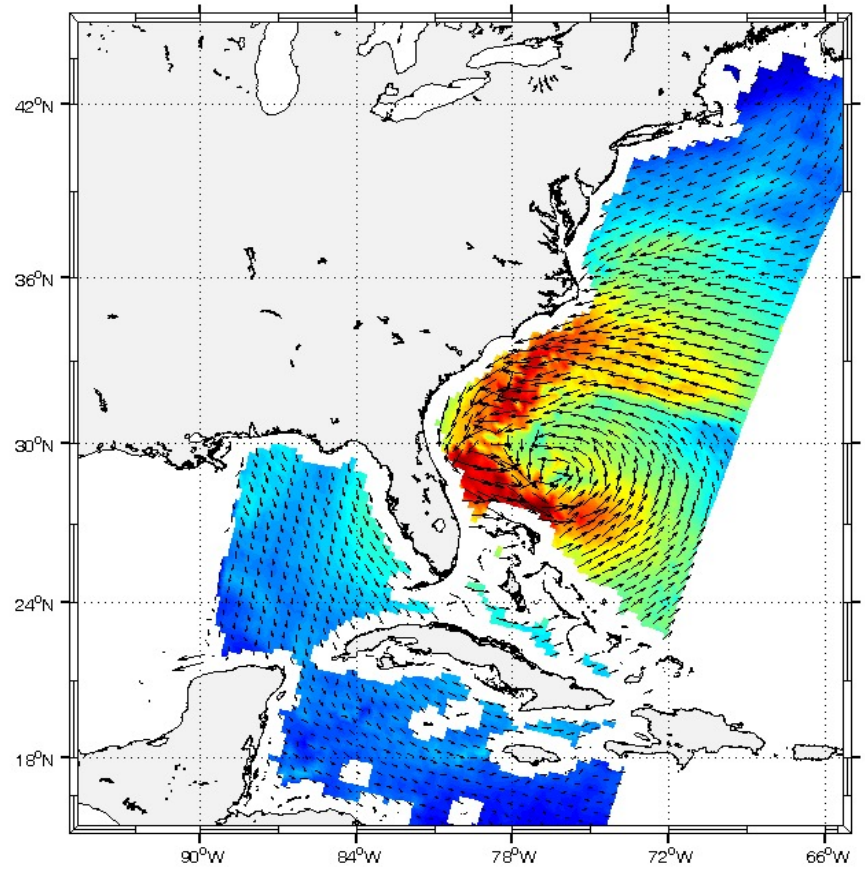


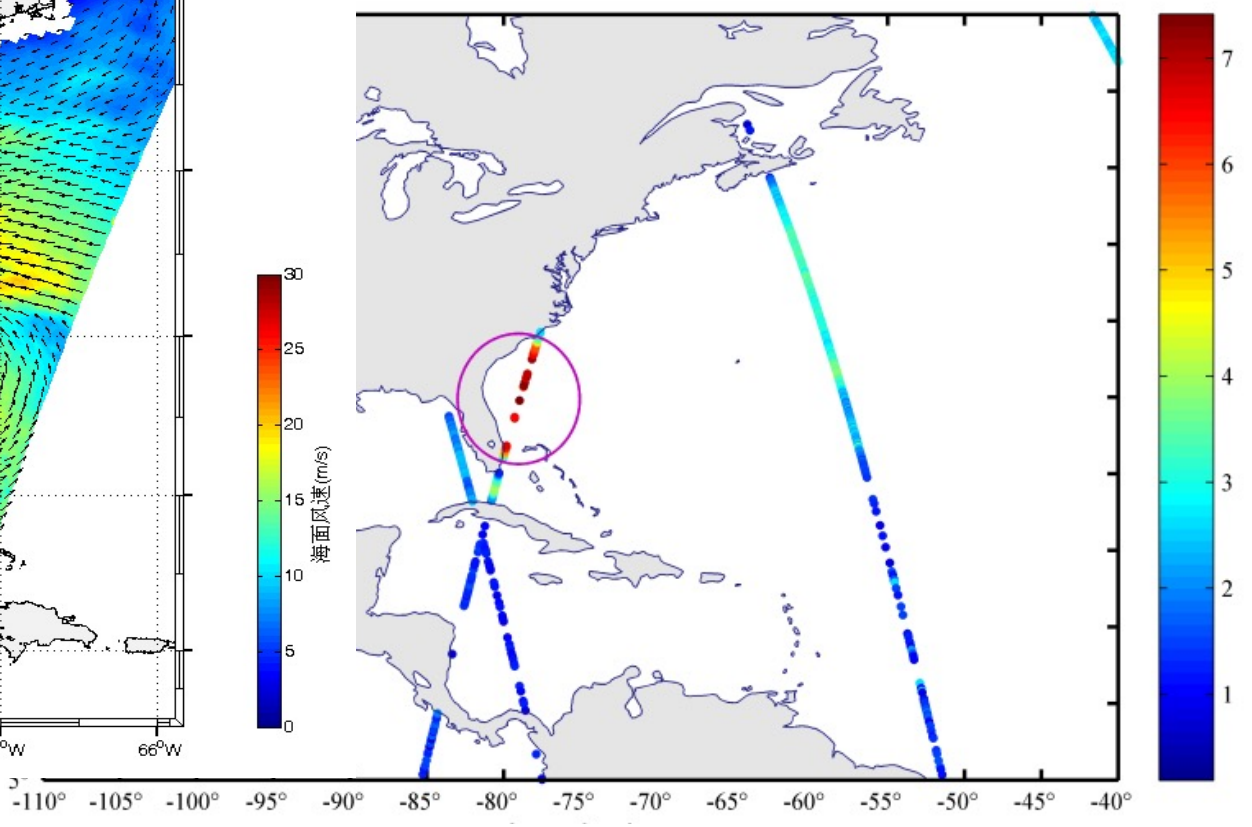
The NDBC buoys observations are used to validate HY2A-SCAT wind vectors. The RMS error of wind speed and wind direction are 1.051 m/s and 16.122° respectively for the whole year of 2012.

For Wind Production Application:

1. **ECMWF** is running a HY-2 assimilation experiment, **the results is good quality and hope receive HY-2A NRT data;**
2. **KNMI** has run OSEs with HY-2A test. The HY-2A wind assess its impact for the meso-scale model;
3. **Meteo France, UK Met Office and Deutsche Wetter Dienst (Germany)** to be contribute to the qualification and the validation of HY-2A wind measurements for assimilation purpose. **There are more related interests on HY-2A data assimilation on the world.**

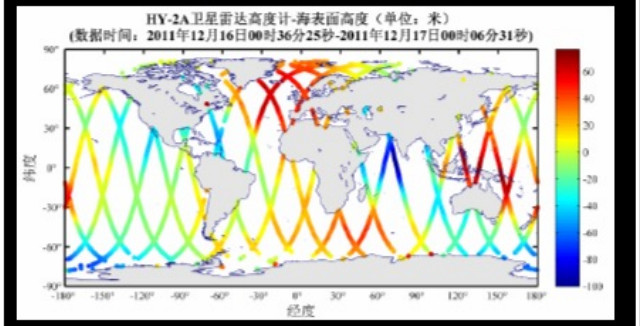
Oct 27, 2012, simultaneous observation of Hurricane Sandy by HY-2A SCAT for wind and ALT for SWH



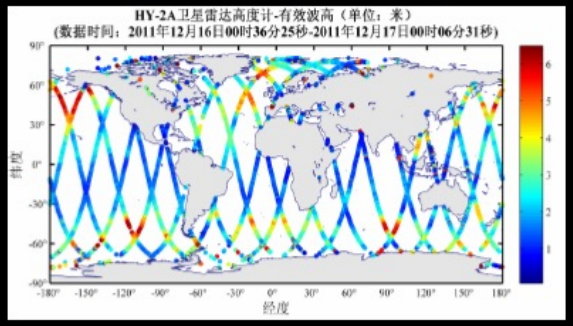


SSL, SWH measurement

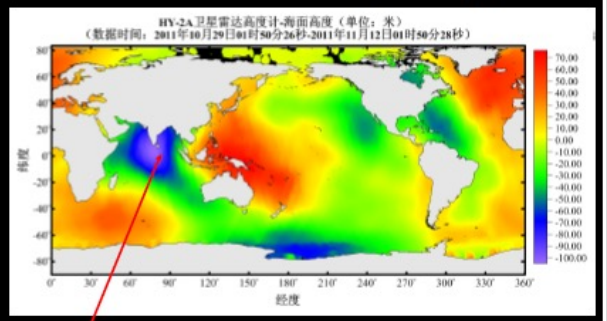
Sea Surface Level



Significant Wave Height

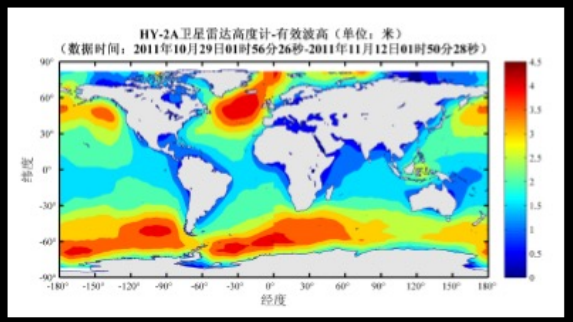


Sea Surface Level (14 Days)

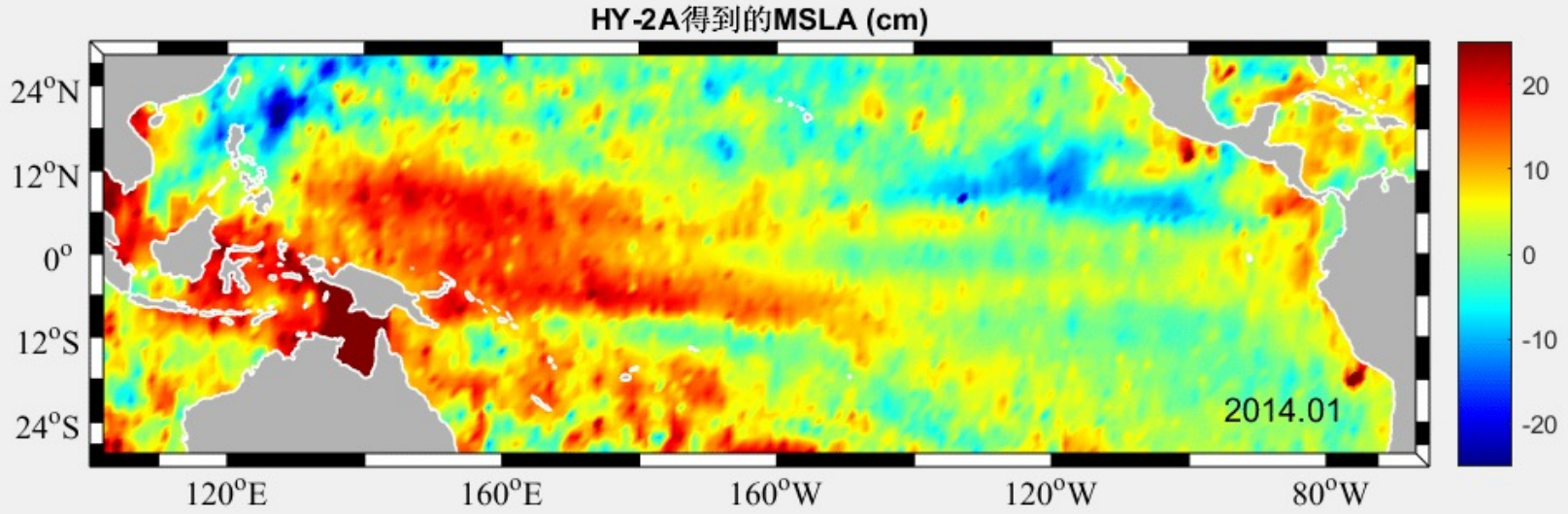


Mid-Indian Basin (-100m)

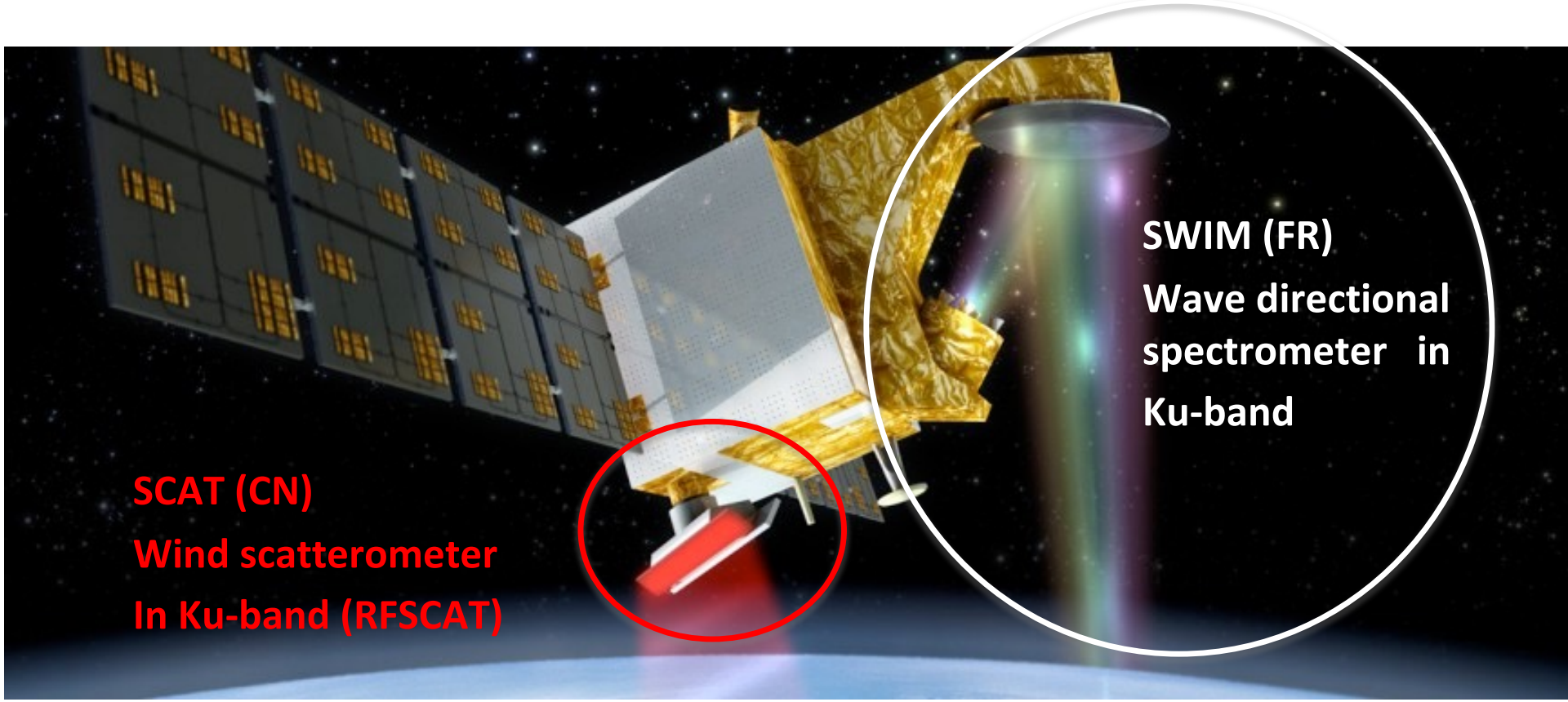
Significant Wave Height (14 Days)



HY-2A Altimeter: Monitoring of 2015-2016 El Niño



CFOSAT (China-France Oceanography Satellite)



