11/08/29	29_32
11/10/01	29_32
11/12/03	29_32
11/08/29	29_33
11/08/30	30_31
11/08/30	30_32
11/08/30	30_33

2.2 CLAUDIA1

CLAUDIA1-CAI calculates the clear-sky confidence levels (CCL) for every threshold test and their comprehensive integration (Ishida and Nakajima, 2009). Integrated-CCL of 0 means that the pixel is cloudy and 1 means that the pixel is cloud-free. Ambiguous pixels between cloudy and cloud-free are described by numerical values from 0 to 1. The threshold below which the integrated-CCL counts the pixel as cloud-free for GOSAT FTS L2 is 0.33, otherwise the pixel is regarded as cloudy (Yoshida et al., 2010). The flow of the algorithm is shown in Fig. 6.

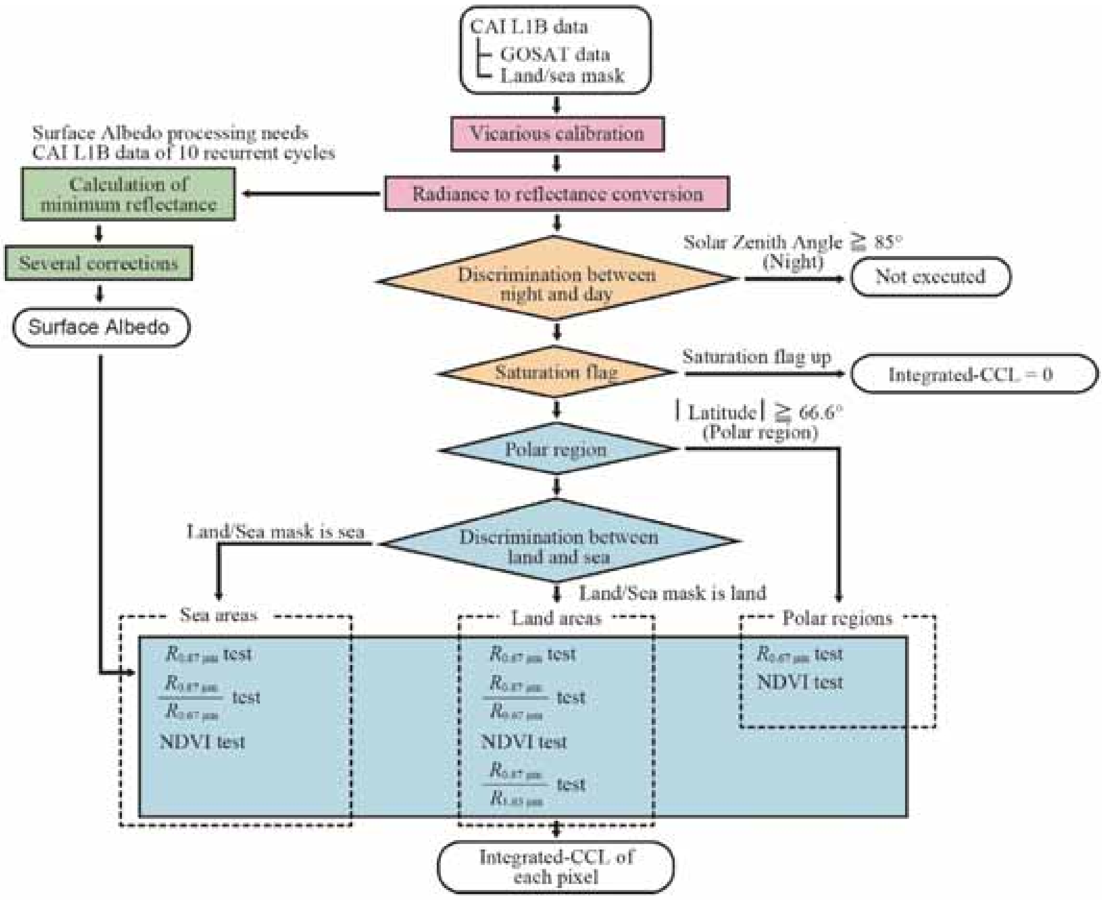


Figure 6: Flow chart for CLAUDIA1-CAI. For sun-glint areas, the thresholds are further increased based on the $R_{0.87\ \mu m}$ test. CCL: confidence level; $R_{wavelength}$: reflectance; NDVI: normalized difference vegetation index. (2 column)

2.3 New cloud discrimination algorithm (CLAUDIA3)

CLAUDIA1 performs cloud discrimination by using thresholds set based on experience. The new cloud discrimination algorithm (CLAUDIA3, Ishida et al., 2018) uses SVM to decide the thresholds objectively by using multivariate analysis. SVM is a supervised pattern recognition method. First, it determines the following items using training samples of typical clear and cloudy pixels: 1) a decision function to discriminate between two classifications (clear and cloudy), 2) the thresholds, and 3) the support vectors, which are training samples specified by the decision function. The support vectors are decided in a high-dimensional feature space of the training samples. Next, it performs cloud discrimination by using the decision function, thresholds, and support vectors it determined. CLAUDIA3 applies the kernel trick (Boser et al., 1992) to soft-margin SVM (Cortes and Vapnik, 1995). The kernel uses a second-order polynomial (Eq. (1))

there is a verb missing here …

$$K(x_i, x) = \frac{(\mathbf{x}_i \bullet \mathbf{x} + 1)^2}{2}, \qquad (1)$$

where K is the kernel function, $\boldsymbol{x}_i$ is the support vectors, and $\boldsymbol{x}$ is input data. The flow of CLAUDIA3-CAI is explained in Fig. 7. For CLAUDIA3-CAI, an integrated-CCL of 0.5 corresponds to the separating hyperplane of clear support vectors and cloudy support vectors. In this study, we used two kinds of support vector: (1) support vectors generated by using MODIS data in February for cloud discrimination between November and April, and (2) support vectors generated by using MODIS data in August for cloud discrimination between May and October based on a previous study (Oishi et al., 2017).

