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Prepared by JMA
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Discussed in WG II

VALIDATION OF AHI ON HIMAWARI-9 IN L1 AND L2 PRODUCTS

On December 13 2022, JMA switched over operation from the Himawari-8 (H-8) geostationary satellite to its Himawari-9 (H-9) successor after a significant period of data quality monitoring for AHI data from the latter based on parallel observation.
Himawari-9 AHI radiometric calibration bias and image navigation errors have been stable, as have data from the Himawari-8 AHI. Evaluation based on Himawari-9/AHI observation conducted in parallel with Himawari-8 AHI observation from September to December 2022 indicates INR performance of approximately 0.3 km (for reference mapping) and 60 m (between bands) at the sub-satellite point for both Himawari-8 and Himawari-9. Radiometric calibration biases for Himawari-9 VNIR bands are within 5% for B01 to B05 and 5–8% for B06, and those for IR bands are less than 0.3 K.
Evaluation results for AMV, H-9 and H-8 AMVs exhibit similar characteristics and qualities. No significant difference is observed in the statistical properties CSR data for Band 8 (6.2 μm) and Band 10 (7.3 μm), but for Band-9 (6.9 μm) the distribution of O-B for H-9 CSR shows slightly higher temperatures than for H-8. All meteorological parameters of cloud properties derived from H-9 data are similar to those of H-8.
For Himawari-9 SSTs, JMA introduced calibration correction for input brightness temperature data calculated utilizing GCOM-C observation data in addition to the retrieval algorithm, which is the same as that used for Himawari-8 SSTs. For the Himawari-9 sunshine duration product, estimation involves the use of satellite data corrected using solar diffuser observation data to reduce the effects of post-training sensor degradation.

Action/Recommendation proposed: None.

1 INTRODUCTION

On December 13 2022, JMA switched over operation from the Himawari-8 (H-8) geostationary satellite to its Himawari-9 (H-9) successor after a period of data quality monitoring for AHI data from the latter (starting on 27 September 2022) based on parallel observation.
This working paper reports on Himawari-9 data validation for Level 1/2 products and on adjustment of SST and Sunshine Duration products.

2 VALIDATION OF HIMAWARI-9 LEVEL-1 PRODUCTS

2.1 Data quality (image navigation and registration)

JMA/MSC provides the information on Himawari-9 image navigation performance at the following webpage:

Himawari Navigation Monitoring:
https://www.data.jma.go.jp/mscweb/data/monitoring/navigation.html

The page provides landmark analysis maps for monitoring of absolute navigation performance, co-registration analysis maps for monitoring of relative navigation performance among AHI bands, and information on related trends. Absolute navigation performance is analyzed via landmark matching using observation imagery and referential maps, and relative navigation performance is analyzed via pattern matching between imagery of monitored and reference bands. The results of landmark analysis and co-registration analysis for Himawari-9 indicate data stability.

JMA started full operation of Himawari-9 satellite on 13 December 2022, with the previous Himawari-8 moving into a backup role.

Figures 1 and 2 show the results of landmark analysis for Himawari-8/9 and co-registration analysis. Outcomes based on B13 (10.4 μm) data indicate one-month averaged landmark errors of 0.26 and 0.27 km in November 2022 for Himawari-8/ and -9 data, respectively, demonstrating similar navigation accuracy. Inter-band co-registration performance was evaluated with reference to B13 (10.4 μm). Although performance varies by band, verification for both satellites showed values of less than 60 m, which corresponds to 0.03 pixels for all bands at the sub-satellite point. In both figures, Himawari-8 and 9 exhibit comparable performance.

