A COMPARATIVE ANALYSIS OF GLOBAL LAND COVER CHANGE BETWEEN CCI-LC AND MCD12

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ABSTRACT: Several research institutes have provided time series global land cover maps which are used as input data for various environmental assessments. But the accuracy assessment of land cover changes derived from these time series global land cover maps are limited. Because it is difficult to create time series validation dataset on a global scale. In this study, accuracy of land cover change detection was evaluated by comparing two time series global land cover datasets. CCI-LC (Climate Change Initiative Land Cover) provided by ESA (European Space Agency) and MCD12 (MODIS Land Cover Collection 6) provided by NASA (National Aeronautics and Space Administration)/USGS (United States Geological Survey) are selected for the mutual comparison. The differences in the characteristics of these datasets were compared through the literature review. As the result, it was found that both land cover datasets are considering the consistency of time-series changes in the process of creation for each pixel base, but those methodologies were different. We then analyzed land cover change on two patterns: the one is to use the original classification system in each land cover dataset (the IGPB 17 classes for MCD12 and the UN-LCCS 22 classes for CCI-LC), and the other is to use the integrated seven classes converted from original classification system. The comparisons were made from four perspectives: (1) 18-year land cover change point comparison, (2) 18-year land cover change frequency comparison, (3) the agreement of the combination of changes between composite maps of 2001-2009 and 2010-2018, and (4) Visual interpretation of land cover change using Google Earth. From these analyses, it was found that the agreement of the points of no land cover change between CCI-LC and MCD12 for 18 years were 79.0 % before the class integration and 88.6 % after the class integration. Contrary, agreement points of land cover change at least once were only 1.1 % before the integration and 0.5 % after the integration. It was also found that the disagreement points (20.0 % before the integration and 10.9 % after the integration) happens much wider in MCD12 than those in CCI-LC and MCD12 class change in points also happens much more. We then composite the time series CCI-LC and MCD12 data into two time series data, i.e. 2001-2009 and 2010-2018. The majority of class in each point during the periods are selected as the representative class. We found that the class in no landcover change points almost agreed in the two datasets. But, at the rest of the points, there are many disagreements in the class change combination after the class integration. As the result of visual interpretation using Google Earth images, it is difficult to determine which one is better. The causes of these discrepancies could be influenced by the differences of satellite sensors, the creating process, the resolution, and class definition. To discuss more strictly which time series global land cover dataset has high quality of change detection, a time series validation dataset is essential. In addition, it is necessary to clarify the definition of "land cover change."

1. INTRODUCTION

Land cover changes are caused by change of various natural environments and human activities. It is important to understand exactly the location and phenomena through time series land cover maps. Land cover maps and land cover change data also play an important role as input data for surface models such as the Earth system for simulating the circulation of energy, water, carbon, etc. (Sulla-Menashe et al., 2019).

Currently, several research institutes are providing time-series global land cover maps to meet these needs. NASA (National Aeronautics and Space Administration) / USGS (United States Geological Survey) combines images acquired from MODIS (Moderate Resolution Imaging Spectroradiometer) installed in Terra and Aqua, and also uses additional metrics in order to produce Collection 6 MODIS Land Cover (MCD12) (Sulla-Menashe et al., 2019). There are annual archives from 2001 to 2018, with resolutions of 500m and 0.05 degrees. ESA (European Space Agency) has produced a time-series global land cover map called CCI-LC by combining sensors such as MERIS FR / RR, SPOT-VGT, AVHRR, and PROBA-V (Defourny et al., 2017). There are annual archives from 1992 to 2018, with resolutions of 300m and 1km. In addition, Liu et al. produced a time-series global land cover map called GRASS-GLC which use various input data, such as GRASS (Global Land Surface Satellite) CDRs (Climate data records) created from AVHRR, LAI, NDVI, FAPAR, ET, GPP, BBE, ABD-WSA-NIR, ABD-BSA-WSA-shortwave (Liu et al., 2020). There are annual archives from 1982 to 2015, with a resolution of 5km. These time-series global land cover maps are useful for various purposes because of their different resolutions and class definitions.