Global ocean surface wind vector and directional wave spectrum

Observation requirements

▶SWIM measurements and requirements

Directional wave spectra at a scale of 70 x 90 km

Wavelength range 70m-500m

10% accuracy on wavelength, 15° accuracy on direction

Significant wave height and wind speed along-track

10% on SWH (or 50 cm whichever is better)

rms <2 m/s on wind speed

Normalized radar cross-section from 0° to 10°

Absolute accuracy of ±1 dB

Relative accuracy between incidences ± 0.1 dB

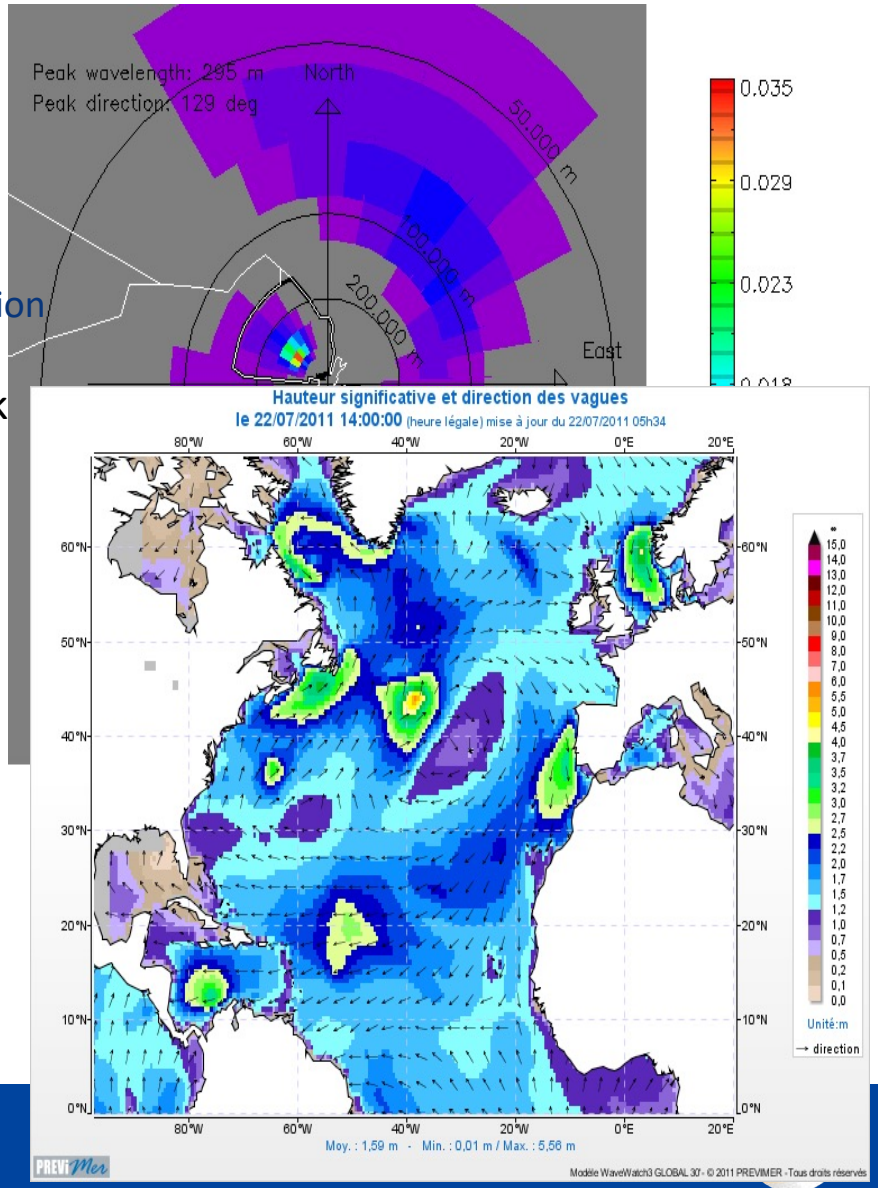
▶SCAT measurements and requirements

Wind vector

50 km resolution cell (25 km experimental)

accuracy: 2m/s rms @5~24m/s, 20° wind direction

Backscattering coefficient : ± 0,5dB



SWIM (France):

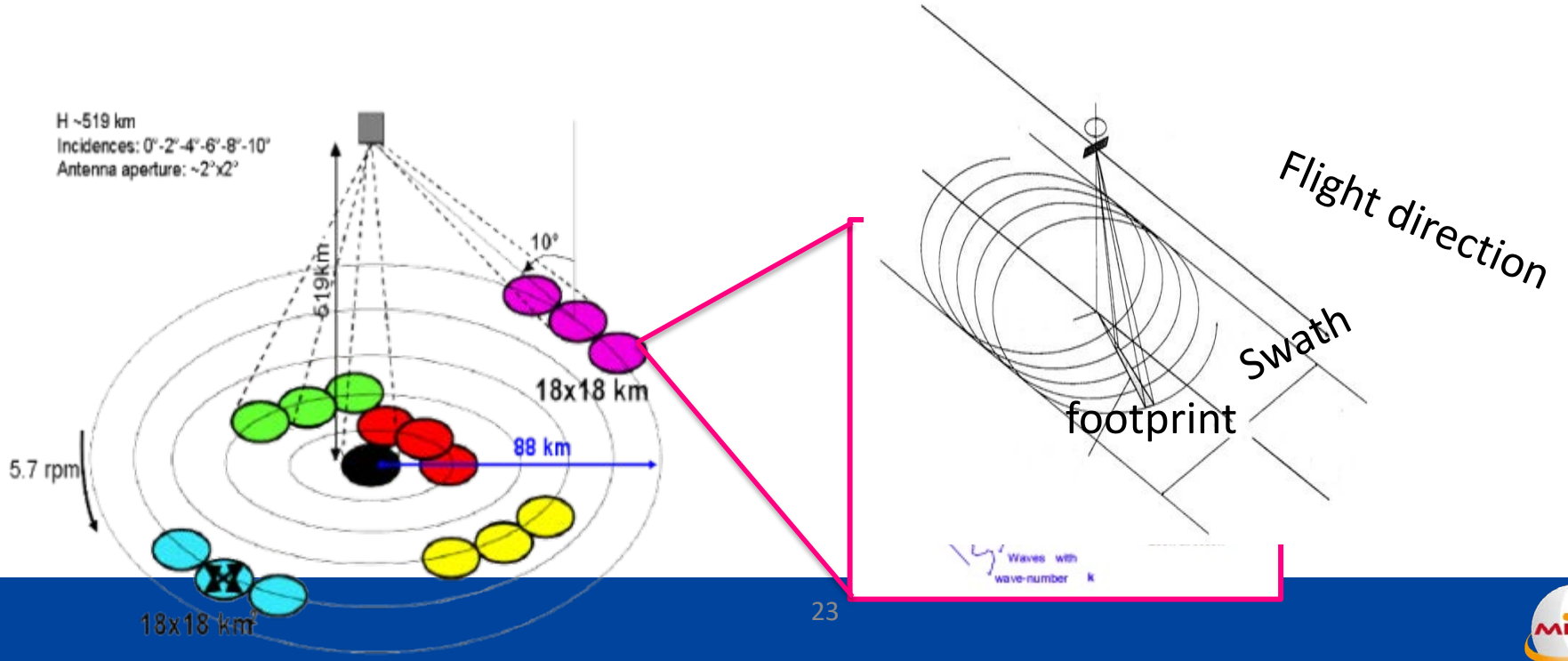
Wave scatterometer

- radar 13.6 GHz,
- single polarization (linear),
- low incidence angle multi-beams (0- 10°),
- scanning in azimuth (360°),
- high range resolution,
- real aperture (no SAR processing)

SCAT (China):

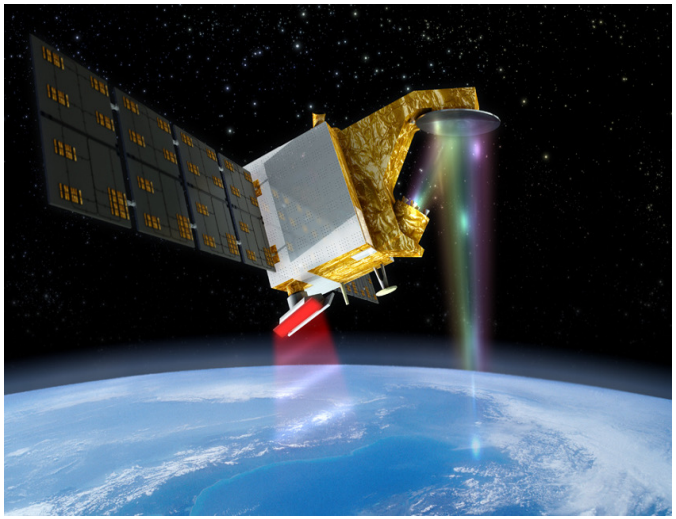
Wind scatterometer

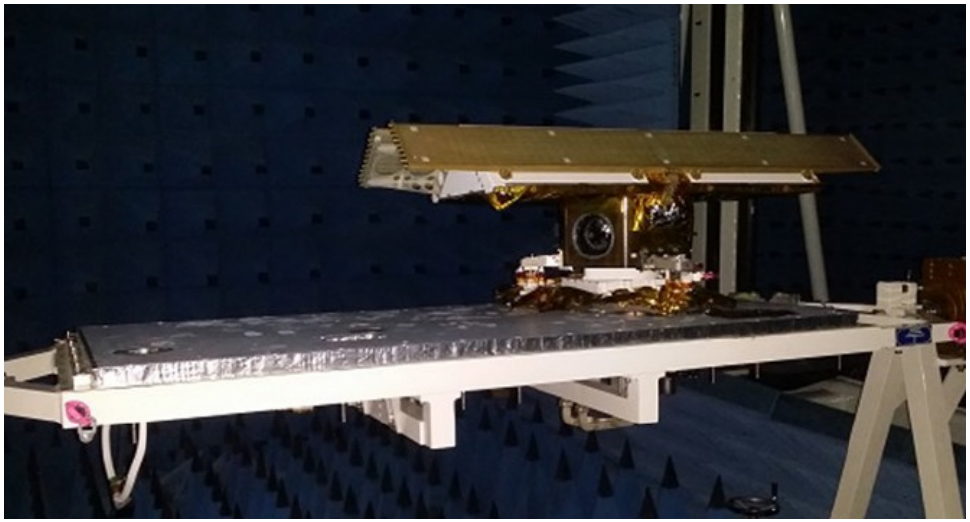
- radar 13.256 GHz,
- Dual polarisation (HH, VV),
- « fan beam » geometry,
- medium incidence angles (20-50°),
- scanning in azimuth (360°),



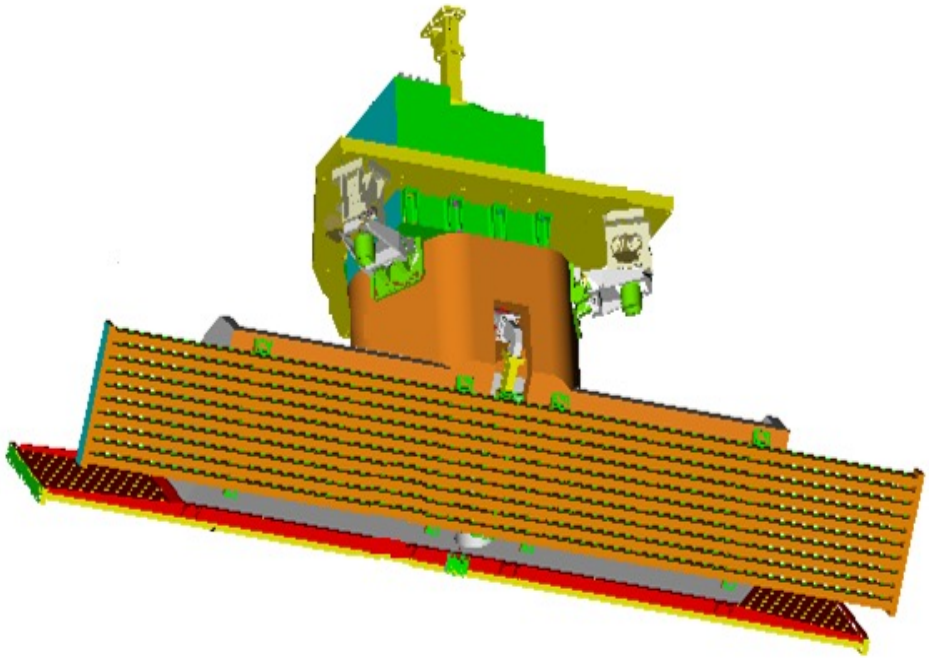
SCAT: a rotating fun-beam scatterometer for CFOSAT (2018, in development)

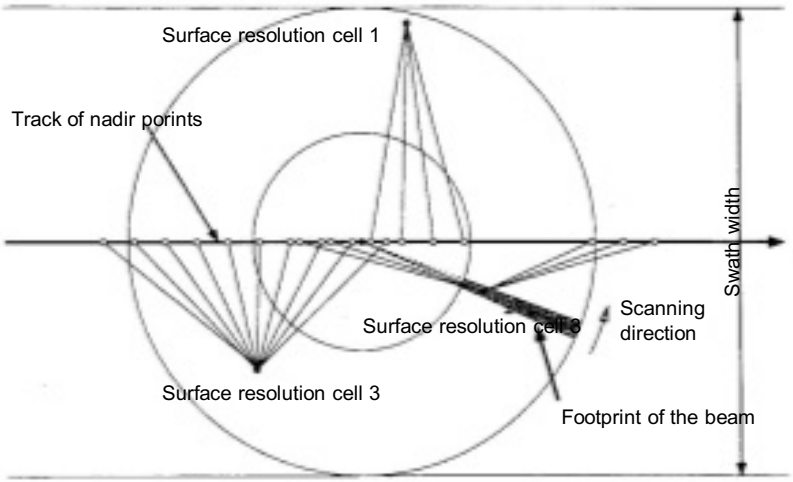
CFOSAT: China-France Oceanography Satelite
2 Payloads: SWIM (CNES/Thales), SCAT (CNSA/NSSC)
Global ocean surface wind vector and directional wave spectrum
SCAT: 1st RFSCAT (better wind retrieval by multiple looking-angles)