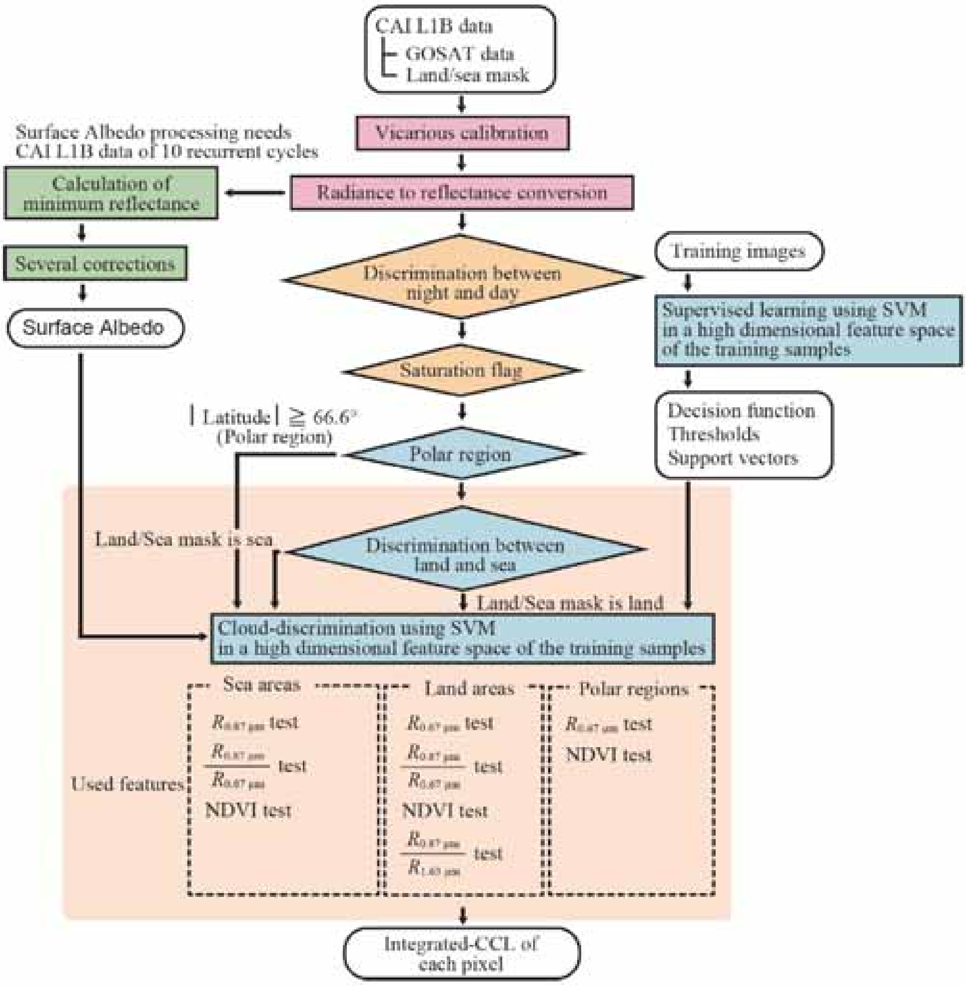


Figure 7: Flow chart for CLAUDIA3-CAI. CCL: clear-sky confidence level; Rwavelength: reflectance; NDVI: normalized difference vegetation index. (2 column)

2.4 Analysis procedure for rainforests

The analysis procedure consists of the following steps (Fig. 8).

1) Cut 400 × 400 pixels around the centre of CAI L1B images.

2) Perform visual inspection of the pixels cut from the CAI L1B images.

We performed a visual inspection of the presence or absence of clouds in every pixel.

3) Perform cloud discrimination by using CLAUDIA1-CAI and CLAUDIA3-CAI.

For CLAUDIA1-CAI, we produced output images setting the integrated-CCL threshold to 0.33. For CLAUDIA3-CAI, we produced output images setting the integrated-CCL threshold to 0.5.

4) Compare output with visual inspection.

We coloured the images by comparing the visual inspection images with the output images pixel-by-pixel.

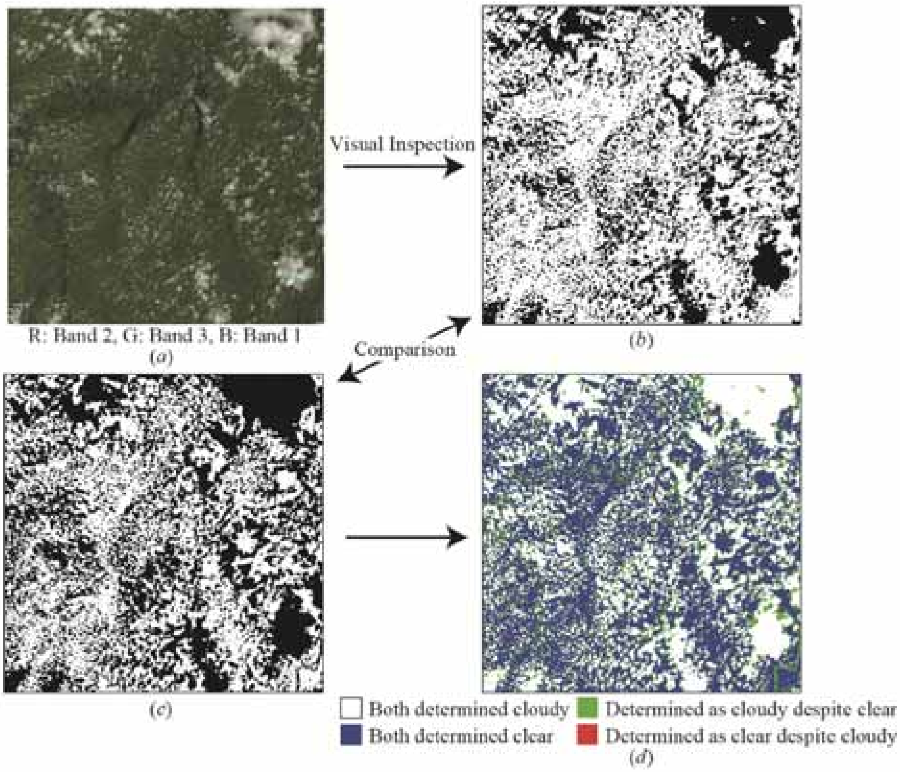


Figure 8: Analysis procedure. (a) CAI L1B image. (b) Visual inspection image of CAI L1B. (c) Output image from CLAUDIA1-CAI (CAI L2 cloud flag product) or CLAUDIA3-CAI. Pixels that are determined as cloudy are black. (d) Comparison of the visual inspection image and the output image. Pixels that are determined as cloudy in both are white. Pixels that are determined as clear in both are blue. Pixels that are determined as cloudy in the output image

b and c are "masks" rather than "images" I think?