There are several studies that evaluated the accuracy of these time-series global land cover datasets by inter comparison. Hua et al. evaluated the spatial consistency of GLC2000, CCI-LC, MCD12, GLOBCOVER, and GLC NMO using multiple quantitative indicators (Hua et al., 2018). This study showed that the spatial consistency of these global datasets varies considerably depending on region. In addition, Liu et al. evaluated the accuracy of CCI-LC, MCD12 and GRASS-GLC using FLUXNET and a part of FROM-GLC_v2 samples (Liu et al., 2020). These inter comparisons are carried out every single year base and are not verified that focus on land cover changes.

Therefore, this study focused on “land cover change” and evaluated the accuracy of time-series global land cover maps. MCD12 and CCI-LC were evaluated relatively by comparing the land cover changes. We reviewed the differences in the process of creating a time-series global land cover maps and compared the differences and similarities.

2. COMPARING THE PROCESS OF CREATING A TIME-SERIES GLOBAL LAND COVER MAP BY LITERATURE REVIEW

The methods for creating time-series global land cover maps of CCI-LC and MCD12 were compared. Table 1 shows the outlines of CCI-LC and MCD12 datasets.

In the process of creating the land cover map of CCI-LC, a baseline 10-year global LC map is first created from the composite MERIS FR / RR images from 2003 to 2012 using a combination of supervised and unsupervised classification of GlobCover (Bontemps et al., 2011). Then a change module is executed. The change is detected at 1 km first, and then drawn at 300 m. The change module first maps the dynamics of the ground surface by analyzing the 1km pixel-based annual time series global classification from 1992 to 2015. These classifications are derived from the AVHRR time series from 1992 to 1999, the SPOT-VGT time series from 1999 to 2013, and the PROBA-V time series from 2014 to 2015. However, in order to avoid detection of errors in the changes due to the inter-annual variability in classification, with the exception of 2014 and 2015, processing is performed on the assumption that each change has to be confirmed over more than two successive years in the classification times series (Defourny et al., 2017). The changes were detected among CCI land cover classes grouped into six IPCC land cover categories: cropland, forest, grassland, wetland, settlement, and other land. This avoids false change detection between semantically close classes.

The process of creating a land cover map for MCD12 is divided into four main steps (Sulla-Menashe et al., 2019). First, daily C6 NBAR (Collection 6 MODIS Nadir BRDF-Adjusted Reflectance) data were sampled at five-day time steps and then smoothed and gap-filled using penalized smoothing spline because of computationally infeasible at global scale for the entire MODIS record (Sulla-Menashe et al., 2019). To reduce data volumes and provide useful features to the Random Forests classification algorithm, the smoothed NBAR data are summarized at each pixel to create annual metrics based on prescribed percentiles and the standard deviation in each spectral band in each year at each pixel (Sulla-Menashe et al., 2019). Second, the classification is performed by the Random Forests algorithm. Third, nested classification is performed using some independent supplemental information and class conditional probabilities produced by the Random Forests. Fourth, the Hidden Markov Model (HMM) is used to reduce false time series changes. This approach uses a forward-backward fitting HMM algorithm to estimate posterior marginal probabilities for each class at each pixel (Sulla-Menashe et al., 2019).

Therefore, the sensors and the classification method used are completely different. However, both methods consider the consistency of the time series.

Table 1 Specification for time series global land cover datasets

Time-series global land cover dataset	**CCI-LC** (Defourny et al., 2017)	**MCD12 C6** (Sulla-Menashe and Friedl, 2018)
Input data source	MERIS FR/RR, SPOT-VGT, AVHRR, PROBA-V	MODIS
Resolution	300m, 1km	500m, 0.05deg
Period	1992-2018	2001-2018
Classifier	Supervised and Unsupervised	Random forest
Classification system	UN-LCCS	IGBP, UMD, LAI, BGC, PFT and LCCS
Correction of land cover change	Assume that the changes at the IPCC class definition do not occur for at least two years.	Hidden Markov models
Overall Accuracy	About 71% by evaluated with area weighting in the validation data (Defourny et al., 2017).	73.6% by cross-validation of training database with IGBP definition (NASA, 2019).

