Development of Cloud and Shadow Free MODIS Compositing Technique with Atmospheric Radiative Simulation

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Abstract

In this study, cloud and shadow free compositing technique with MODIS quarter kilometers (QKM) spatial resolution in channel 1 and 2 are newly developed, validated and implemented. MODIS finer spatial resolution QKM results in the detection of shadows induced by the direct sunbeam occlusion with cloud or terrain. The previous cloud-free compositing methodologies, mostly developed on AVHRR sensors, has much emphasis on cloud screening, but it causes the contamination of cloud or terrain induced shadows in the composed imagery. To overcome this problem, firstly, spectral characteristics on a variety of land cover types are investigated in fine and shadow conditions. It is based on the idea that a radiance of a pixel is decomposed into five categories including direct radiation, path radiance, and the percentage of component is computed using 6S code, the most commonly used radiative transfer simulation technology. As a result, a compositing method based on an enhanced minimum second red criteria is considered to be appropriate to achieve our objectives. Secondly, the 10-days composite images are created using four methods including maximum NDVI criterion (MaxN), minimum red criterion (MinR), second minimum red criterion (SMinR), enhanced second minimum criteria (ESMinR) over Japan main islands using 1-year of Terra MODIS data received at the direct broad casting system at University of Tokyo campus. Finally, the comparative performances of the above mentioned four compositing methods are judged from five criterion including cloud screening, satellite zenith angle, smoothness of the imagery, snow/ice identification and shadow. It is concluded that the newly developed ESMinR method produces fairly consistent results with possible refinements and more sophisticated method to overcome both cloud contamination and shadow problem.

Key words: Terrain shadow, radiative transfer simulation, enhanced second minimum red criteria

1. Introduction

1.1 Background of This Study

In land applications of satellite remote sensing, not only cloud but also cloud-shadow is regarded as a source of errors. MODIS channel 1 and 2's higher spatial resolution in quarter kilometers can capture a more detailed land surface features such as cloud-shadow that can not be discernible with MODIS or AVHRR 1 kilometer footprint (Justice *et al*., 1998). There are mainly two types of studies that deal with cloud shadow. One is to estimate cloud height according to cloud type and compute a area shaded by a cloud in a sun-target-sensor geometry (Simpson, 2000). The other is to distinguish between non-shadowed and shadowed pixels using a time series of data on a target pixel (Simpson, 1998). Not so much attention has been paid to cloud shadow problems in land applications and an operational data processing method is indispensable to minimize an effect of cloud shadow over various land surface properties in a wide range of aerosol conditions and a sun-target-sensor geometry.

1.2 Objective of This Study

The objective of this study is to develop a cloud and shadow free compositing technique with MODIS MODIS quarter

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kilometers (QKM) spatial resolution in channel 1 and 2. Firstly, spectral characteristics on a variety of land cover types are investigated in fine and shadow conditions. Secondly, the 10-days composite images are created using four methods including maximum NDVI criterion (MaxN), minimum red criterion (MinR), second minimum red criterion (SMinR), enhanced second minimum criteria (ESMinR) over Japan main islands using 1-year of Terra MODIS data. Finally, the comparative performances of the above mentioned six compositing methods are judged from five criterion including cloud screening, satellite zenith angle, smoothness of the imagery, snow/ice identification and shadow.

2. Methodology

2.1 Modeling of a Shadow Pixel

In normal radiative transfer process, a top of atmosphere reflectance is composed of five components; direct solar irradiance E0 diffuse solar irradiance Ed environment irradiance E_e background radiance Lb and path radiance L_p (Sandmeier *et al*., 1997). When a target pixel is interrupted by a cloud, a direct sun beam component is missing and it results in a decrease of reflected energy from a target pixel. A ratio of a reflectance of non-shadowed (fine) pixel R_{fine} to that of shadowed pixel R_{shadow} is defined by an equation (1);

$$R_{shadow} / R_{fine} = \{ (Lp + Lb + I0) \times (Ed + Ee) \} / \{ Lp + Lb + I0 \times (Ed + Ee + E0)\} \quad (1)$$

