Scientific Innovations in FengYun Satellite Research and Applications
风云卫星研究与应用中的科学创新

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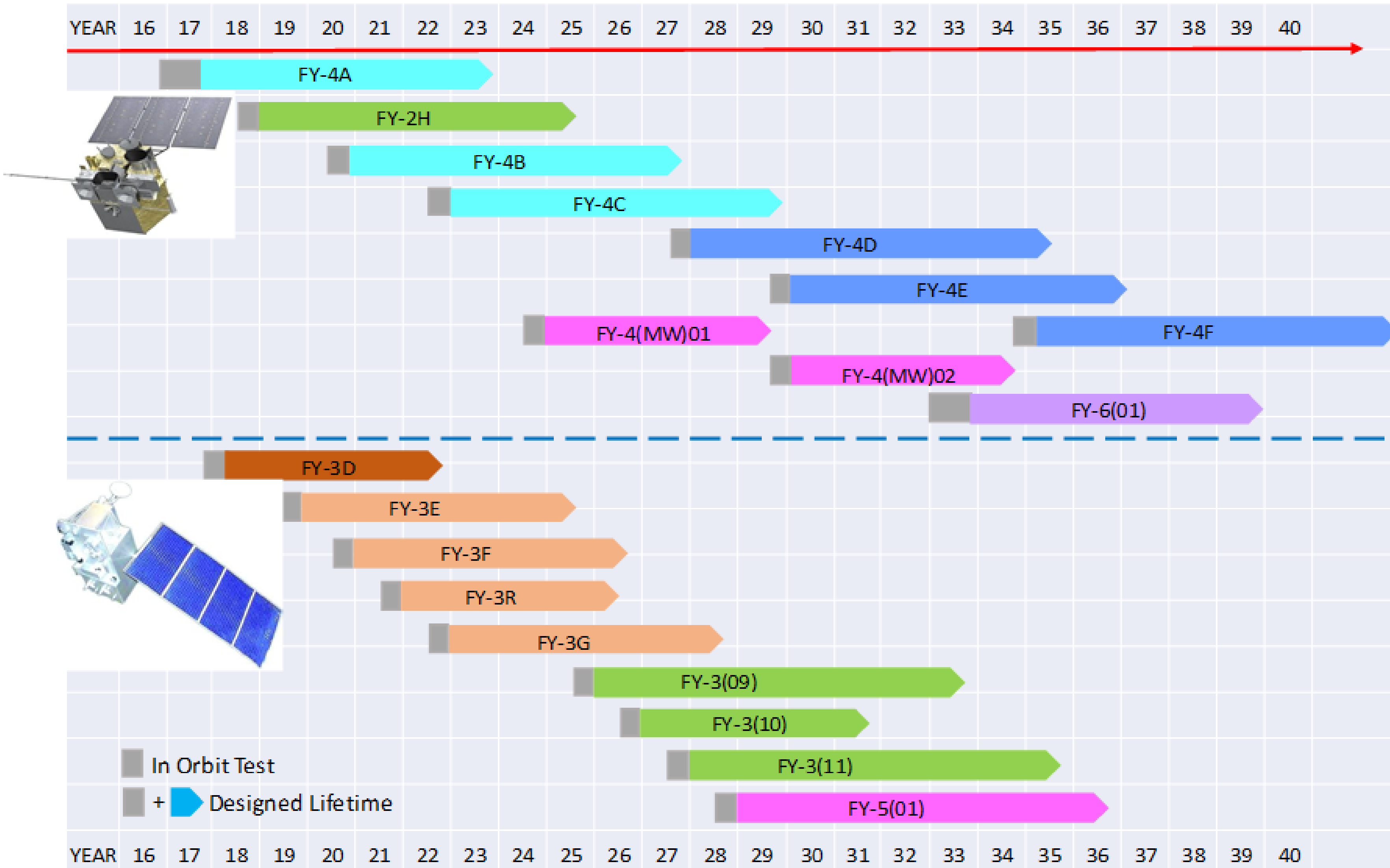
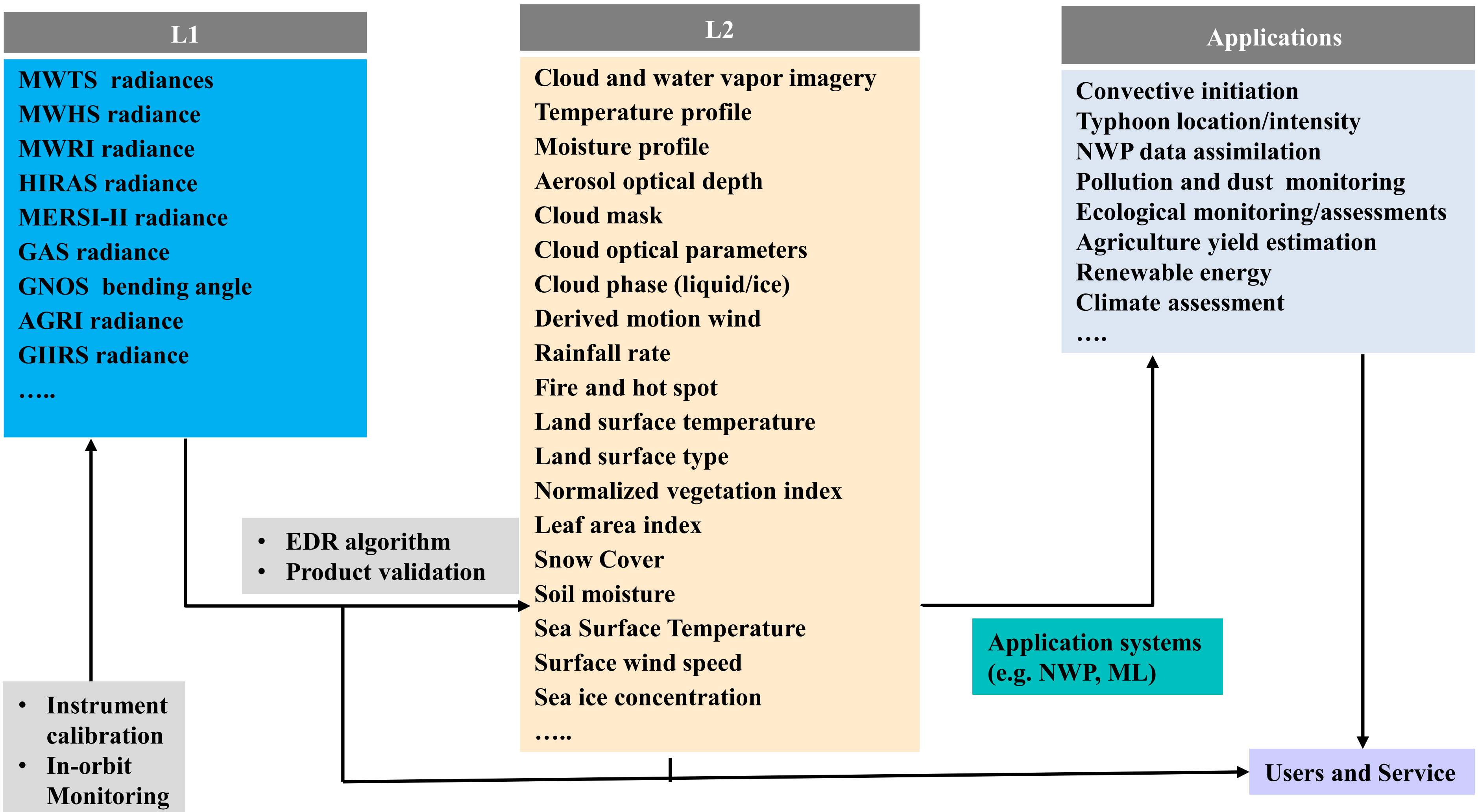
Outline

- Overview of FengYun satellite mission
- Innovative FY calibration and product validation
- Innovative uses of FY satellite data for CMA operations
- Critical sciences and technologies required for future developments
- Summary and Conclusions

Fengyun Meteorological Satellite by 2040

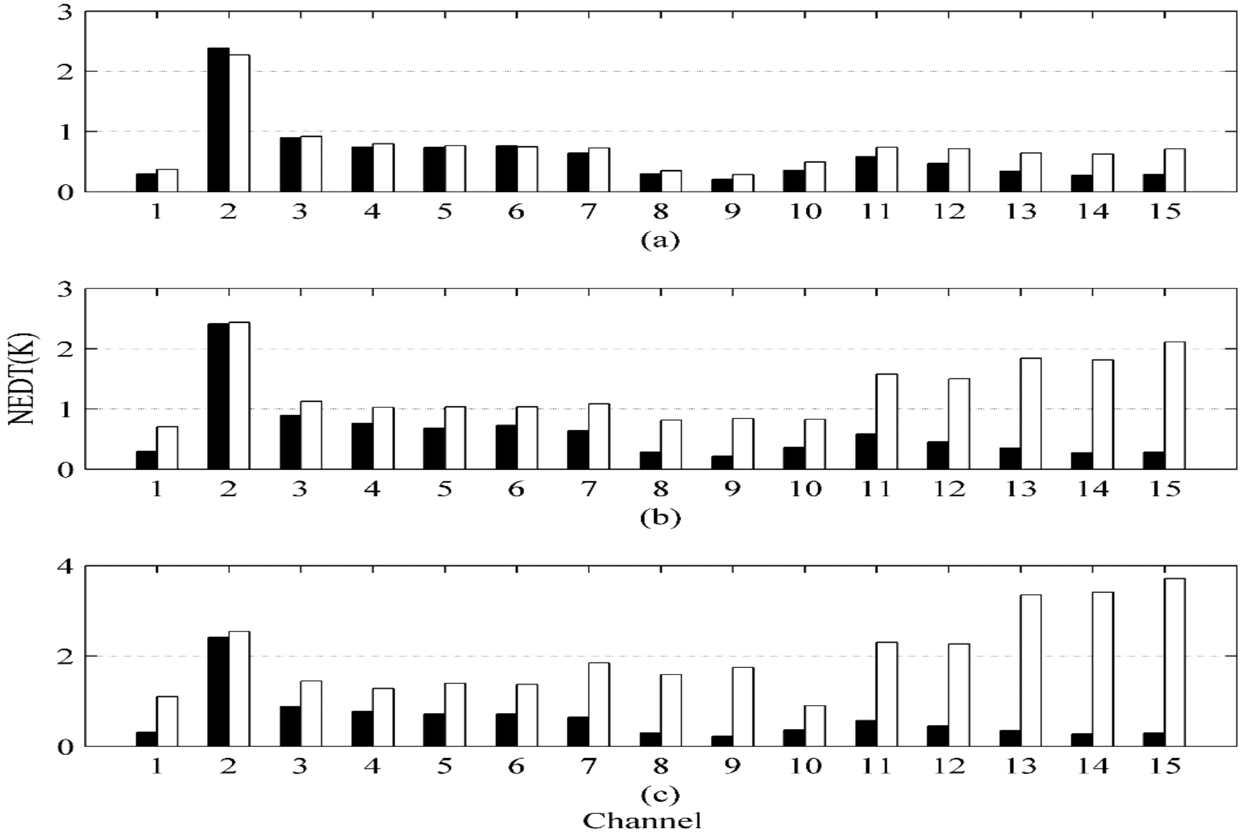


Satellite Data Records and Their Applications



How to Assess Instrument Noise Correctly?

MWHS Noise Characterization

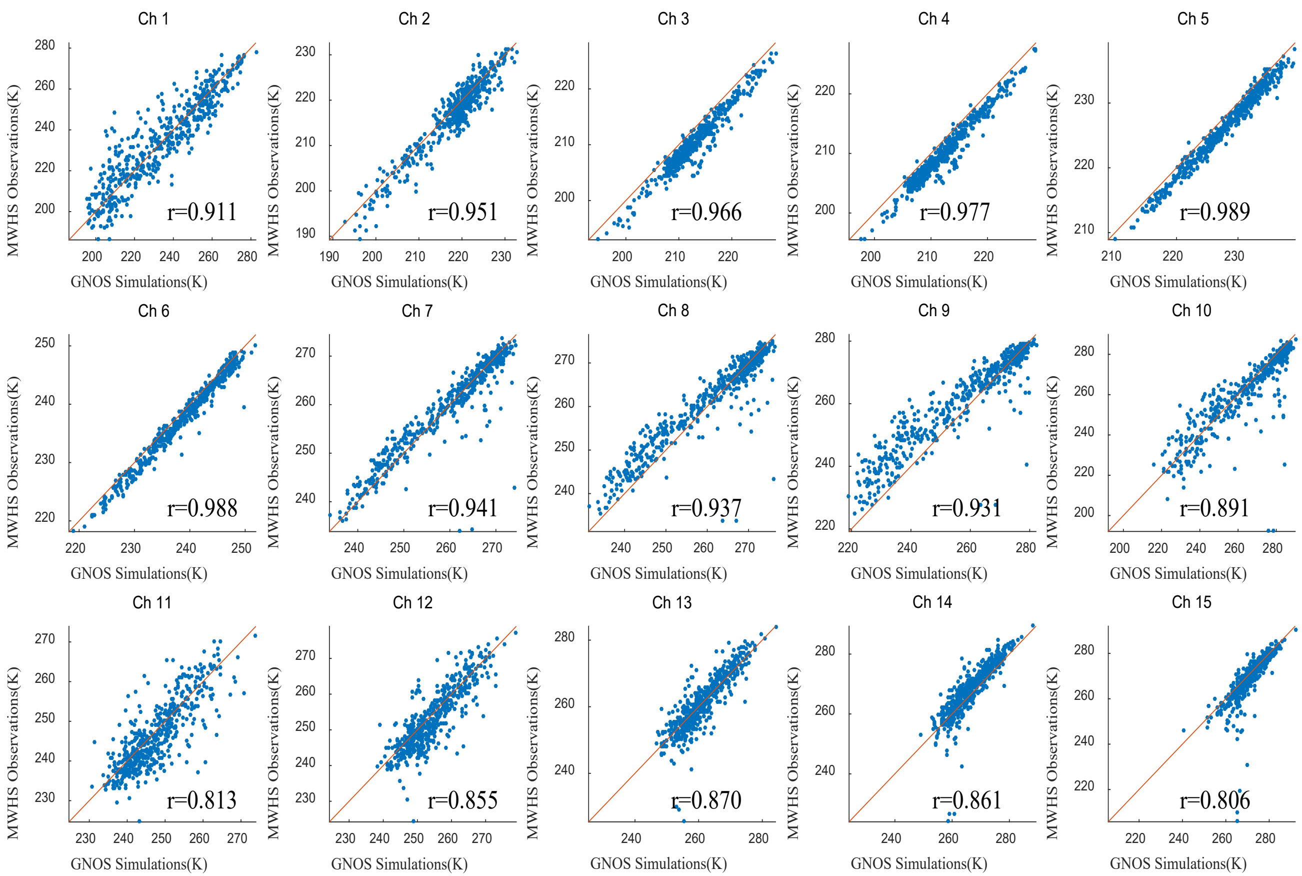


NEDT estimated from Allan deviation (black bar) and standard deviation (white) for all 15 channels. The number of scan of warm counts used for calculation is (a) 100; (b) 300 and (c) 500, respectively, from the orbit of 3340 on July 8, 2018

The noise derived from Allan deviation does not depend on the number of scan lines and is very reliable for noise calculation