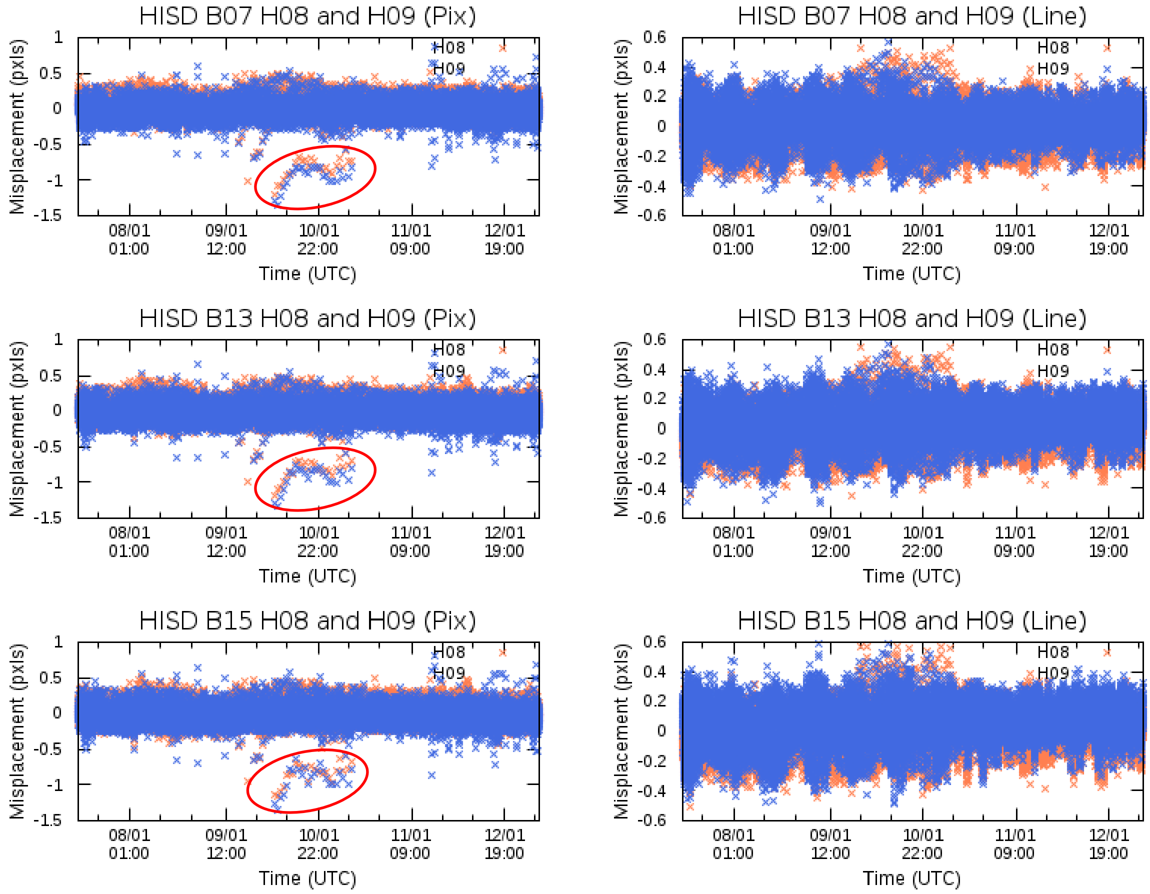

Figure 1 Navigation performance based on landmark analysis of B07 (3.9 μm), B13 (10.4 μm) and B15 (12.4 μm) of Himawari-8/9. Landmark errors from 7 July to 13 December 2022 for the Himawari-8 (orange crosses) and -9 AHIs (blue crosses) are shown. The red circles show midnight data point in the eclipse period. It is considered that relatively large deviation occurs at the time of updating for ground system orbit information.

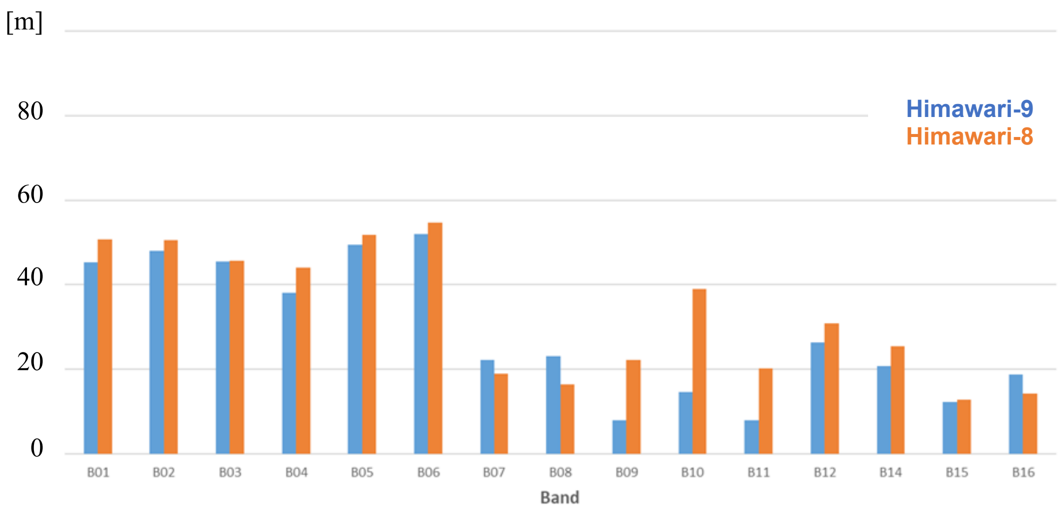

Figure 2 Inter-band co-registration performance with reference to B13 (10.4 μm), 24-hour average of observation data from Himawari-8/9 on 18 Oct. 2022. Values are approximately 60 m or less, with band-related and seasonal variations.