2.2 Radiative Transfer Simulation of Shadow Pixel

In order to simulate reflectance values of non-shadowed and shadowed pixels, R_{shadow}/R_{fine} , a radiative transfer simulation was conducted with 6S code for MODIS channel 1 and 2. 6S models a radiative transfer process in a sun-target-sensor geometry including a trapping effect. It is the most commonly used simulation code that provides several types of sensors' response functions (Vermote *et al*., 1999). Input parameters required to run 6S code are as follows; date, solar zenith angle, satellite zenith angle, relative azimuth angle, sensor type, visibility, atmospheric profile, aerosol mode, elevation and target type. Table 1 shows those of used in this study.

3. Results and Discussions

3.1 Result of a Radiative Transfer Simulation

Figure 1 shows a result of a radiative transfer simulation to estimate a sensitivity of R_{shadow}/R_{fine} over a variety of observing conditions including solar zenith angle, satellite zenith angle, relative azimuth angle and visibility.

3.1.1 Solar zenith angle

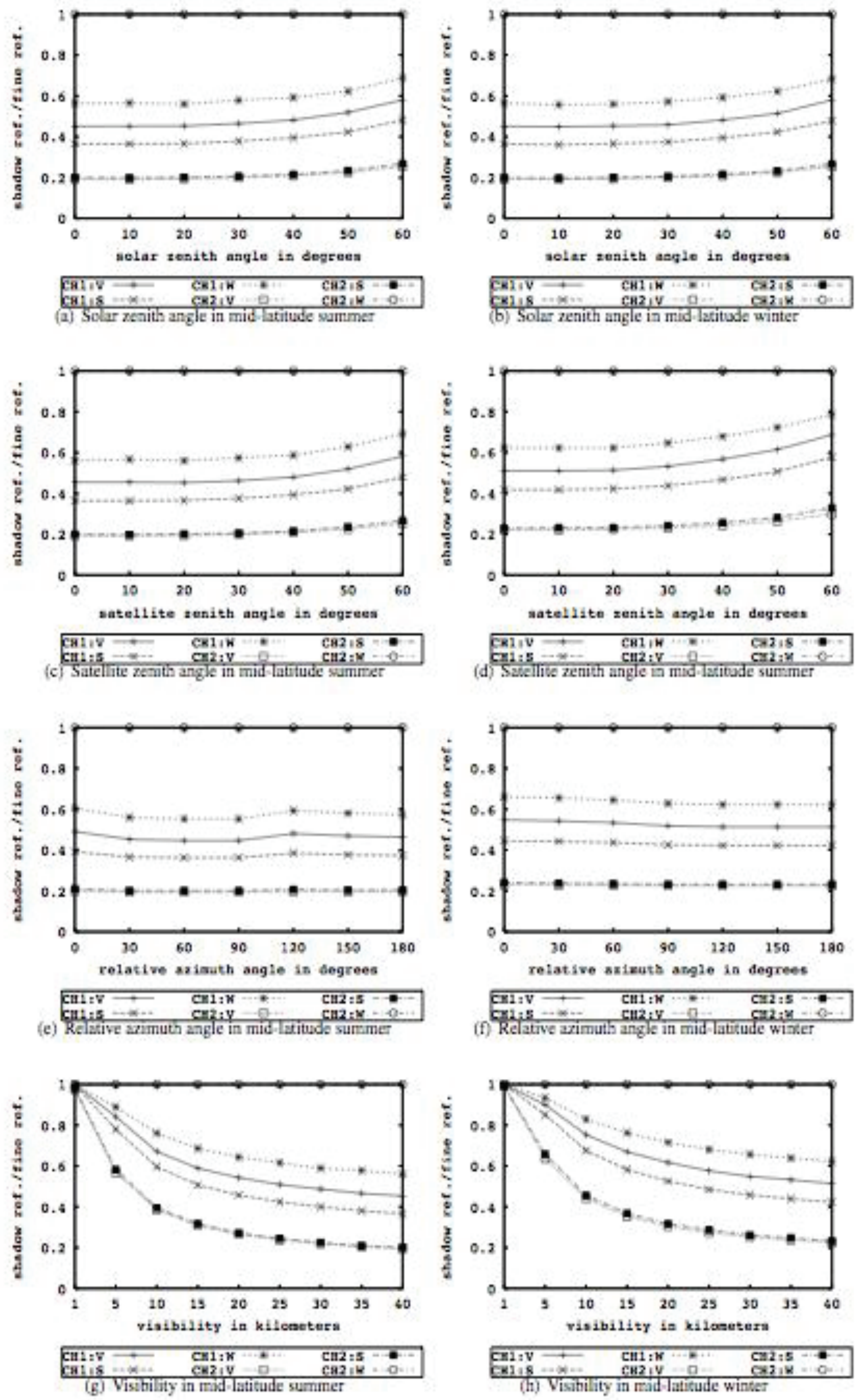
Figure 1 (a) and (b) represent a variation of R_{shadow}/R_{fine} as a function of solar zenith angle in mid-latitude summer and mid-latitude winter aerosol model, respectively. It implies that R_{shadow}/R_{fine} increases as solar zenith angle increases in vegetation, soil and water categories. R_{shadow}/R_{fine} values of channel 1 are from 0.4 to 0.6 and those of channel 2 are from 0.2 to 1.0. This is because water pixel has a very low reflectance value and it is difficult to distinguish it from cloud-shadow pixel.

