

# Assimilation of high temporal GIIRS radiance in GRAPES

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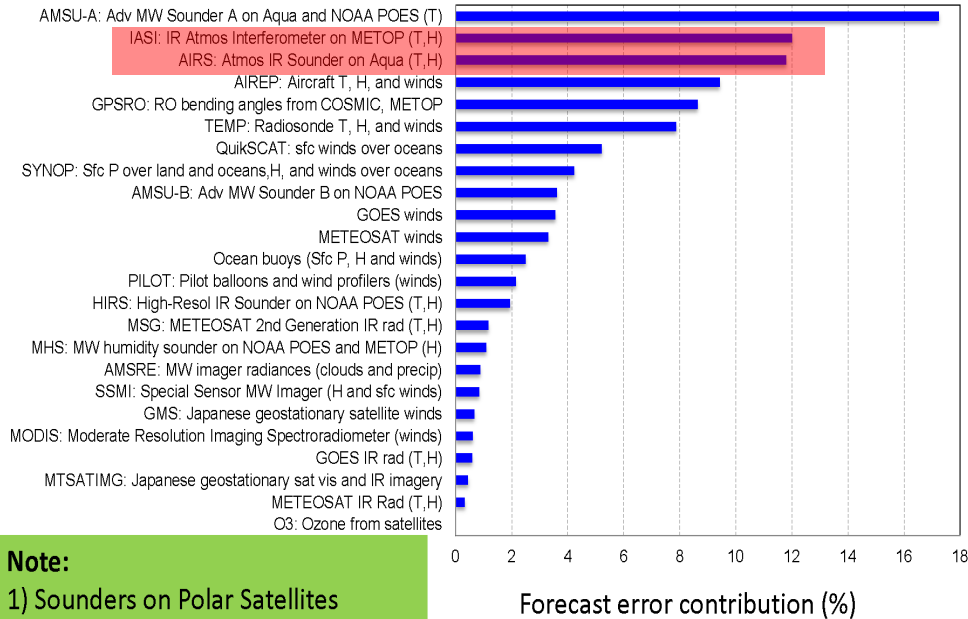
ITSC22, Québec, Canada  
31 October – 6 November 2019

# Outline

- **Background: WHY Geo. SOUNDER ?**
- **Evaluation and Assimilation of GIIRS in 4D-Var**
- **Targeted Observing using GIIRS for HIW**
- **Future Perspective: Global Geo. SOUNDERS**

# Why do we need GEO hyperspectral IR sounders?

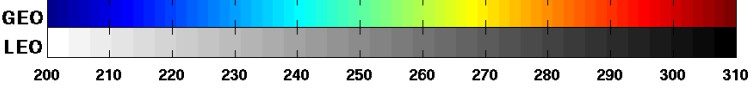
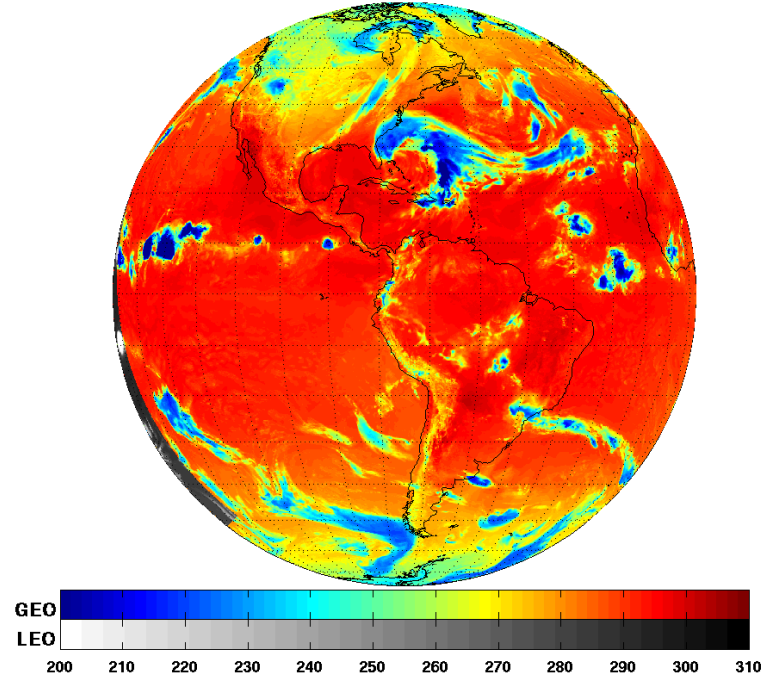
Operational ECMWF system September to December 2008. Averaged over all model layers and entire global atmosphere. % contribution of different observations to reduction in forecast error.



**Note:**  
 1) Sounders on Polar Satellites reduce forecast error most  
 2) Results are relevant for other NWP Centers, including NWS/NCEP

Courtesy: Carla Cardinali and Sean Healy, ECMWF

AIRS Tb (K) at 10.9 μm 2012-10-27 00:00:00 UTC

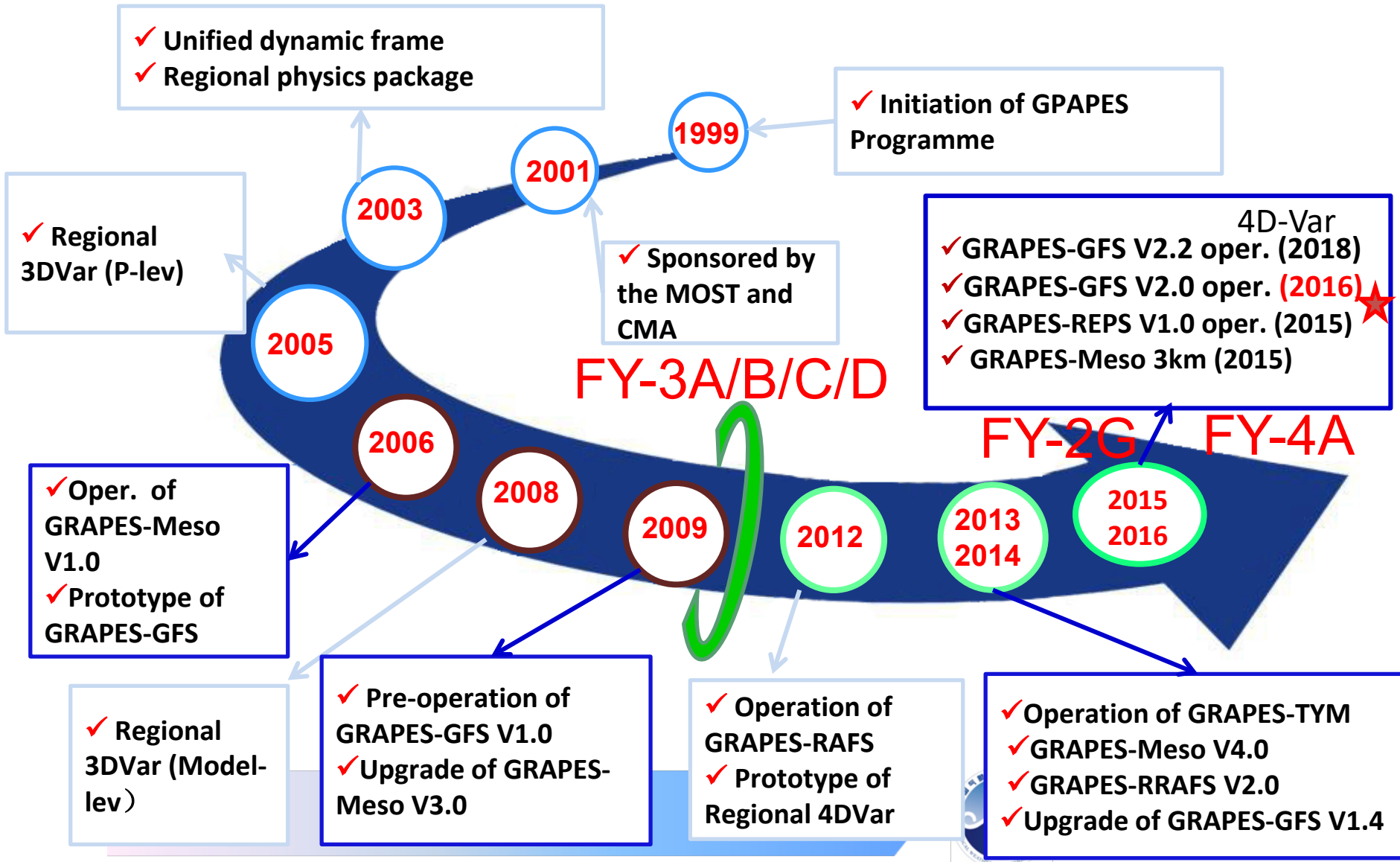


- Compared with LEO: **Larger spatial coverage and higher temporal resolution** for regional models
- Compared with microwave sounders: finer vertical resolution

Q: GEO high temporal resolution observations GEO provide critical information for nowcasting, what is the impact in NWP models, for example, on storm forecasts?

# Milestones of GRAPES

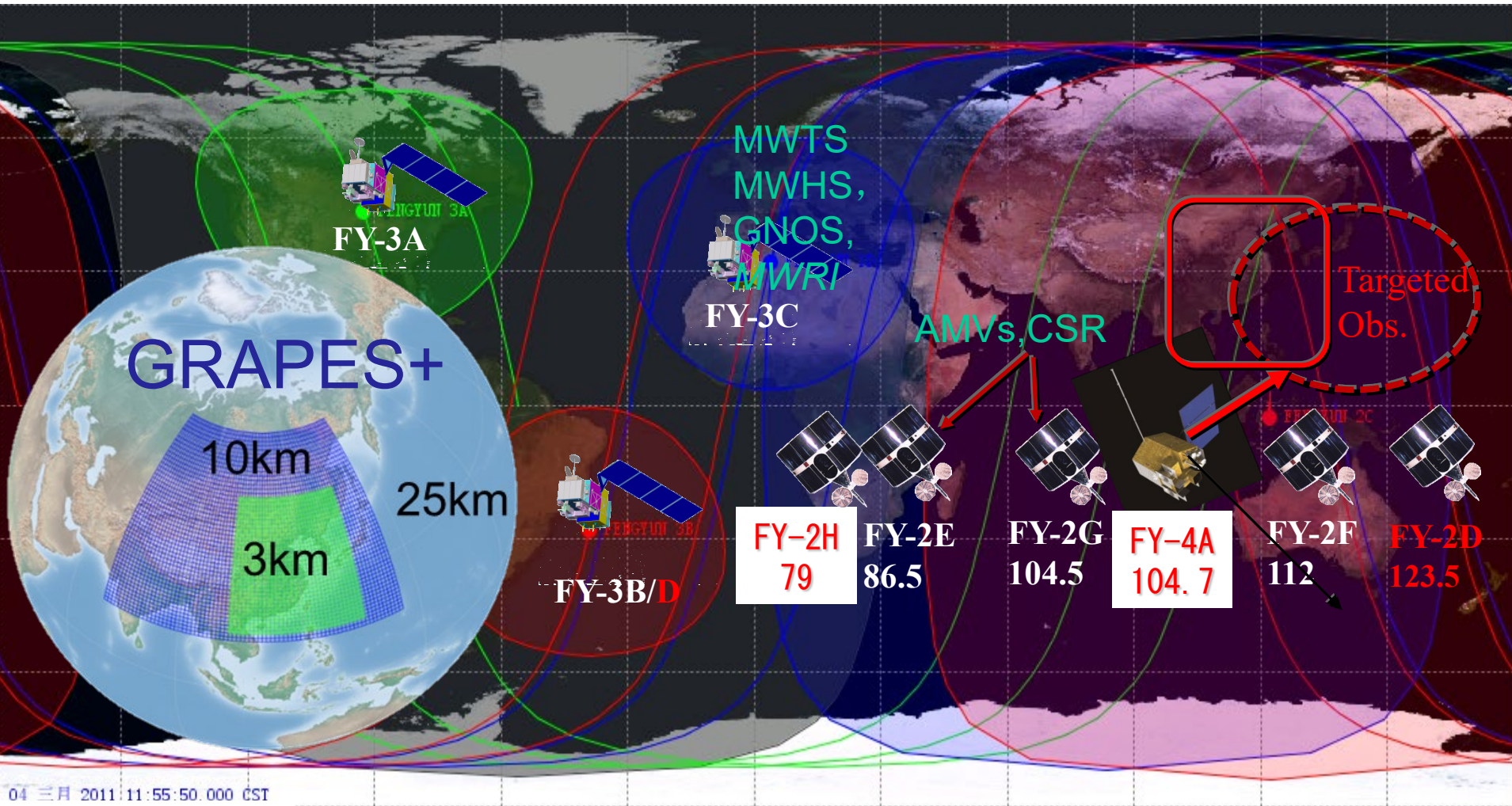
**GRAPES** = **G**lobal/**R**egional **A**ssimilation **P**rEdiction **S**ystem





# Geostationary Satellite Sounding: **FY-4A GIIRS**

## Opportunities for Targeted Observing

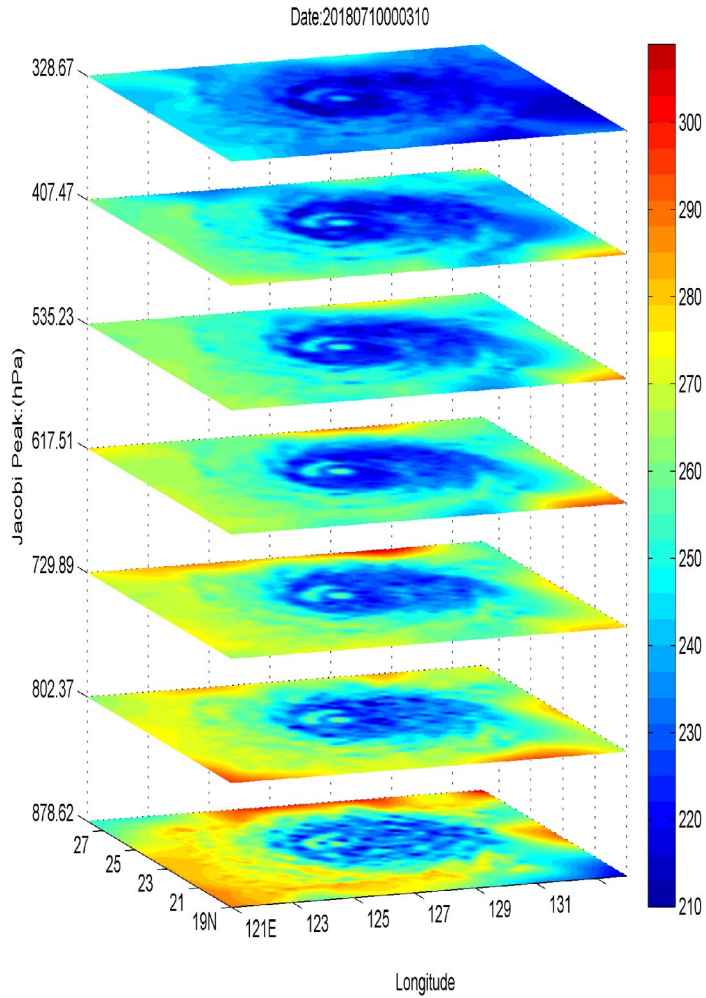
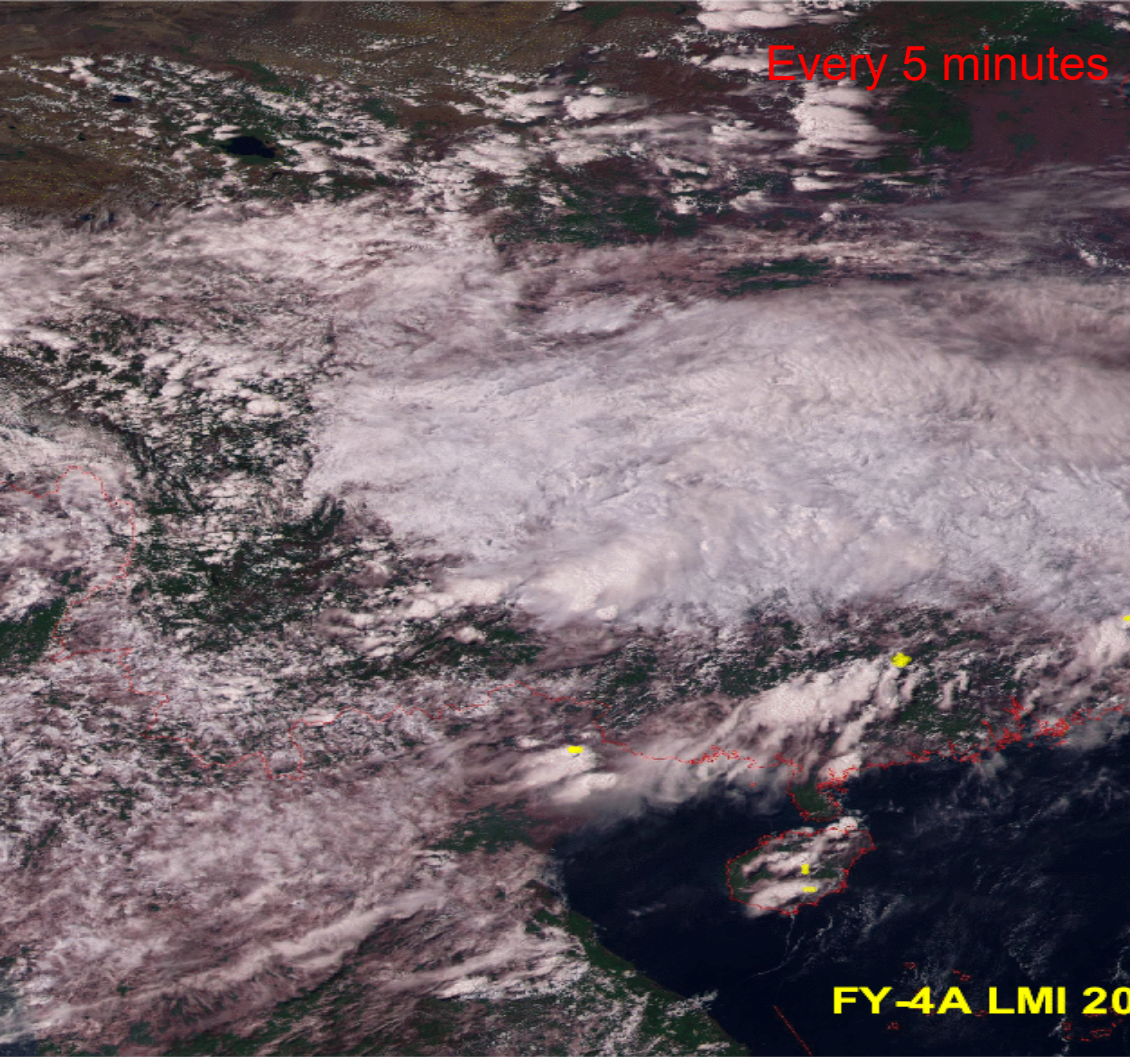


Forecast Oriented Observing by FY-4A GIIRS to improve HIW



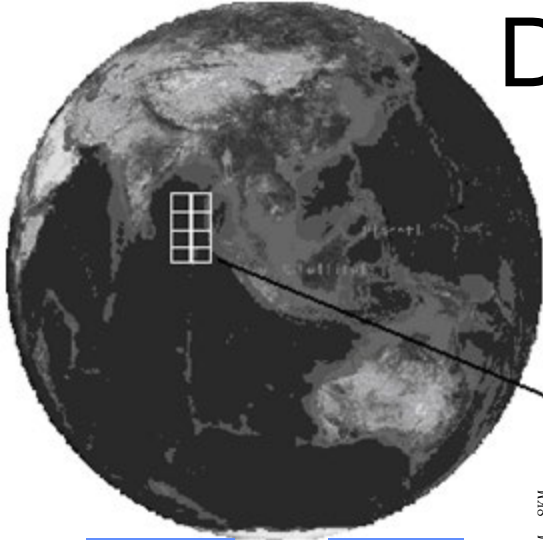
# GREAT opportunity with FY-4A

FY-4A: AGRI(Imager)+LMI(Lightning)+GIIRS(Sounding)