Table 2 Class definition

Integrated 7 classes	**CCI-LC (UN-LCCS class No.)** (Defourny et al., 2017)	**MCD12 (IGBP class No.)** (Sulla-Menashe et al., 2019)
Forest	50/60/70/80/90/100	1/2/3/4/5/8/9
Grassland	100/120/130/140/150	6/7/10
Cropland	10/20/30/40	12/14
Built-up	190	13
Wetland	160/170/180	11
Water, snow and ice	210/220	15/17
Barren	200	16

3. MATERIAL AND METHOD

In this study, CCI-LC and MCD12 were used to perform comparative analysis of land cover changes. In this section, the data and the comparison method are described.

3.1 Material

First, the comparison period was set from 2001 to 2018. CCI-LC with 300 m resolution and MCD12 with 500 m resolution were used. To eliminate the effects of difference of area depending on latitudes, the projections of both global land cover datasets have been aligned with the Sinusoidal. In addition, CCI WB-Map v4.0 (Lamarche et al., 2017) was used to mask the ocean in these global land cover datasets. Considering the differences in spatial resolution between these data, about 171.5 million points obtained as a result of systematic sampling of points in the land area every 30 arcseconds of latitude and longitude were investigated.

UN-LCCS for CCI-LC and IGBP for MCD12 were used for the classification systems (Table 2). In addition, in order to make relative comparisons in a common class, we integrated the classes as rational as possible from the class definition of each original classification systems. The integrated classes are shown in the first column of Table 2.

3.2 Comparison Methods

Comparison methods were made from four perspectives: (1) 18-year land cover change points comparison, (2) 18-year land cover change frequency comparison, (3) the agreement of the combination of changes between composite maps of 2001-2009 and 2010-2018, and (4) Confirmation of the land cover change using Google Earth.

In the land cover change points comparison, the locations where land cover changes occurred at least once between 2001 and 2018 are mapped, and they were compared between CCI-LC and MCD12. In addition, we create a matrix of change at least once/no change in 18 years to clarify the degree of agreement between CCI-LC and MCD12. Here, 0: change, 1: no change, each element of the matrix are presented follows: M_{00}: change in both map A and map B, M_{10}: change only in map A, M_{01}: change only in map B, M_{11} : no change in both map A and map B. Then, the matrix is calculated as follows:

$$M_{kl} = \frac{\sum_{j=1}^{N} m_{A_j B_j}}{N} \times 100\%, \quad m_{A_j B_j} = \begin{cases} 1 & \text{if } A_j = k \text{ and } B_j = l \\ 0 & \text{else} \end{cases} \quad (k, l = 0, 1) \tag{1}$$

Where,

$$A_j = \prod_{i=2002}^{2018} a_{ij}, \quad a_{ij} = \begin{cases} 0 & \text{if } a_{ij} \neq a_{(i-1)j} \\ 1 & \text{else} \end{cases} \tag{2}$$

$$B_j = \prod_{i=2002}^{2018} b_{ij}, \quad b_{ij} = \begin{cases} 0 & \text{if } b_{ij} \neq b_{(i-1)j} \\ 1 & \text{else} \end{cases} \tag{3}$$

i is year of map, j is allocation of arbitrary pixel on map, a_{ij} is class on map A, b_{ij} is class on map B, and A_j and B_j are change at least once/no change for 18 years at the pixels j on each map, N is the total number of pixels in the land area, and M_{kl} is the element of the matrix. The matrixes were calculated in both the original classification system and the integrated seven classes. The effect of integrating class definition is examined.

In the land cover change frequency comparison, we compared the number of changes in each pixel to evaluate differences in the methodologies, i.e. the HMM for MCD12 and the one used in CCI-LC. The integrated seven classes case is discussed.