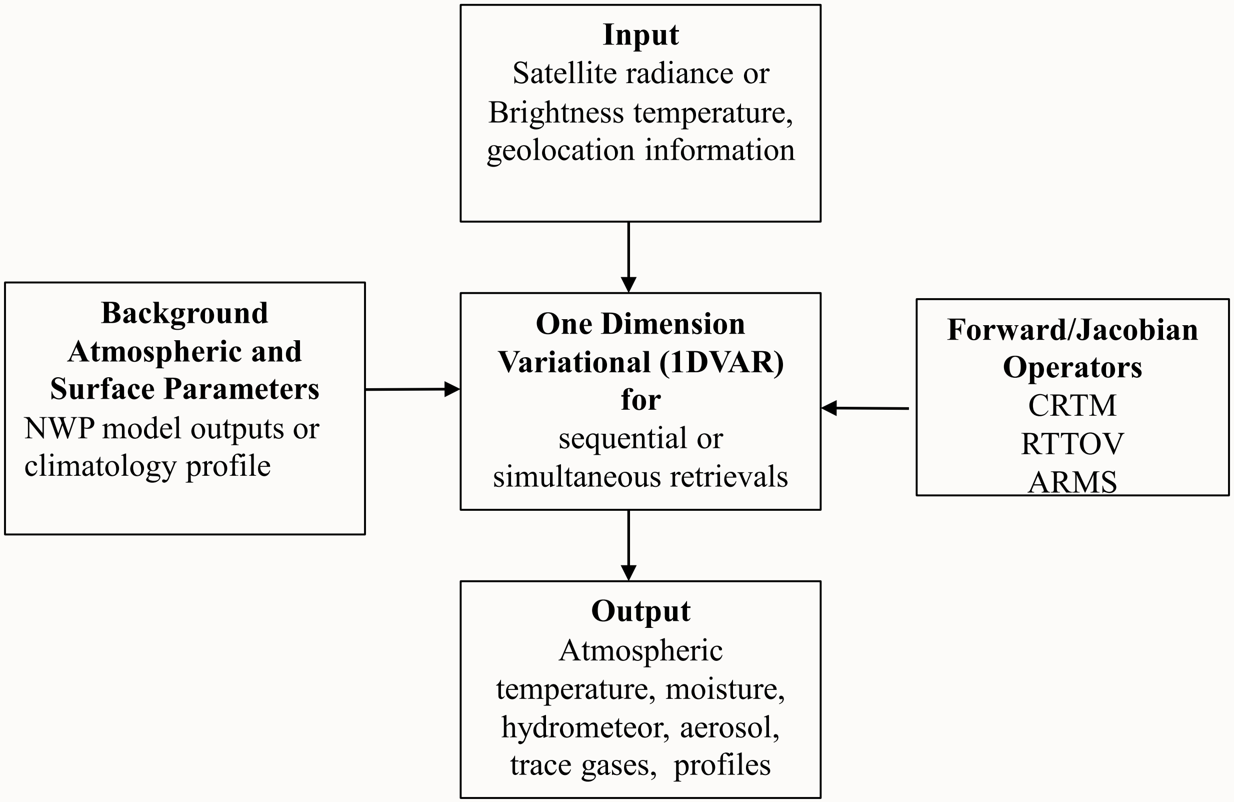
How to Validate Level 1B Data?

MWHS Bias Assessment



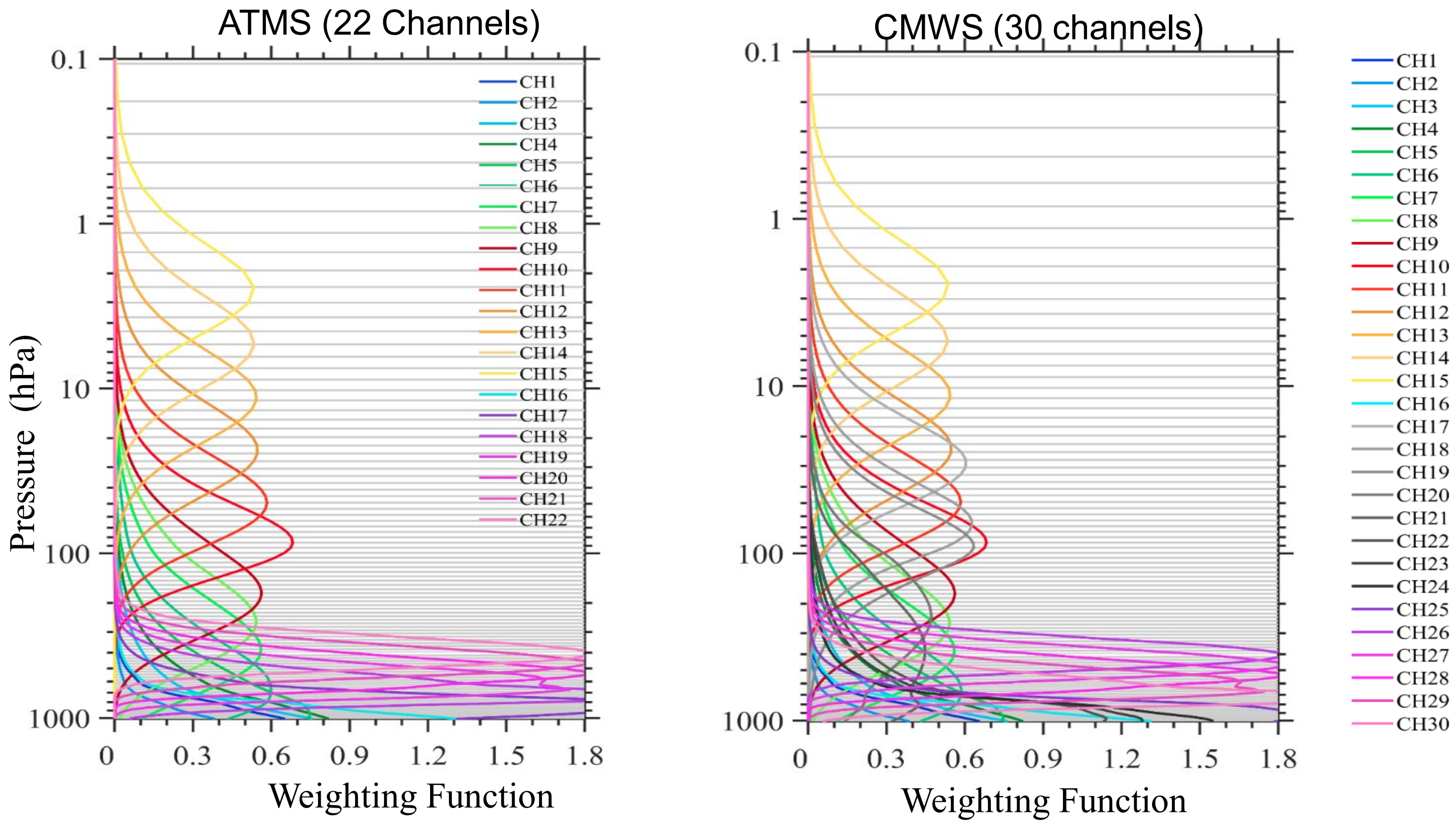
GPSRO profile data are proved to be the best for simulating the upper air microwave sounding channel radiances which can be used for vicarious calibration of microwave sounding instrument

Multisensor Remote-sensing Testbed



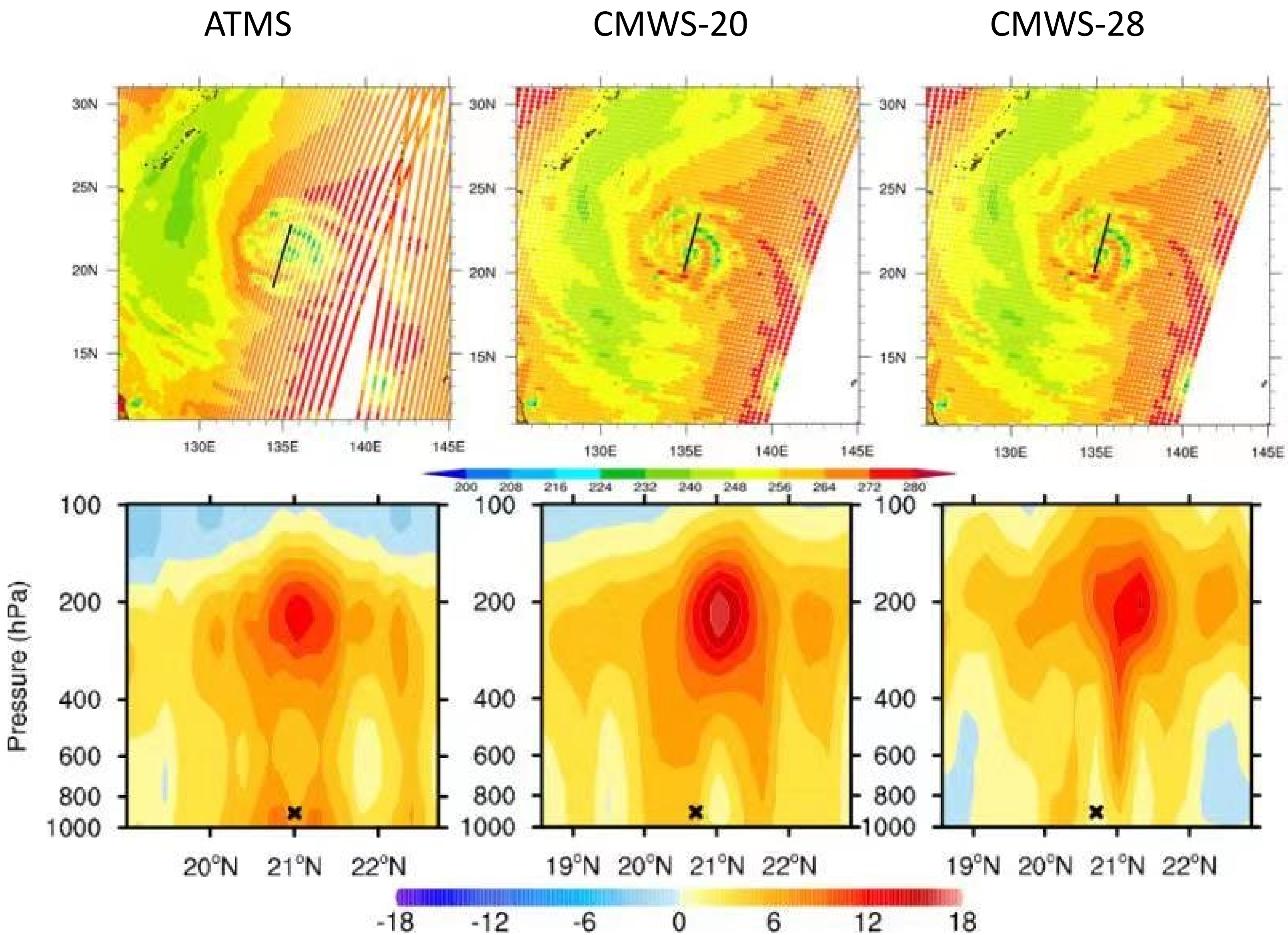
- Algorithm valid in all-weather conditions, over all-surface types
- Model& instrumental errors are input to algorithm
- Background and observation error covariances are scene-dependent.
- Selection of background from climatology, NWP forecasts, and regressions
- Selection of channels to use and parameters to retrieve

Comparison of FY-3D and NOAA Microwave Sounding Capability



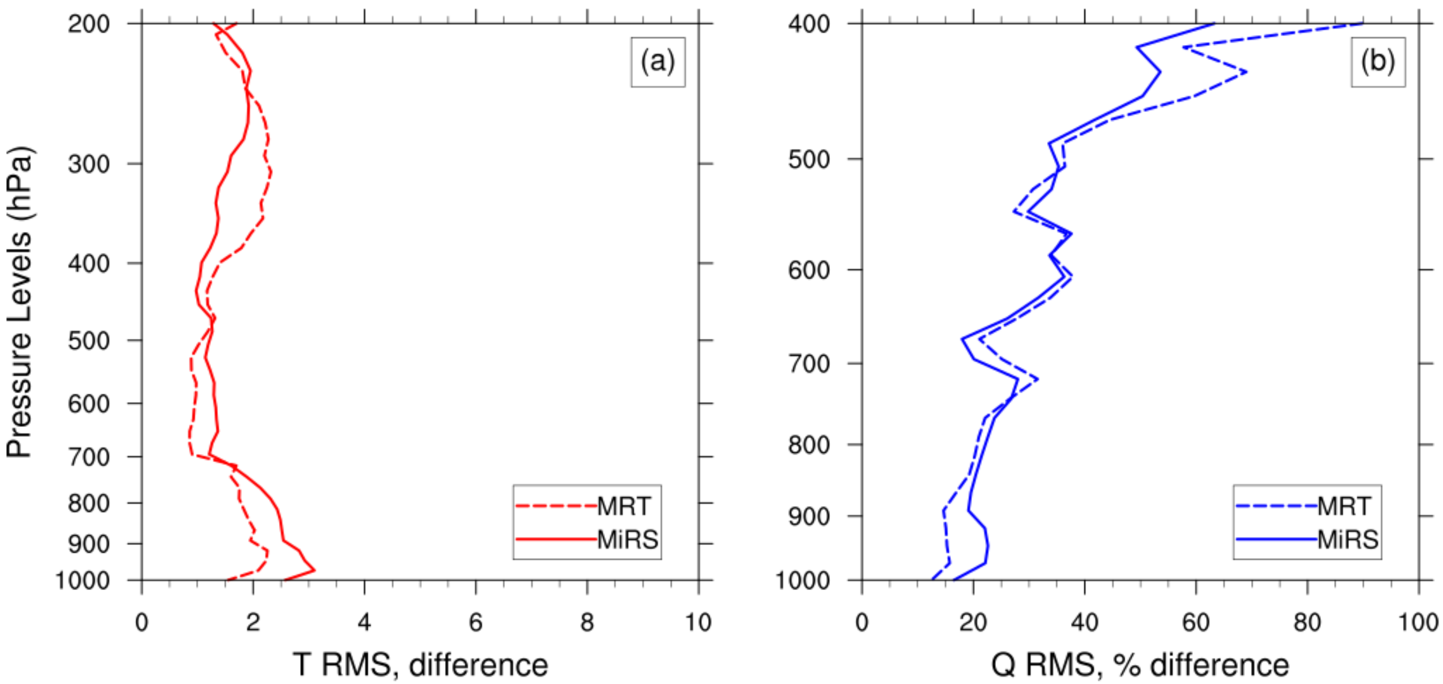
Combined microwave sounding Suite (CMWS) from FY-3D MWTS and MWHS has a better vertical resolution for atmospheric sounding comparing to ATMS