2.2 Data quality (radiometric calibration)

Himawari-9 radiometric calibration performance information is also available at:

Himawari Calibration Portal:
https://www.data.jma.go.jp/mscweb/en/oper/calibration/calibration_portal.html

Certain validation methods are developed under the GSICS framework. For the visible and near-infrared (VNIR) bands (B01 (0.47 μm) to B06 (2.3 μm)), the results of evaluation using radiative transfer calculation with reference to MODIS and evaluation based on direct comparison (the ray-matching approach) with observation by VIIRS are shown on the webpage. Calibration performance monitoring for infrared bands (B07 (3.9 μm) to B16 (13.3 μm)) involves reference to the hyperspectral infrared sounders mounted on polar-orbiting satellites.

Calibration performance for Himawari-8/9 VNIR bands in September 2022 is shown in Table 1 and figure 3. Himawari-8/9 AHI data are consistent with references up to around 5%, although differences from references and validation methods are seen. For instance, AHI observations divided by reference values for Himawari-9 B02 data are 0.95 to 1.02, and values for Himawari-8 are similar. This indicates that B02 values have biases from -5 to +2% for these references, and Himawari-8 and 9 monitoring data are similar. The bias of -8 to -5% for B06 is relatively large. The sensitivity of Himawari-9/AHI VNIR bands is stable in the months after parallel observation commencement. Monitoring will be continued.

AHI-9	RTM Aqua/MODIS	RTM Terra/MODIS	Ray-match. SNPP/VIIRS	Ray-match. N20/VIIRS
B01 (0.47)	1.005	1.014	1.009	1.032
B02 (0.51)	0.955	0.965	0.998	1.020
B03 (0.64)	0.947	0.957	0.964	0.992
B04 (0.86)	0.976	0.989	0.972	1.007
B05 (1.61)	0.987	0.977	0.993	1.025
B06 (2.26)	0.936	0.922	0.926	0.951

AHI-8	RTM Aqua/MODIS	RTM Terra/MODIS	Ray-match. SNPP/VIIRS	Ray-match. N20/VIIRS
B01 (0.47)	0.962	0.973	0.963	0.986
B02 (0.51)	0.951	0.961	0.991	1.014
B03 (0.64)	0.970	0.981	0.989	1.013
B04 (0.86)	0.979	0.993	0.974	1.010
B05 (1.61)	1.040	1.031	1.054	1.090
B06 (2.26)	0.946	0.931	0.941	0.967

Table 1 AHI/reference ratios based on regression of AHI observation and references. RTM represents the radiative transfer model-based approach. The data periods are September 1 – 30 2022 for the RTM-based approach and September 2 – 30 2022 for the ray-matching approach.

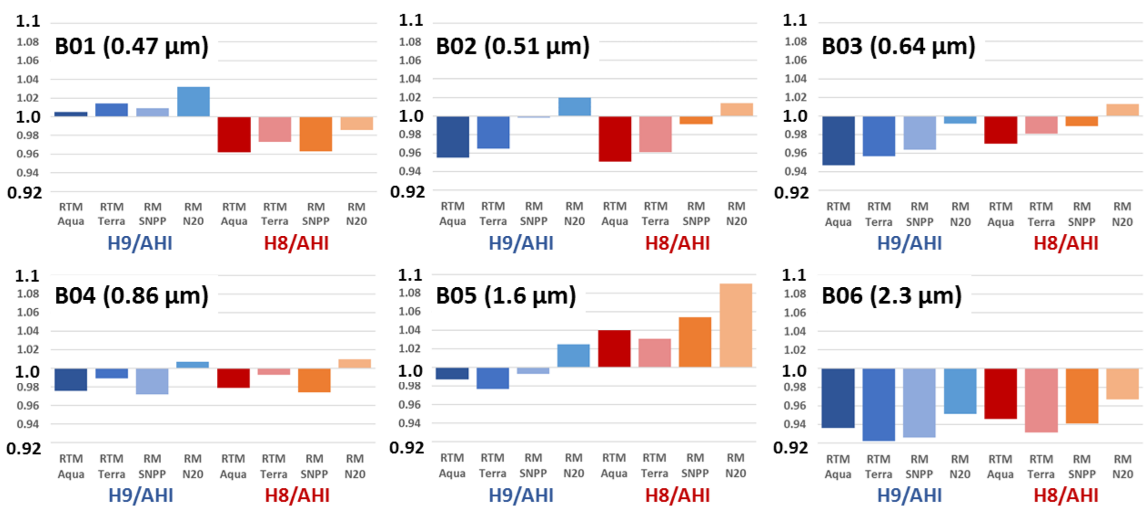

Figure 3 As per Table 1

Figure 4 shows infrared-band brightness temperature bias with hyper spectral sounders used for references. The observed brightness temperatures of Himawari-8/9 are within 0.3 K of the references, and the difference between the two satellites is also within 0.3 K. The trends of the bias for each infrared band of Himawari-8/9 (Fig. 5) indicate stability in the range of 0.3 K.