and clear in the visual inspection image are green. Unusual pixels that are determined as clear in the output image and cloudy in the visual inspection image are red. (2 column)

3 Results

In this study, "accuracy" is defined as the ratio of the number of pixels for which the standard image and output from the cloud discrimination algorithm agree to the total number of pixels in the input image. "Overlook" is defined as the ratio of the number of pixels judged clear in the output and cloudy in the standard image to the number of pixels that were judged cloudy in the standard image. "Overestimate" is defined as the ratio of the number of pixels judged cloudy in the output and clear in the standard image to the number of pixels judged clear in the standard image. These definitions are written as follows.

$$\text{Accuracy} = \frac{\text{Both cloudy} + \text{Both clear}}{\text{Total number of pixels}}, \tag{2}$$

$$\text{Overlook} = \frac{\text{Clear despite cloudy}}{\text{Both cloudy} + \text{Clear despite cloudy}}, \tag{3}$$

$$\text{Overestimate} = \frac{\text{Cloudy despite clear}}{\text{Both clear} + \text{Cloudy despite clear}}. \tag{4}$$

3.1 Results for various land cover types

Figure 9 shows the monthly average accuracy, overlook, and overestimate for an integrated-CCL threshold of 0.33 for CLAUDIA1-CAI and 0.5 for CLAUDIA3-CAI. We used the CLAUDIA1-CAI result as the standard image.

In Australia and Algeria, Overlook was greater than Overestimate; the average of Overlook was 44.2 % (the lowest Overlook was 20.5 % in December in Australia), against the average of Overestimate was 0.4 % (the highest Overestimate was 3.5 % in January in Algeria). These mean that there was tendency that CLAUDIA3-CAI judged clear, despite CLAUDIA1-CAI judged cloudy in Australia and Algeria.

In Japan, Borneo, Canada, and Alaska, Overestimate was greater than Overlook; the average of Overlook was 1.6 % (the highest Overlook was 3.2 % in August), against the average of Overestimate was 13.7 % (the lowest Overestimate was 7.2 % in May) in Japan; the average of Overlook was 1.0 % (the highest Overlook was 2.3 % in July), against the average of Overestimate was 39.2 % (the lowest Overestimate was 24.2 % in April) in Borneo; the average of Overlook was 2.9 % (the highest Overlook was 8.8 % in July), against the average of Overestimate was 51.8 % (the lowest Overestimate was 23.2 % in July) in Canada; the average of Overlook was 11.9 % (the highest Overlook was 27.5 % in August), against the average of Overestimate was 50.3 % (the lowest Overestimate was 20.3 % in July) in Alaska. These mean that there was tendency that CLAUDIA3-CAI judged cloudy, despite CLAUIDA1-CAI judged clear in Japan, Borneo, Canada, and Alaska.

In Thailand and Mongolia, there was seasonal variation. In Thailand, Overlook was greater than Overestimate from March to May, and Overestimate was greater than Overlook from June to February; the average of Overlook was 12.7% (the lowest Overlook was 9.2% in May), against the average of Overestimate was 6.3% (the highest Overestimate was 7.7% in April) from March to May; the average of Overlook was 2.2% (the highest Overlook was 7.1% in February), against the average of Overestimate was 25.8% (the lowest Overestimate was 10.0% in January) from June to February. In Mongolia, Overestimate was greater than Overlook from February to March, and Overlook was greater than Overestimate from April to January; the average of Overlook was 4.0% (the highest Overlook was 4.1% in March), against the average of Overestimate was 40.1% (the lowest Overestimate was 37.8% in March) from February to March; the average of Overlook was 20.4% (the lowest Overlook was 11.9% in July and August), against the average of Overestimate was 6.1% (the highest Overestimate was 14.5% in December) from April to January.

Figure 10 compares the output images of CLAUDIA1-CAI and CLAUDIA3-CAI for select cases in each region.

In Australia and Algeria, CLAUDIA3-CAI could identify bright surface, however, there were a few oversights of the edges of clouds.