For the agreement of the combination of changes between composite maps of 2001-2009 and 2010-2018, we composite the time series CCI-LC and MCD12 data into two time series data, i.e. 2001-2009 (prior) and 2010-2018 (latter). The majority of class in each point during the periods are selected as the representative class. By comparing this combination of CCI-LC and MCD12 and calculating the agreement, the detection accuracy of land cover change is assessed. Here, the number of classes is k, and $i, j = k(p-1) + q, p, q = 1,2, \dots, k,$ then the agreement of land cover change of composite map A with composite map B is defined as follows:

$$X_i = \frac{x_{ii}}{\sum_{j=1}^{k^2} x_{ij}} \times 100\% \tag{4}$$

Where,

$$x_{ij} = \sum_{l=1}^{N} c_l, \quad c_l = \begin{cases} 1 & \text{if } i = k(a_{prior,l} - 1) + a_{latter,l} \text{ and } j = k(b_{prior,l} - 1) + b_{latter,l} \\ 0 & \text{else} \end{cases} \tag{5}$$

Here, $a_{prior,l}$ and $a_{latter,l}$ are the class numbers of 2001-2009 and 2010-2018 at pixel l on the composite map A, respectively, and $b_{prior,l}$ and $b_{latter,l}$ are the class numbers of 2001-2009 and 2010-2018 at pixel l on the composite map B, respectively. In this case, k equal seven as the integrated class is used. So, all the combination (k^2) will be 49. To find the agreement of the land cover change of composite map B with the land cover change of composite map A, i and j, and a and b can be replaced for the cross comparison.

Finally, in confirmation of the land cover change using Google Earth, we focused on the change from “Forest to Cropland” between 2008 and 2018. Three cases, i.e. CCI-LC and MCD12 both changed, CCI-LC only and MCD12 only are visually checked.

4. RESULTS AND DISCUSSION

4.1 Comparison of The Land Cover Change Points for 18 Years

Fig. 1 and Fig. 2 show the results of mapping the points that changed at least once between 2001 and 2018 in the original class and the integrated seven classes, respectively. Red indicates that the change at least once in both CCI-LC and MCD12, green indicates that in MCD12 only, and blue indicates that in CCI-LC only.

Table 3 and Table 4 also are matrixes showing the agreement of the change/no change corresponding to Fig.1 and Fig. 2, respectively. In both CCI-LC and MCD12, 79.0 % in original classes and 88.6 % in integrated seven classes of the entire land area shows “no change for 18 years.” Therefore, it should be noted that the content discussed in this study focuses on the remaining 10% to 20% of "changes at least once for 18 years". Note that even if the two maps match change/no change, the classes and time of change do not always match between the two land cover maps.

In the original classes, only MCD12 showed "change" at 17.5%, which is widely distributed except in the Sahara Desert, Amazon basin, central Asia and middle east and central Australia. On the other hand, only CCI-LC is “change” at 2.1%, especially the desert climate (BWk) in the Köppen Geiger climate classification (Beck et al., 2018), such as the western part of Australia, the boundary between the Sahara Desert and forests in Africa, and around Kazakhstan (BWk, BWh) and step climate (BSh) regions are prominent. Of the “change” points, 1.1% agreed between the CCI-LC and MCD12.