Comparison of ATMS and CMWS Warm Core



Comparison of Atmospheric Profiles Derived from ATMS using MRT and MIRS

Dropsonde 0-900 km from TC center

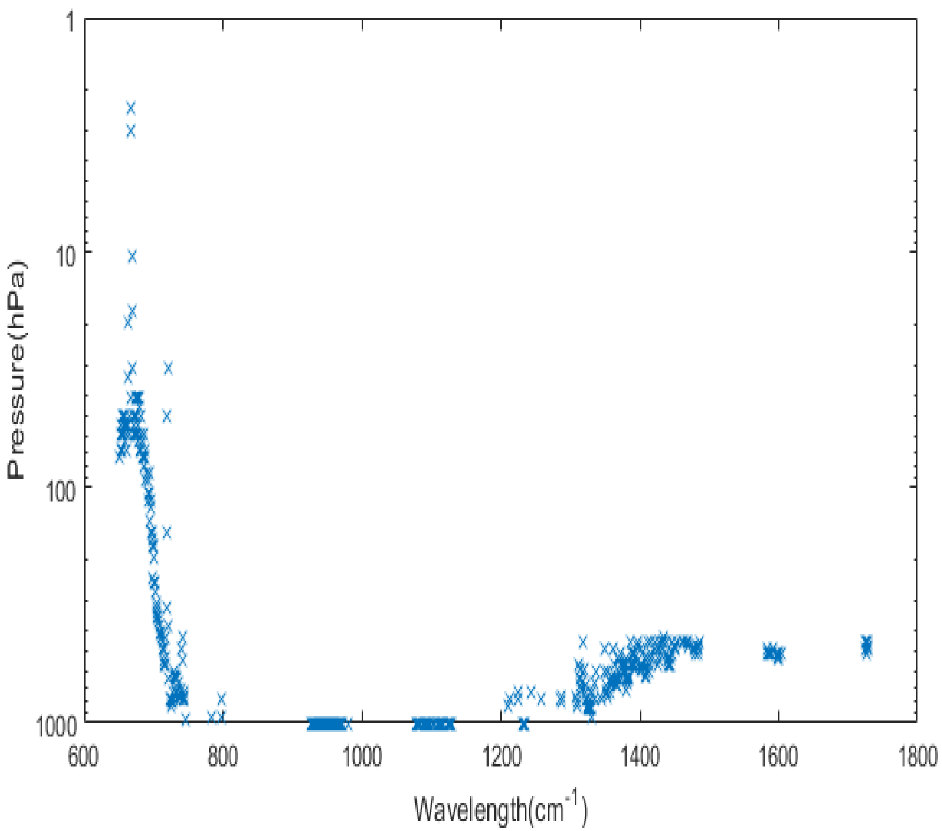


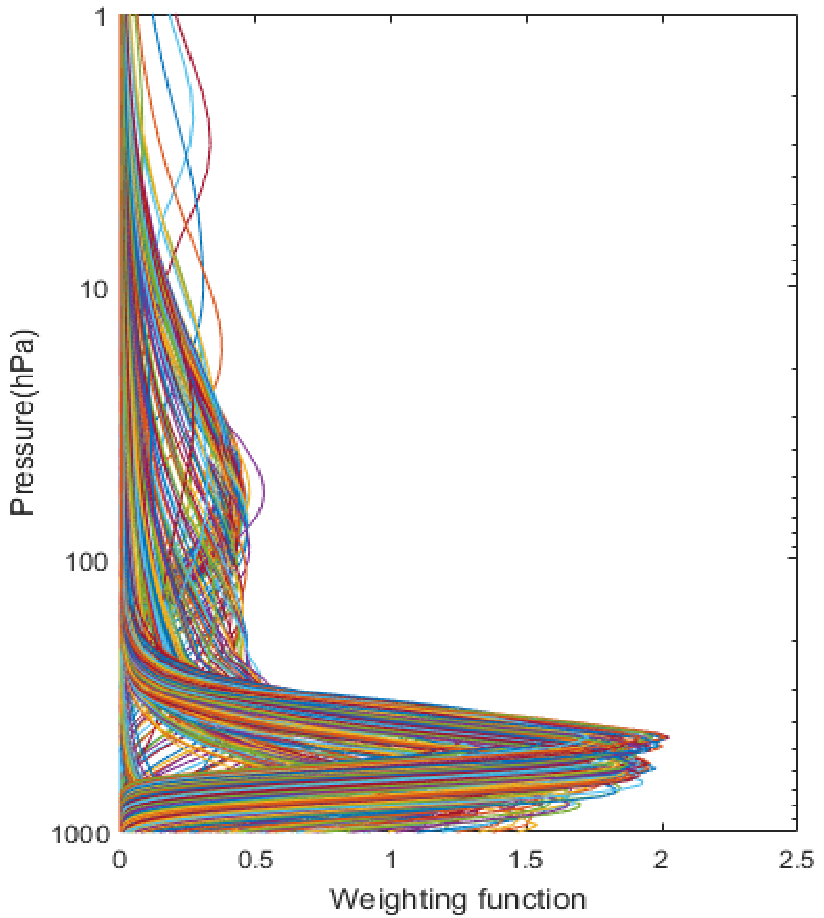
Collocation threshold: within 33 km & within 30 minutes. Number of collocated dropsondes: 281

Atmospheric profiles from MRT has better accuracy in lower to mid-troposphere.

Slide courtesy of Hu Hao, CAMS

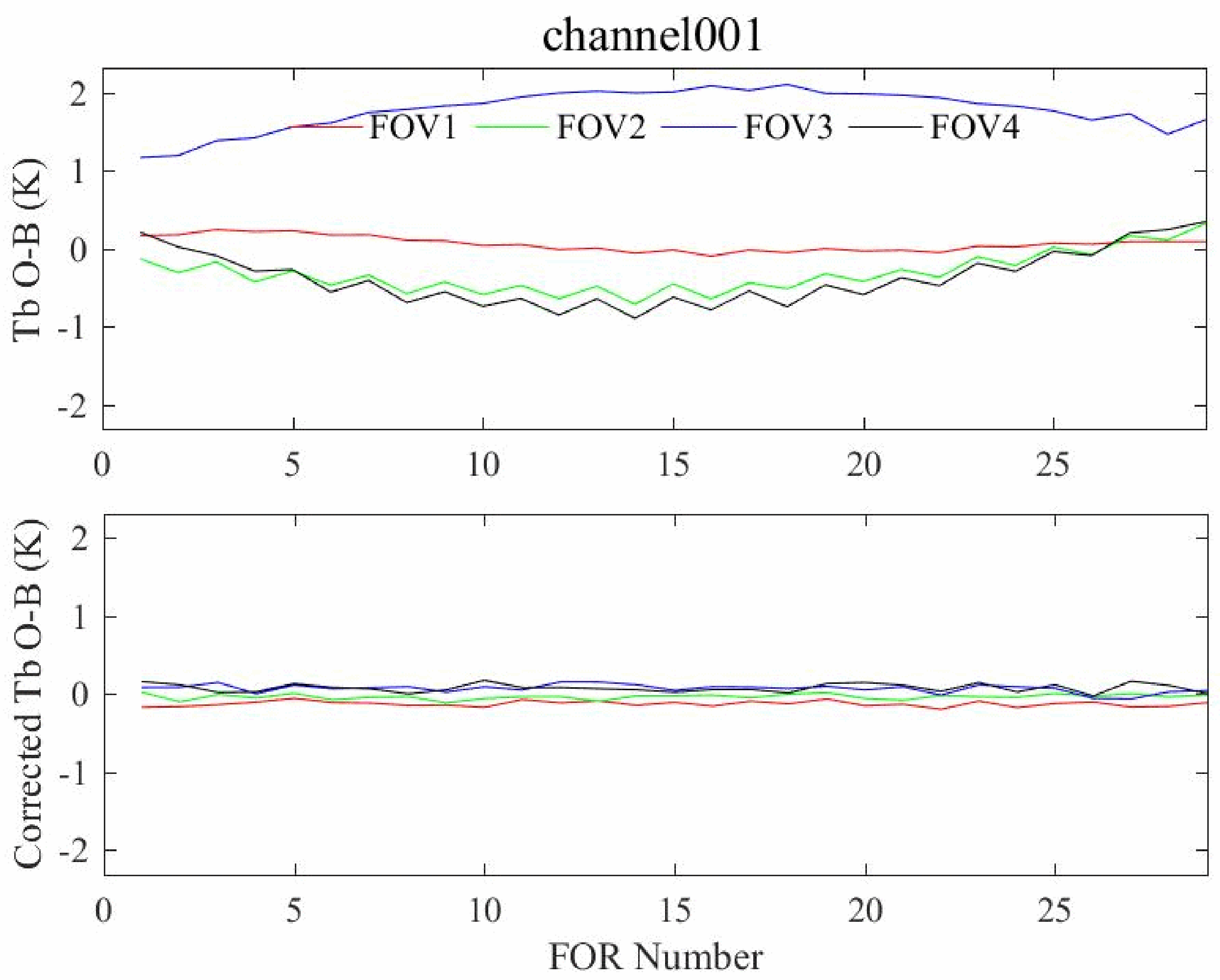
HIRAS Channel Selection





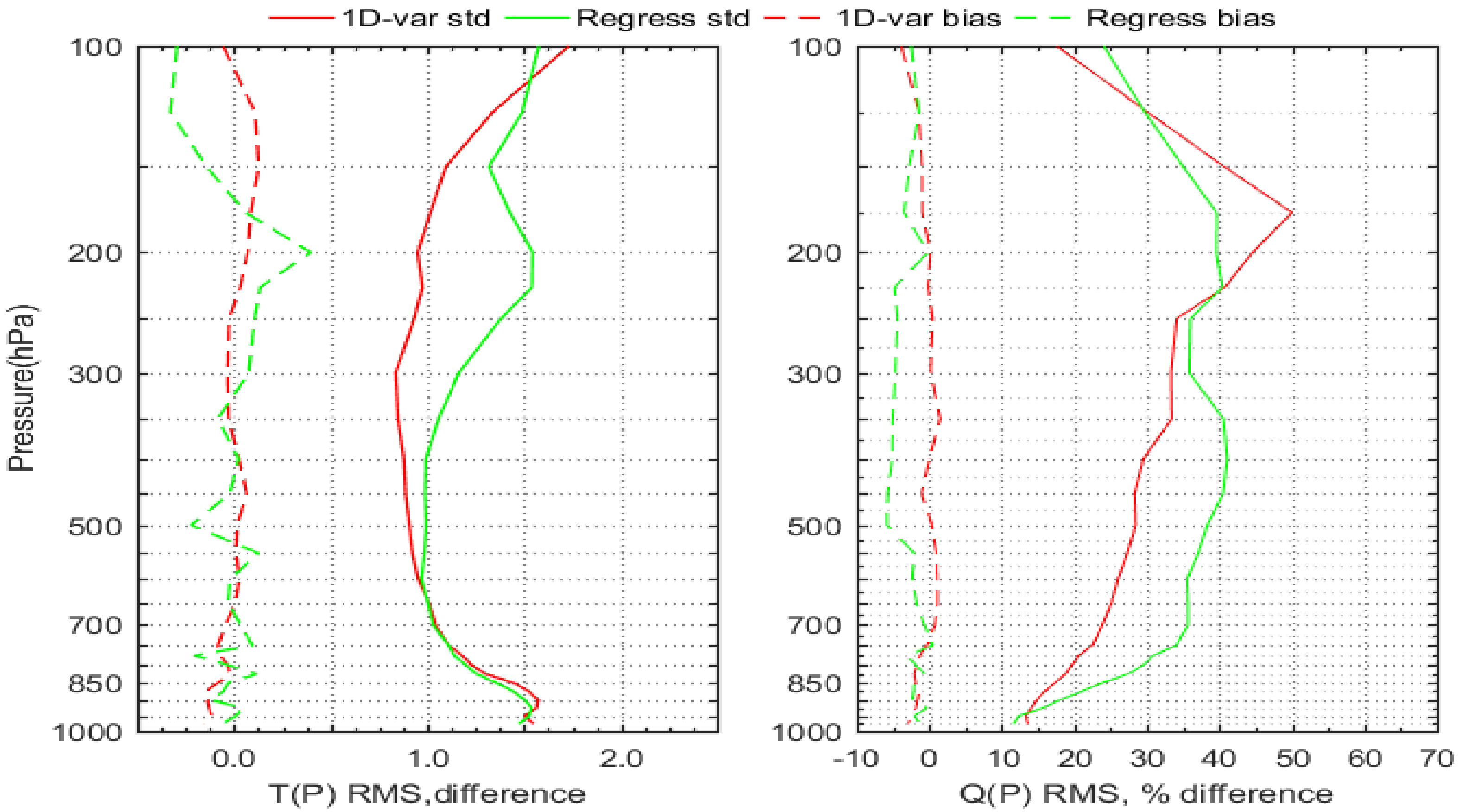
- Principal component analysis is used for channel selection.
- 450 channels is selected,

HIRAS FOV Dependent Bias Correction



- Significant bias variation between four FOVs
- Asymmetric bias between twenty-nine FORs
- Bias correction for every FOVs and FORs

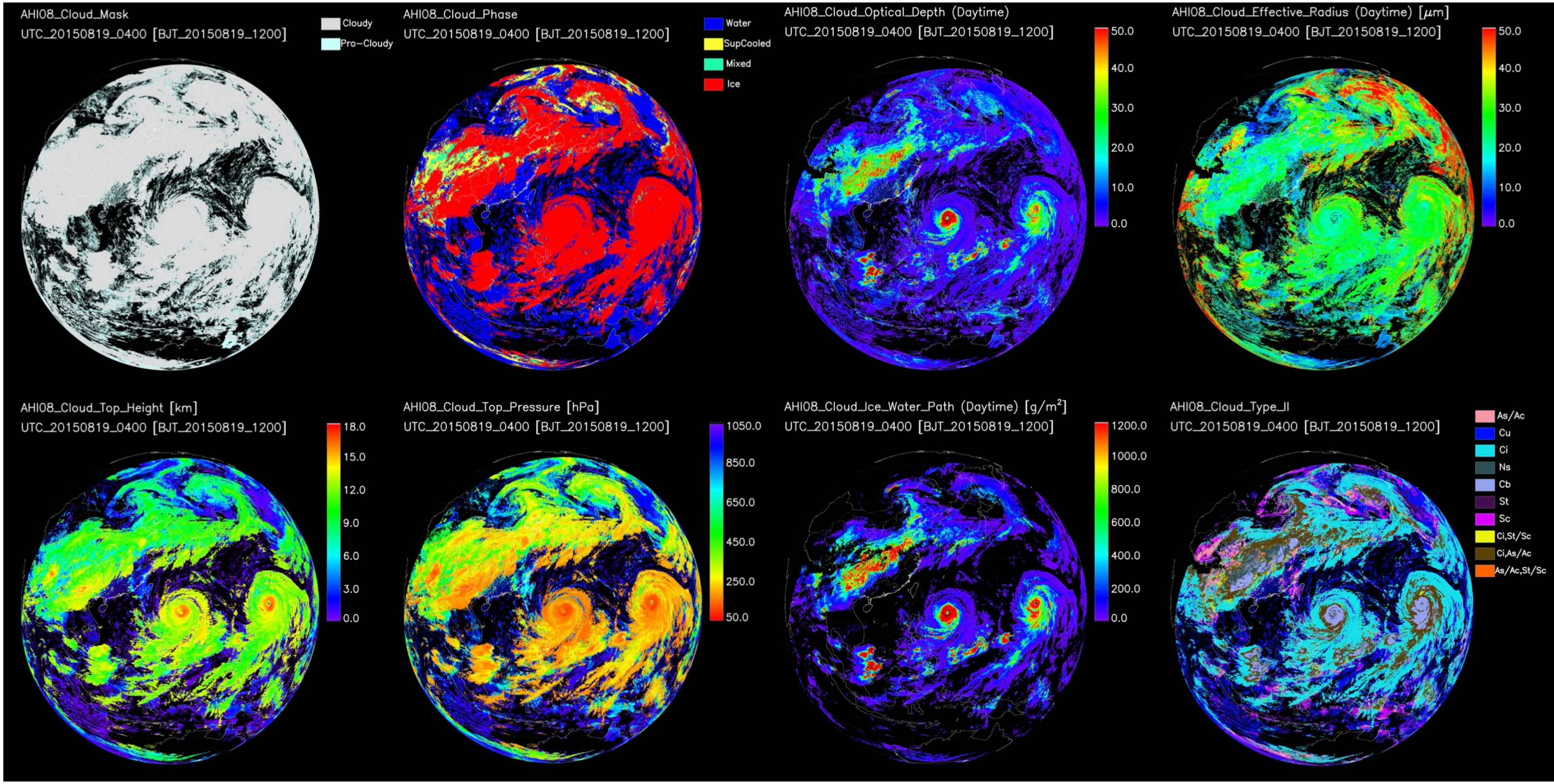
FY-3D HIRAS Derived Atmospheric Profiles