Typhoon "Maria" Every 15 minutes (1650 Channels)

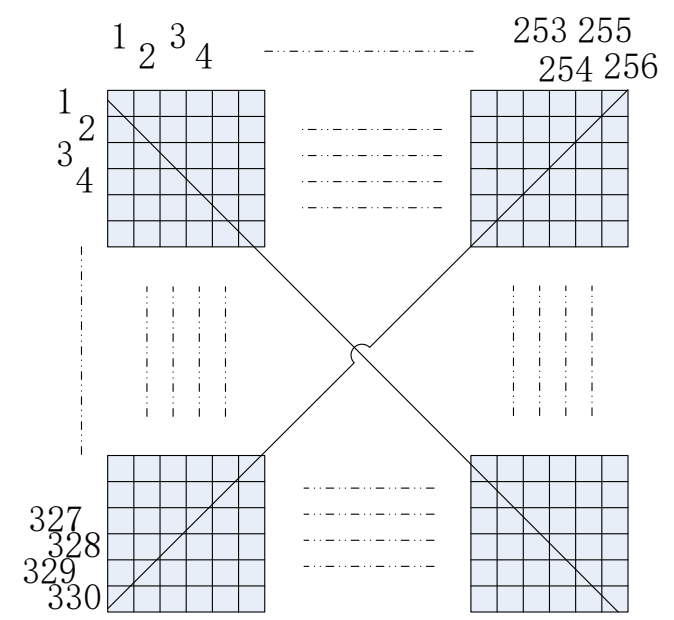
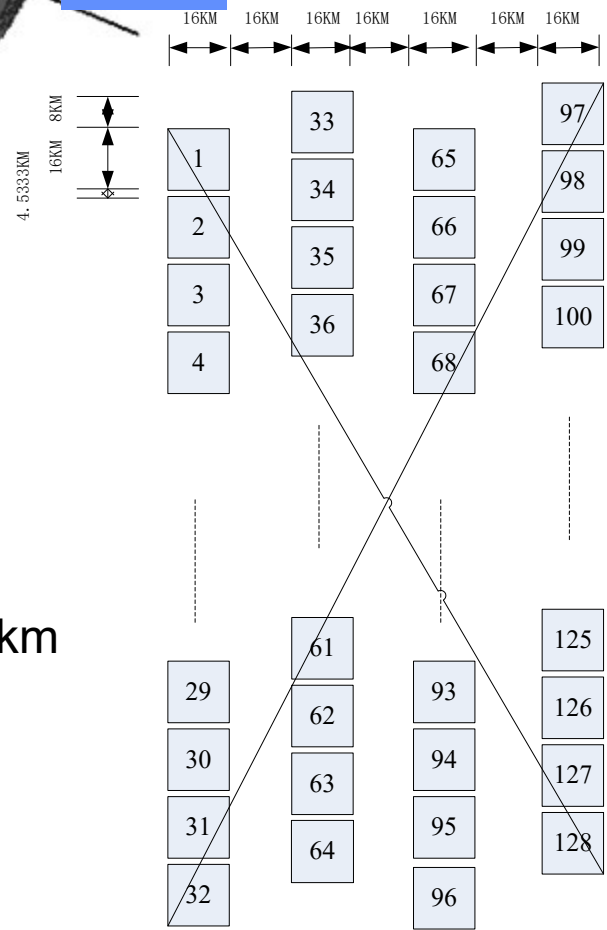
# Design of Field Of Regard (FOR)



North  
↓  
South

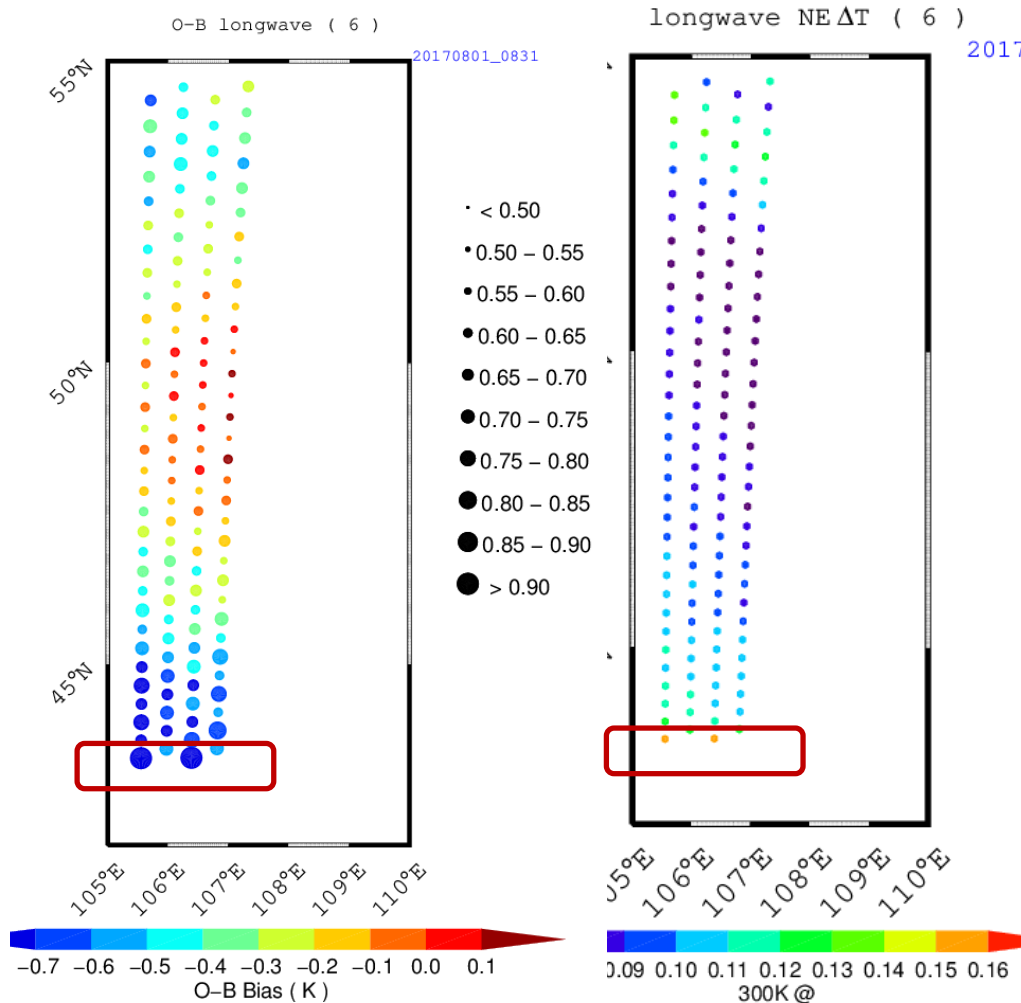
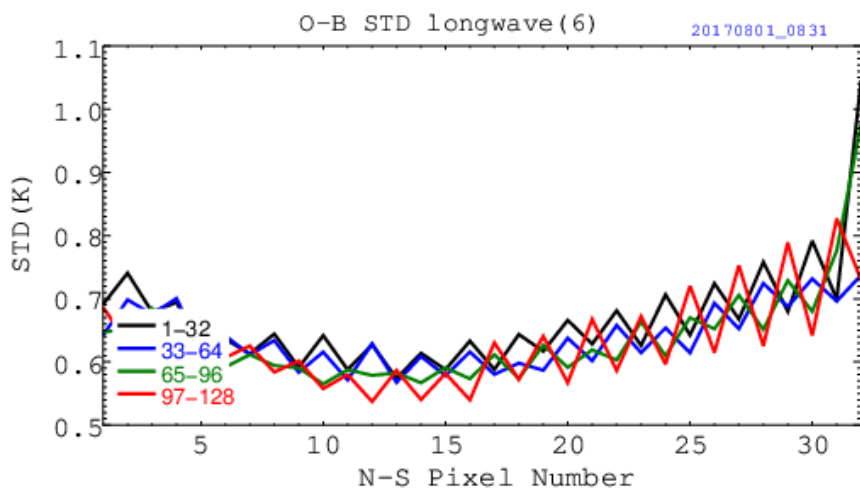
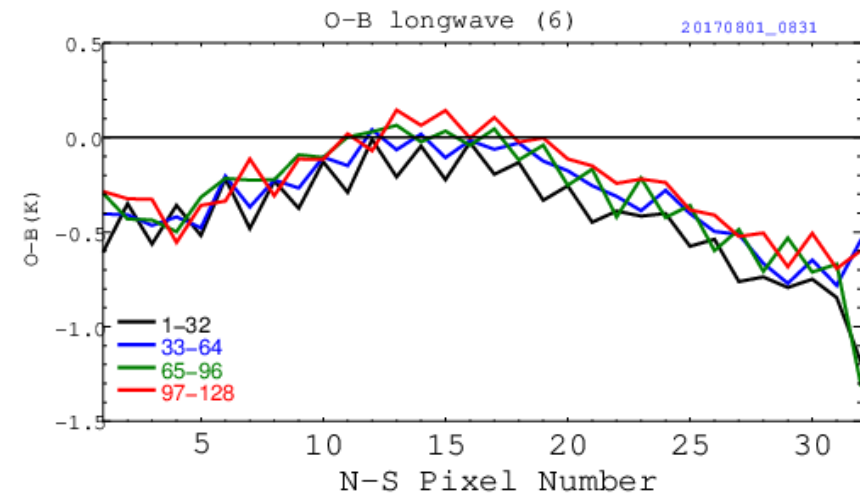
West → East

2.0 hours to cover the Area:  
15N-65N , 75E-135E  
High temporal for targeted area



FOR: 648kmX112km  
FOV: 16km

# FOR dependent bias and std (CH6, 300hPa)

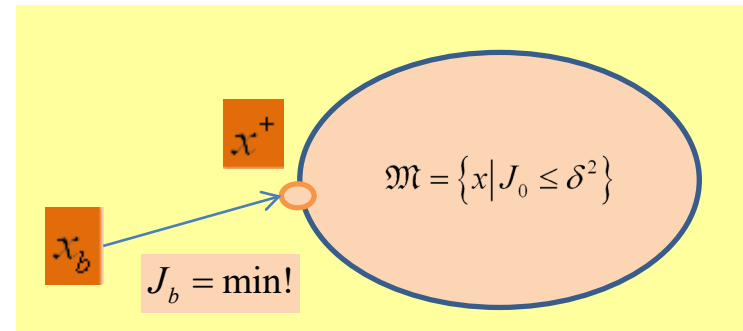


# Constrained VarBC

→ Regularization : **C**onstrained **B**ias **C**orrection(CBC), CVarBC

$$\|\mathbf{b}\| \leq \|\mathbf{e}\|_{\text{calibration}} + \|\mathbf{e}\|_{\text{RT model}} + \|\mathbf{e}\|_{\text{other}}$$

$$2J(\mathbf{x}, \boldsymbol{\beta}) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x}) + (\boldsymbol{\beta} - \boldsymbol{\beta}_b)^T \mathbf{B}_\beta^{-1} (\boldsymbol{\beta} - \boldsymbol{\beta}_b) + [\mathbf{y} - H(\mathbf{x}) - h(\mathbf{x}, \boldsymbol{\beta})]^T \mathbf{R}^{-1} [\mathbf{y} - H(\mathbf{x}) - h(\mathbf{x}, \boldsymbol{\beta})]$$



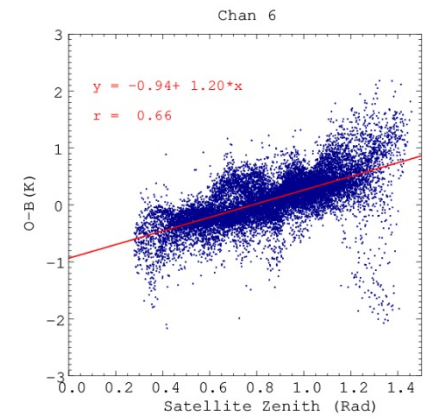
$$J_b = \min_{x \in m}$$

$$m = \{x \mid J_0 \leq \delta\}$$

$$\|h(\mathbf{x}, \boldsymbol{\beta}) - b_0\| \leq \delta^2$$

$$2J(\mathbf{x}, \boldsymbol{\beta}) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x}) + (\boldsymbol{\beta} - \boldsymbol{\beta}_b)^T \mathbf{B}_\beta^{-1} (\boldsymbol{\beta} - \boldsymbol{\beta}_b) + [\mathbf{y} - H(\mathbf{x}) - h(\mathbf{x}, \boldsymbol{\beta})]^T \mathbf{R}^{-1} [\mathbf{y} - H(\mathbf{x}) - h(\mathbf{x}, \boldsymbol{\beta})] + \alpha^2 [h(\mathbf{x}, \boldsymbol{\beta}) - \mathbf{b}_0]^T \mathbf{R}_b^{-1} [h(\mathbf{x}, \boldsymbol{\beta}) - \mathbf{b}_0]$$

Physical constraints

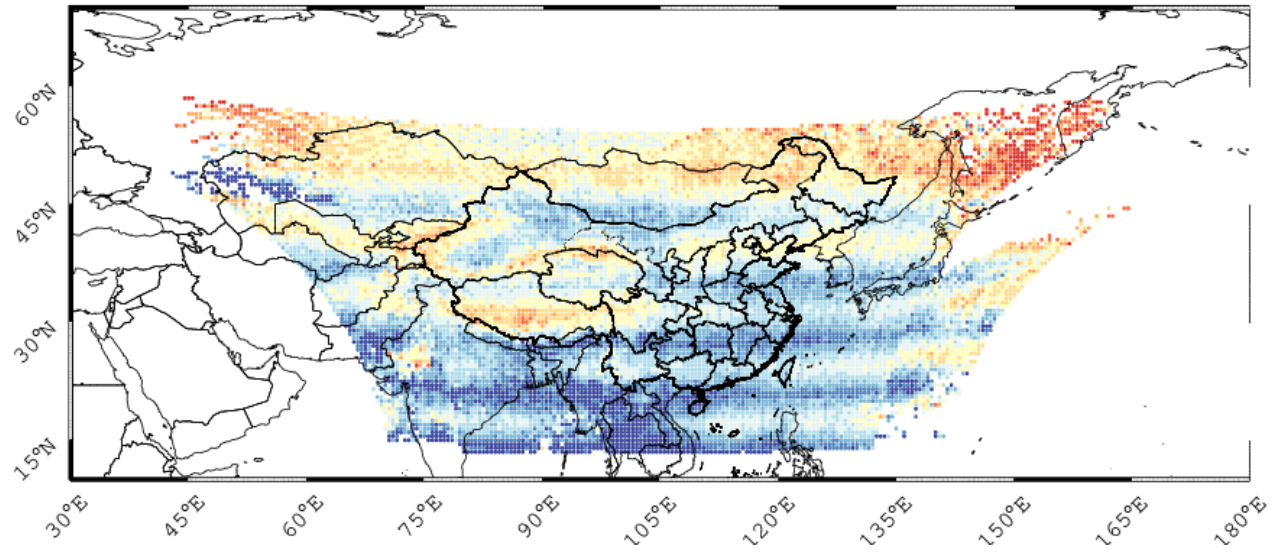




**Before FOV BC**

O-B Bias longwave (6)

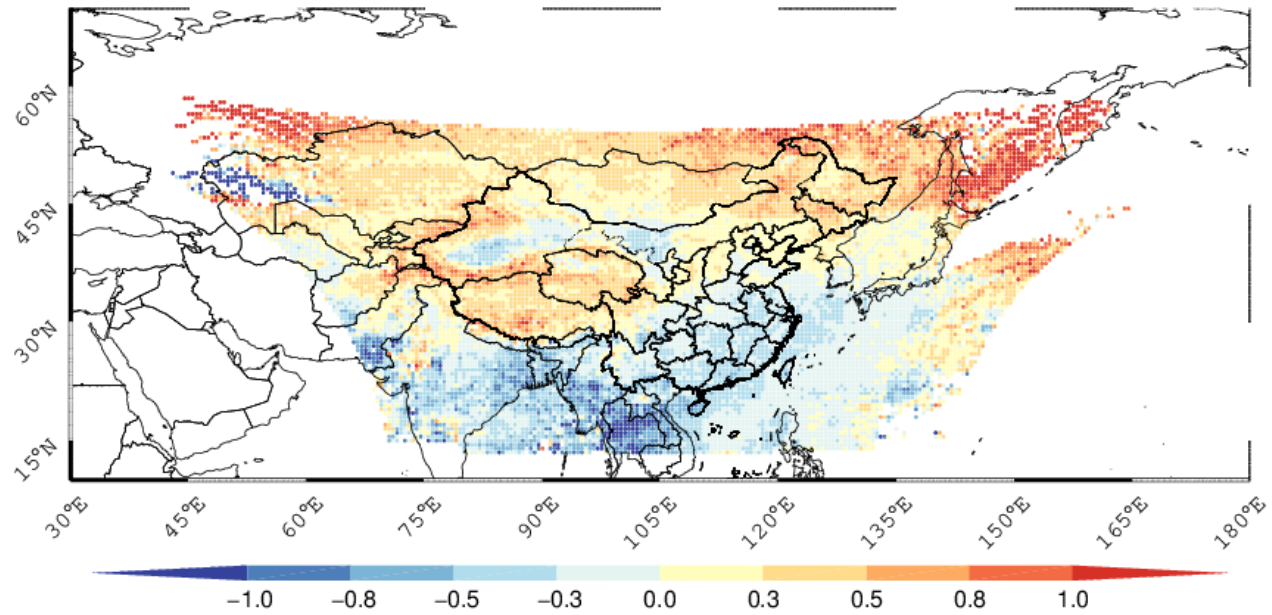
20170801\_0831



**After FOV BC**

O-B Bias longwave (6)

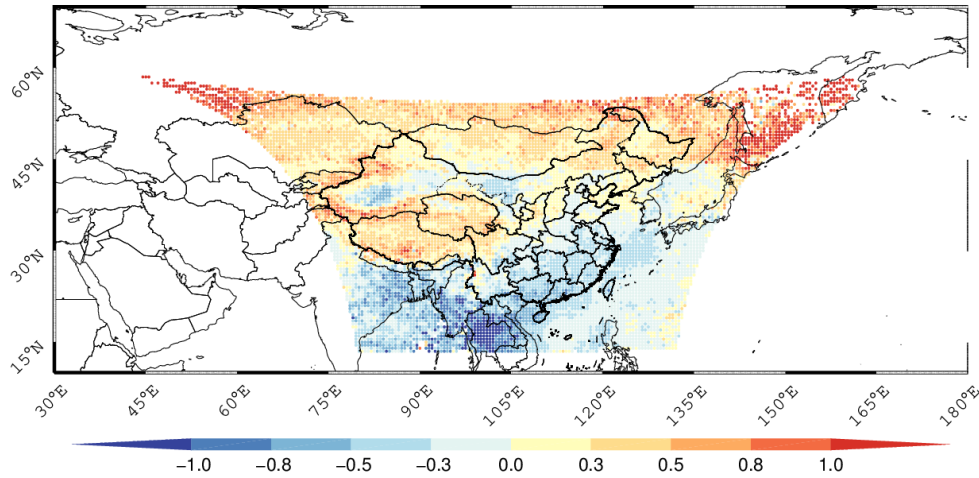
20170801\_0831



# Bias Dependence on satellite zenith angle

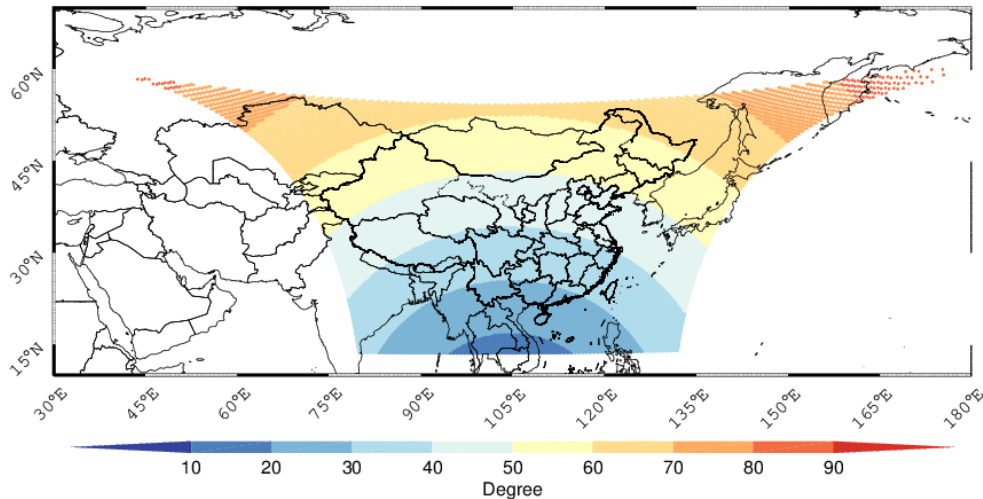
O-B Bias longwave (6)