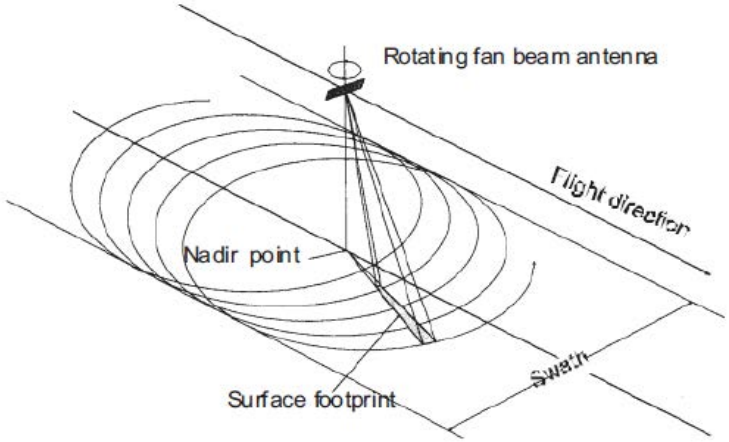




SCAT instrument

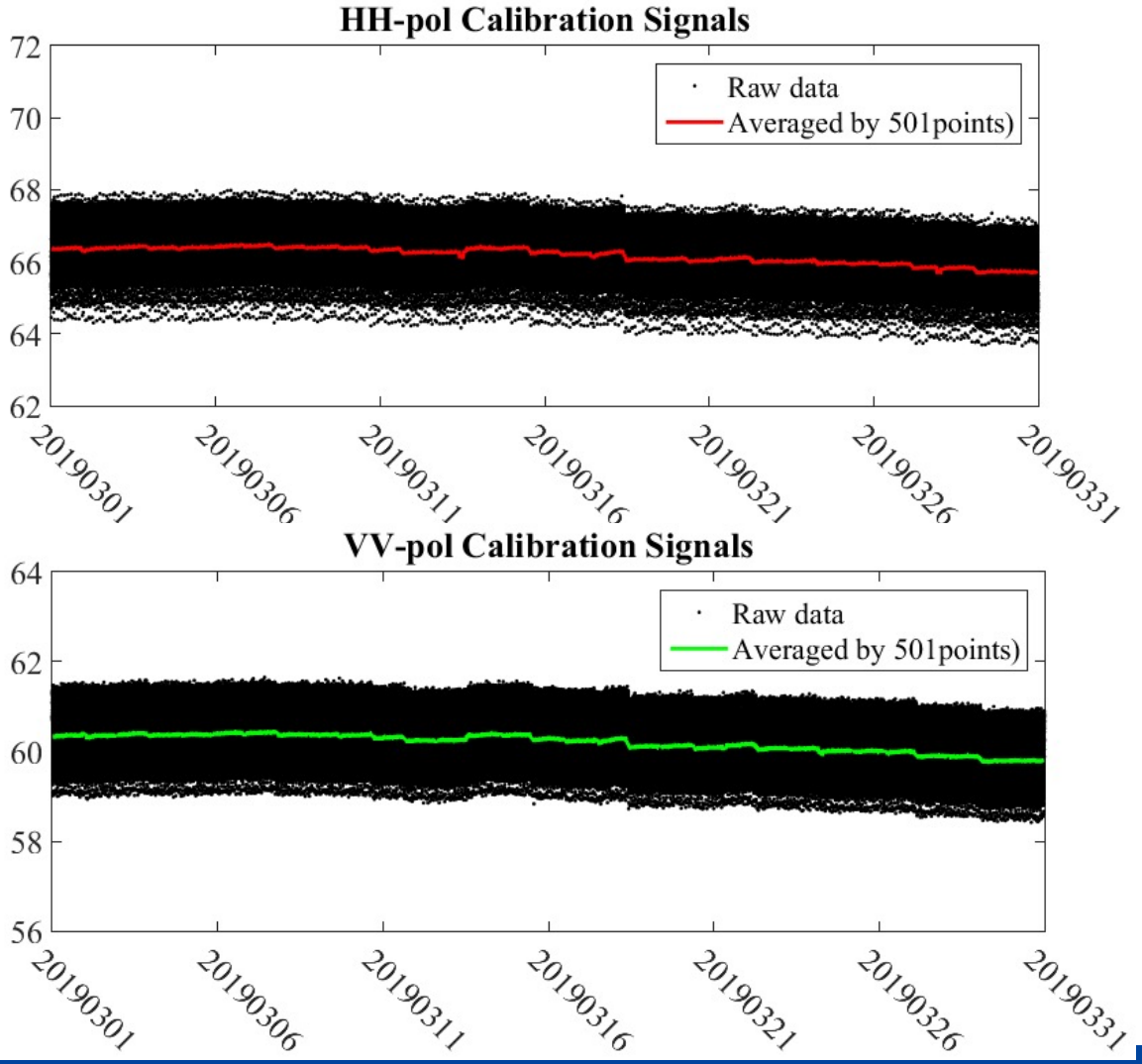






- On-board digital processing
- Fan-beam antenna with 26-46° incidence
- Rotating antenna at 3.4 rotations/min

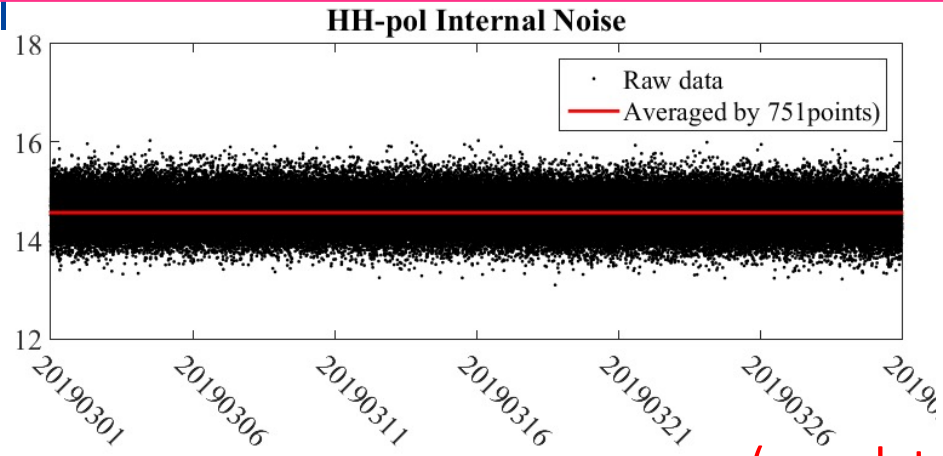
Calibration and Noise Signals

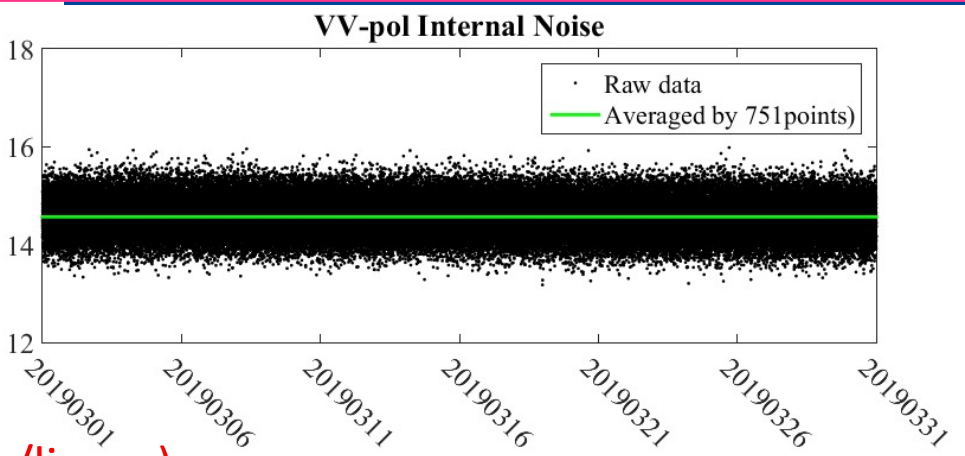


- Steady calibration signals show that both the transmitter and the receiver of the scatterometer work properly.
- The internal calibration signal change slightly with the environment temperature.

(raw data/linear)

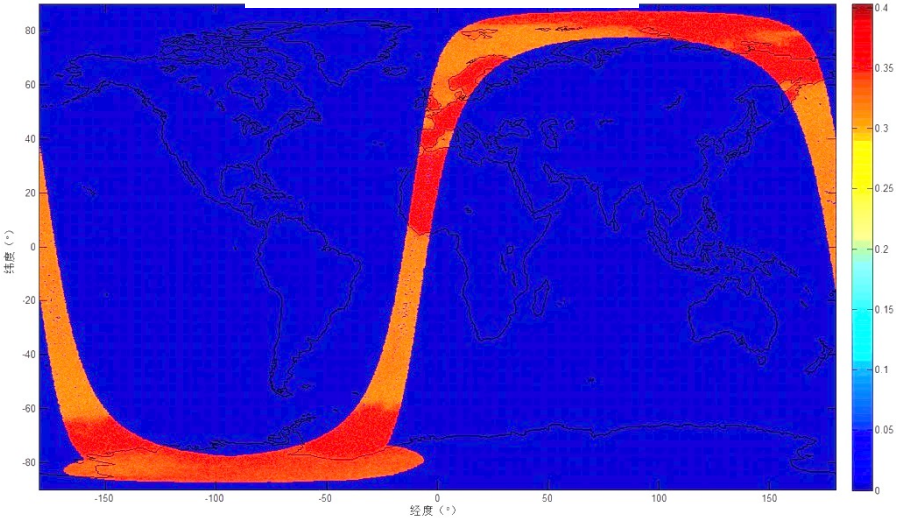
Calibration and Noise Signals



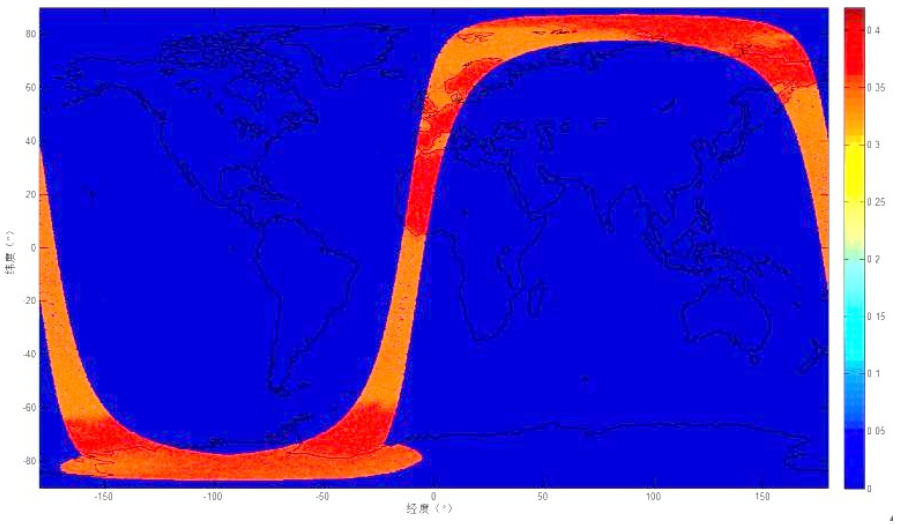


(raw data/linear)

HH-pol External Noise

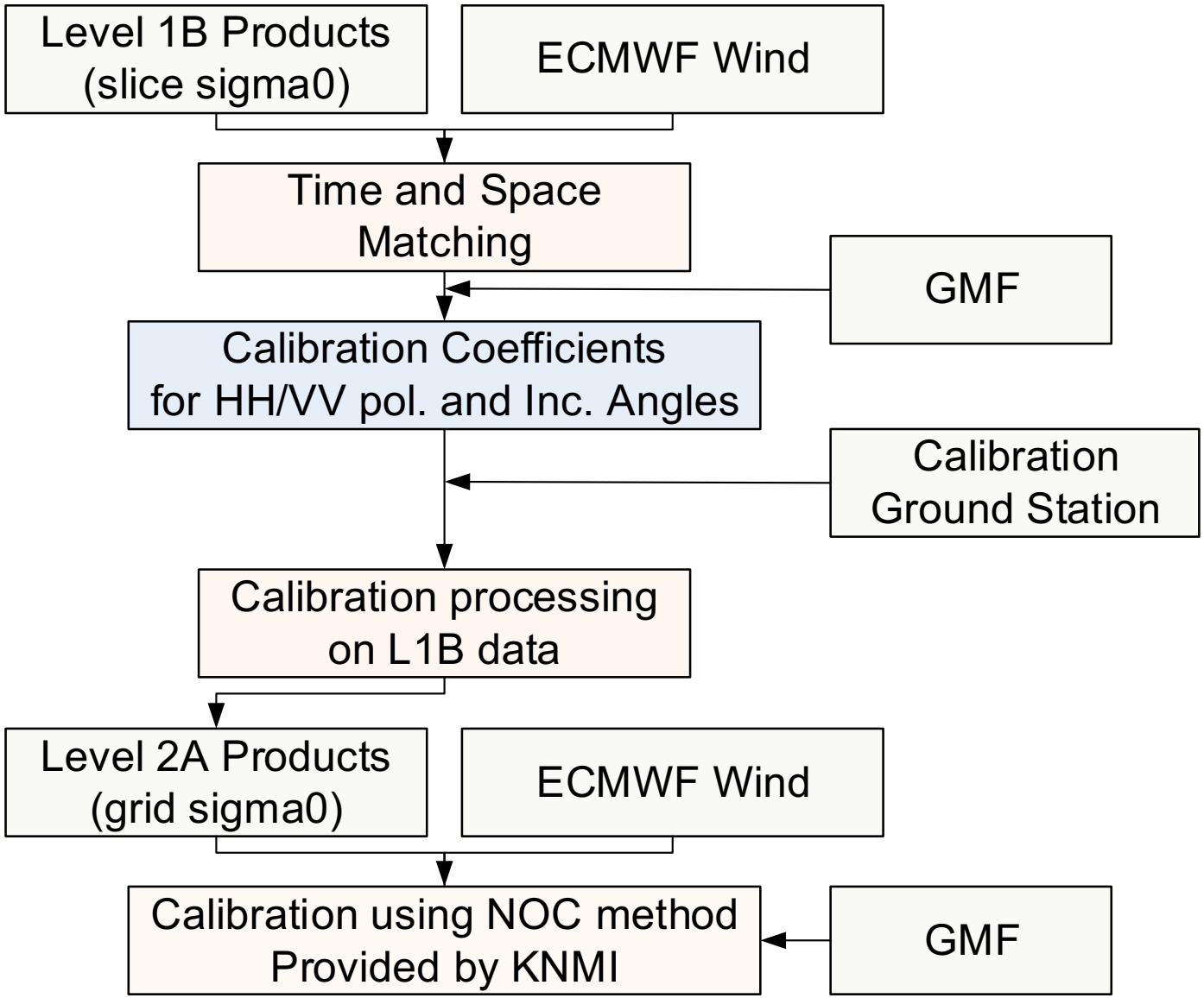


VV-pol External Noise



- The internal noise is stable, because the internal noise source is from a matched load inside the temperature-controlled cabinet of the satellite
- The external noise energy changes with the land-sea alternating and variation of surface emission

CFOSAT SCAT Calibration Flow



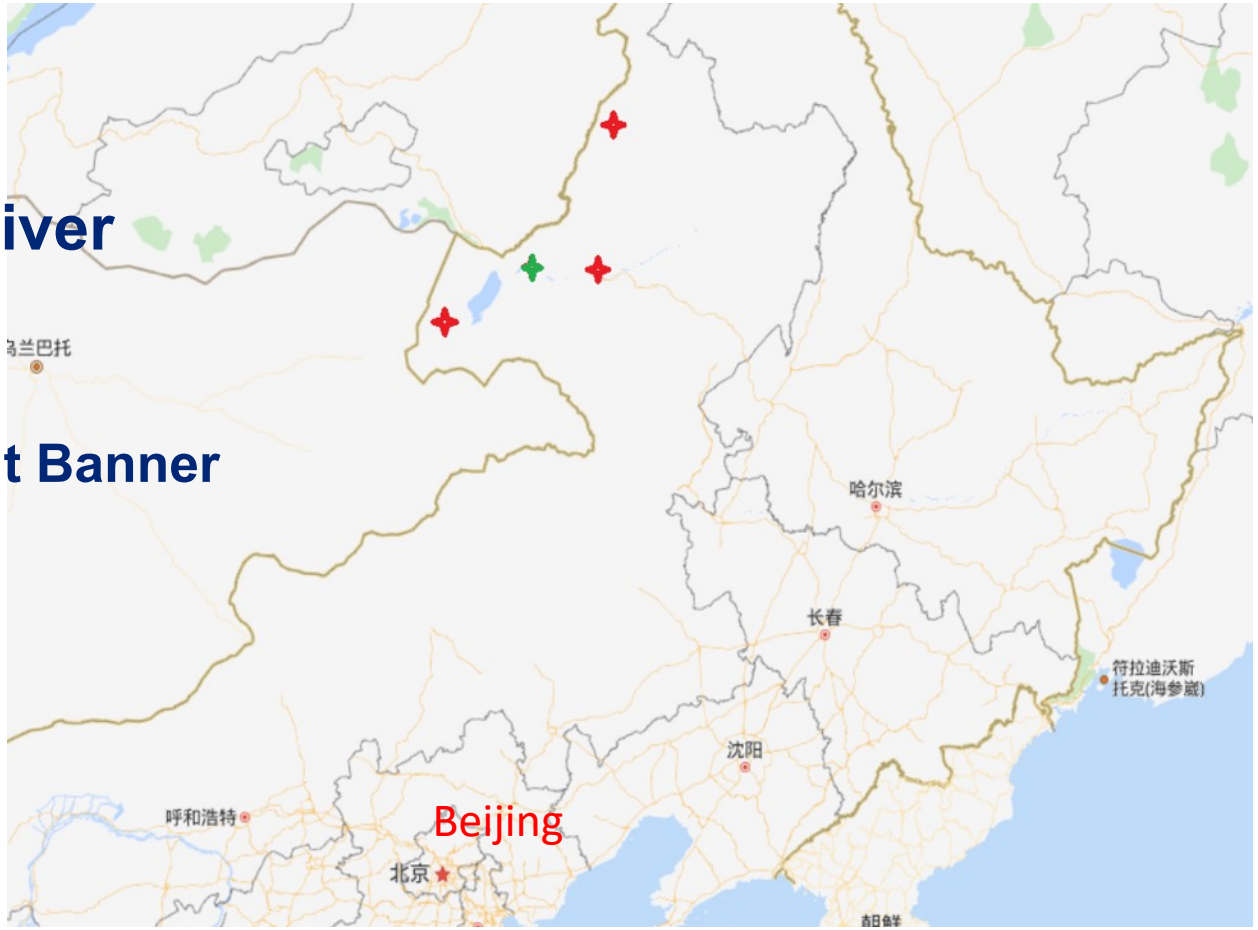
NOC: Numerical Ocean Calibration

CFOSAT SCAT Ground Station Calibration

- CFOSAT SCAT Ground Station Calibrations were carried out at Inner Mongolian from 6th June to 2nd July.
- 1 Transponder and 3 Passive receivers calibrate at the same time