AHI9	AIRS	N20/CrIS	IASI-B	IASI-C	AHI8	AIRS	N20/CrIS	IASI-B	IASI-C
B07 (3.9)	0.09	-	-0.12	-0.11	B07 (3.9)	0.04	-	-0.13	-0.13
B08 (6.2)	-	-0.17	-0.20	-0.20	B08 (6.2)	-	-0.16	-0.19	-0.19
B09 (6.9)	-0.09	0.03	0.00	0.00	B09 (6.9)	-0.33	-0.21	-0.24	-0.23
B10 (7.3)	-0.20	-0.12	-0.15	-0.14	B10 (7.3)	-0.22	-0.12	-0.14	-0.14
B11 (8.6)	-	-	-0.09	-0.08	B11 (8.6)	-	-	-0.07	-0.06
B12 (9.6)	-0.20	-0.12	-0.21	-0.17	B12 (9.6)	-0.25	-0.19	-0.28	-0.24
B13 (10.4)	-0.04	-0.02	-0.06	-0.05	B13 (10.4)	0.06	0.07	0.03	0.04
B14 (11.2)	-0.05	-0.03	-0.07	-0.06	B14 (11.2)	0.07	0.08	0.04	0.05
B15 (12.4)	-0.04	-0.06	-0.10	-0.09	B15 (12.4)	0.01	-0.02	-0.05	-0.04
B16 (13.3)	-0.10	-0.15	-0.18	-0.17	B16 (13.3)	0.15	0.10	0.07	0.09

Table 2 Brightness temperature bias of Himawari-8/9 IR bands with reference to observation from hyper-spectral sounders such as Aqua/AIRS, NOAA-20/CrIS, Metop-B/IASI and Metop-C/IASI, showing values in brightness temperature equivalent to a clear-sky sea surface. The data period is 2 – 30 September 2022. Bias wrt. CrIS at B07, bias wrt. AIRS at B08 and bias wrt. AIRS and CrIS at B11 are omitted due to large uncertainty.

