Retrieval and Evaluation of Atmospheric Temperature and Humidity Profile using Geostationary Hyperspectral Infrared Sounder

16 November 2022

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NMSC

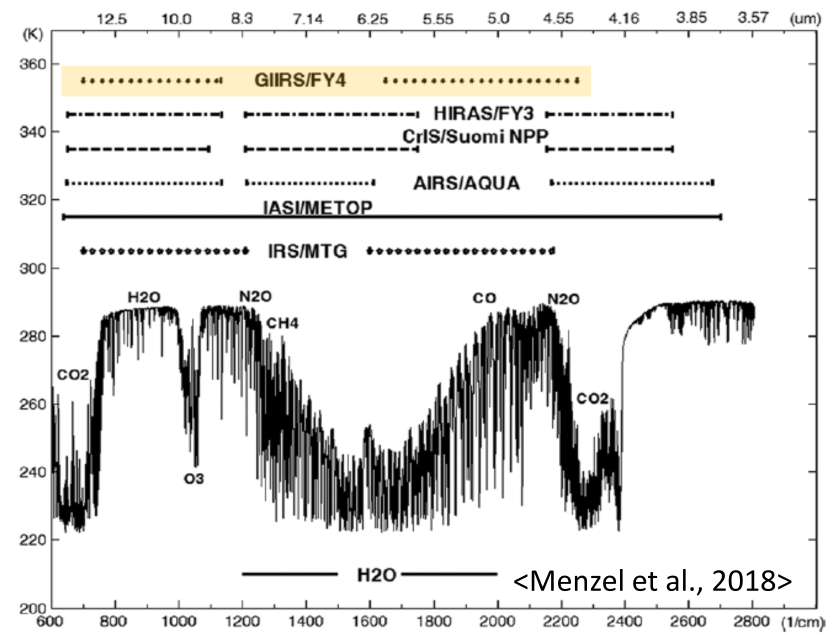
Contents

Introduction

Introduction

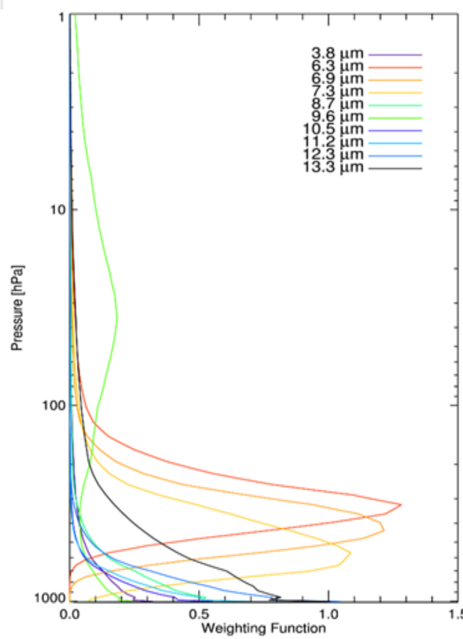
- The hyperspectral Infrared (IR) sounder is useful for monitoring climate change, weather forecasting, and data assimilation of NWP (Menzel et al., 2018)
- It has thousands of channels and high vertical resolution, so more detailed vertical temperature and humidity information can be obtained (Yang et al., 2017)
- The FY-4A GIIRS is the first hyperspectral IR sounder on board a geostationary weather satellite, complementing the IR sounder in polar orbit (XUE et al., 2022)

The spectral coverage of Hyperspectral IR sounder

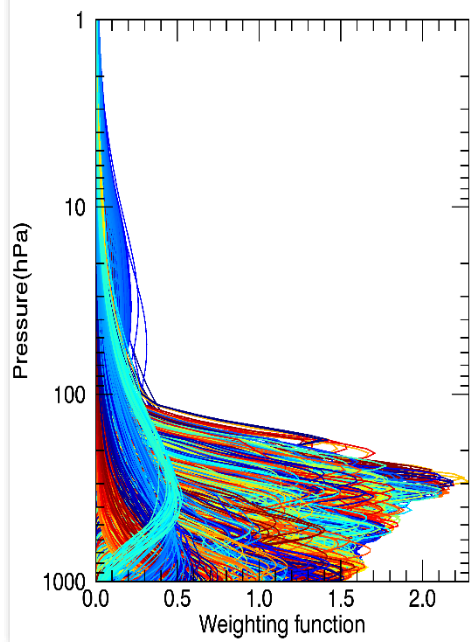


<Menzel et al., 2018>

AMI Weighting Function

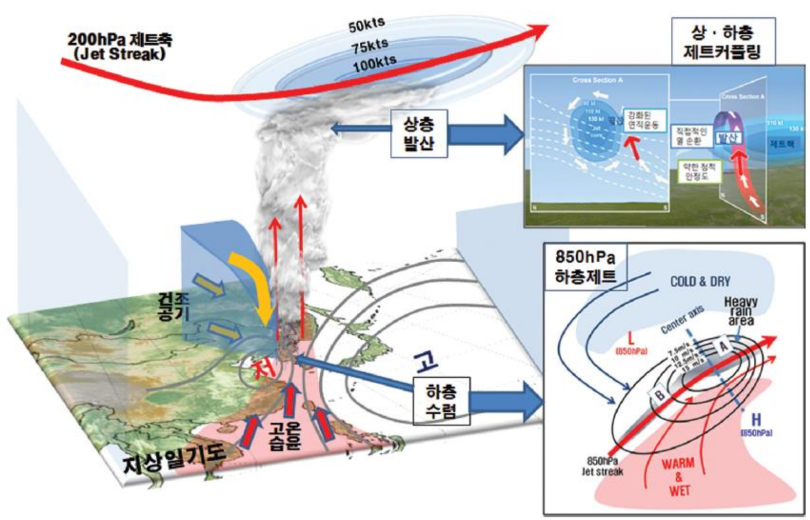


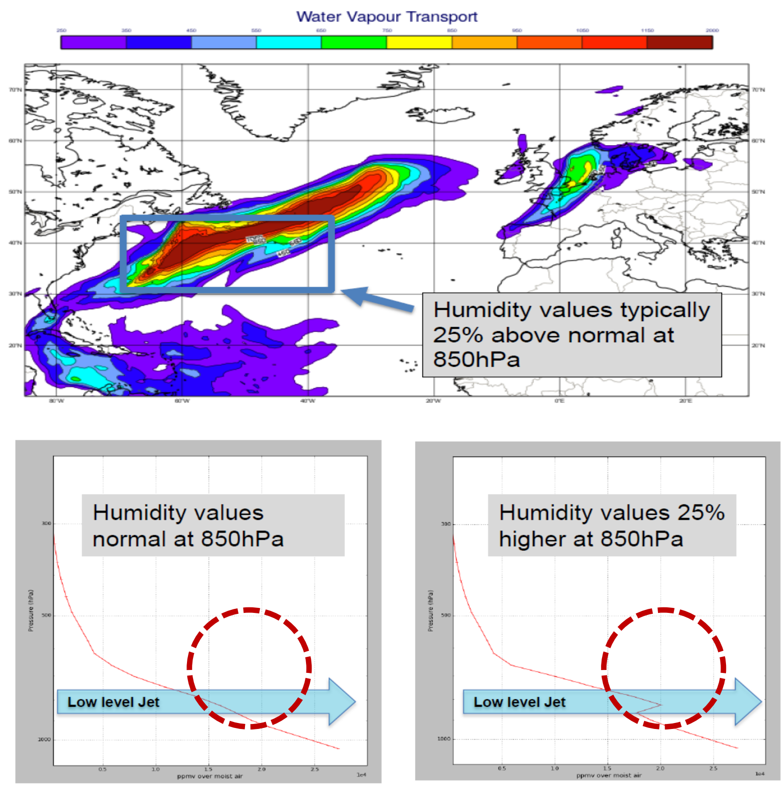
GIIRS Weighting Function



Introduction

- The GIIRS provides the temporal, horizontal, and vertical resolution required for the diagnosis and prediction of severe weather (XUE et al., 2022)
- KMA developed a 1D-VAR based atmospheric profiles using FY-4A GIIRS data and GK2A AMI Atmospheric Profiles (AAP) algorithm for application to nowcasting