20170801\_0827



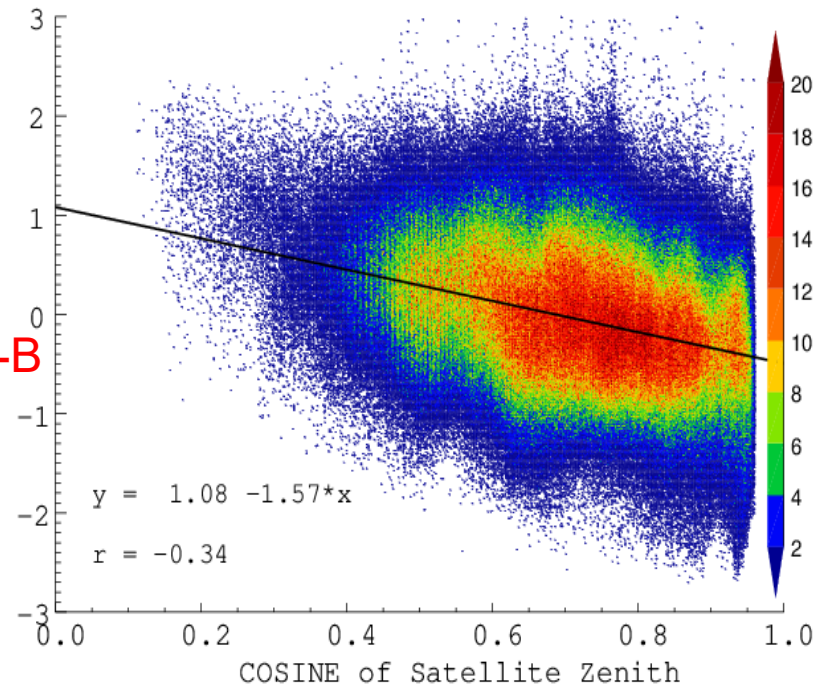
Satellite Zenith

20170828\_0000



O-B

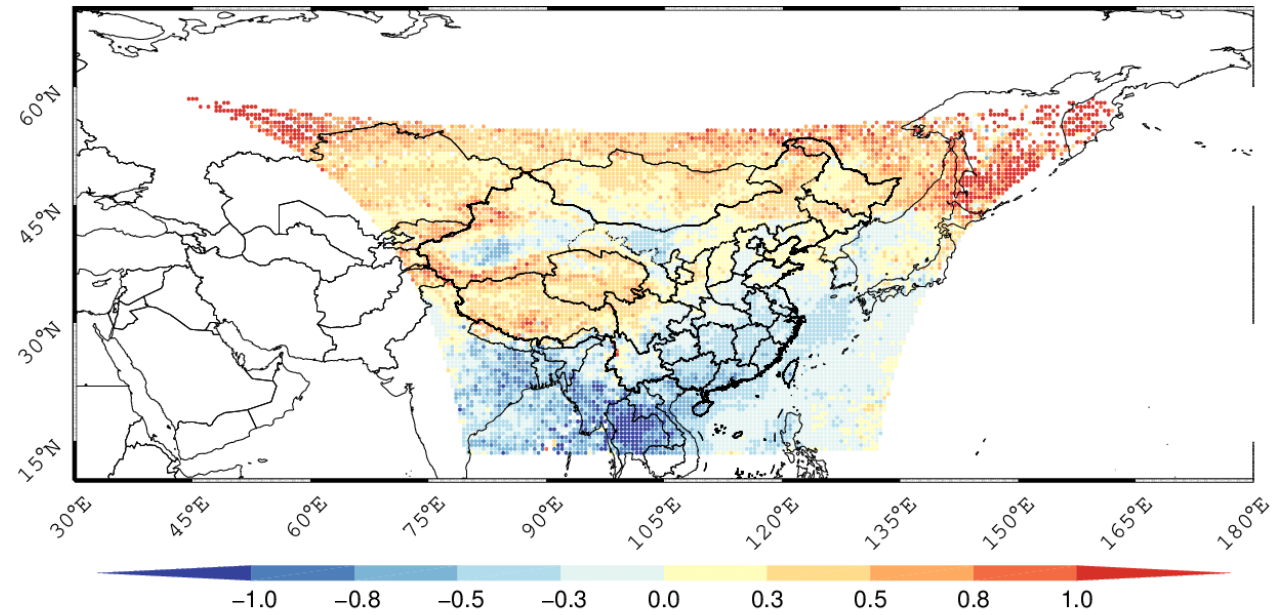
Chan 6



## After FOV BC

O-B Bias longwave (6)

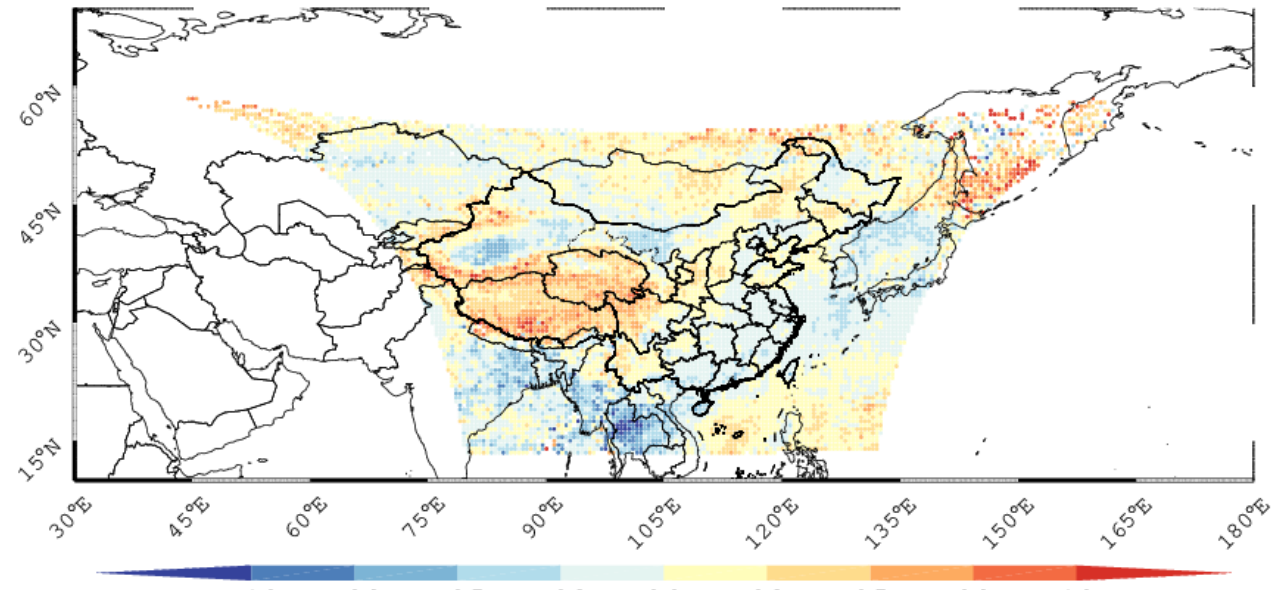
20170801\_0827



## After FOV & Satzen BC

O-B Bias longwave (6)

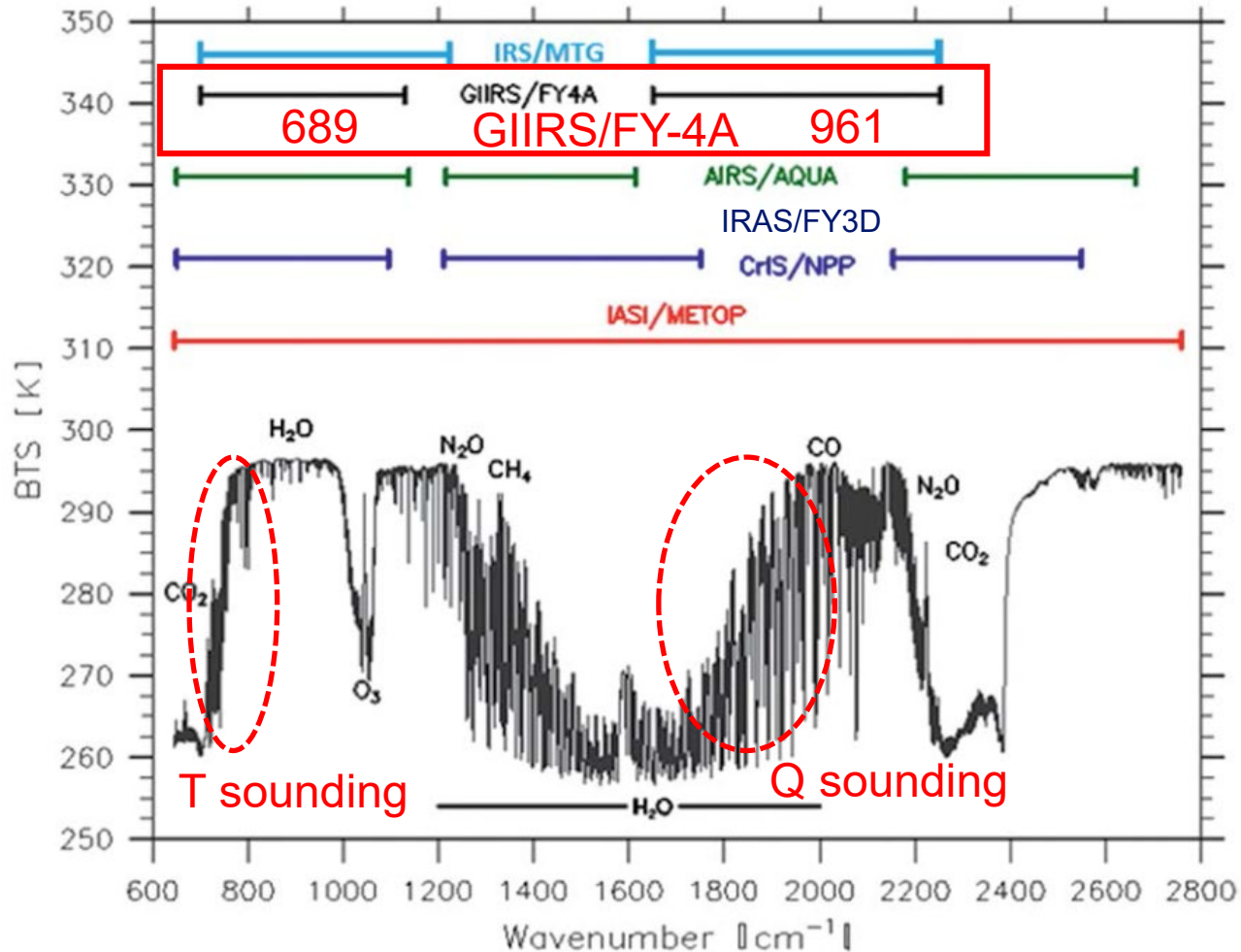
20170801\_0827





# GIIRS spectral coverage and comparisons with others

The First Hyperspectral IR sounder on GEO orbit



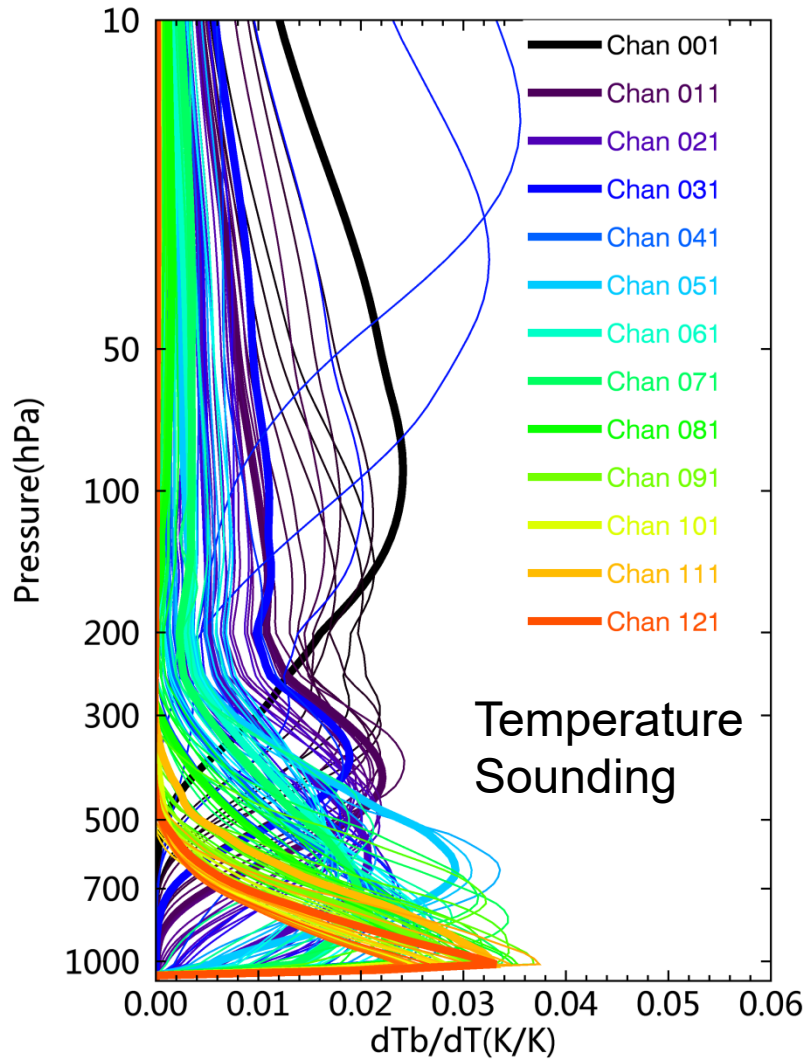
Yang J, Zhang Z, Wei C, Lu F. : 2017,

Introducing the new generation of Chinese geostationary weather satellites – FengYun 4 (FY-4) [J]. Bulletin of the American Meteorological Society. DOI:10.1175/BAMS-D-16-0065.1

# Jacobians of FY-4A GIIRS

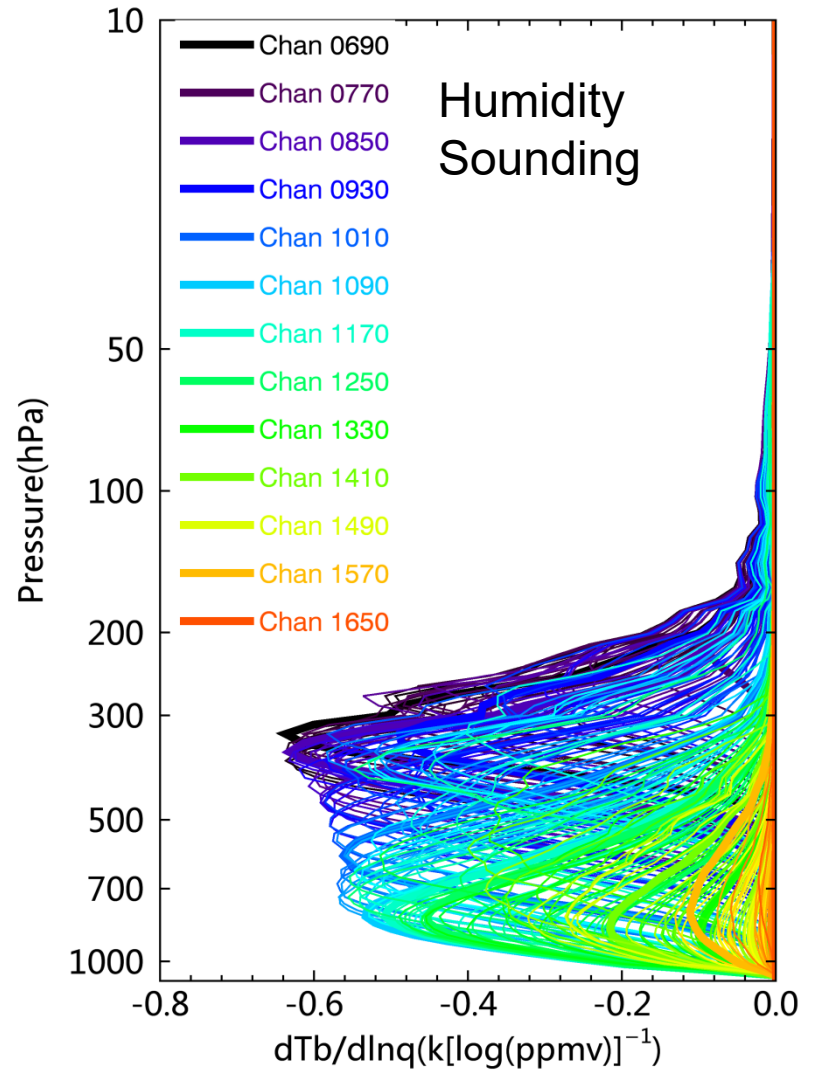
689 channels

Jacobian\_T

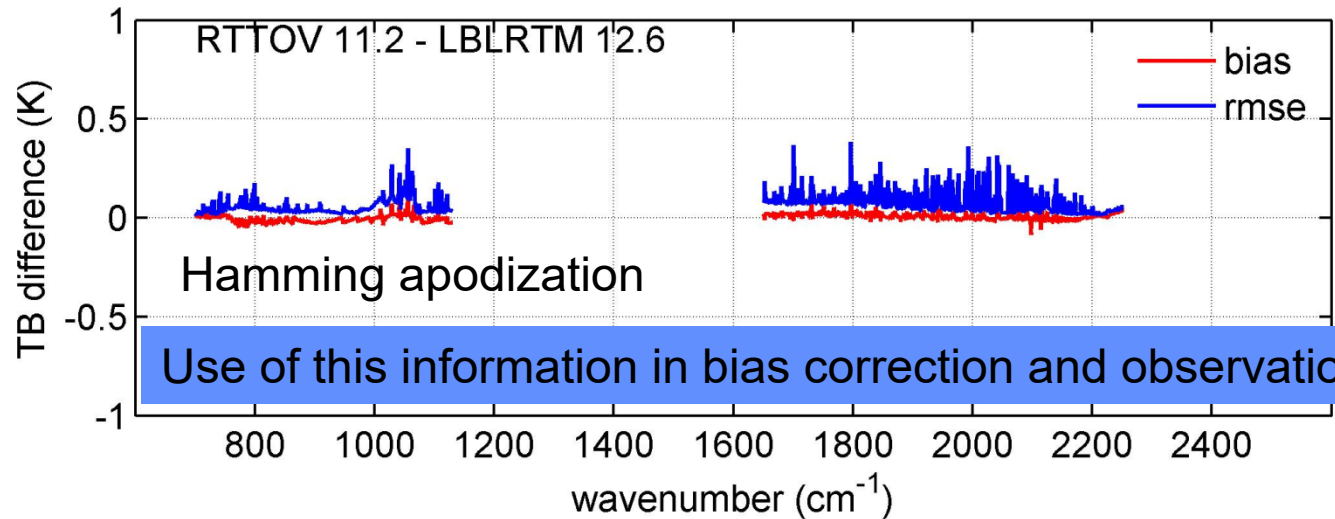
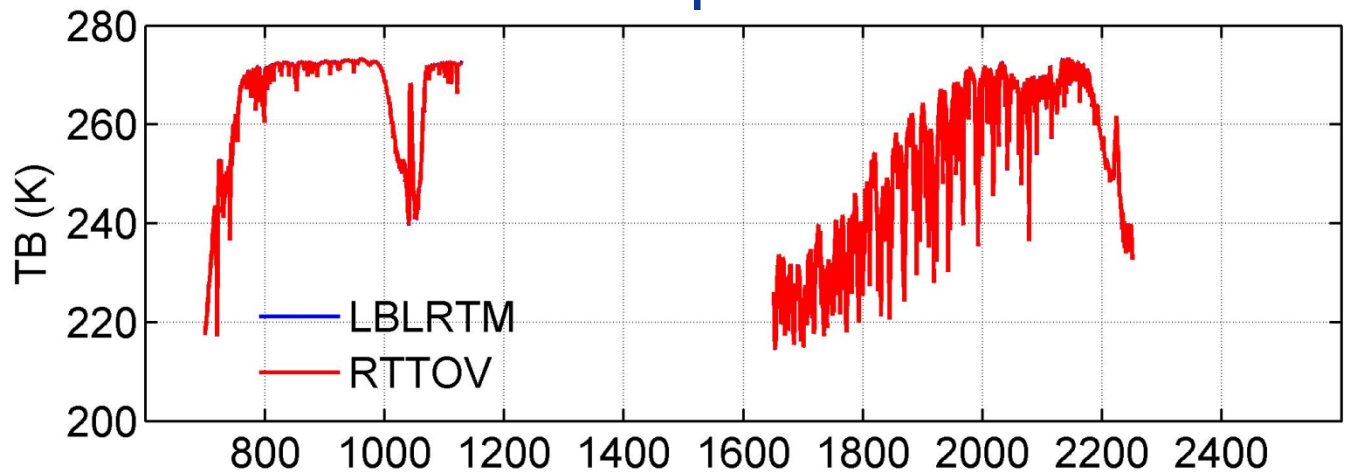