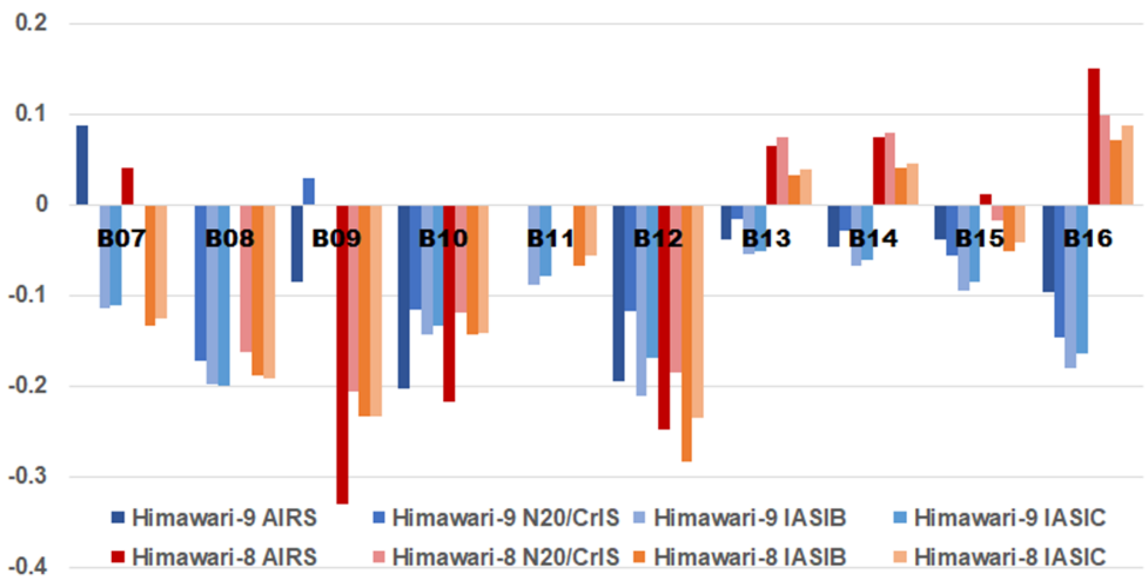

Figure 4 As per Table 2

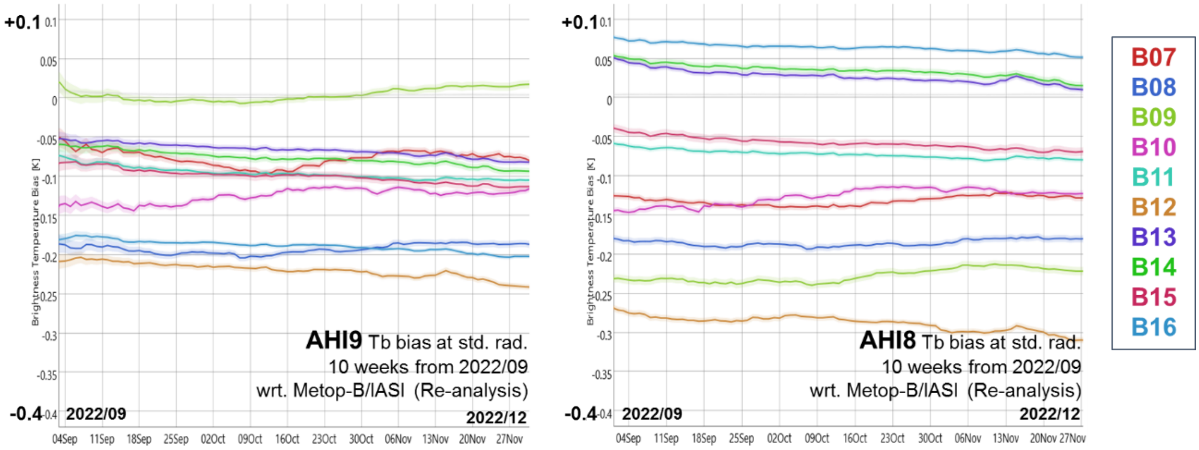

Figure 5 Brightness temperature bias trends of Himawari-8 and 9 AHI infrared bands from 27 September to 13 December 2022 based on analysis developed under the GSICS framework. The bias of each band in the brightness temperature equivalent to clear-sky sea surface is shown with reference to Metop-B/IASI, and is stable within 0.3 K. The figure was produced with the GSICS Calibration Products Plotting Tool [1].

Diurnal variations for the Himawari-8/9 AHIs are also monitored using hyperspectral infrared sounder references (Figure 6). There is no significant variation, and the ranges of brightness temperature bias are comparable for both.

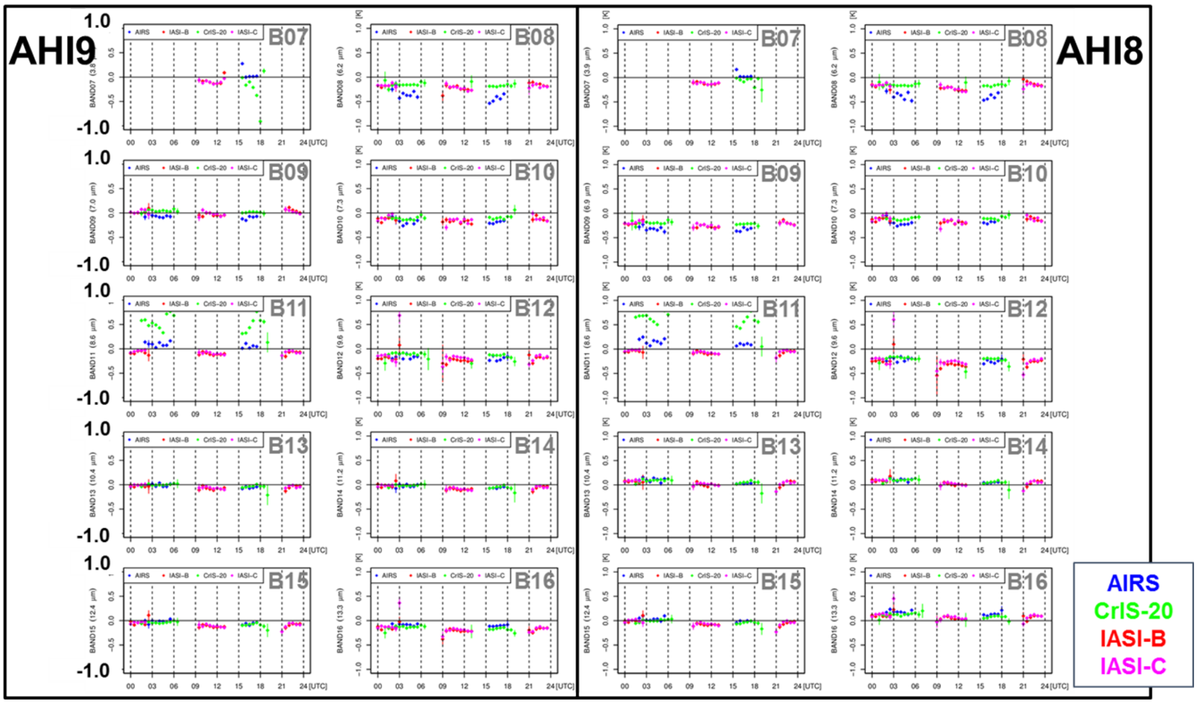

Figure 6 Diurnal variation of brightness temperature bias between AHI and hyper sounder data. Blue: Aqua/AIRS; green: NOAA-20/CrIS; red: Metop-B/IASI; magenta: Metop-C/IASI. Only nighttime results are shown for Band 7 (3.9 µm) to avoid the effects of sunlight. Note that the results for AHI B07 vs. CrIS, B08 vs. AIRS, and Band 11 vs. CrIS/AIRS exhibit larger uncertainty due to wide spectral gaps between AHI and reference sensor data.