3.1.2 Satellite zenith angle

Figure 1 (c) and (d) represent a variation of R_{shadow}/R_{fine} as a function of satellite zenith angle in mid-latitude summer and mid-latitude winter aerosol model, respectively. It implies that R_{shadow}/R_{fine} increases as satellite zenith angle increases in vegetation, soil and water categories. R_{shadow}/R_{fine} values of channel 1 are from 0.4 to 0.6 and those of channel 2 are from 0.2 to 0.3 in vegetation and soil, respectively.

Table 1. Input parameters for 6S code to simulate radiative transfer

Items	Variables
Date	February and August 1st
Solar zenith angle	0-60 degrees (every 10 degrees)
Satellite zenith angle	0-60 degrees (every 10 degrees)
Relative azimuth angle	0-180 degrees (every 30 degrees)
Sensor type	MODIS channel 1 and 2
Visibility	0-40 kilometers (every 5 kilometers)
Atmospheric profile	Mid-latitude summer and winter
Aerosol model	Continental
Elevation	0 meter
Target type	Vegetation, soil and water



(a) Solar zenith angle in mid-latitude summer
(b) Solar zenith angle in mid-latitude winter
(c) Satellite zenith angle in mid-latitude summer
(d) Satellite zenith angle in mid-latitude summer
(e) Relative azimuth angle in mid-latitude summer
(f) Relative azimuth angle in mid-latitude winter
(g) Visibility in mid-latitude summer
(h) Visibility in mid-latitude winter

Figure 1. Simulation of R_{shadow}/R_{fine} over a variety of observing and atmospheric conditions

3.1.3 Relative azimuth angle

Figure 1 (e) and (f) represent a variation of R_{shadow}/R_{fine} as a function of relative azimuth angle in mid-latitude summer and mid-latitude winter aerosol model, respectively. It implies that R_{shadow}/R_{fine} have constant values as relative azimuth angle increases in vegetation, soil and water categories. R_{shadow}/R_{fine} values of channel 1 are from 0.4 to 0.6 and those of channel 2 are constant value, 0.2.

3.1.4 Visibility

Figure 1 (g) and (h) represent a variation of R_{shadow}/R_{fine} as a function of visibility in mid latitude summer and mid-latitude winter aerosol model, respectively. It implies that R_{shadow}/R_{fine} decreases as visibility increases in vegetation, soil and water categories. R_{shadow}/R_{fine} values of channel 1 are from 0.4 to 1.0 and those of channel 2 are from 0.2 to 1.0.