961 channels

Jacobian\_q



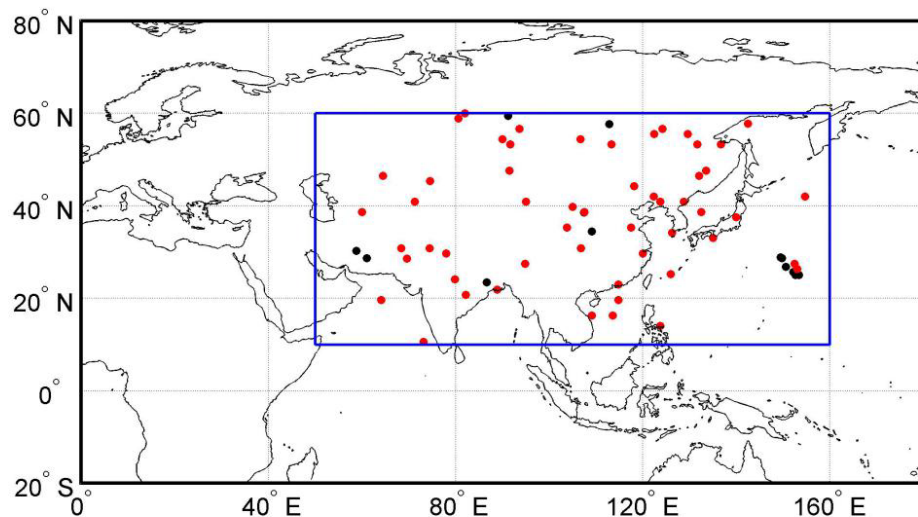
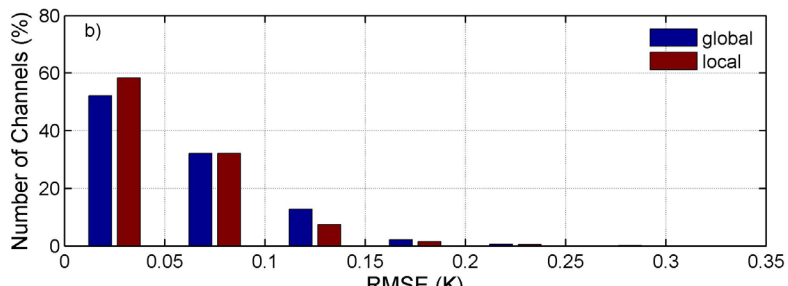
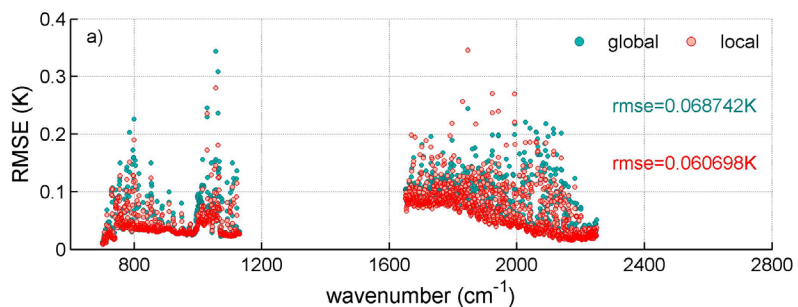
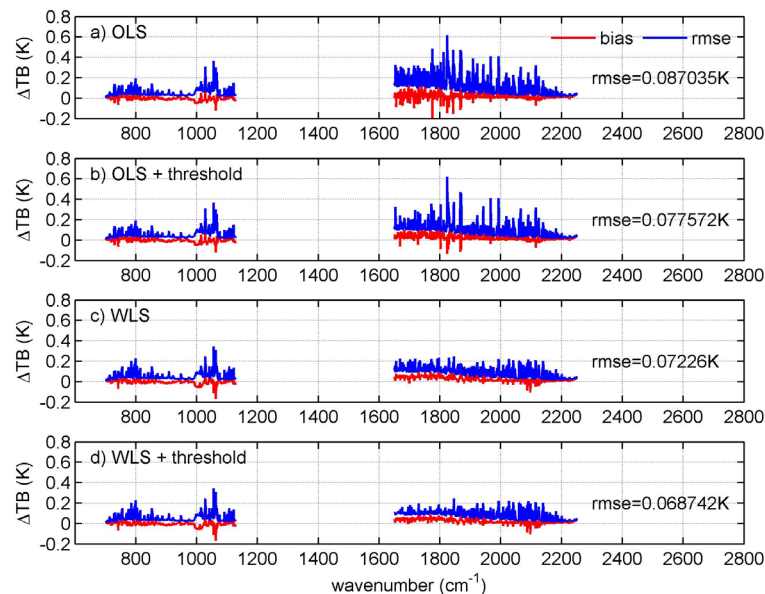
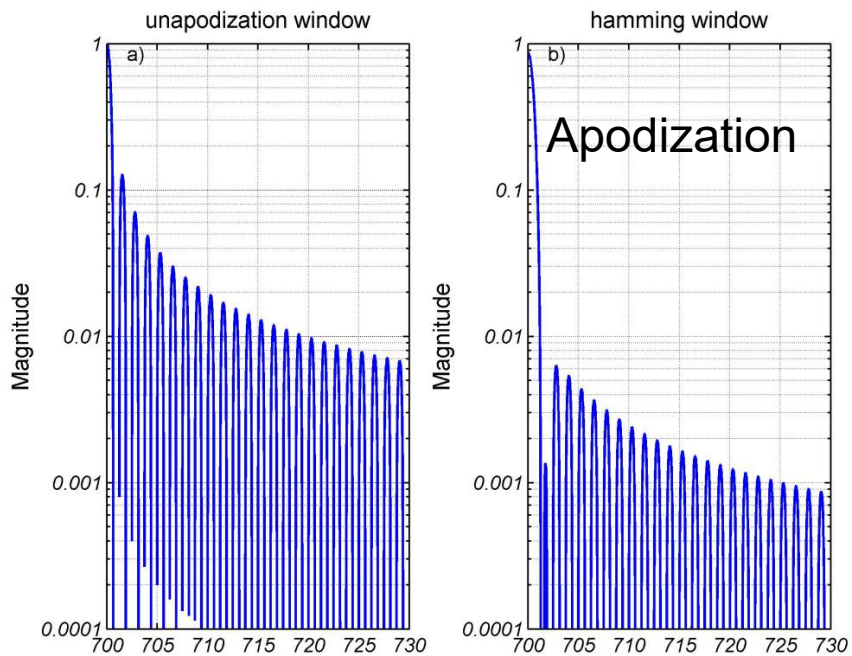
# FY4A GIIRS Observation Operator: RTTOV-GIIRS



Di, D., Jun Li, Wei Han, W. Bai, C. Wu, and W. Paul Menzel, 2018: Enhancing the fast radiative transfer model for FengYun-4 GIIRS by using local training profiles, *Journal of Geophysical Research - Atmospheres*, DOI: 10.1029/2018JD029089.

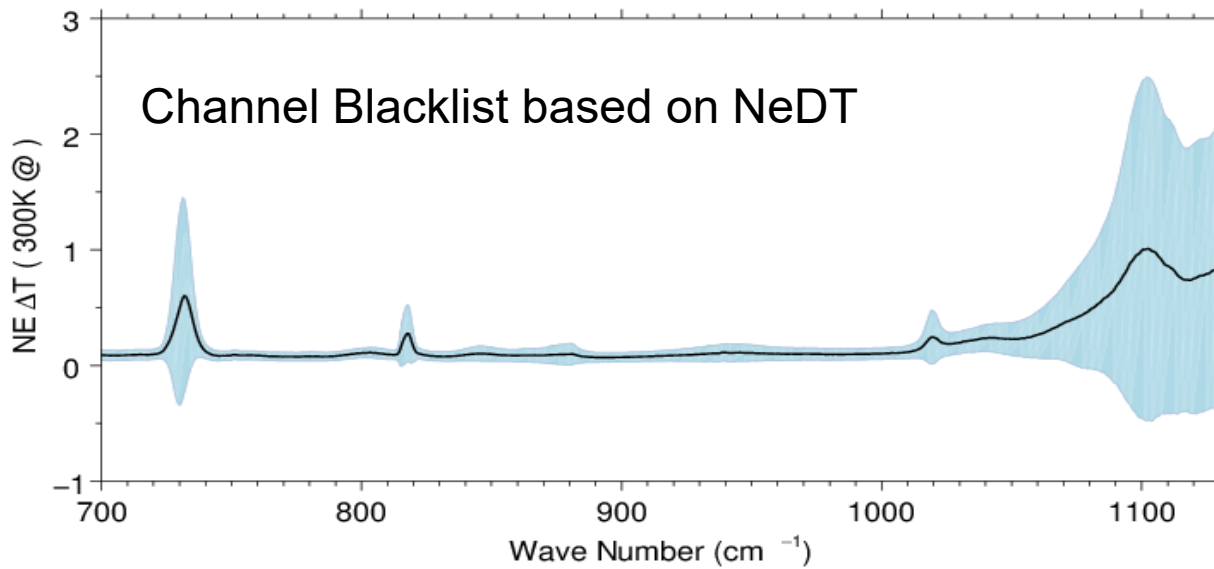
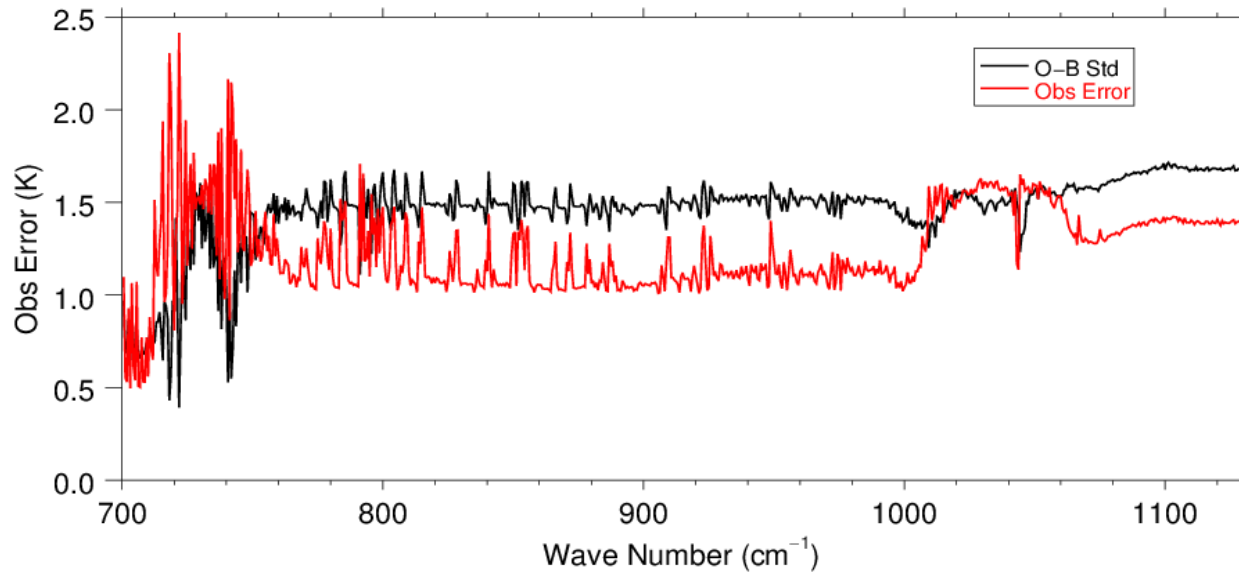
<https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2018JD029089>

# Local Training RTTOV coefficients for GIRS/FY-4A



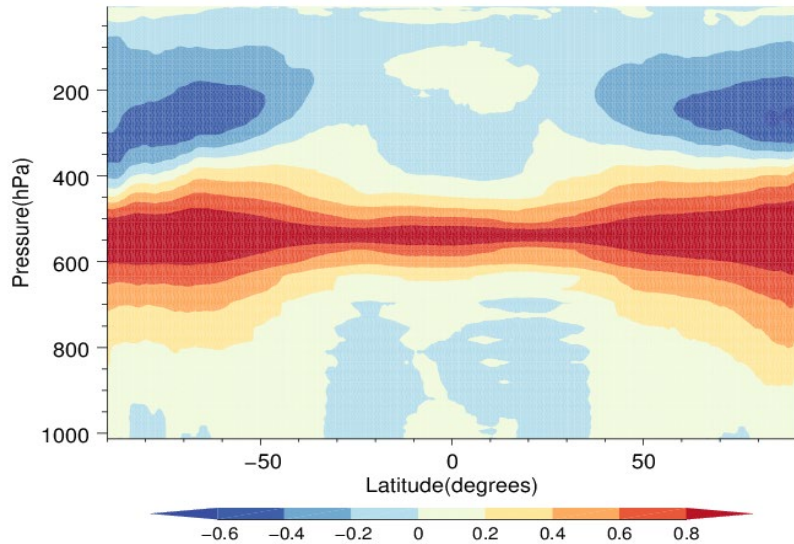
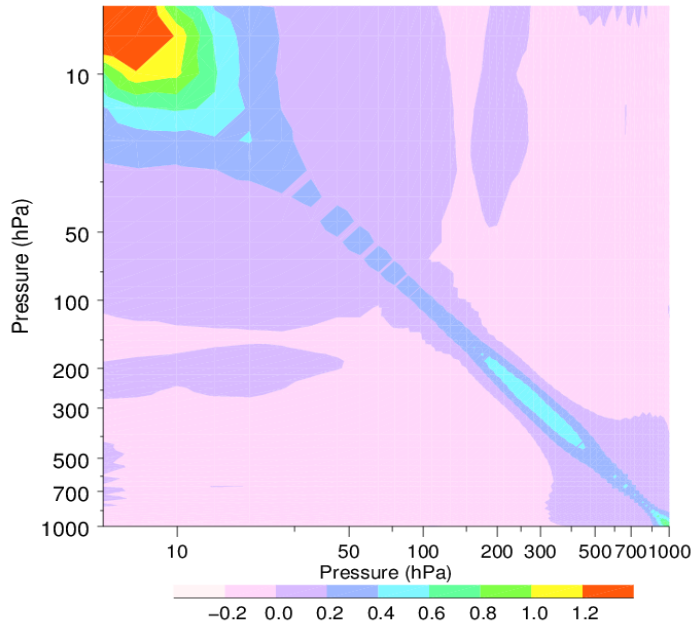
Local training profiles

# Observation Error Estimation





# GIIRS channel selection

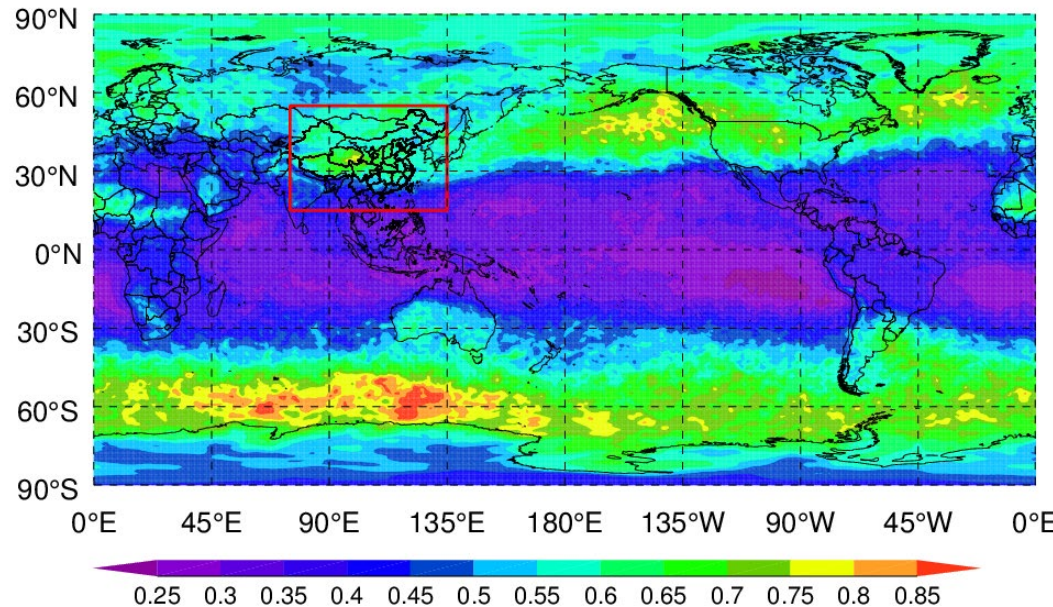


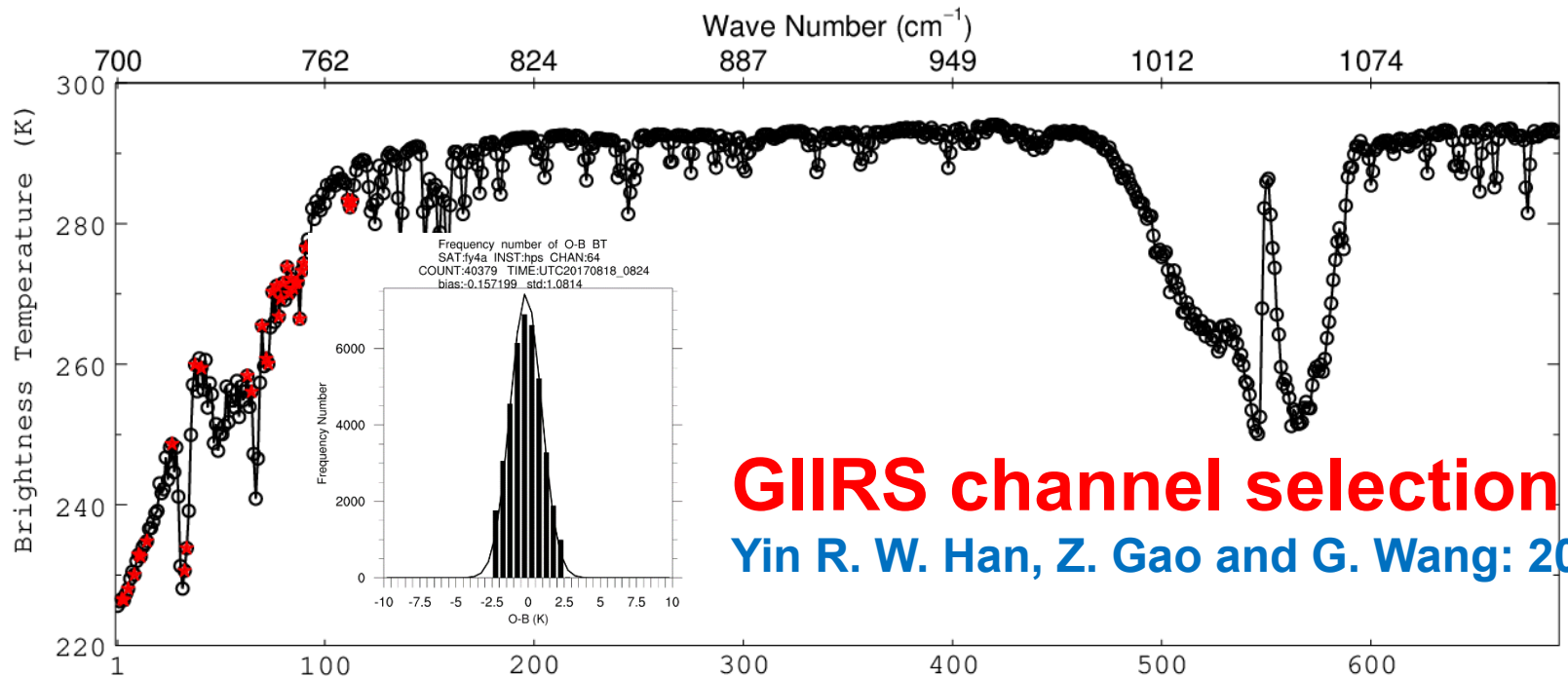
$$ER = \frac{1}{2} \log_2 \left( \frac{|\mathbf{B}|}{|\mathbf{A}|} \right)$$

$$\mathbf{A}_i = \mathbf{A}_{i-1} - \frac{\mathbf{A}_{i-1} \mathbf{h} (\mathbf{A}_{i-1} \mathbf{h})^T}{1 + (\mathbf{A}_{i-1} \mathbf{h})^T \mathbf{h}}$$