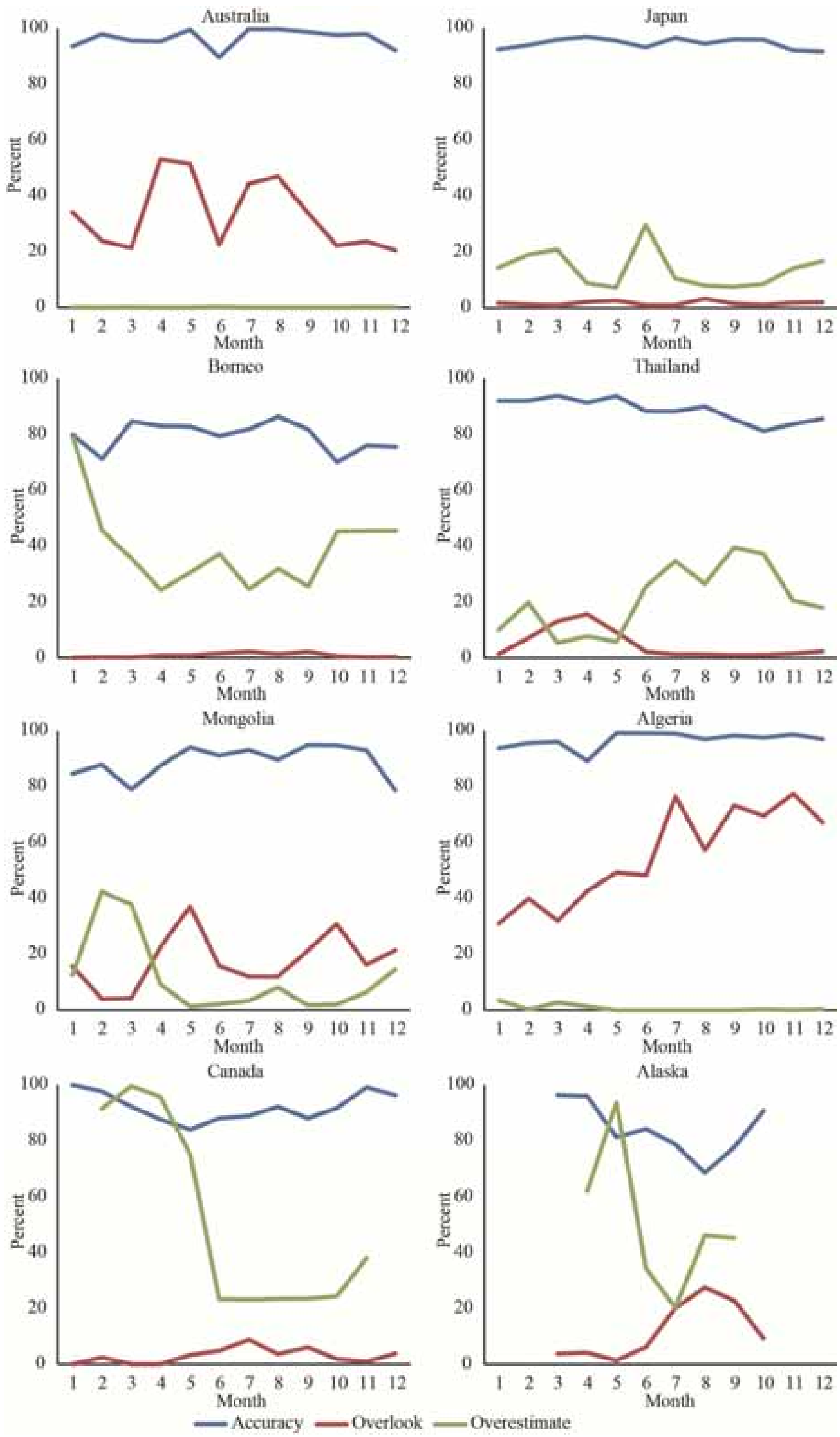
In Japan, CLAUDIA3-CAI misjudged vegetation areas as clouds.

In Borneo, CLAUDIA3-CAI could identify optically thin clouds.

In Canada and Alaska, they were snow or ice covered scenes. Since the CAI is not equipped with any thermal infrared bands, cloud discrimination based on the temperature at the top of clouds is not feasible. Accordingly, it is difficult to discriminate between ice or snow and clouds. The difference or coincidence between CLAUDIA1-CAI and CLAUIDA3-CAI was attributed to this source of error.

In Thailand, CLAUDIA3-CAI could judge smokes as non-clouds, despite CLAUDIA1-CAI judged clouds, however, there were oversights of optically thin clouds and the edges of clouds on 3 April 2013. Furthermore CLAUDIA3-CAI misjudged clear muddy rivers and boundaries between land and water as cloudy. This was also reported about CLAUDIA1-CAI in previous study (Oishi et al. 2014). Conversely, CLAUDIA3-CAI could identify optically thin clouds on 2 September 2012.

In Mongolia, it was snow covered scene on 3 February 2013 in the same as Canada and Alaska. On the other hand CLAUDIA3-CAI could identify bright surface, however, there were a few oversights of the edges of clouds on 2 June 2012.



Australia
Japan
Borneo
Thailand
Mongolia
Algeria
Canada
Alaska
Percent
Month
Accuracy
Overlook
Overestimate

Figure 9: Monthly average accuracy, overlook, and overestimate for various land cover types. Blue line indicates "Accuracy", red line indicates "Overlook, and green line indicates "Overestimate". (2 column)

