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Convective Cloud RGB Product and Its Application to Tropical Cyclone Analysis Using Geostationary Satellite Observation

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Abstract: Red-Green-Blue (RGB) imagery techniques are useful for both forecasters and public users because they are intuitively understood, have advantageous visualization, and do not lose observational information. This study presents a novel RGB convective cloud product and its application to tropical cyclone analysis using Communication, Oceanography, and Meteorology (COMS) satellite observations. The RGB convective cloud product was developed using the brightness temperature differences between WV (6.75 μm) and IR1 (10.8 μm), and IR2 (12.0 μm) and IR1 (10.8 μm) as well as the brightness temperature in the IR1 bands of the COMS, with the threshold values estimated from the Korea Meteorological Administration (KMA) radar observations and the EUMETSAT RGB recipe. To verify the accuracy of the convective cloud RGB product, the product was applied to the center positions analysis of two typhoons in 2013. Thus, the convective cloud RGB product threshold values were estimated for WV-IR1 (−20 K to 15 K), IR1 (210 K to 300 K), and IR1-IR2 (−4 K to 2 K). The product application in typhoon analysis shows relatively low bias and root mean square errors (RMSE)s of 23 and 28 km for DANAS in 2013, and 17 and 22 km for FRANCISCO in 2013, as compared to the best tracks data from the Regional Specialized Meteorological Center (RSMC) in Tokyo. Consequently, our proposed RGB convective cloud product has the advantages of high accuracy and excellent visualization for a variety of meteorological applications.

Keywords: RGB composite image, convective clouds, Typhoon, GEO, satellite remote sensing

1. Introduction

The first geostationary operational meteorological satellite; Communication, Oceanography and Meteorology (COMS), with five channels including one visible and four infrared (IR) was successively launched in 2010 and will be operated by the Korea Meteorological Administration (KMA) until 2020. COMS, at 128.2°E offers a spatial coverage of the Western Pacific region (Woo et al., 2018). It also has a similar spatial, temporal, spectral, and radiometric resolution as Himawari-7 (MTSAT-2) and the Geostationary Operational Environmental Satellite (GOES)-3rd generation satellites. The second geostationary operational meteorological satellite, GEO-KOMPSAT 2A, as a successor to COMS, was launched in 2018. GEO-KOMPSAT 2A has an Advanced Meteorological Imager (AMI) similar to those of GOES-R and Himawari-8/9 satellites. In addition, Japan launched Himawari 3rd generation satellites, including Himawari-8 and -9 in 2014 and 2016, respectively. The United Sates launched the GOES-R, -S, -T, U in 2016, 2017, 2019, and 2024, respectively. Table 1 summarizes the spectral characteristics of the GEO-KOPMSAT 2A/AMI, Himawari 8/9/AHI, GOES-R/ABI, and COMS/ Meteorological Imager (MI) sensors. In the era of next-generation geostationary meteorological satellites, most geostationary meteorological satellites observe the Earth with 16 channels including three visible and 13 IR bands. The spatial resolution is doubled from 4km to 2km

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at nadir for the IR channels.

RGB compositing techniques has been helpful for operational users, such as forecasters, because of their multispectral information content and no loss of satellite- observed information. The RGB was a breakthrough for the detection of various phenomena, enabling multi-channel compression to maximize the visualization, but preserving the cloud patterns as well as providing continuity in time (WMO, 2007). Many of RGB compositing techniques has been developed, for example, for the identification of air mass, dust properties, microphysics, volcanic ashes, snow cover, clouds, fog, and many other geophysical variables (WMO, 2007). In the first RGB composite satellite imagery workshop (held in Boulder, U.S.A. during June 5-6, 2007), standards and guidance on RGB imagery was recommended (WMO, 2007). In the second RGB satellite products workshop (held at Seeheim in Germany on September 17-19, 2012), the RGB standards and best practices to support operational forecasting applications and training were accessed (WMO, 2012).

This study presents a novel RGB convective cloud product based on the infrared channels using COMS satellite data, and its application to the center positions of typhoons to verify its advantage in satellite remote sensing.

2. Data and Methods

2.1. RGB color model

The RGB color model is physically based on the tri-chromatic theory, where three color components of lights such as red, green, and blue can make any visible color (Ford and Roberts,1998). Thus, any color can be decomposed into red, green, and blue components as follows (Ford and Roberts,1998; Ban et al., 2017):

$$C_{i,j,k}=R_i\cdot\hat{\imath}+G_j\cdot\hat{\jmath}+B_k\cdot\hat{k},\ \ 0\le i,j,k<2^n \tag{1}$$

where $C_{i,j,k}$ is the color. R_i, G_j, and B_k are the units of red, green, and blue colors, repectively. i, j, and k represent the red, green, and blue color saturations from 0 to 2^n, respectively. n is the bit number of the display system. $\hat{\imath}$, $\hat{\jmath}$, and $\hat{k}$ are the unit vectors in RGB color space, respectively (Ban et al., 2017).

