THE INFRARED ATMOSPHERIC SOUNDER ONBOARD FY-3A SATELLITE

Qi Chengli Zhang Peng, Liu Hui, Ma Gang
Assistant Professor, National Satellite Meteorological Center, China Meteorological Administration
No. 46, South Street of Zhong-Guan-Cun, District Haidian, Beijing 100081 China
Tel: 86-10-68409407 Fax: 86-10-62183844
E-mail: qicl@nsmc.cma.gov.cn

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ABSTRACT: FY-3A meteorological satellite is the second generation of polar-orbit meteorological satellite in China which plans to be launched in May, 2008. It loads 11 instruments and some new instruments are carried for the first time. IRAS is one of the atmospheric vertical sounding instruments, its aim is providing multi-channel brightness temperature that in the spectral range of visible to long-wave infrared for direct radiance assimilation and retrievals of global atmospheric temperature profiles, humidity profiles, ozone column contents, cloud parameters ,etc. The spectral channels and instrument configuration of IRAS are designed similar to HIRS instrument that onboard NOAA polar-orbit satellite series. This paper give a introduction about IRAS designed instrument configuration, and some pre-launch study results about system spectral response function, laboratory infrared radiometric calibration, laboratory visible and near infrared integrating sphere calibration.

1. INTRODUCTION

FY-3 meteorological satellite is the second generation of polar-orbit meteorological satellite in China, it will carry some new instruments for the first time. IRAS is one of the primary instruments onboard FY-3, the aim is providing multi-channel data for direct radiance assimilation and retrievals of global atmospheric temperature profiles, humidity profiles, ozone contents, cloud parameters ,etc. Some distinctness are exist between IRAS/FY-3 and HIRS/3 on NOAA series, for instance in the spectral channels, there are 26 channels convolved 20 infrared channels and 6 visible, near-infrared and short-wave infrared channels on IRAS, while 20 channels convolved 19 infrared channels and 1 visible channel for HIRS/3. Secondly there are 4 inner warm blackbodies on HIRS/3 and each blackbody has 5 measurements, for IRAS each blackbody has only one measurement (Chengli Qi, 2005).

Since March, 2005, the IRAS flight model was developed and the tests and experiments were performed according to the schedule. Based on the radiative calibration experiment data of FY-3A/InfraRed Atmospheric Sounder (IRAS), we calculated laboratory calibration coefficients, and these coefficients can be directly used by the IRAS data pre-processing when on-orbit calibration failed. The output signals noise and the noise equivalent differential radiance(NEDN) and albedo (NEDρ)are derived and compared with specifications. Lastly the laboratory calibration errors sources are studied and calibration accuracy was assessed.

2. SPECTRAL PARAMETERS OF IRAS

Since the IRAS does not have onboard spectral calibration system, consequently prelaunch system SRFs are determined and used in processing all IRAS radiance data. Before the instrument components are equipped together the prelaunch spectral calibration involves measuring the filter transmittance, and the spectral response of all other optical piece parts including detectors, beam splitters, mirrors, and lenses (Changyong Cao,2004). The system level SRFs are generated by multiplying the filter transmittance with the optical piece part response and shown by Fig1(limited by the paper length, only show channel 1-8). The central wave-number and bandwidth of 26 channels and calculated and described by Table 1.

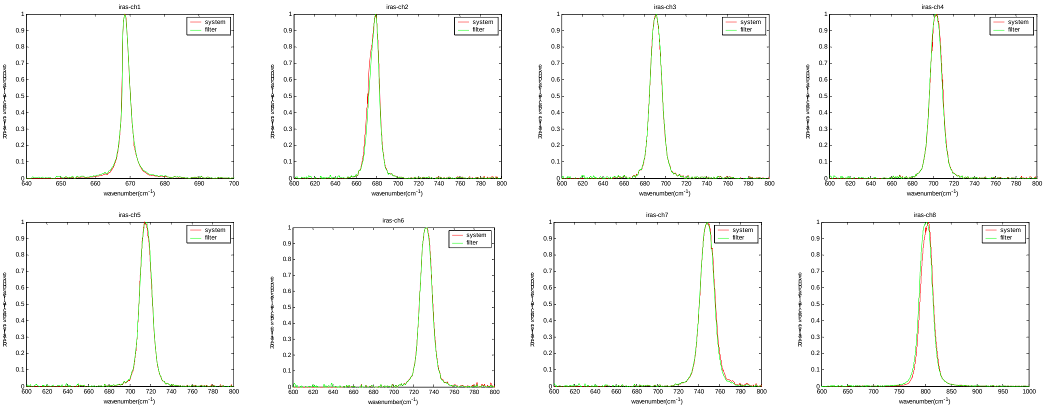

Fig 1. spectral response functions of IRAS flight model, green lines representing the filter SRFs and red one for system level SRFs.

