HIRAS on-orbit performance and future development

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Abstract: 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. The FY-3D HIRAS provides infrared (IR) radiance spectra measurements in three spectral bands: the long wave IR (LWIR) band from 650 to 1135 cm^{-1}, middle wave IR (MWIR) band from 1210 to 1750 cm^{-1}, and short wave IR (SWIR) band from 2155 to 2550 cm^{-1}. The ground system processes the interferogram measurements into calibrated radiance spectra. In each cross-track scan, there are 29 observations, each with a field-of-regard (FOR) comprising an array of 2×2 field-of-views (FOVs). In a six-month intensive campaign period, the HIRAS system was tuned, characterized and validated. For the operational Level 1 product, the radiance noise levels meet the specifications. The spectral frequency accuracy was improved by maximizing the spectral correlation between the measured and simulated spectra through tuning the instrument-line-shape parameters. The absolute spectral frequency biases are less than 3ppm for all the three bands, and spectral bias standard deviations are less than 3 ppm in the LWIR and MWIR bands and are about 3~5 ppm in the SWIR band. The radiometric calibration uncertainties were assessed by the comparisons of the radiance spectra between HIRAS and other IR hyper-spectral sensors on different satellites. The radiance differences of the cross-sensor comparisons are in general less than 0.3, 0.7 and 1.0 K in the LWIR, MWIR and SWIR bands, respectively. The HIRAS spectra were also compared with the spectra simulated with a fast radiative transfer model.

1. FY-3D HIRAS Measurement Characteristics

Parameters	Specification
Scan Period	10s
View angle	1.1°
Pixels per scan line	116
Scan angle	± 50.4°
Radiometric calibration accuracy	1K, expected 0.7K
Spectral calibration accuracy	10ppm, expected 7ppm
*Sensitivity (NEΔT@280K)	0.15～0.4K LWIR 0.1～0.7K MWIR 0.3～1.2K SWIR
Direction pointing bias	＜±0.25°

The HIRAS cross-track measurement scan sequence consists of 33 interferogram sweeps, including 29 Earth Scenes(ES), 2 Deep Space (DS) views, and 2 Internal Calibration Target (ICT) measurements. Each interferometer sweep takes 250 milliseconds and one complete scan sequence takes 10 seconds. The step angle of the ES view between two adjacent positions is 3.6°, and the full swath width scan angle is ±50.4°. The view angle of each FOV is 1.1°, corresponding to a nadir spatial resolution of 16 km. The scan direction is from the right to the left when one faces towards the satellite moving direction (positive X). The four small colored circles or ellipses are the footprints of the FOVs on the ground for each of the three bands, and the big black circles or ellipses enclosing the four FOVs represent the areas of field-of-regards (FORs)

2. FY-3D HIRAS Spectral Characteristics

Band	Spectral Range (cm^{-1})	Spectral Resolution (cm^{-1})		MPD(cm)		Number of Channels		spectral apodization
		DR	FR	DR	FR	DR	FR	
LWIR	650～1135 (15.38μm～8.8 μm)	0.625	0.625	0.8	0.8	781	781	NO
MWIR	1210～1750 (8.26μm～5.71 μm)	1.25	0.625	0.4	0.8	437	869	NO
SWIR	2155～2550 (4.64μm～3.92 μm)	2.5	0.625	0.2	0.8	163	637	NO
Total						1381	2287	