3 VALIDATION OF HIMAWARI-9 LEVEL-2 PRODUCTS

Himawari-8/9 Level-2 products, including Atmospheric Motion Vector (AMV), Clear Sky Radiance (CSR) and High-resolution Cloud Analysis Information (HCAI) data are generated by JMA/MSC and provided via the Global Telecommunication System (GTS) and the JMA Data Dissemination System (JDDS). This section describes the results of validation for the Himawari-9 AHI Level-2 products.

3.1 AMV

The Meteorological Satellite Center of the Japan Meteorological Agency (MSC/JMA) provides hourly AMV data from Himawari-8/9 via GTS in Binary Universal Form for Data Representation (BUFR) format. Himawari-8/9 AMVs are outlined in an MSC technical report at https://www.data.jma.go.jp/mscweb/technotes/msctechrep62-4.pdf.

For the evaluation period of 28 September – 11 October 2022, spatial distributions of wind vectors and estimated heights calculated from Himawari-8/9 were similar, as were histograms for wind speed/direction, estimated height and quality index (QI). Little significant difference in the bias tendency in practical use was observed. The O-B wind speed bias and root mean square vector difference (RMSVD) of Himawari-8/9 AMV wind vectors were also similar, and no significant difference was seen from observation error settings by NWP users. This evaluation suggests that Himawari-9 AMV usage with Himawari-8 AMV settings will not be problematic.

3.2 Fundamental Cloud Product

The Fundamental Cloud Product (FCP) is an essential meteorological resource derived from satellite observation, both for use in weather analysis and for application in the output of other products (e.g., CSR and SST). FCP provides data on cloud mask, cloud top height, cloud type, and cloud phase for each pixel of the Himawari-8/9 infrared bands.
Himawari-8/9 cloud mask hit ratios compared to MODIS cloud products are generally similar. Himawari-8 and Himawari-9 cloud top heights can be treated similarly because, in addition to the significant coefficients of correlation between the values for both (0.9+), mean errors and standard deviations of cloud top height against MODIS are also similar.

3.3 CSR

CSR products provide area-averaged brightness temperatures for cloud-free pixels. The data are used for operational assimilation systems at NWP centers.
In comparison of Himawari-8/9 CSR data against background departure (O-B) histograms, Himawari-9 CSR O-B distributions for B08 (6.2 μm) and B10 (7.3 μm) are similar to those for Himawari-8, but slightly higher temperatures (~0.2K) than with Himawari-8 are observed for B09 (6.9 μm). The differences are consistent with those of radiometric calibration, and are probably associated with sensor characteristics.

3.4 High-resolution Cloud Analysis Information (HCAI)

High-resolution Cloud Analysis Information (HCAI) is a satellite-derived analysis product based on Himawari observation. It provides grid point data on cloud mask, snow-ice mask, cloud classification and cloud altitude.
Comparison with Himawari-8/9 HCAI shows consistency rates generally greater than 0.9 for snow/ice mask, dust mask, cloud type and cloud mask. There is no significant difference in distribution for cloud top height and cloud type classification.
Himawari-9 HCAI cirrus values tend to be slightly greater for both day and night, while Himawari-8 HCAI low cloud tends to be slightly greater at night. For snow-ice mask, the area of snow-covered land derived from Himawari-9 data tends to be slightly smaller, while the sea ice area is similar.

4 ADJUSTMENT OF HIMAWARI-9 LEVEL-2 PRODUCTS

This section describes the adjustment procedure for Himawari-9 Level-2 products, which are sensitive to sensor characteristics.

4.1 Sea Surface Temperature (SST)

Himawari SST data are generated from IR band observation for JMA SST analysis products using an algorithm developed by the Japan Aerospace Exploration Agency (JAXA) [4].
JMA introduced calibration correction for input brightness temperature data in addition to usage of the Himawari-8 SST retrieval algorithm. Correction parameters are calculated utilizing GCOM-C observation data from JAXA.
Without calibration correction, Himawari-9 SST values are around 0.3K lower than those of Himawari-8 on average over the full disk due to differences in sensor characteristics. There is also a lower bias of around 0.8K (mean error) against in-situ data (from drifting buoys and other sources) as shown in Figure 7 (left).
Corrected Himawari-9 data match in-situ data more closely than non-corrected data.