- Data between June 2018 to May 2019 are used for retrieval, validation with ERA5 reanalysis
- 1DVAR is better than regression and machine learning
- The mean temperature RMS is about 1K between 200hPa and 700hPa

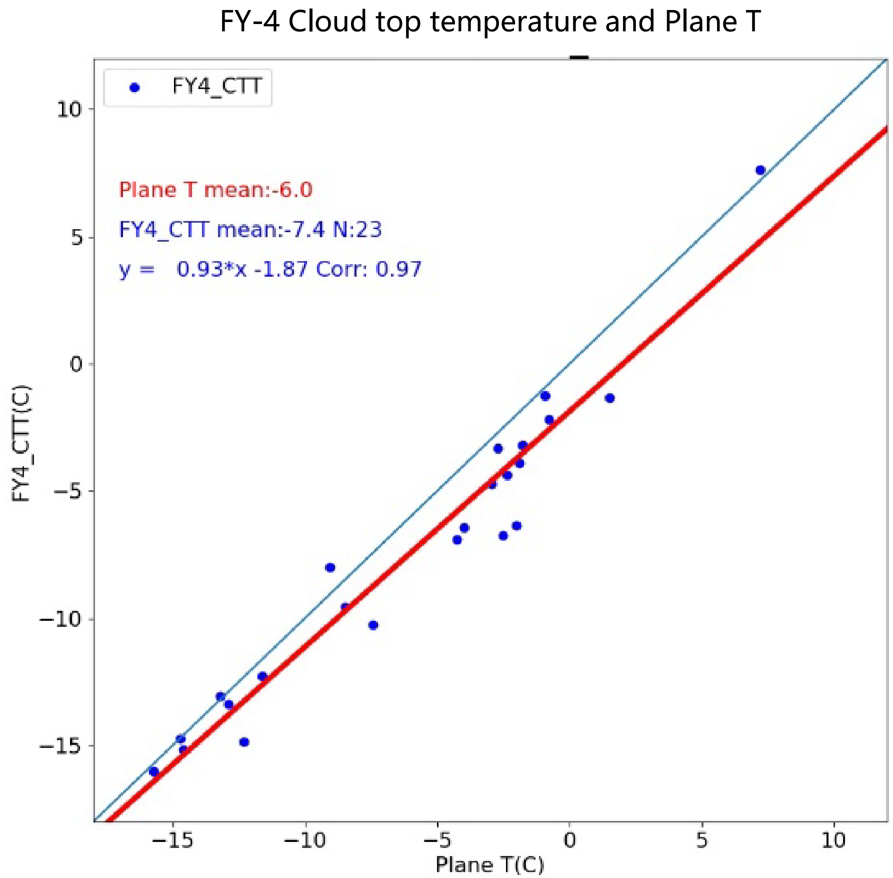
Slide courtesy of He Yanfeng, Anhui Meteorological Bureau

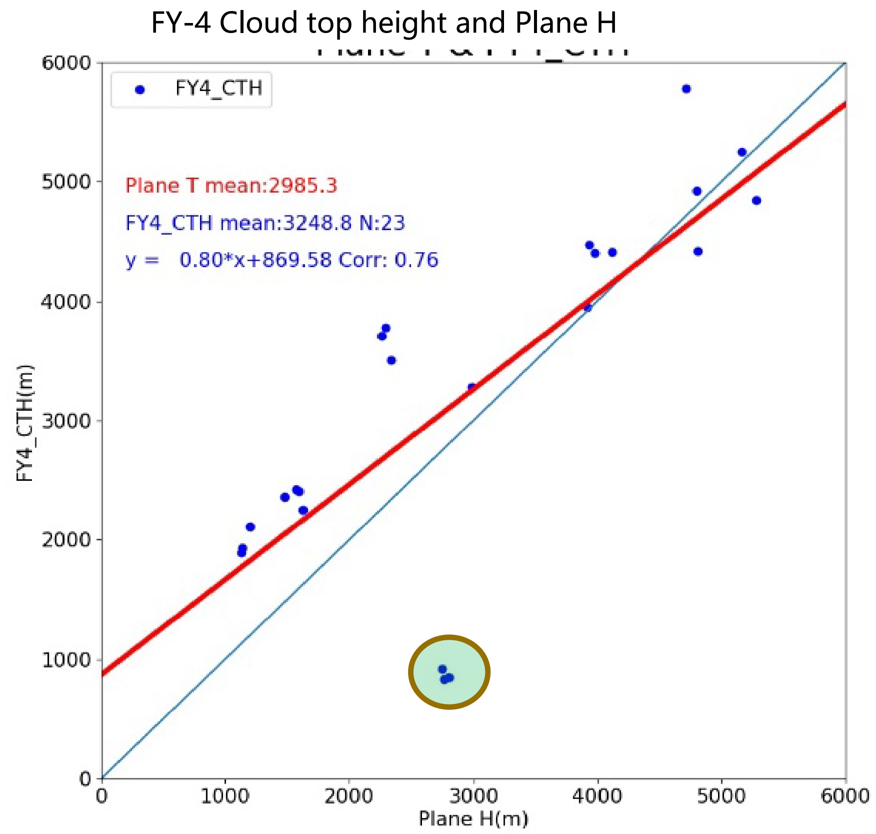
Cloud Products from FY-4A AGRI



Slide courtesy of Min Min, Sun Yet-Sun University

Validation of FY-4A AGRI Cloud Top Temperature and Height Using Aircraft Ka Radar Observation

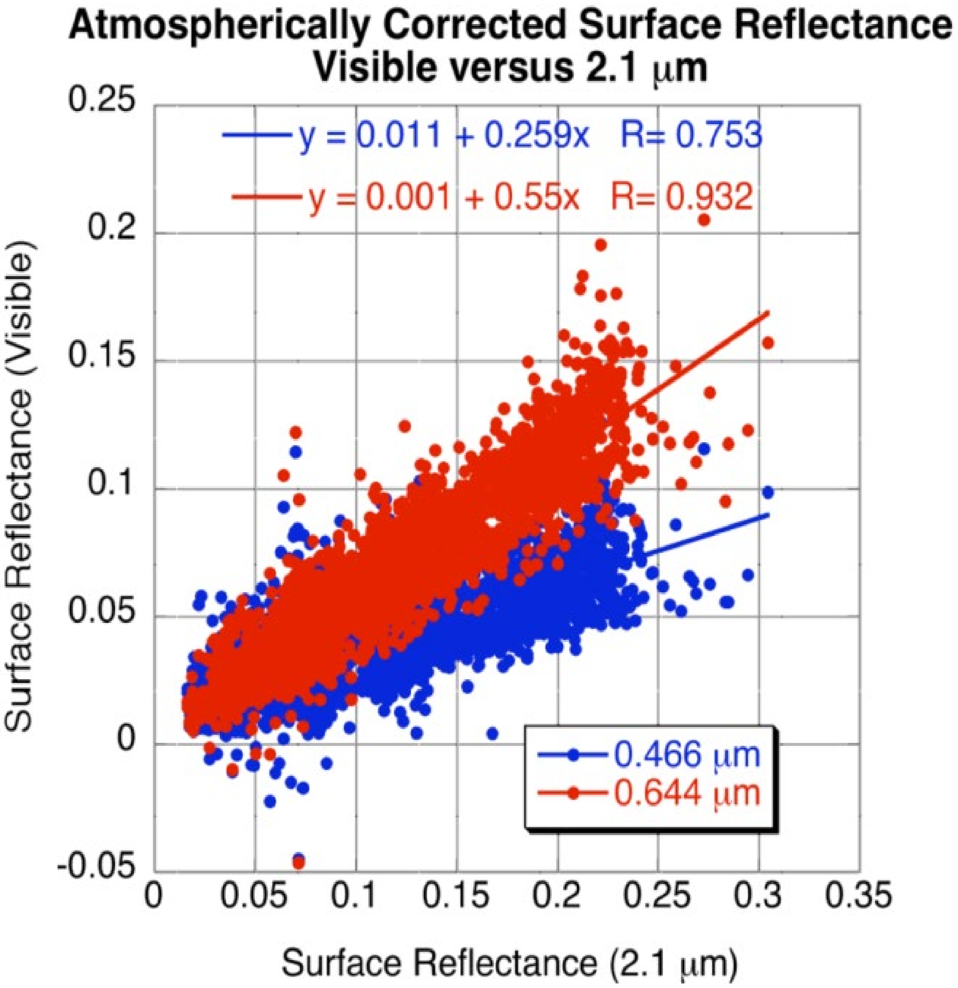




Slide courtesy of Zhou Yuqian, CAMS

FY-3D MERSI AOD Retrieval Algorithm

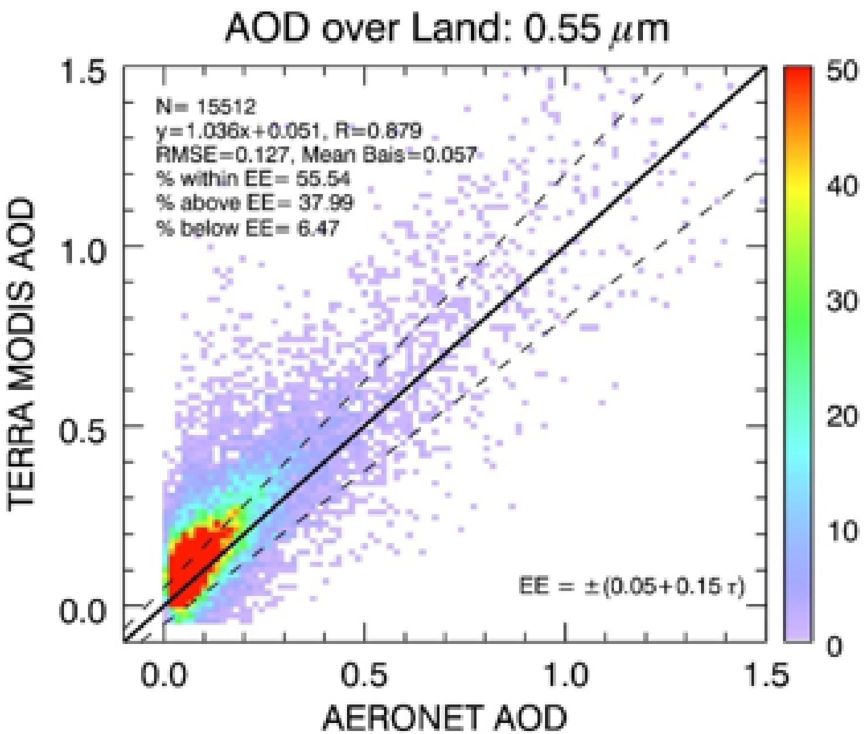
- Bands: 0.41, 0.47, 0.55, 0.66, 0.86, 1.24, 1.64, and 2.13 µm
- Ocean- dark target
  - reflectance contrast between cloud-free atmosphere and ocean reflectance (**dark**)
  - aerosol optical thickness (0.55-2.13 µm)
  - size distribution characteristics (fraction of aerosol optical thickness in the fine particle mode; effective radius)
- Land – dark target
  - dense dark vegetation and semi-arid regions determined where aerosol is most transparent (2.13 µm)
  - contrast between Earth-atmosphere reflectance and that for dense dark vegetation surface (0.47 and 0.66 µm)
  - aerosol optical thickness (0.47 and 0.66 µm)
  - fraction of aerosol optical thickness in the fine particle mode
- Land – bright target
  - Deep blue for bright reflecting surfaces using 0.41, 0.47, and 0.66 µm



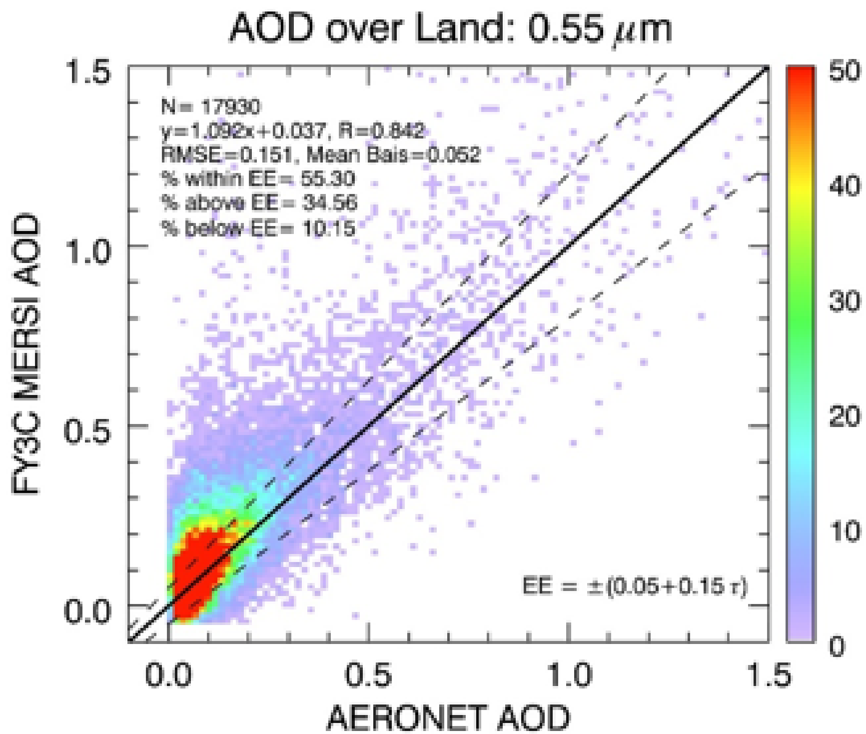
Slide Courtesy of Leiku Yang, Henan Polytechnic University