- About 90% of precipitation in Summer in East Asia is caused by low-level jet
- Monitoring of areas where water vapor in the lower layers is rapidly increasing
  - Analyze the position and intensity of the lower jets
  - Can be used for heavy rain forecasting

Reference: ECMWF, 2017, Potential for MTG-IRS to impact the forecasting of severe precipitation cases

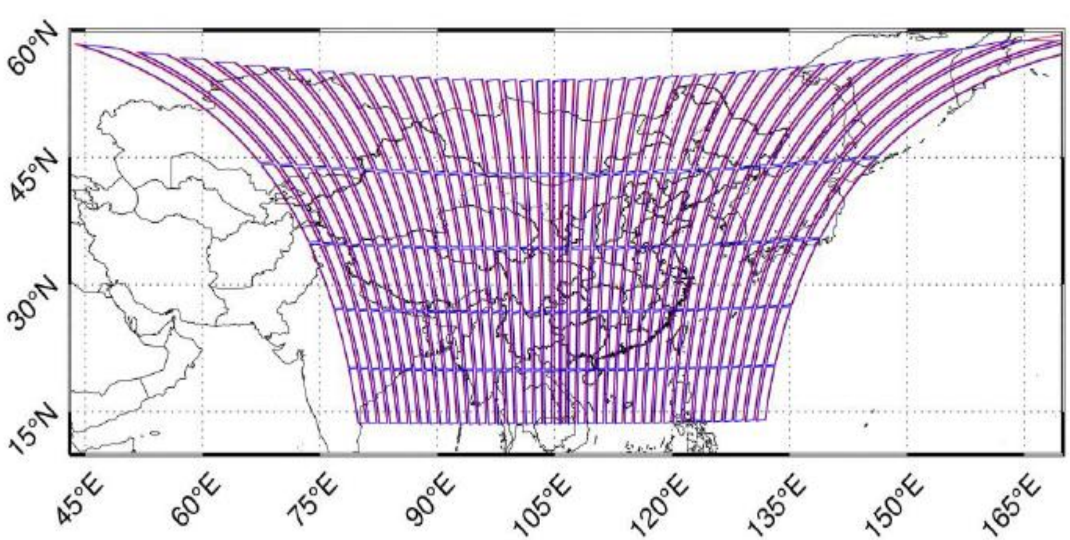
Data & Method

Data & Method

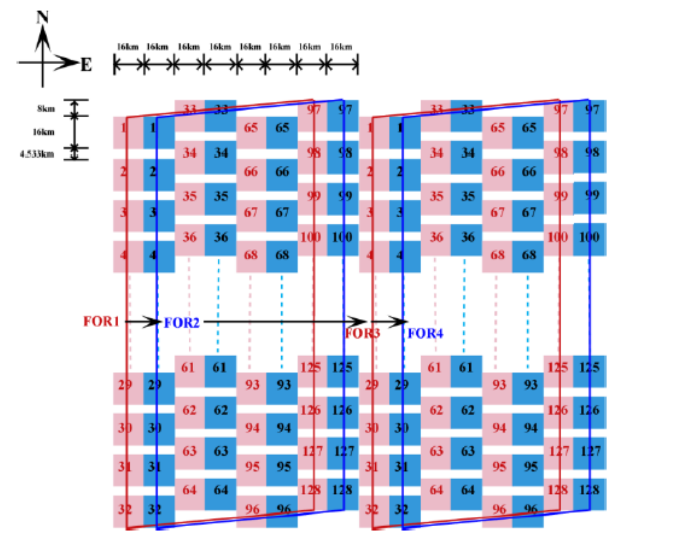
Geostationary Interferometric Infrared Sounder (GIIRS)

- The GIIRS on board FY-4A launched in December 2016 is the first geostationary hyperspectral infrared sounder

Satellite/ Sensor	Spectral bandwidth	Channels	Spectral resolution	Spatial resolution	Temporal resolution
FY4A/GIIRS	700~1,130 cm^{-1}	689	0.625 cm^{-1}	16 km	67 min (China area)
	1,650~2,250 cm^{-1}	961			



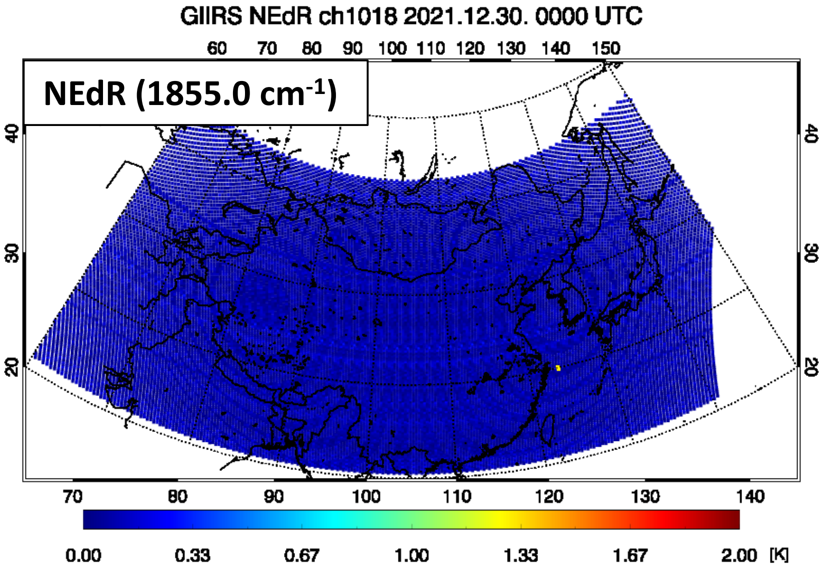
➢ Regional observation coverage of GIIRS (Yin et al., 2020)

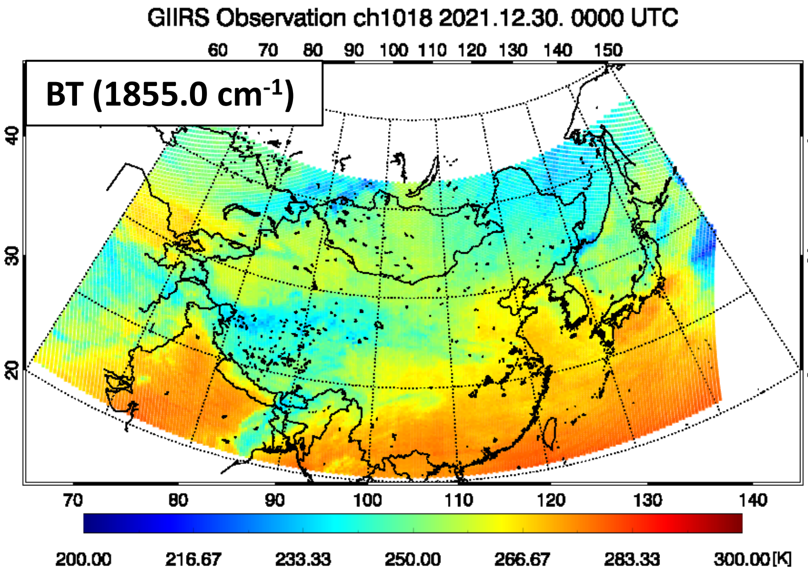


➢ Scanning mode of GIIRS every two adjacent FORs (Yin et al., 2020)