3.2 Proposal of a New Compositing Method

The above mentioned simulation showed that R_{shadow}/R_{fine} value of MODIS channel 1 is from 0.2-0.8 and that of channel 2 is from 0.2-0.6. Minimum reflectance in the red channel (channel 1) (MinR), to limit atmospheric effects and enhance green vegetation, but it is subjected to a inclusion of cloud shadows (Takeuchi, *et al*., 2004). To overcome this problem, Enhanced Minimum reflectance in the red channel (ESMinR) is introduced to limit both atmospheric effects and cloud shadows. Figure 2 shows a processing flow of ESMinR method. It is based on the idea of MinR method and is on the assumption that cloud shadow pixel exists at most once during a compositing period (10 days). If a pixel is shadowed by cloud, a pixel with second minimum reflectance in the red channel is selected as a representative value of that period. A pixel is defined as a cloud shadow when R_{shadow}/R_{fine} of channel 1 and channel 2 are lower than threshold values 0.8 and 0.6, respectively, that are derived from the results of radiative transfer simulation.

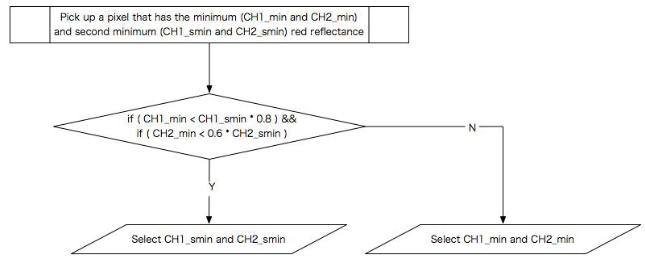


Figure 2. A processing flow of Enhanced Second Minimum Red compositing method (ESMinR)

Then 10-days composite images over Japan (30N-50N, 124E-149E) have generated with four types of approaches; maximum NDVI criterion (MaxN), minimum red criterion (MinR), second minimum red criterion (SMinR), enhanced second minimum criteria (ESMinR).

Figure 3 shows the result of 10-days cloud-free images with four types of compositing methods during Feb. 1-10, 2006. The performance of those four types of methods are evaluated over a range of land cover types including forest, snow and ice, urban and open water.