CFOSAT SCAT Ground Station Calibration

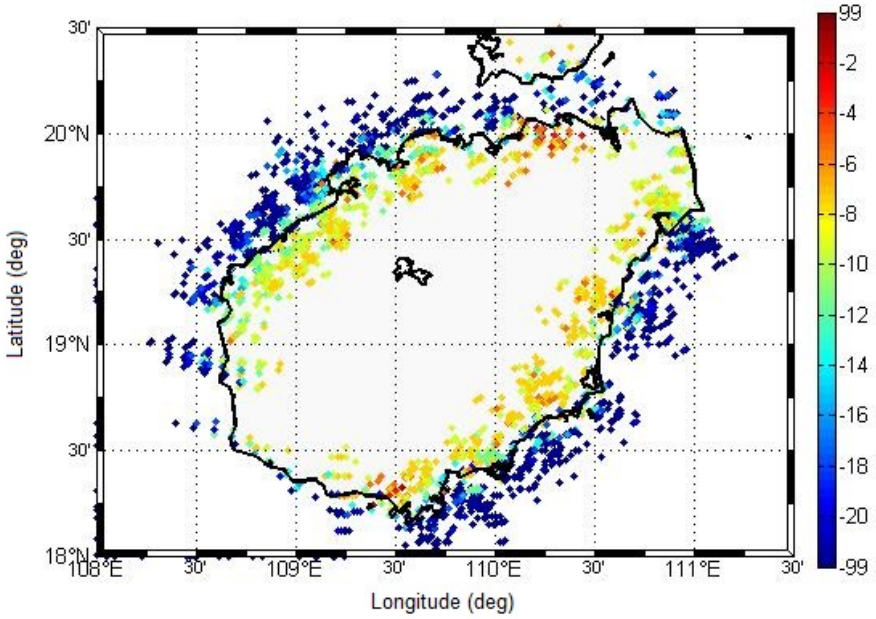
- 1 Transponder
  - Chagang
- 3 Passive Receiver
  - Hailaer
  - Erguna
  - Xin Barag Right Banner

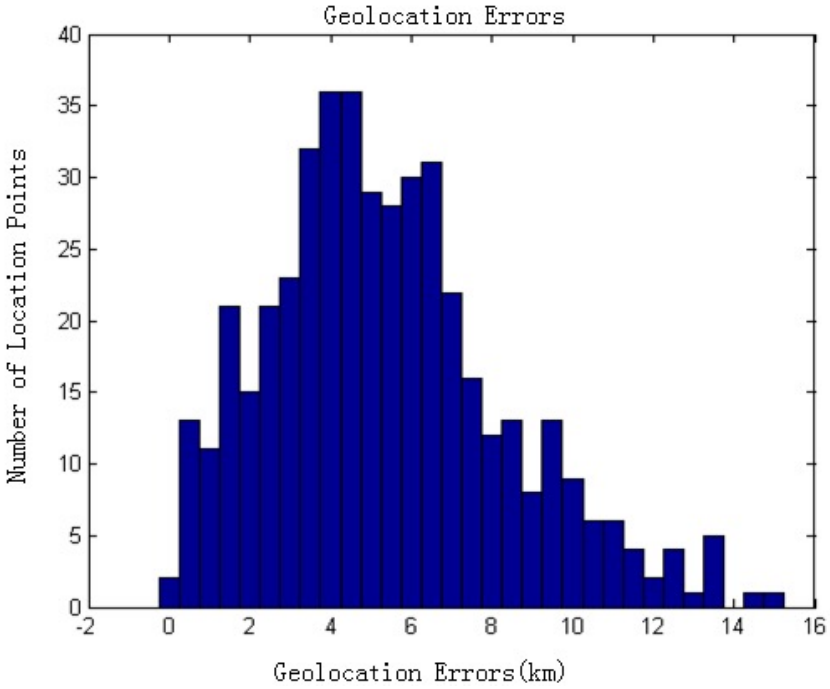


Transponder Location [49.259386,118.096787]deg

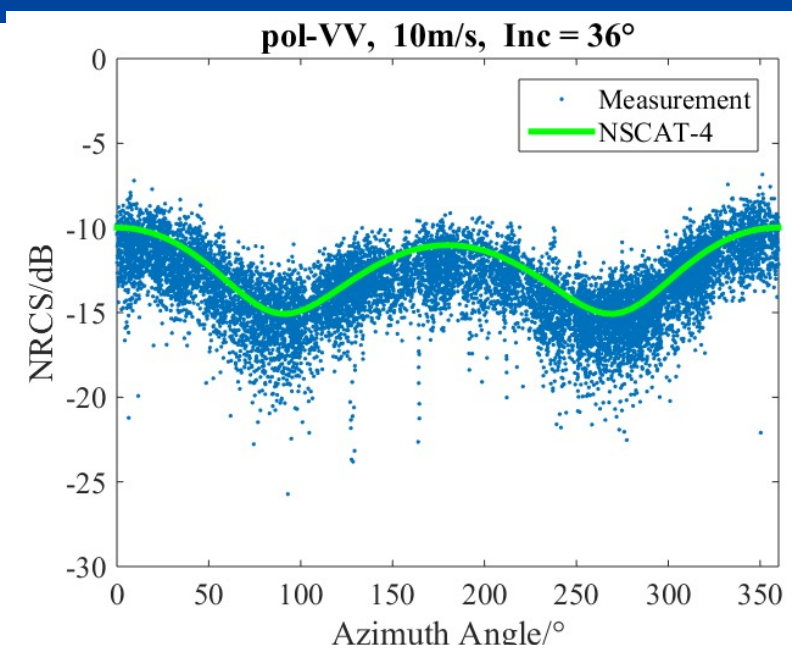
Geolocation Errors Evaluation

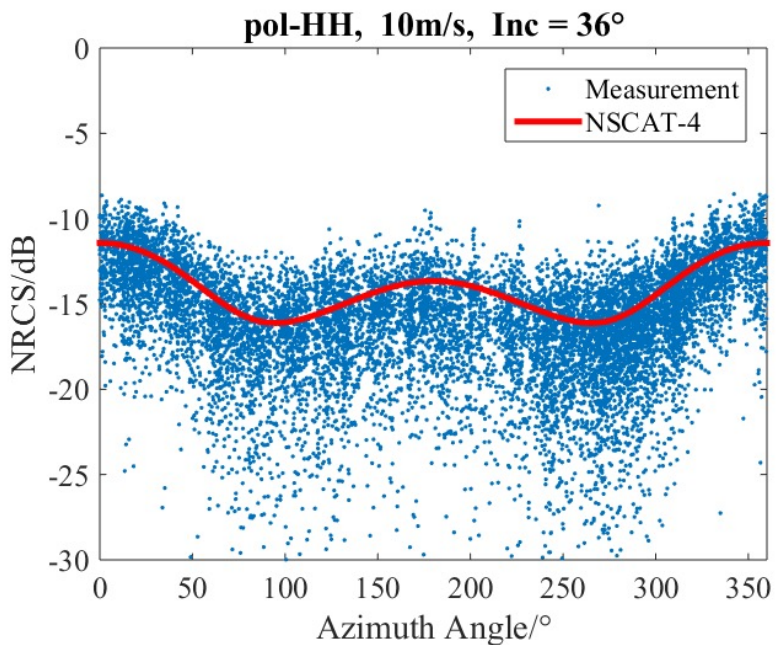
- Geolocation errors is about 6.48km，root mean square error is about 7.25km;