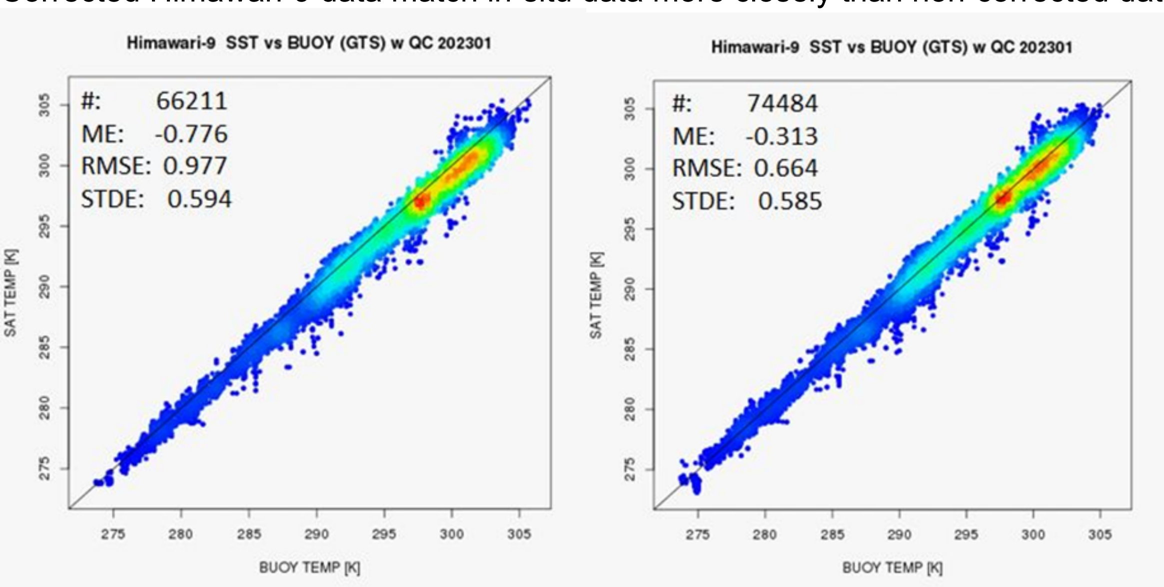

Figure 7: Himawari-9 SST comparison with in-situ data on January 2023.
Left: original; right: corrected.

4.2 Sunshine Duration

JMA provides a sunshine duration product [5] from Himawari-8/9 data as an element of its Weather Analysis Map [6] product, which is 2-D gridded output providing ground-surface meteorological information. Estimation of sunshine durations is based on batch machine learning, with B03 data being dominant and sensitive. A 6.4% degradation of B03 corresponds to almost a 1-minute BIAS in 1-hour sunshine duration data. To reduce the effects of post-training sensor degradation, estimation is conducted with satellite data corrected using solar diffuser observation data [7] during Himawari-8 operation. Since the switchover to Himawari-9, correction from satellite data collected during the 8/9 parallel observation term has been added (Figure 8) as a temporary measure. Batch learning using 1-year Himawari-9 data will be applied in the future.

