

Article

Calibration Optimization for Long-Term Consistency of the FY-3B Infrared Atmospheric Sounder

Jiawei He ^{1,†} , Xinpan Yuan ^{1,†} , Chengli Qi ^{2,3,4,*}, Shaomin Xie ¹, Wenguang Gan ¹  and Yongqiu Jiang ¹

¹ School of Computer Science and Artificial Intelligence, Hunan University of Technology, Zhuzhou 412000, China; m24077500021@stu.hut.edu.cn (J.H.); xpyuan@hut.edu.cn (X.Y.); m24085400029@stu.hut.edu.cn (S.X.); m23085400015@stu.hut.edu.cn (W.G.); m25081200027@stu.hut.edu.cn (Y.J.)

² National Satellite Meteorological Center (National Center for Space Weather), China Meteorological Administration, Beijing 100081, China

³ Innovation Center for FengYun Meteorological Satellite (FYSIC), China Meteorological Administration, Beijing 100081, China

⁴ Key Laboratory of Radiometric Calibration and Validation for Environmental Satellites/Key Laboratory of Space Weather, CMA, Beijing 100081, China

* Correspondence: qicl@cma.gov.cn

† These authors contributed equally to this work.

Highlights

What are the main findings?

- A three-step SSC–NCO–AQC refinement chain improves FY-3B/IRAS cross-calibration consistency against Metop-A/IASI SNO matchups from 2010 to 2019.
- Most CO₂ absorption channels show mean biases reduced from over 1 K to below 0.2 K, with substantially narrowed uncertainty envelopes after integrated correction.

What is the implication of the main finding?

- The approach yields a more homogeneous long-term radiance record suitable for climate applications and inter-satellite harmonization.
- The lightweight framework complements the operational FY-3B/IRAS calibration workflow without altering its fundamental structure.

Abstract

The Feng Yun-3B (FY-3B) Infrared Atmospheric Sounder (IRAS) provides key infrared observations for numerical weather prediction (NWP) and climate applications, but long-term consistency is affected by three factors: spectral response function (SRF) central wavenumber shifts, changes in the nonlinear coefficient of the instrument in orbit, and fixed brightness-temperature (BT) uniformity screening. We propose a three-step refinement chain consisting of SRF central wavenumber shift correction (SSC), in-orbit nonlinearity-coefficient optimization (NCO), and channel-dependent adaptive quality control (AQC). First, SSC conducts fine adjustment of SRF central wavenumbers by jointly minimizing mean bias and standard deviation, reducing uncertainty by about 10–25% in sensitive absorption channels. Second, NCO refines the quadratic term under two-point anchoring constraints, recentring mean biases toward zero without changing linear gain. Third, AQC applies channel-dependent BT-uniformity thresholds to suppress scene-driven variance while preserving sample representativeness. Using FY-3B/IRAS and Meteorological Operational Satellite Programme-A/Infrared Atmospheric Sounding Interferometer (Metop-A/IASI) simultaneous nadir overpass (SNO) matchups from 2010–2019, the integrated SSC–NCO–AQC chain substantially improves cross-calibration consistency: most CO₂ channels show mean biases reduced from >1 K to <0.2 K, with narrower uncertainty en-



Academic Editor: Stefano Pignatti

Received: 7 May 2026

Revised: 30 June 2026

Accepted: 9 July 2026

Published: 1 August 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

velopes, while window channels remain stable. The results support more reliable long-term radiometric consistency and cross-year comparability for FY-3B/IRAS.

Keywords: FY-3B/IRAS; cross-calibration consistency; SRF central wavenumber shift correction (SSC); nonlinearity-coefficient optimization (NCO); adaptive quality control (AQC)

1. Introduction

Satellite Infrared Atmospheric Sounders form a cornerstone of modern atmospheric observing systems, providing vertically resolved information on temperature, humidity, and trace gases for NWP, climate trend detection, and environmental monitoring [1–3]. As part of China's second-generation operational meteorological satellite series, FY-3B/IRAS observes the atmosphere in 20 broadband infrared channels covering major absorption channels and window regions, supporting the retrieval of temperature and humidity profiles as well as surface parameters [4,5]. The scientific value of these observations depends critically on maintaining radiometric accuracy and long-term stability, because even small calibration bias drifts may propagate into data assimilation applications, bias correction schemes, and climate data records, ultimately degrading application reliability [6–14].

Significant progress has been made in infrared radiometric calibration, including two-point onboard calibration, vicarious calibration, and inter-satellite cross-calibration. For hyperspectral instruments such as the Atmospheric Infrared Sounder (AIRS), Cross-track Infrared Sounder (CrIS), and IASI, detailed pre-launch characterization and mature radiometric correction frameworks have been developed [8]. For broadband instruments, extensive efforts have examined SRF uncertainties, detector nonlinearity, stray-light contamination, and scene-uniformity screening strategies [15–26]. Moreover, the Global Space-based Inter-Satellite Calibration System (GSICS) framework provides standardized methodologies for bias monitoring, harmonization, and benchmark transfer for geostationary and polar-orbiting sensors [11,27]. For the FY-3 satellite series in particular, previous studies have analyzed cross-calibration, bias characterization, and long-term stability for both hyperspectral and broadband sensors, including the Medium Resolution Spectral Imager (MERSI) and Microwave Radiation Imager (MWRI) instruments et al. [28–30].

Despite these advances, several limitations hinder the construction of a homogeneous long-term radiance record for FY-3B/IRAS. Operational FY-3B/IRAS Level-1 (L1) brightness temperatures have supported routine applications since launch, yet cross-comparisons against Metop-A/IASI indicate that several CO₂ absorption channels exhibit systematic biases on the order of 0.5–1 K and show non-negligible long-term drift, whereas most window channels remain comparatively stable. Seasonal and high-latitude matchup subsets further reveal increased scatter and time-varying offsets, indicating that operational data quality, while generally usable, is not yet homogeneous enough for undifferentiated long-term climate-oriented use without additional refinement. First, for SRF, the pre-launch measurement uncertainty, as well as its changes during the launch process and over time after entering orbit, may not be fully captured by the nominal spectral characterization, which can induce Kelvin-level biases in broadband channels with steep radiance gradients after spectral convolution. Second, the issue is not that the detector's nonlinearity is weak, but rather that its nonlinear response characteristics may change in orbit, rendering the coefficients from pre-launch tests obsolete and preventing accurate measurements once in orbit, resulting in temperature-dependent bias in cross-calibration records [31–34]. Third, fixed BT-uniformity thresholds—widely used in cross-calibration—fail to account

for channel sensitivities and instrument evolution, reducing the robustness of long-term statistics. These issues motivate refinement beyond the operational calibration workflow.

To address these long-standing challenges, this study develops a unified calibration-refinement framework integrating SRF central wavenumber adjustment, nonlinearity-coefficient correction, and adaptive BT-uniformity quality-control thresholding. The approach first retrieves effective SRF central wavenumber shifts using hyperspectral reference radiances to reduce spectral-mismatch-induced biases. It then estimates the quadratic nonlinearity coefficient under the constraint of the deep-space and onboard-blackbody calibration anchor points. Finally, we introduce a channel-dependent adaptive BT-uniformity threshold, enabling a balanced trade-off between scene-variability control and sample representativeness. Together, these components form a lightweight consistency-oriented refinement chain that operates alongside the operational workflow without altering its fundamental structure.

Extensive analyses using FY-3B/IRAS and Metop-A/IASI SNO matchups from 2010 to 2019 demonstrate substantial improvements in radiometric consistency. Bias magnitudes are reduced across absorption and window channels, dispersion is narrowed, and cross-year variability is stabilized, yielding a more homogeneous long-term radiance record suitable for climate applications and inter-satellite harmonization.

2. Data and Instruments

2.1. Datasets and Reference Instrument

The primary datasets used in this study consist of L1 brightness-temperature observations from IRAS onboard FY-3B and hyperspectral radiances from IASI onboard Metop-A. IRAS is one of the key payloads of FY-3B, equipped with 20 infrared channels spanning major atmospheric absorption channels and window regions. Its calibration accuracy and data quality directly affect its effectiveness in numerical weather forecasting, climate monitoring, and atmospheric environment studies. In contrast, the Infrared Atmospheric Sounding Interferometer (IASI) is a Fourier-transform spectrometer with spectral coverage of approximately $645\text{--}2760\text{ cm}^{-1}$ and a spectral sampling interval of 0.25 cm^{-1} , and provides highly stable on-orbit calibration that has been widely adopted as a reference instrument for infrared radiometric inter-calibration [11,35,36].

The year 2014 is used first as a stepwise validation case year to diagnose calibration behavior and illustrate the sequential SSC–NCO–AQC workflow before extending the analysis to the full 2010–2019 record. This choice does not mean that 2014 is uniquely qualified: other mission years also provide four-season coverage and dense Metop-A/IASI SNO overlap. Rather, a single case year offers a compact setting for stepwise evaluation and for presenting intermediate figures and tables, while the decade-long dataset is reserved for long-term consistency assessment.

The full-lifecycle record of IRAS from 2010 to 2019 is then employed to assess long-term consistency and the robustness of the improvements across the instrument lifetime. The availability of decade-long observations enables investigation of the temporal evolution of calibration accuracy at different stages of the instrument's life [37,38]. By comparing the case-year results with those derived from the full-lifecycle dataset, the effectiveness of the calibration enhancements can be comprehensively evaluated.

In the data processing stage, IASI hyperspectral radiances are spectrally convolved with the IRAS spectral response functions (SRFs) to map the high-resolution spectra into IRAS channel-equivalent radiances [39–42]. This procedure ensures spectral comparability between the two instruments. Together with ancillary information such as IRAS central wavenumbers, SRF measurements, reference calibration coefficients, and onboard-

blackbody temperatures, a complete dataset is constructed to support cross-calibration and uncertainty analysis.

2.2. Instrument Characteristics and Key Parameters

Table 1 summarizes the operational characteristics of the 20 infrared channels of FY-3B/IRAS [1], including central wavenumber, central wavelength, spectral bandwidth, main absorbing gases, and maximum energy contribution layer. These parameters directly determine the channel sensitivity to different atmospheric layers and the accuracy of the radiometric measurements, and thus form the basis for calibration and cross-calibration studies. The CO₂ absorption channels (1–7) near 15 μm are primarily sensitive to atmospheric temperature profiles, with contribution layers ranging from the lower stratosphere (30 hPa) down to the lower troposphere (900 hPa). The window channels (8, 9, 19, and 20) in the 11 μm and 4 μm regions mainly respond to surface and cloud-top radiation, providing information on surface temperature and cloud properties. The ozone-sensitive channel (10) at 9.71 μm reflects absorption in the lower stratosphere (around 25 hPa), while channels 11–13 in the 6–7 μm region capture water vapor features with contributions from 500 to 800 hPa. Channels 14–17 in the 4.4–4.6 μm channels are influenced by N₂O and CO₂/N₂O absorption, probing different tropospheric layers, and channel 18 at 4.19 μm corresponds to a CO₂ absorption channel with broad atmospheric sensitivity. Taken together, these channels cover major absorption channels and window regions, enabling retrievals of temperature and humidity profiles, trace-gas detection, and surface monitoring.

Table 1. Characteristics of the 20 infrared channels of FY-3B/IRAS [1].

Channel	Central Wavenumber (cm ^{−1})	Central Wavelength (μm)	Bandwidth (cm ^{−1})	Main Absorbing Gases	Maximum Energy Contribution Layer (hPa)
1	669	14.95	3	CO ₂	30
2	680	14.71	10	CO ₂	60
3	690	14.49	12	CO ₂	100
4	703	14.22	16	CO ₂	400
5	716	13.97	16	CO ₂	600
6	733	13.84	16	CO ₂ /H ₂ O	800
7	749	13.35	16	CO ₂ /H ₂ O	900
8	802	12.47	30	Window	Surface
9	900	11.11	35	Window	Surface
10	1030	9.71	25	O ₃	25
11	1345	7.43	50	H ₂ O	800
12	1365	7.33	40	H ₂ O	700
13	1533	6.52	55	H ₂ O	500
14	2188	4.57	23	N ₂ O	1000
15	2210	4.57	23	N ₂ O	950
16	2235	4.47	23	CO ₂ /N ₂ O	700
17	2245	4.45	23	CO ₂ /N ₂ O	400
18	2388	4.19	25	CO ₂	Atmosphere
19	2515	3.98	35	Window	Surface
20	2660	3.76	100	Window	Surface

The calibration performance of IRAS is primarily limited by two categories of factors. The first is uncertainty in spectral response parameters, such as small shifts in central wavenumber or variations in SRF shape, which can introduce significant biases in absorption channels. The second is instrument noise and nonlinear response characteristics, which become particularly important under high brightness temperature or weak-signal

conditions. Consequently, the accuracy and stability of these key parameters must be carefully accounted for when designing calibration improvements and performing uncertainty analysis [43,44].

As introduced in Section 2.1, IASI provides a stable hyperspectral reference suitable for convolving high-resolution radiances into IRAS-equivalent channels. Here, IASI radiances are spectrally convolved into IRAS-equivalent channels to diagnose channel biases and uncertainty sources in IRAS and to provide a physically consistent basis for improving calibration algorithms and enhancing long-term radiometric consistency [15,45,46].

2.3. IRAS Calibration Method

The on-orbit calibration of FY-3B/IRAS relies on two calibration references: deep space (external) and the internal onboard blackbody. The instrument operates in a 40-scan-line cycle, alternating between calibration mode and Earth-observation mode. In calibration mode, the scan mirror points to deep space and to the internal blackbody to acquire reference signals; in Earth-observation mode, the scan mirror points to the Earth's atmosphere to acquire scientific data. The calibration of each infrared channel is thus anchored to these two references.

The raw satellite output is a digital number (DN), which must be converted into physical radiance through calibration equations. A quadratic polynomial is generally used, as given in Equation (1) [1],

$$r = a_0 + a_1 C_v + a_2 C_v^2, \quad (1)$$

where C_v denotes the observed counts, r the radiance, and a_0 , a_1 , and a_2 the intercept, slope, and quadratic calibration coefficients, respectively. During pre-launch thermal-vacuum calibration tests, the instrument observed a series of temperature-controlled standard blackbodies (200–340 K) to obtain coefficients over the full dynamic range. In orbit, since only deep space (near-zero radiance, external reference) and the internal onboard blackbody can be used as calibration references, typically only a_0 and a_1 are updated, while a_2 retains its pre-launch value.

