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Progress of CMA in Hpyer-spectral sounders

Executive summary

This working paper describes the progress of hyper-spectral soundings onboard both GEO and LEO platforms performed by CMA. As the first GEO hyper-spectral sounder (GIIRS) in FY-4A satellite, its L1 radiance has been improved significantly in 2019 and is generally accepted by NWP and T/H profile retrieval applications, where its spectral shifts (less than 5ppm for LW band and less than 10ppm for MW band) and radiometric accuracy (less than 1K for most channels) behave reasonable well. The main enhanced specifications of FY-4B/C GIIRS are particularly to meet the increasing requirements for NWP and retrieval uses, including the more symmetric layout of sensor array and the higher spatial resolution. The L1 radiance of GIIRS is operationally assimilated in GRAPES model. HIRAS onboard FY-3D satellite completed its 2nd decontamination in 2019, where MW and SW bands FOV3 solar contamination was eliminated by adjustment of cold space viewing angle. Its calibration accuracies are general less than 0.3, 0.7 and 1.0 K in the LWIR, MWIR and SWIR bands, respectively. Mean and standard deviation of its spectral bias relative to the line-by-line simulated spectra are within 5 ppm. HIRAS data has been in operational retrievals of atmospheric T and WV profiles and OLR products, and in test applications of NWP, atmospheric composition retrieval, and global stratospheric gravity wave research.

Action/Recommendation proposed: None

Progress of CMA in Hpyer-spectral sounders

1. GIIRS

The Geostationary Interferometric InfraRed Sounder (GIIRS) onboard Fengyun-4A (FY-4A) satellite was launched on December 11, 2016. GIIRS is the first geostationary (GEO) Fourier transform spectrometer (FTS) sounder to provide high temporal resolution (at the order of 10-100 minutes) information on the atmospheric state for numerical weather prediction (NWP) and nowcasting, which is of course beyond the observing capability from low earth orbiting (LEO) satellites, and should benefit monitoring and forecasting applications at regional scales.
Since the FY-4A satellite was launched at the end of 2016, the development of GIIRS L1 products has been continually progressing, and can be divided into three stages: commissioning and prototype establishment; user readiness and experimental application; and validation and improvement. In general, each of these stages has taken around a one-year period to complete. For the first stage from December 2016 to November 2017, the commissioning of GIIRS, including testing and validation of observation functions and in-orbit capabilities in both radiometric and spectral aspects, was the main task while the prototype of GIIRS L1 processing was being established. The GIIRS L1 processing generated some useful products for rigorous spectral validation as well as the following quantitative applications. For the second stage from December 2017 to the end of 2018, after implementing a four-month user-readiness programme, the focus shifted to optimizing GIIRS observation modes to user requirements and training potential users. Two primary applications are performed experimentally, i.e. NWP and the retrieval of temperature and humidity (T/H) profiles. However, other than the official release of version-1 (V1) processing for GIIRS L1 products, no substantial improvements were performed on either spectral or radiometric performances before 2019.

1.1 FY-4A/GIIRS status updates in 2019

Fortunately, the real turning point occurred in the third stage, where many improvements in GIIRS L1 spectrum quality were fulfilled sequentially. Since the beginning of 2019, GIIRS/L1 V1 data has been made available for international users, which has promoted the enhancement of GIIRS/L1 quality, especially for the spectral and radiometric accuracies, which have faced careful scrutiny from the global community. Hence, from January to July 2019, more improvements, i.e. robust FCE correction, additional subsample location alignment to yield more accurate interferometric information, and a whole new spectral calibration with both spectra unification and spectral shift correction, were achieved while the overall processing and software frameworks were updated completely. In August 2019, the GIIRS/L1 version-2 (V2) replaced its predecessor (V1). Due to a tiny coding error in the spectral shift correction, GIIRS/L1 V2 data showed an unexpected error in the spectral accuracy which was promptly corrected by inversing some parameters in the algorithms in October. This fixed version, V2 plus (V2+), was made possible thanks to support from experts at both the Space Science and Engineering Centre at University of Wisconsin-Madison (SSEC/UW) and the European Centre for Medium-Range Weather Forecasts (ECMWF). Based on the V2 algorithm, with the coding error correction as well as an improved radiometric calibration equation with a double-reflected compensation, GIIRS/L1 version-3 (V3) data was made available in November 2019, where the spectral shifts for each detector are determined by minimizing the RMS difference between GIIRS and IASI brightness temperatures (BTs). This is a vital milestone, where the spectral and radiometric qualities of GIIRS/L1 data are comprehensively accepted by both domestic and international communities although there are still some unsolved problems, e.g. relative lower accuracies in both radiometric and spectral aspects in MW band, to be investigated further.