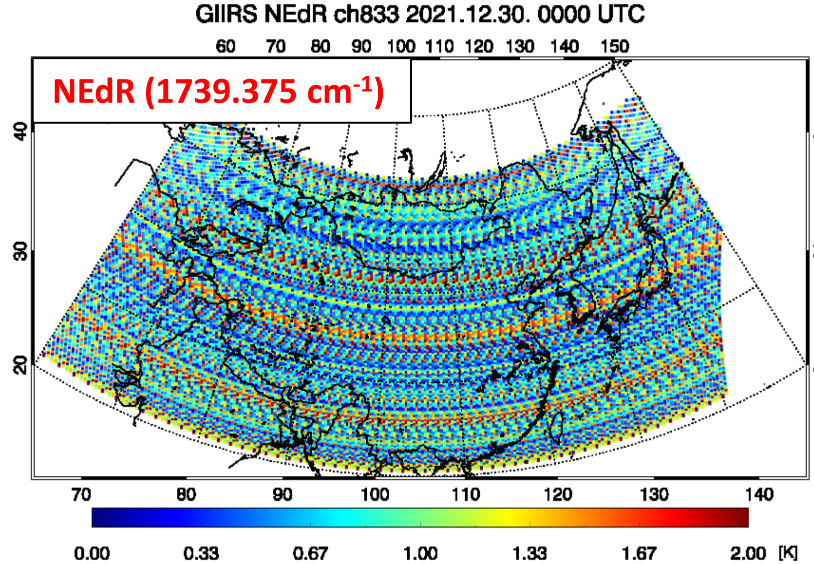
Data & Method

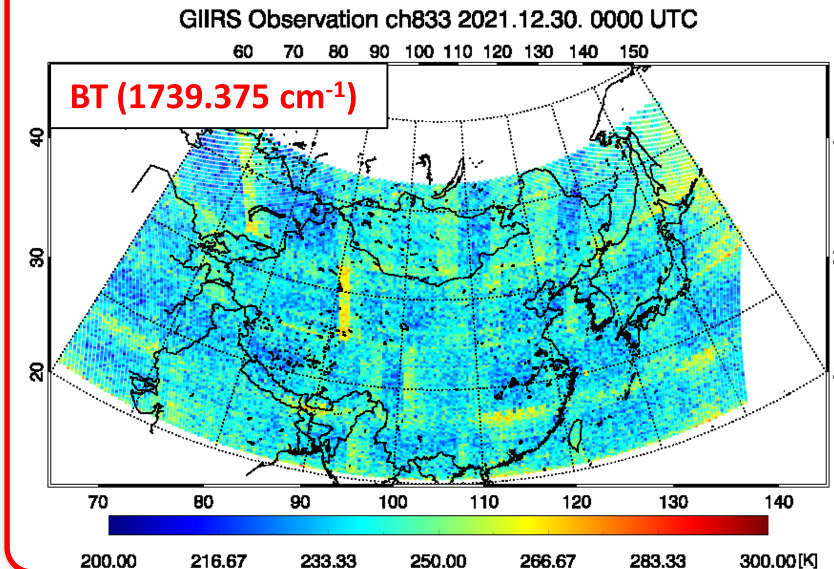
Small NEdR of FY-4A/GIIRS





Large NEdR of FY-4A/GIIRS





Data & Method

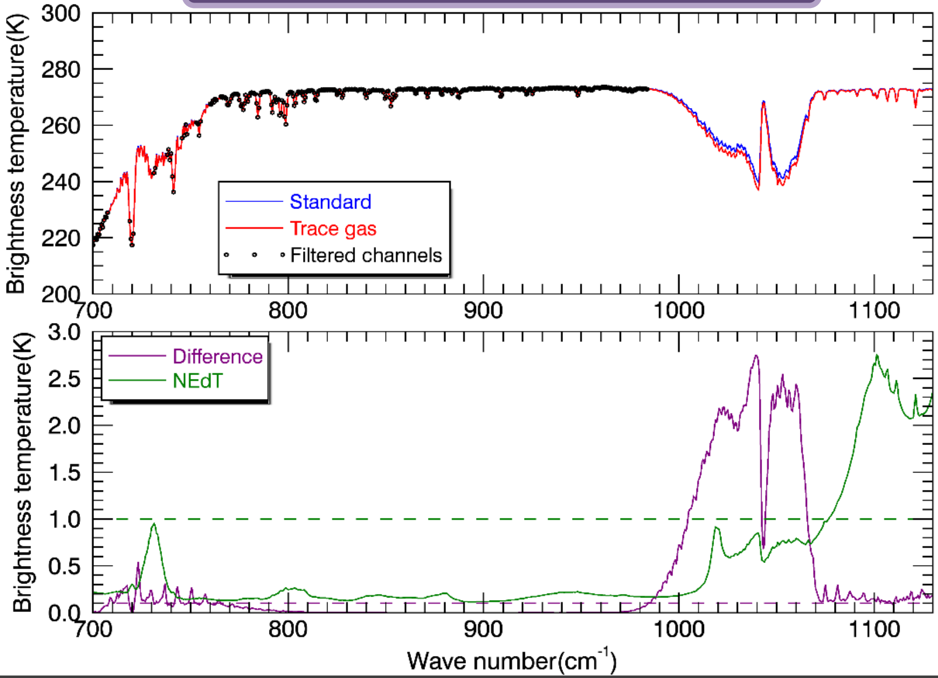
Selection of FY-4A GIIRS channels

- **(STEP 1) Excluding channels with large noise equivalent differential temperature (NEdT) or strong trace gases (O_3, N_2O, CO, CH_4) absorption**

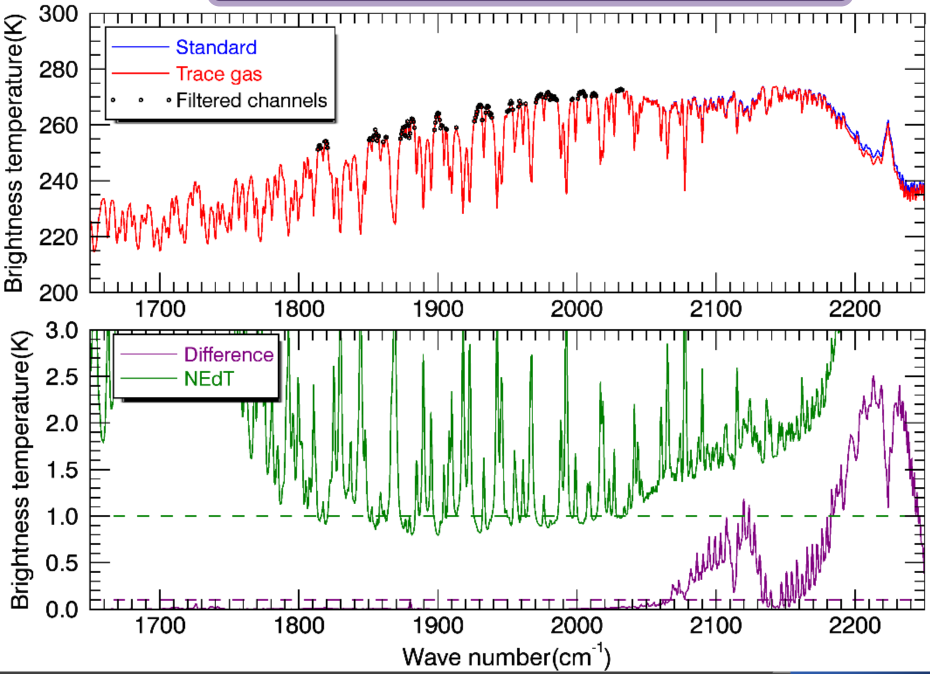
  - Using the difference between background BT and BT when the trace gas concentration is increased by 20% (RTTOV model simulation)

  - Selection of channels with sensitivity to trace gases less than 0.1 K and GIIRS NEdT less then 1 K (total of 515)

Long-wave IR (700~1130 cm^{-1})



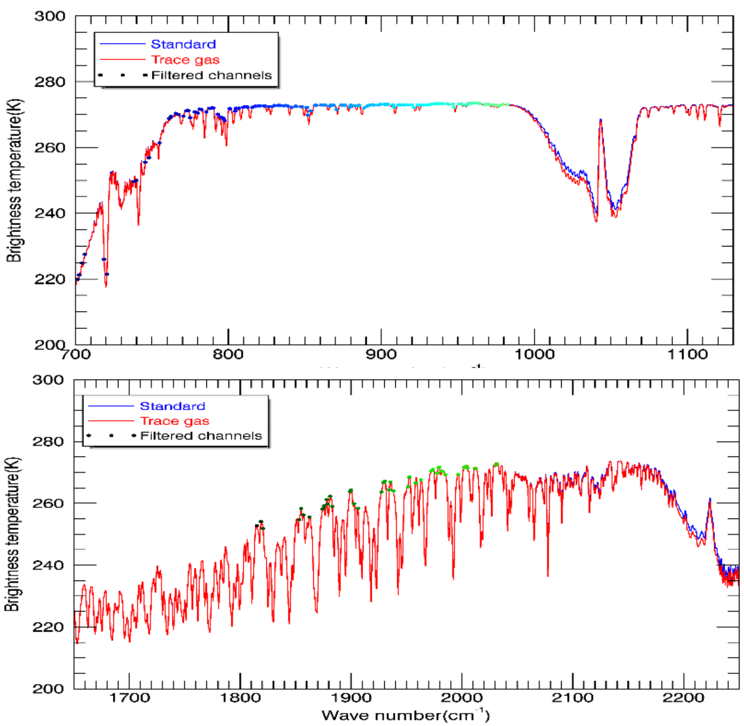
Mid-wave IR (1650~2250 cm^{-1})