For each channel, the calibration coefficients are obtained by solving the quadratic calibration equations with a known a_2 . Exploiting that the deep-space radiance is negligible ($r_s \approx 0$), one has

$$a_1 = \frac{r_b - a_2(C_b^2 - C_s^2)}{C_b - C_s}, \quad (2)$$

$$a_0 = -a_2 C_s^2 - a_1 C_s, \quad (3)$$

where C_b and C_s are the mean counts of the blackbody and deep space, respectively, and r_b is the blackbody radiance computed from Planck's law in Equation (4).

$$r_b(\nu) = \frac{2hc^2\nu^3}{\exp\left(\frac{h\nu}{kT_{bb}}\right) - 1}, \quad (4)$$

where h is Planck's constant, c is the speed of light, k is Boltzmann's constant, ν is the channel central wavenumber, and T_{bb} is the internal blackbody temperature. Equation (4) describes the blackbody radiance at temperature T_{bb} as a function of wavenumber ν .

$$T_b = \frac{h\nu}{k \ln\left(1 + \frac{2hc^2\nu^3}{r}\right)}, \quad (5)$$

where T_b is the brightness temperature corresponding to the channel radiance r . Here, r denotes the channel-integrated radiance obtained from calibrated Earth-view counts, whereas

r_b in Equation (4) is the blackbody reference radiance used in the two-point calibration. Equation (5) is the inverse Planck function, used to convert radiance into brightness temperature. Differentiating Equation (5) with respect to r gives the inverse-Planck derivative $\partial T_b / \partial r$, which is used in the spectral- and nonlinearity-error propagation below.

To ensure consistency between Earth-observing scan lines, calibration coefficients are linearly interpolated between two adjacent calibration events. Following the operational FY-3B/IRAS level-1 radiometric processing chain [1], a bandwidth correction factor is also applied when converting calibrated blackbody counts to channel-integrated effective radiance; because the SSC, NCO, and AQC refinements developed below operate on OPE radiances and brightness temperatures, this operational step is cited here but not re-derived. Through these procedures, IRAS accomplishes the DN–radiance–brightness temperature calibration chain, providing the operational baseline (OPE) for subsequent recalibration and uncertainty analysis.

2.4. Cross-Calibration Data and Methods

To evaluate the on-orbit calibration accuracy of FY-3B/IRAS and to support subsequent improvements, this study adopts an SNO-based cross-calibration framework that has been widely used in previous inter-satellite calibration studies [27,31,47–51]. Under SNO conditions, the two satellites observe nearly the same atmospheric scene within a short time interval and a small spatial-separation distance, which minimizes discrepancies caused by atmospheric evolution and surface changes. Following the common practice in the literature and the operational FY-3B/IRAS cross-calibration procedure, the temporal difference is limited to within 5 min, the spatial-separation distance is constrained to within 10 km, and the relative difference in the cosine of satellite zenith angles is required to be less than 0.1, thereby ensuring good geometric consistency.

Since IASI provides hyperspectral radiances while IRAS operates with broadband channels, spectral harmonization is required before comparison. Following the standard approach [15,39,40], the IASI radiances are convolved with the IRAS spectral response functions using

$$R_{IASI \rightarrow IRAS} = \frac{\int_{\nu_1}^{\nu_2} R_{IASI}(\nu) SRF_{IRAS}(\nu) d\nu}{\int_{\nu_1}^{\nu_2} SRF_{IRAS}(\nu) d\nu}, \quad (6)$$

where $R_{IASI}(\nu)$ denotes the IASI radiance at wavenumber ν , and $SRF_{IRAS}(\nu)$ is the SRF of IRAS. The convolved radiance $R_{IASI \rightarrow IRAS}$ can then be directly compared with the IRAS measurements.

In line with the operational FY-3B/IRAS processing chain, an environment-representativeness check is first applied to suppress the impact of scene inhomogeneity on the SNO matchups. Following standard SNO scene-homogeneity screening practice [31], BT uniformity is defined as the scene-level variability characterized by

$$\sigma_{Tb} = \sqrt{\frac{1}{N} \sum_{i=1}^N (T_{b,i} - \bar{T}_b)^2}, \quad (7)$$

where N is the number of IRAS pixels within the co-located SNO scene footprint used for each matchup sample, $T_{b,i}$ represents the brightness temperature of the i -th pixel, and $\bar{T}_b$ is the scene mean. In the baseline operational configuration, the BT-uniformity acceptance threshold is set to $\sigma_{Tb} / \bar{T}_b < 0.01$; this threshold limit value must be distinguished from the BT-uniformity definition itself. Only samples that satisfy this threshold, together with the other screening conditions, are retained.

In the current IRAS operational system, a fixed BT-uniformity threshold σ_{thr} is typically adopted and applied uniformly across all channels and throughout the entire mission

lifetime. Although this simple configuration is easy to implement and offers a certain degree of robustness, it cannot adequately account for differences in channel-dependent sensitivity or for the long-term evolution of instrument performance. The threshold σ_{thr} and the BT-uniformity statistic σ_{Tb} defined in Equation (7) must not be confused.

After applying temporal, spatial, and geometric constraints, together with spectral harmonization and the BT-uniformity screening described above, a high-quality FY-3B/IRAS–Metop-A/IASI matchup database is obtained. This database is not a new cross-calibration method, but rather the SNO-based operational and literature-standard framework tailored to FY-3B/IRAS and used here as the foundation for channel-level bias diagnosis, evaluation of calibration improvements, and comprehensive uncertainty analysis [15,47]. Figure 1 shows the spatial density distribution of FY-3B/IRAS–Metop-A/IASI SNO matchups for channel 1. Higher densities are concentrated in high-latitude regions near the poles, which is consistent with the orbital geometry of the two satellites [49,50].

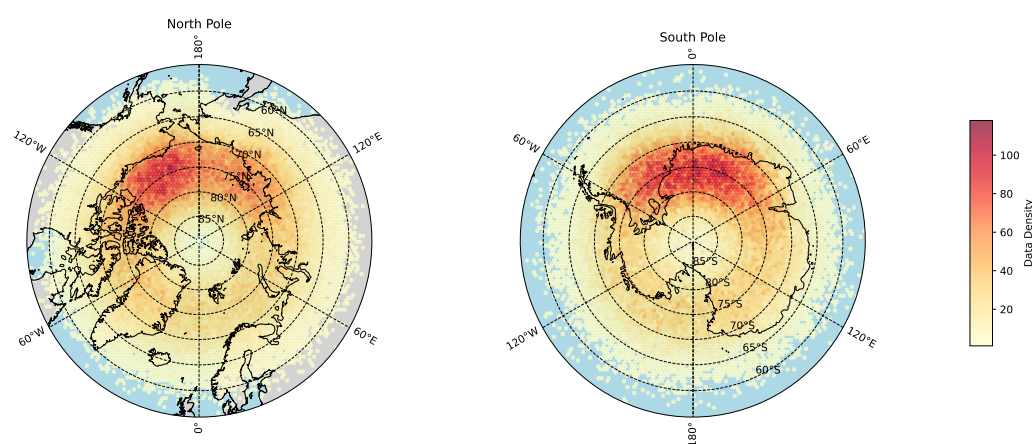


Figure 1. Landscape map of the spatial density distribution of FY-3B/IRAS–Metop-A/IASI SNO matchups for channel 1. The color scale indicates the number of valid matchup samples, where blue denotes regions with almost no samples, yellow represents low-density regions, and red corresponds to high-density regions.

3. Methodology

3.1. Spectral Response Function Central Wavenumber Shift Correction (SSC)

The SRF participates in both the operational calibration chain and the cross-calibration chain of IRAS. In the calibration chain, the SRF determines the effective weighting of the onboard-blackbody radiance, thereby affecting the conversion from counts to radiance and subsequently to brightness temperature. In the cross-calibration chain, the SRF is used to convolve IASI hyperspectral radiances into IRAS-equivalent channel radiances, ensuring spectral consistency. Therefore, a shift in the central wavenumber, denoted as $\Delta\nu$, propagates through both chains simultaneously. In strong absorption channels such as CO_2 and H_2O , where the scene radiance gradient with respect to wavenumber is large, even a small $\Delta\nu$ can be amplified into a significant brightness-temperature bias. On orbit, slow thermal-mechanical stress release, optical-component aging, contamination, and long-term radiation exposure can all induce gradual SRF central wavenumber drift and slight SRF-shape evolution. SSC addresses this specific error mode by allowing only a limited shift of the SRF central wavenumber while keeping the SRF shape unchanged.

In the calibration chain, the effective blackbody radiance is obtained by an SRF-weighted integral,

$$r_b^{\text{eff}}(\Delta\nu) = \frac{\int_{\nu_1}^{\nu_2} B(\nu, T_{bb}) S(\nu - \Delta\nu) d\nu}{\int_{\nu_1}^{\nu_2} S(\nu - \Delta\nu) d\nu}, \quad (8)$$

where $B(\nu, T_{bb})$ is the Planck function, $S(\nu)$ is the channel SRF, and $\Delta\nu$ is the central wavenumber shift. Given a fixed quadratic coefficient a_2 , the calibration coefficients derived from blackbody and deep-space views are expressed as

$$a_1(\Delta\nu) = \frac{r_b^{\text{eff}}(\Delta\nu) - a_2(C_b^2 - C_s^2)}{C_b - C_s}, \quad (9)$$

$$a_0(\Delta\nu) = -a_2C_s^2 - a_1(\Delta\nu)C_s, \quad (10)$$

where C_b and C_s denote the mean counts of the blackbody and deep space, respectively. Equations (9) and (10) parallel Equations (2) and (3), but replace the nominal blackbody radiance r_b with the SRF-shifted effective radiance $r_b^{\text{eff}}(\Delta\nu)$ in Equation (8). Through $r_b^{\text{eff}}(\Delta\nu)$, the shift $\Delta\nu$ changes (a_0, a_1) and therefore affects the stability and consistency of L1 brightness temperatures.

In the cross-calibration chain, IASI hyperspectral radiances must be convolved into IRAS broadband channels [39,40,45]:

$$R_{\text{IASI} \rightarrow \text{IRAS}}(\Delta\nu) = \frac{\int_{\nu_1}^{\nu_2} R_{\text{IASI}}(\nu) S(\nu - \Delta\nu) d\nu}{\int_{\nu_1}^{\nu_2} S(\nu - \Delta\nu) d\nu}, \quad (11)$$

where, if $\Delta\nu \neq 0$, the convolution result deviates systematically from the nominal SRF case. For small shifts, a first-order approximation (with normalized SRF $\tilde{S}$) yields the brightness-temperature sensitivity

$$\Delta T_b \approx \left(\frac{\partial T_b}{\partial R} \right) \left(-\Delta\nu \int \frac{\partial R(\nu)}{\partial \nu} \tilde{S}(\nu) d\nu \right), \quad (12)$$

indicating that ΔT_b is proportional to the SRF-weighted spectral gradient of the scene radiance. In absorption channels, where $\partial R / \partial \nu$ is large, channel brightness temperatures are especially sensitive to $\Delta\nu$.

In addition to the first-order expansion in Equation (12), we further quantify SRF-misregistration sensitivity using the Jacobian

$$K_\nu = \frac{\partial T_b}{\partial \nu}, \quad (13)$$

which measures how brightness temperatures respond to perturbations in spectral alignment. Equation (13) follows from differentiating the inverse-Planck mapping in Equation (5) and therefore complements the first-order expansion in Equation (12). Because both $\partial T_b / \partial R > 0$ and the spectral gradient $\partial R / \partial \nu$ vary strongly among channels, the magnitude of K_ν can differ by more than an order of magnitude between $\text{CO}_2/\text{H}_2\text{O}$ absorption channels and window regions. Combining Equation (12) with the inverse-Planck derivative yields the full error-propagation chain

$$\Delta T_b \approx \left(\frac{\partial T_b}{\partial R} \right) \left(\frac{\partial R}{\partial \nu} \right) \Delta\nu, \quad (14)$$

which expresses the same first-order propagation as in Equation (12) while separating the spectral-gradient term explicitly, clarifying that SRF misregistration influences brightness temperatures through spectral-gradient amplification rather than through the calibration-polynomial form itself [39,45].

Channels whose radiance spectra are nearly flat within the SRF bandwidth (e.g., CH08–CH10 and some midwave channels) have very small $\partial R / \partial \nu$, so their sensitivity K_ν is weak. In these channels, discrepancies are more likely to reflect detector nonlinearity,

noise, or geometric mismatch than spectral misregistration, which helps explain why SRF tuning yields limited improvement there.

To quantify SSC consistently, two indicators are used throughout the analysis: calibration accuracy (mean bias) and uncertainty (standard deviation). For a matchup sample set $\{i = 1, \dots, N\}$ such as SNOs, the brightness-temperature difference under a given $\Delta\nu$ is defined as

$$\Delta T_i(\Delta\nu) = T_i^{\text{IRAS}}(\Delta\nu) - T_i^{\text{ref}}(\Delta\nu), \quad (15)$$

where T_i^{IRAS} is the calibrated IRAS brightness temperature (affected by $\Delta\nu$ through r_b^{eff} and (a_0, a_1)), and T_i^{ref} is the reference brightness temperature obtained by convolving IASI spectra into IRAS channels (also including $\Delta\nu$). The calibration accuracy (mean bias) and uncertainty (standard deviation) are then given by

$$\mu(\Delta\nu) = \frac{1}{N} \sum_{i=1}^N \Delta T_i(\Delta\nu), \quad (16)$$

$$\sigma(\Delta\nu) = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (\Delta T_i(\Delta\nu) - \mu(\Delta\nu))^2}, \quad (17)$$

when sample weighting or quality control (e.g., uniformity thresholds) is required, these definitions extend naturally to weighted forms μ_w and σ_w , where w_i encodes priorities such as scene homogeneity, geometric consistency, and cross-channel scene variability.