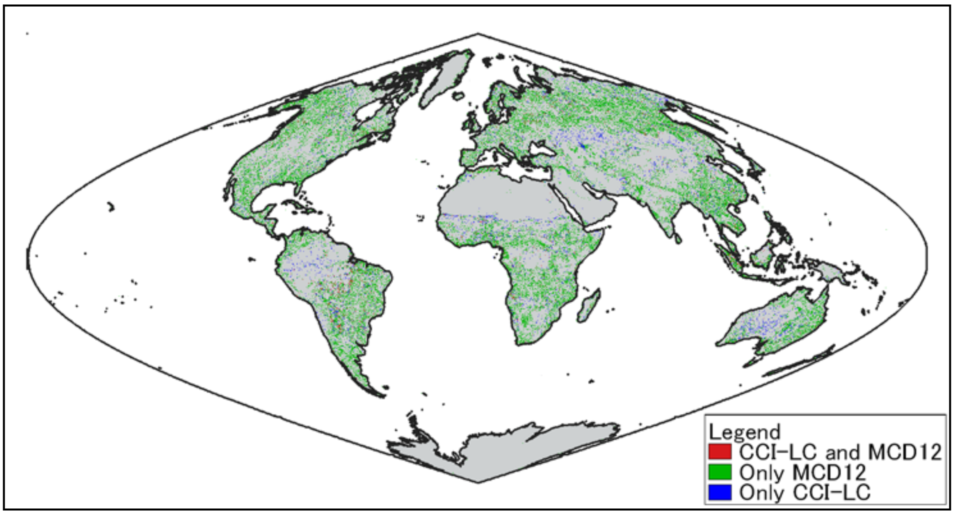

Figure 1 Changed points at least once from 2001 to 2018 (CCI-LC: UN-LCCS class, MCD12: IGBP class)

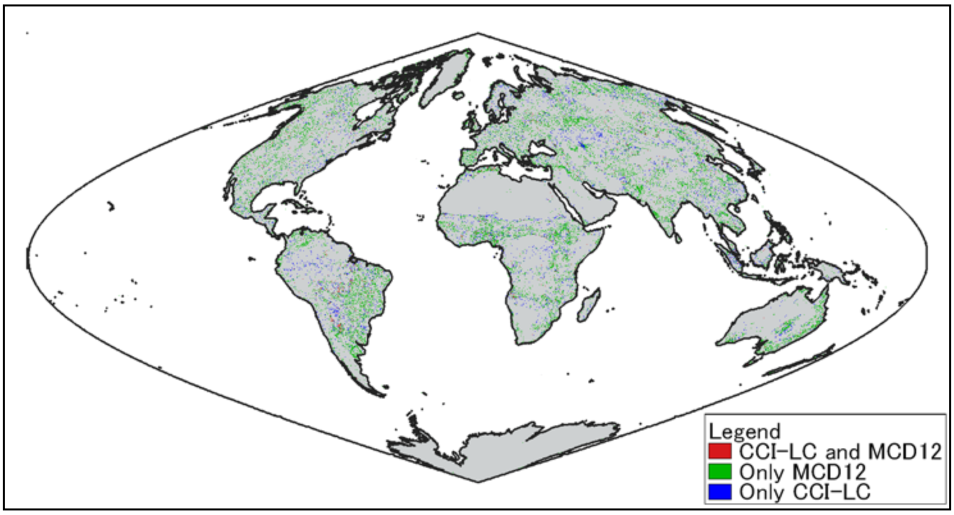

Figure 2 Changed points at least once from 2001 to 2018 (Integrated seven classes)

Table 3 Rate of the points which changed at least once from 2001 to 2018 (original classes)

		CCI-LC (UN-LCCS)		Total
		Change	No change	
MCD12 (IGBP)	Change	1.1%	17.8%	18.9%
	No change	2.2%	79.0%	81.1%
Total		3.3%	96.7%	

Table 4 Rate of the points which changed at least once from 2001 to 2018 (integrated classes)

		CCI-LC		Total
		Change	No change	
MCD12	Change	0.5%	8.7%	9.3%
	No change	2.2%	88.6%	90.7%
Total		2.7%	97.3%	

In the integrated seven classes, it is noticeable that the ratio of “change” in MCD12 is became half compared to the changes in the original class. This indicates that MCD12 detects changes between relatively close classes (e.g. grassland and open shrubland). On the other hand, the ratio of “change” only in CCI-LC in the integrated seven classes was almost the same as in the original class. This is thought to be that change detection is performed by the IPCC integrated class in the process of creation of CCI-LC, so that close classes are not regarded as changes.

4.2 Comparison of land cover change frequency for 18 years

A confusion matrix of the frequency of changes between CCI-LC and MCD12 during the 18 years from 2001 to 2018 were generated (Table 5). As the result, there was a maximum of 16 times changes in MCD12. On the other hand, CCI-LC changed up to five times. In CCI-LC, there is no change more than six times in 18 years. This is because only when the land cover continues for two years or more after the change, it is treated as "change" in CCI-LC.