The appropriate selection of satellite observation data is determined empirically using the characteristics of spectral bands (Ban et al., 2017). In this study, we are mapping three different satellite-observed data such as brightness temperature (T_B) or reflectance to red, green, and blue colors of RGB color space, respectively. Therefore, the R_i, G_j, and B_k can be expressed as a function of T_Bs at three different channels of satellite sensors. We matched the maximum and minimum values of T_B at each channel i, j, and k to the range of R_i, G_j, and B_k color saturations from 0 to 2^n as follows (Ban et al., 2017):

$$R_i=2^n\cdot\left[\frac{T_{B,i}-T_{B,MIN}}{T_{B,MAX}-T_{B,MIN}}\right]^{\frac{1}{\Gamma}},\ \text{at channel } i \tag{2}$$

$$G_j=2^n\cdot\left[\frac{T_{B,j}-T_{B,MIN}}{T_{B,MAX}-T_{B,MIN}}\right]^{\frac{1}{\Gamma}},\ \text{at channel } j \tag{3}$$

$$B_k=2^n\cdot\left[\frac{T_{B,k}-T_{B,MIN}}{T_{B,MAX}-T_{B,MIN}}\right]^{\frac{1}{\Gamma}},\ \text{at channel } k \tag{4}$$

where $T_{B,i}$, $T_{B,j}$, and $T_{B,k}$ are the brightness temperatures observed at three different channels i, j, and k of the satellite sensors, respectively. Γ is the correction factor.

In this study, we use T_Bs at COMS/MI 6.75 μm band and two LWIR bands of 10.8 μm, and 12.0 μm as input data into a new RGB image product for convective cloud detection with Γ=T1 and n=8. COMS, as a geostationary satellite, has a temporal resolution for the full disk of the Earth every 30 minutes. For the rapid scan mode, COMS observes the Korean Peninsula in the rapid scan mode every seven to eight minutes. Next, we first describe the three channel RGB product for convective cloud detection. We then apply the proposed RGB method to analyze the center of typhoons and finally; we compare the results with best-track data.

2.2. RGB products for convective clouds

We develop a RGB composite product for detecting convective cloud combining the brightness temperature differences between WV (6.75 μm)-IR1 (10.8 μm), and IR2 (12.0 μm)-IR1 (10.8 μm), and the brightness temperature in the IR1 bands of the COMS satellite. The split window IR channel difference (IR1-IR2) is usually used for discriminating the clouds from aerosol or dust. An IR channel difference (WV-IR1) is useful for recognizing the developing convective clouds (Kurino, 1997); and IR1 channel is useful to detecting the surfaces and clouds.

Our RGB product can be explained as a combination of three satellite algorithm-based products. In addition, the presented RGB imagery has the advantage that there is no discontinuity from day to night because all selected channels are IR bands. For the RGB imagery, the split window IR channel difference (IR1-IR2) regulates the red color. The IR channel difference (WV-IR1) corresponds to the green color. The brightness temperature at channel IR1 is regulated by the blue color (Kim et al., 2013).

We present the threshold values (Kim et al., 2012) based on the ground radar observation (rain rate datasets observed from the Korea radar network system using a recent Convective Rainfall Rate (CRR) Look-Up Table (LUT), one of the Nowcasting products in EUMETSAT/NWCSAF (SAFNWC, 2009) compared with COMS satellite observations from May to September in 2011 and 2012, i.e., for a total of ten months.

2.3. Center location analysis of Typhoons Danas and Francisco in 2013: a case study

Consequently, Typhoons Danas (from October 6, 2013 00:00 UTC to October 9, 2013 00:00 UTC) and Francisco (from October 17, 2013 18:00 UTC to October 25, 2013 21:00 UTC) are used to estimate the accuracy of the proposed three channel convective cloud RGB product. In this study, we used the center location analysis data of Typhoons Danas and Francisco provided by the Joint Typhoon Warning Center (JTWC) and the Cooperative Institute for Meteorological Satellite Studies (CIMSS).

Table 1. Comparison of the GEO-KOMPSAT2A/AMI, Himawari-8/AHI, GOES-R ABI, and COMS/MI spectral bands

COMS MI	AMI	AHI	ABI
Central wavelength (μm)			
	0.47	0.46	0.47
	0.511	0.51	-
0.67	0.64	0.64	0.64
	0.856	0.86	0.865
	1.38	-	1.378
	1.61	1.6	1.61
	-	2.3	2.25
3.75	3.830	3.9	3.90
	6.241	6.2	6.185
6.75	6.952	7.0	6.95
	7.344	7.3	7.34
	8.592	8.6	8.50
	9.625	9.6	9.61
10.8	10.403	10.4	10.35
	11.212	11.2	11.20
12.0	12.364	12.3	12.30
	13.31	13.3	13.30

The center locations of typhoons using the proposed RGB product were compared to that of the best-track analysis data obtained from the Regional Specialized Meteorological Center (RSMC) Tokyo-Typhoon Center.