SSC estimates the optimal central wavenumber shift $\Delta\nu^*$ as a channel-level constant that balances bias removal and dispersion control,

$$\Delta\nu^* = \arg \min_{|\Delta\nu| \leq \Delta\nu_{\max}} \left(\mu(\Delta\nu)^2 + \lambda \sigma(\Delta\nu)^2 \right), \quad (18)$$

where $\mu(\Delta\nu)$ and $\sigma(\Delta\nu)$ are the mean bias and standard deviation defined in Equations (16) and (17), $\Delta\nu_{\max}$ is the maximum acceptable channel shift (typically $2\text{--}3 \text{ cm}^{-1}$), and λ is a weighting factor in the SSC merit function balancing bias removal and dispersion control. Here, $\Delta\nu$ and $\Delta\nu^*$ are not the same: $\Delta\nu$ denotes a trial central wavenumber shift during optimization, whereas $\Delta\nu^*$ denotes the optimal shift obtained from Equation (18). To avoid overfitting, $\Delta\nu^*$ is applied as a channel-level, stage-specific constant and used consistently in both the calibration chain (effective blackbody radiance and coefficient derivation) and the cross-calibration chain (IASI convolution), preserving internal and external consistency.

Although $\Delta\nu^*$ is derived from SNO matchups, it is expected to reflect an instrument-level misregistration rather than a scene-dependent feature. Consistently, the bias-minimizing $\Delta\nu$ remains stable when the dataset is stratified by season, surface type, or viewing geometry.

Because SNO matchups concentrate at high latitudes, their brightness-temperature is colder and range is narrower than the global distribution. Representativeness is assessed by checking whether $\Delta\nu^*$ depends mainly on the spectral-gradient structure rather than absolute scene temperature. Since $\partial R / \partial \nu$ varies smoothly with temperature, $\Delta\nu^*$ changes little when matchups are stratified by latitude or brightness temperature, supporting its transferability to non-polar scenes.

3.2. Nonlinearity-Coefficient Optimization (NCO)

After SSC reduces spectral-misregistration effects, residual discrepancies can still persist because deep space (not an onboard reference) and the onboard internal blackbody only lock the endpoints of the counts-to-radiance mapping. This leaves room for a smooth interior-mode mismatch over the operational dynamic range. In practice, a slowly varying

change in nonlinear response characteristics can appear as an effective second-order behavior once the instrument operates under realistic thermal and radiometric loading [32,33]. NCO targets this degree of freedom by estimating the quadratic coefficient a_2 in orbit as a channel-level constant, while keeping the operational updates of a_0 and a_1 intact.

For any fixed a_2 , the two-point references (near-zero deep space with radiance $r_s \simeq 0$ and the internal blackbody with radiance r_b) uniquely determine a_1 and a_0 via Equations (2) and (3). Hence, the endpoints (C_s, r_s) and (C_b, r_b) remain anchored, while the interior curvature of $r(C_v)$ is governed solely by a_2 . Writing $a_2 = a_{2,0} + \delta a_2$ relative to the pre-launch value $a_{2,0}$ and enforcing that both endpoints stay fixed, the induced radiance change over the interior can be expressed in closed form as

$$\begin{aligned}\delta r(C_v) &= \delta a_2 \left[C_v^2 - (C_b + C_s)C_v + C_b C_s \right] \\ &= \delta a_2 (C_v - C_b)(C_v - C_s),\end{aligned}\quad (19)$$

i.e., the canonical two-point “shape function.” After the inverse Planck mapping $T_b = \Phi(r)$, a first-order linearization yields

$$\begin{aligned}\delta T_b(C_v) &\approx \left(\frac{\partial T_b}{\partial r} \right) \delta r(C_v) \\ &= \left(\frac{\partial T_b}{\partial r} \right) \delta a_2 (C_v - C_b)(C_v - C_s).\end{aligned}\quad (20)$$

Equation (20) clarifies how an a_2 update appears under two-point anchoring. When scene counts cluster around the mid-level $C_m = (C_b + C_s)/2$ with a limited span, the product $(C_v - C_b)(C_v - C_s)$ varies slowly and keeps a constant sign over most populated scenes. Multiplied by the smooth factor $\partial T_b / \partial r > 0$, the resulting δT_b behaves nearly like a constant offset across the effective signal range. This is why tuning a_2 tends to re-center residual brightness temperatures toward zero while leaving the local slope almost unchanged.

Although the quadratic term a_2 is not fixed by the two calibration endpoints, its effective identifiability improves on orbit because SNO matchups populate a broad interior portion of the operational count range. Over this region, the shape function $(C_v - C_b)(C_v - C_s)$ spans a sufficiently large range to distinguish different a_2 values after mapping through the inverse-Planck derivative. This motivates estimating a_2 in orbit as a channel-level constant.

Consistent with this behavior, NCO estimates the in-orbit coefficient a_2^* through a bias re-centering objective with a gentle tether to the pre-launch prior:

$$a_2^* = \arg \min_{a_2 \in \mathcal{A}} \left\{ \underbrace{\left(\mathbb{E}_w[\Delta T(C_v; a_2)] \right)^2}_{\text{re-centering}} + \lambda_r (a_2 - a_{2,0})^2 \right\}, \quad (21)$$

where $\Delta T(C_v; a_2) = T_b^{\text{IRAS}}(C_v; a_2) - T_b^{\text{ref}}$ denotes the brightness-temperature bias for each matchup, and $\mathbb{E}_w[\cdot]$ is a quality-weighted average (with weights encoding scene uniformity, geometric consistency, and cross-channel scene variability). The first term drives the weighted mean bias toward zero, while the regularization term $\lambda_r > 0$ discourages implausibly large departures from the pre-launch value $a_{2,0}$ and stabilizes the estimate.

Physical admissibility additionally requires radiometric monotonicity over the operational count range,

$$\frac{dr}{dC_v} = a_1(a_2) + 2a_2 C_v > 0, \quad C_v \in [C_{\min}, C_{\max}], \quad (22)$$

which induces a compact, channel-specific feasible interval $\mathcal{A} = [a_2^{\min}, a_2^{\max}]$ after substituting $a_1(a_2)$ from the two-point solution, where $a_1(a_2)$ denotes the linear calibration coefficient obtained from Equation (2) when the quadratic coefficient is fixed at a_2 . Within $\mathcal{A}$, the objective in Equation (21) is strictly convex in a_2 , so a one-dimensional line search (e.g., golden-section) or Newton's method using $\partial\Delta T/\partial a_2$ yields a unique minimizer. The operational workflow remains unchanged: $a_0(a_2^*)$ and $a_1(a_2^*)$ continue to be updated from deep-space/blackbody at each calibration event (and interpolated between events), while a_2^* is held as a channel-level constant within a stable operating stage.

For channels such as CH18–CH20, updating a_2 can be numerically ill-conditioned. Their effective count range may be too narrow or strongly noise dominated, so the shape function does not unfold cleanly over the populated signal space. In addition, pronounced absorption-channel curvature (especially for CH18) weakens the validity of the first-order linearization, and low SNR inflates residual variance, obscuring the already subtle second-order signature. In these cases, NCO is intentionally disabled and the operational a_2 is retained to avoid unstable, scene-dependent behavior.

3.3. Adaptive Quality Control (AQC) via Brightness-Temperature Uniformity

In cross-calibration workflows, BT-uniformity screening plays a central role in ensuring the reliability of matched scenes [5,31]. Conventional practice applies a single fixed threshold across all channels to exclude samples affected by excessive scene inhomogeneity. While straightforward, this uniform setting inevitably leads to a trade-off: overly strict thresholds suppress scene-driven scatter but drastically reduce sample availability—especially at high latitudes, during convectively active seasons, or under cloud-perturbed conditions—whereas overly permissive thresholds retain more samples at the cost of increased scatter, thereby degrading calibration accuracy and inflating uncertainty.

To address this limitation, we formulate the uniformity screening as an AQC problem, in which the threshold is allowed to vary with channel. The central idea is to anchor the screening criterion to the empirical distribution of scene-level BT variability, so that it reflects channel-specific scene variability rather than relying on a static, one-size-fits-all rule.

Scene uniformity is characterized by the standard deviation σ_{Tb} defined in Equation (7). Within the AQC framework, the acceptance threshold becomes an adaptive function of channel c :

$$\sigma_{thr}(c) = Q_p(\{\sigma_{Tb}(c)\}), \quad (23)$$

where Q_p denotes a quantile operator applied to the BT-uniformity statistic σ_{Tb} , and $\sigma_{thr}(c)$ is the channel-dependent acceptance threshold; the two quantities should not be confused. In practice, selecting the 90% or 95% quantile yields a robust balance between suppressing scene-driven scatter and retaining sample representativeness. For window channels with inherently low scene variability, the resulting thresholds are naturally stricter, preserving high calibration fidelity; for absorption channels with stronger scene variability, the thresholds are correspondingly more permissive to maintain statistical stability.

Relative to fixed-threshold screening, the AQC strategy offers several advantages. It accommodates physical differences among channels and yields more stable estimates of calibration accuracy and uncertainty by maintaining an optimal balance between scene-variability control and sample representativeness.

Importantly, AQC operates strictly at the level of sample selection. It leaves the calibration coefficients, SRF convolution, and radiometric-response model unchanged, and therefore does not interfere with the physical corrections introduced by SSC or NCO. Empirically, the improvements from SSC, NCO, and AQC accumulate in an approximately additive manner, confirming that AQC functions as a downstream quality-control module rather than as an additional calibration adjustment.

Within the overall refinement chain, AQC complements SSC and NCO by stabilizing the matchup database and suppressing scene-driven variance that cannot be addressed through physical calibration alone. For scene homogeneity control in cross-comparison, noise is not a suitable indicator; as a specific instrumental performance parameter, noise cannot be used for this purpose. Instead, the variability of observation scenes across channels should be adopted. Its role is therefore to ensure statistical robustness and cross-year comparability, rather than to correct intrinsic radiometric biases.

4. Results

4.1. Evaluation of Spectral Response Function (SRF) Shift Correction

Figure 2 summarizes the sensitivity of FY-3B/IRAS brightness-temperature differences to SRF central wavenumber shifts across all 20 infrared channels. For each channel, the figure shows a column pair: the left panel gives ΔBT_{mean} (mean bias) and the right panel gives ΔBT_{std} (dispersion); red and blue curves denote daytime and nighttime SNO matchups, respectively. The following discussion refers to channels by number and specifies which metric is considered.

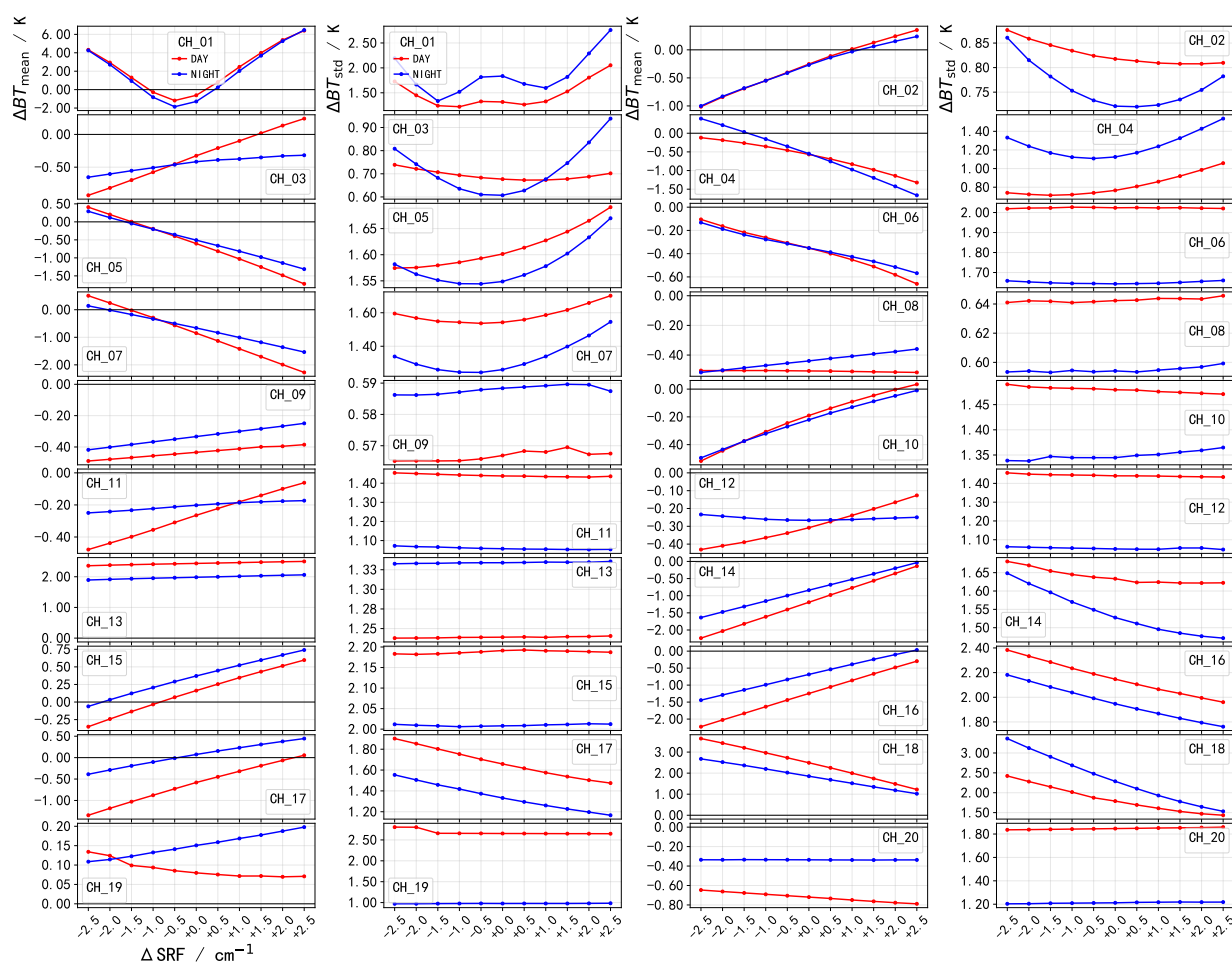


Figure 2. Mean and standard deviation of FY-3B/IRAS brightness-temperature differences versus trial SRF central wavenumber shifts (-2.5 to $+2.5$ cm^{-1}) for all 20 channels. Red and blue curves denote daytime and nighttime SNO matchups; column pairs show ΔBT_{mean} and ΔBT_{std} .