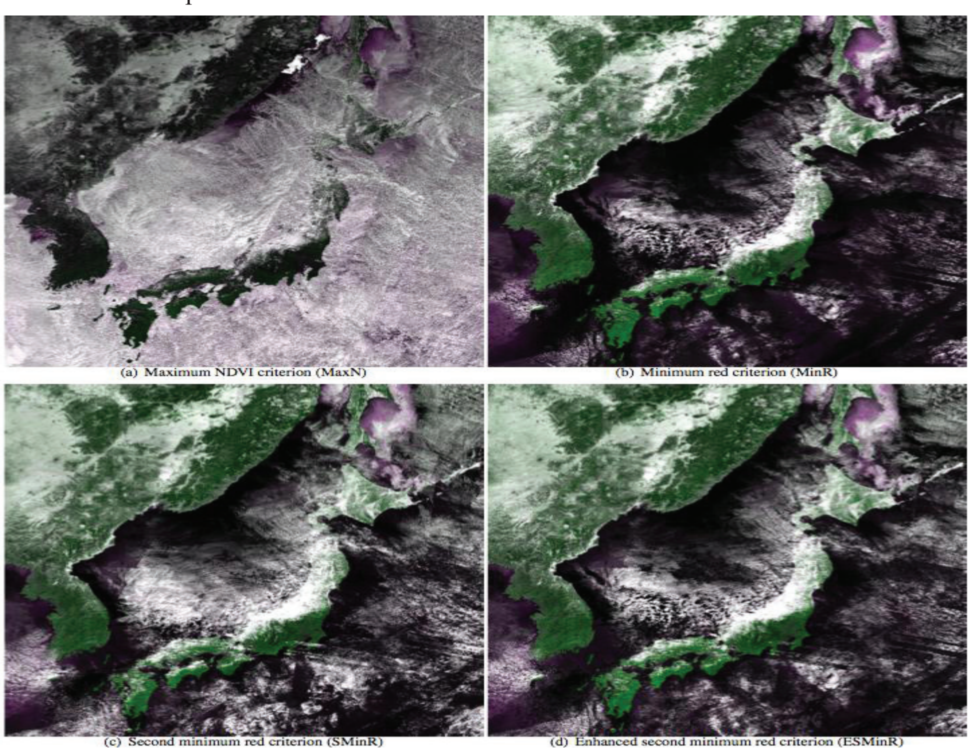


Figure 3. Comparison of 10-days cloud-free images with four types of compositing methods (February 1-10, 2006)

Figure 4 shows the result of 10-days cloud-free images with four types of compositing method in forest. MaxN and MinR methods have lot of shades shown in dark colors contrasted by brighter colors of forest covered area. SMinR method has less clouds than MinR, however, cloud shadows still remains over the entire coverage. ESMinR is not enough to remove cloud shadows resulting in a save level of performance with SMinR.

Figure 5 shows the result of 10-days cloud-free images with four types of compositing method in snow and ice. ESMinR method completely removed cloud shadows over the entire image whereas the other methods including MaxN, Min R and SMinR are effected by cloud shadows as darkly enhanced in the snow covered are a in brighter tone.

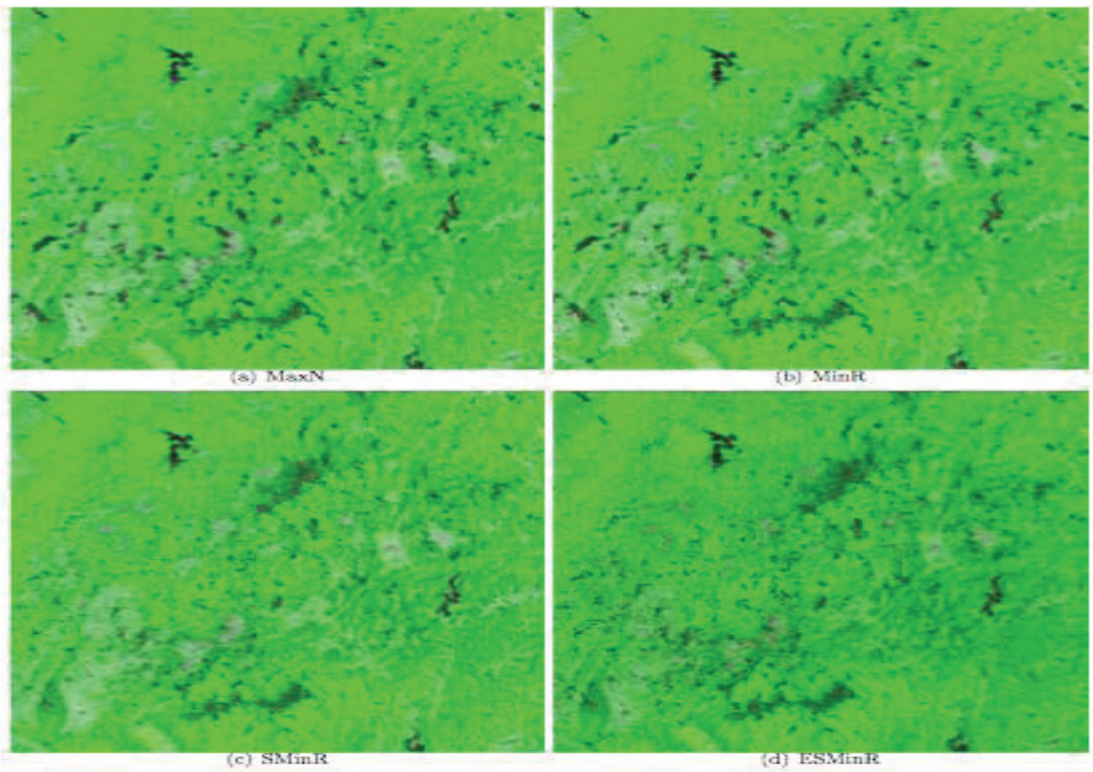


Figure 4. Comparison of 10-days cloud-free images with four types of compositing methods in forest