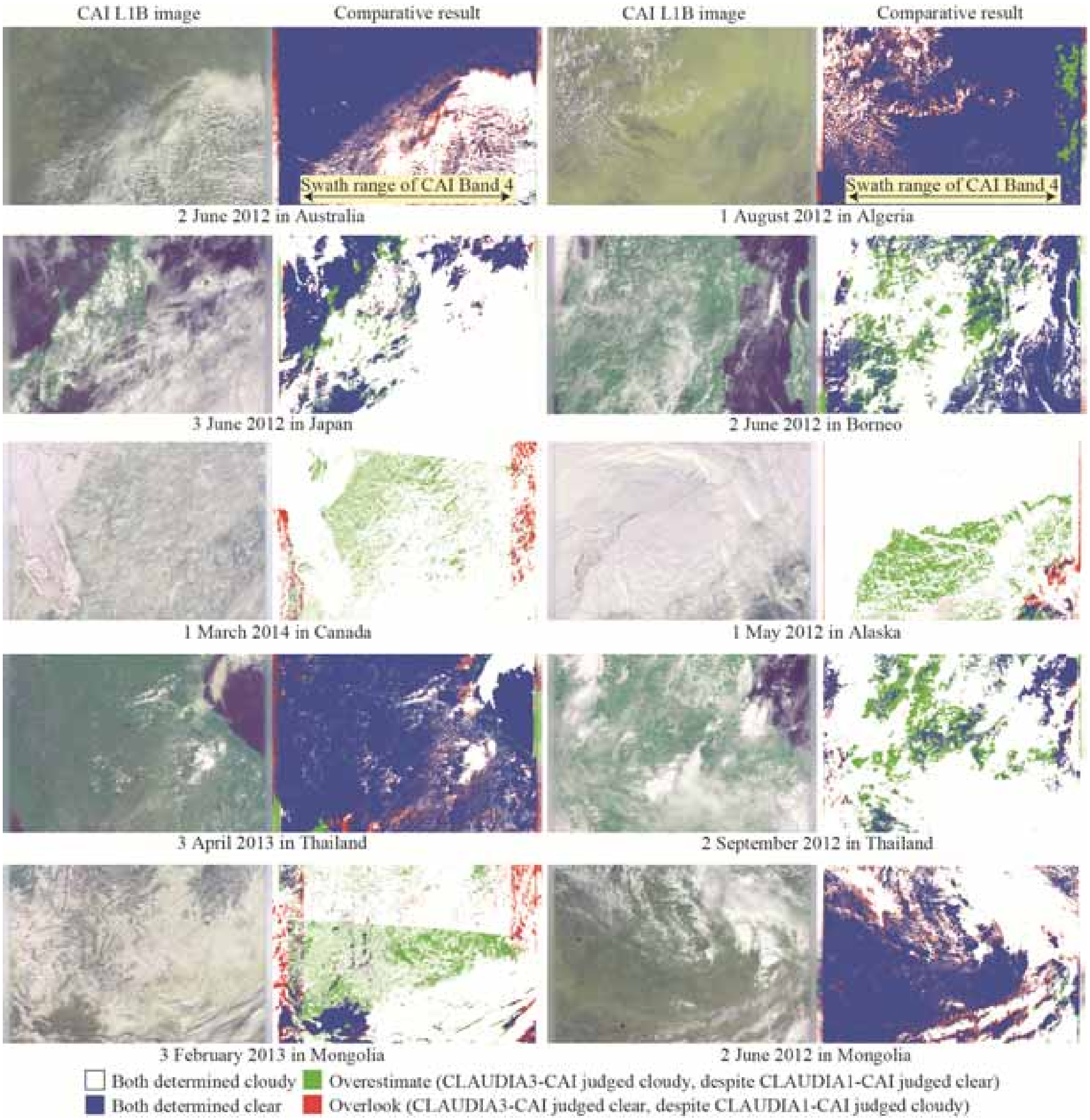


Figure 10: CAI L1B images (R: Band 2, G: Band 3, B: Band 1) and comparative results of CLAUDIA1-CAI and CLAUDIA3-CAI for various land cover types. (2 column)

3.2 Results in the Amazon

Figure 11 compares the visual inspection images and the output images for four select cases in the Amazon: low cloud cover, high cloud cover, small scattered clouds, and optically thin clouds. We used the visual inspection result as the standard image.

CLAUDIA3-CAI produced fewer overlooked clouds but slightly more overestimated clouds than CLAUDIA1-CAI did. CLAUDIA3-CAI misjudged clear muddy rivers on 23 August 2011 in CAI Path 29, Frame 32 and the surroundings of clouds on 1 April 2011 in CAI Path 29, Frame 32. The maximum accuracy values of CLAUDIA3-CAI and the CLAUDIA1-CAI occur at different integrated-CCL values with the thresholds for the Amazon. Fig. 12 shows the average accuracy, overlook, and overestimate of all the data in the Amazon for all 19 cases. These results indicate that the most suitable integrated-CCL thresholds are 0.75 for CLAUDIA1-CAI and 0.5 for CLAUDIA3-CAI in the Amazon. Since curved lines of overestimate and overlook intersect, CLAUDIA3-CAI can appropriately determine the boundary between cloud and clear-sky.