In the $15\text{ }\mu\text{m}$ CO_2 temperature-sounding channels (CH01–CH07), the ΔBT_{mean} curves (left panels) change rapidly and nonlinearly with trial $\Delta\nu$: even $\text{sub-}\text{cm}^{-1}$ perturbations translate into K-level bias excursions, consistent with the steep radiance gradients in this spectral region. The corresponding ΔBT_{std} curves (right panels) show a parallel growth

in spread over the same shift range. By contrast, window channels (CH08–CH10, CH19, CH20) remain nearly insensitive in both metrics, as the radiance spectra are comparatively flat within their passbands. H₂O channels (CH11–CH13) and the N₂O/CO₂ mixed set (CH14–CH17) fall in between in both mean and standard deviation, while CH18 at 4.19 μm behaves closer to CO₂ channels in ΔBT_{mean} because of its broad absorption contribution. A clear day–night contrast appears in strong-absorption channels such as CH01–CH05 and CH14–CH17: in the left panels, daytime ΔBT_{mean} curves tend to show larger offsets than nighttime curves, and in the right panels, daytime ΔBT_{std} is similarly elevated, consistent with enhanced surface–atmosphere thermal contrast steepening the effective radiance gradients.

Using Figure 2, channel-specific optimal SRF central wavenumber shifts $\Delta\nu^*$ are determined by minimizing the joint objective in Equation (18), which balances accuracy (mean bias) and uncertainty (standard deviation) over a representative SNO ensemble. The estimates indicate that twelve channels (CH01, CH02, CH04–CH07, CH11, and CH14–CH18) exhibit small but systematic deviations of their effective SRF central wavenumbers from the pre-launch nominal positions. These offsets are generally within about 1 cm^{-1} and tend to be negative, consistent with subtle spectral misregistration accumulated during on-orbit operation; they are therefore corrected through fine-tuning of $\Delta\nu^*$. The remaining channels (CH03, CH08–CH10, CH12, CH13, CH19, and CH20) show minimal sensitivity across the tested shift range, with both ΔBT_{mean} and ΔBT_{std} remaining statistically stable; their nominal SRFs are preserved and treated as stable reference channels for long-term consistency. After applying the optimized SRF central wavenumbers to the twelve sensitive channels, the cross-calibration biases become more symmetric around zero and the standard deviation decreases by roughly 10–25%, with the clearest improvements in CH01–CH06 (15 μm CO₂) and CH14–CH17 (around 4.5 μm). As can be seen from Table 2, minor but systematic spectral misalignment is a primary contributor to inter-sensor bias in absorption channels, and its correction improves radiometric consistency without disturbing stable window channels.

Figure 3 compares the operational SRF (OPE, red) with the SSC-adjusted SRF (blue) for the twelve spectrally sensitive channels and provides a compact reference for the magnitude and direction of the applied central wavenumber adjustments, while keeping SRF shapes unchanged. For most channels, $\Delta\nu^*$ remains small: typically about $1\text{--}3\text{ cm}^{-1}$ with modest inter-channel variation. CH18 adopts the largest adjustment (approximately 5.5 cm^{-1}), consistent with its broad CO₂ absorption structure. The adjustments are deliberately kept limited to preserve pre-launch SRF characterization and channel-to-channel comparability, avoid over-perturbing the effective blackbody weighting in the calibration chain and the IASI→IRAS spectral mapping, and reduce the risk of overfitting the SNO sample set.

With SRF adjustments applied, the SSC series (blue) in Figure 4 is visibly tighter than the OPE baseline (red) throughout 2014. At the monthly scale, the curves for all twelve corrected channels lie closer to the zero line and show reduced seasonal excursions, suggesting that scene-dependent spectral misregistration has been largely compensated. The monthly means become more stable and less biased, yielding a year-long evolution that is physically more coherent and less affected by spurious offsets.

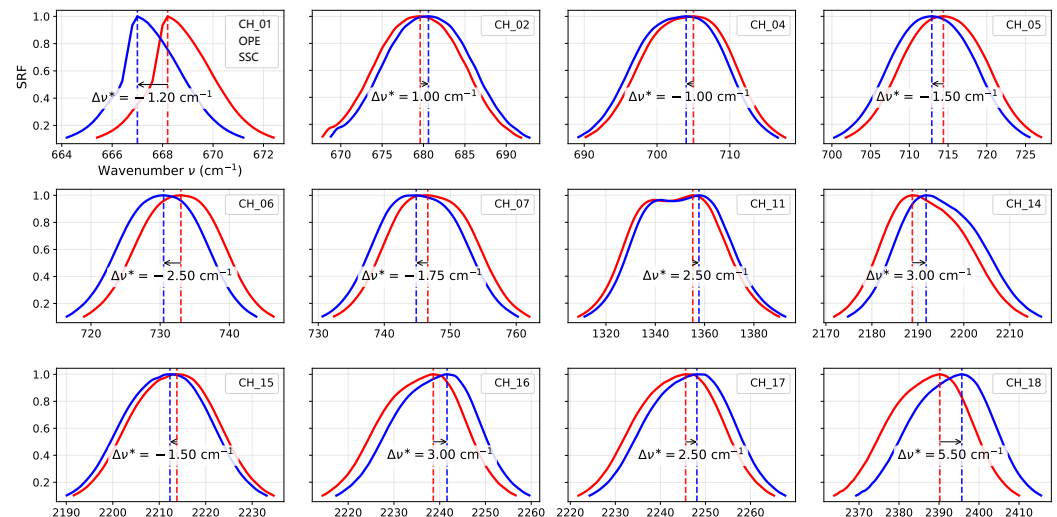


Figure 3. Spectral response functions for the twelve selected FY-3B/IRAS channels (CH01, CH02, CH04–CH07, CH11, CH14–CH18). Each panel compares the operational SRF (red) with the SSC-adjusted SRF (blue); dashed lines mark peak locations, and arrows indicate the applied central wavenumber offset $\Delta\nu^*$ (cm^{-1}).

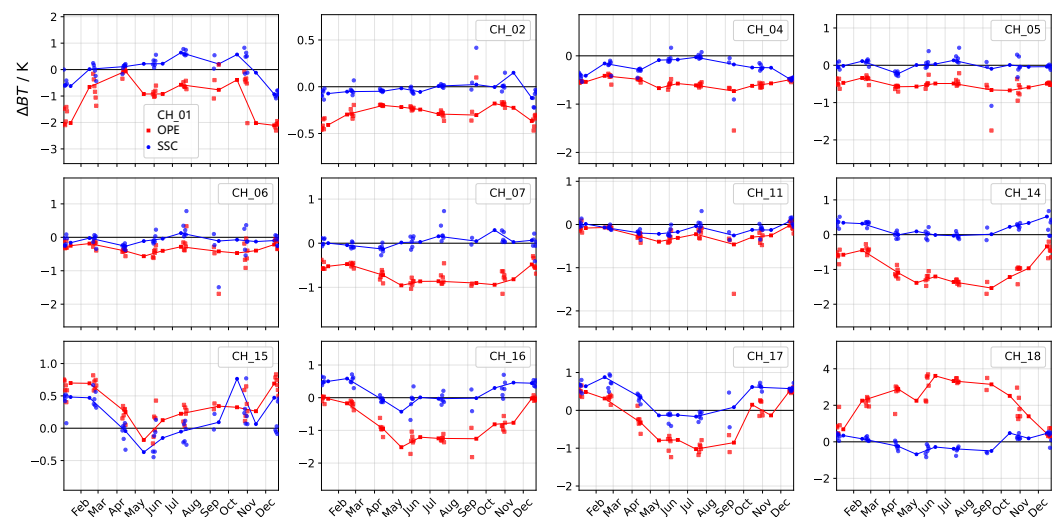


Figure 4. Time series of brightness-temperature differences between FY-3B/IRAS and Metop-A/IASI in 2014 after calibration and cross-calibration using the adjusted SRF. Each subplot corresponds to one corrected channel. The red line denotes the OPE baseline, the blue line denotes the calibration with the adjusted SRF (SSC); dots indicate daily SNO matchups, and line vertices mark monthly means.

The channel-wise response follows the earlier spectral-sensitivity diagnosis. In the $15\ \mu\text{m}$ CO_2 temperature-sounding group (CH01–CH07), the operational record often shows seasonally varying offsets; under SSC these offsets contract toward zero and inter-month scatter decreases. In the midwave set (CH11, CH14–CH17; $7.4\text{--}4.5\ \mu\text{m}$), SSC further suppresses residual curvature and seasonal asymmetry. CH18, which is especially sensitive due to broad CO_2 absorption, shows the clearest stabilization: monthly means return closer to zero and the amplitude of excursions shrinks, highlighting the importance of accurate central wavenumber placement for this channel.

Quantitatively, SSC reduces both absolute mean bias and month-to-month variability. For most channels, the standard deviation of monthly means decreases by roughly 15–35% relative to OPE, with the largest gains in CH01–CH06 and CH14–CH17. This indicates improved accuracy without introducing artificial trends, and provides a solid basis for extending the method to the full mission record and to multi-year consistency assessments.

Figure 5 complements the time-series comparison by showing the probability distributions of FY-3B/IRAS–Metop-A/IASI brightness-temperature differences (ΔBT) for the twelve recalibrated channels in 2014. Under OPE (red dashed), the distributions are typically broader and often shifted away from zero, especially in CO₂ and N₂O absorption channels, implying systematic bias and scene-dependent effects. Under SSC (blue solid), the distributions become narrower and more symmetric around zero, indicating that the dominant spectral-mismatch component has been suppressed.

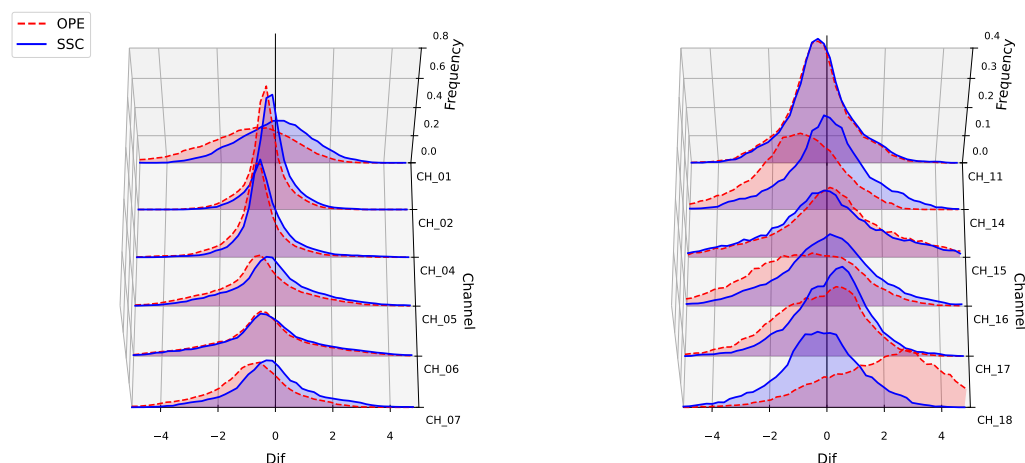


Figure 5. Landscape comparison of the probability distributions of brightness-temperature differences (ΔBT) between FY-3B/IRAS and Metop-A/IASI in 2014 after SRF adjustment. Each curve corresponds to one recalibrated channel. Red dashed lines denote the OPE baseline, and blue solid lines denote the SRF-adjusted calibration (SSC).

From the 15 μm CO₂ group (CH01–CH07) to the 4.5–4.2 μm N₂O/CO₂ mixed channels (CH14–CH18), SSC consistently reduces mean offsets and dampens long-tail deviations associated with warmer scenes. For less sensitive channels such as CH11, OPE and SSC nearly overlap, reinforcing that SRF adjustment does not inject additional noise where spectral sensitivity is low.

Table 2 provides a concise view of how SSC operates in practice. After the SRF central wavenumbers are adjusted, the absorption-dominated channels exhibit a much more balanced behavior in cross-calibration. The biases no longer persistently lean to one side, and their distributions appear closer to what would be expected from natural scene variability rather than from a systematic spectral mismatch. This response is consistent with correcting a channel-level misregistration that sits upstream of both the calibration chain and the IASI-to-IRAS convolution, and therefore manifests most clearly where the radiance spectrum varies rapidly with wavenumber.

The contrast between absorption channels and window regions is equally informative. Window channels remain largely unchanged after SSC, which serves as a physical consistency check rather than a shortcoming of the method. When the scene spectrum is locally flat within the passband, shifting the SRF central wavenumber has little leverage, so the statistics are expected to stay stable. In this sense, SSC does not impose artificial improvements across all channels but selectively acts where the underlying spectral sensitivity makes such a correction meaningful, reducing the risk of over-tuning to specific years or matchup subsets.

Table 2. Comparison of mean and standard deviation of brightness-temperature differences before and after SRF shifts in 2014.

Channel (Shift, cm^{-1})	OPE		SSC		OPE vs. SSC	
	ΔBT_{mean} (K)	ΔBT_{std} (K)	ΔBT_{mean} (K)	ΔBT_{std} (K)	ΔBT_{mean} (K)	ΔBT_{std} (K)
1 (−1.2)	−1.092	1.761	0.080	1.300	1.012	0.461
2 (+1.0)	−0.281	0.864	−0.010	0.770	0.271	0.094
3 (−)	−0.384	0.753	−	−	−	−
4 (−1.0)	−0.550	1.033	−0.290	0.920	0.260	0.113
5 (−1.5)	−0.526	1.615	−0.025	1.565	0.501	0.050
6 (−2.5)	−0.309	1.870	−0.120	1.840	0.189	0.030
7 (−1.75)	−0.743	1.607	0.010	1.415	0.733	0.192
8 (−)	−0.367	1.814	−	−	−	−
9 (−)	−0.316	1.567	−	−	−	−
10 (−)	−0.160	1.825	−	−	−	−
11 (+2.5)	−0.199	1.458	−0.115	1.245	0.084	0.213
12 (−)	−0.255	1.310	−	−	−	−
13 (−)	2.317	1.574	−	−	−	−
14 (+3.0)	−0.983	1.608	0.100	1.555	0.883	0.053
15 (−1.5)	0.302	2.111	−0.010	2.095	0.292	0.016
16 (+3.0)	−0.911	2.044	0.025	1.835	0.886	0.209
17 (+2.5)	−0.191	1.696	0.255	1.320	−0.064	0.376
18 (+5.5)	2.263	2.184	−0.145	1.945	2.118	0.239
19 (−)	0.096	1.515	−	−	−	−
20 (−)	−0.240	2.870	−	−	−	−

Midwave channels show a more moderate response. In these channels, SSC tends to realign the residual distributions and suppress part of the systematic bias, while leaving a non-negligible fraction of the structure intact. This behavior suggests that although spectral misregistration contributes to the observed discrepancies, other factors such as detector response characteristics or scene-dependent weighting within the channel also play a role. As a result, SSC functions here primarily as a bias-alignment step rather than a complete removal of all error sources.