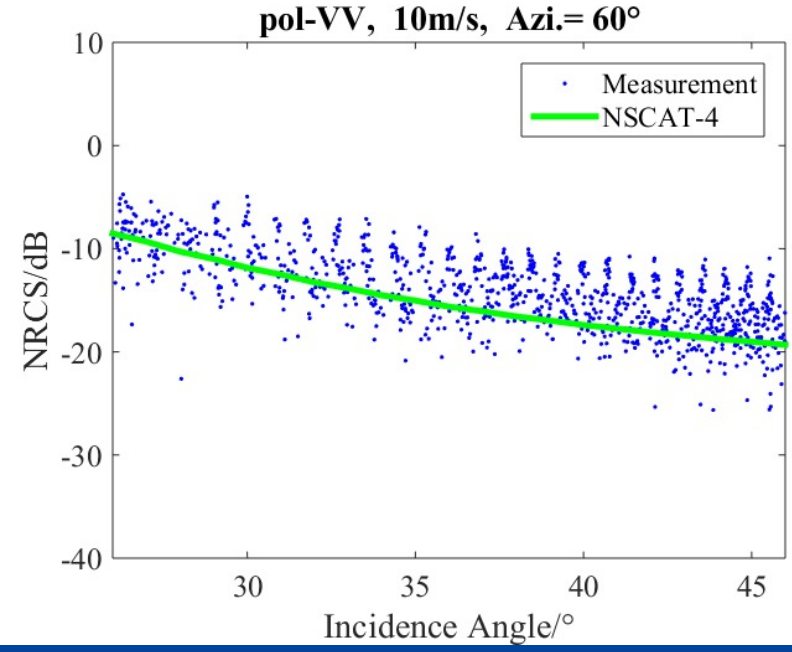


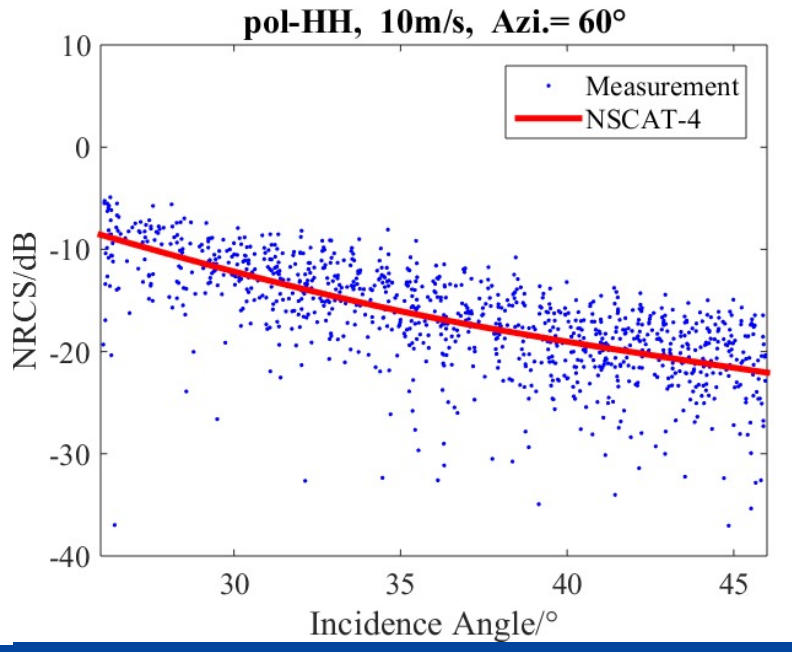


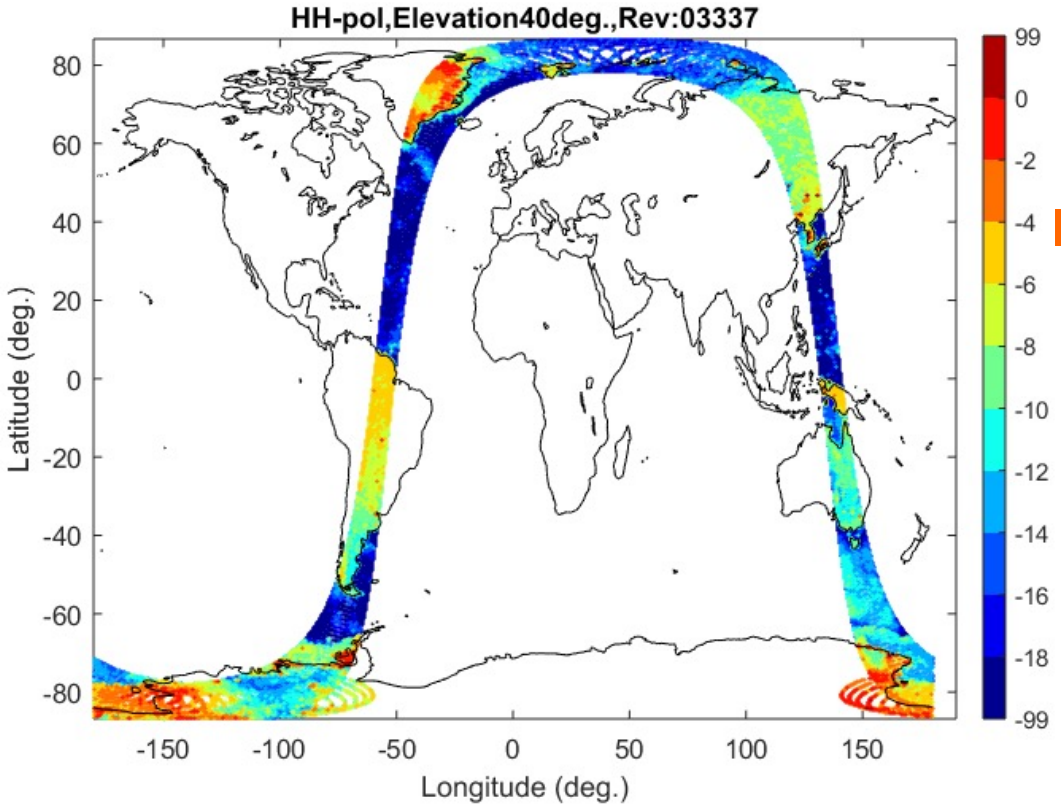
CFOSAT SCAT Sigma0



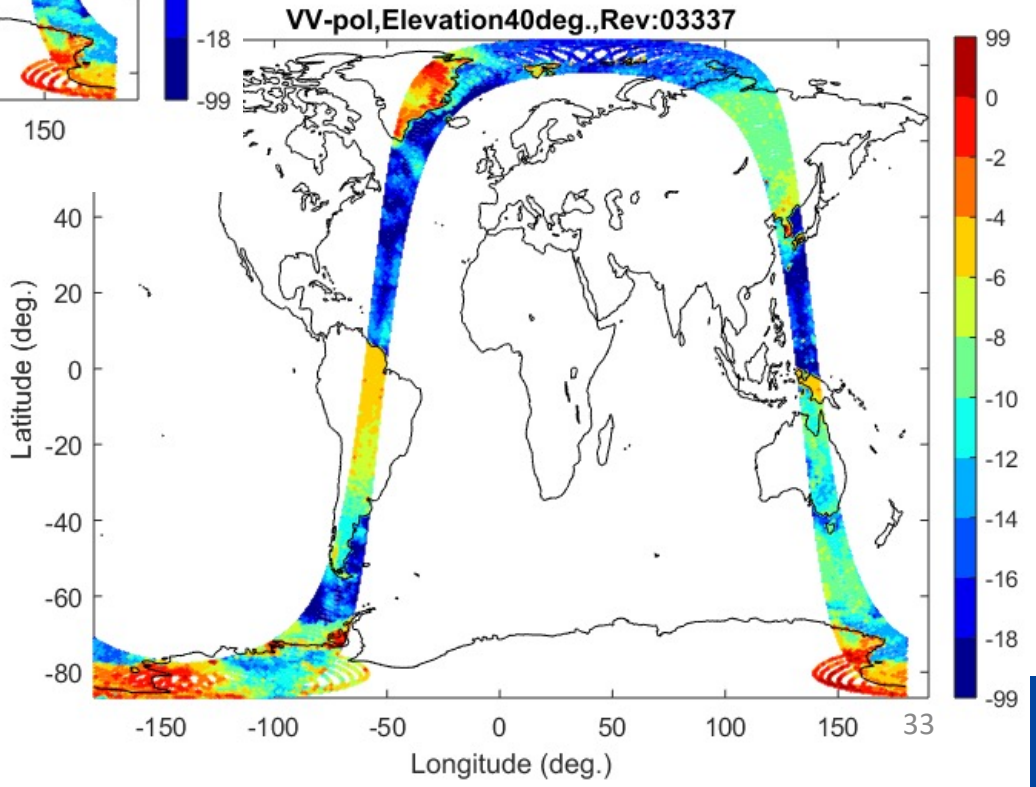






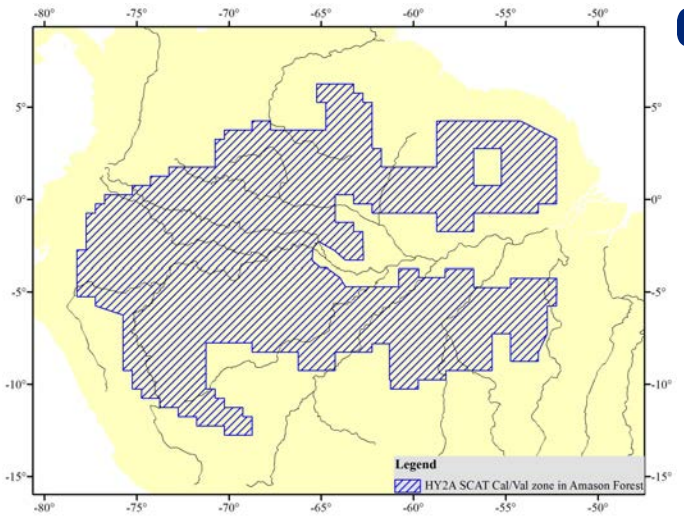


- **CFOSAT SCAT Sigma0 single revolution product**

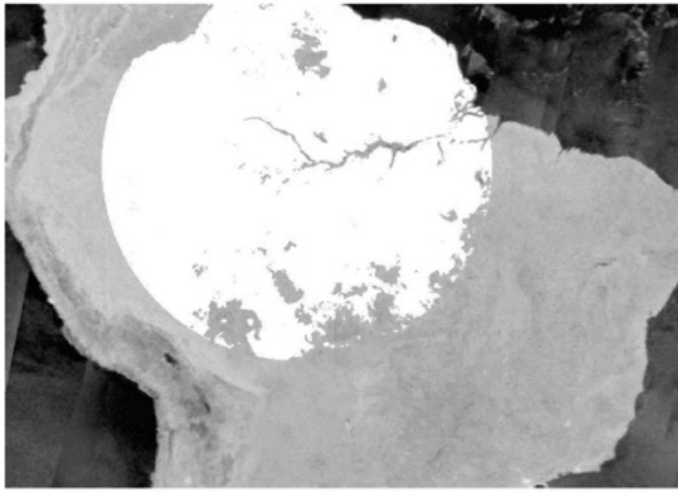


Amazon rainforest Sigma0 Validation

- **Measurement noise: by monitoring the width of the sigma0 histogram.**
- **Azimuth response of sigma0: by monitoring the sigma0 in azimuth angle.**
- **L 0: by of th**

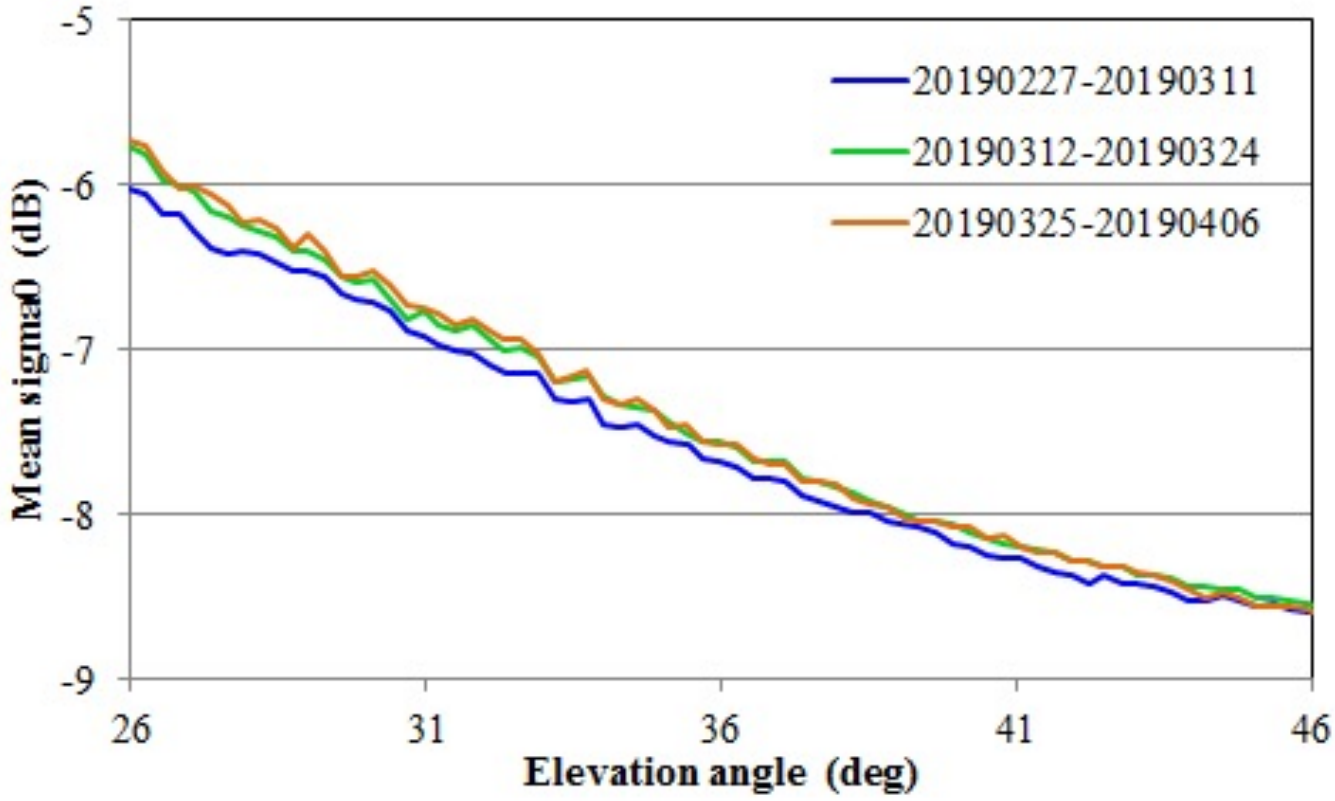


The selected zone for HY-2 and CFOSAT scatterometers

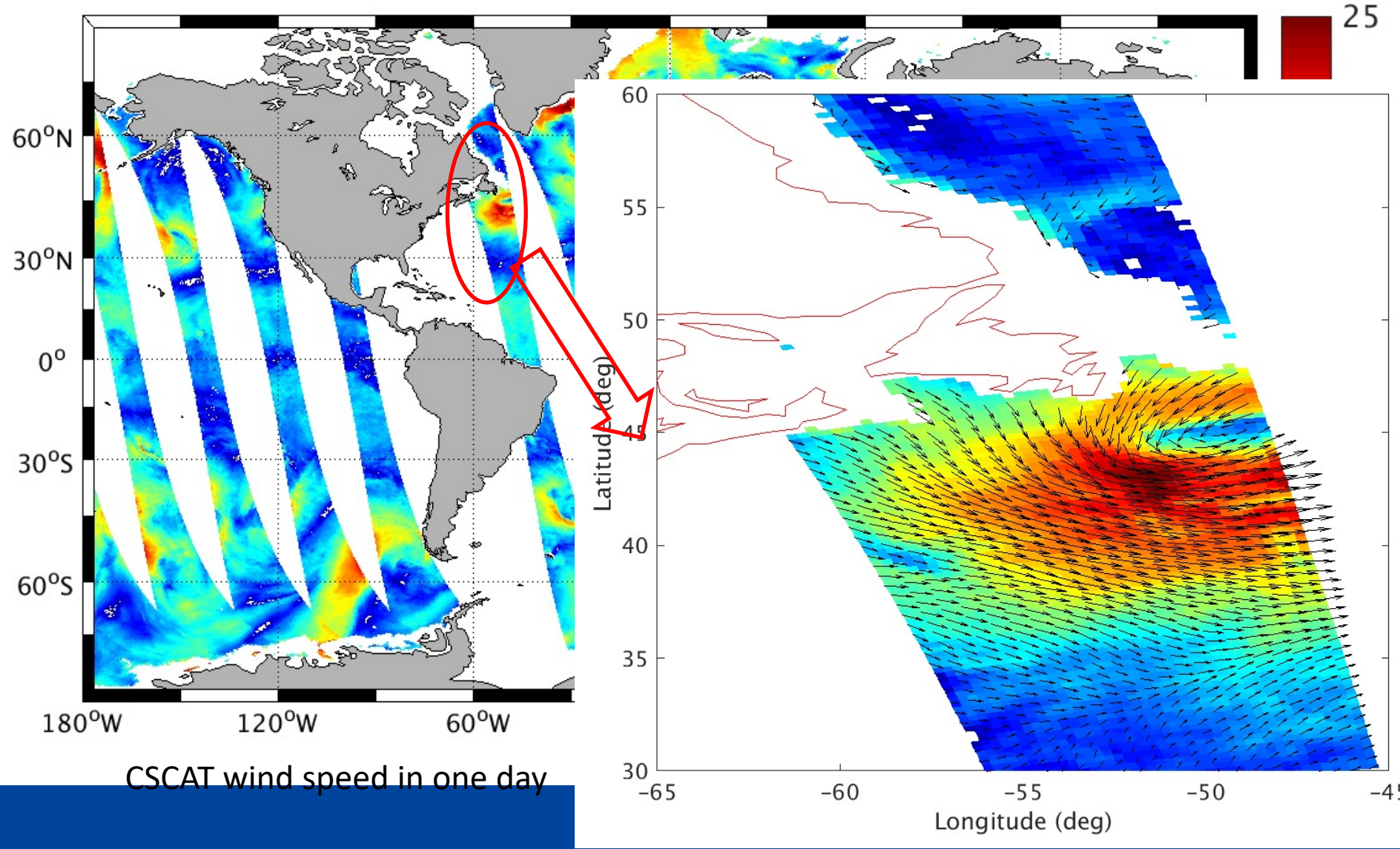


[Kunz and Long, 2005]