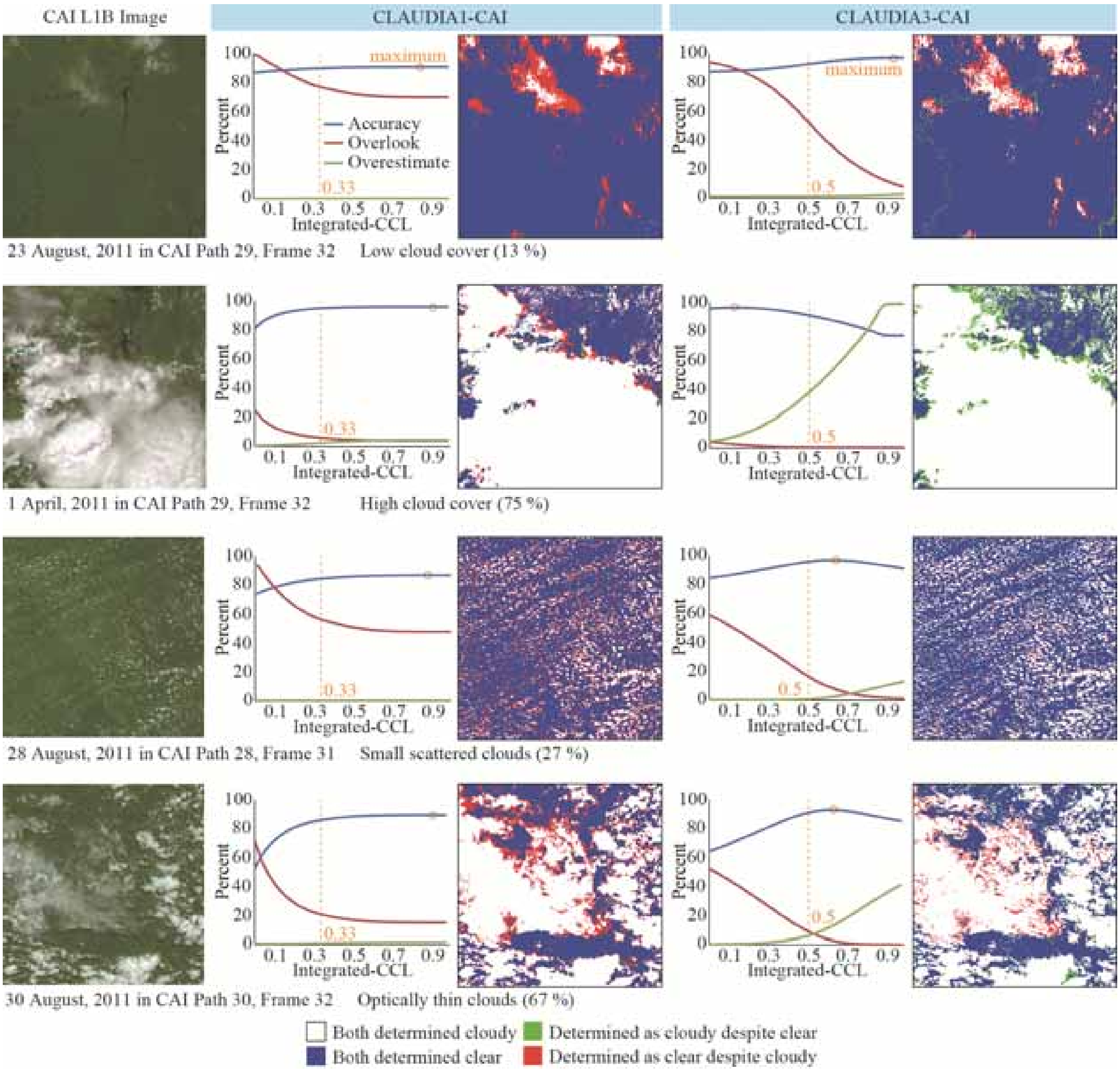


Figure 11: Comparison of the visual inspection images and the output images in the Amazon. Orange circles indicate the maximum accuracy values. Orange dotted lines indicate the integrated-CCL thresholds. Blue line indicates "Accuracy", red line indicates "Overlook, and green line indicates "Overestimate". (2 column)

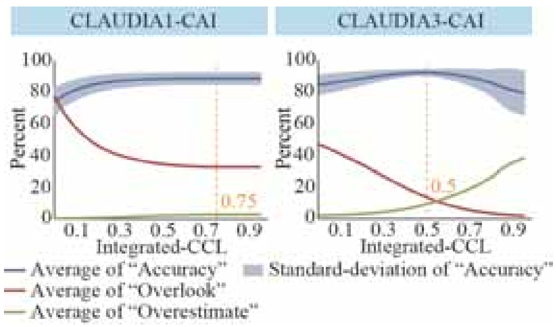


Figure 12: Average accuracy, overlook, and overestimate for all data for the Amazon. The most suitable integrated-CCL thresholds are 0.75 for CLAUDIA1-CAI and 0.5 for CLAUDIA3-CAI in the Amazon. (single column)

Table 4 shows the results for an integrated-CCL threshold of 0.33 for CLAUDIA1-CAI and 0.5 for CLAUDIA3-CAI, and Table 5 shows the results for an integrated-CCL threshold of the maximum accuracy values in Fig. 12 (CLAUDIA1-CAI: 0.75, CLAUDIA3-CAI: 0.5). There was no notable change in the accuracies with the season or location. When the integrated-CCL threshold was 0.33 for CLAUDIA1-CAI and 0.5 for CLAUDIA3-CAI, the accuracies were 87.0 % and 92.0 %, respectively. When the accuracy of CLAUDIA1-CAI was higher than that of CLAUDIA3-CAI, optically thick clouds covered a wide area of the input images. Furthermore, when the integrated-CCL threshold was 0.75 for CLAUDIA1-CAI and 0.5 for CLAUDIA3-CAI, the accuracy was the highest, at 88.3 % and 92.0 %, respectively. In the both cases, the accuracy of CLAUDIA3-CAI was higher than that of CLAUDIA1-CAI.

Table 4: Results for integrated-CCL thresholds of 0.33 for CLAUDIA1-CAI and 0.5 for CLAUDIA3-CAI in the Amazon.

		Accuracy (%)		Overlook (%)		Overestimate (%)	
Date (yy/mm/dd)	Location (CAI Path_Frame)	CLAUDIA1 (0.33)	CLAUDIA3 (0.5)	CLAUDIA1 (0.33)	CLAUDIA3 (0.5)	CLAUDIA1 (0.33)	CLAUDIA3 (0.5)
11/08/28	28_31	84.6	95.1	56.6	16.9	0.0	0.5
11/08/28	28_32	80.6	92.9	49.7	7.5	0.1	6.9
11/08/28	28_33	92.0	95.9	11.6	13.4	7.4	2.4
11/08/29	29_31	87.6	93.8	27.2	9.5	0.3	3.5
10/08/28	29_32	89.8	90.8	32.6	9.9	1.7	9.0
11/02/03	29_32	86.6	92.9	35.5	2.4	0.5	9.9

11/04/01	29_32	95.0	91.6	5.8	0.1	2.1	36.6
11/06/03	29_32	89.9	90.2	38.1	4.1	0.8	11.7
11/08/02	29_32	77.9	90.6	71.0	27.3	0.1	1.5
11/08/08	29_32	84.5	92.9	66.0	26.3	0.1	1.2
11/08/14	29_32	87.8	93.2	77.4	36.0	0.1	1.4
11/08/23	29_32	90.0	92.2	77.8	54.0	0.1	1.0
11/08/29	29_32	79.6	91.0	52.4	19.7	0.1	2.2
11/10/01	29_32	87.1	92.2	33.9	5.5	0.1	9.1
11/12/03	29_32	82.8	93.4	30.7	1.7	0.1	12.9
11/08/29	29_33	90.6	90.8	20.8	15.1	2.3	5.6
11/08/30	30_31	85.7	85.1	24.7	9.2	3.2	21.0
11/08/30	30_32	86.0	91.4	20.9	10.2	0.4	5.5
11/08/30	30_33	94.9	93.0	11.1	3.6	1.5	9.1
Average		87.0	92.0	39.1	14.3	1.1	7.9

Table 5: Results for integrated-CCL thresholds of the maximum accuracy values in Fig. 11 (CLAUDIA1-CAI: 0.75, CLAUDIA3-CAI: 0.5) in the Amazon.