CH17 illustrates the practical boundary of center-shift correction. In this channel, dispersion can be reduced without a corresponding improvement in mean alignment, implying that the dominant residual structure is not governed by a single, uniform spectral offset. Instead, the remaining discrepancies are more consistent with scene-dependent or brightness-dependent effects that cannot be fully captured by a rigid SRF shift. SSC therefore removes only the component linked to spectral-gradient amplification, while leaving behind an interior-mode distortion characteristic of radiometric-response nonlinearity.

Taken together, the table supports a coherent interpretation. SSC effectively suppresses systematic errors driven by spectral-gradient amplification in absorption channels, while leaving spectrally insensitive window channels essentially unchanged. The residual curvature and incomplete re-centering observed in a small number of channels point to detector-response nonlinearity as the next dominant error source. This motivates the subsequent focus on NCO, which targets the interior structure of the counts-to-radiance mapping that persists after spectral alignment.

4.2. Performance of Nonlinearity-Coefficient Optimization

Table 3 summarizes the quadratic nonlinearity coefficient obtained in the operational configuration and after NCO, which follows SSC in the overall pipeline. The update is applied only to the quadratic term a_2 , while the offset a_0 and the linear gain a_1 remain constrained by the deep space view and the onboard blackbody, so the optimization acts

as a correction to the interior curvature of the radiometric mapping without changing the two-point anchoring geometry.

Table 3. Comparison of quadratic nonlinearity coefficients before and after the in-orbit optimization.

Channel	OPE	NCO	Δ (NCO–OPE)
1	-2.63×10^{-4}	2.50×10^{-4}	5.13×10^{-4}
2	-5.27×10^{-7}	-5.27×10^{-7}	–
3	-1.00×10^{-7}	1.34×10^{-6}	1.44×10^{-6}
4	7.88×10^{-8}	1.34×10^{-7}	5.52×10^{-8}
5	9.10×10^{-8}	9.10×10^{-8}	–
6	-2.43×10^{-7}	-6.80×10^{-7}	-4.37×10^{-7}
7	-9.68×10^{-8}	-9.68×10^{-8}	–
8	3.59×10^{-8}	-3.66×10^{-7}	-4.02×10^{-7}
9	1.39×10^{-8}	-1.38×10^{-7}	-1.52×10^{-7}
10	4.10×10^{-8}	-3.49×10^{-7}	-3.90×10^{-7}
11	2.79×10^{-8}	-1.06×10^{-7}	-1.34×10^{-7}
12	5.42×10^{-8}	-5.69×10^{-7}	-6.23×10^{-7}
13	3.19×10^{-7}	5.23×10^{-6}	4.91×10^{-6}
14	-3.72×10^{-9}	2.42×10^{-8}	2.79×10^{-8}
15	-2.68×10^{-9}	-2.68×10^{-9}	–
16	-4.30×10^{-9}	-4.30×10^{-9}	–
17	-3.20×10^{-9}	6.40×10^{-8}	6.72×10^{-8}
18	-2.64×10^{-9}	-2.64×10^{-9}	–
19	-2.13×10^{-9}	-2.13×10^{-9}	–
20	6.23×10^{-11}	6.23×10^{-11}	–

The channels that receive a clear a_2 update are those for which the residual curvature remains visible after SSC and can be stably inferred from the quality weighted least squares objective constructed on ΔBT . For these channels, the optimization reduces the systematic interior shape mismatch that otherwise persists even when spectral harmonization has been applied. In contrast, channels marked with no change in the last column keep their original a_2 . This outcome indicates that for those channels, the residual curvature is already weak within the effective signal range, or the available dynamic span and matchup quality do not provide enough leverage to estimate a stable interior correction, or the channel is treated conservatively to preserve its anchoring role in the long term radiometric chain. Overall, the update pattern follows the spectral behavior in a physically consistent manner, with absorption-dominated and midwave channels showing stronger need for nonlinearity adjustment, while window-like and weak-absorption channels remain close to linear in the practical operating regime.

Figure 6 visualizes FY-3B/IRAS–Metop-A/IASI brightness-temperature differences (ΔBT) after SSC (red line) and after the subsequent nonlinearity-coefficient update (NCO, blue line). Across all twelve panels, the dominant and consistent feature is an almost rigid translation of the fitted regression toward the zero-residual axis when moving from SSC to NCO, while the local slope of the fit remains essentially unchanged. This pattern is exactly what the two-point-anchored theory introduced earlier predicts: with deep space and the onboard blackbody fixing the endpoints, adjusting the quadratic term a_2 modifies the interior via the two-point shape function in Equation (19), and its first-order effect on T_b in Equation (20) is nearly constant over the populated signal range when counts cluster around mid-level, yielding re-centering without gain change.

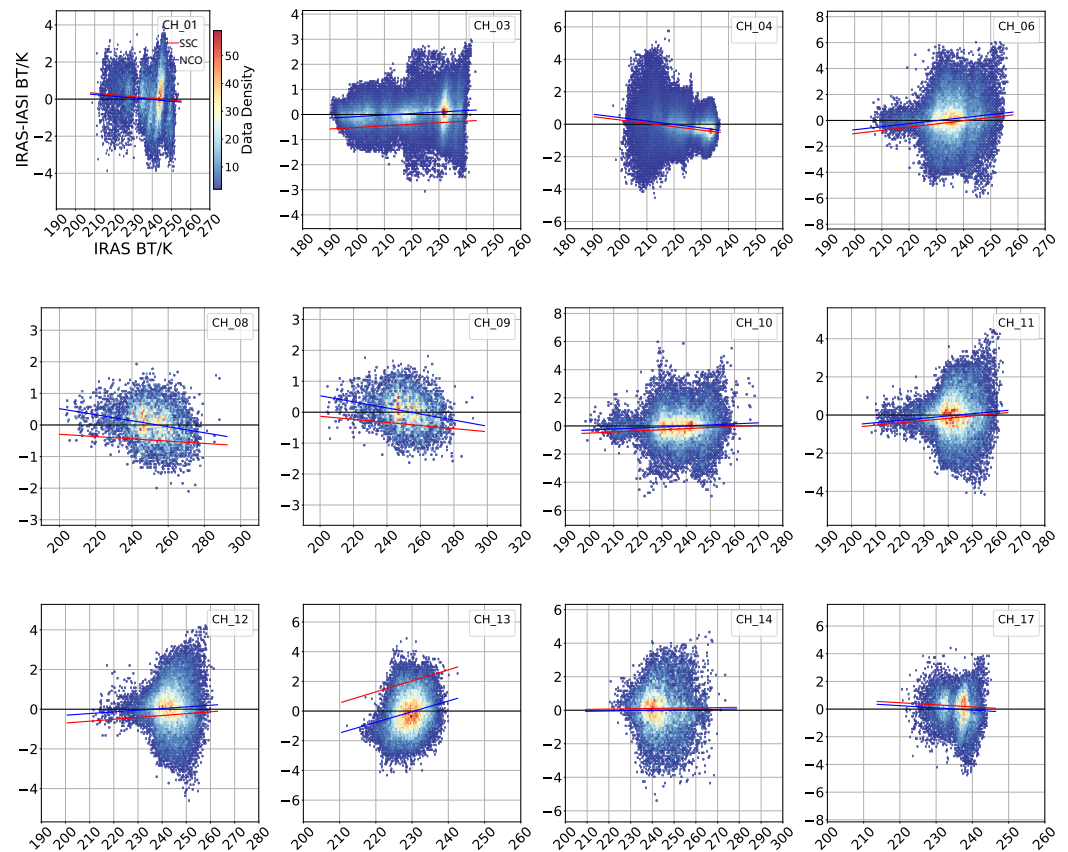


Figure 6. FY-3B/IRAS–Metop-A/IASI brightness-temperature residual scatter (12 channels, 3 × 4). Only NCO points (blue cloud) are plotted; the blue line is the regression fitted to these NCO points, and the red line is the regression for the SSC-only case, overlaid for reference. CH01 shows the NCO point-density color bar; the other panels share the same color scale.

Channel-wise, the magnitude of this translation varies systematically with spectral sensitivity. Channels in strong absorption (e.g., the CO₂ temperature-sounding set near 15 μ m and the mid-wave CO₂/N₂O group) exhibit the largest re-centering, consistent with their steeper radiance–wavenumber gradients that amplify interior-curvature mismatch into residual bias; by contrast, window-like or weak-absorption channels show a much smaller offset correction. This ordering is physically expected under Equation (20): where scenes project a broader or more skewed count distribution relative to (C_b , C_s)—as is typical for absorption-dominated channels—the product $(C_v - C_b)(C_v - C_s)$ averages to a larger magnitude and yields a more visible constant shift in T_b .

Importantly, the persistence of nearly identical slopes between SSC and NCO across panels indicates that the linear gain governed by the two strong references remains intact, i.e., the update to a_2 does not induce a first-order change in local sensitivity. This preserves channel-to-channel comparability and avoids artificial tilting of the residual–signal relation, which is a desirable property for long-term consistency studies.

Figure 7 presents the 2014 time series of FY-3B/IRAS–Metop-A/IASI brightness-temperature differences ΔBT for twelve channels, contrasting the SSC-only calibration (red) with the subsequent nonlinearity-coefficient update (NCO, blue). Across channels, the most salient and persistent feature is an almost rigid vertical translation of the monthly-mean trajectory toward $\Delta BT \approx 0$ when moving from SSC to NCO, whereas the intra-annual shape—its seasonal undulation and the timing of extrema—remains essentially unchanged. Daily SNO pairs (points) continue to fluctuate around the monthly means with comparable amplitude before and after the update, indicating that the adjustment primarily removes

a channel-dependent offset without materially altering short-term variability. This is precisely the temporal counterpart of the regression-space behavior reported in Figure 6, i.e., re-centering without gain change.

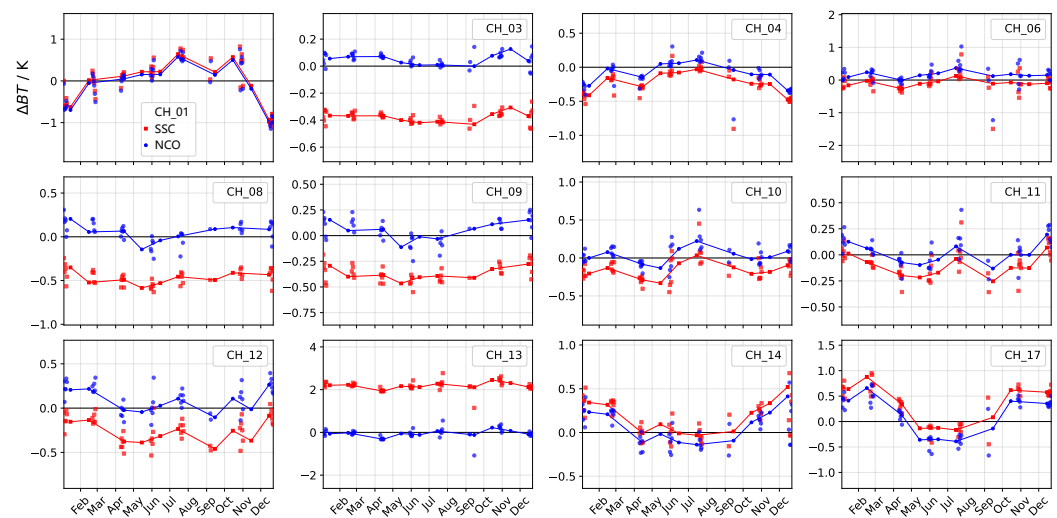


Figure 7. Brightness-temperature difference (ΔBT) time series in 2014 for FY-3B/IRAS versus Metop-A/IASI after SSC and subsequent NCO. Each panel corresponds to one channel: the red curve is the SSC-only result, and the blue curve is the result with NCO applied on top of SSC. Points are daily SNO matchups; the polyline connects monthly means.

The magnitude of the re-centering also exhibits a clear spectral ordering. Channels dominated by strong atmospheric absorption—such as the long-wave CO_2 temperature-sounding set near $15\ \mu\text{m}$ and the mid-wave $\text{CO}_2/\text{N}_2\text{O}$ group—show the largest month-by-month bias removal, bringing their trajectories tightly around zero throughout the year. In contrast, window or weak-absorption channels undergo only modest nudges toward zero, consistent with their smaller interior-curvature mismatch after SSC. Notably, these differences manifest as nearly constant vertical offsets rather than slope changes: the seasonal envelopes (amplitude and phase) remain intact from SSC to NCO, which again supports the two-point-anchored interpretation that deep space and the onboard blackbody fix the endpoints while the quadratic term adjusts only the interior bias.

A second, complementary perspective comes from the dispersion about the monthly means. While NCO does not uniformly compress the day-to-day scatter across all channels, the variance relative to the translated mean is visually stable, indicating that the update does not induce artificial tilting or seasonal distortion. In channels where the SSC trajectory exhibited a clear sign-definite offset (consistently positive or negative through most months), NCO removes this baseline displacement with minimal collateral change to the spread. Such behavior is desirable for long-term consistency studies: it improves inter-sensor agreement by eliminating residual biases yet preserves intrinsic geophysical variability and the comparability of seasonal signatures across channels.