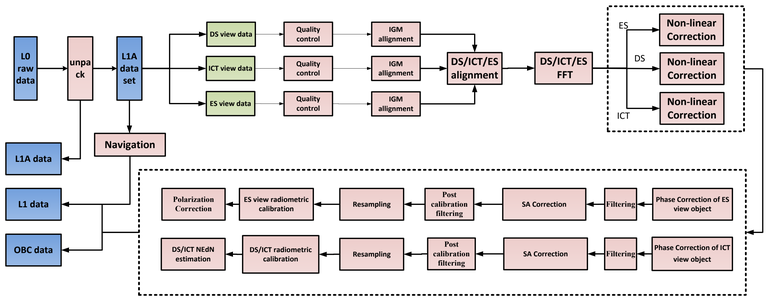

Fig. 1. HIRAS operational DPPS flowchart

3. Radiance noise assessment

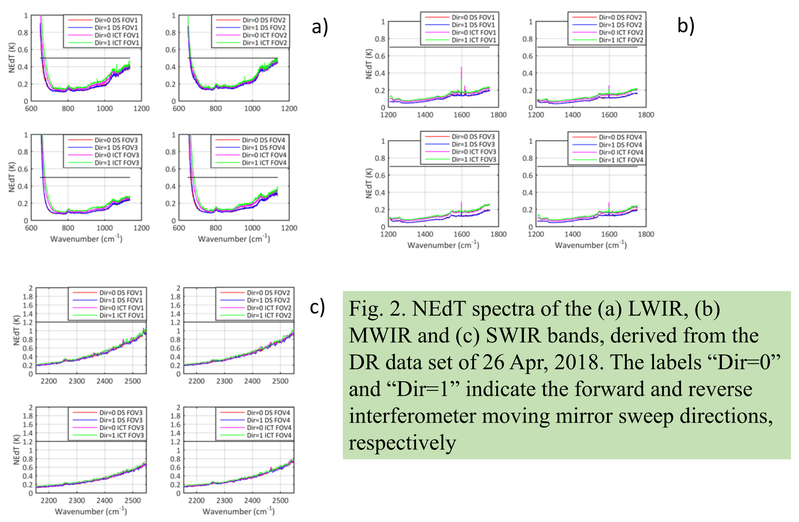

Fig. 2. NEdT spectra of the (a) LWIR, (b) MWIR and (c) SWIR bands, derived from the DR data set of 26 Apr, 2018. The labels "Dir=0" and "Dir=1" indicate the forward and reverse interferometer moving mirror sweep directions, respectively

4. Geolocation assessment

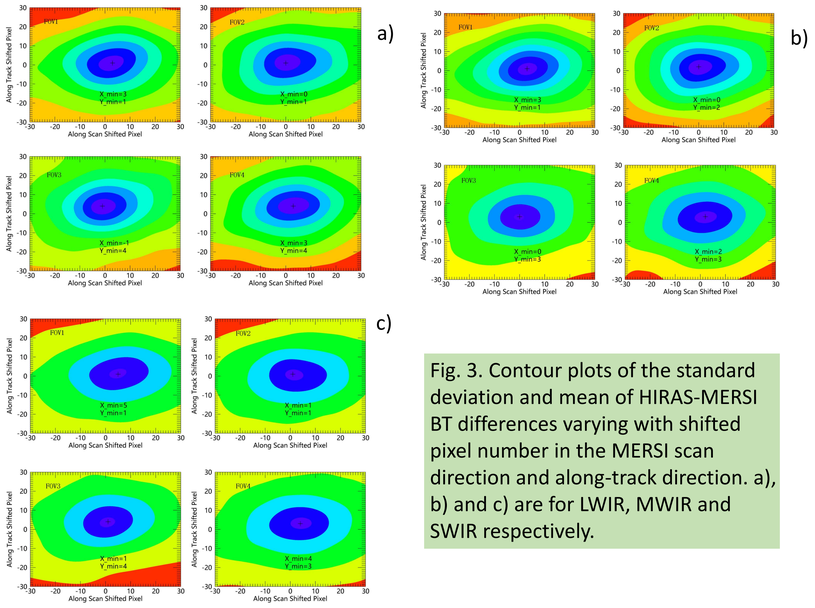

Fig. 3. Contour plots of the standard deviation and mean of HIRAS-MERSI BT differences varying with shifted pixel number in the MERSI scan direction and along-track direction. a), b) and c) are for LWIR, MWIR and SWIR respectively.

5. Spectral calibration evaluation

Table 3. Mean and standard deviation(std) of the spectral bias relative to the line-by-line simulated spectra. (D1: 5 March, 2018, corresponding to the early phase data status after launch; D2: 20-26 Apr, 2018, corresponding to the second phase data status that alignment of stationary mirror and calibration parameters refinements were completed; D3: 26-30 May, 2018, data status are same as D2 but only for validate)

Spectral bias		mean（ppm）				Std(ppm)			
		FOV1	FOV2	FOV3	FOV4	FOV1	FOV2	FOV3	FOV4
LWIR	D1	38.30	32.14	24.97	29.82	1.01	0.77	0.75	1.08
	D 2	0.31	0.44	1.28	3.29	1.70	1.67	1.41	1.84
	D 3	-1.63	-1.21	0.04	1.92	1.62	1.51	1.51	1.74
MWIR	D 1	-15.18	-4.68	-10.81	-3.50	1.18	2.14	2.59	1.83
	D 2	-1.92	0.03	-0.31	-0.65	2.48	2.39	2.08	1.99
	D 3	-2.75	-1.49	-1.54	-2.18	2.67	2.65	2.35	2.59
SWIR	D 1	/	/	/	/	/	/	/	/
	D 2	1.70	0.62	1.09	3.72	3.10	4.47	2.97	2.60
	D 3	-0.13	1.16	1.74	2.49	3.27	3.61	2.57	2.25