- **Long-term stability of sigma0**
- **Computed on 10km*12.5km slices**

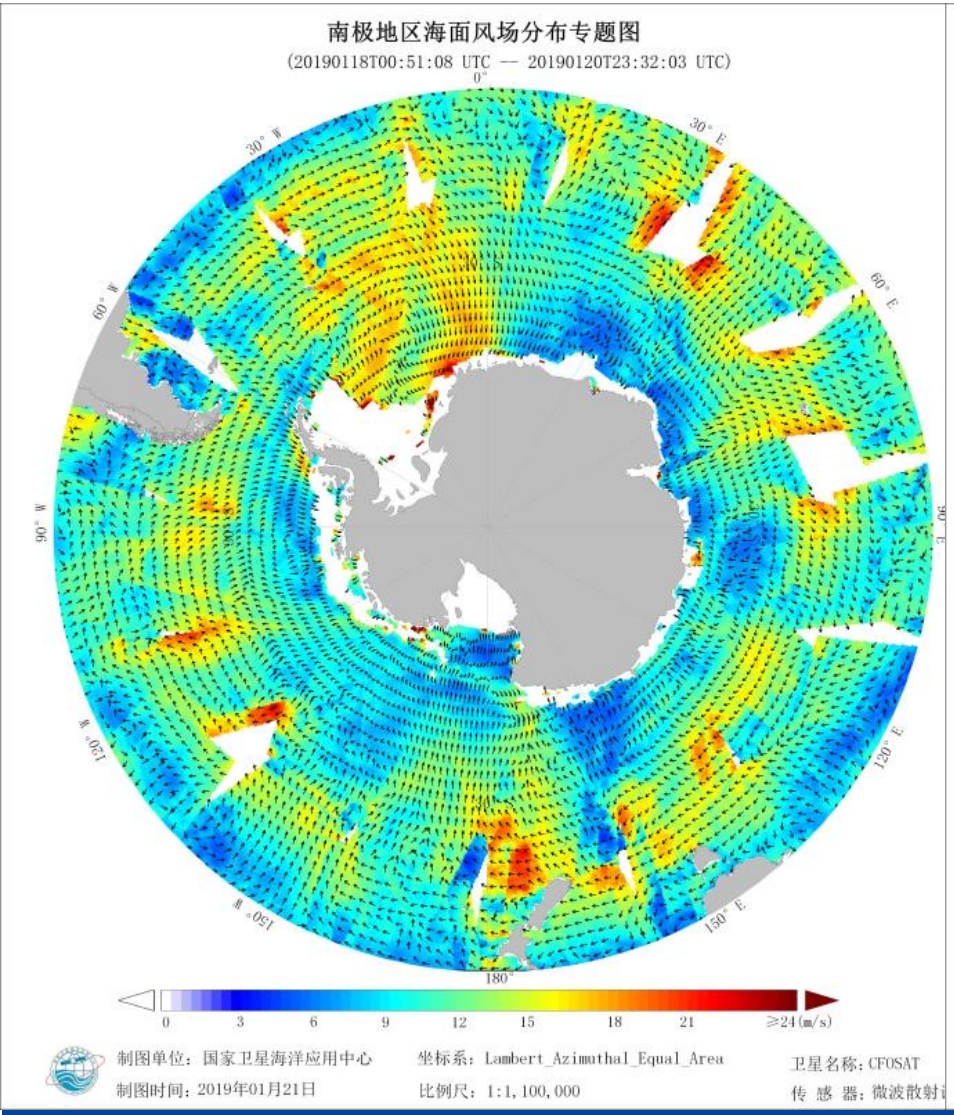


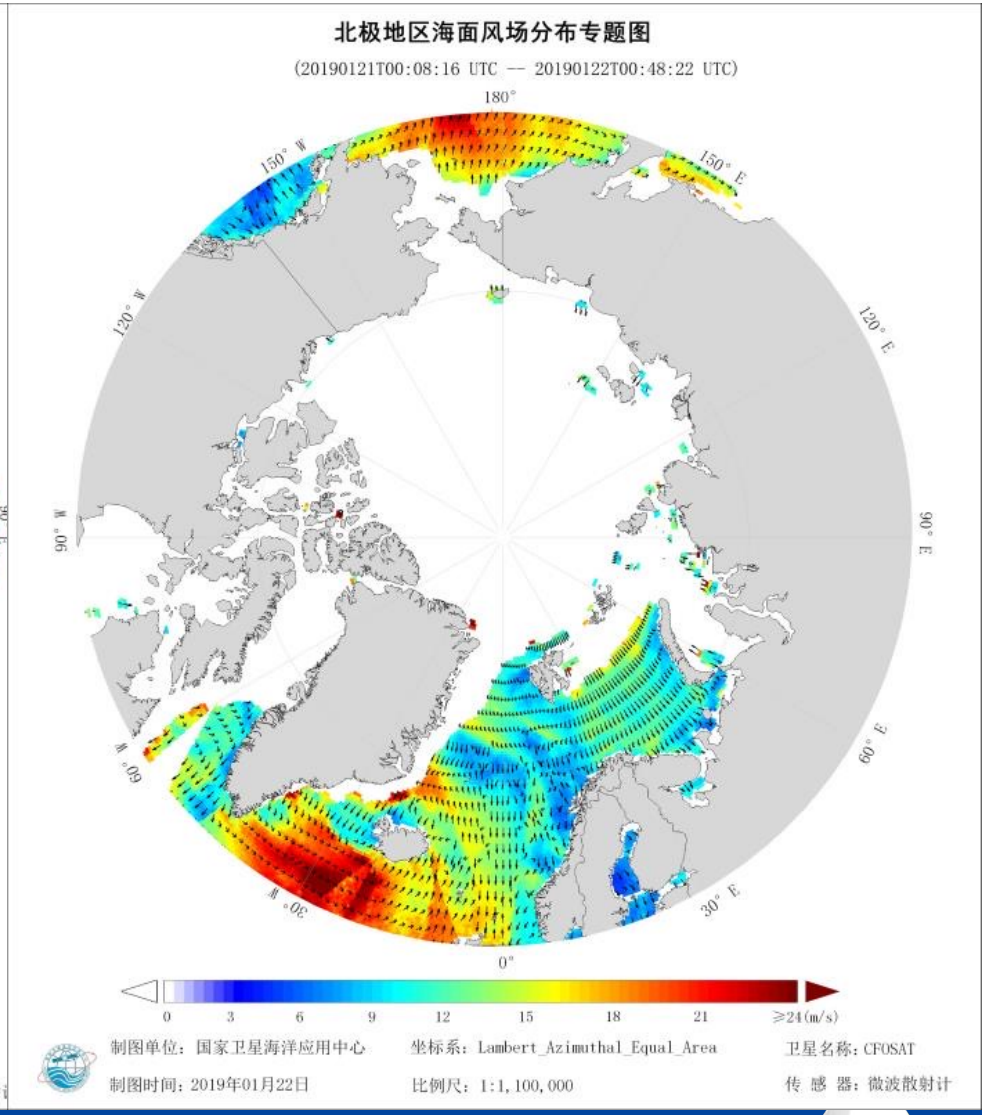
- CFOSAT SCAT Wind Products



CSCAT wind speed in one day

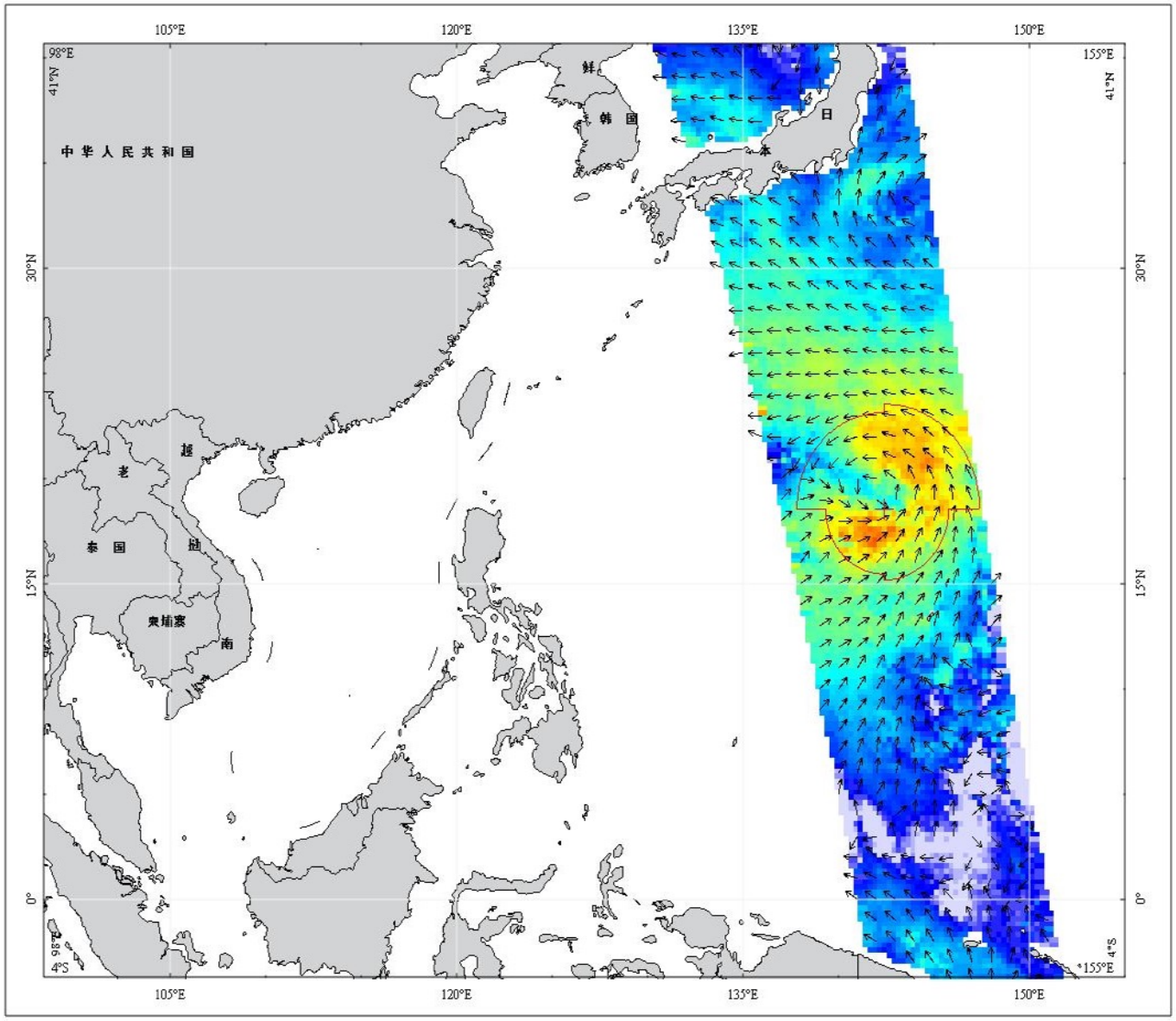
- CFOSAT SCAT Wind Products





2019年第10号台风“罗莎”

(20190806T09:24:02 UTC -- 20190806T09:35:46 UTC)



台风眼时间：20190806T09:30:01

台风眼位置：142° 23′ 23″ E
18° 33′ 33″ N

十级风半径：(KM)	NaN	NaN
	NaN	NaN
七级风半径：(KM)	499	337
	308	459

最大风速值：17.7 (m/s)

≥35(m/s)
30
25
20
15
10
5
0

坐 标 系： CGCS2000

比 例 尺： 1：22,138,000

卫星名称：CFOSAT

传 感 器：微波散射计

轨 道 号：4261

制图单位：国家卫星海洋应用中心

制图时间：2019年08月06日

Follow-on (next generation, Payload upgrade

HY-2

- **Radar altimeter: swath and precision**
  - Wide Swath Interferometric Radar Altimeter
  - Nadir-looking Synthetic Aperture Radar Altimeter
- **Radar Scatterometer: high wind and all-weather**
  - Ku-C dual frequency polarized scatterometer
- **Radiometric Imager:**
  - Full-polarimetric microwave imager

CFOSAT==》 wind and wave missions

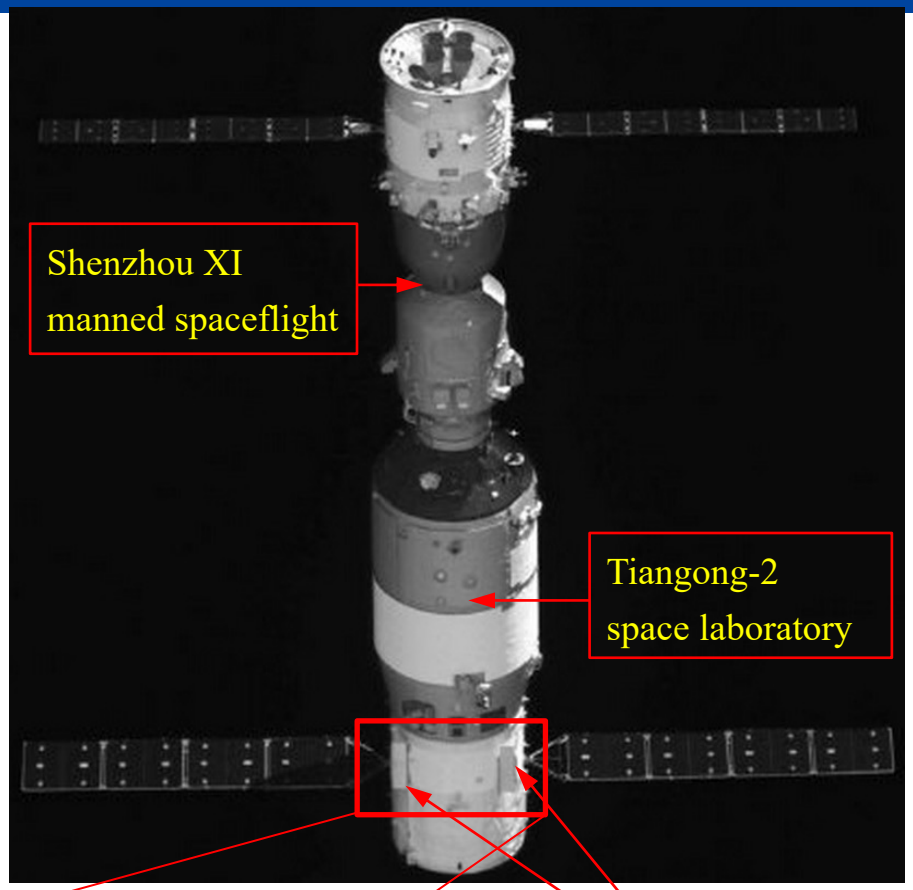
- **Radar scatterometer: ocean current capability**
  - Doppler scatterometer
  - Ku-Ka dual-frequency for higher resolutions

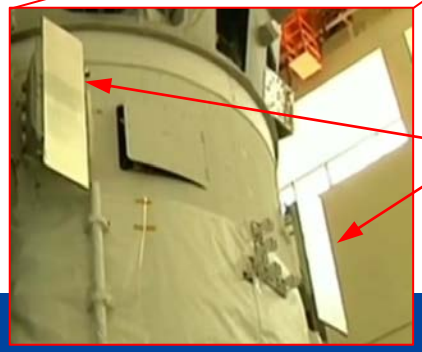
Tiangong-2 Interferometric Imaging Radar Altimeter

- **Interferometric Imaging Radar Altimeter (InIRA)**
  - Ku-band (13.58GHz) wide swath inteferometric radaer altimeter
  - Flown on Chinese Tiangong-2 space laboratory
  - Launched on September 15, 2016
- **Objectives:**
  - wide-swath sea surface height at mesoscale and sub-mesoscale, sea waves and sea winds.
  - Inland waters, e.g., lakes and rivers, coasts.

HY-2 Follow-On Pathfinder Mission

Tiangong-2 InIRA

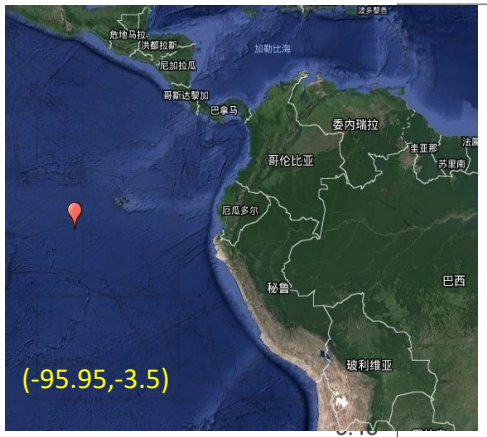


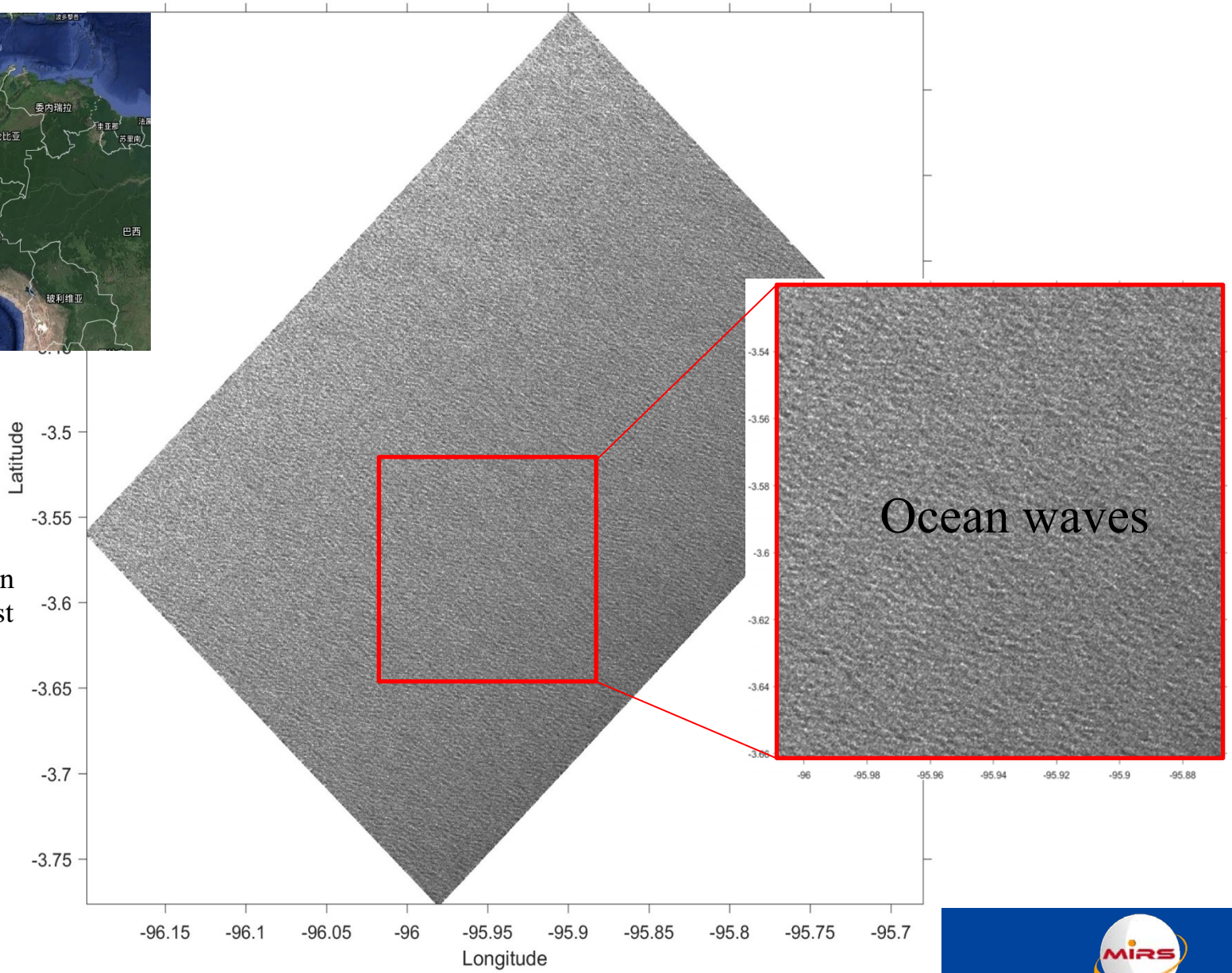


Antennas of Tiangong-2 InIRA

Parameters of Tiangong-2 InIRA	
Frequency	Ku band
Bandwidth	40MHz
Range resolution	200m~30m
Azimuth resolution	30m
Swath	30-35km
Orbit error	20cm
Vertical accuracy of sea surface	20cm absolute vertical accuracy in a 5km × 5km raster
Vertical accuracy of land surface	1~5m absolute vertical accuracy in a 200m × 200m raster
Accuracy of wave direction	15°