Taken together with the regression-based evidence, the time-series results substantiate the earlier theoretical expectation: with the two strong references anchoring offset and linear gain, updating the quadratic coefficient operates as an interior-bias corrector that recenters ΔBT without altering local sensitivity. Practically, this yields year-round trajectories that are closer to zero yet otherwise unchanged in shape, thereby enhancing radiometric accuracy while maintaining stability of seasonal patterns.

Table 4 quantifies the effect of the nonlinearity update on the year-2014 FY-3B/IRAS–Metop-A/IASI matchups and, more importantly, clarifies how the update behaves across channels. The dominant signature is a channel-dependent re-centering of ΔBT_{mean} toward

zero, while ΔBT_{std} changes are secondary. This is the expected footprint of an a_2 -only adjustment under the two-point anchoring: the endpoints remain fixed by the deep-space view and the onboard blackbody, so the update mainly removes an interior bias that appears as an offset in ΔBT rather than a gain-like reshaping.

Table 4. Mean and standard deviation of brightness-temperature differences before and after nonlinearity-coefficient adjustment in 2014.

Channel	SSC		NCO		SSC vs. NCO	
	ΔBT_{mean} (K)	ΔBT_{std} (K)	ΔBT_{mean} (K)	ΔBT_{std} (K)	ΔBT_{mean} (K)	ΔBT_{std} (K)
1	0.080	1.300	0.002	1.292	0.078	0.008
2	−0.010	0.770	—	—	—	—
3	−0.384	0.753	0.060	0.642	0.324	0.111
4	−0.290	0.920	−0.123	0.920	0.167	0.000
5	−0.025	1.565	—	—	—	—
6	−0.120	1.840	0.118	1.829	0.002	0.011
7	0.010	1.415	—	—	—	—
8	−0.367	1.814	0.022	0.643	0.345	1.171
9	−0.316	1.567	0.017	0.608	0.299	0.959
10	−0.160	1.825	−0.015	1.412	0.145	0.413
11	−0.115	1.245	0.004	1.242	0.111	0.003
12	−0.255	1.310	0.057	1.240	0.198	0.070
13	2.317	1.574	−0.030	1.285	2.287	0.289
14	0.100	1.555	0.003	1.535	0.097	0.020
15	−0.010	2.095	—	—	—	—
16	0.025	1.835	—	—	—	—
17	0.255	1.320	0.030	1.325	0.225	−0.005
18	−0.145	1.945	—	—	—	—
19	0.096	1.515	—	—	—	—
20	−0.240	2.870	—	—	—	—

The response is not uniform across the spectrum. Absorption-sensitive channels are the primary beneficiaries: their scene radiances tend to sample a broader and more skewed count distribution relative to the two reference points, which makes residual interior curvature more visible after SSC and therefore more identifiable in the ΔBT -based objective. As a result, these channels show a clearer re-centering of the mean bias. Window-like or weak-absorption channels, by contrast, are already closer to linear over the effective operating range after SSC, so their mean shifts are smaller and the update, when applied, behaves conservatively. In this sense, the table reflects a physically consistent selectivity: NCO acts where curvature-driven mismatch is both present and estimable, and it largely leaves near-linear channels unchanged.

The dispersion behavior provides a complementary check. Where the update is effective, the day-to-day spread around the translated mean is either preserved or modestly reduced, indicating that NCO is not injecting additional variability. This is consistent with the regression- and time-series evidence in Figures 6 and 7: the residual–signal relation is re-centered with little change in slope, and the seasonal envelope remains intact. The fact that some channels show limited change in ΔBT_{std} despite a clear mean correction is therefore not a weakness; it simply indicates that NCO targets systematic interior bias rather than short-term noise sources.

A small subset behaves more weakly, exemplified by cases where the mean is pulled toward zero but the dispersion is essentially unchanged. This pattern is consistent with limited dynamic leverage for curvature control in those channels: the matchup count distribution may cluster in a narrower region of the radiometric curve, making the interior

mode less influential on variance even though its mean imprint is still detectable. Overall, the channel-wise statistics support the intended role of NCO within the pipeline: after SSC has harmonized spectral mismatch, the remaining curvature-induced offset is selectively suppressed without disturbing linear gain or the temporal structure, improving year-scale agreement while maintaining stability of the residual variability.

Channels left unmodified in Table 4 (marked “–”) are precisely those for which the methodology did not warrant a stable a_2 update—either because the residual curvature was already negligible under SSC (limited identifiability of the interior mode), the usable dynamic range and matchup quality offered insufficient leverage, or the channel serves as a radiometric anchor in the long-term chain. Importantly, wherever an update was applied, the mean moved toward zero while the slope of the residual–signal relation remained essentially unchanged (cf. Figure 6), preserving linear gain and channel-to-channel comparability. These outcomes validate the design goal of the nonlinearity step: remove the interior-curvature-induced offset left after spectral harmonization, with minimal impact on sensitivity, thereby improving year-scale accuracy and stabilizing uncertainty statistics.

4.3. Effectiveness of Brightness-Temperature Uniformity Threshold Adjustment

On top of SSC and NCO, we further evaluate AQC over the full mission lifetime (2010–2019). The thresholds follow the previously introduced channel-dependent adaptive scheme: stricter for window channels with intrinsically low scene variability and moderately relaxed for strong-absorption channels with larger scene variability, so as to balance scene-variability control against sample retention while preserving the same SNO pairing rules as before.

Figure 8 shows the all-life scatter of IRAS against IASI for the operational baseline. The dominant issue is not the correlation itself, but the way the main ridge sits relative to the $y = x$ reference: a non-negligible intercept and a slight tilt indicate that zero-bias and unity-gain are not simultaneously satisfied over the full dynamic range. Once these small deviations accumulate across seasons and years, they become visible as a persistent offset in long-term statistics and weaken the comparability of different channels and different mission phases.

In addition, the operational scatter contains small detached clusters and streak-like structures that are difficult to interpret as natural atmospheric regimes. Their geometric appearance is more consistent with occasional processing residues or quality-screening leakage, which can both bias the global regression and inflate the apparent spread. In a full-lifetime evaluation, these low-frequency but persistent artifacts are particularly harmful because they disproportionately affect the tails of the distribution and broaden uncertainty estimates.

After superimposing AQC on top of “SRF correction + a_2 optimization,” the scatter in Figure 9 tightens toward the $y = x$ line. The improvement is expressed in two coupled ways: the principal ridge becomes more compact, and the regression fit moves closer to the 1:1 reference, indicating that the retained matchups better represent radiometrically homogeneous scenes. Meanwhile, many of the detached clusters are strongly attenuated or disappear, which is consistent with AQC preferentially removing matchups dominated by intra-footprint inhomogeneity rather than applying ad hoc outlier deletion. Because the thresholds are channel-dependent, this tightening is achieved without collapsing the sampling diversity across seasons and latitudes.

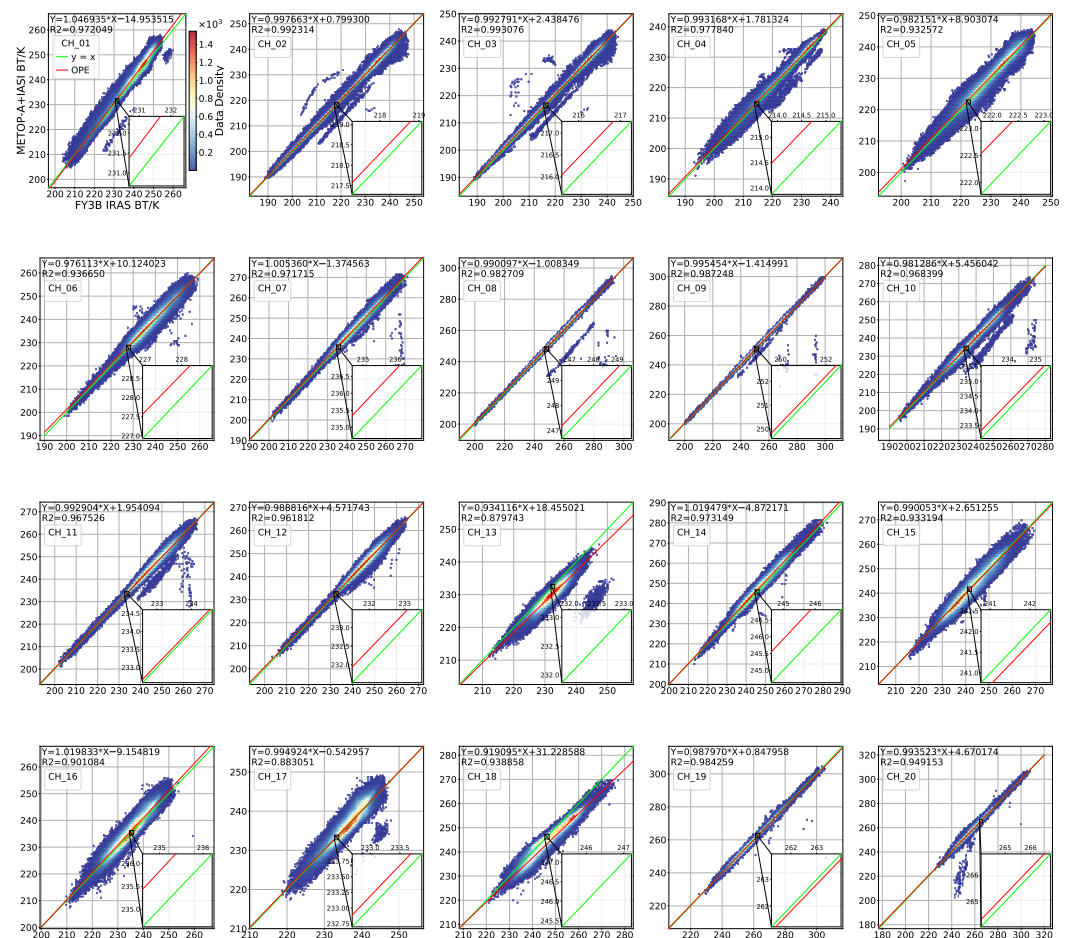


Figure 8. All-life scatter of FY-3B/IRAS vs. Metop-A/IASI (OPE). Each panel is one channel; samples are SNO day–night combined pairs from 2010–2019. The green line is the 1:1 reference ($y = x$), and the red line is the overall regression for the OPE baseline. Hexagonal bins indicate SNO pair density, with the color bar shown on CH01; the inset box provides a local zoom.

The all-life monthly time series in Figure 10 provide the same message in the temporal domain. Relative to OPE, AQC yields monthly means that stay closer to zero and uncertainty envelopes that are visibly narrower, while the year-to-year evolution remains continuous. This behavior suggests that the rule mainly trims scene-driven variability and sporadic artifacts, rather than reshaping the underlying geophysical signal. The effect becomes more noticeable in periods and regions where heterogeneity is naturally higher (e.g., convective seasons and high-latitude winters), which is exactly where a uniformity-based filter should carry more weight.

These results match the intended role of AQC as a data-quality complement: it does not modify the two-point anchoring or the per-channel gain established by SSC and NCO, but stabilizes matchup statistics through channel-dependent adaptive thresholding that respects spectral characteristics. When SSC, NCO, and AQC are applied in sequence, the full-lifetime distribution of ΔBT becomes more centered and more compact while maintaining temporal coverage, which is essential for long-term consistency and trend assessment.

Combining Table 5 with the preceding scatter and time-series analyses leads to a consistent interpretation: relative to OPE, the pipeline up to AQC improves both the centering of the residual distribution and its compactness, and the two improvements are linked to different error sources. The mean shift reflects the suppression of systematic bias that becomes more visible once heterogeneous scenes are down-weighted, whereas the standard-deviation reduction reflects the removal of scene-inhomogeneity-driven spread

and sporadic anomalous clusters. In other words, AQC behaves less like a numerical tweak and more like a statistically consistent re-selection of matchups that better satisfy the uniform-scene assumption underlying inter-calibration.

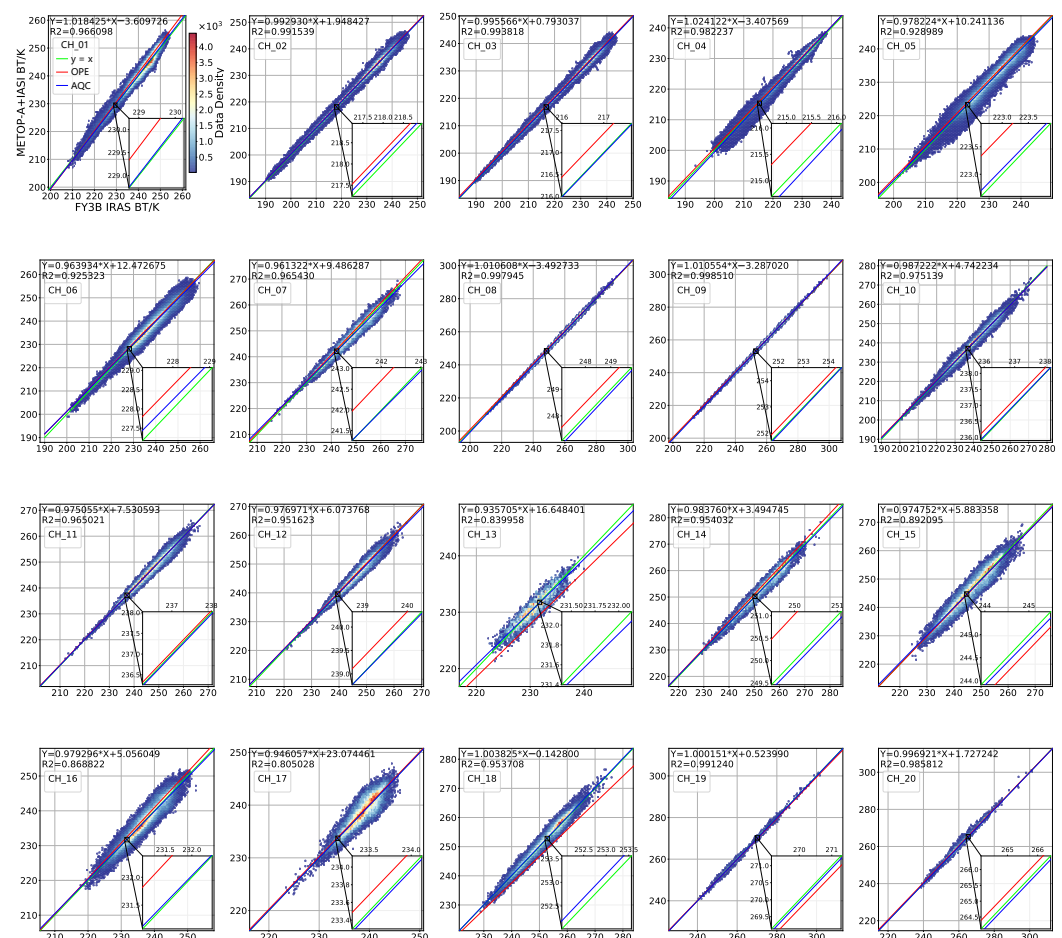


Figure 9. All-life scatter after applying the dynamic BT-uniformity thresholds (AQC) on top of SRF correction and nonlinearity (a_2) optimization. Each panel is one channel; the green line is the 1:1 reference ($y = x$), the red line is the OPE baseline, and the blue line is the AQC regression fit. Hexagonal bins indicate SNO pair density, with the color bar shown on CH01; the inset box provides a local zoom.