Collard, 2007

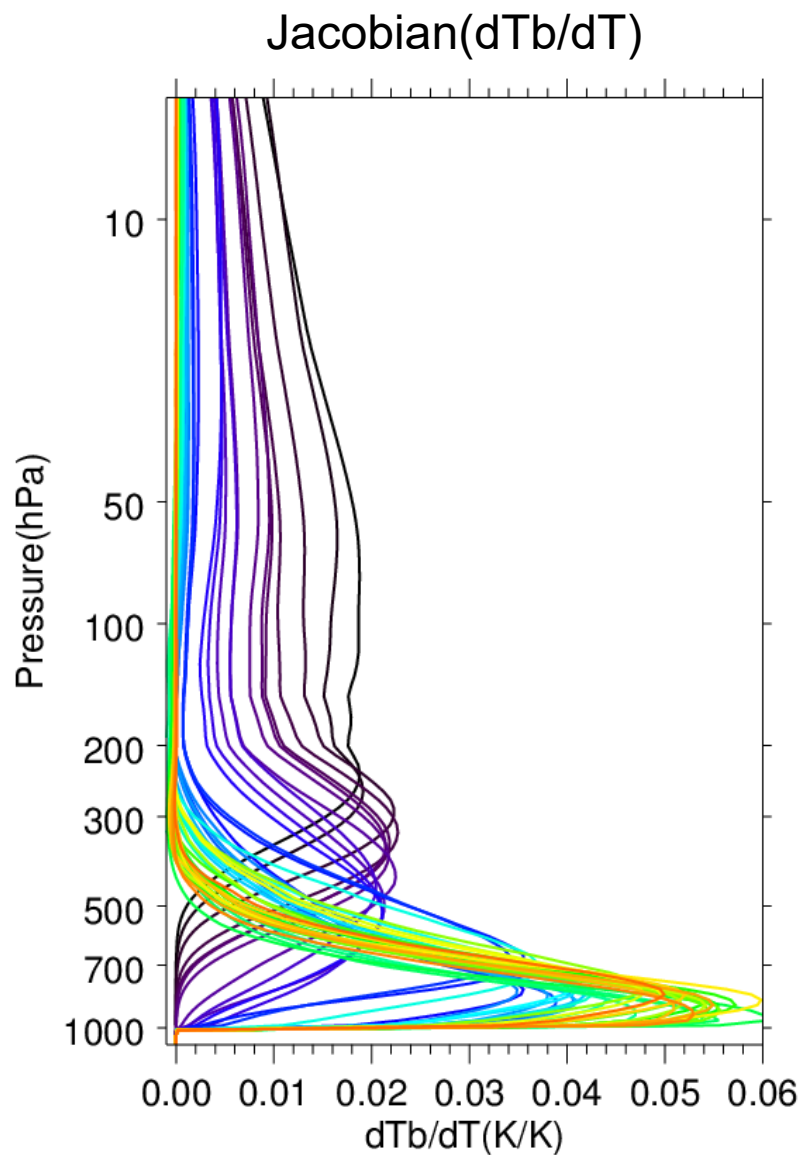
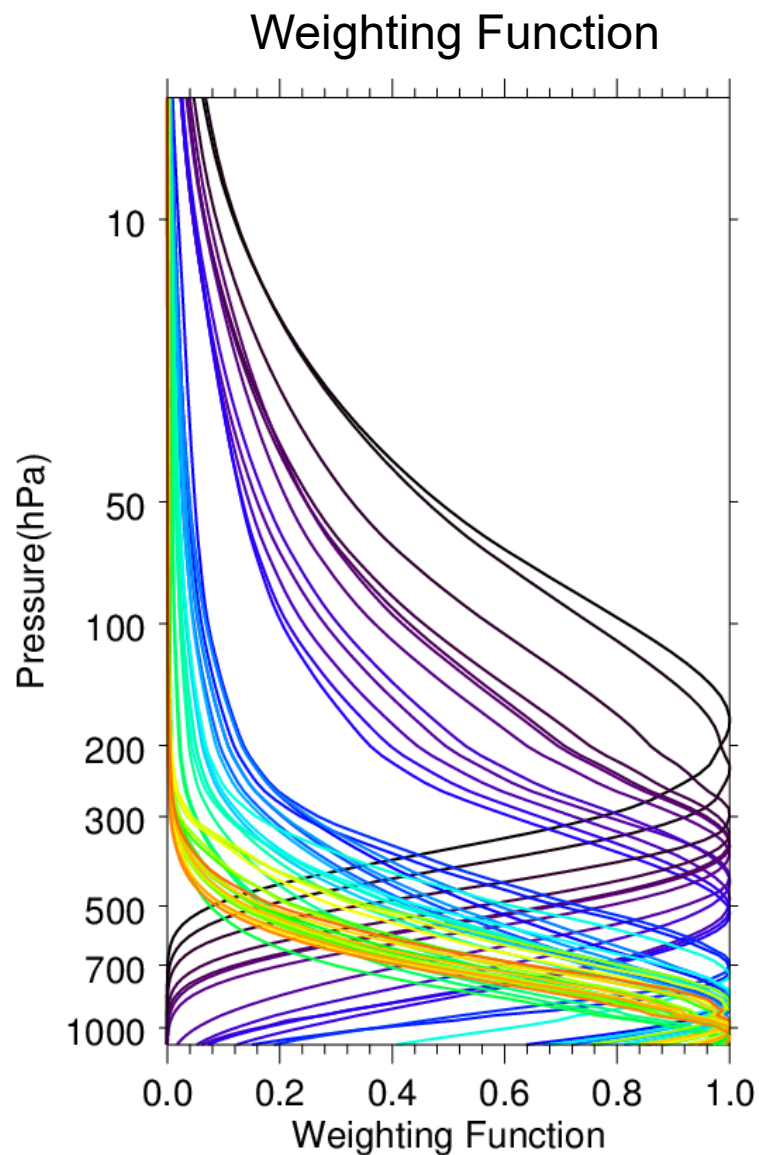
Background Error : B(temperature)





Chan	Wave Length (μm)	Chan	Wave Length (μm)	Chan	Wave Length (μm)	Chan	Wave Length (μm)	Chan	Wave Length (μm)
3	14.26	27	13.96	70	13.46	80	13.34	88	13.26
4	14.25	33	13.89	72	13.43	82	13.32	89	13.25
6	14.22	34	13.88	73	13.42	83	13.31	90	13.23
9	14.18	38	13.83	75	13.40	84	13.30	91	13.22
11	14.16	41	13.79	77	13.38	85	13.29	111	13.01
12	14.15	63	13.54	78	13.37	86	13.28	112	13.00
15	14.11	65	13.51	79	13.36	87	13.27	113	12.99

# GIIRS Selected Temperature Sounding Channels





# Impact of FY-4A GIIRS on Forecast over East Asia (August 2017)

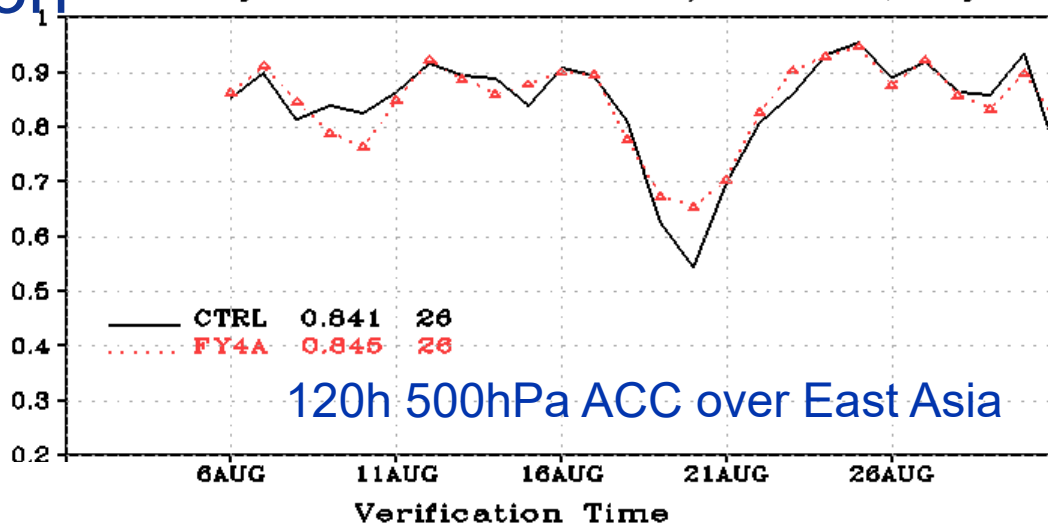
GRAPES gloal 4D-Var

CTRL : OPER

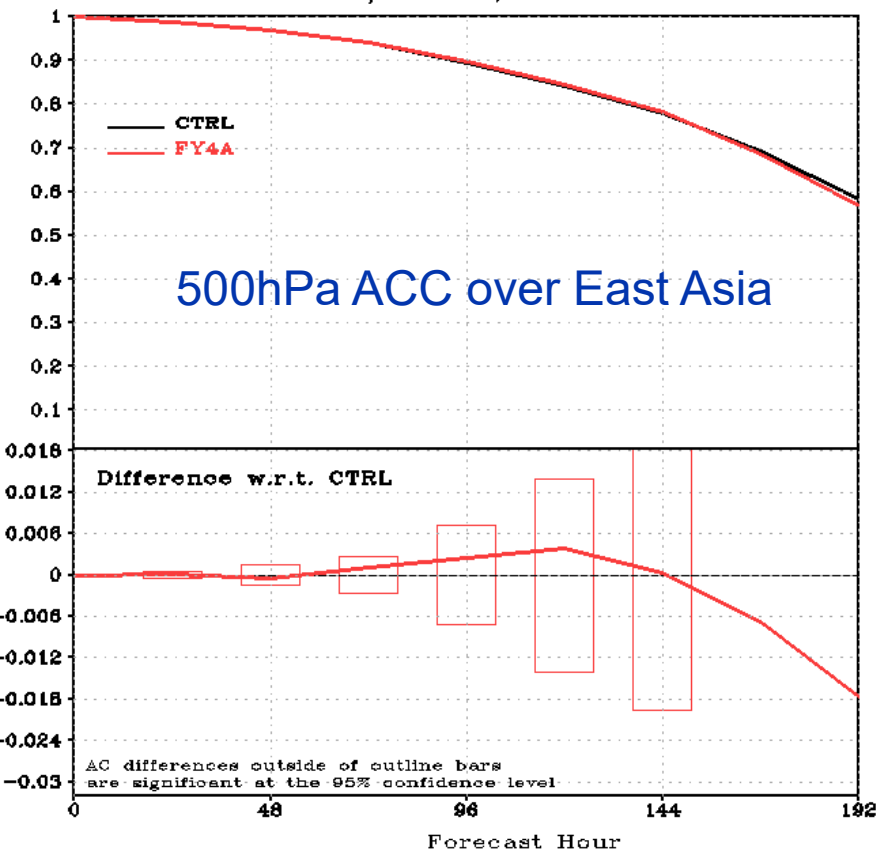
GIIRS : OPER

+GIIRS Temp. Sounding

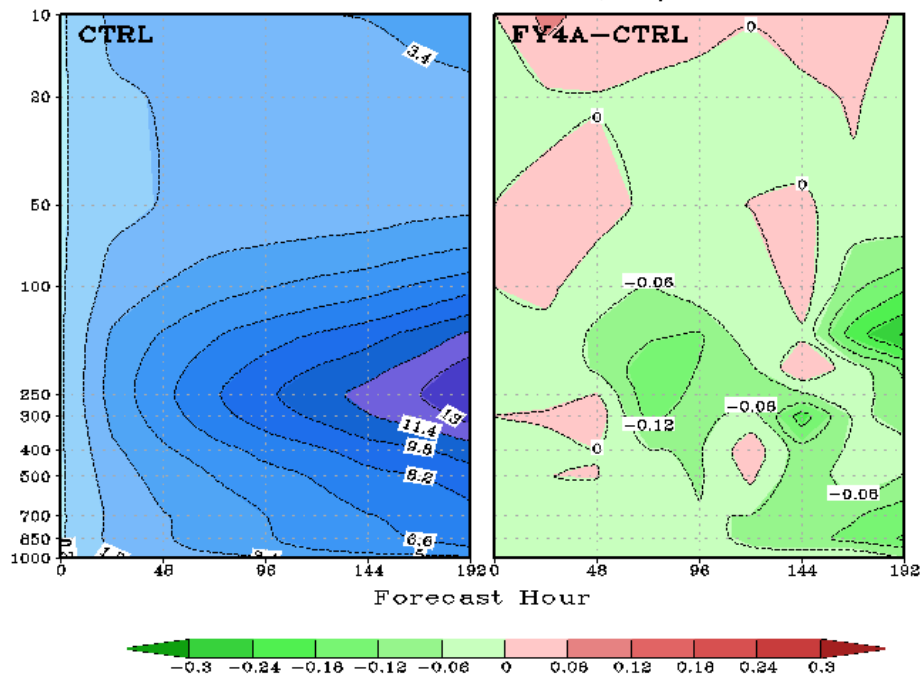
Anomaly Correl: HGT P500 G2/EASI 12Z, Day 5



AC: HGT P500 G2/EASI 12Z, 20170801-20170831



WIND: RMSE  
20170801-20170831 Mean, G2/EASI 12Z

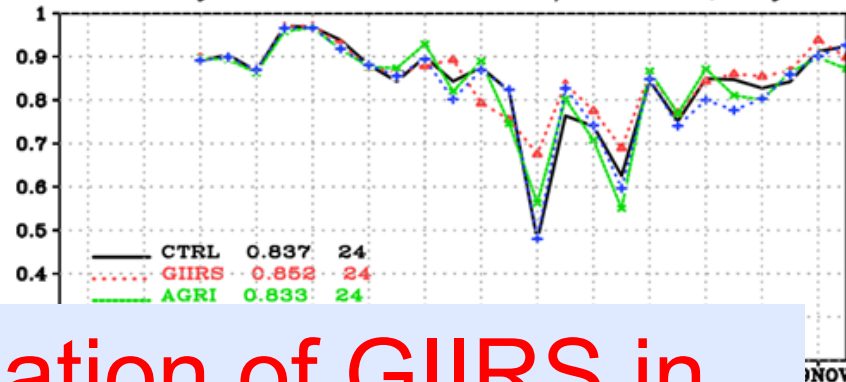


Impact on wind RMSE(green mean reduction)

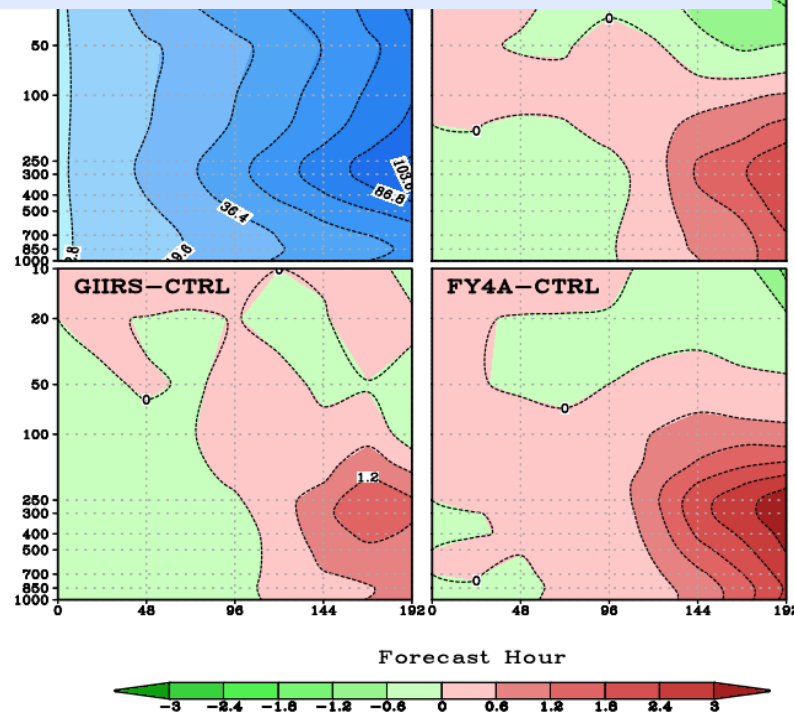
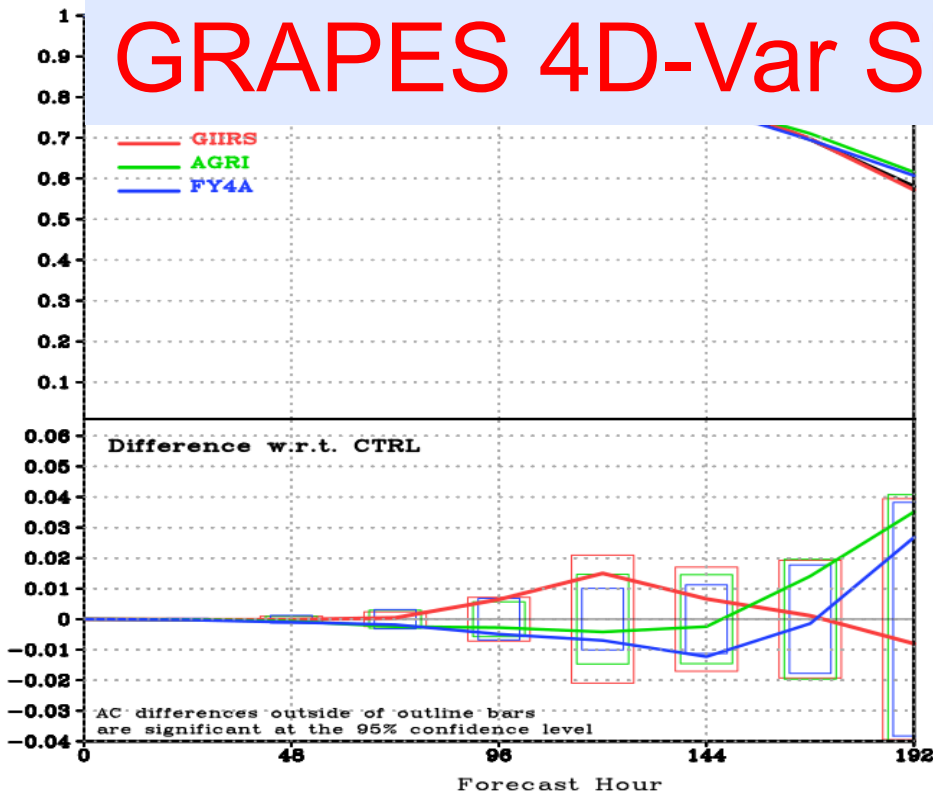
# Impact of FY-4A GIIRS over East Asia (November 2018)