Table 1 The spectral channel characteristics of 26 channels of IRAS

Channel No	Cen-wavenumber specifications	Calculated Cen-wavenumber	Band-width specifications	Calculated band-width
1	669	669.09	3	3.54
2	680	677.1	10	11.45
3	690	691.24	12	12.33
4	703	703.15	16	12.76
5	716	715.41	16	12.75
6	733	732.58	16	13.04
7	749	748.01	16	15
8	802	803.51	30	25.75
9	900	900.3	35	29.92
10	1030	1033.12	25	21.26
11	1345	1337.51	50	47.79
12	1365	1361.49	40	36.99
13	1533	1527.42	55	50.15
14	2188	2189.64	23	22.06
15	2210	2212.37	23	23.02
16	2235	2237.82	23	21.55

17	2245	2250.12	23	22.8
18	2388	2393.53	25	24.06
19	2515	2512.28	35	30.96
20	2660	2656.99	100	76.49
21	14500	14304.82	1000	766.66
22	11299	11285.7	385	349.21
23	10638	10606.61	550	417.77
24	10638	10580.34	200	160.16
25	8065	8112.87	650	567.23
26	6098	6041.61	450	398.99

3. THEORY AND METHOD FOR IRAS LABORARY CALIBRATION

For the thermal infrared channels of IRAS calibration was carried in vacuum environment. The temperature of Infrared standard source blackbody changed from 220K to 330K and the radiance computed by PLANCK radiance of blackbody convolved with channel SRFs. Equation (1)-(2) are quadratic and linear calibration equations that describe the quantitative relations between output counts and received radiance, $DN_{i,j}$ represent averaged counts output at ith temperature and jth channel. a0、a1、a2 are calibration coefficients (NOAA KLM USER'S GUIDE, 1998). These coefficients are derived by using the instrument measuring data and the calculated radiance of standard source blackbody at different temperature in a certain range.

$$R_{i,j} = a0 + a1 * DN_{i,j} + a2 * DN_{i,j}^{\ 2} \quad (1)$$

$$R_{i,j} = a0 + a1 * DN_{i,j} \quad (2)$$

Another aim of calibration experiment is deriving the instrument measuring sensitivity, same as noise equivalent differential radiance(NEDN). When the standard source blackbody are in 290K temperature the counts of thermal channels are averaged and get the standard deviation σ_y , σ_y is in fact the noise signal of 290K target temperature, counts samples are not less than 50 continuous scan lines. NEDN are calculated through:

$$NEDN = \sigma_y * a_1 \quad (3)$$

For IRAS channel 21-26 are in spectral range of visible to short wave infrared, so such channels the laboratory calibration are done with the utilization of integrating sphere. The calibration coefficients are obtained by the same way of equation (2)-(3), only the PLANCK radiance of blackbody replaced by the radiance of integrating sphere at a certain number of lamps. The counts standard deviation of status that all lamps closed was used to determine the noise equivalent differential radiance(NEDN) same with equation (3). NEDN (mW/(cm^2*sr*um)) converted to noise equivalent differential albedo (NEDρ,W/(m^2. um)) by

$$\rho = \frac{100 * \pi * L}{E_0 * \cos\theta} \tag{4}$$

$$E_0 = \frac{\int_{\lambda_0}^{\lambda_1} E(\lambda) S(\lambda) d\lambda}{\int_{\lambda_0}^{\lambda_1} S(\lambda) d\lambda} \tag{5}$$

L is NEDN, E_0 is channel equivalenced solar spectrum (W/(m^2. um)) and E is solar spectrum, $S(\lambda)$ are the channel SRFs.

4. LABORARY CALIBRATION EXPERIMENT RESULTS AND ANALYSIS

4.1 NEDN and NEDρ of IRAS

NEDN reveals the minimal signal that the instrument can identify, indicates the measuring ability, so it is a role specification representing instrument performance. According to the infrared vacuum calibration data, NEDN of the first 20 channels at 290K showed in Table 2. All the NEDN of thermal infrared channels meet the specifications and there is potential of improving the sensitivity for channel 11 to 13, nevertheless there is little gap between the practical instrument sensitivity level and that of operational infrared vertical sounders.

noise equivalent differential albedo of the rest 6 channels exhibited in Table 3.