Across channels, the gains appear in different forms. Some channels are dominated by long-term bias in OPE and therefore benefit mainly through re-centering; others are dominated by scene heterogeneity and therefore benefit mainly through dispersion tightening. This spectrum-dependent behavior is physically reasonable: absorption-sensitive channels tend to be more affected by heterogeneous temperature/humidity structure along the line of sight, while window channels are more sensitive to surface emissivity contrasts and cloud edges. The adaptive thresholds allow these differences to be handled without enforcing a one-size-fits-all cutoff, which explains why the improvement is visible at both scatter and time-series levels without obvious loss of temporal continuity.

Overall, the OPE-versus-AQC contrast indicates that dynamic uniformity thresholding selectively suppresses dispersion and bias introduced by scene inhomogeneity and processing residues, making the channel-wise ΔBT distributions more centered and compact. This materially strengthens full-lifetime consistency and improves the reliability of cross-year mosaicking and long-term trend assessment, while keeping the radiometric model itself unchanged.

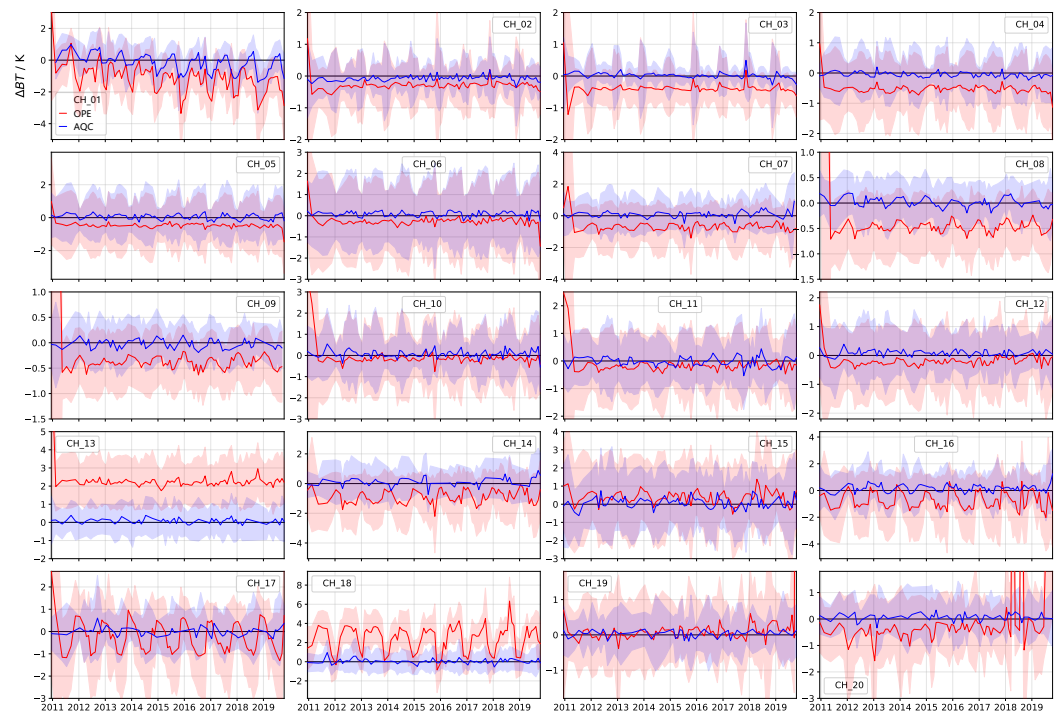


Figure 10. FY-3B/IRAS versus Metop-A/IASI all-life (monthly) time series of brightness-temperature differences (ΔBT). Each channel covers 2010–2019: the red polyline shows the OPE monthly mean, and the blue polyline shows the monthly mean after applying dynamic BT-uniformity thresholding (AQC) on top of SRF correction and nonlinearity optimization; the shaded envelopes indicate the monthly uncertainty for each series.

Table 5. Channel-wise comparison of brightness-temperature mean differences and standard deviations before and after improvement for FY-3B/IRAS.

Channel	OPE		AQC		OPE vs. AQC	
	ΔBT_{mean} (K)	ΔBT_{std} (K)	ΔBT_{mean} (K)	ΔBT_{std} (K)	ΔBT_{mean} (K)	ΔBT_{std} (K)
1	−1.092	1.761	−0.212	1.383	0.880	0.378
2	−0.281	0.864	−0.060	0.750	0.221	0.114
3	−0.384	0.753	0.054	0.633	0.330	0.120
4	−0.550	1.033	−0.086	0.862	0.465	0.171
5	−0.526	1.615	0.159	1.473	0.367	0.142
6	−0.309	1.870	0.181	1.852	0.128	0.017
7	−0.743	1.607	0.198	1.368	0.544	0.239
8	−0.367	1.814	0.050	0.520	0.317	1.295
9	−0.316	1.567	0.000	0.466	0.316	1.101
10	−0.160	1.825	0.037	1.344	0.123	0.482
11	−0.199	1.458	0.099	1.140	0.099	0.318
12	−0.255	1.310	0.179	1.136	0.076	0.174
13	2.317	1.574	0.053	1.186	2.264	0.388
14	−0.983	1.608	0.121	1.490	0.863	0.118
15	0.302	2.111	0.105	1.999	0.198	0.112
16	−0.911	2.044	0.065	1.680	0.846	0.364
17	−0.191	1.696	0.072	1.268	1.119	0.428
18	2.263	2.184	−0.155	1.338	2.108	0.846
19	0.096	1.515	0.086	0.823	0.010	0.692
20	−0.413	2.870	−0.240	1.140	0.173	1.731

5. Discussion

Beyond FY-3B/IRAS, the proposed method can serve as a reference for recalibration of other infrared instruments, such as next-generation infrared hyperspectral instruments including HIRAS-II [12,52–55].

Over the full mission lifetime, channel biases and uncertainties are markedly reduced, yet some limitations remain. Residuals can still increase during seasonal transitions and in challenging regimes (e.g., high-latitude winters and convectively active periods), and gains are not fully uniform across channels. Future work will focus on stratified corrections by season/latitude/surface type, spectral-group threshold refinement with robust regression, and better control of reference harmonization and viewing-geometry effects to further stabilize long-term trends.

6. Conclusions

This paper presented and validated a three-step consistency optimization chain for FY-3B/IRAS calibration and cross-calibration that combines SSC, NCO, and AQC. The chain preserves the deep-space and onboard-blackbody anchors, yet steadily reduces bias and uncertainty across the full instrument lifetime by acting on complementary parts of the measurement and matchup pipeline.

In practice, each step targets a distinct error-correction mode. SSC mitigates the amplified impact of spectral misregistration in absorption channels, improving the alignment between the effective bandpass and the reference convolution. Under the two-point anchoring constraint, refining the quadratic term mainly recenters the residuals toward the zero line with negligible change in linear gain, consistent with the interior-shape effect of a_2 . AQC does not modify calibration physics; instead, it regulates matchup quality in a channel-aware manner, suppressing variance driven by scene inhomogeneity and residual processing artifacts. Because these modes act on different components of the overall chain, their benefits accumulate with limited mutual interference, matching the monotonic improvement observed when applying SSC, NCO, AQC sequentially.

Full-lifetime evaluation reveals two operational features that are explicitly alleviated by the proposed chain. One is the persistent intercept and gain departure between the dominant regression ridge and the $y = x$ reference, which can accumulate into errors in cross-year compositing and long-term trend diagnostics. The other is the presence of small clusters and streaks detached from the main ridge, which are more plausibly linked to Level-0 (L0)–L1 processing residues than to natural atmospheric groupings; such features can exert undue leverage on regressions and inflate dispersion. After applying SSC–NCO–AQC, the regressions move closer to the reference and the dispersion becomes more compact, while temporal and spatial coverage is maintained.

Time-series and scatter analyses are mutually consistent. Monthly means lie closer to zero and uncertainty envelopes narrow across channels, with especially clear benefits during convectively active seasons and high-latitude winters. For channels that were already stable, we still observe measurable tightening, indicating that the adaptive screening does not over-filter the data but selectively targets scene-driven variance. These results provide a stronger basis for long-term consistency assessment, cross-year mosaicking, and detection of subtle radiometric trends.

A residual long-term trend remains visible in a small number of channels, most notably CH01, where the brightness-temperature differences exhibit a gradual downward drift with time. This behavior is physically plausible for CO₂ temperature-sounding channels: their relatively low scene radiance and steep spectral gradients make them particularly sensitive to subtle, cumulative changes in detector responsivity, optical throughput, or the effective emissivity of the onboard blackbody. When such degradations evolve slowly

over years, they manifest as a coherent, monotonic trend rather than as scene-dependent scatter. Because this type of drift cannot be fully removed by static SRF alignment or by a quadratic refinement constrained by two fixed reference points, it is interpreted here as a residual signature of instrument aging rather than as an artifact introduced by the calibration algorithm.

Author Contributions: Conceptualization, C.Q. and J.H.; methodology, J.H., X.Y. and C.Q.; software, J.H.; validation, J.H., X.Y. and C.Q.; formal analysis, J.H.; investigation, J.H. and X.Y.; data curation, J.H.; writing—original draft preparation, J.H.; writing—review and editing, C.Q., X.Y., S.X., W.G. and Y.J.; visualization, J.H.; supervision, C.Q.; project administration, C.Q. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number U2242212; the Hunan Provincial Natural Science Foundation of China, grant number 2025JJ70028; and the Scientific Research Project of Education Department of Hunan Province, grant number 24A0401.

Data Availability Statement: The FY-3B data used in this study are publicly available in the FY-3B satellite archive at the FENGYUN Satellite Data Center. These datasets were derived from the public-domain resources available at <https://satellite.nsmc.org.cn/portalsite/default.aspx?currentculture=en-US>. The Metop-A/IASI data are provided by EUMETSAT and can be accessed through the EUMETSAT Earth Observation Portal and the EUMETSAT Data Centre at <https://www.eumetsat.int>.

Acknowledgments: The authors thank the FENGYUN Satellite Data Center and EUMETSAT for providing data support.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Qi, C.; Chen, Y.; Liu, H.; Wu, C.; Yin, D. Calibration and validation of the InfraRed Atmospheric Sounder onboard the FY3B satellite. *IEEE Trans. Geosci. Remote Sens.* **2012**, *50*, 4903–4914. [\[CrossRef\]](#)
2. Yang, Z.; Zhang, P.; Gu, S.; Hu, X.; Tang, S.; Yang, L. Capability of Fengyun-3D Satellite in Earth System Observation. *J. Meteorol. Res.* **2019**, *33*, 1093–1104. [\[CrossRef\]](#)
3. Wang, L.; Chen, S.; Hu, X.; Niu, X.; Xu, H.; Wang, J.; Miao, S.; Liu, H.; Qi, C.; Sun, L.; et al. FY-3F MERSI-III on-orbit calibration methodology and performance of reflective solar bands. *IEEE Trans. Geosci. Remote Sens.* **2025**, *63*, 5625815. [\[CrossRef\]](#)
4. Xiao, H.; Ai, J.; Yang, J.; Chen, K.; Wang, X.; Gao, P.; Han, Z.; Hu, X.; Qi, C.; Wang, L.; et al. Sampling correction approach with interpolation sliding window for FY-3D/MERSI-II on-orbit calibration. *IEEE Trans. Geosci. Remote Sens.* **2025**, *63*, 5401611. [\[CrossRef\]](#)
5. He, Y.; Liu, Q.; Zhang, Y. Dynamic scene-driven threshold adjustment in SNO calibration of FY-3 series infrared sounders. *Remote Sens.* **2023**, *15*, 377. [\[CrossRef\]](#)
6. Zou, X. Studies of FY-3 observations over the past 10 years: A review. *Remote Sens.* **2021**, *13*, 673. [\[CrossRef\]](#)
7. Tobin, D.C.; Revercomb, H.E.; Knuteson, R.O.; Best, F.A.; Smith, W.L.; Ciganovich, N.N.; Dedecker, R.G.; Dutcher, S.; Ellington, S.D.; Garcia, R.K.; et al. Radiometric and spectral validation of Atmospheric Infrared Sounder observations with ground-based and airborne interferometers. *J. Geophys. Res. Atmos.* **2006**, *111*, D9. [\[CrossRef\]](#)
8. Loveless, M.; Knuteson, R.; Revercomb, H.; Borg, L.; DeSlover, D.; Martin, G.; Taylor, J.; Iturbide-Sanchez, F.; Tobin, D. Comparison of the AIRS, IASI, and CrIS infrared sounders using simultaneous nadir overpasses. *Earth Space Sci.* **2023**, *10*, e2023EA002878. [\[CrossRef\]](#)
9. Shaw, J.; Anderson, C.; Choate, M.; Micijevic, E. *Landsat Geometric and Radiometric Calibration*; USGS Fact Sheet no. 2024–3039; U.S. Geological Survey: Reston, VA, USA, 2024. [\[CrossRef\]](#)
10. Goldberg, M.D.; Qu, Y.; McMillin, L.M.; Wolf, W.; Zhou, L.; Divakarla, M. AIRS near-real-time products and algorithms in support of operational numerical weather prediction. *IEEE Trans. Geosci. Remote Sens.* **2003**, *41*, 379–389. [\[CrossRef\]](#)
11. Hewison, T.J.; Wu, X.; Yu, F.; Tahara, Y.; Hu, X.; Kim, D.; Koenig, M. GSICS inter-calibration of infrared channels of geostationary imagers using Metop/IASI. *IEEE Trans. Geosci. Remote Sens.* **2013**, *51*, 1160–1170. [\[CrossRef\]](#)
12. Wu, C.; Qi, C.; Hu, X.; Gu, M.; Yang, T.; Xu, H.; Lee, L.; Yang, Z.; Zhang, P. FY-3D HIRAS radiometric calibration and accuracy assessment. *IEEE Trans. Geosci. Remote Sens.* **2020**, *58*, 3965–3976. [\[CrossRef\]](#)