- ◆ Neutral to positive impact
- ◆
- ◆ Positive impact for high impact weather

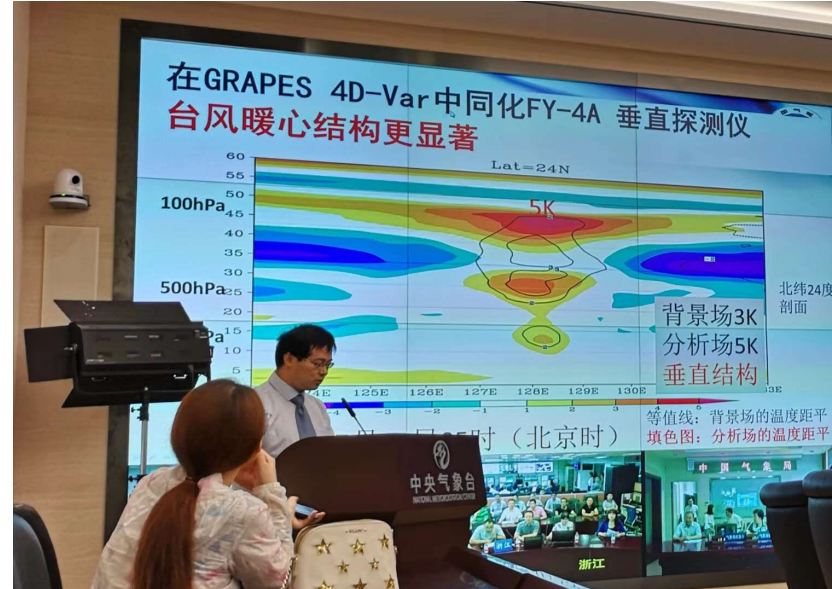
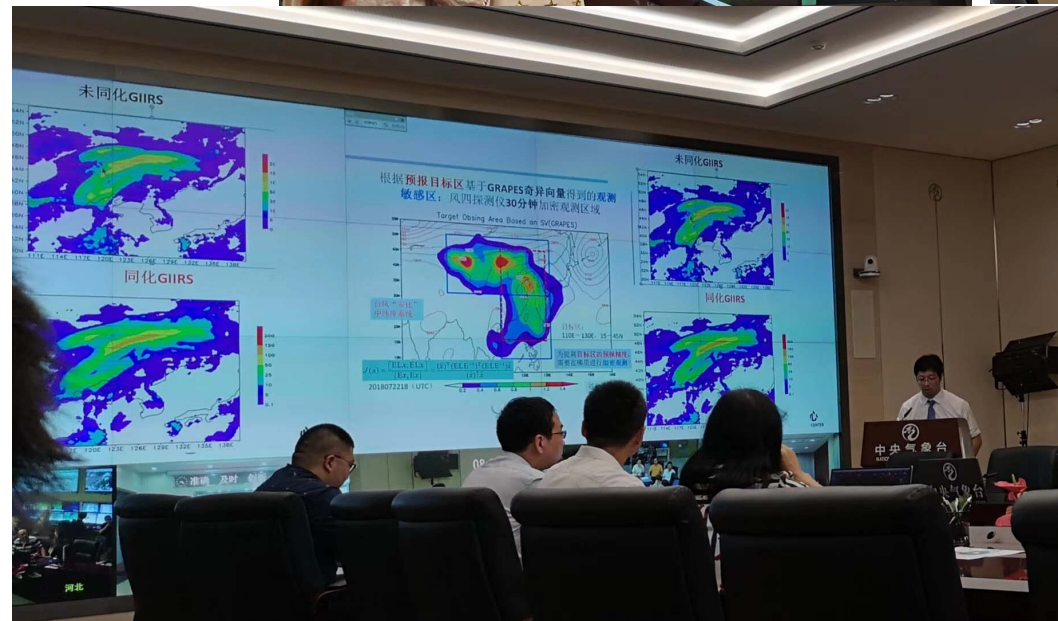
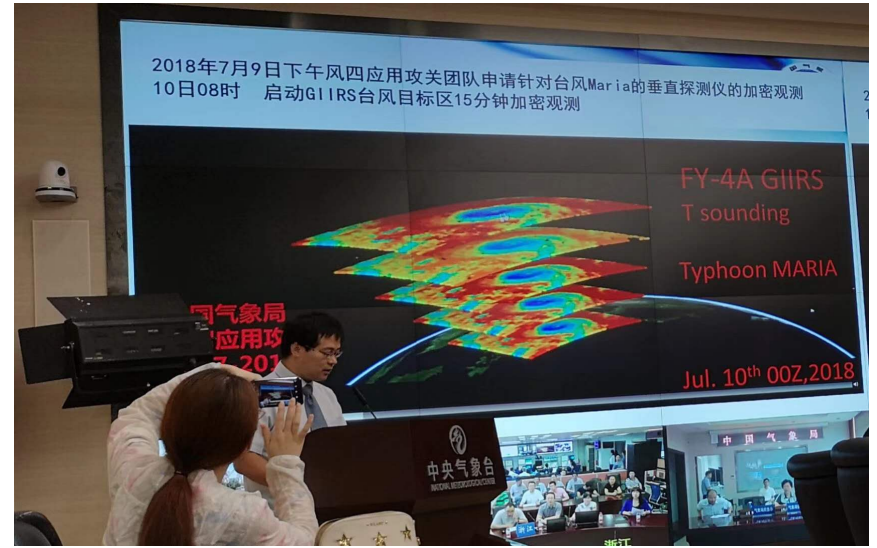
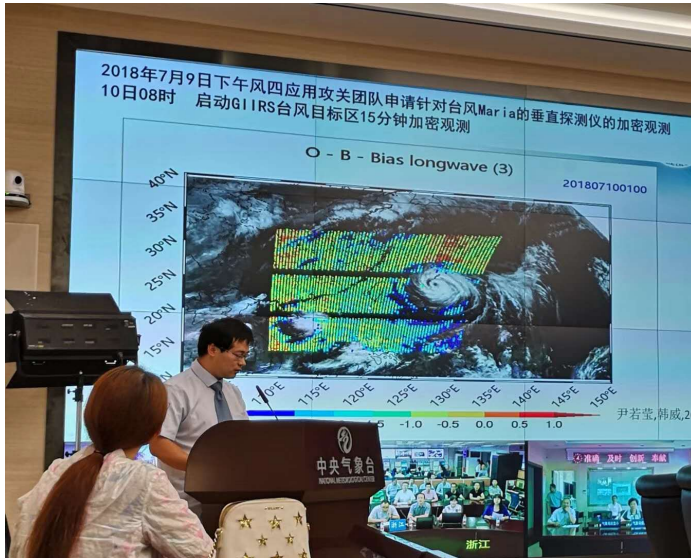
Anomaly Correl: HGT P500 G2/EASI 00Z, Day 5



## Operational Assimilation of GIIRS in GRAPES 4D-Var Since Dec. 25<sup>th</sup> 2018



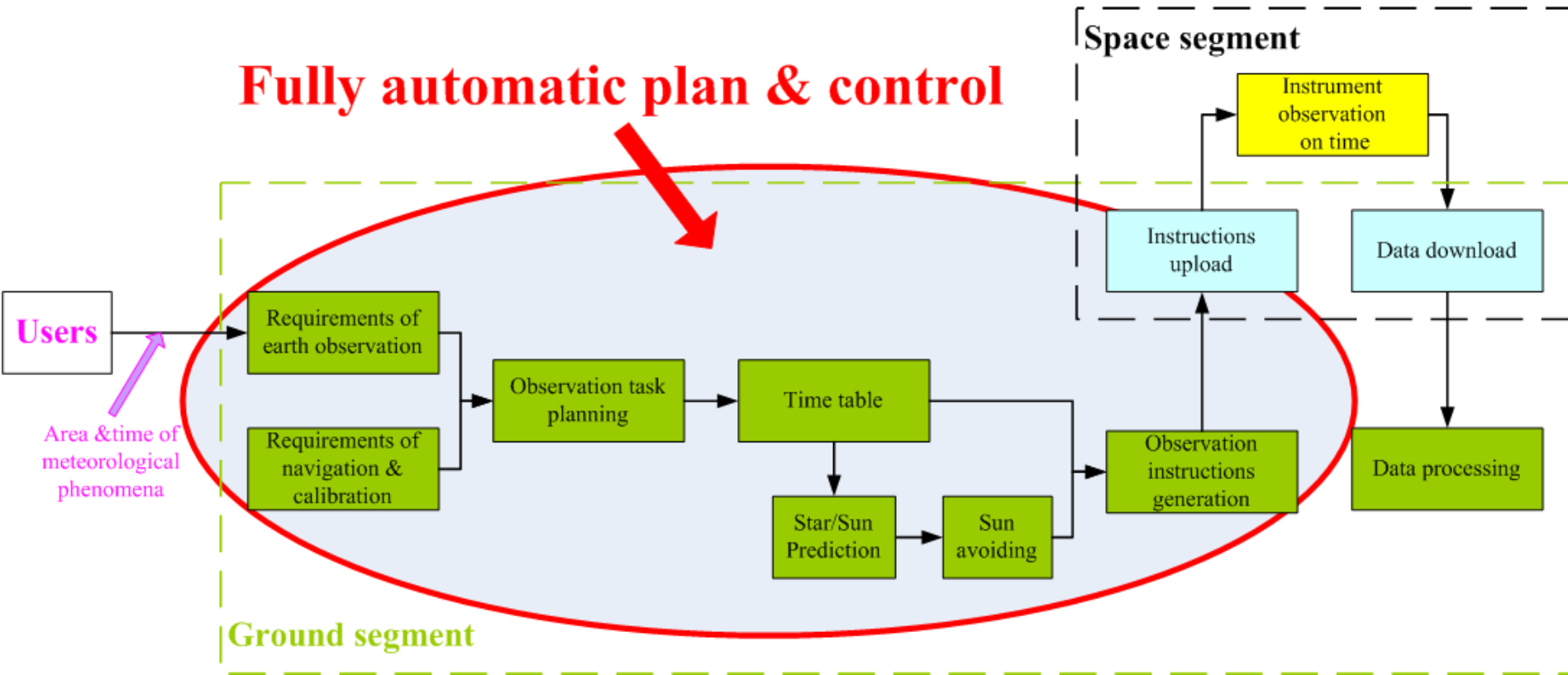
# FY-4A REAL-TIME Experiments for Typhoons(2018)



# REALTIME Targeted Observing for Typhoons in 2018

- **High Temporal** Sounding(15 minutes)
  - Typhoon Maria: July 9<sup>th</sup> -11<sup>th</sup> ,2018 (every 15 minutes)
- **Ambil: Clear Sky** Intelligent Sounding
  - NWP guided GIIIRS sounding
- **High Temporal Sounding over Sensitive Area**
  - Typhoon Ambil: July 23<sup>rd</sup> – 24<sup>th</sup> ,2018 (every 30 minutes)
  - Typhoon Mangkhut: Sep. 12<sup>th</sup> -15<sup>th</sup> ,2018 (every 30 minutes)



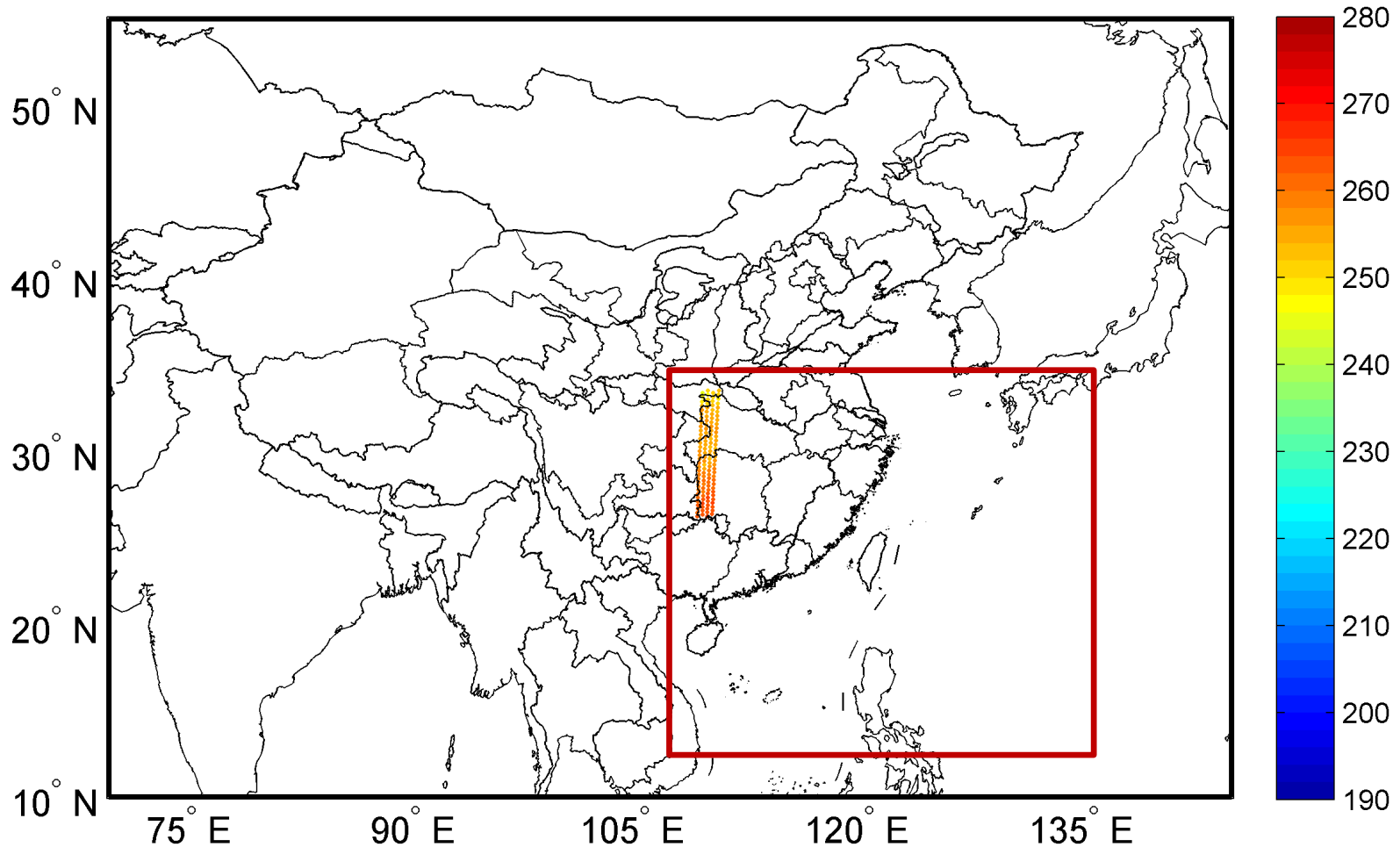


**Automatic & flexible instruction generation of FY-4A NRS** (navigation and registration system), based on users' requirement, navigation and calibration requirement and sun avoiding

# Starting 00Z (UTC) 10 July 2018

## GIIRS provides observations every 15 minutes

Date:20180710000000\_001(regx)