Table 2 NEDN of IRAS (channel 1-20)

Channel	NEΔN specification (mW/(m^2.sr.cm^{-1}))	Calculated NEΔN (mW/(m^2.sr.cm^{-1}))	NEdT（K）
1	4.00	2.33	1.456
2	0.80	0.58	0.359
3	0.60	0.41	0.251
4	0.35	0.33	0.2
5	0.32	0.31	0.188
6	0.36	0.32	0.193
7	0.30	0.28	0.172
8	0.20	0.14	0.088
9	0.15	0.11	0.068
10	0.20	0.12	0.088
11	0.23	0.07	0.081
12	0.30	0.08	0.095
13	0.30	0.08	0.135
14	0.01	0.006	0.071
15	0.01	0.005	0.065

16	0.01	0.006	0.073
17	0.01	0.005	0.066
18	0.01	0.004	0.084
19	0.01	0.004	0.121
20	0.002	0.0015	0.079

Table 3 NED ρ of IRAS (channel 21-26)

Channel	channel equivalenced solar spectrum mw/(cm^2.sr.um)	NEΔN mw/(cm^2.sr.um)	NED ρ (%)	NED ρ specification(%)
21	45.2084	0.0083828	0.013% A	0.1%A
22	30.80	0.0057065	0.018% A	0.1%A
23	27.388	0.0048677	0.017% A	0.1%A
24	27.241	0.0028129	0.02% A	0.1%A
25	14.949	0.0038334	0.028% A	0.1%A
26	7.197	0.0015293	0.018% A	0.1%A

4.2 Estimation of calibration errors

In strict vacuum and cold environment, the impact of atmospheric radiance and perturbation nearly be ignored, the factors that determine infrared calibration accuracy mainly include four terms: the radiative uncertainness of standard blackbody source, radiative from standard blackbody reflect by instrument mirror and blackbody observed by instrument viewing filed, radiative of instrument background, and channel NEDT. The estimated errors of each term and the general error given by Table 4. It shows the calibration errors of thermal infrared channels less than 1K except channel 1 by reason of its so narrow band-width.

In dark room for the integrating sphere calibration, the causes that result in calibration error mostly are: the accuracy of integrating sphere, radiation coupling between instrument and sphere, spectrum difference between solar and integrating sphere, stray light and the last term is NED ρ. Estimated errors described in Table 5, the calibration errors of channel 21-26 less than 10%.

Table 4 infrared channels calibration error estimation

channel	Temperature uncertainness of standard blackbody source (K)	Secondary reflection radiation (K)	instrument background radiation (K)	NEDT(K)	General error(K)
1	0.367	0.147	0.168	1.456	1.518044
2	0.364	0.146	0.166	0.359	0.557
3	0.357	0.143	0.164	0.251	0.487642
4	0.351	0.141	0.161	0.2	0.457168
5	0.346	0.138	0.159	0.188	0.446525

6	0.338	0.135	0.156	0.193	0.440516
7	0.332	0.133	0.154	0.172	0.425691
8	0.310	0.124	0.145	0.088	0.374493
9	0.279	0.112	0.132	0.068	0.33531
10	0.244	0.098	0.119	0.088	0.301737
11	0.189	0.076	0.097	0.081	0.239723
12	0.186	0.074	0.096	0.095	0.241481
13	0.165	0.066	0.088	0.135	0.239896
14	0.115	0.046	0.070	0.071	0.159003
15	0.114	0.046	0.070	0.065	0.155682
16	0.113	0.045	0.069	0.073	0.157747
17	0.112	0.045	0.069	0.066	0.153903
18	0.106	0.042	0.067	0.084	0.156668
19	0.101	0.040	0.065	0.121	0.17512
20	0.095	0.038	0.063	0.079	0.143802

Table 5 visible to short wave infrared channels calibration error estimation

channel	integrating sphere accuracy (%)	instrument and sphere radiation coupling (%)	spectrum difference(%)	stray light(%)	NED ρ (%)	General error(%)
21	3	0.31	2.57	1	0.013	4.756328
22	5.1	0.31	1.1	1	0.018	5.921487
23	5.1	0.31	3.4	1	0.017	6.74758
24	5.1	0.31	3.77	1	0.02	6.863443
25	5.1	0.31	1.08	1	0.028	5.787454
26	5.1	0.31	0.395	1	0.018	5.221346

5. CONCLUSION

The laboratory calibration experiment results revealed that channel sensitivity NEDN and NED ρ meet the functional requirements specifications of IRAS. Estimated calibration errors for infrared channels are less than 1K@290K except the first channel because of its very narrow band-width, for VIS-SW channels the errors less than 10%.

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