13. Fan, L.; Jiang, Z.; Yu, S.; Liu, Y.; Wang, D.; Chen, M. A general on-orbit absolute radiometric calibration method compatible with multiple imaging conditions. *Remote Sens.* **2024**, *16*, 3503. [\[CrossRef\]](#)
14. Aumann, H.H.; Broberg, S.; Manning, E.; Pagano, T. Radiometric Stability Validation of 17 Years of AIRS Data Using Sea Surface Temperatures. *Geophys. Res. Lett.* **2019**, *46*, 12504–12510. [\[CrossRef\]](#)
15. Jiang, G.M.; Li, S.; Wang, Z.Y. Intercalibration of IRAS/FY-3B infrared channels with IASI/MetOp-A 1C data. *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.* **2017**, *10*, 5387–5395. [\[CrossRef\]](#)
16. Jiang, G.M.; Wang, Z.Y.; Wang, J. Inter-calibration of VIRR/FY-3A/B split-window channels with AIRS/Aqua and IASI/MetOp-A measurements. *Int. J. Remote Sens.* **2016**, *37*, 1392–1407. [\[CrossRef\]](#)
17. Li, W.X.; Jiang, G.M.; Li, G.; Li, C. Intercalibration of advanced Himawari imager's infrared channels with IASI/MetOp-B 1C data. *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.* **2018**, *11*, 1589–1599. [\[CrossRef\]](#)
18. Xu, N.; Wu, P.; Ma, G.; Hu, Q.; Hu, X.; Wu, R. In-flight spectral response function retrieval of a multispectral radiometer based on the functional data analysis technique. *IEEE Trans. Geosci. Remote Sens.* **2021**, *60*, 5604210. [\[CrossRef\]](#)
19. Qi, C.; Wu, C.; Hu, X.; Xu, H.; Lee, L.; Zhou, F.; Gu, M.; Yang, T.; Shao, C.; Yang, Z.; et al. High spectral infrared atmospheric sounder (HIRAS): System overview and on-orbit performance assessment. *IEEE Trans. Geosci. Remote Sens.* **2020**, *58*, 4335–4352. [\[CrossRef\]](#)
20. Hu, Y.; Li, X.M.; Dou, C.; Jia, G.; Hu, Z.; Xu, A.; Ren, Y.; Yan, L.; Wang, N.; Cui, Z.; et al. Absolute radiometric calibration evaluation of the thermal infrared spectrometer onboard SDGSAT-1. *Int. J. Digit. Earth* **2023**, *16*, 4492–4511. [\[CrossRef\]](#)
21. Zhang, H.; Tang, H.; Liu, X.; Dou, X.; Qian, Y.; Chen, W.; Li, K. Evaluation of the radiometric calibration of ZY1-02E thermal infrared data. *Remote Sens.* **2023**, *15*, 3905. [\[CrossRef\]](#)
22. Tang, H.; Xie, J.; Dou, X.; Zhang, H.; Chen, W. On-orbit vicarious radiometric calibration and validation of the ZY1-02E thermal infrared sensor. *Remote Sens.* **2023**, *15*, 994. [\[CrossRef\]](#)
23. Li, Y.; Bao, Y.; Jiang, K.; Wang, H.; Zhao, Y. On-orbit radiometric calibration and performance of GF-5A wide thermal infrared imager. *Preprints* **2025**, *2025*, 202509.1456. [\[CrossRef\]](#)
24. Wang, J.; Qi, C.; Hu, X.; Zhang, Z.; Lee, L.; Zhang, P. Assessment and correction of FY-3D/HIRAS spectral calibration error caused by silica gel gas contamination. In *Proceedings of the IGARSS 2024-2024 IEEE International Geoscience and Remote Sensing Symposium, Athens, Greece, 7–12 July 2024*; IEEE: New York, NY, USA, 2024; pp. 6412–6415. [\[CrossRef\]](#)
25. Wang, L.; Hu, X.; Chen, L.; He, L. Consistent calibration of VIRR reflective solar channels onboard FY-3A, FY-3B, and FY-3C using a multisite calibration method. *Remote Sens.* **2018**, *10*, 1336. [\[CrossRef\]](#)
26. Xie, X.; Zou, X.; Wang, H. In-orbit calibration of FengYun-3C microwave radiation imager: Nonlinearity correction. *IEEE Trans. Geosci. Remote Sens.* **2020**, *58*, 8121–8133. [\[CrossRef\]](#)
27. Goldberg, M.; Ohring, G.; Butler, J.; Cao, C.; Datla, R.; Doelling, D.; Gärtner, V.; Hewison, T.; Iacovazzi, B.; Kim, D.; et al. The Global Space-Based Inter-Calibration System. *Bull. Amer. Meteorol. Soc.* **2011**, *92*, 467–475. [\[CrossRef\]](#)
28. Zhang, W.L.; Jiang, G.M. Intercalibration of FY-3C MWRI over forest warm-scenes based on microwave radiative transfer model. *IEEE Trans. Geosci. Remote Sens.* **2021**, *60*, 5301011. [\[CrossRef\]](#)
29. Zeng, Z.Q.; Jiang, G.M. Intercalibration of FY-3C MWRI against GMI using the ocean microwave radiative transfer model. *IEEE Access* **2020**, *8*, 153749–153762. [\[CrossRef\]](#)
30. Xu, N.; Chen, L.; Hu, X.; Zhang, L.; Zhang, P. Assessment and Correction of on-Orbit Radiometric Calibration for FY-3 VIRR Thermal Infrared Channels. *Remote Sens.* **2014**, *6*, 2884–2897. [\[CrossRef\]](#)
31. Gu, Z.; Chen, L.; Dai, H.; Tian, L.; Hu, X.; Zhang, P. The uncertainty of SNO cross-calibration for satellite infrared channels. *Remote Sens.* **2023**, *15*, 3313. [\[CrossRef\]](#)
32. Guo, Q.; Liu, Y.; Wang, X.; Hui, W. A new non-linearity correction method for the spectrum from the Geostationary Interferometric Infrared Sounder on board Fengyun-4 satellites and its preliminary assessments. *Atmos. Meas. Tech.* **2024**, *17*, 4613–4627. [\[CrossRef\]](#)
33. Chen, R.; Cao, C. Physical analysis and recalibration of MetOp HIRS using IASI for cloud studies. *J. Geophys. Res. Atmos.* **2012**, *117*, D03103. [\[CrossRef\]](#)
34. Zhang, B.; Cao, C.; Liu, T.-C.; Shao, X. Spectral Recalibration of NOAA HIRS Longwave CO₂ Channels toward a 40+ Year Time Series for Climate Studies. *Atmosphere* **2021**, *12*, 1317. [\[CrossRef\]](#)
35. Hilton, F.; Armante, R.; August, T.; Barnet, C.; Bouchard, A.; Camy-Peyret, C.; Capelle, V.; Clarisse, L.; Clerbaux, C.; Coheur, P.F.; et al. Hyperspectral Earth Observation from IASI: Five Years of Accomplishments. *Bull. Amer. Meteorol. Soc.* **2012**, *93*, 347–370. [\[CrossRef\]](#)
36. Blumstein, D.; Chalon, G.; Carlier, T.; Buil, C.; Hebert, P.; Maciaszek, T.; Ponce, G.; Phulpin, T.; Tournier, B.; Simeoni, D.; et al. IASI instrument: Technical overview and measured performances. *Infrared Spaceborne Remote Sens. XII* **2004**, *5543*, 196–207. [\[CrossRef\]](#)
37. Jiang, M.X.; Jiang, G.M.; Chen, H. Evaluation and correction of the radiometric calibration biases in MERSI-RM/FY-3G middle infrared and thermal infrared channels against MODIS/Aqua channels. *IEEE Trans. Geosci. Remote Sens.* **2025**, *63*, 5404610. [\[CrossRef\]](#)

38. Zeng, J.; Zhao, H.; Su, Y.; Lan, Q.; Han, Q.; Zhang, X.; Wang, X.; Xu, Z.; Hu, Z.; Du, X.; et al. Radiometric cross-calibration and performance analysis of HJ satellites. *Remote Sens.* **2025**, *17*, 3569. [[CrossRef](#)]
39. Di, D.; Min, M.; Li, J.; Gunshor, M.M. The radiance differences between wavelength and wavenumber spaces in convolving hyperspectral infrared sounder spectrum to broadband for intercomparison. *Remote Sens.* **2019**, *11*, 1177. [[CrossRef](#)]
40. Wu, W.; Liu, X.; Xiong, X.; Li, Y.; Yang, Q.; Wu, A.; Kizer, S.; Cao, C. An accurate method for correcting spectral convolution errors in intercalibration of broadband and hyperspectral sensors. *J. Geophys. Res. Atmos.* **2018**, *123*, 9238–9255. [[CrossRef](#)]
41. Jiang, G.M.; Zou, Y.; Chen, H. Assessment and correction of the on-orbit radiometric calibration in FY-3D MERSI-2 thermal infrared channels. *IEEE Trans. Geosci. Remote Sens.* **2022**, *60*, 5003510. [[CrossRef](#)]
42. Qi, C.; Gu, M.; Wu, C.; Hu, X. Calibration method of high spectral infrared atmospheric sounder onboard FY-3D satellite. In *Proceedings of the 3rd International Symposium of Space Optical Instruments and Applications, Beijing, China, 26–29 June 2016*; Springer Proceedings in Physics; Springer: Cham, Switzerland, 2017; Volume 192. [[CrossRef](#)]
43. Ma, L.; Zhao, Y.; Li, W.; Yang, R.; Wang, R.; Wang, N.; Han, Q.; Lu, X.; Huang, F.; Zhao, J. Top-of-atmosphere radiometric reference model for stable land sites and its application to GF6/WFI. *Remote Sens. Environ.* **2025**, *326*, 114796. [[CrossRef](#)]
44. Chen, R.; Guan, L.; Liu, M.; Qu, L. Cross-calibration of HY-1D/COCTS thermal emissive bands in the South China Sea. *Remote Sens.* **2024**, *16*, 292. [[CrossRef](#)]
45. Cao, C.; Goldberg, M.D.; Wang, L. Spectral bias estimation of historical HIRS using IASI observations for improved fundamental climate data records. *J. Atmos. Ocean. Technol.* **2009**, *26*, 1378–1387. [[CrossRef](#)]
46. Chen, R.; Cao, C. Cross-calibration of HIRS aboard NOAA satellites using IASI. In *Earth Observing Systems XVI*; SPIE: Bellingham, WA, USA, 2011; Volume 8153, p. 81531E. [[CrossRef](#)]
47. Cao, C.; Weinreb, M.; Xu, H. Predicting simultaneous nadir overpasses among polar-orbiting meteorological satellites for the intersatellite calibration of radiometers. *J. Atmos. Ocean. Technol.* **2004**, *21*, 537–542. [[CrossRef](#)]
48. Kato, S.; Kouyama, T. Automated vicarious radiometric validation of spaceborne thermal infrared radiometers using deep learning-based cloud filtering. *Infrared Phys. Technol.* **2025**, *141*, 104617. [[CrossRef](#)]
49. Thankappan, M.; Christopherson, J.; Cantrell, S.; Ryan, R.; Pagnutti, M.; Bright, C.; Naughton, D.; Ruslaner K.; Wang, L.W.; Hudson, D.; et al. Concept of a satellite cross-calibration radiometer for in-orbit calibration of commercial optical satellites. *Remote Sens.* **2024**, *16*, 1333. [[CrossRef](#)]
50. Pagnutti, M.; Ryan, R.E.; Frommeyer, J.; Cuervo, D.; Sitton, D. Methods and results for evaluating commercial hyperspectral instruments as satellite cross-calibration radiometers. *J. Appl. Remote Sens.* **2025**, *19*, 027501. [[CrossRef](#)]
51. Cao, C.; Xu, H.; Sullivan, J.; McMillin, L.; Ciren, P.; Hou, Y. Intersatellite Radiance Biases for the High-Resolution Infrared Radiation Sounders (HIRS) on board NOAA-15, -16, and -17 from Simultaneous Nadir Observations. *J. Atmos. Ocean. Technol.* **2005**, *22*, 381–395. [[CrossRef](#)]
52. Chen, H.; Guan, L. A bias correction scheme for FY-3E/HIRAS-II observation data assimilation. *Atmos. Meas. Tech.* **2025**, *18*, 5591–5606. [[CrossRef](#)]
53. Huang, J.; Ma, G.; Liu, G.; Li, J. Direct assimilation of FY-3E hyperspectral infrared observations from HIRAS-II. *Weather Forecast.* **2025**, *40*, 2443–2457. [[CrossRef](#)]
54. Liang, Z.; Gu, D.; Li, R.; Liu, J.; Zhai, C.; Su, H.; Lau, A.K. Advancing atmospheric detection of weakly absorbing trace gases using FY-3E/HIRAS-II observations. *Environ. Sci. Technol. Lett.* **2025**, *12*, 848–855. [[CrossRef](#)] [[PubMed](#)]
55. Di D.; Liu, Y.; Li, J.; Zhou, R.; Li, Z.; Gong, X. Inter-Calibration of Geostationary Imager Infrared Bands Using a Hyperspectral Sounder on the Same Platform. *Geophys. Res. Lett.* **2023**, *50*, e2022GL101628. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.