Starting 00Z (UTC) 10 July 2018

GIIRS provides observations every 15 minutes

2018-07-10-0000

FY-4A GIIRS  
T sounding

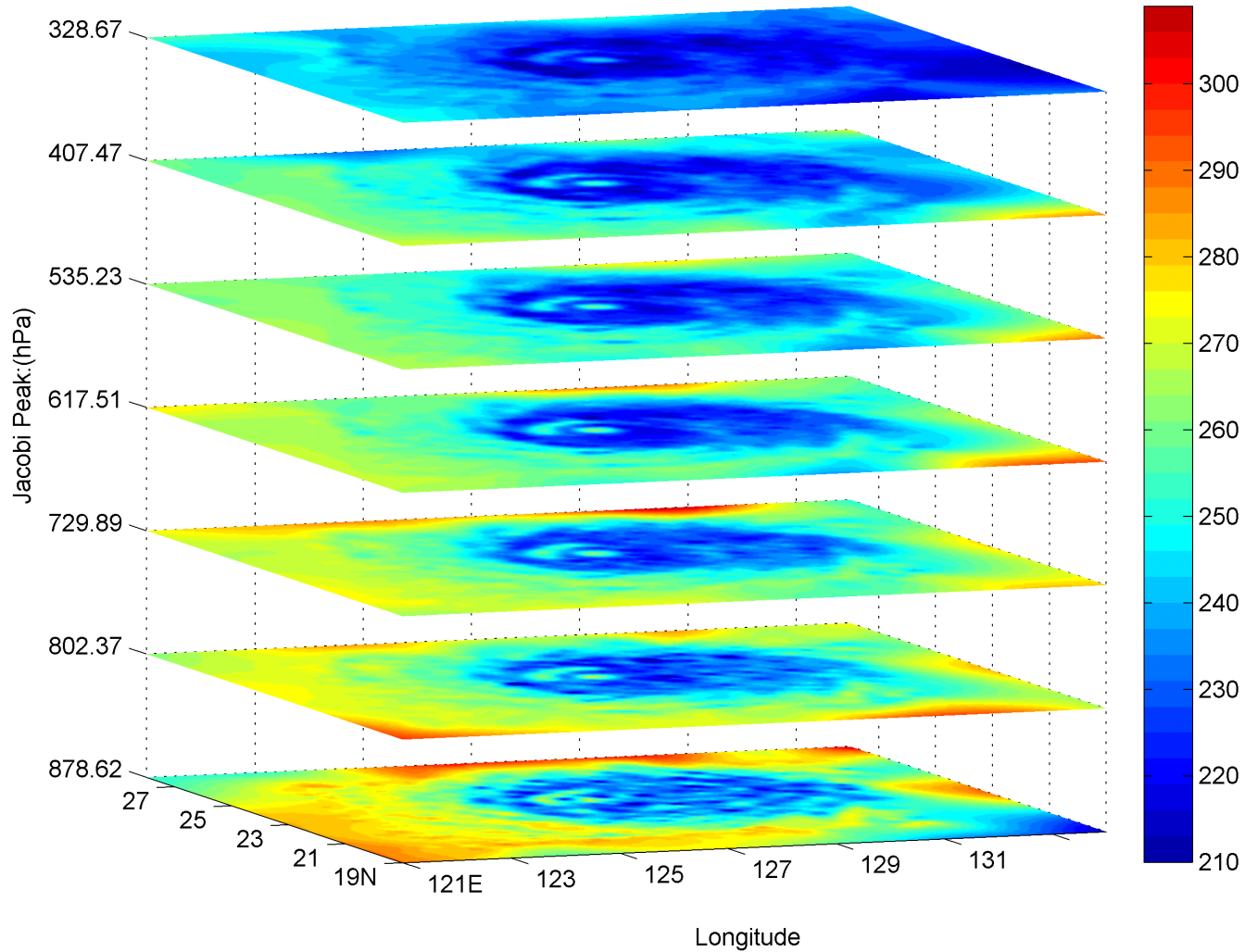
Typhoon MARIA

1650 channels

Jul. 10<sup>th</sup> 00Z, 2018

# FY-4A GIIRS humidity sounding (Every 15 minutes)

Date:20180710000310



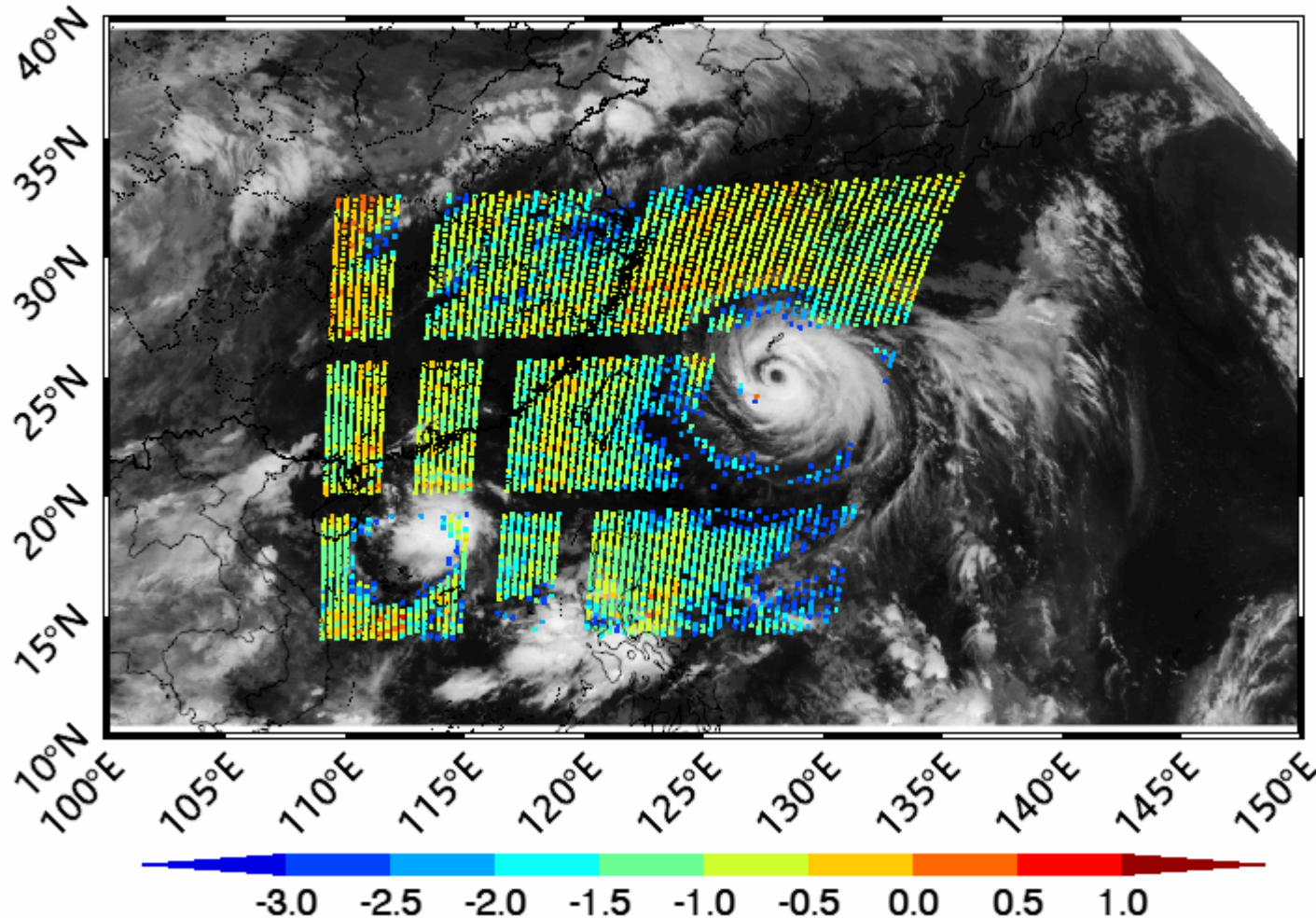


# Temperature channel peaking around 200 hPa, assimilated in GRAPES-GFS with 4D-Var system

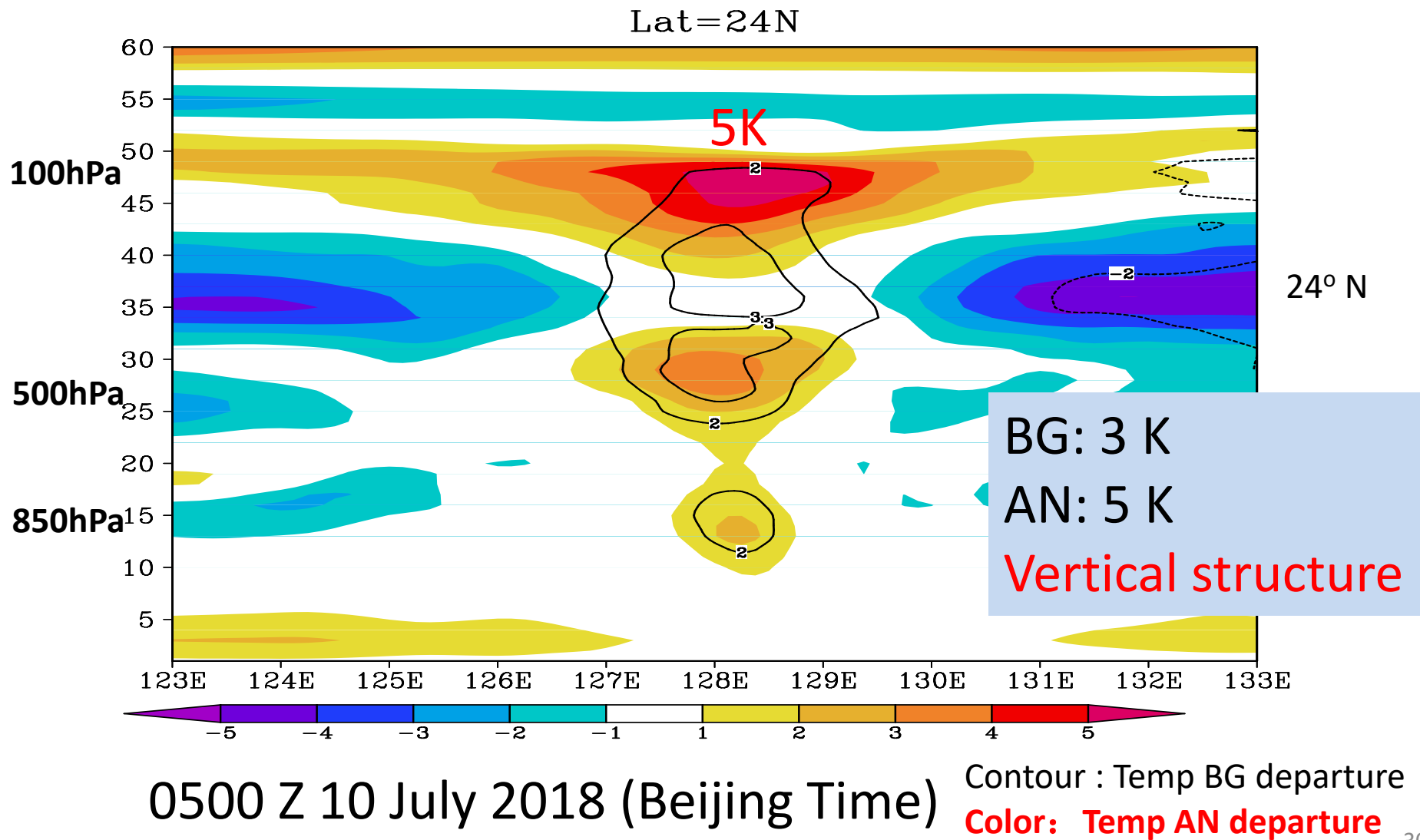
O - B - Bias longwave (3)

201807100000

Weighting function: 200hPa



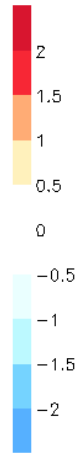
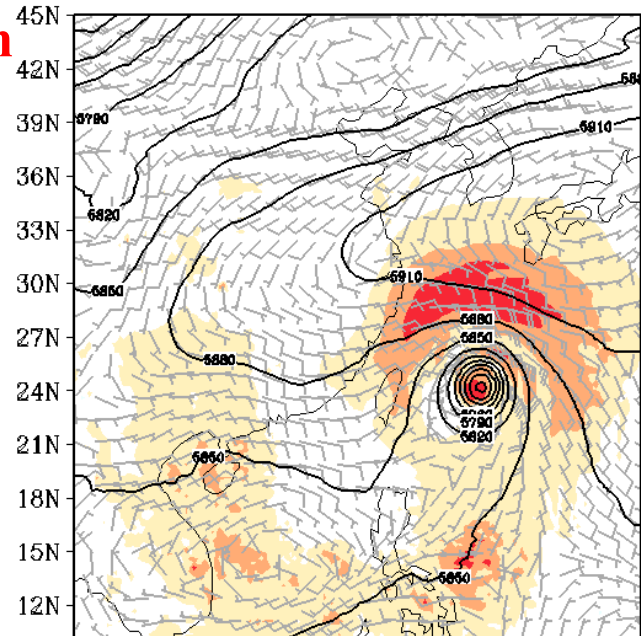
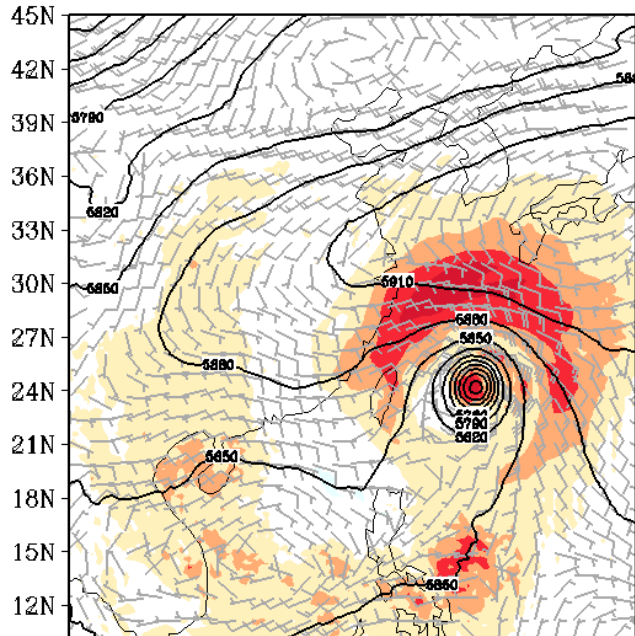
# Impact of assimilating high temporal GIRS observations on analysis: **Warm core is enhanced**



15min

30min

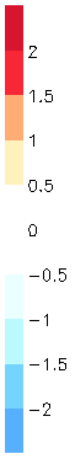
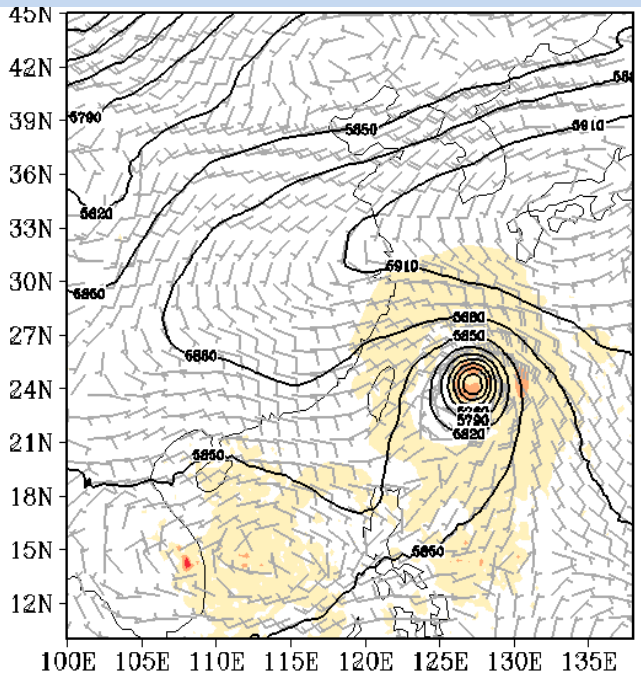
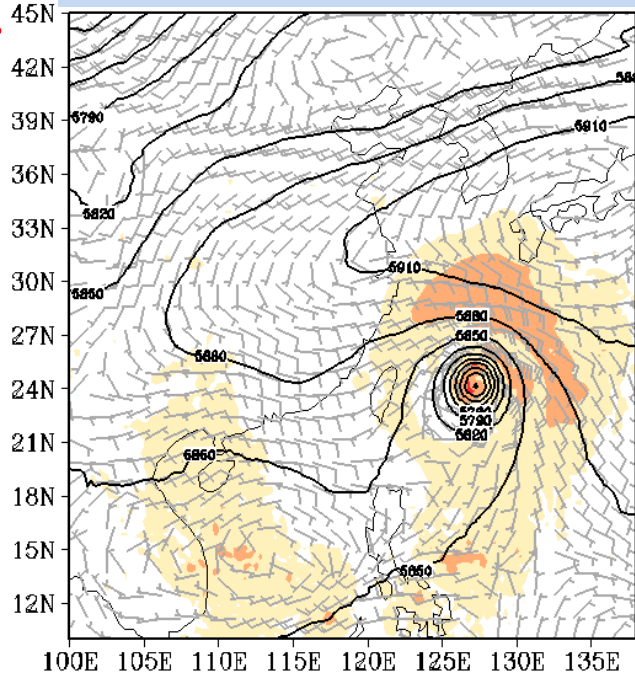
00Z, July  
10, 2018



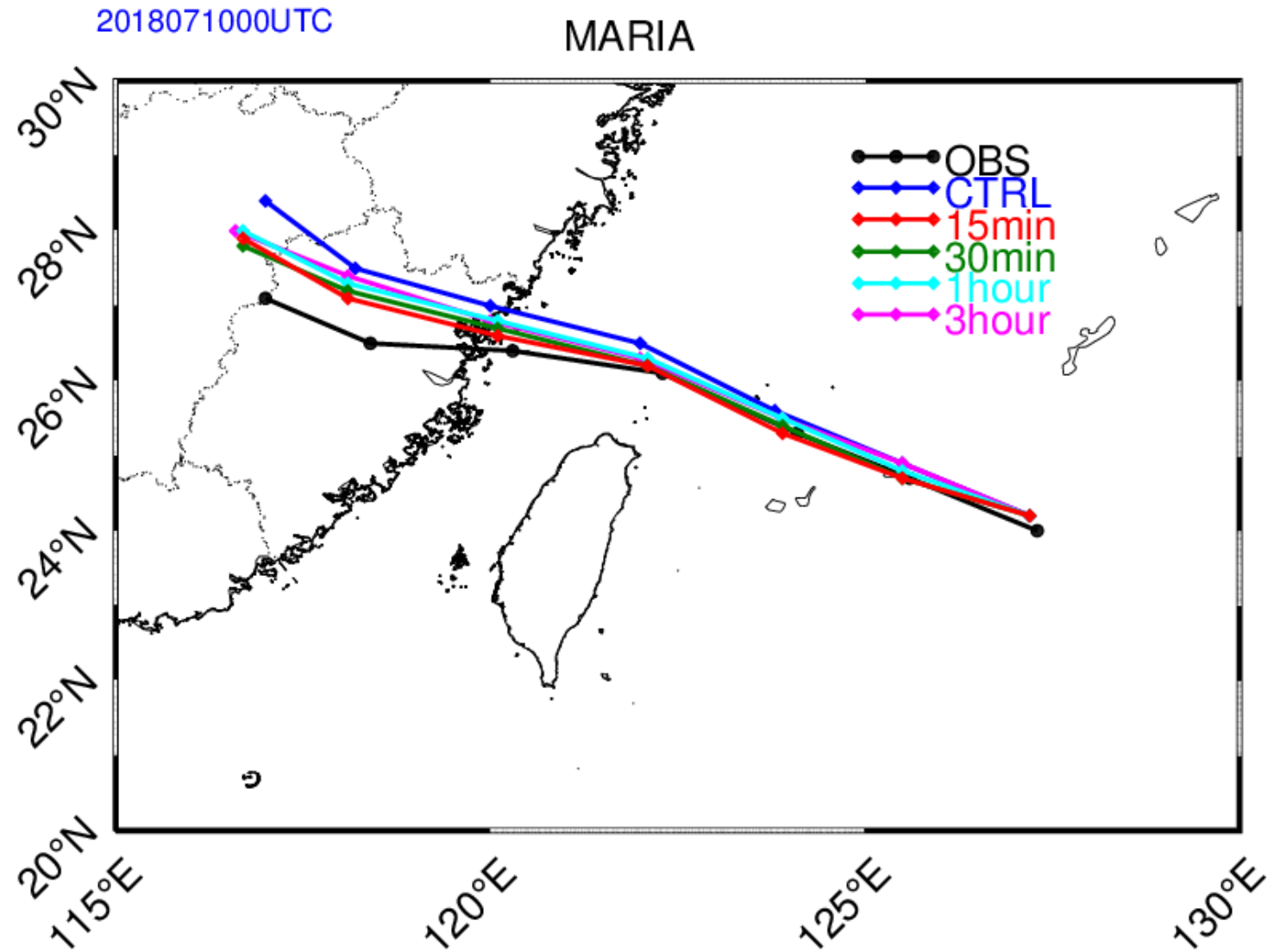
Temperature Analysis Increments with different temporal resolution