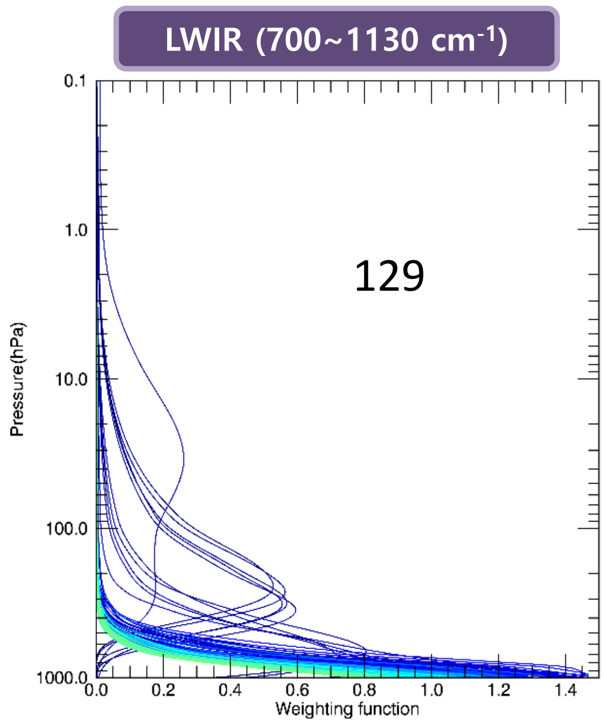


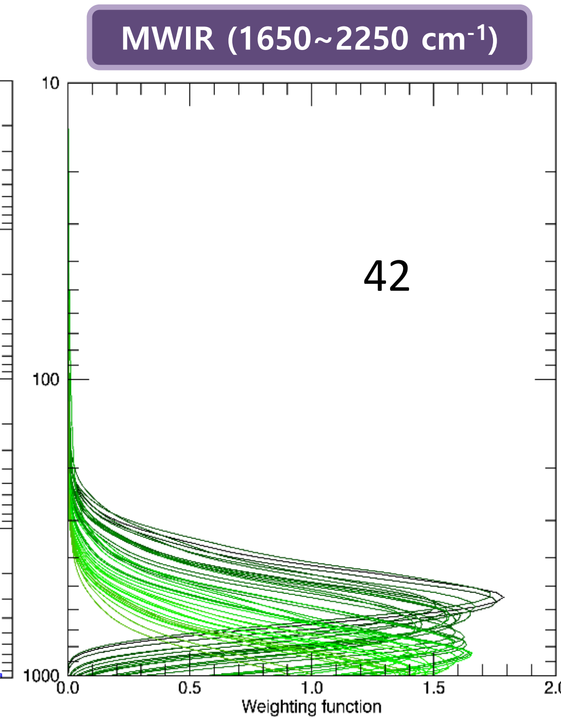
Data & Method

Selection of FY-4A GIIRS channels

- **(STEP 2) Channel selection considering absorption of other trace gases (total of 171)**
  - Excluding absorption of other trace gases that may be included in the RTTOV model simulation
  - Select the channel with the highest BT (local maximum) by grouping 3 adjacent channels, starting with the lowest wavenumber of the channels selected in step 1







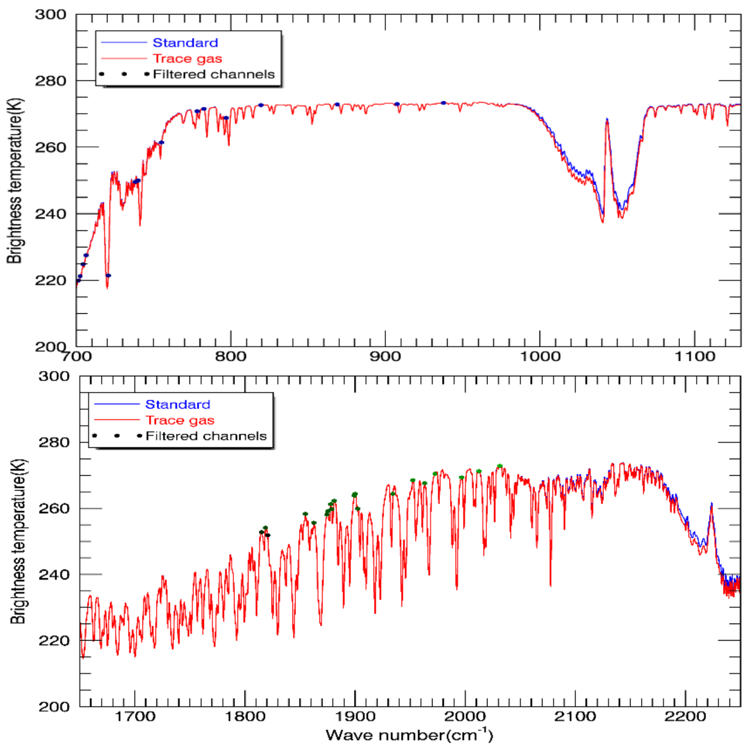
Data & Method

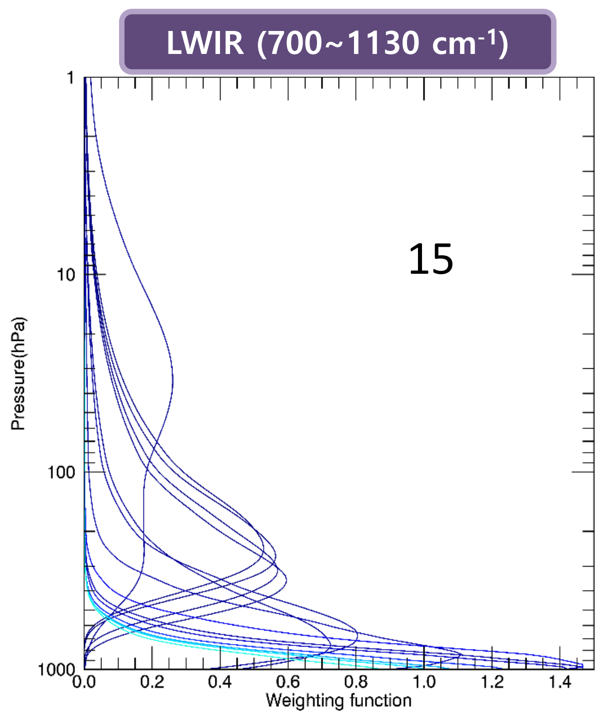
Selection of FY-4A GIIRS channels

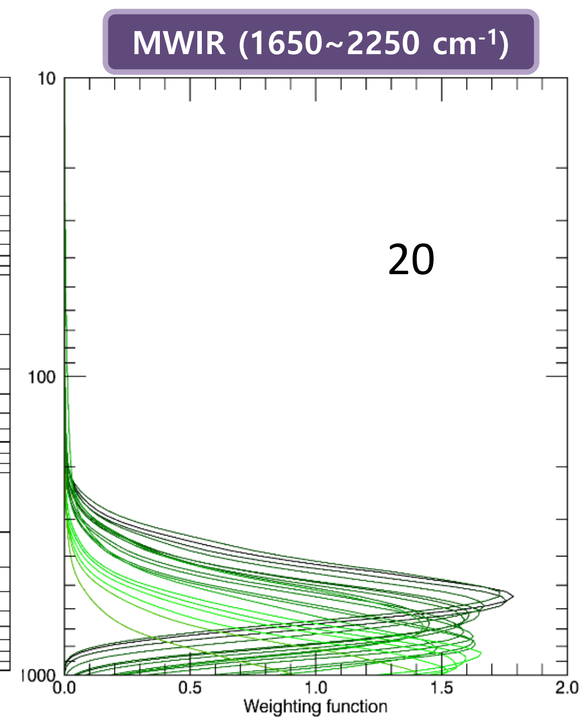
- **(STEP 3) Channel selection considering the vertical distribution of the channel weighting function (total of 35)**