Table 5 Confusion matrix regarding the land cover frequency from 2001 to 2018 (integrated seven classes)

			CCI-LC						
			No change	Number of changes					Column Total
				1	2	3	4	5	
MCD12	No change		151847364	3694741	44822	2909	787	253	155590876
	Number of changes	1	7621261	525495	8464	564	1	0	8155785
		2	4697336	272919	5047	132	0	0	4975434
		3	1621607	82375	1397	57	0	0	1705436
		4	665959	30629	517	12	0	0	697117
		5	211789	9030	128	3	0	0	220950
		6	74432	2795	42	2	0	0	77271
		7	25661	854	7	0	0	0	26522
		8	10221	316	7	0	0	0	10544
		9	4584	146	0	0	0	0	4730
		10	2085	71	0	0	0	0	2156
		11	966	41	0	0	0	0	1007
		12	390	17	0	0	0	0	407
		13	130	3	0	0	0	0	133
		14	45	0	0	0	0	0	45
		15	7	0	0	0	0	0	7
		16	2	0	0	0	0	0	2
	Row Total		166783839	4619432	60431	3679	788	253	171468422

4.3 The agreement of the combination of changes between composite maps of 2001-2009 and 2010-2018

We created two composite images from 2001 to 2009 and from 2010 to 2018 and calculated a confusion matrix of the combinations of those changes. Of these, the results of the agreement are shown in Table 6. Between CCI-LC and MCD12, the agreement for "no change" was generally high except for wetland and cropland, but the agreement for "change" was generally low. Many of the wetlands on CCI-LC were often forest on MCD12. This is consistent with the description of the MCD12 product (Sulla-Menashe and Friedl, 2018) that is written: "wetland is underestimated." In addition, the agreement of cropland of "no change" is greatly different in CCI-LC and MCD12, for example, in the land cover map of 2018, the area of cropland is about 8.8% in MCD12 and about 17.3% in CCI-LC. This is probably because the difference in definition of cropland between IGBP (MCD12) and UN-LCCS (CCI-LC). Focusing on the "change" results, most of the "change" classes in CCI-LC were in one of the "no change" classes in MCD12, and vice versa.

The number of pixels of "no change" is quite large. So, the two maps only taking account of "change" combinations were also compared. As a result, when CCI-LC was evaluated by MCD12, half of combination of all change classes were matched with MCD12, and vice versa. Therefore, it was found that the change combinations of CCI-LC and MCD12 were partially consistent.

Table 6 Agreement of the combination of land cover change between the composite maps of 2001-2009 and 2010-2018

Composite of 2001 - 2009	**Composite of 2010 - 2018**	**Evaluate CCI-LC with MCD12**	**Evaluate MCD12 with CCI-LC**
Forest	Grassland	11.5%	2.6%
Forest	Cropland	1.2%	1.0%
Forest	Built-up	1.0%	1.2%
Forest	Wetland	1.6%	0.1%
Forest	Water, snow and ice	6.1%	31.7%
Forest	Barren	0.1%	0.5%
Grassland	Forest	5.1%	0.9%
Grassland	Cropland	3.7%	0.9%
Grassland	Built-up	1.9%	9.6%
Grassland	Wetland	0.3%	0.0%
Grassland	Water, snow and ice	5.3%	3.1%
Grassland	Barren	3.0%	0.6%
Cropland	Forest	1.1%	1.0%
Cropland	Grassland	2.2%	0.2%
Cropland	Built-up	2.0%	23.3%
Cropland	Wetland	0.2%	0.4%
Cropland	Water, snow and ice	6.1%	35.0%
Cropland	Barren	3.8%	5.1%
Built-up	Forest	-	-
Built-up	Grassland	-	-
Built-up	Cropland	-	-
Built-up	Wetland	-	-
Built-up	Water, snow and ice	-	-
Built-up	Barren	-	-
Wetland	Forest	1.2%	0.6%
Wetland	Grassland	0.9%	0.1%
Wetland	Cropland	0.0%	0.3%
Wetland	Built-up	0.1%	0.6%
Wetland	Water, snow and ice	1.4%	1.5%
Wetland	Barren	0.0%	0.0%
Water, snow and ice	Forest	0.3%	0.8%
Water, snow and ice	Grassland	5.6%	2.2%
Water, snow and ice	Cropland	0.6%	23.3%
Water, snow and ice	Built-up	0.0%	0.0%
Water, snow and ice	Wetland	1.1%	1.3%
Water, snow and ice	Barren	7.2%	1.2%
Barren	Forest	0.0%	0.0%
Barren	Grassland	6.0%	2.3%
Barren	Cropland	4.9%	38.2%
Barren	Built-up	1.4%	13.8%
Barren	Wetland	0.0%	0.0%
Barren	Water, snow and ice	17.0%	0.7%
Forest	Forest	86.0%	74.4%
Grassland	Grassland	74.5%	65.5%
Cropland	Cropland	42.5%	89.5%
Built-up	Built-up	63.2%	46.6%
Wetland	Wetland	15.7%	40.3%
Water, snow and ice	Water, snow and ice	91.0%	97.5%
Barren	Barren	88.2%	84.8%