1hour

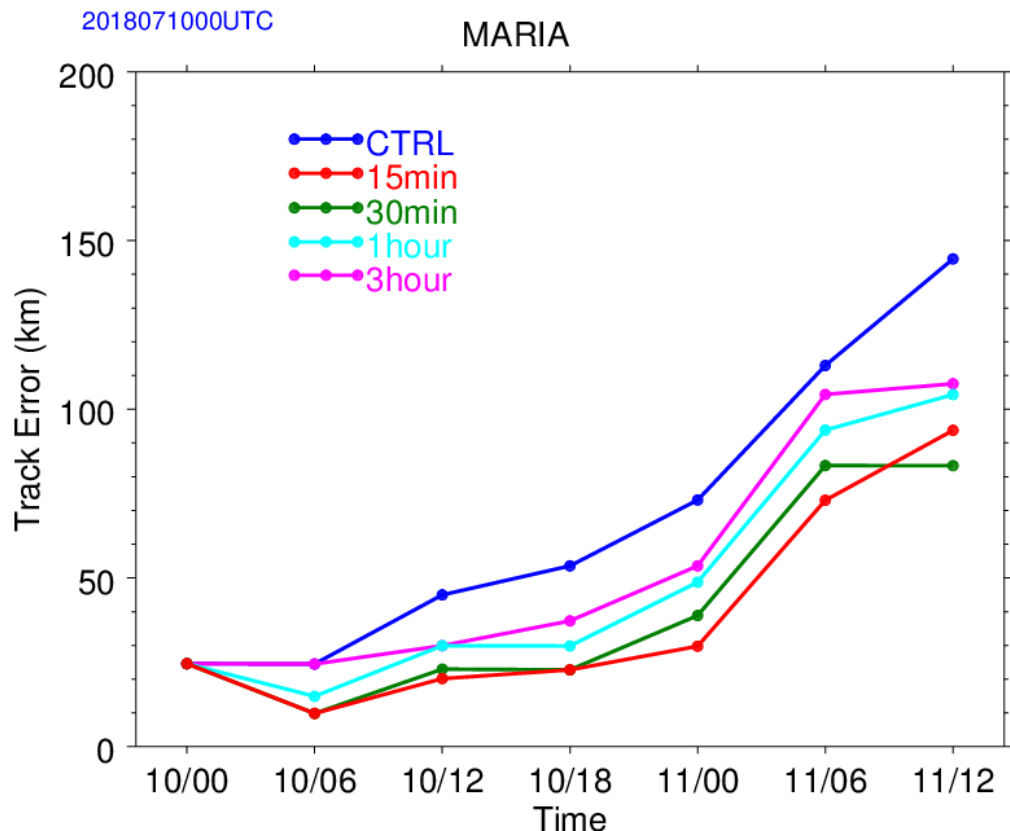
3hour



# Impact of GIRS high temporal observations on Typhoon Maria forecasts (72-h)



# Impact of GIRS on Typhoon Maria Track forecasts

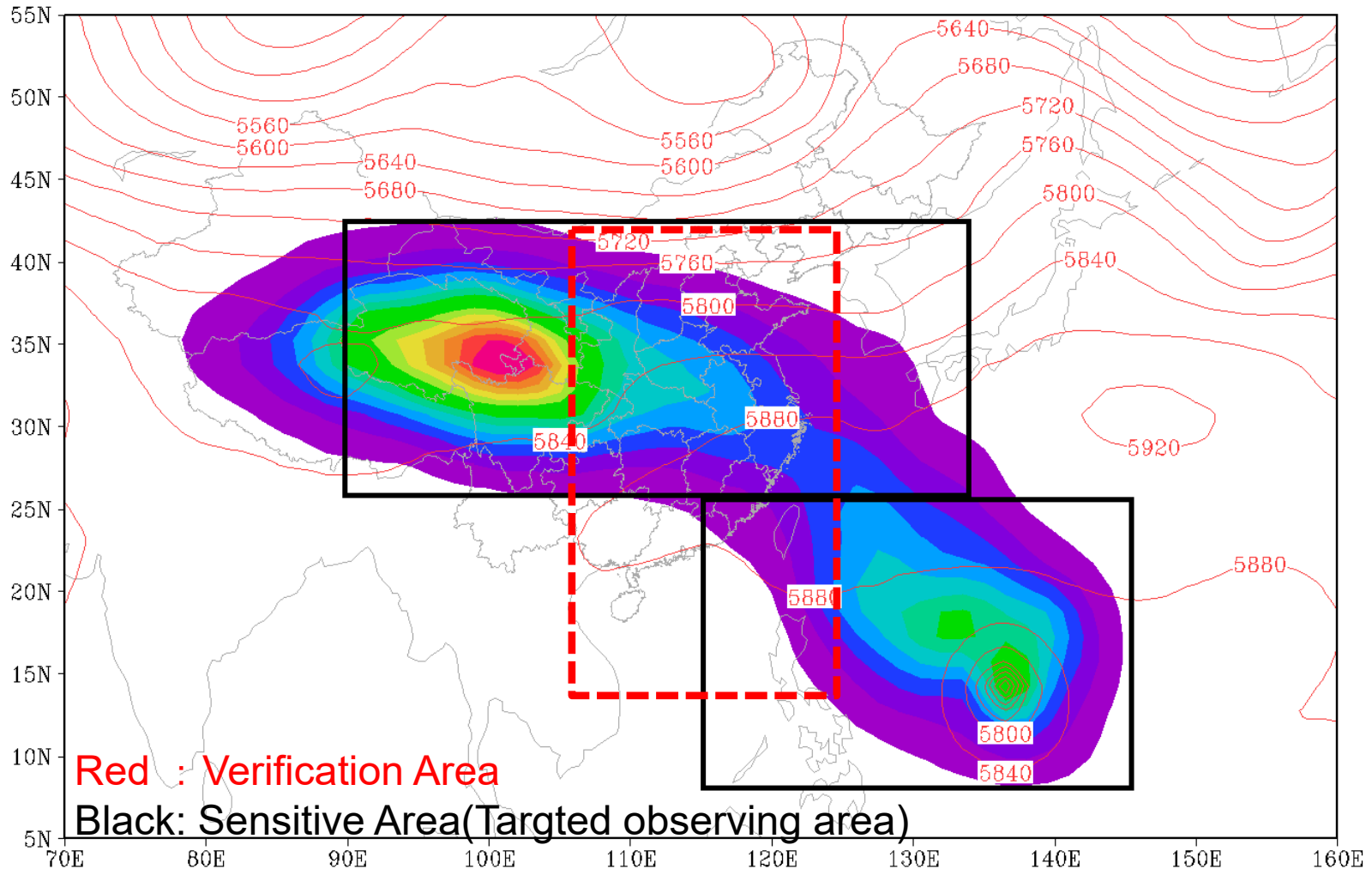


Time Resolution	00 (%)	06 (%)	12 (%)	18 (%)	24 (%)	30 (%)	36 (%)	Mean Ratio (%)
15min	0	59.84	55.17	57.52	59.29	35.36	35.15	43.19
30min	0	59.84	48.93	57.52	46.84	26.26	42.39	40.25
1hour	0	39.10	33.47	44.30	33.31	16.95	27.82	27.84
3hour	0	0	33.47	30.43	26.71	7.59	25.60	17.69

# Typhoon Mangkhut: Targeted Observing Using FY-4A GIIRS

$$\langle \delta \mathbf{X}(t_1), \delta \mathbf{X}(t_1) \rangle_{E_1} = \langle L \delta \mathbf{X}(t_0), L \delta \mathbf{X}(t_0) \rangle_{E_0} = \langle L^* L \delta \mathbf{X}(t_0), \delta \mathbf{X}(t_0) \rangle_{E_0}$$

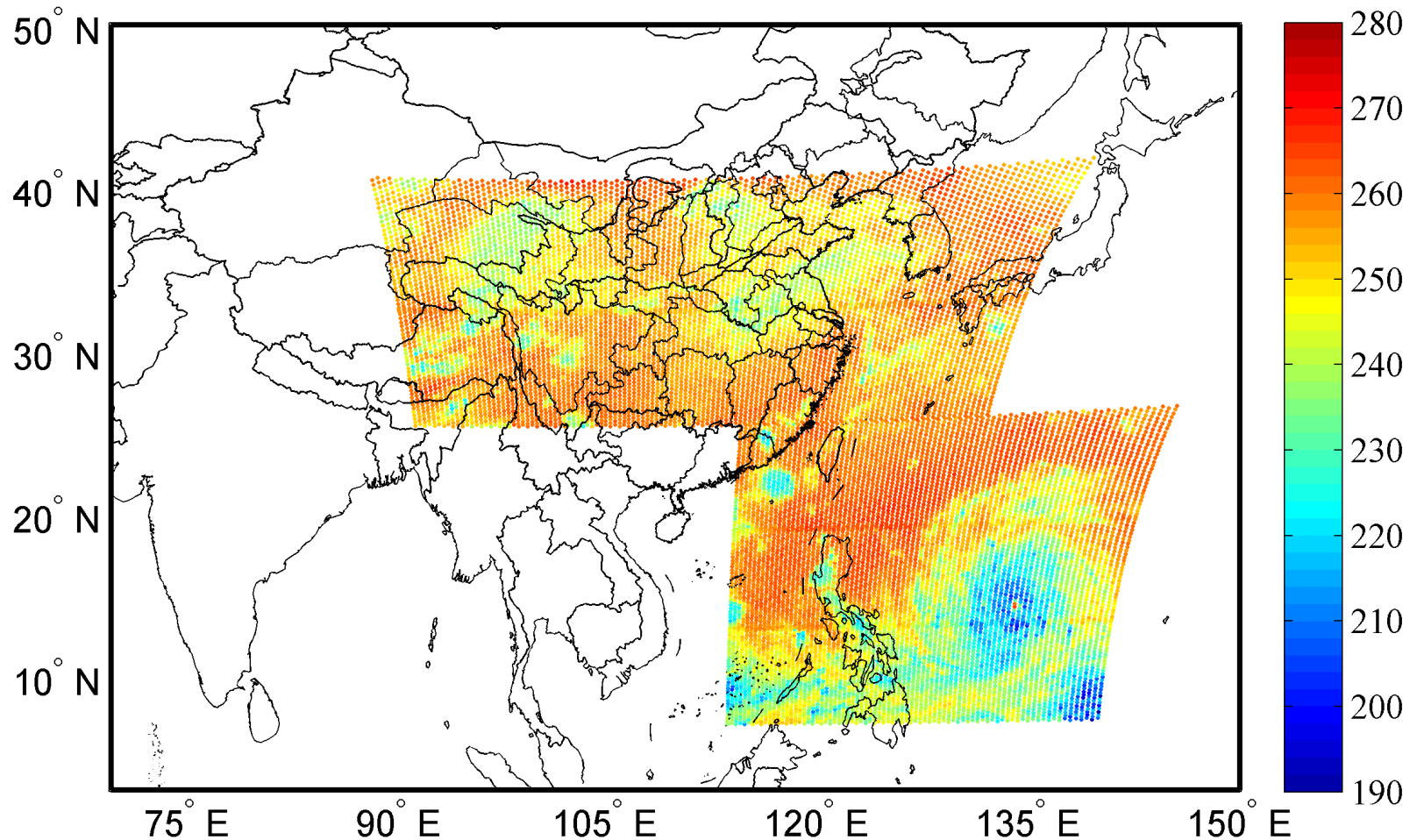
Sensitive Area Based on SV(GRAPES) at 2018091200





# Target observing using GIRS Typhoon Mangkhut 2018

Date:20180912110000\_20180912112212(GIRS:Ch993)

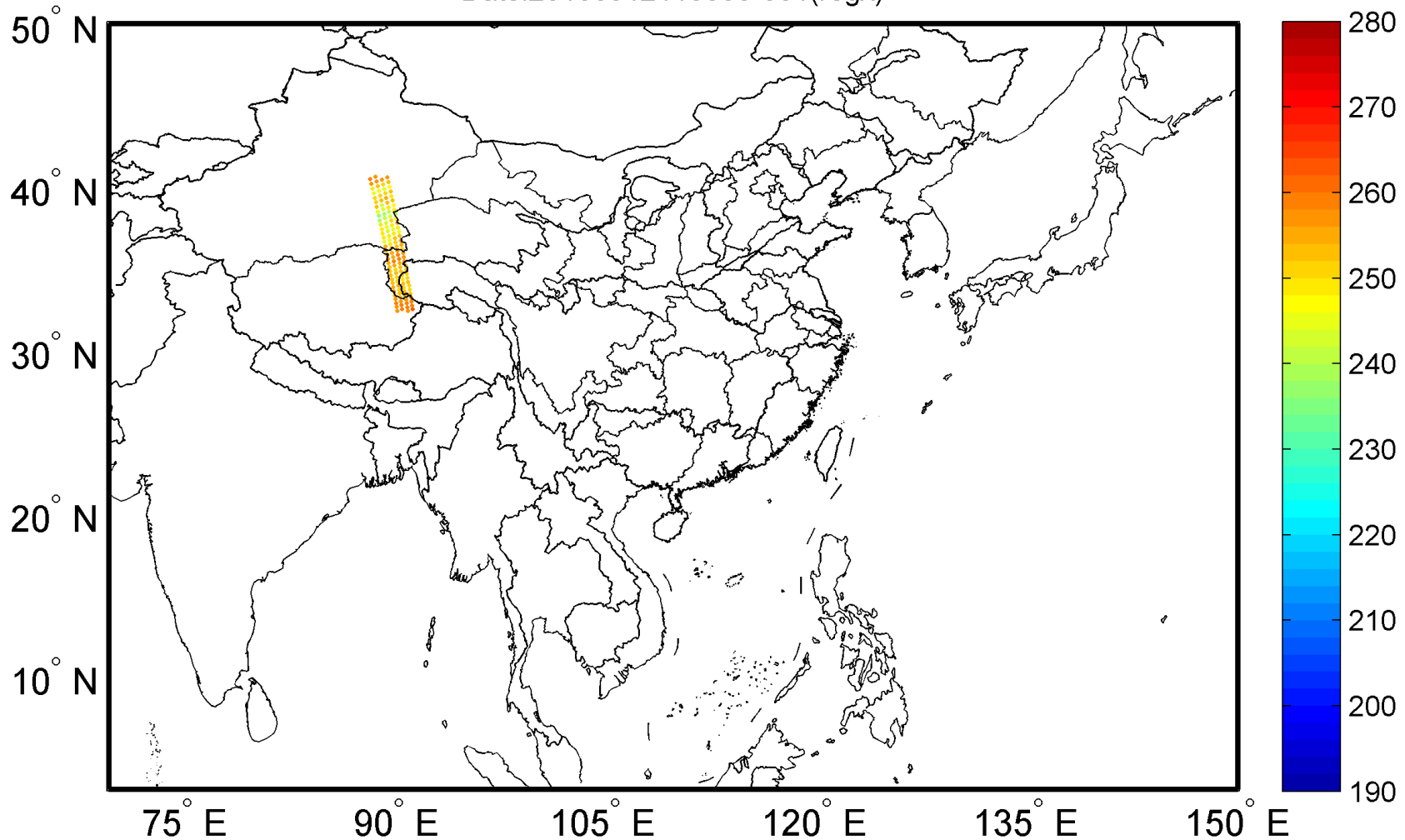


# The targeted observation received in 1 minute

- Apply : NWPC apply for the target observing;
- Aproved : CMA and NSMC approved the application;
- Targeted Observing : FY-4A GIIRS begin targeted observing!

**1 hour**

Date:20180912110000-001(regx)

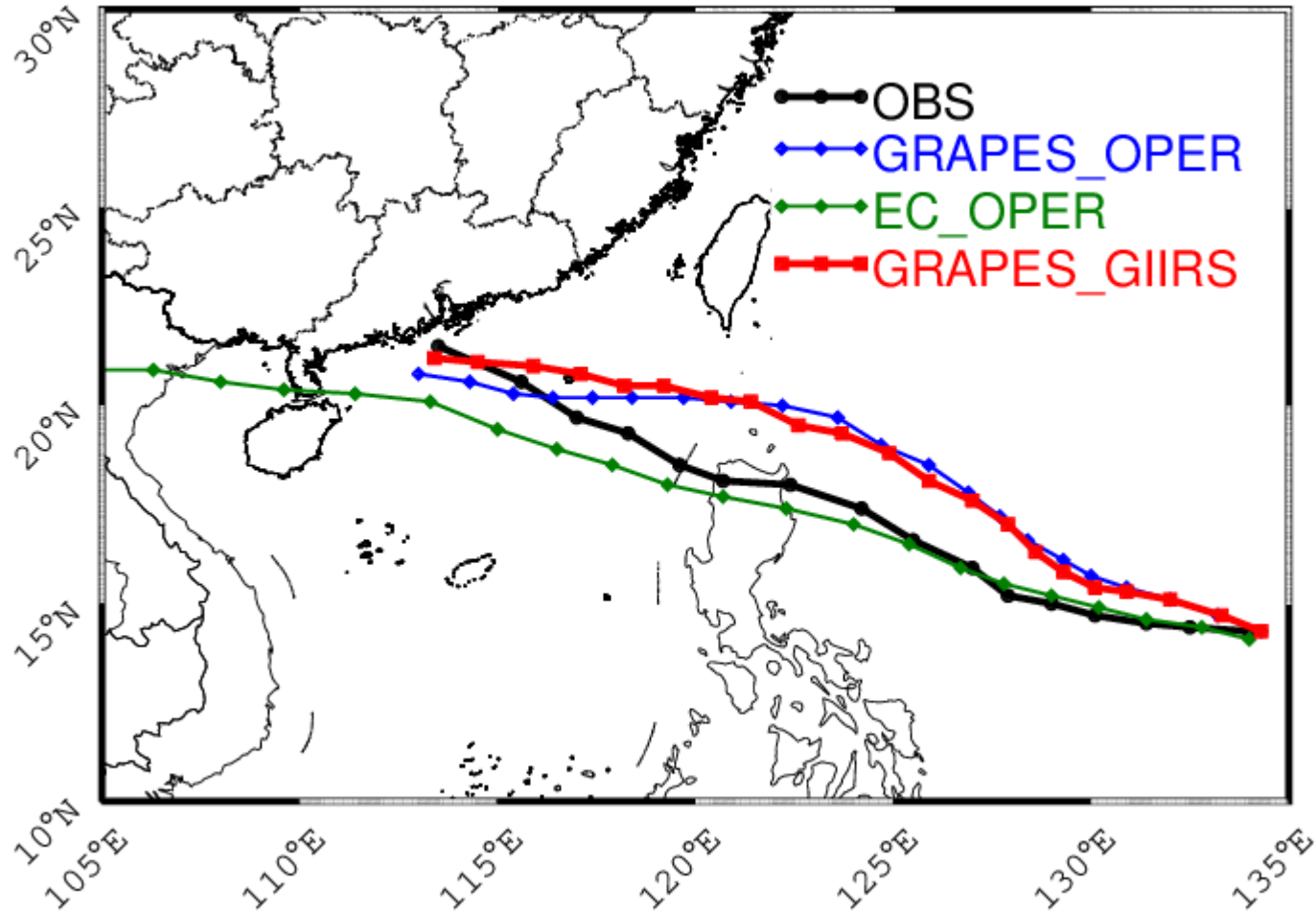




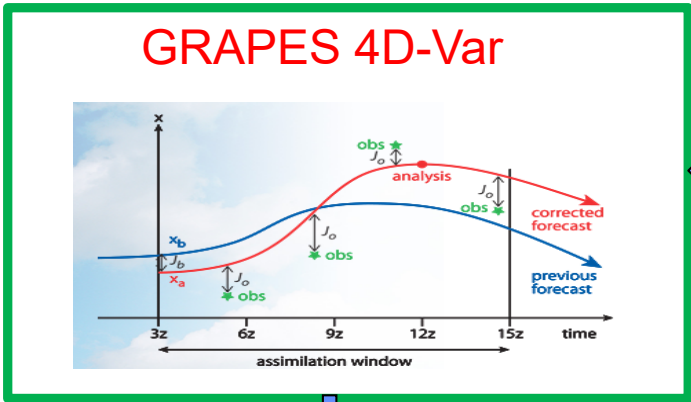
# Improved the forecast of Typhoon Mangkhut by targeted observing using FY-4A GIIRS

2018091212UTC

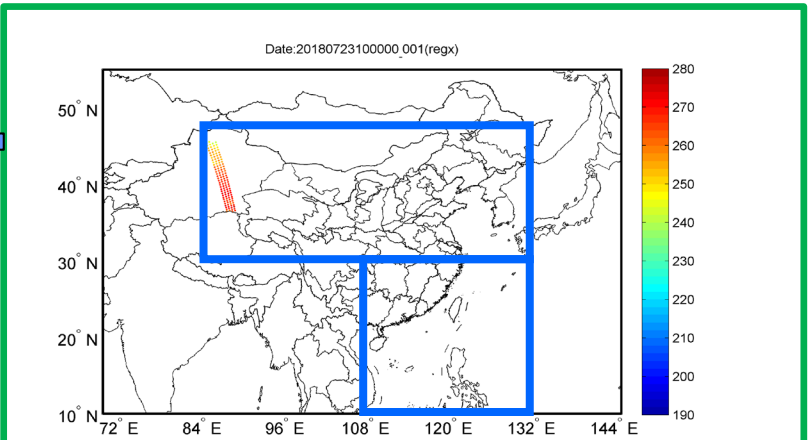
MANGKHUT



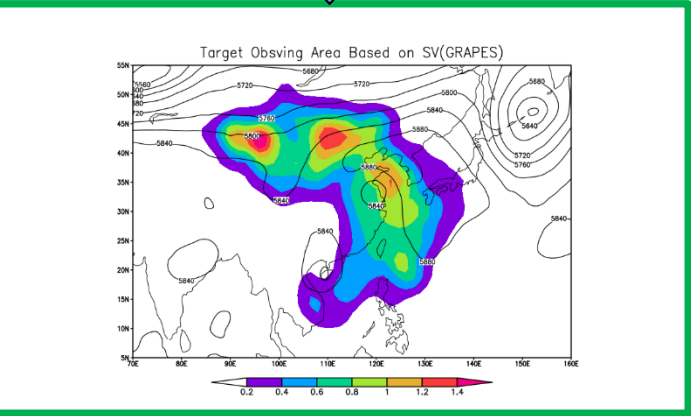
# FY-4A GIIRS Targeted Observing for Typhoon Forecasts



Assimilation of targeted obs.



GRAPES SVs Sensitive area



Every 30 minutes sounding in sensitive area



Improve the high impact weather through targeted observing strategy using FY-4A high temporal sounding

# Data and Experience Sharing of FY-4A GIIRS

- GIIRS L1 data (brightness temperature) has been available since January 24, 2019.

- Data download: <http://data.nsmc.org.cn>

- Document: <http://fy4.nsmc.org.cn/portal/cn/theme/FY4A.html>



- Targeted Observation Data in 2018 and 2019

- Typhoon Maria: July 9<sup>th</sup> -11<sup>th</sup> ,2018 (every 15 minutes)

- Typhoon Ambil: July 23<sup>rd</sup> – 24<sup>th</sup> ,2018 (every 30 minutes)

- Typhoon Mangkhut: Sep. 12<sup>th</sup> -15<sup>th</sup> ,2018 (every 30 minutes)

- Typhoon Lekima: Aug. 08<sup>th</sup> -10<sup>th</sup> ,2019 (every 30 minutes)

- Observation Operator for GIIRS

- RTTOV(V9.3, V12.1)



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# Summary and Future Perspective

- **GREAT opportunities** provided by FY-4A for targeted observing
  - Potential operational use for high impact weather prediction
  - Typhoon
- **Cooperation on the use of FY-4A**
  - Observation Operator (RTTOV coefficients)
  - Data and experience sharing
  - Cooperation on FY-4A targeted observing to improve hurricane forecasts
- **Future Perspective**

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