Validation of AOD Retrieved from MERSI vs. MODIS

Data period： 201406~201505



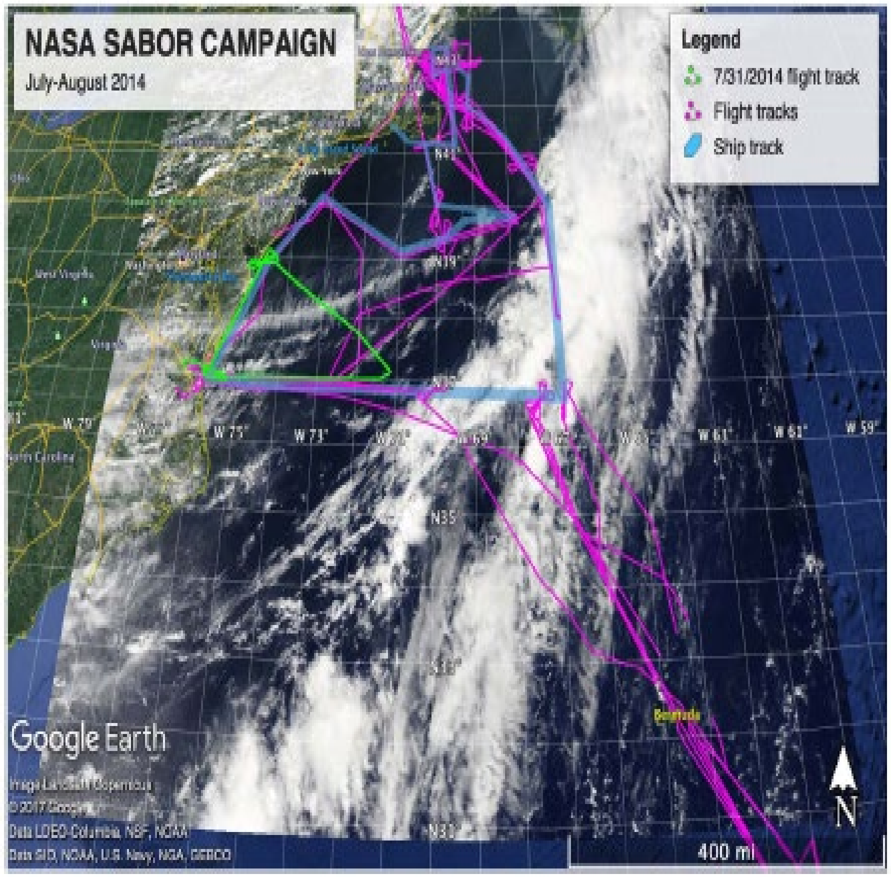
MODIS/TERRA **C6**

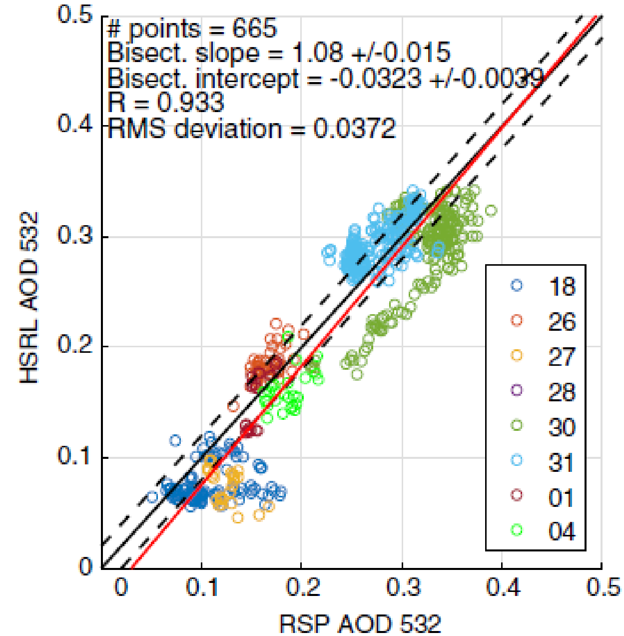


MERSI/FY3C

Slide Courtesy of Leiku Yang, Henan Polytechnic University

Validation of AOD Using Ground-Based Lidar Measurements





SABOR campaign RSP MAPP and HSRL-1 optical depth correlations at 532 nm using HSRL AOD product after a clouds-above-aircraft mask was applied. Each color represents a different day between 18 July to 4 August 2014. The one-to-one line is colored in black, and the dashed black lines represent the desired $\pm 1\sigma$ accuracy. The red line represents the least-squares bisector.

Slide Courtesy of Lei Yong, CMA/Atmospheric Sounding Center

Retrieval of Normalized Vegetation Index (NDVI) at Top of Canopy

$$\rho^{TOA}(\mu_s,\mu_v,\varphi)=T^0(\mu_s,\mu_v)\left[\rho_{R+A}^{TOA}(\mu_s,\mu_v,\varphi)+\frac{\rho_t(\mu_s,\mu_v,\varphi)}{1-\rho_t(\mu_s,\mu_v,\varphi)S}T^H(\mu_s,\mu_v)T_{R+A}^{\downarrow}(\mu_s)T_{R+A}^{\uparrow}(\mu_v)\right]$$

$\rho^{TOA}(\mu_s,\mu_v,\varphi)$: TOA reflectance

$\rho_{R+A}(\mu_s,\mu_v,\varphi)$: TOA moleccular and aerosol reflectance

$\rho_t(\mu_s,\mu_v,\varphi)$: surface reflectance

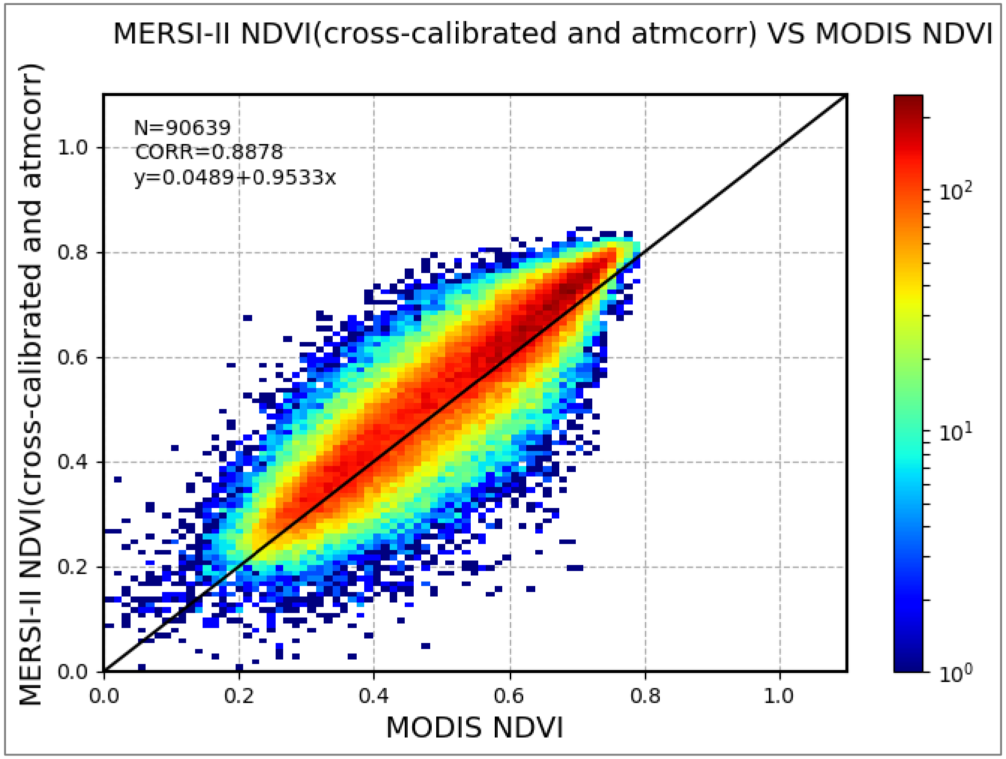
$T^0(\mu_s,\mu_v)$: ozone transmittance

$T^H(\mu_s,\mu_v)$: water vapor transmittance

$T_{R+A}^{\downarrow}(\mu_s)$: downwelling transmittance

$T_{R+A}^{\uparrow}(\mu_v)$: upwelling transmittance

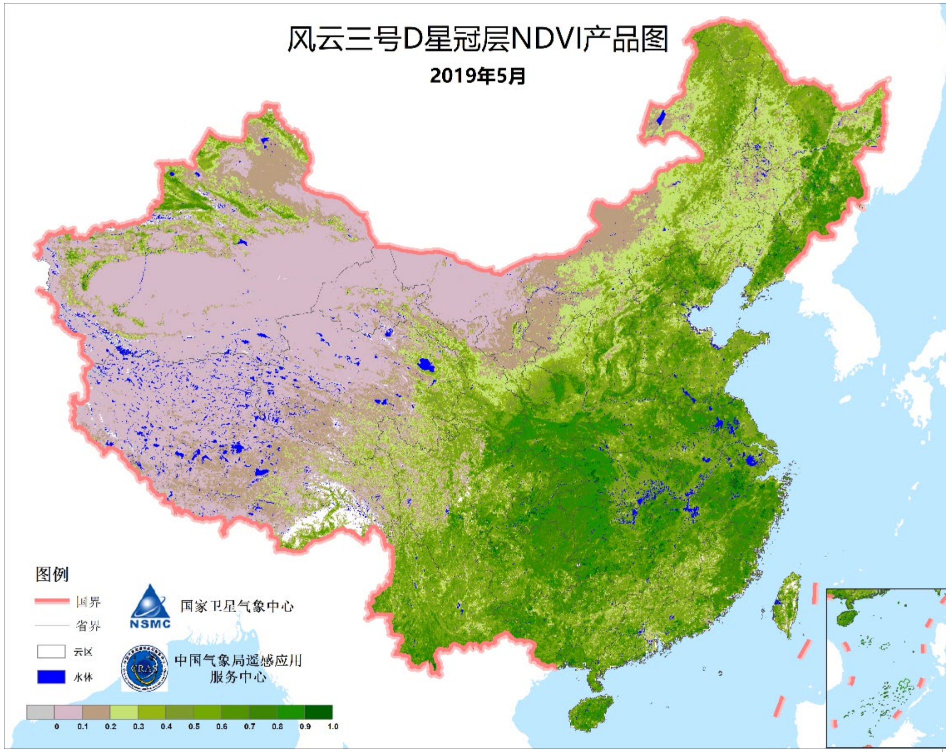
S: surface spherical albedo



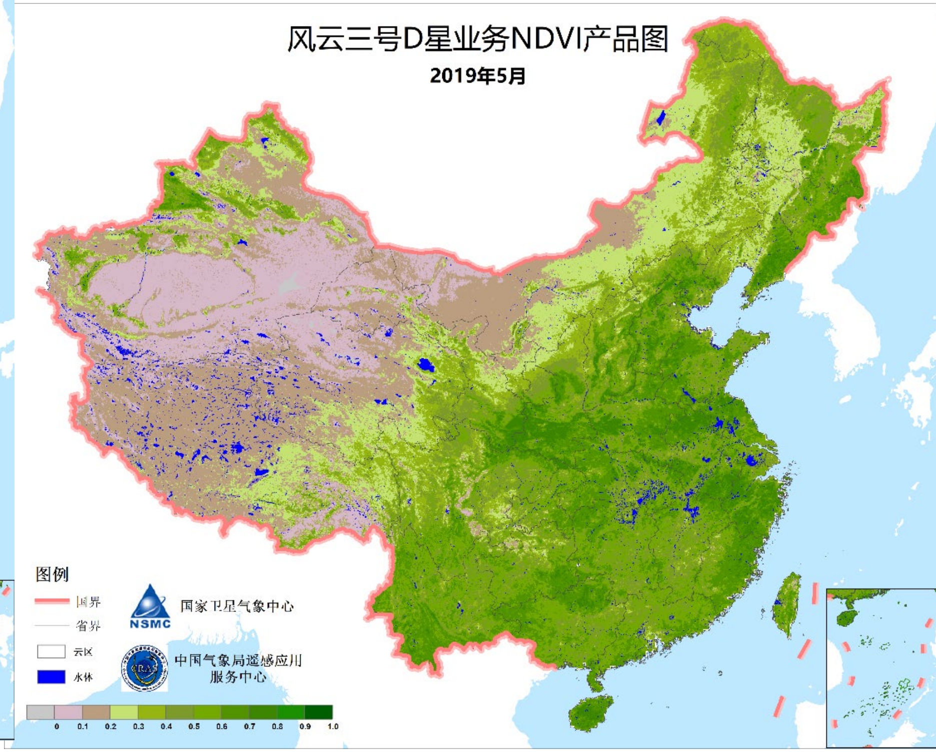
Slide courtesy of Han Xiuzhen, NSMC

FY-3D MERSI-II Derived NDVI

NDVI at TOC



NDVI at TOA



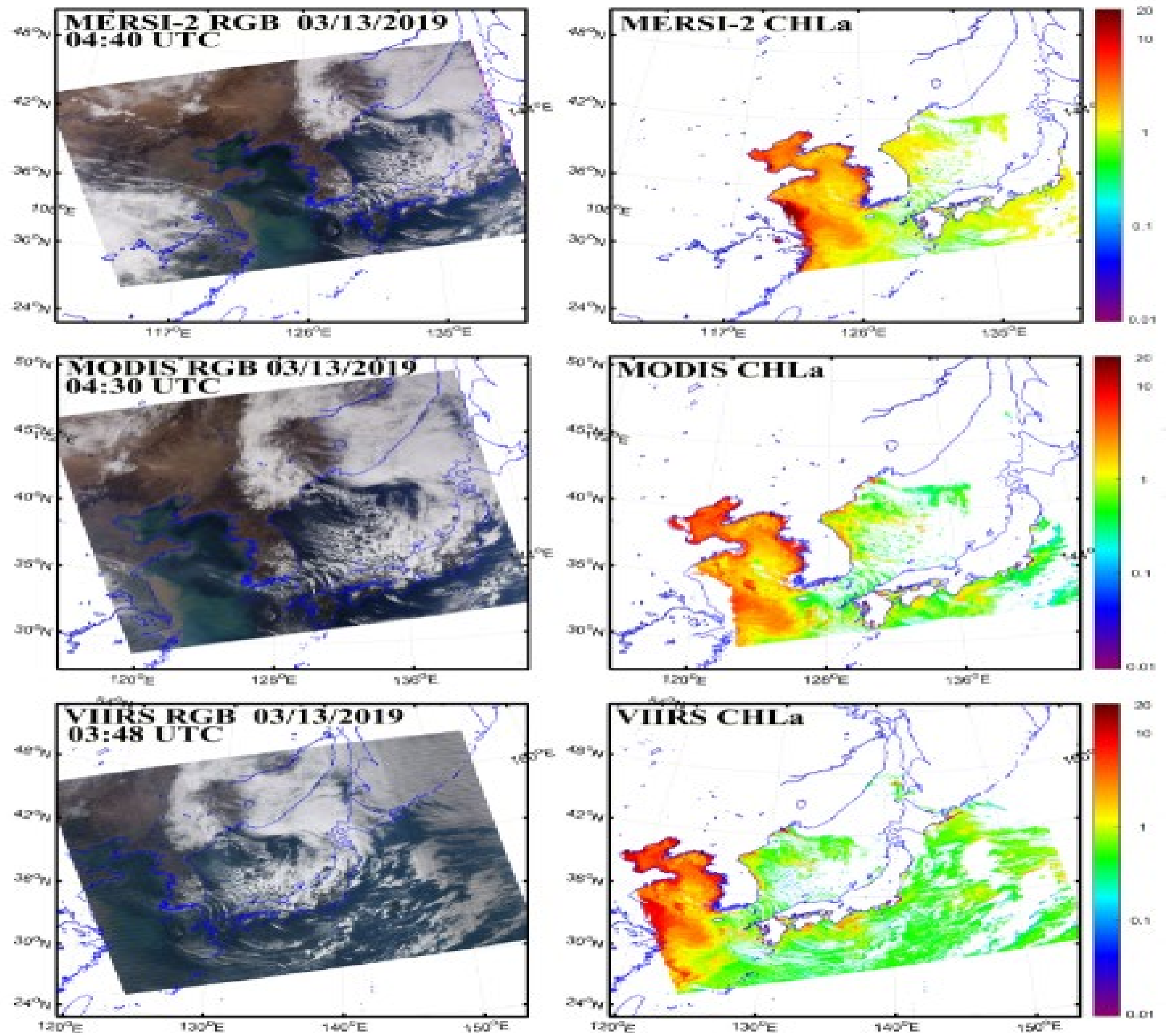
2019年5月NDVI合成图

Comparing with TOA NDVI from FengYun-3D MERSI, TOC NDVI have higher greenness in Northeast China, Jiangnan, South China, Loess Plateau and many other places

Slide courtesy of Han Xiuzhen, NSMC

Remote Sensing of Ocean Color from FY-3D MERSI-II

- OCSMART developed by Knut Stamnes was expanded for FY-3D MIRSI-II to retrieve the ocean and water quality parameters.
- Parameters include suspended matter, dissolved organic matter, chlorophyll and other substances.
- OCSMART directly relate the reflectivity of the top of the atmosphere to atmospheric and water body parameters .
- The simulation data sets including atmospheric aerosol concentration, water nutrient elements, chlorophyll concentration are used to train an ocean color algorithms through machine learning.