1.2 FY-4A/GIIRS calibration accuracy

Under the SNO mechanism recommended by GSICS, observation pairings are determined with a new full-overlap matching method which is utilized for intercalibration between GIIRS/L1 V3 and IASI measurements for a 7-day period (November 8-14, 2019). For all the matched SNOs, the mean BT biases of all the channels in both LW and MW bands are evaluated, and the absolute mean BT biases of uncontaminated channels are significantly less than those of contaminated ones. Meanwhile, for the two uncontaminated spectral regions, the variability of mean BT biases between different channels in the LW band is smaller than that of the MW one, which may be caused by the relative lower sensitivity or larger spectral shifts of the MW band. The primary assessments of GIIRS/L1 V3 compared with IASI in both spectral and radiometric aspects are listed in Table 1.1. Specifically, for the uncontaminated regions, the BT biases of 93% of channels in the LW band and 50% of channels in MW band are less than the requirements of 1.5K, where 71% of LW channels and 16% of MW channels are in even better agreement at less than 0.5K. Nevertheless, the mean BT biases among all the uncontaminated channels are -0.1K and -0.3K for LW and MW bands, respectively. And, for spectral characteristics, due to a limited number of paired SNOs with such a full-overlap matching, only mean and STD values of spectral shifts among all the detectors are evaluated, i.e. 2ppm mean, 8ppm standard deviation for the LW band and 8ppm mean, 7ppm standard deviation for MW one.

Table 1.1 Spectral and radiometric calibration accuracies of GIIRS/V3 evaluated by intercalibrating with IASI during November 8-14, 2019

Band	Radiometric Calibration for Uncontamined Region (LW:465chs; MW:621chs)				Spectral Calibration	
	chs:$\Delta BT \in (0, 0.5K]$	chs:$\Delta BT \in (0.5K, 1.0K]$	chs:$\Delta BT \in (1.0K, 1.5K]$	Mean BT Bias	Mean (ppm)	STD (ppm)
LW	331	71	30	-0.1K	2ppm	8ppm
MW	100	108	102	-0.3K	8ppm	7ppm

Supported by many experts from international agencies (i.e. SSEC/UW and ECMWF), a lot of independent evaluations of GIIRS/L1 V3 have been performed. Particularly, regarding the spectral calibration, intercomparisons between GIIRS and CrIS were performed for the measurements during a period from November 8 to December 15 2019 provided by SSEC/UW. The spectral homogeneity among the four vertical columns for each band are almost identical with each other, while the absolute spectral shifts of both LW and MW bands are less than 5ppm and 10ppm respectively, which is of sufficient accuracy for NWP use.
In general, it has been shown that the spectral accuracy (i.e. spectral shifts) of GIIRS are lower than 10ppm in both bands and the radiometric accuracy (i.e. BT biases) are around 1K for most uncontaminated channels in LW band.

1.3 Current Status of GIIRS Application (NWP and retrieval)

GIIRS L1 radiance from V3 algorithm has been available for both domestic and international communities since November 2019, where the main temperature and humidity profiles products are produced routinely. More detailed evaluations are therefore needed before these products can be utilized for end users. As for NWP applications, GIIRS L1 data are operationally assimilated in GRAPES model of CMA since the end of 2018, where the prediction of tropical cyclone track is significantly improved during the past two years.

1.4 Future Requirements of GIIRS on FY-4B/C

For the future requirements of GIIRS on FY-4B/C, the spectral region of LW band extends from 700cm^{-1} to 680^{-1} and 650cm^{-1} gradually, the main purpose of which is to enhance the capabilities of temperature sounding as well as spectral calibration with the CO_2 absorption bands. Meanwhile, the spatial resolution is also improved from 16km to 12km, and 4-8km in FY-4B/C respectively, to increase the utilization efficiency of GIIRS observations, particularly for the FOV contaminated by cloud targets.

2. HIRAS

The High spectral Infrared Atmospheric Sounder (HIRAS) is the first Chinese Fourier Transform Michelson interferometer onboard the FengYun 3D (FY-3D) polar orbiting meteorological satellite launched on 15 November 2017, and have been in operation status since Jan 1, 2019 with L1 data dissemination.

2.1 FY-3D/HIRAS status updates in 2019

The FY-3D HIRAS was activated on 16 Nov, 2017. After three months of out gassing, the detectors were powered up on 1 Mar, 2018 and the instrument began its routine measurements. The early data checkout work started on 1 March and lasted 2 months. Following the instrument checkout period is the four months of ICV, which was ended in August of 2018 and HIRAS was in operational status in Jan, 2019.

The FY-3D HIRAS has been suffering signal attenuation due to the absorption of the silica gel gas that appears in the path of the interferometer optical system. The silica gel gas volatilizes from the silica gel material used for bonding some of the optical components, and the gas amount slowly increases with time. The decontamination operation is scheduled once per eight months, which will restore the NEdT values to the original levels.
There are two instrument status updates in 2019, first is instrument heating and decontamination performed on Oct 21, 2019.
The second instrument status update is cold space view angle adjustment. FY-3D/HIRAS data began to be provided to the Met Office for assimilation tests in April 2019, the evaluation of which reveals the abnormal negative deviations of Detector 3 in the middle wave band in some areas. The HIRAS team performed analysis and found that the original deep space spectra of FOV3 in the middle wave (MW) and short wave (SW) bands were abnormal, detector 3 is abnormally high in deep space observation in the range of 90-120 ° of the solar zenith angle, which leads to the abnormal deviation in calibration bias. The analysis of the observations at different deep space scanning angles shows that the DS spectra at angles of -94.93 °, -91.30 °, -87.69 °, -84.09 °were not affected by solar contamination, so the deep space pointing angle was decided to set from -71 ° to -87 °.