Tiangong-2 InIRA Image: Pacific Ocean

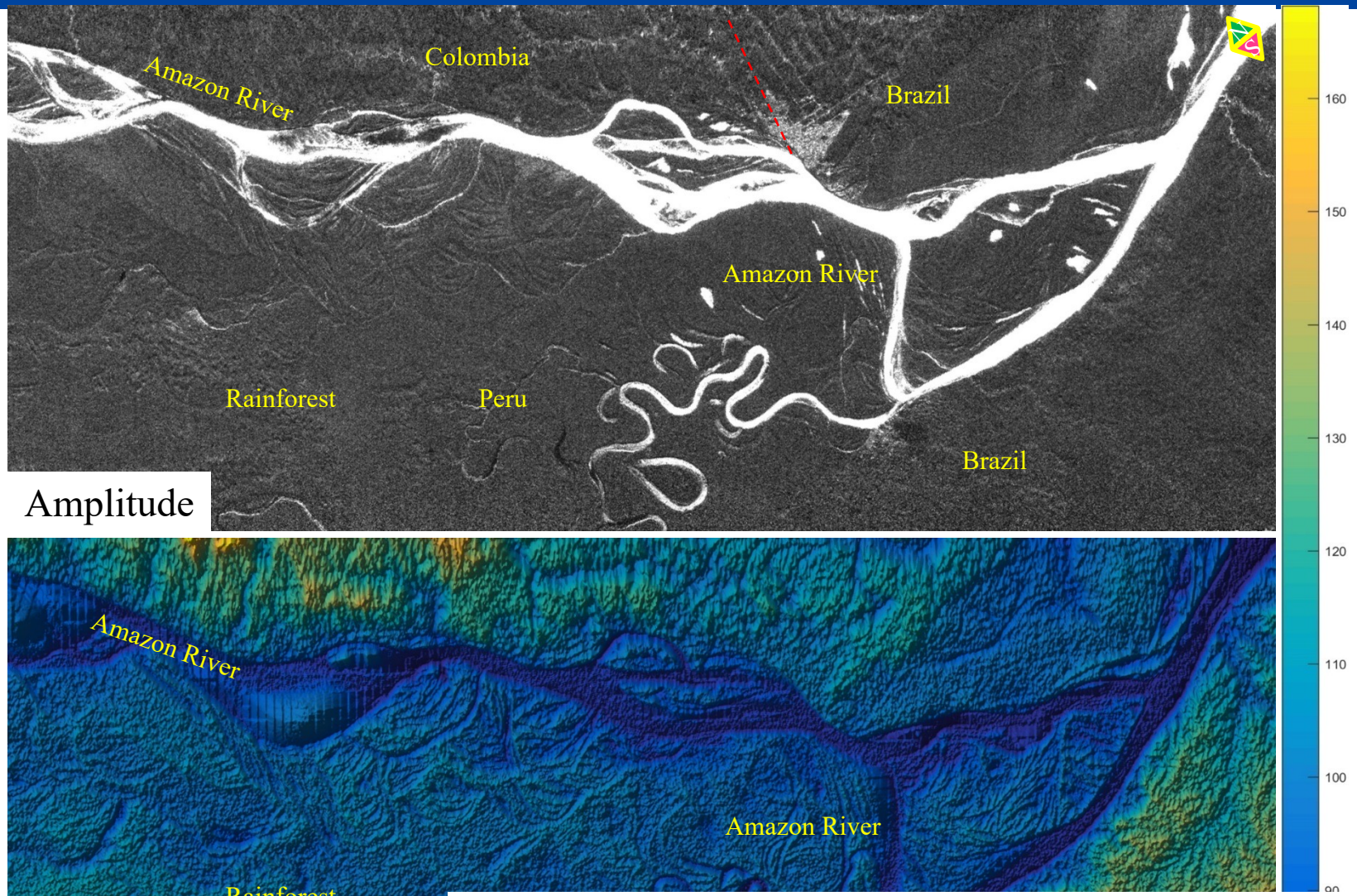




Eastern Pacific Ocean at about 1800km west of Ecuador, South America

Observation time: 2016.09.23, 10:14

Tiangong-2 InIRA Image: Inland river

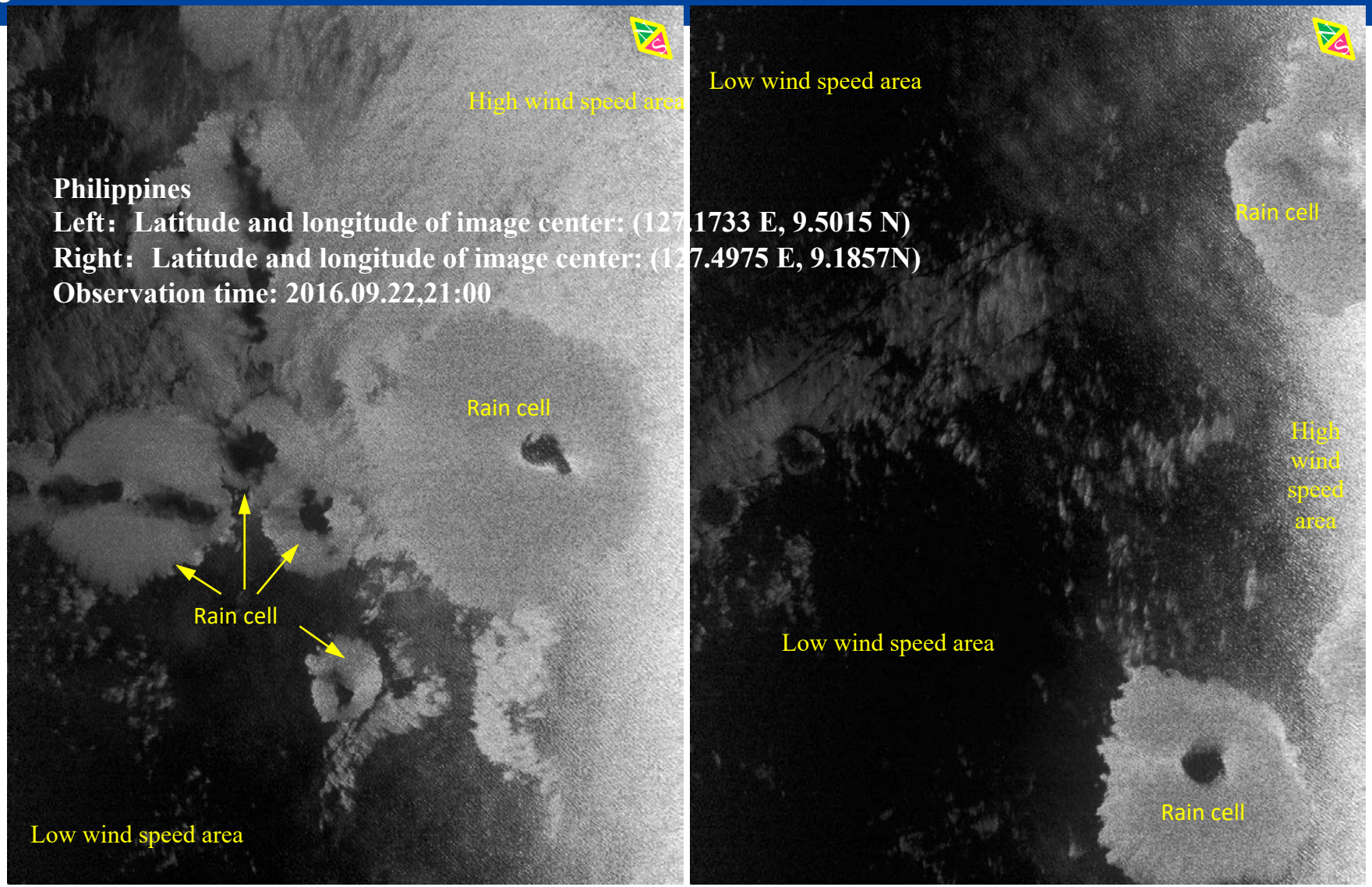


Amplitude

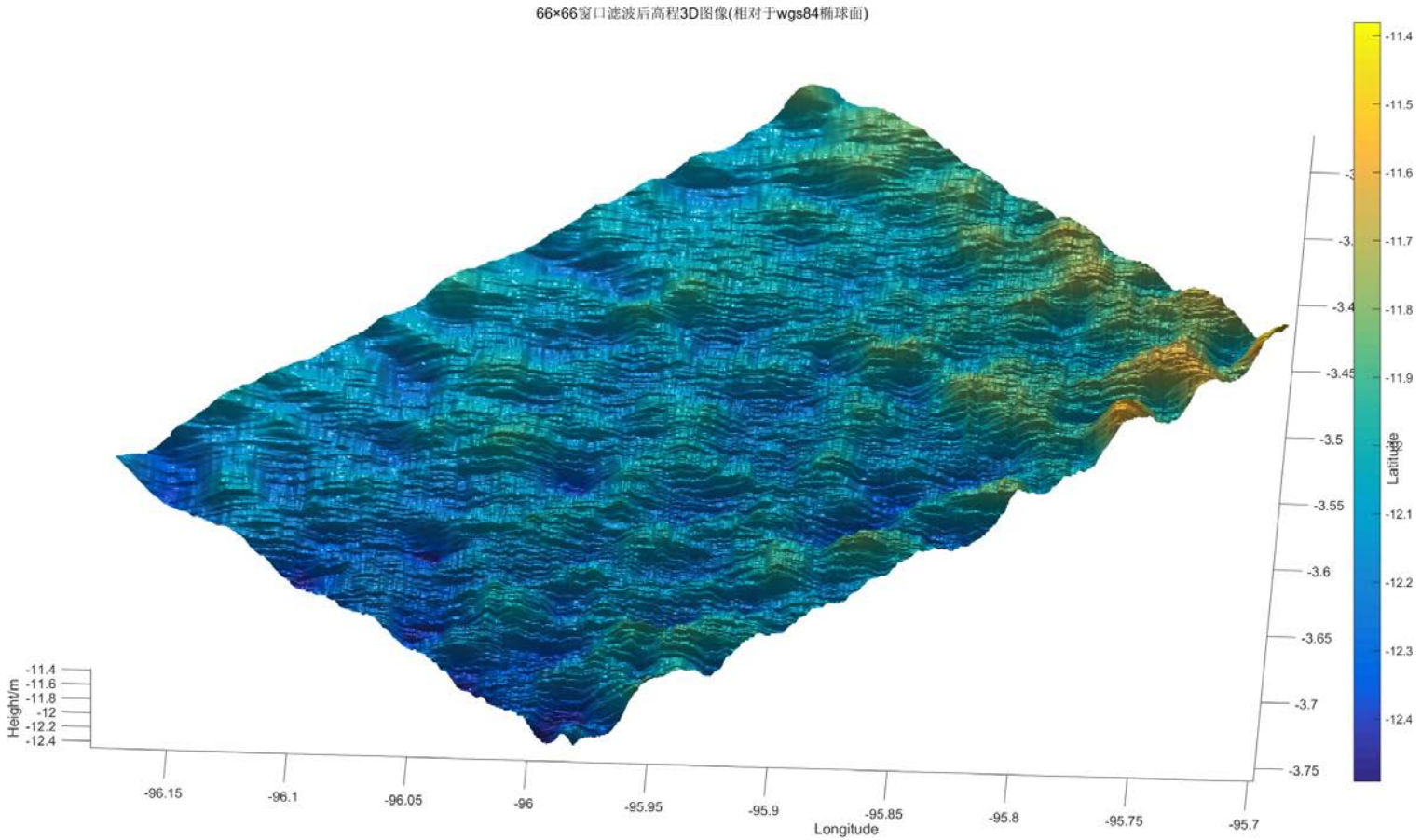
DEM

Amazon rainforest at the junction of Brazil, Peru and Colombia
Image Size: 79.3km x 33.6km
Latitude and longitude of image center: (70.0533W, 4.2122S)
Observation time: 2016.09.23, 10:56

Tiangong-2 InIRA Image: Rain cells

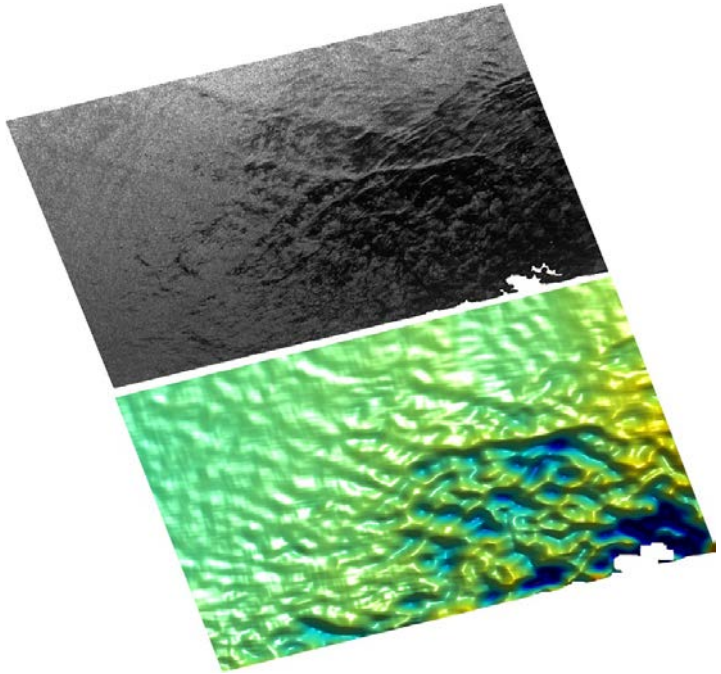


Tiangong-2 InIRA Image: Sea surface topography (spatial resolution 2km × 2km)