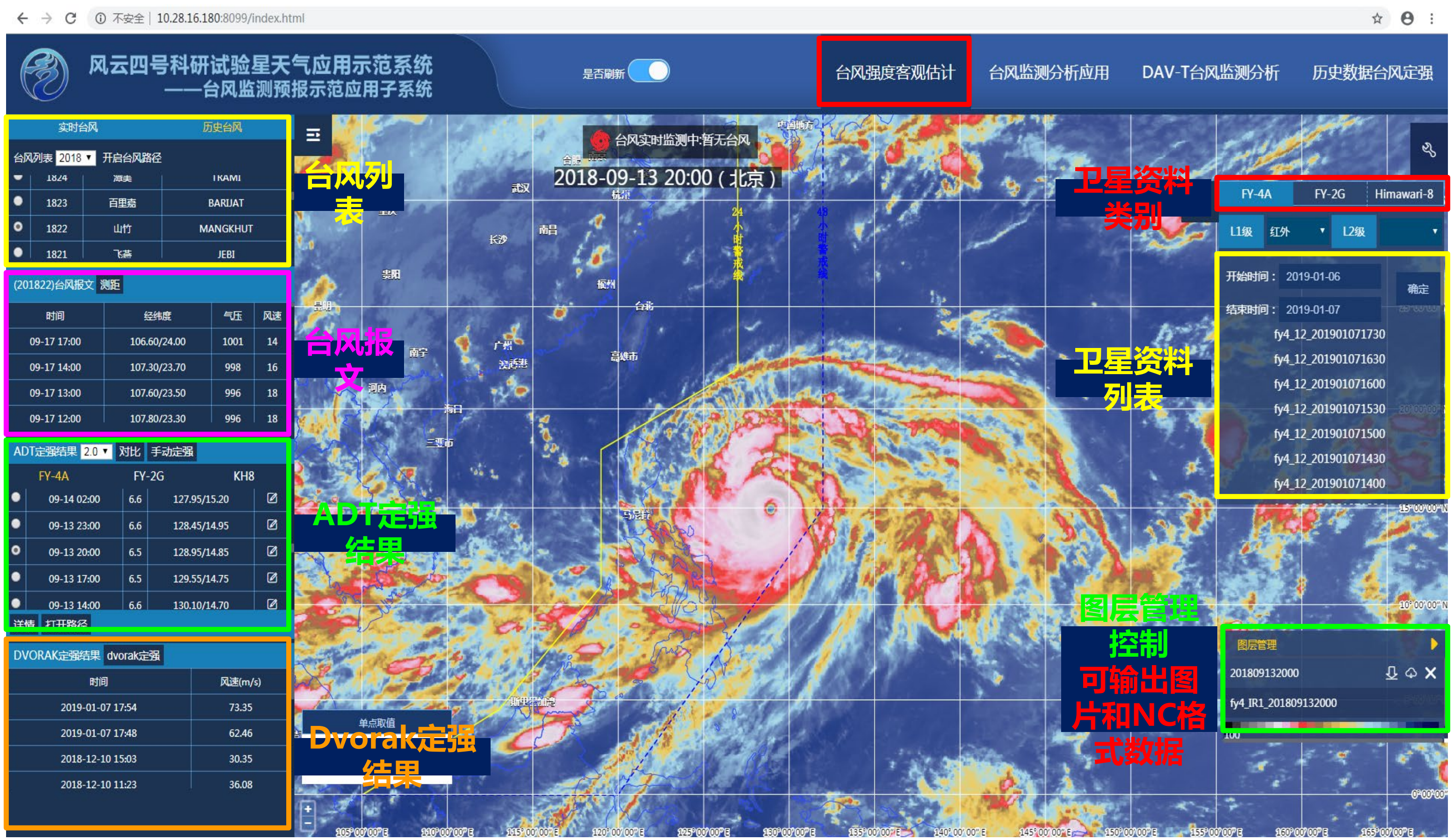


Slide courtesy of Knut Stamnes, Steven Institute of technology, New Jersey .

FengYun Satellite Application Segments and Leadership at CMA

- Severe storm monitoring (NMC-Xu Yinglong)
- Ecological monitoring and assessments (NSMC-Han Xiuzhen)
- NWP data assimilation in GRAPES (CNWP-Li Juan/Han Wei)
- Agro-meteorology applications (NMC-Wu Mengxin)
- Energy (Public Weather Service Center- Shen Yanbo)
- Climate assessments (NCC-Nie Suping)
- Weather Modification (CAMS-Zhou Yuqian)

FengYun Satellite Weather Application Demonstration System



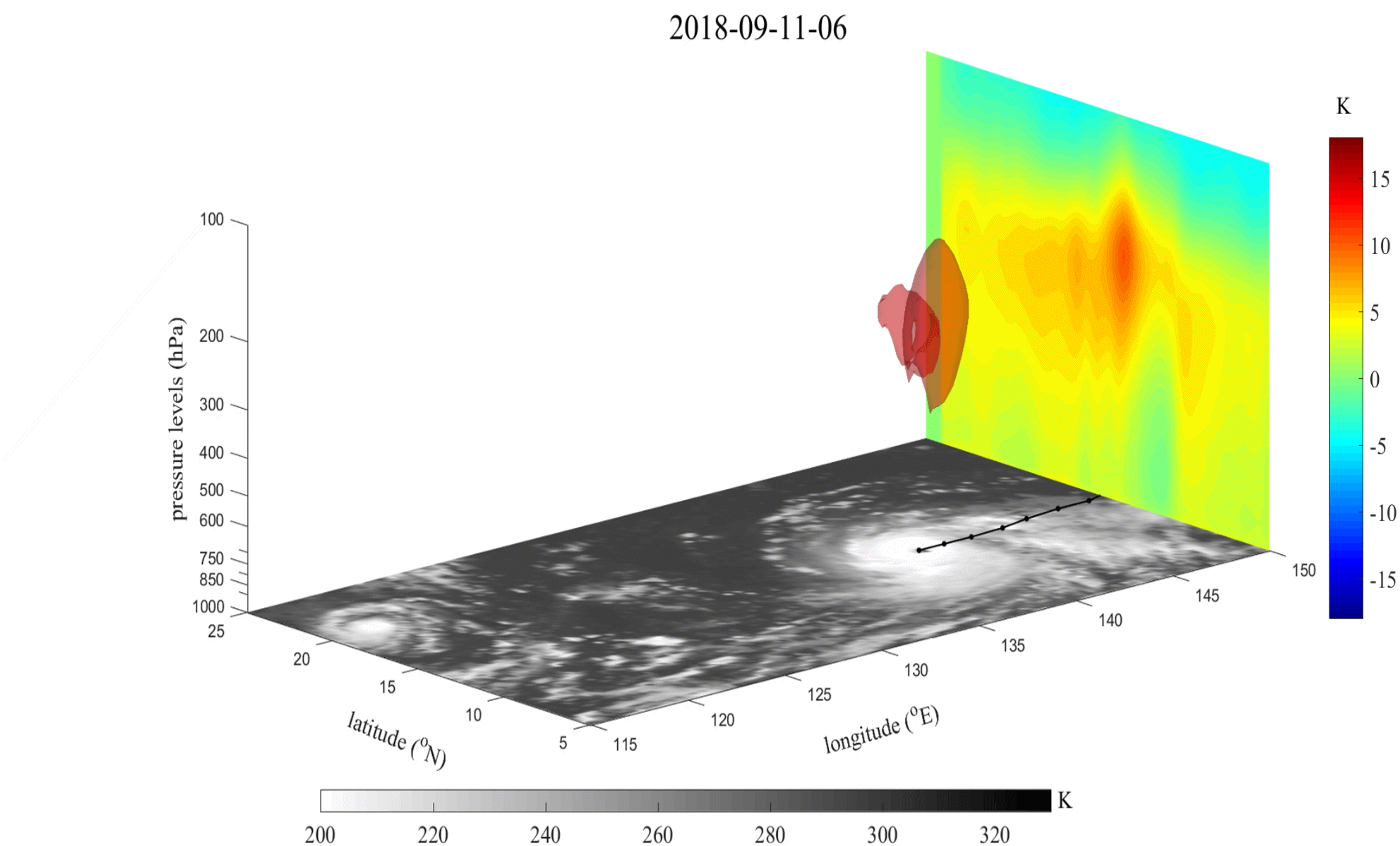
Slide courtesy of Xu Yinglong, NMC

Typhoon Intensity Errors Estimated from FY-2/4

			Typhoon Name	Best Track	New Algorithm	Difference	Data Sources
序号	年份	时间	台风/飓风中英文名称	中国气象局 美国国家飓风中心 业务或最佳路径强度（m/s）	台风强度 客观估计结果 （m/s）	台风强度 客观估计误差 （m/s）	台风强度 客观估计 所使用的卫星
1	2005	8月28日20时	卡特里娜（Katrina）	**74.5**	**72.0**	**2.5**	GRIDSAT
2	2014	7月18日14时	威马逊（Rammasun）	**72**	**69.4**	**2.6**	GRIDSAT
3	2015	10月23日08时	帕特丽夏（Patricia）	**77.1**	**79.7**	**2.6**	GRIDSAT
4	2015	10月23日20时	帕特丽夏（Patricia）	**95.1**	**87.4**	**7.7**	GRIDSAT
5	2017	8月23日11时	天鸽（Hato）	**52**	**52**	**0**	FY-2G
6	2017	8月23日11时	天鸽（Hato）	**52**	**50**	**2**	GRIDSAT
7	2017	10月21日14时	兰恩（Lan）	**58**	**58**	**0**	FY-2G
8	2017	10月21日14时	兰恩（Lan）	**58**	**52**	**6**	HIMAWARI-8
9	2017	9月20日02时	玛莉亚（Maria）	**74.5**	**72.0**	**2.5**	GRIDSAT
10	2017	9月20日08时	玛莉亚（Maria）	**77.1**	**79.7**	**2.6**	GRIDSAT
11	2018	9月12日08时	山竹（Mangkhut）	**65**	**60**	**5**	FY-4A
12	2018	9月13日20时	山竹（Mangkhut）	**65**	**60**	**5**	FY-4A
13	2018	9月14日02时	山竹（Mangkhut）	**65**	**60**	**5**	FY-4A
14	2018	10月24日02时	玉兔（Yutu）	**50**	**52.4**	**2.4**	FY-4A
15	2018	10月24日08时	玉兔（Yutu）	**60**	**62.8**	**2.8**	FY-4A
16	2018	10月24日14时	玉兔（Yutu）	**70**	**72.0**	**2**	FY-4A
17	2018	10月24日20时	玉兔（Yutu）	**72**	**76.6**	**4.6**	FY-4A
18	2018	10月25日02时	玉兔（Yutu）	**68**	**76. 6**	**8.6**	FY-4A
19	2018	10月25日08时	玉兔（Yutu）	**65**	**69.3**	**4.3**	FY-4A
20	2018	10月26日08时	玉兔（Yutu）	**58**	**61.6**	**3.6**	FY-4A
21	2018	10月27日20时	玉兔（Yutu）	**62**	**65.3**	**3.3**	FY-4A
22	2018	10月28日02时	玉兔（Yutu）	**60**	**66.6**	**6.6**	FY-4A
23	2018	10月28日08时	玉兔（Yutu）	**58**	**65.3**	**7.3**	FY-4A
平均误差						**3.9**	

Slide courtesy of Xu Yinglong, NMC

Monitoring Typhoon Mangkhut Warm Core Evolution Using FY-3D MWTS and MWHS



Himawari-8 Band 13 (10.4 µ m) Brightness Temperature (K)

Slide courtesy of Hu Hao, CAMS

Assessing Ecological Condition

Technical Criterion from Ministry of Ecology and Environment (MEE)

生态环境状况评价技术规范(生态环境部, HJ192-2015)

$$EI = 0.35 \times BRI + 0.25 \times VCI + 0.15 \times WNDI + 0.15 \times (100 - LSI) + 0.10 \times (100 - PLI) + ERI$$

where

BRI: biological richness index, 0-100

VCI: vegetation coverage index, 0 - 100

WNDI: water network denseness index, 0 -100

LSI: land stress index, 0 - 100

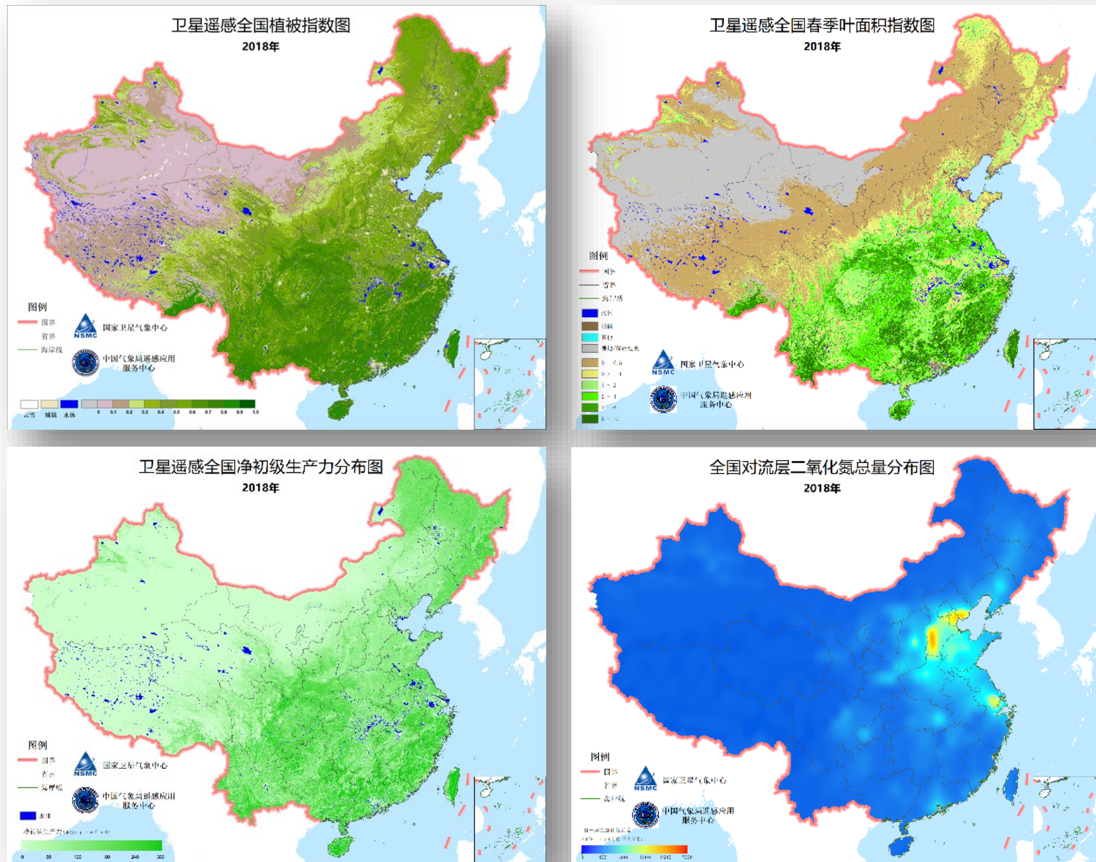
PLI: pollution load index, 0 - 100

ERI: environmental restriction index reflecting a major ecological destruction and heavy environmental pollution