2.2 FY-3D/HIRAS calibration accuracy
The HIRAS radiance uncertainty was assessed by comparing the HIRAS measurements with the CrIS and IASI measurements. The mean BT differences are less than 0.3K, 0.7K and 1.0K in the LWIR, MWIR and SWIR bands, respectively. The standard deviations of the BT difference are 0.2~0.5K for the LWIR band, 0.2~1.5K for the MWIR band, and about 1.0 K in the 2200 cm^{-1} nearby channels, up to 3.0 K in the windows channels and up to 5.0 K in the CO_2 region for the SWIR band.
The accuracy of the spectral calibration is usually measured by the spectral frequency bias in ppm relative to the reference spectrum simulated with a line-by-line (LBL) radiative transfer (RT) model. As listed in table 2.1, the absolute spectral frequency biases are less than 3ppm for all the FOVs in three bands except that the biases for FOV 4 in LWIR and SWIR bands are slightly exceed 3 ppm. The spectral bias standard deviations are less than 3 ppm in the LWIR and MWIR bands and about 3~5 ppm in the SWIR band.

Table 2.1 Mean and standard deviation (std) of the spectral bias relative to the line-by-line simulated spectra

pectral bias	mean（ppm）				Std(ppm)			
	FOV1	FOV2	FOV3	FOV4	FOV1	FOV2	FOV3	FOV4
LW	-1.63	-1.21	0.04	1.92	1.62	1.51	1.51	1.74
MW	-2.75	-1.49	-1.54	-2.18	2.67	2.65	2.35	2.59
SW	-0.13	1.16	1.74	2.49	3.27	3.61	2.57	2.25

2.3 Current Status of HIRAS Application (NWP and retrieval)
HIRAS data has been in operational data distribution since Jan, 2019 and retrievals of atmospheric temperature and water vapor profiles and OLR products were generated operationally in CMA. L1 data has been in test applications of NWP, atmospheric composition retrieval, and global stratospheric gravity wave research. Preliminary results from CMA NWP center reveals that after assimilated HIRAS observation， It can control the error growth significantly and has a positive contribution to the global analysis quality which gives promising expectation about its application.

2.4 Future Requirements of HIRAS on FY-3E/F/G
Following the FY-3D satellite, the third batch of the Fengyun 3(FY-3) series will consist of four satellites and the HIRAS will fly on three of them. The second HIRAS will fly on the FY-3E satellite in an early-morning orbit with a local time of around 6:00 A.M, scheduled to launch in end of 2020. The results from the orbit simulation and the observing system experiments (OSE) indicate that the early-morning orbit satellite, together with the morning orbit and the afternoon orbit satellites, can provide the initial meteorological fields for the numerical weather prediction (NWP) model without any gap on the global scale every 6 hours, so that the forecast period and the forecast accuracy can be improved for both the hemispheric and the regional scales. The FY-3E HIRAS will have a number of upgrades, including the number of detectors from the current 4 to 9 per band and a full coverage of the spectral range from 650 to 2550 cm^{-1} without any spectral gaps.

Summary
FY-4A/GIIRS L1 radiance is generally accepted by NWP and T/H profile retrieval applications, where the spectral shifts (less than 5ppm for LW band and less than 10ppm for MW band) and radiometric accuracy (less than 1K for most channels) behave reasonable well. Furthermore, the main enhancements of FY-4B/C specifications are generally for the continuous increasing for NWP and retrieval uses. Quick scanning observation for the local convection monitoring is under considered with the more experimental & exploring cases. Others aspects, i.e. atmospheric chemistry, air quality and greenhouse gases, are still not considered at least for GIIRS, while some hyperspectral sensors on GEO platform with their spectral coverage within visible and ultraviolet regions can fulfill such a goal.

FY-3D/HIRAS is in stable operational status currently and the 2nd decontamination was completed in Dec, 2019. HIRAS MW and SW bands FOV3 solar contamination was eliminated by adjustment of cold space viewing angle from -71°to -87 °. Calibration accuracy are general less than 0.3, 0.7 and 1.0 K in the LWIR, MWIR and SWIR bands, respectively. Mean and standard deviation(std) of the spectral bias relative to the line-by-line simulated spectra are within 5 ppm. HIRAS data has been in operational retrievals of atmospheric T and WV profiles and OLR products, and been in test applications of NWP, atmospheric composition retrieval, and global stratospheric gravity wave research.