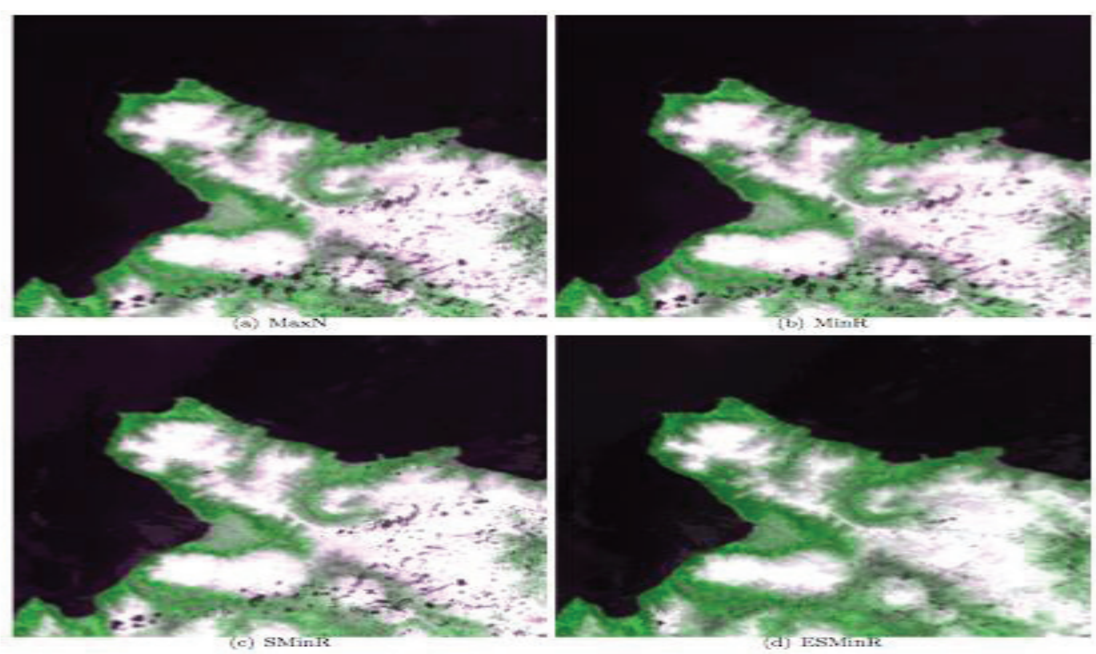


Figure 5. Comparison of 10-days cloud-free images with four types of compositing methods in snow and ice

Figure 6 shows the result of 10-days cloud-free images with four types of compositing method in urban. MaxN and MinR have a patch of cloud over the urban area, however, SMin R and ESMinR do not have any cloud shadows.

Figure 7 shows the result of 10-days cloud-free images with four types of compositing method in water. All the four methods do no have any significant cloud shadow effects, however, SMinR has the least patches of cloud shadows among four of them.