An area with high biodiversity and biological richness, good vegetation cover, more water, less land stress and pollution is in a good ecosystem condition

Critical EDRs for Ecological Assessments

- Vegetation coverage
- Vegetation net primary productivity
- Soil moisture
- Land surface type
- Land surface temperature
- Air quality products (AOD, PM2.5, O3)

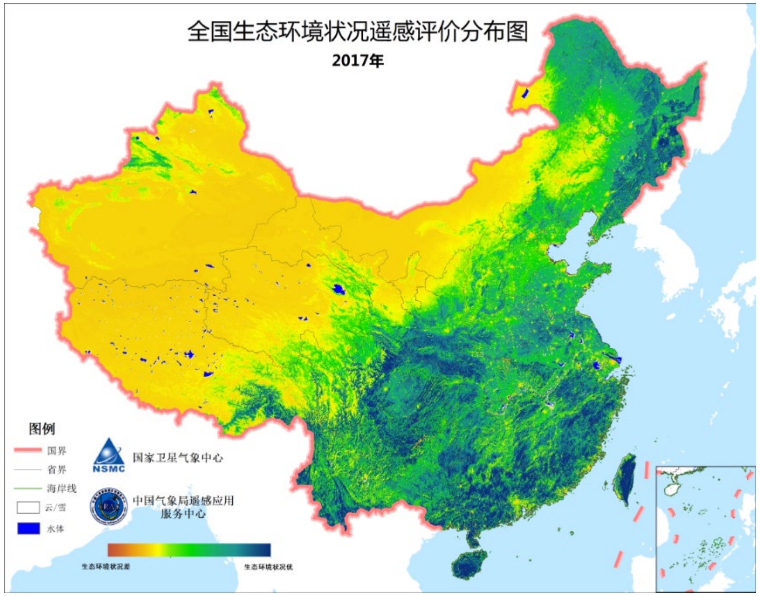


Slide courtesy of Han Xiuzhen et.al, NSMC

Ecological Index (EI) from MODIS Products

$$EI_{EOS} = -0.0565 \times LST + 0.5926 \times F + 0.7086 \times NDVI + 0.3305 \times NPP - 0.1828 \times VPDI + 0.028 \times LUCC$$

In the formula, EI is the ecological environment condition index, LST is the surface temperature, F is the greenness index, NDVI is the normalized vegetation index, NPP is the net primary productivity, VPDI is the drought index, and LUCC is the land use type.



Slide courtesy of Han Xiuzhen et.al, NSMC

- The principal component analysis is performed for each parameter and the first PCA component is used to determine the contribution of each parameter to EI. This weight setting is stable.

- Notice the coefficients of greenness degree, vegetation index and NPP are all positive, indicating that they jointly contribute positively to better ecology; while the coefficients of heat (surface temperature) and dryness (soil moisture) are negative, indicating that they have a negative impact on the ecological environment

Assimilation of FY Data in CMA Global and Regional Assimilation and Prediction System (GRAPES)

Instrument Name

- MicroWave Temperature Sounder (MWTS)
- MicroWave Humidity Sounder (MWHS)
- MicroWave Radiation Imager (MWRI) – In Operation
- GNSS Radio Occultation Sounder (GNOS)
- Hyperspectral Infrared Atmospheric Sounder (HIRAS)
- Advanced Geosynchronous Radiation Imager (AGRI)
- Geosynchronous Infrared Interferometric Sounder (GIIRS)

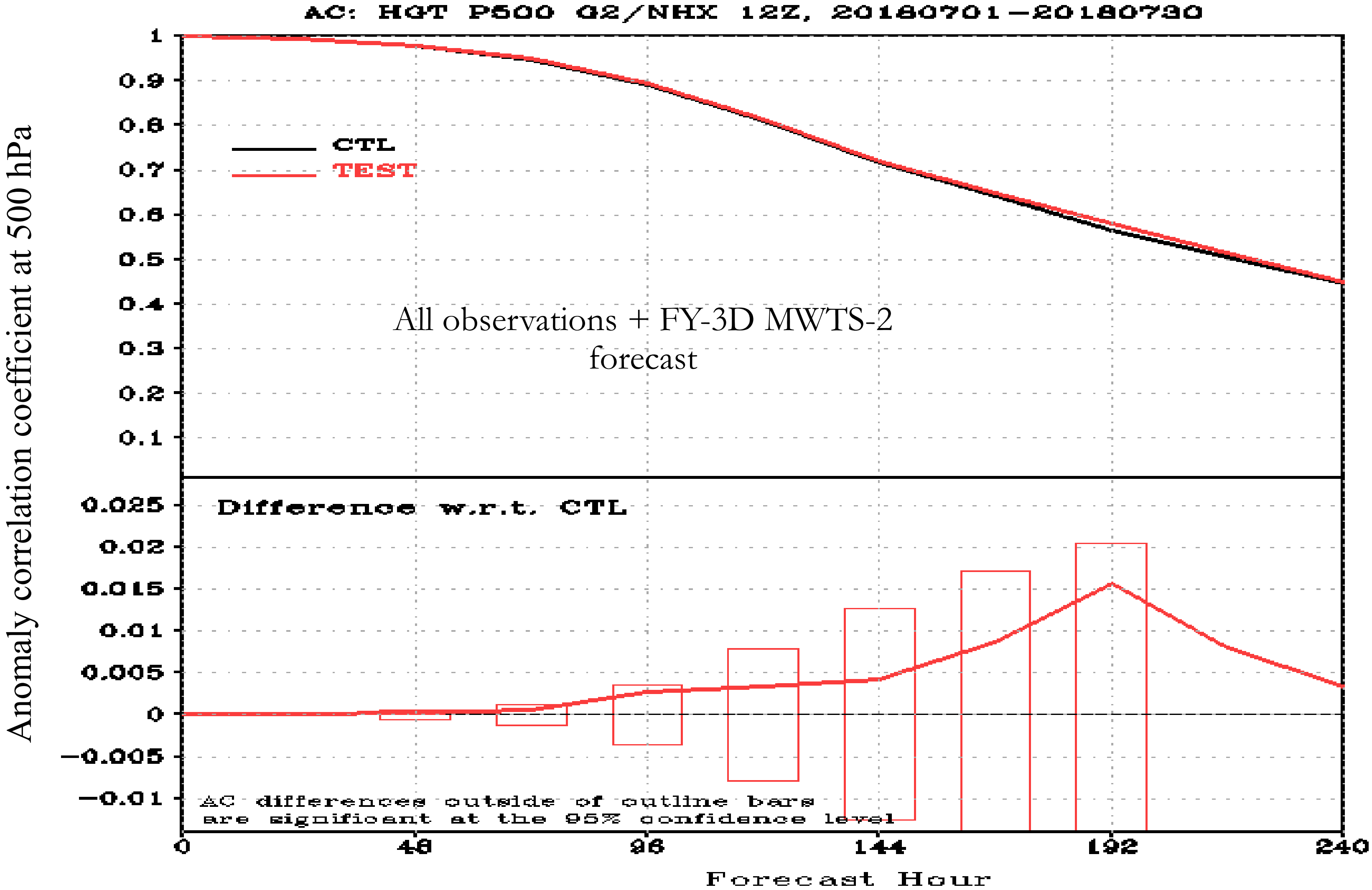
Status in GRAPES

- operationally used
  - ✓ MWHS-2 (FY-3C/D)
  - ✓ GNOS (FY-3C)
  - ✓ GIIRS (FY-4A)
  - ✓ AMV(FY-2D/E/G)
- to be operationally used soon
  - ➢ GNOS (FY-3D)
  - ➢ HIRAS (FY-3D)
  - ➢ MWTS-2 (FY-3D)
  - ➢ MWRI (FY-3C/D)
- on-going research
  - ○ AGRI(FY-4A)

Slide courtesy of Li Juan, CMA NWPC.

Assimilation of FY-3D MWTS Data in GRAPES

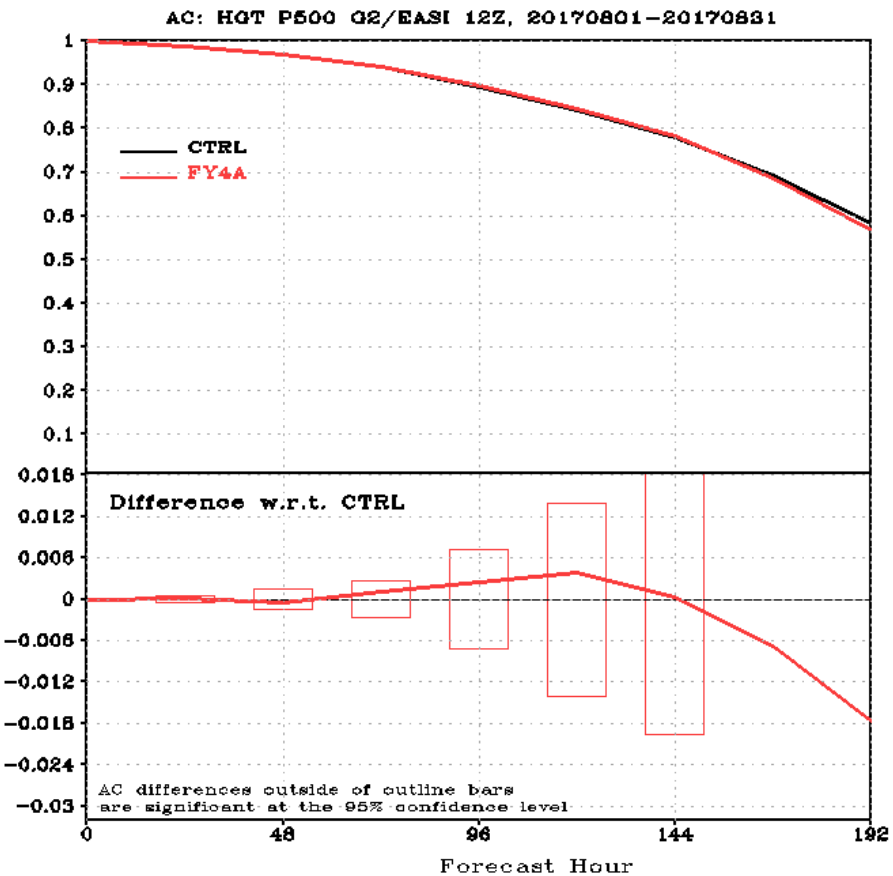
Neutral to positive impact

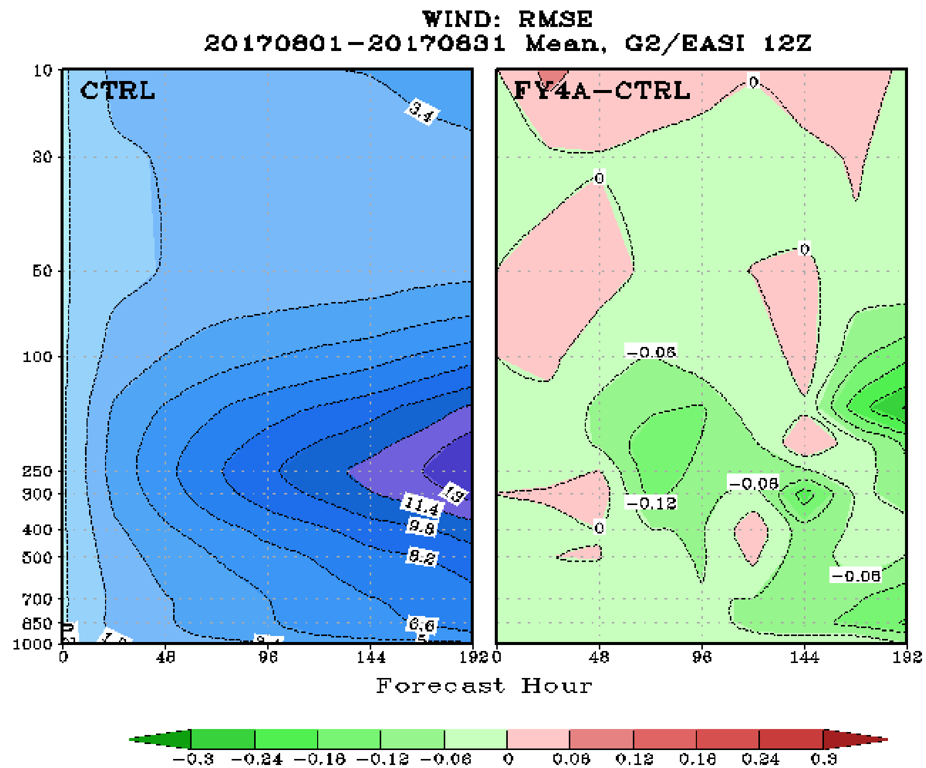


Slide courtesy of Li Juan, CMA NWPC.

FY-4A GIIRS Impacts in GRAPES 4DVAR

GRAPES global 4D-Var
CTRL ： OPER
GIIRS ： OPER+GIIRS Temp. Sounding





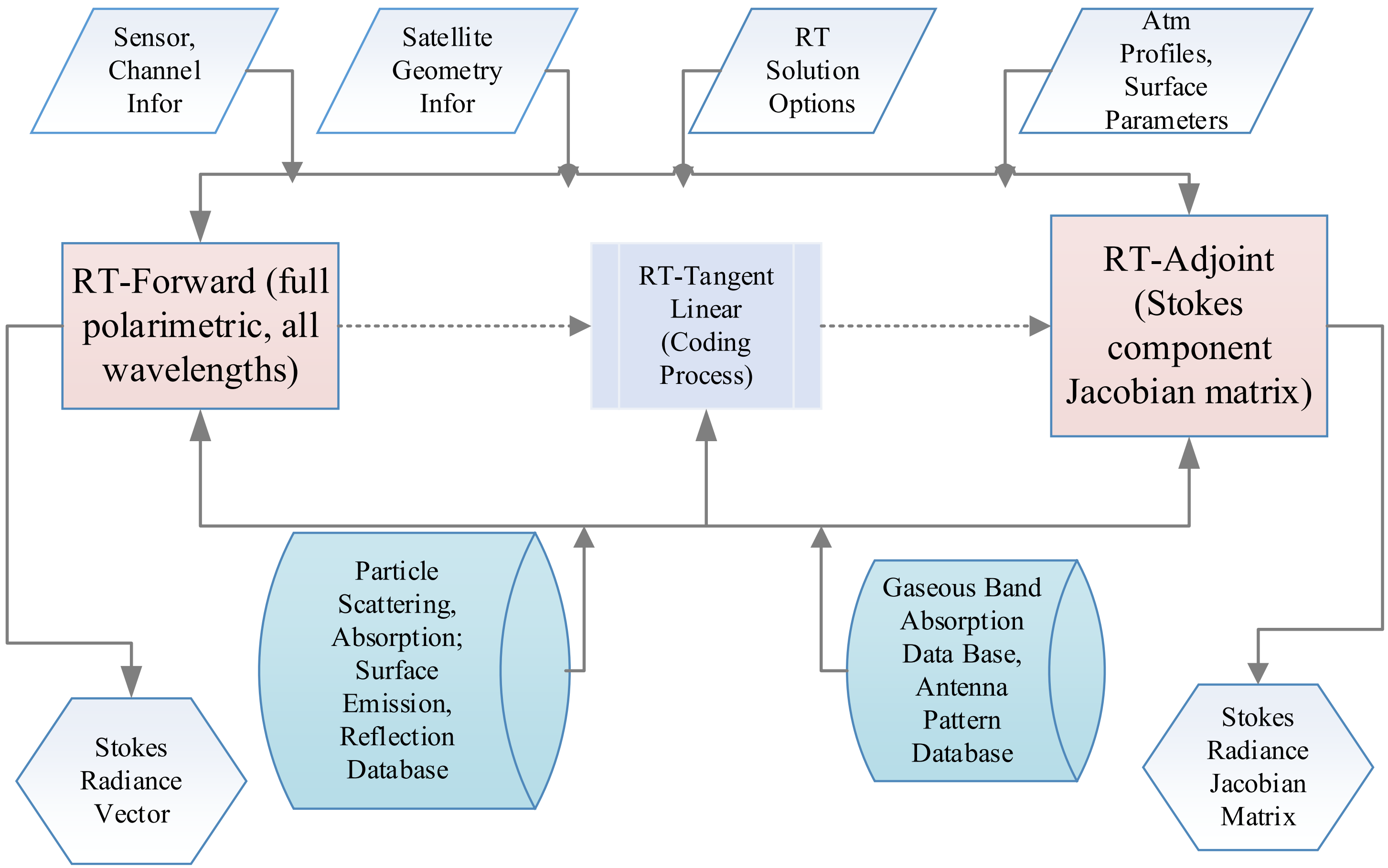
Impact on wind RMSE (green mean reduction)

Slide courtesy of Han Wei, CMA NWPC.