		Accuracy (%)		Overlook (%)		Overestimate (%)	
Date (yy/mm/dd)	Location (CAI Path_Frame)	CLAUDIA1 (0.75)	CLAUDIA3 (0.5)	CLAUDIA1 (0.75)	CLAUDIA3 (0.5)	CLAUDIA1 (0.75)	CLAUDIA3 (0.5)
11/08/28	28_31	86.9	95.1	47.9	16.9	0.0	0.5
11/08/28	28_32	84.2	92.9	40.2	7.5	0.2	6.9
11/08/28	28_33	83.6	95.9	7.1	13.4	18.1	2.4
11/08/29	29_31	89.6	93.8	21.8	9.5	1.2	3.5
10/08/28	29_32	90.6	90.8	23.5	9.9	4.0	9.0
11/02/03	29_32	88.9	92.9	27.8	2.4	1.4	9.9
11/04/01	29_32	96.2	91.6	3.7	0.1	4.1	36.6
11/06/03	29_32	90.9	90.2	29.3	4.1	2.4	11.7

11/08/02	29_32	80.1	90.6	63.6	27.3	0.3	1.5
11/08/08	29_32	85.9	92.9	59.4	26.3	0.2	1.2
11/08/14	29_32	88.8	93.2	70.1	36.0	0.2	1.4
11/08/23	29_32	90.9	92.2	70.3	54.0	0.1	1.0
11/08/29	29_32	82.2	91.0	45.5	19.7	0.2	2.2
11/10/01	29_32	89.7	92.2	26.6	5.5	0.4	9.1
11/12/03	29_32	86.7	93.4	23.3	1.7	0.5	12.9
11/08/29	29_33	90.9	90.8	13.5	15.1	6.4	5.6
11/08/30	30_31	87.1	85.1	20.4	9.2	4.9	21.0
11/08/30	30_32	89.9	91.4	14.7	10.2	1.0	5.5
11/08/30	30_33	95.1	93.0	7.0	3.6	3.6	9.1
Average		88.3	92.0	32.4	14.3	2.6	7.9

3.3 Results in Borneo

Figure 13 compares the results of the visual inspection images and the output images for two select cases in Borneo: small scattered clouds and optically thin clouds. We used the visual inspection result as the standard image. The comparison of the results for Borneo is similar to that for the Amazon. Figure 14 shows the average accuracy, overlook, and overestimate of all data for all cases in Borneo. These results indicate that the most suitable integrated-CCL thresholds are 0.85 for the CLAUDIA1-CAI and 0.35 for CLAUDIA3-CAI in Borneo. Since curved lines of overestimate and overlook intersect as same as the Amazon cases, CLAUDIA3-CAI can appropriately determine the boundary between cloud and clear-sky.

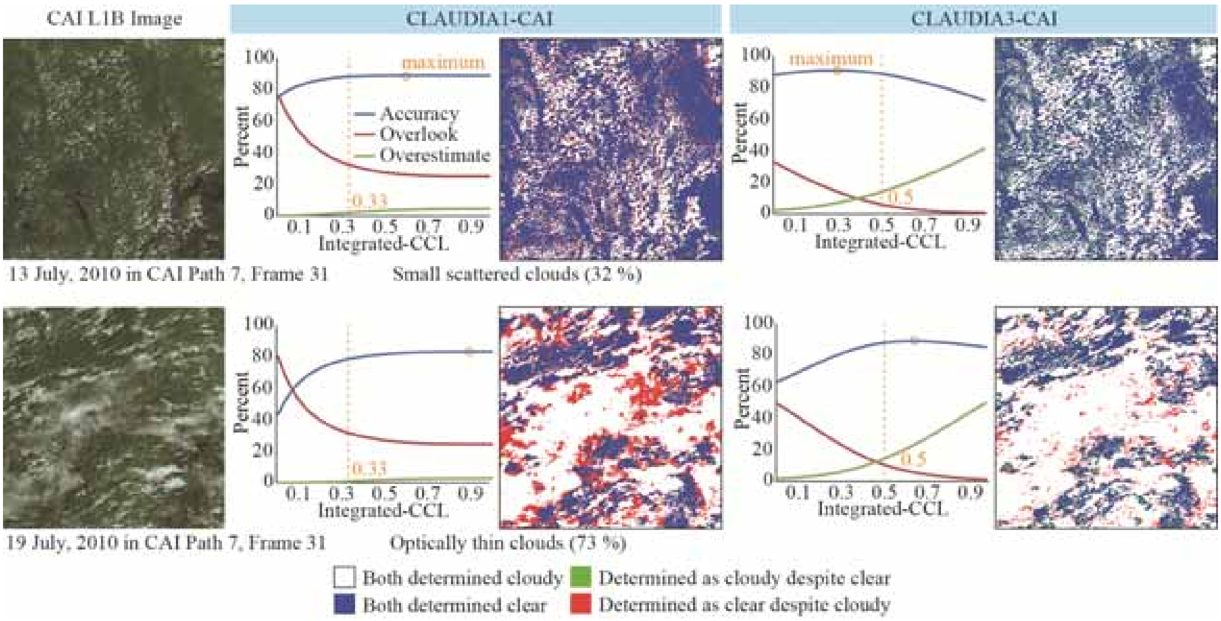


Figure 13: Comparison of the visual inspection images and the output images in Borneo. Orange circles indicate the maximum accuracy values. Orange dotted lines indicate the integrated-CCL thresholds. Blue line indicates "Accuracy", red line indicates "Overlook, and green line indicates "Overestimate". (2 column)

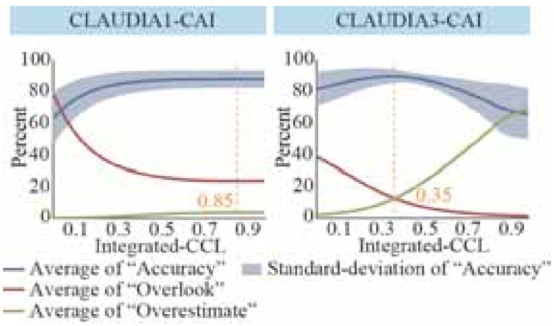


Figure 14: Average accuracy, overlook, and overestimate for all data for Borneo. The most suitable integrated-CCL thresholds are 0.85 for CLAUDIA1-CAI and 0.35 for CLAUDIA3-CAI in Borneo. (single column)