  - Selection of channels to resolve overlapping of weighting functions of the selected channels in step 2

  - Select the channel with the largest weighting function peak vertically







Data & Method

Pre-processing of FY-4A GIIRS data

Systematic bias correction

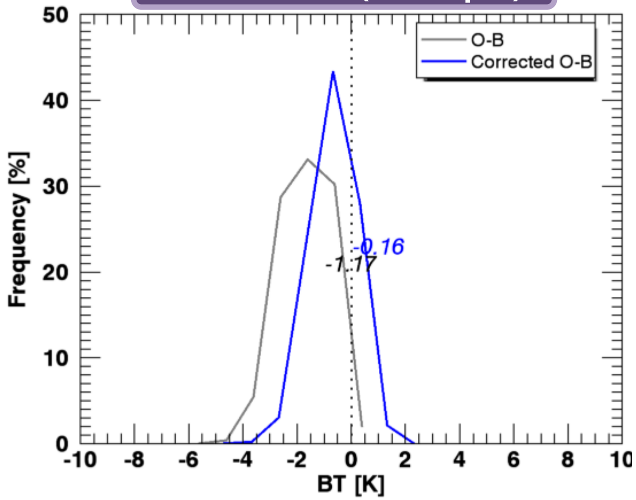
- Bias correction of GIIRS radiance using coefficients(C_0, C_1) calculated from GIIRS observed radiance ($Radiance_{obs}$) and the simulated clear sky radiance ($Radiance_{reference}$) by NWP model (UM) analysis data (Hewison et al., 2013; Lee et al., 2017)

$$Radiance_{obs} = C_0 + C_1 \times Radiance_{reference}$$

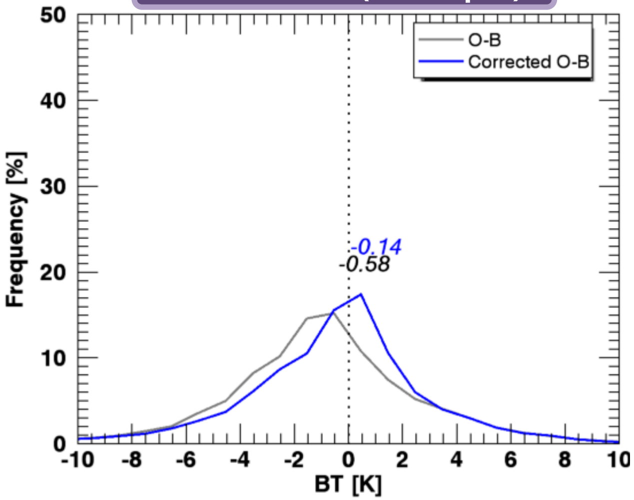
$$Corrected\ radiance_{obs} = (Radiance_{obs} - C_0)/C_1$$

O-B comparison before and after bias correction

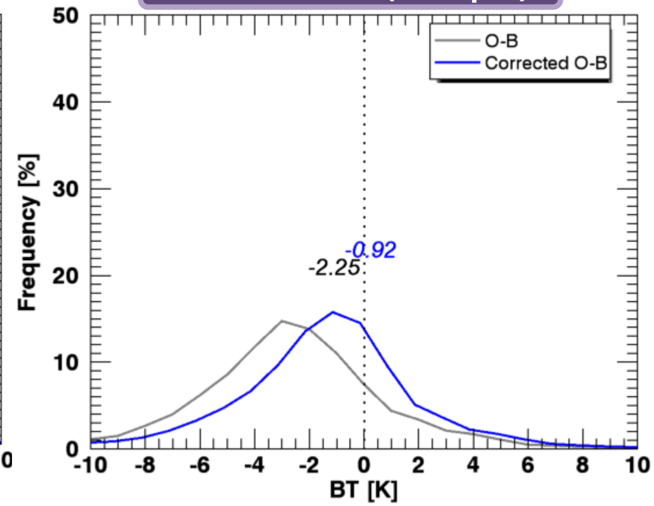
704.375cm^{-1} (14.20 μm)



796.875cm^{-1} (12.55 μm)



1934.375cm^{-1} (5.17 μm)



Data & Method

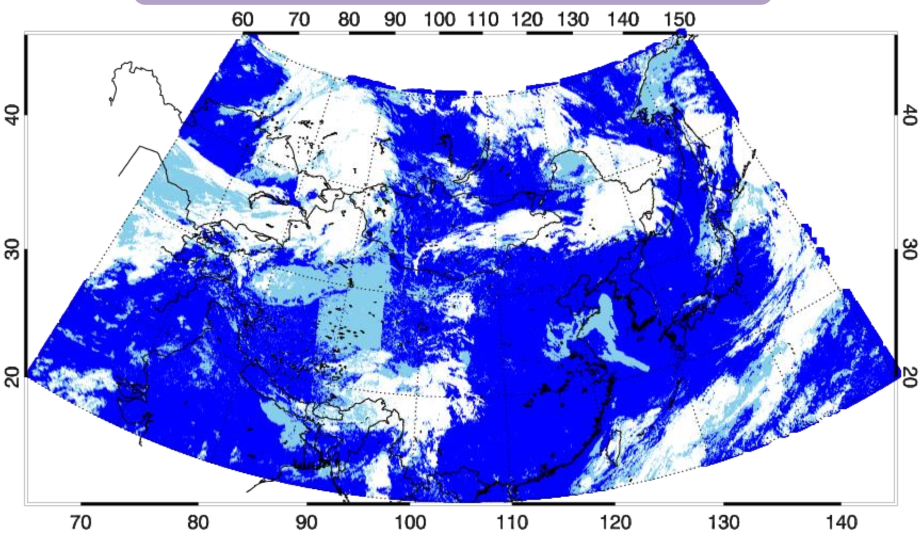
Pre-processing of FY-4A GIIRS data

Temporal and spatial matching

- Matching NWP model, GK2A CLD, Land/sea mask data with GIIRS grid
- **Only use clear sky pixels** (Probably cloud is also included in the cloud area)

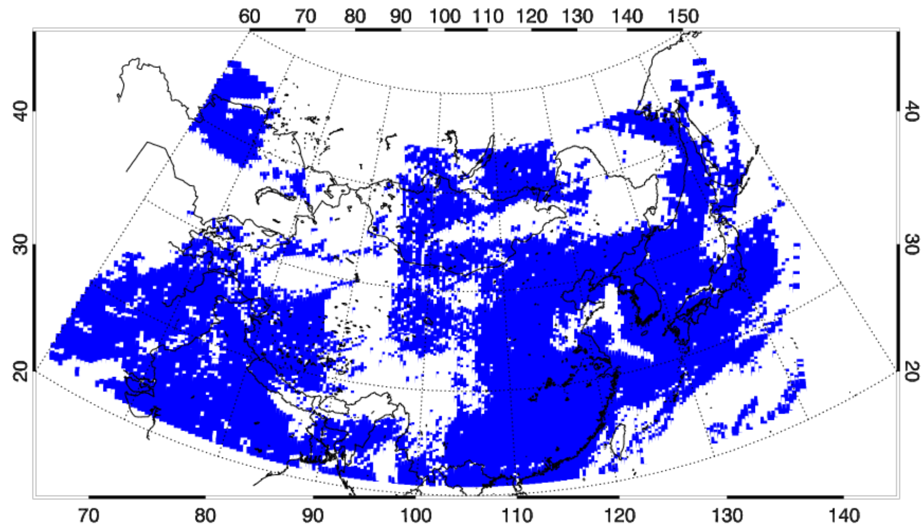
Ex) Cloud detection on 8 April 2022 at 0000 UTC