Accelerating Research to Operation in FengYun Satellite Programs

- Transition the Advanced Radiative Transfer Modeling System (ARMS) to NWP data assimilation
- Transition the multisensor remote sensing testbed for FY atmospheric sounding
- Use FY microwave products in NMC system to enhance the typhoon monitoring capability
- Generate the long-term NDVI data records from FY series of instruments and connect with EOS and NOAA NDVI data records
- Develop comprehensive techniques for assessing the ecological conditions and functions

Advanced Radiative Transfer Modeling System (ARMS）



ARMS is designed with the state-of-the art radiative transfer sciences, cutting edge software engineering, and flexible interfaces with other fast models. It will serve for many CMA applications including NWP data assimilation, satellite ground processing in instrument calibration and environmental parameters

Weng, F., X. Yu, Y. Duan, J. Yang, J. Wang, AAS, 2019

2019 International Workshop on Radiative Transfer Model for Satellite Data Assimilation, Tianjin, China

On April 29 to May 3, 2019, CMA, EMCWF and JCSRA jointly hosted a joint workshop on radiative transfer models for satellite data assimilation at Tianjin, China. More than 100 scientists from China, US, UK, Germany and Japan attended the workshop.

A science steering committee for radiative transfer (SSC4RT) was formed and 9 distinguished scientists are selected as SSC members. Several critical actions will be taken after the workshop.

The participants reported the major progresses in developing the fast radiative transfer models for satellite data assimilations. In past, the NWP community primarily uses RTTOV (Europe) and CRTM (US). Now, China is developing the Advanced Raditaive Transfer Modeling System (ARMS) for Chinese satellite data applications. The SSC recognized the significance of ARMS and will be the third pillar, after RTTOV and CRTM.

National and Regional Remote Sensing Service

China National Remote Sensing Operational Framework

National Remote Sensing Operational Products and Service

- Chinese Remote Sensing Product Requirements and Quality Assurance
- Operational Products Generation, Proving Ground Demonstration and Transition to Operation
- National Unified Operational Service Platform
- Satellite data reception, quality control and data sharing service
- Major technology Advances, Ground-Based Validation
- International User Services and Technical Exchange

National Remote Sensing Operational Consultation and Discussions

Provincial Special Remote Sensing Operational Service

Province	Proving Ground Center	Theme
XiZang Guizhou	Mountain and High Plain District Ecological Remote Sensing Proving Ground Center	Mountain
GuangDong ChongQing	Ocean, River-bank District Ecological Remote Sensing Proving Ground Center	Water
HeiLong Jiang, Guangxi, Fujian	Forest Ecology Remote Sensing Proving Ground Center	Forest
HeNan, Shan Dong	Cropland Ecological Remote Sensing Proving Ground Center	Cropland
HuNan, JiangSu	Water Ecological Remote Sensing Proving Ground Center	Lake
Inner Mogolia, QingHai	Grassland Ecological Remote Sensing Proving Ground Center	Grassland
ShangHai, HeBei	Atmospheric Environment Ecological Remote Sensing Proving Ground Center	Atmosphere
XinJiang, LiaoNing	Desert snow wetland Ecological Remote Sensing Proving Ground Center	Land
BeiJing	City Ecology Remote Sensing Proving Ground Center	City

Provincial Remote Sensing Service	Service Area	International Service
Plan local remote sensing service	Agriculture	"Belt & Road"
Provincial remote sensing data acquisition and data service	Forest	Asean
Local evaluation and applications of national-level products and local feedbacks	Water Resources	Shanghai-Agreement
Develop special remote sensing application, product and service enhancement	Ecological Environment	China Arabian
Provincial-level guidance to local government, technical support and training	Academia and University	China-Africa
	…...	……

Assessing Ecological Function: Wind Prevention and Sand Fixation - 防风固沙

Technical Criterion of Ecosystem Status Evaluation

生态环境状况评价技术规范(环境保护部, HJ192-2015)

EC_{wpsf}= 0.60*[0.24*vegetation coverage index + 0.1*protected area ratio*100+0.22*forest area ratio + 0.22 * water and wet land area ratio + 0.14*(100-farm and construction land area ratio*100) + 0.10*(100-land desertification area ratio*100] + 0.40*[0.45*(100-major pollutant emission intensity)+0.10*rate of pollutant emission meeting the standard*100+0.10*city polluted water collective processing rate*100+0.15*rate of water quality reaching the standard*100+0.15*rate of air quality reaching the standard*100+0.05*rate of collective drinking water source reaching the standard *100]

Assessing Ecological Function: Water and Soil Conservation -水土保持

Technical Criterion of Ecosystem Status Evaluation

生态环境状况评价技术规范(环境保护部, HJ192-2015)

EC_{wsc} = 0.60*[0.23*vegetation coverage index + 0.13*protected area ratio*100+0.23*forest area ratio + 0.18 * water and wet land area ratio + 0.13*(100-farm and construction land area ratio*100) + 0.10*(100-moderate to high land desertification area ratio*100] + 0.40*[0.45*(100-major pollutant emission intensity)+0.10*rate of pollutant emission meeting the standard*100+0.10*city polluted water collective processing rate*100+0.15*rate of water quality reaching the standard*100+0.15*rate of air quality reaching the standard*100+0.05*rate of collective drinking water source reaching the standard *100]

Assessing Ecological Function: Water Conservation -水源涵养

Technical Criterion of Ecosystem Status Evaluation

生态环境状况评价技术规范(环境保护部, HJ192-2015)

EC_{wc} = 0.60*[0.25*water conservation index + 0.20*protected area ratio*100+0.15*forest area ratio + 0.10*grass area ratio+0.15 water and wet land area ratio + 0.15*(100-farm and construction land area ratio*100)] + 0.40*[0.45*(100-major pollutant emission intensity)+0.10*rate of pollutant emission meeting the standard*100+0.10*city polluted water collective processing rate*100+0.20*rate of water quality reaching the standard*100+0.10*rate of air quality reaching the standard*100+0.05*rate of collective drinking water source reaching the standard *100]+ecological capability adjustment index

Assessing Ecological Function: Biodiversity Conservation -生物多样性维护

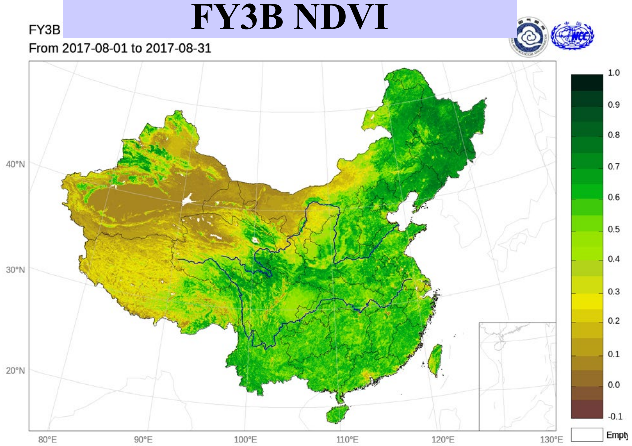
Technical Criterion of Ecosystem Status Evaluation

生态环境状况评价技术规范(环境保护部, HJ192-2015)

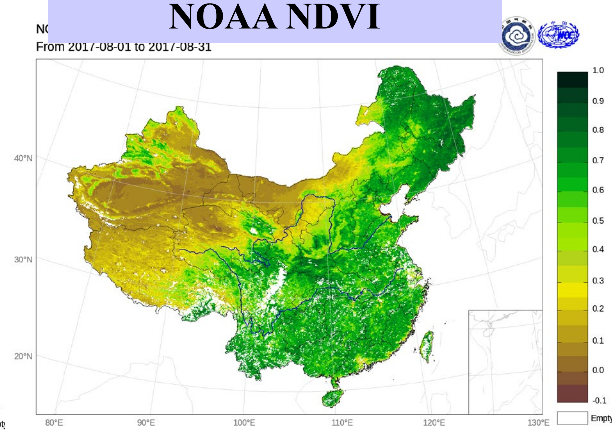
EC_{bc} = 0.60*[0.23*biological richness index + 0.20*protected area ratio*100+0.15*forest area ratio + 0.10*grass area ratio+0.15 water and wet land area ratio + 0.15*(100-farm and construction land area ratio*100)] + 0.40*[0.45*(100-major pollutant emission intensity)+0.10*rate of pollutant emission meeting the standard*100+0.10*city polluted water collective processing rate*100+0.20*rate of water quality reaching the standard*100+0.10*rate of air quality reaching the standard*100+0.05*rate of collective drinking water source reaching the standard *100]+ecological capability adjustment index

Mission Dependent NDVI Products

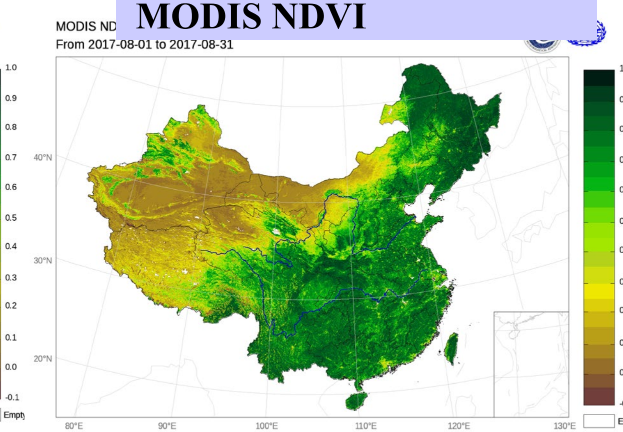
FY3B NDVI



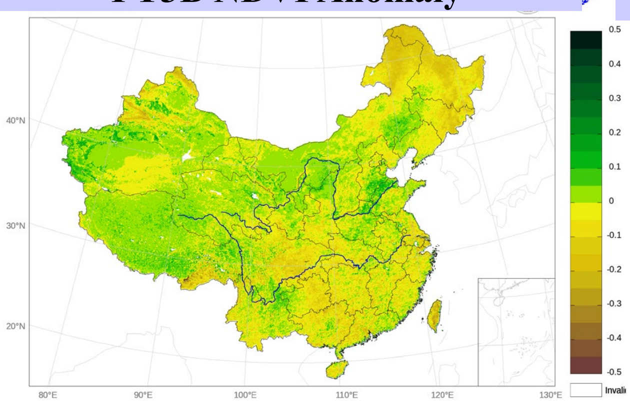
NOAA NDVI



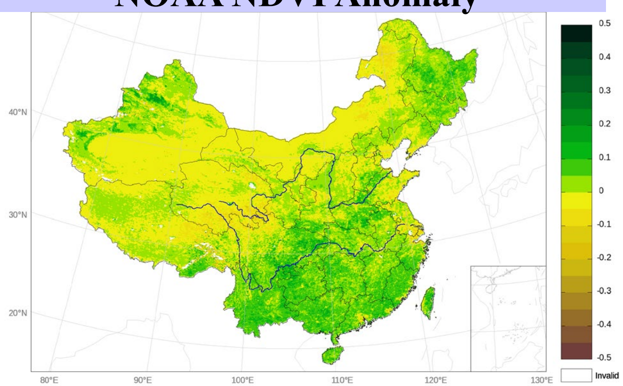
MODIS NDVI



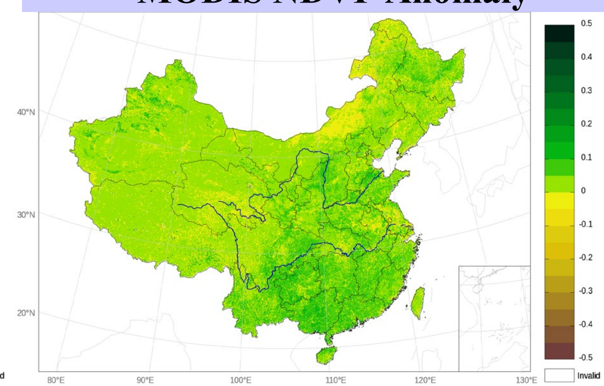
FY3B NDVI Anomaly



NOAA NDVI Anomaly



MODIS NDVI Anomaly



Assessing ecology conditions from different satellite missions could be significantly different.

Slide courtesy of Nie Suping, NCC

A JMR Special Issue for Satellite Ecological Remote Sensing

JMR征稿：卫星生态遥感与应用专刊

JMR-CMS 气象学报英文版JMR 4月17日

Journal of Meteorological Research

专刊征文启事

题目：卫星生态遥感与应用

Satellite Ecological Remote Sensing and Applications

近十年，卫星观测已广泛用于生态环境监测。2018年生态遥感年报首次提出2000年至2017年全国植被覆盖率增加3.7%。同时，全国及重点区域气溶胶光学厚度相对于16年的平均值下降了19.3%。2018年2月12日，美国航天局推特报告指出，"世界变得比20年前更绿了"，"来自'NASA地球'的卫星资料显示，是中国和印度的人类活动主导了地球变绿！"。过去，人们怀疑从卫星观测得到的地球变绿可能与卫星仪器性能衰变或一系列卫星数据衔接不良造成的结果。本期专刊将介绍用于国家生态监测的最先进的卫星遥感反演算法和产品应用。为这一专刊投稿的作者多是来自卫星仪器定标，产品算法反演和应用的研究业务一线专家和骨干。该专刊将为气象卫星生态遥感与环境监测奠定坚实的基础，并将推动气象卫星在国家生态文明建设中的应用，部分文章还将深入研究中国生态变化与天气和气候变化的关系。

Papers for this special issue are solicited for, although not limited to, the following topics:

1. Remote sensing fundamentals of land and ocean products from satellites.
2. Atmospheric air quality products from satellites.
3. Applications of satellite derived products for monitoring of ecological environment.
4. Impacts of meteorological conditions and climate variability on ecology.

Slide courtesy of Yi Lan, JMR

Summary and Conclusions

- Innovative algorithms are being tested for Fengyun satellites and generate the products with a quality similar or better than those from other missions.

- Many of Fengyun satellite application facilities have been established at CMA and research institutes, making very impressive progresses.

- FengYun satellite program requires developments of critical sciences and technologies such as fast and accurate radiative transfer models, advanced data assimilation system, severe weather monitoring, and ecological assessment tools, etc

- Uses of FY satellite for ecological assessments are unique and reflect China's national priority (“绿水青山就是金山银山”- Lucid Waters and Lush Mountains are Invaluable Assets)