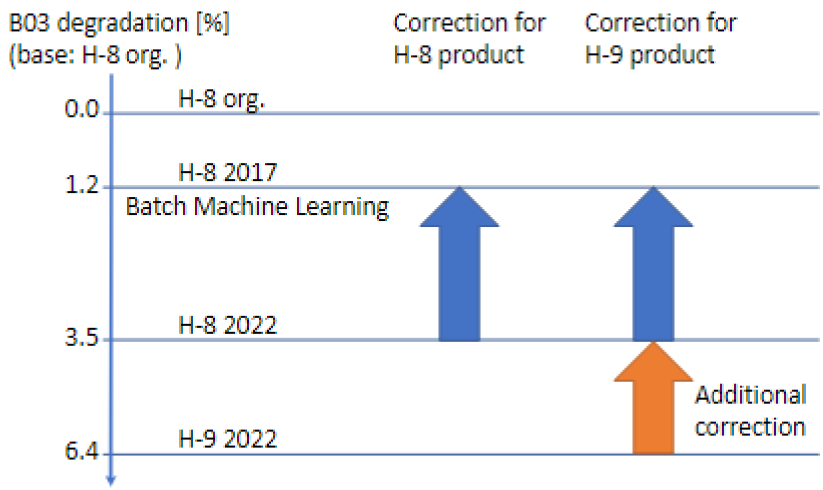

Figure 8 Correction of B03 data for sunshine duration product in 2022

5 CONCLUSION

The operational switchover from Himawari-8 to Himawari-9 was conducted on 13 December 2022 following a period of parallel data dissemination from 27 September. Himawari-9 AHI radiometric calibration bias and image navigation errors have been stable, as have data from the Himawari-8 AHI. Evaluation based on Himawari-9/AHI observation conducted in parallel with Himawari-8 AHI observation from September to December 2022 indicates INR performance of approximately 0.3 km (for reference mapping) and 60 m (between bands) at the sub-satellite point for both Himawari-8 and Himawari-9. Radiometric calibration biases for Himawari-9 VNIR bands are within 5% for B01 to B05 and 5–8% for B06, and those for IR bands are less than 0.3 K.
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For Himawari-9 SSTs, JMA introduced calibration correction for input brightness temperature data calculated utilizing GCOM-C observation data in addition to the retrieval algorithm, which is the same as that used for Himawari-8 SSTs. For the Himawari-9 sunshine duration product, estimation involves the use of satellite data corrected using solar diffuser observation data to reduce the effects of post-training sensor degradation.

References

[1] EUMETSAT, GSICS Calibration Products Plotting Tool, http://gsics.tools.eumetsat.int/plotter/, (Last access: 20 March 2023)

[2] Paul C. Griffith, 2015, "Advanced Himawari Imager (AHI) Design and Operational Flexibility", Sixth Asia/Oceania Meteorological Satellite Users' Conference, Tokyo, Japan, 10 November 2015

[3] Japan Meteorological Agency, 2017, "Himawari-8/9 Himawari Standard Data User's Guide version 1.3", https://www.data.jma.go.jp/mscweb/en/himawari89/space_segment/hsd_sample/HS_D_users_guide_en_v13.pdf, (Last access: 20 March 2023)

[4] Y. Kurihara, H. Murakami, and M. Kachi, 2016: Sea surface temperature from the new Japanese geostationary meteorological Himawari-8 satellite. Geophys. Res. Letters. DOI: 10.1002/2015GL067159.

[5] JMA, 2021: Sunshine duration product based on estimation from 2.5-minute Himawari-8 observation data, CGMS-49 WP-05.

[6] JMA, Weather Analysis Map Home Page, https://www.data.jma.go.jp/obd/bunpu/index_en.html, (Last access: 20 March 2023)

[7] JMA/MSC, 2022: Update of Calibration Information Used to Correct Himawari-8 AHI Sensitivity Trend, https://www.data.jma.go.jp/mscweb/en/oper/eventlog/Update_of_Calibration_Information_2022.pdf, (Last access: 20 March 2023)

Appendix: Himawari-9/AHI L1 data calibration related parameters

Band	EW direction [urad]		NS direction [urad]	
	Specification (less than)	Ground test result	Specification (less than)	Ground test result
1	28	20	28	11
2	28	24	28	10
3	14	13	14	8
4	28	23	28	12
5	56	38	56	19
6	56	41	56	19
7	56	42	56	24
8	56	42	56	25
9	56	44	56	27
10	56	44	56	27
11	56	46	56	28
12	56	45	56	27
13	56	45	56	28
14	56	47	56	30
15	56	47	56	31
16	56	48	56	33

Table A-1 IFOV size for the EW and NS directions. IFOV size is defined from the spatial response function as an angle whose width is 50% of the total integrated spatial response function. The values differ from those of angular sampling distances (ASDs), which are 13 and 12 micro-radians for Himawari-8/9, respectively, in the E-W direction. ASD values in the N-S direction are the same as those shown in the Specification column. Himawari Standard Data (HSD) are also resampled to the equivalents of 14, 28, and 56 micro-radians for the N-S and E-W directions depending on the band [2]. The values are 14 micro-radians for B03, 28 for B01, B02 and B04, and 56 for other bands. The resampling policy, image size and format of HSD for the Himawari-9 AHI are the same as those for Himawari-8.

Band	SNR
1	750.1
2	710.0
3	470.4
4	492.3
5	1014.0
6	739.3
7	247.9
8	490.4

Band	SNR
9	1746.3
10	552.1
11	2594.7
12	2639.5
13	2093.8
14	2840.3
15	2271.3
16	1469.3

Table A-2 Signal-to-noise ratio (SNR) for visible and near-infrared bands (left) and infrared bands (right). SNR estimation is based on blackbody observation for infrared bands and on solar diffuser observation for visible and near-infrared bands. Values are averages derived from observation conducted on 7 and 22 February 2023 after application of coherent noise reduction (except for B09).

	B01	B02	B03	B04	B05	B06
100% albedo [W/m^2/sr/mm]	641.4976	602.0405	518.6763	309.3310	77.5492	23.9091

Table A-3 These values are used to convert observed radiances to albedo (a.k.a. normalized radiances). The S_0/π value in the HSD user's guide [3] corresponds to the 100% albedo values.