GK2A Cloud detection



Cloud Probably cloud Clear

Collocated Cloud detection

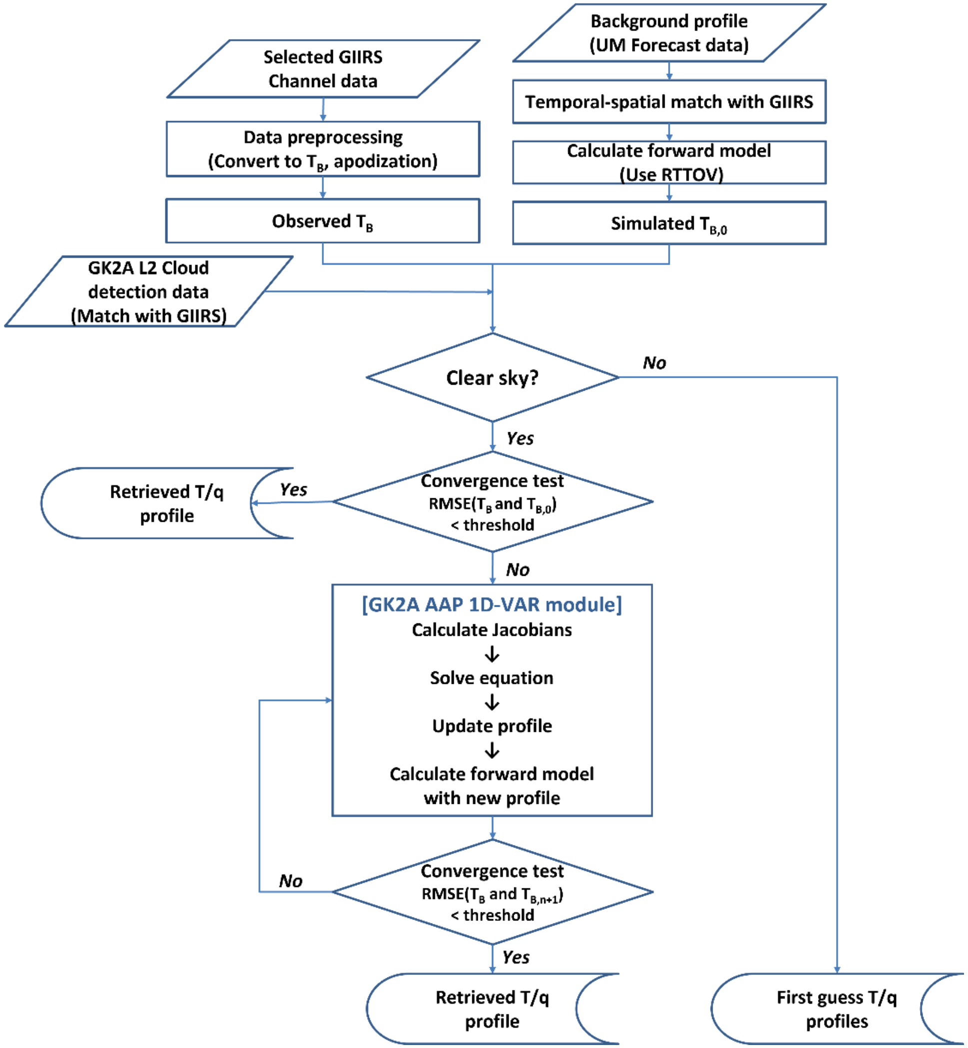


Cloud Clear

Data & Method

FY-4A GIIRS based atmospheric profile retrieval algorithm

- *Utilization of FY-4A GIIRS data and GK2A AAP 1D-VAR module*



- Flow chart of retrieval algorithm with GIIRS data

❖ Input data

- FY-4A GIIRS L1 datasets
- GK2A Cloud detection (CLD)
- NWP model (UM) forecast fields
- Background error covariance matrix
- Observation error covariance matrix (NEdT of the GIIRS)

❖ Forward Model

- RTTOV v13.1

❖ Spatial and temporal resolution

- 16 km / 1 hour (China area)

❖ Product

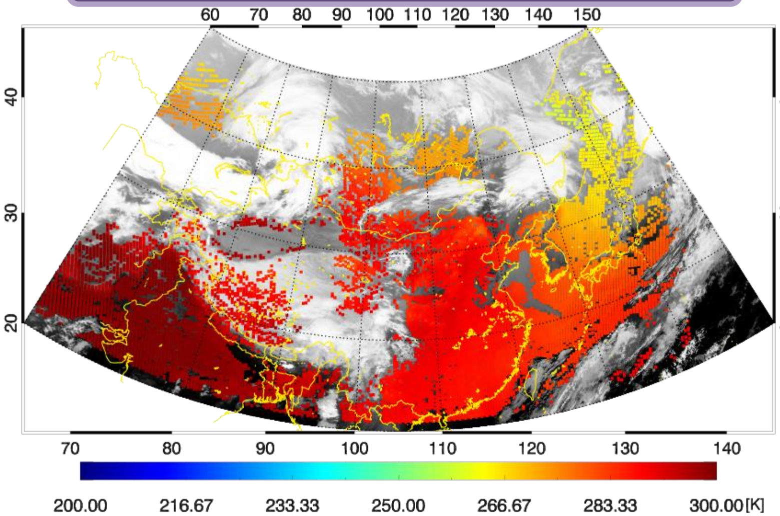
- 54-levels T & q profiles using Iterative optimal estimation method (Rodgers, 2000)