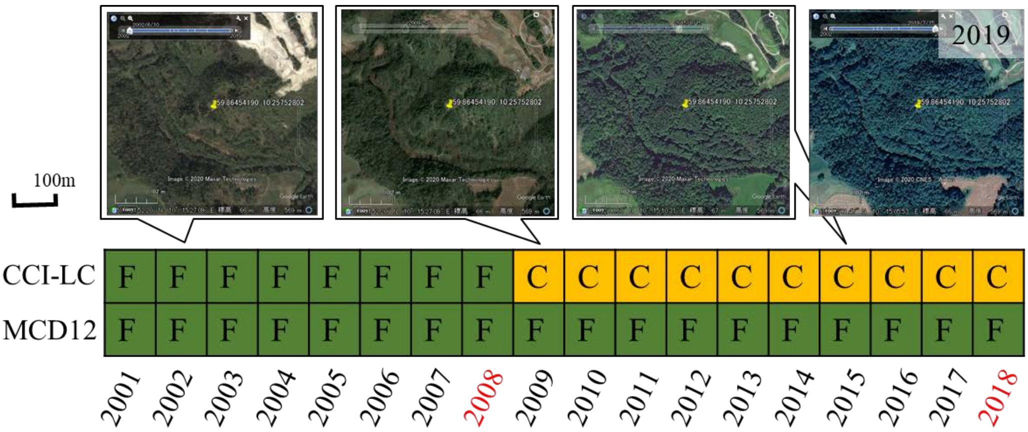

Figure 3 Time series land cover maps and Google Earth image at the point where changed from Forest to Cropland only in CCI-LC between 2008 and 2018 (the location is 59.86454190, 10.25752802)

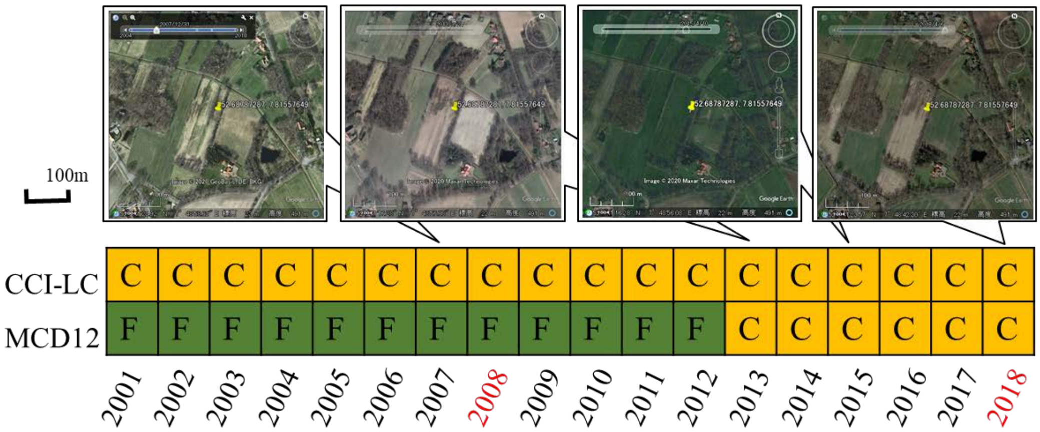

Figure 4 Time series land cover maps and Google Earth image at the point where changed from Forest to Cropland only in MCD12 between 2008 and 2018 (the location is 52.68787287, 7.81557649)