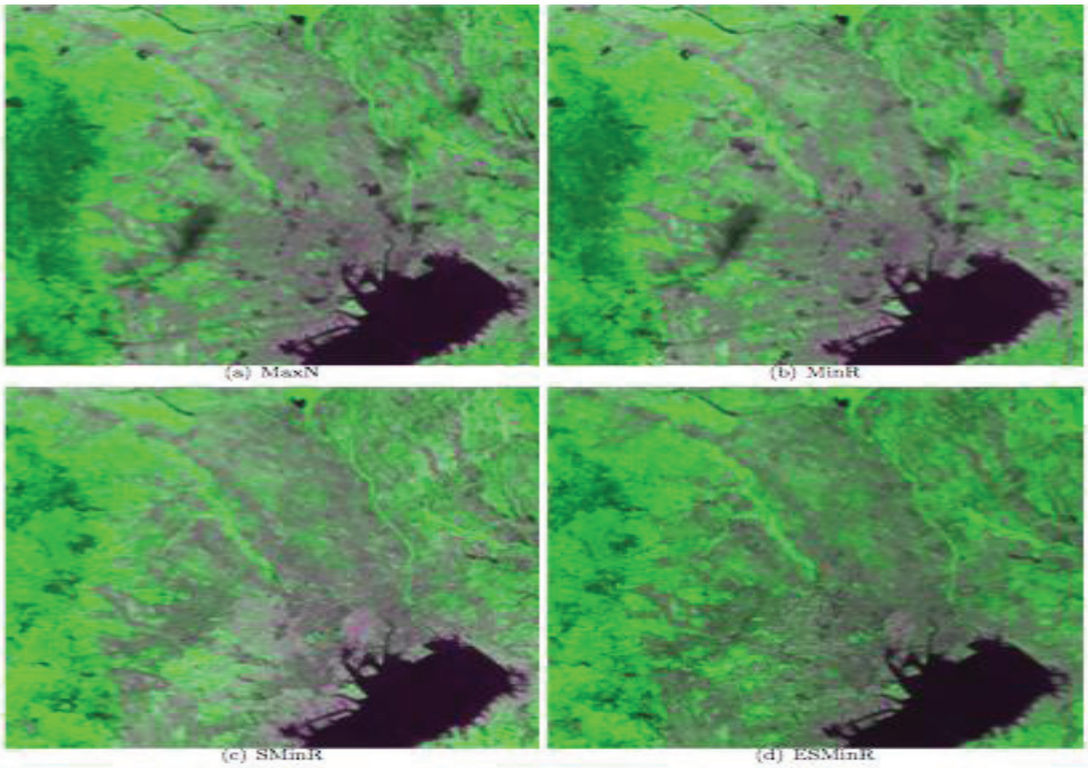


Figure 6. Comparison of 10-days cloud-free images with four types of compositing methods in urban