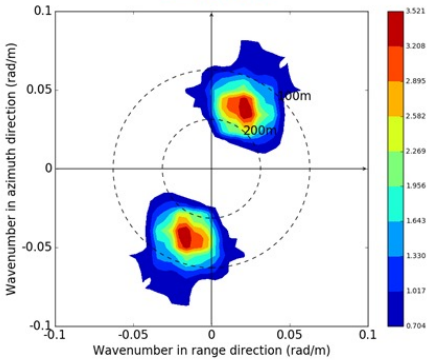


South Pacific

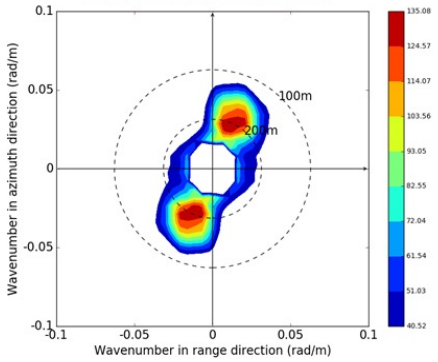
Wave Spectrum by InIRA



图像谱



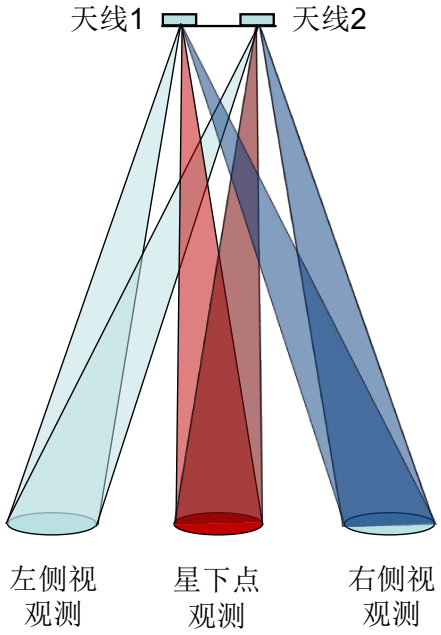
反演的海浪谱



Wide-Swath Radar Altimeter for HY-2 Follow-On Missions

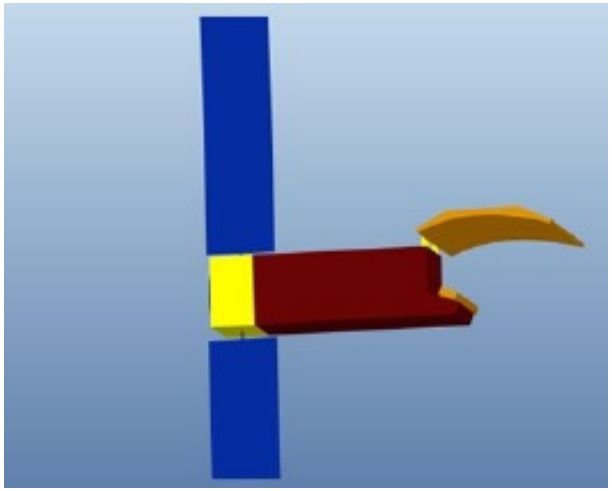
Future plan and Progresses:

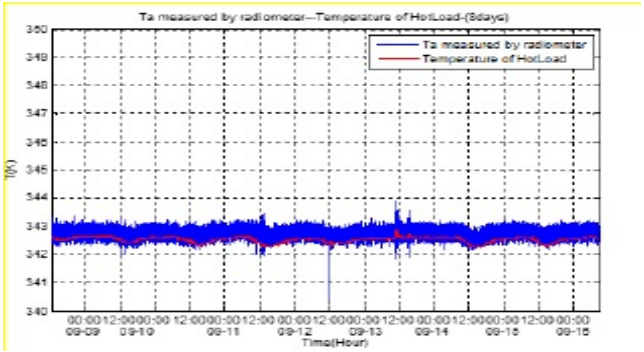
- The next-generation ocean dynamic environment mission satellite (HY-2 FO) is under development;
- Payload technology verification started in 2017 and scheduled for launch in 2021 ~ 2022;
- The interferometric imaging radar altimeter onboard will operate on near-nadir swaths on both sides of the satellite track with imaging swath ~ 200km.
- The accuracy of sea surface level is ~5cm at spatial resolution of 5km x 5km, with high precision orbit determination (from HY-2)



Interferometric Microwave Radiometer for Chinese Ocean Salinity Mission

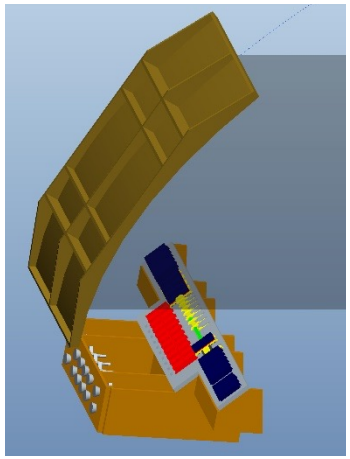
- L-band: Ocean salinity
- C, K band: SST and roughness

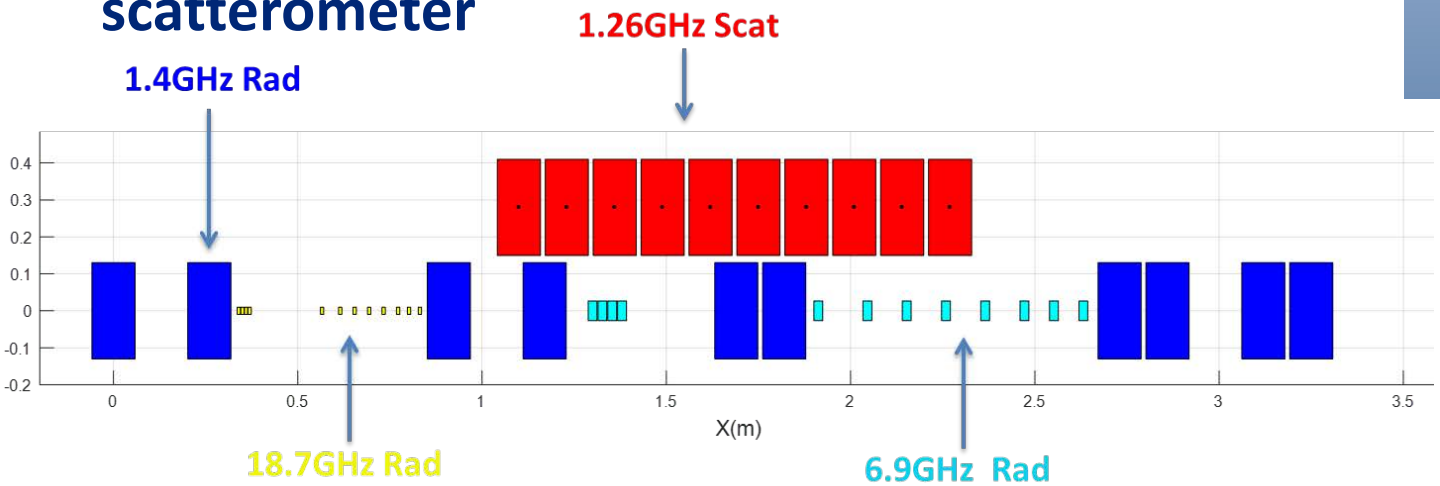


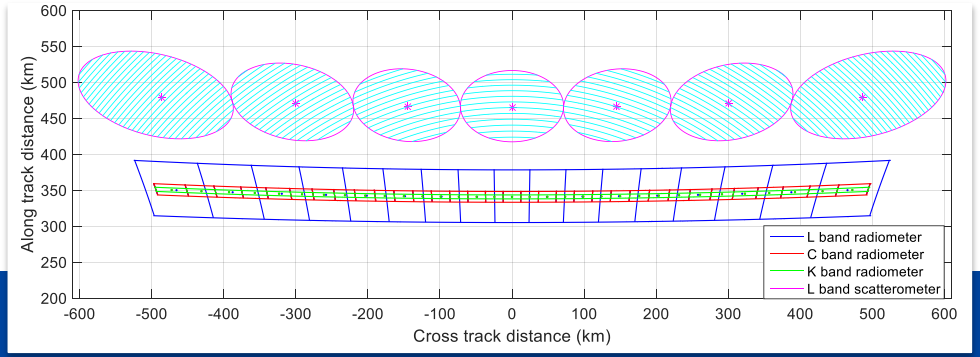


MICAP: Microwave Imager Combined Active and Passive

- **Instrument Type: a suit of active/passive instrument package**
  - **Passive part: L/C/K band one-dimensional**
  - **Active Part: L-band DBF (digital beamforming) scatterometer**







MICAP/SCAT

Frequency	1.26GHz
Trans. BW	4MHz
Trans. Peak Power	≥200W
PRF	100Hz
Pulse Width	1ms
Rec. BW	5MHz
Calibration Stability	0.1dB

MICAP/RAD

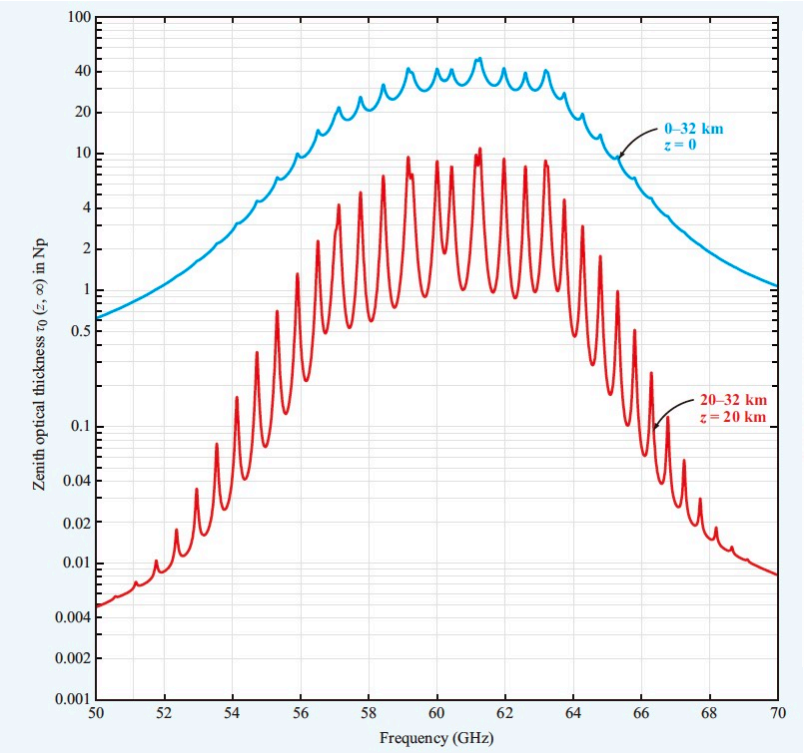
Frequency	L-band（1.4GHz）	C-band（6.9GHz）	K-band（18.7GHz）
Bandwidth	25MHz	200MHz	200MHz
Polarisation	V/H/T3	V/H	V/H
Spatial Resolution	AL-track：75km X-track：50-100km	AL-track：15km X-track：25-50km	AL-track：8km X-track：25-50km
NeDT（boresight）	0.15K (75km sampling interval)	0.5K (15km sampling interval)	0.5K (15km sampling interval)
Stability	0.12K@3天	/	/
Swath	≥ 950km	≥ 950km	≥ 950km

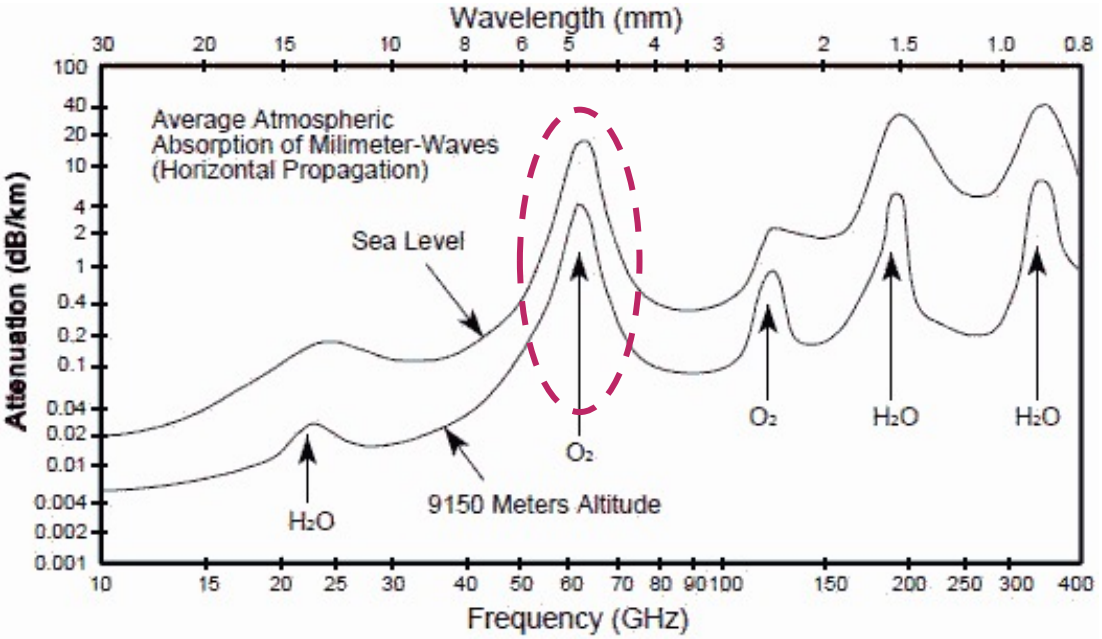
Advanced Microwave Atmospheric Sounder (AMAS) for FY-3 Follow-ons

- FY-3 (Fengyun, Wind and Cloud): China's polar orbit meteorological satellites
- Future FY-3 Microwave sounder requirements
  - Integrated temperature and humidity sounding
  - Enhanced cloud ice capability
  - Enhanced vertical resolutions
- Microwave Radiometer for micro/cubesats

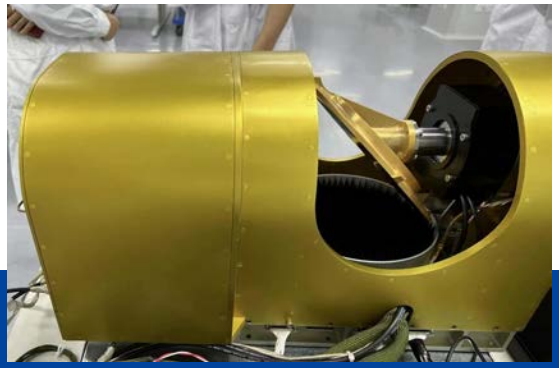
Microwave sounder for FY-3 Follow-on

Ch No.	Center Freq(GHz)	pol	BW (MHz)	NEDT (K)	3dB Beam Width	Spectral no.
1	23.8	V	100-400	0.2	5.2°	1
2	31.4	V	1000	0.2	5.2°	1
3	50~60GHz (spectrometer)	H	2-2000MHz programmable	0.4@ 200MHz	2.2°	Digital spectrometer
4	89.0	V	1500	0.3	2.2°	1
5	118GHz (spectrometer)	V	2-2000MHz	0.3@ 500MHz	2.2°	~20
6	166	H	1500	0.3	1.1°	1
7	183GHz	H	2-2000MHz	0.3@ 500MHz	1.1°	~10
8	229GHz	H	1500	0.3	1.1°	1


Zenith optical thickness $\tau_0(z,\infty)$ in Np
0–32 km
$z = 0$
20–32 km
$z = 20$ km
Frequency (GHz)


Wavelength (mm)
Average Atmospheric
Absorption of Milimeter-Waves
(Horizontal Propagation)
Sea Level
9150 Meters Altitude
O_2
H_2O
Attenuation (dB/km)
Frequency (GHz)

Microwave sounder for cubesats



Ch No.	Center Freq(GHz)	pol	BW (MHz)	Range (K)	NEDT (K)
1	89.0	H	1500	3—340	0.5
2	118.75±0.08（30）	H	60	3—340	2.5
3	118.75±0.2（60）	H	100	3—340	1.5
4	118.75±0.4（100）	H	200	3—340	1.0
5	118.75±0.8（180）	H	200	3—340	1.0
6	118.75±1.1（220）	H	300	3—340	1.0
7	118.75±1.6（300）	H	300	3—340	1.0
8	118.75±2.1（380）	H	300	3—340	1.0
9	118.75±3.0（490）	H	300	3—340	1.0
10	118.75±3.6(600)	H	500	3—340	0.8
11	118.75±4.3(700)	H	500	3—340	0.8
12	118.75±4.9(800)	H	500	3—340	0.8
13	166.0	V	1500	3—340	0.8
14	183.31±1	V	500	3—340	1.0
15	183.31±1.8	V	1000	3—340	0.8
16	183.31±3	V	1000	3—340	0.8
17	183.31±4.5	V	1500	3—340	0.8
18	183.31±7	V	1500	3—340	0.8

Summary

- Started from M3RS/SZ-4 in 2002;
- Focus on atmospheric/meteorological and oceanographic applications
- Support the development of FY-3 series, HY-2 series, CFOSAT, COSM…
- Preparation for next generation started