Table 6 shows the results for an integrated-CCL threshold of 0.33 for CLAUDIA1-CAI and 0.5 for CLAUDIA3-CAI, and Table 7 shows the results for an integrated-CCL threshold of the maximum accuracy values in Fig. 14 (CLAUDIA1-CAI: 0.85, CLAUDIA3-CAI: 0.35). There was no notable change in the accuracies with the season or location, similar to the results for the Amazon. For an integrated-CCL threshold of 0.33 for CLAUDIA1-CAI and 0.5 for CLAUDIA3-CAI, the accuracy was 84.8 % and 86.9 %, respectively. Furthermore, for an integrated-CCL threshold of 0.85 for CLAUDIA1-CAI and 0.35 for CLAUDIA3-CAI, the highest accuracies of 87.5 % and 88.8 %, respectively, were obtained. In both cases, the accuracy of CLAUDIA3-CAI was greater than that of CLAUDIA1-CAI.

Table 6: Results for integrated-CCL thresholds of 0.33 for CLAUDIA1-CAI and 0.5 for CLAUDIA3-CAI in Borneo.

		Accuracy (%)		Overlook (%)		Overestimate (%)	
Date	Location	CLAUDIA1	CLAUDIA3	CLAUDIA1	CLAUDIA3	CLAUDIA1	CLAUDIA3
(yy/mm/dd)	(CAI Path_Frame)	(0.33)	(0.5)	(0.33)	(0.5)	(0.33)	(0.5)
10/04/02	7_30	89.7	91.7	28.8	1.7	0.1	12.0
10/01/02	7_31	85.6	85.0	25.8	1.8	0.6	31.1
10/04/02	7_31	94.8	85.4	8.3	0.6	3.5	22.8
10/07/01	7_31	90.8	92.2	29.0	5.0	0.4	9.0
10/07/07	7_31	76.5	85.9	54.2	22.5	0.5	7.8
10/07/13	7_31	88.2	89.1	32.6	5.8	2.0	13.3
10/07/19	7_31	77.1	88.4	31.1	11.0	1.0	13.5
10/07/28	7_31	70.6	81.5	44.8	8.2	1.1	37.5
10/09/02	7_31	89.3	87.8	37.8	6.5	1.3	14.2
10/11/01	7_31	85.8	81.8	20.6	0.4	1.2	54.7
Average		84.8	86.9	31.3	6.3	1.2	21.6

Table 7: Results for integrated-CCL thresholds of the maximum accuracy values in Fig. 13 (CLAUDIA1-CAI: 0.85, CLAUDIA3-CAI: 0.35) in Borneo.

		Accuracy (%)		Overlook (%)		Overestimate (%)	
Date	Location	CLAUDIA1	CLAUDIA3	CLAUDIA1	CLAUDIA3	CLAUDIA1	CLAUDIA3
(yy/mm/dd)	(CAI Path_Frame)	(0.85)	(0.35)	(0.85)	(0.35)	(0.85)	(0.35)
10/04/02	7_30	91.9	94.6	22.3	8.5	0.3	3.8
10/01/02	7_31	89.2	90.7	16.8	8.0	3.6	10.9
10/04/02	7_31	93.8	91.5	4.6	2.3	7.2	12.2
10/07/01	7_31	92.1	93.2	21.5	10.3	1.9	5.3

10/07/07	7_31	79.4	83.5	46.1	33.0	1.6	4.2
10/07/13	7_31	88.9	90.9	25.1	11.4	4.4	7.9
10/07/19	7_31	81.7	83.4	24.1	20.1	2.7	7.1
10/07/28	7_31	77.3	80.7	33.2	18.9	3.2	20.0
10/09/02	7_31	90.3	90.6	29.0	12.3	3.0	8.3
10/11/01	7_31	90.8	89.4	10.9	3.3	5.8	25.5
Average		87.5	88.8	23.4	12.8	3.4	10.5

4 Discussions and conclusions

Comparative results between CLAUDIA1-CAI and CLAUDIA3-CAI for various land cover types indicated that CLAUDIA3-CAI had tendency to identify bright surface and optically thin clouds, however, misjudge the edges of clouds as compared with CLAUDIA1-CAI. There are tradeoffs in maximizing accuracy while minimizing overlook and overestimate. Thus, it is sufficient to change the integrated-CCL threshold according to the purpose. Furthermore, CLAUDIA3-CAI misjudged vegetation areas as clouds in Japan. It is necessary to add clear training data of Japanese vegetation areas for CLAUDIA3.

The averaged accuracy of CLAUDIA3 used with GOSAT CAI data (CLAUDIA3-CAI) was approximately 89.5 % in tropical rainforests, which was greater than that of CLAUDIA1-CAI (85.9 %) for the test cases presented here. This is mainly because, in contrast to CLAUDIA1-CAI, CLAUDIA3-CAI can detect optically thin clouds and the edges of clouds, which prevents cloud-contaminated FTS-2 data from being processed as cloud-free FTS-2 data in the greenhouse gas concentration calculations. However, CLAUDIA3-CAI tends to overestimate the surroundings of clouds, which are judged to be cloudy despite being clear. Thus, CLAUDIA3-CAI is not expected to increase the amount of the FTS-2 data that can be used to estimate greenhouse gas concentrations in tropical rainforests. Conversely, CLAUDIA3-CAI may be able to detect optically thin clouds that cannot be detected by visual inspection.

CLAUDIA3-CAI misjudged clear muddy rivers and boundaries between land and water as cloudy in the same manner as CLAUDIA1-CAI. This has three possible causes: (1) insufficient training data for muddy rivers to distinguish the differences in the spectral reflectance properties of muddy water and other water; (2) deviation of the positions in each CAI band owing to the band-to-band registration error; and (3) insufficient resolution of the surface albedo data. The surface albedo data was generated at 1/8° resolution by separating the land and water region. If the border pixels between land and water regions were mixed pixels, the albedo data of 1/8° areas that include the mixed pixels would be included. To decrease this effect, higher resolution surface albedo data are needed. For boundaries between land and water, the resolution of surface albedo