6. Radiance accuracy assessment

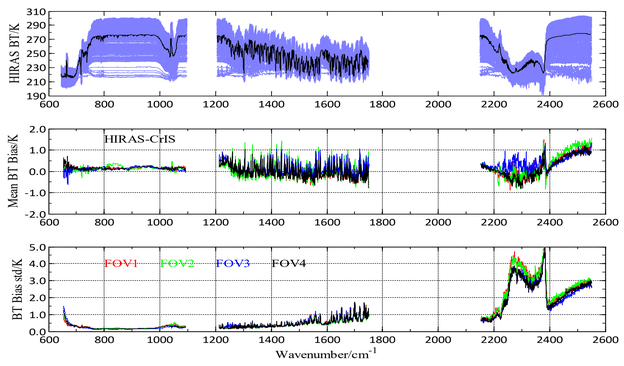

Fig. 4. Radiance comparisons between HIRAS and S-NPP CrIS. (a) The HIRAS BT spectra of the HIRAS-IASI data set collected over 15 days (26 Apr to 10 May, 2018) with 3968 samples spread over the globe. (b) Mean BT differences between HIRAS and CrIS, and (c) standard deviation of the BT differences

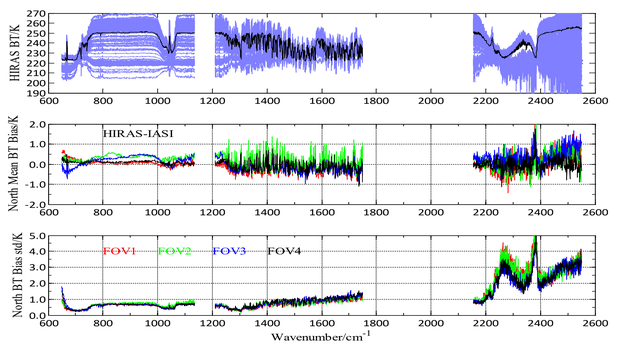

Fig. 5. Similar to Fig. 4. except for the HIRAS and IASI comparisons. The SNO data set was collected in the North Polar regions over 7 days (22 to 28Apr, 2018) with 864 samples

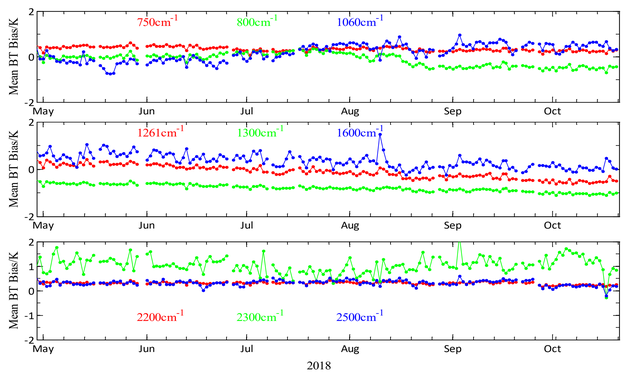

Fig. 6. The time series of the mean BT biases of the HIRAS radiance relative to the RTTOV simulations in selected channels over a six-month period from 29 Apr to 31 Oct 2018. (a) LWIR band, (b) MWIR band and (c) SWIR band

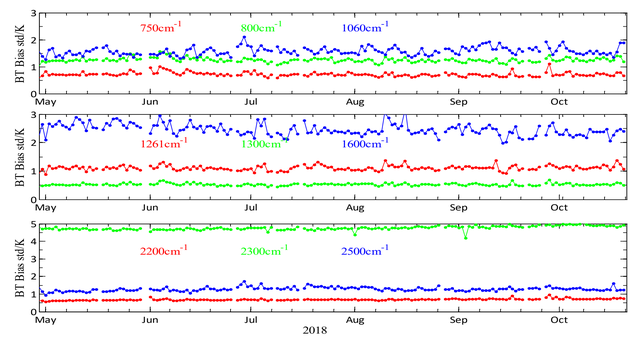

Fig. 7. Similar to Fig. 6. except that the curves are standard deviations of the BT bias

7. Future development

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 2020. 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. HIRAS will provide radiance data for NWP models to improve weather forecast and will also continue to be an important part of the FY-3 Vertical Atmospheric Sounding System (VASS) which provides sounding measurements for the retrieval algorithm to derive atmospheric temperature and water vapor profiles

Band	Spectral Range (cm^{-1})	Spectral Resolution (cm^{-1})	Sensitivity (NEΔT@280K) FY-3D	Sensitivity (NEΔT@280K) FY-3E		Num of Channels
LWIR	650～1136 (15.38μm～8.8 μm)	0.625	0.15(Expectation) 0.4K(Requirement)	650～667 cm^{-1}	0.8K	778
				667～689 cm^{-1}	0.4K	
				689～1000 cm^{-1}	0.2K	
				1000～1136 cm^{-1}	0.4K	
MWIR1	1210～1750 (8.26μm～5.71 μm)	1.25	0.1(Expectation) 0.7K(Requirement)	1210～1538 cm^{-1}	0.2K	433
				1538～1750 cm^{-1}	0.3K	
MWIR2	2155～2550 (4.64μm～3.92 μm)	2.5	0.3(Expectation) 1.2K(Requirement)	2155～2300 cm^{-1}	0.3	159
				2300～2550 cm^{-1}	0.5