Result & Validation

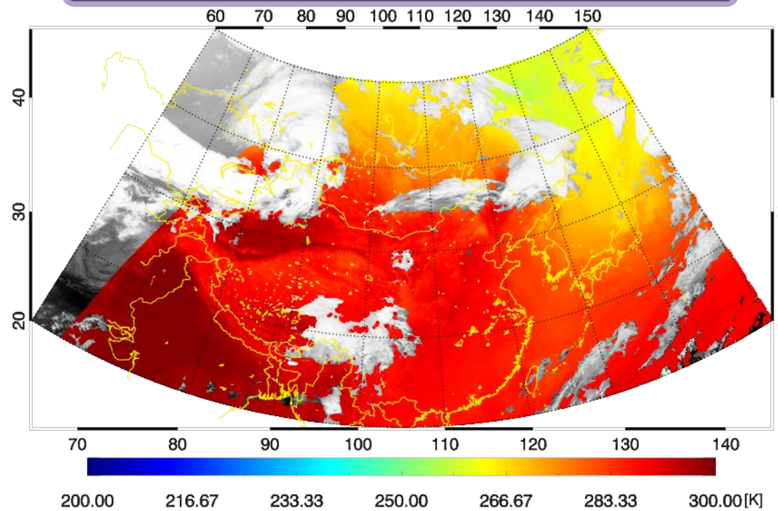
Result

8 April 2022, 0000 UTC

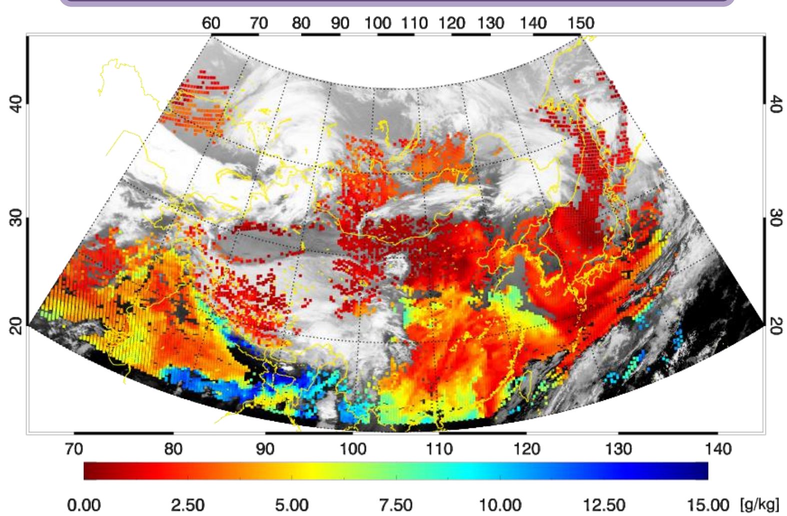
FY-4A GIIRS Retrieval T850



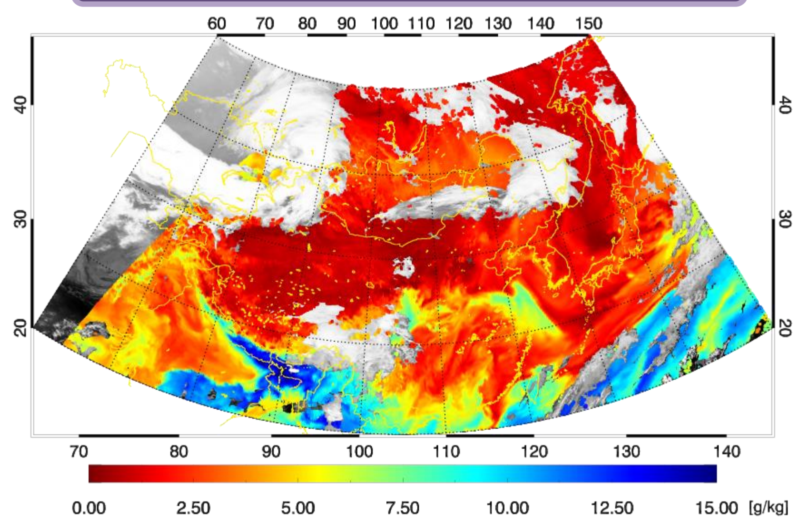
GK2A AAP Retrieval T850



FY-4A GIIRS Retrieval q850



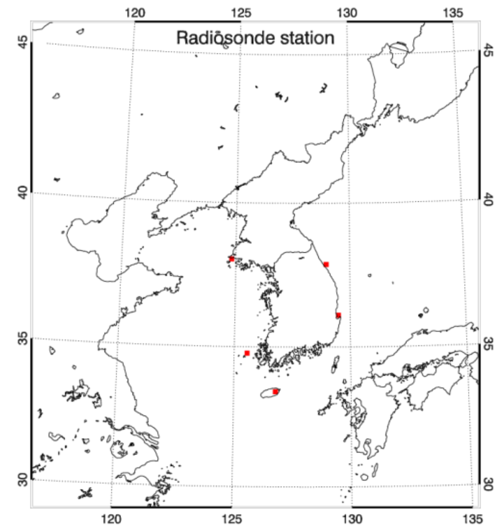
GK2A AAP Retrieval q850



Validation

Data

- Radiosonde data at 0000 and 1200 UTC from June to August 2022
- Utilization of data from 5 sonde stations on the Korean Peninsula



Target

- FY-4A/GIIRS-based T & q profile
- GK2A AMI T & q profile
- AMI and MW sensor T & q profile (AMI+MW)

* Microwave satellite(sensor): Metop-B/C (AMSU-A,MHS), NOAA-19 (ATOVS(AMSU-A, MHS)), S-NPP (ATMS)

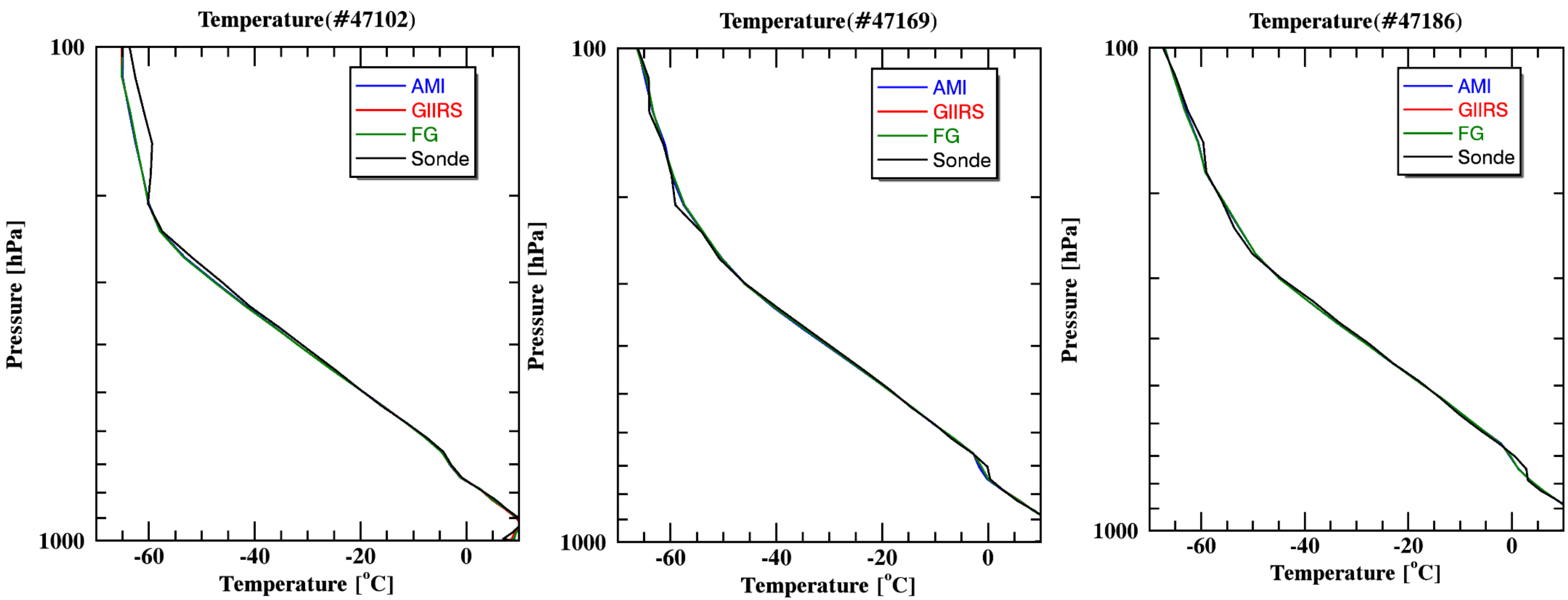
Method

- Averaged data within ±25 km from the sonde station
- AMI and GIIRS use data at the same time as the sonde observation time, and AMII+MW uses data within ±30 minutes
- Clear and successful retrieval

Validation

Comparison with radiosonde

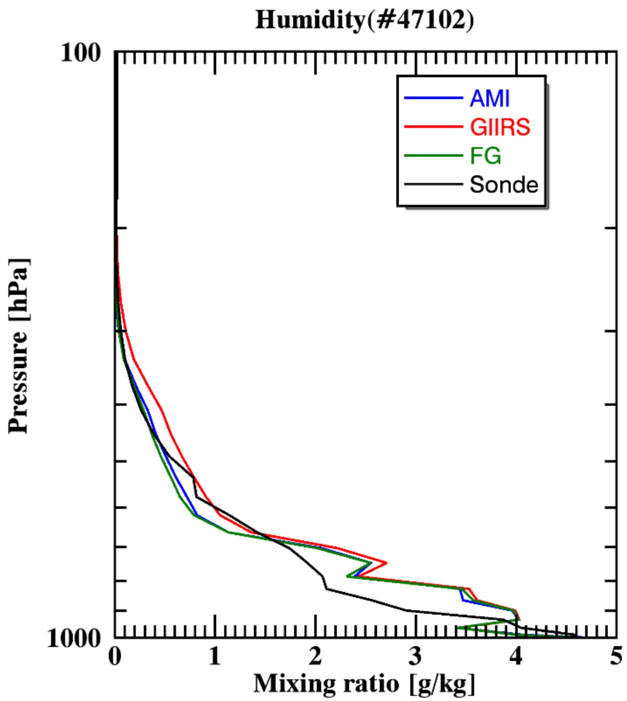
- Temperature profile (8 April 2022, 0000 UTC)
  - The temperature profiles retrieved by AMI and GIIRS data show very similar vertical distributions