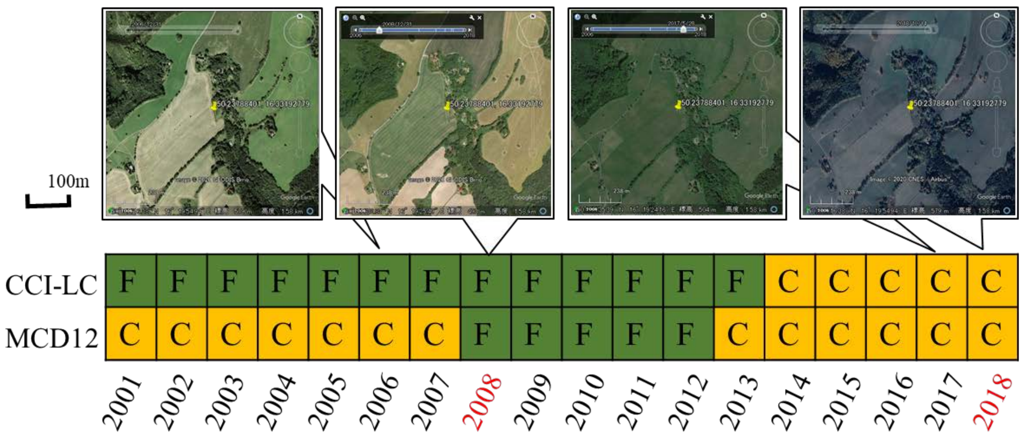

Figure 5 Time series land cover maps and Google Earth image at the point where changed from Forest to Cropland both CCI-LC and MCD12 between 2008 and 2018 (the location is 50.23788401, 16.33192779)

4.4 Confirmation of the land cover change using Google Earth

The land cover changes detected from times series land cover maps were checked by Google Earth image. In this study, only the points that changed from forest in 2008 to cropland in 2018 were checked. There were three cases where the change was shown only by CCI-LC, only by MCD12, or by both. The changes of these cases were checked by the Google Earth images manually.

The results of change from Forest in 2008 to Cropland in 2018 only in CCI-LC, only in MCD12, in both CCI-LC and MCD12 were shown in Fig.3, Fig. 4, Fig. 5, respectively, with the Google Earth images. It was found that all change patterns in land cover maps, including that the case of change patterns in CCI-LC agreed with that of MCD12, could not be identified in the Google Earth images. Three example points were mixed pixels of Forest and Cropland. In addition, CCI-LC tends to classify a pixel into Cropland (Fig. 4) and MCD12 tends to classify a pixel into Forest (Fig. 3).

5. CONCLUSION

In this study, we conducted a comparative analysis of land cover change detection using CCI-CL and MCD12, which are existing time-series global land cover maps. For comparison, the classes of each land cover map were integrated seven classes that were defined in this study. In the integrated seven classes, the points that the land cover change occurred at least once from 2001 to 2018 matched in MCD12 and CCI-LC were around 1%, and MCD12 was more changed than CCI-LC. The number of changes over 18 years was up to 16 times in MCD12, while five times in CCI-LC. This is strongly affected that the difference of methods for considering time-series consistency in the process of creating time-series land cover maps in CCI-LC and MCD12. In addition, as a result of creating a confusion matrix for land cover changes of CCI-LC and MCD12 and evaluating the agreements, the agreements of "no change" were high in almost classes except wetland and cropland. However, the agreements for "change" was very low, and many of the points that CCI-LC stated "change" were "no change" in MCD12 and vice versa. Finally, the change from forest to cropland was checked by Google Earth images. From these experiments, it is concluded that a time-series validation dataset is essential for a more rigorous discussion of the accuracy of land cover change detection. In addition, it is thought that the difference in land cover change between maps can be reduced by clearly defining the land cover change.

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