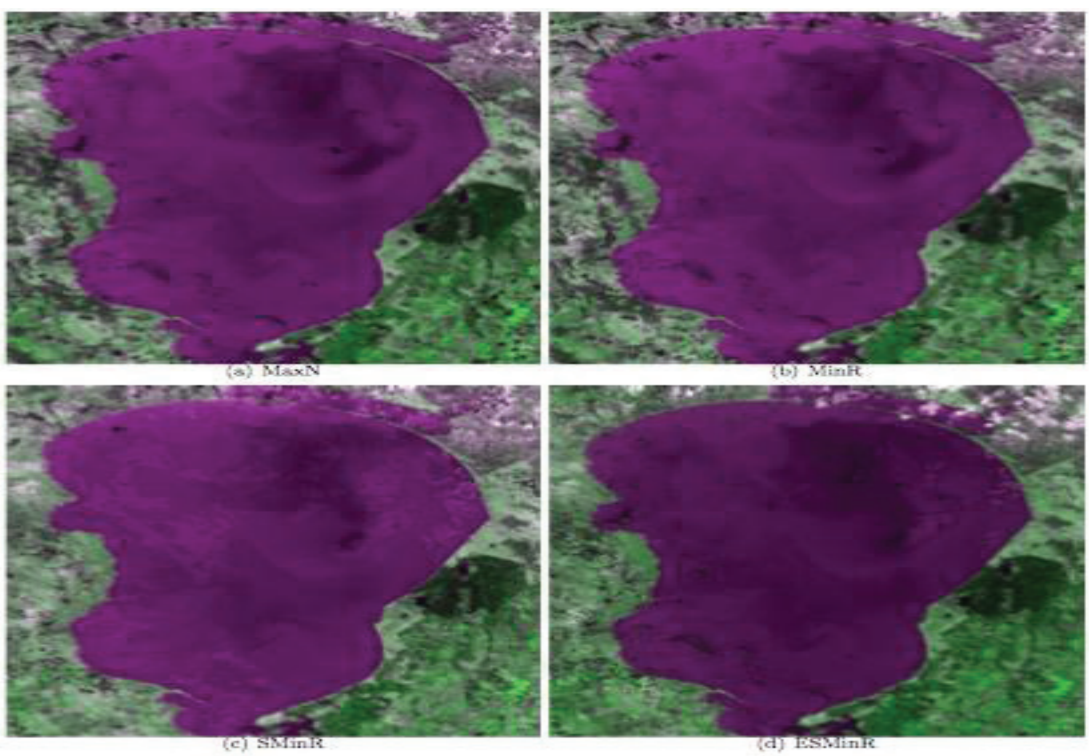


Figure 7. Comparison of 10-days cloud-free images with four types of compositing methods in water

3.3 Comprehensive Evaluation of Compositing Methods

The comparative performances of the above mentioned four compositing methods are judged from five criterion including cloud screening, satellite zenith angle, smoothness of the imagery, snow/ice identification and shadow. The evaluation was conducted over 1-year of data in four scenes; spring (MAM), summer (JJA), autumn (SON) and winter (DJF). Visual interpretation and computation are used to give marks to them. The scores of those methods are shown in Table 2.

This result shows that ESMinR method had the best performance over 1-year of compositing period. MaxN method showed very low performance at any time of the season and it is concluded that it is not appropriate to make cloud-free composite with MODIS data.

Table 2. Comparative performances of four compositing methods judged from five criterion including cloud screening, satellite zenith angle, smoothness of the imagery, snow/ice identification and shadow

Items	MaxN	MinR	SMinR	ESMinR
Cloud screening (Spring)	1	3	2	4
Satellite zenith angle (Spring)	1	4	2	3
Smoothness of the imagery (Spring)	1	3	2	4
Snow/ice identification (Spring)	1	4	2	3
Cloud shadow (Spring)	2	1	3	4
Sum (Spring)	6	15	11	18
Cloud screening (Summer)	1	34	3	2
Satellite zenith angle (Summer)	1	4	2	3
Smoothness of the imagery (Summer)	1	4	2	3
Snow/ice identification (Summer)	1	3	2	4
Cloud shadow (Summer)	2	1	3	4
Sum (Summer)	6	16	12	16
Cloud screening (Autumn)	1	4	2	3
Satellite zenith angle (Autumn)	1	2	4	3
Smoothness of the imagery (Autumn)	1	4	2	3
Snow/ice identification (Autumn)	N/A	N/A	N/A	N/A
Cloud shadow (Autumn)	3	1	2	4
Sum (Autumn)	6	11	10	13
Cloud screening (Autumn)	1	4	2	3
Satellite zenith angle (Autumn)	1	3	4	2
Smoothness of the imagery (Autumn)	1	4	2	3
Snow/ice identification (Autumn)	1	3	2	4
Cloud shadow (Autumn)	2	1	3	4
Sum (Autumn)	6	15	13	16
Total	24	57	46	63

4. Concluding Remarks

In this study, cloud and shadow free compositing technique with MODIS MODIS quarter kilometers (QKM) spatial resolution in channel 1 and 2 are newly developed, validated and implemented. As a result, a compositing method based on an enhanced minimum second red criteria is considered to be appropriate to achieve our objectives. Secondly, the 10-days composite images are created using seven methods including maximum NDVI criterion (MaxN), minimum red criterion (MinR), second minimum red criterion (SMinR), maximum NDVI with constrained scan angle criteria (NMinS), minimum red with constrained scan angle criteria (RMinS), second minimum red with constrained scan angle criteria (SRMinS), enhanced second minimum criteria (ESMinR) over Japan main islands using 1-year of Terra MODIS data received at the direct broad casting system at University of Tokyo campus. Finally, the comparative performances of the above mentioned seven compositing methods are judged from five criterion including cloud screening, satellite zenith angle, smoothness of the imagery, snow/ice identification and shadow. It is concluded that the newly developed ESMinR method produces fairly consistent results with possible refinements and more sophisticated method to overcome both cloud contamination and shadow problem.

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