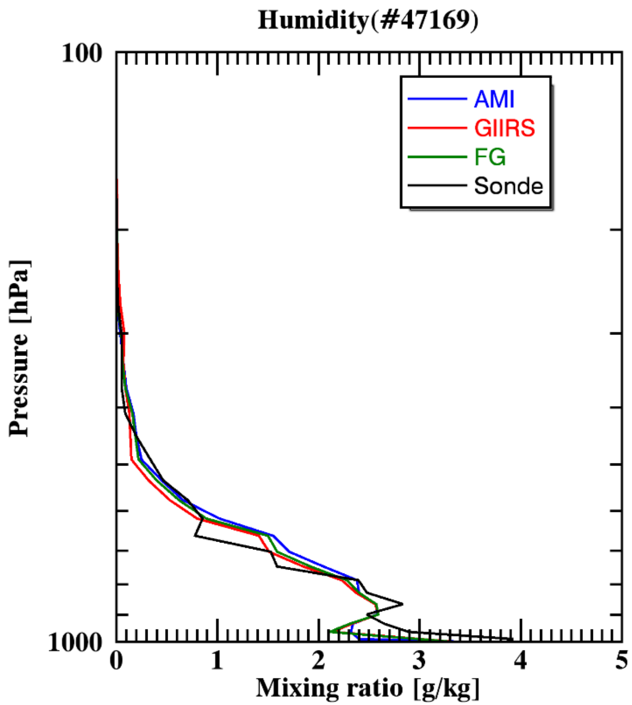


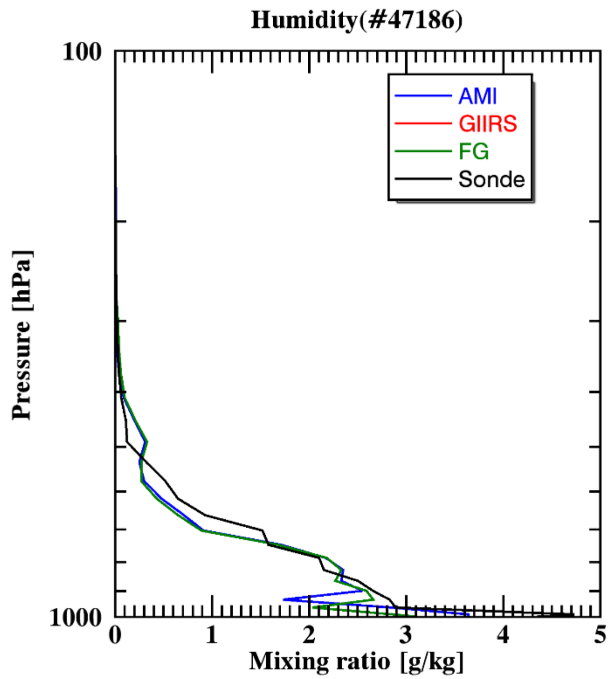
Comparison with radiosonde

- Humidity profile (8 April 2022, 0000 UTC)

  - The humidity profiles is also vertically similar to AMI and GIIRS profiles, but there is a slight difference





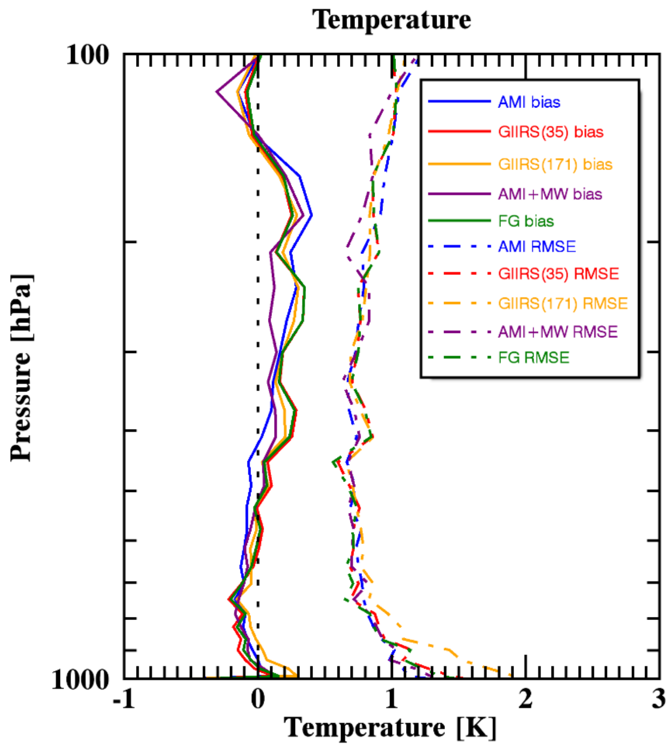


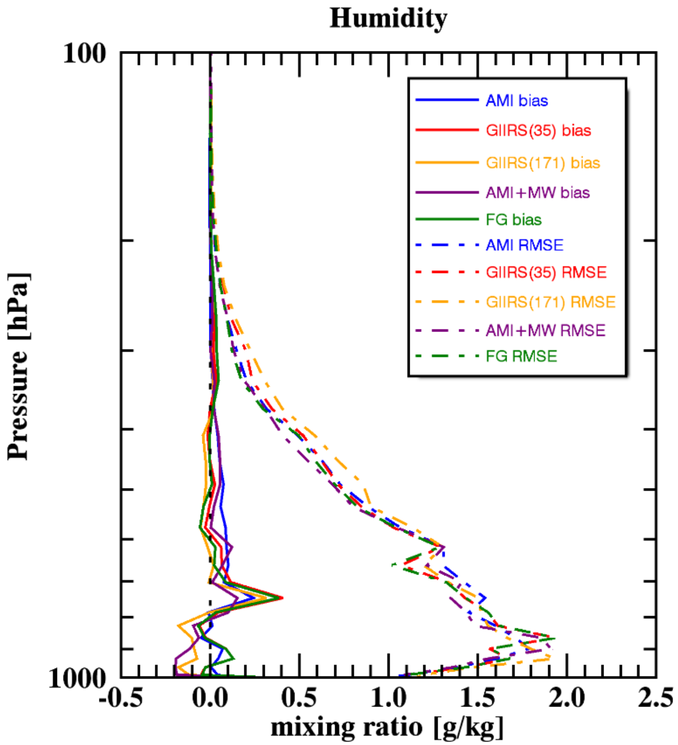
Validation

Validation result

- Compared with the results of 171 channels selected in step 2
- There is a similar difference by altitude, but overall performance is better when using the AMI sensor
- Results using 171 channels have a slightly higher error in the lower troposphere than using 35 channels

→ It is necessary to optimize the algorithm through channel reselection of GIIRS and improvement of error covariance matrix





Validation

Validation result

		Temperature		Humidity	
		Mean bias (K)	Mean RMSE (K)	Mean bias (g/kg)	Mean RMSE (g/kg)
Upper troposphere (100~500hPa)	GIIRS(35)	**0.17**	**0.81**	**0.01**	**0.23**
	GIIRS(171)	**0.14**	**0.81**	**0.00**	**0.26**
	First-guess	0.16	0.81	0.01	0.20
	AMI	0.12	0.80	0.02	0.21
	AMI+MW	0.09	0.77	0.02	0.19
Mid-troposphere (500~850hPa)	GIIRS(35)	**-0.08**	**0.76**	**0.08**	**1.27**
	GIIRS(171)	**-0.06**	**0.85**	**0.01**	**1.31**
	First-guess	-0.08	0.74	0.05	1.26
	AMI	-0.11	0.77	0.08	1.32
	AMI+MW	-0.10	0.76	0.05	1.26
Lower troposphere (850~1050hPa)	GIIRS(35)	**-0.26**	**1.27**	**0.16**	**1.47**
	GIIRS(171)	**-0.19**	**1.59**	**0.00**	**1.53**
	First-guess	-0.21	1.23	0.16	1.47
	AMI	-0.23	1.11	0.07	1.41
	AMI+MW	-0.14	1.12	0.01	1.48
Total (100~1050hPa)	GIIRS(35)	**0.00**	**0.90**	**0.06**	**0.81**
	GIIRS(171)	**0.01**	**1.00**	**0.00**	**0.85**
	First-guess	0.01	0.88	0.06	0.80
	AMI	-0.03	0.86	0.04	0.81
	AMI+MW	-0.02	0.84	0.01	0.80

Summary & Future plans

Summary & Future plans

Summary

- **Development of temperature and humidity profiles retrieval algorithm using FY-4A GIIRS data and 1D-VAR module of GK2A AAP**
  - Channel selection considering GIIRS NEdT, trace gas absorption, and weighting function
  - Pre-procession of FY-4A GIIRS data such as apodization, systematic bias correction
  - Retrieval of temperature and humidity profiles using 1D-VAR module of GK2A AAP
- **Validation results**
  - FY-4A GIIRS and GK2A AAP results show a similar distribution
  - It shows lower accuracy then GK2A AAP when compared to sonde, so continuous improvement of algorithm is required

Future plans

- The sensitivity analysis according to observation and background error covariance matrix
- Improvement of channel selection and observation error covariance calculation
- Long-term validation with more sonde station data

Thank you!

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