3. Results

3.1. RGB product analysis

The KMA CRR LUT is better performed at 10 mm/hr or higher rain rates for East Asia than the NWCSAF CRR in Fig. 1 (Kim et al., 2012). Thus, the channel difference (−20 K to 15 K) between WV and IR1 for the greenish color is determined using the rainfall estimation from matched-up data between COMS and radar data from KMA CRR LUT. From the LUT, the rainfall can be estimated up to 20 mm/h. The dynamic ranges of IR1 for the bluish color are 210 K to 300 K for detecting the wide range of convective clouds. The split window IR

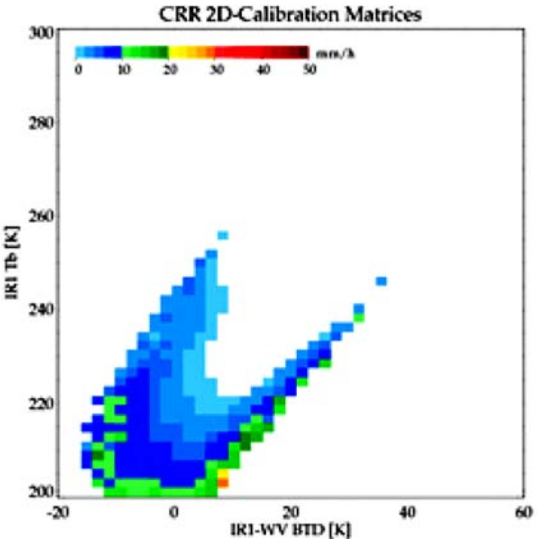

Fig. 1. Lookup table for rainfall intensity using COMS satellite data. The COMS and ground radar (CAPPI-1.5km, CMAX) observation data were spatially and temporally collocated from May to September in 2011 and 2012, i.e., for a total of ten months.

channel difference (10.8-12.0 μm) ranges from −4 K to 2 K in reddish color. This refers to the RGB products for the 24-hour cloud microphysics (Kerkmann, 2005). Table 2 summarizes the threshold values for all RGB channels.

In this RGB product, light greenish color indicates that convective clouds have intensified as WV-IR1 increases. The ocher color demonstrates that the convection is weak because WV-IR1 decreases. Pinkish color represents the mid-level clouds and bluish color indicates the effects from IR1. Figure 2 shows the result of the proposed RGB product for detecting the convective clouds at 02:00 UTC on October 7, 2013. Figures 2(a), 2(b), and 2(c) show the reddish, greenish, and bluish color components of the RGB composite imagery using the threshold values of IR2-IR1, WV-IR1, and IR1, respectively. Figure 2(a) shows the split window IR channel difference (WV-IR1), which is useful to detect the overshooting clouds and cloud top height. Figure

Table 2. Channels and threshold values

RGB Color	Channels	Thresholds (K)
Red	IR2-IR1	-4 to 2
Green	WV-IR1	-20 to 15
Blue	IR1	210 to 300

2(b) shows the split window IR channel difference (WV-IR1), which is useful to detect the overshooting clouds and cloud top height. The greenish colors indicate the developing convective clouds while the dark colors represent dry areas. Figure 2(d) exhibits the result of the RGB composite image using the presented RGB algorithm.

3.2. Center location analysis of Typhoons Danas and Francisco in 2013: a case study

Figures 3(a) and 3(b) show the tracks of the center positions of Typhoons Danas and Francisco analyzed by JTWC, JMA, CIMSS, the presented RGB product, and the RSMC best track. The time series of the relative bias of the center of Typhoons Danas and Francisco are shown in Figs. 3(c) and 3(d), respectively. For both cases, all organizations have carried out similar trajectory analysis of Danas and Francisco compared with the RSMC best-track data. The proposed RGB products show a relatively lower bias and a root-mean-square-error (RMSE) of 23 and 28 km for Danas, and 17 and 22 km for Francisco with those of JTWC, JMA, CIMMS, and RMSC best-track data. Table 3 summarizes the statistical results of bias and RMSE.

Another benefit of the RGB product is the shorter calculation time for determining the center position of the typhoons because of the clear color contrast compared with the satellite images. Figure 4 shows the example of Typhoons Danas in 2013 and Sanba in 2012. The center of the typhoon is easier to locate in the proposed RGB image product, because it shows the development of the convective clouds near the center location of the typhoon with greater color contrast.

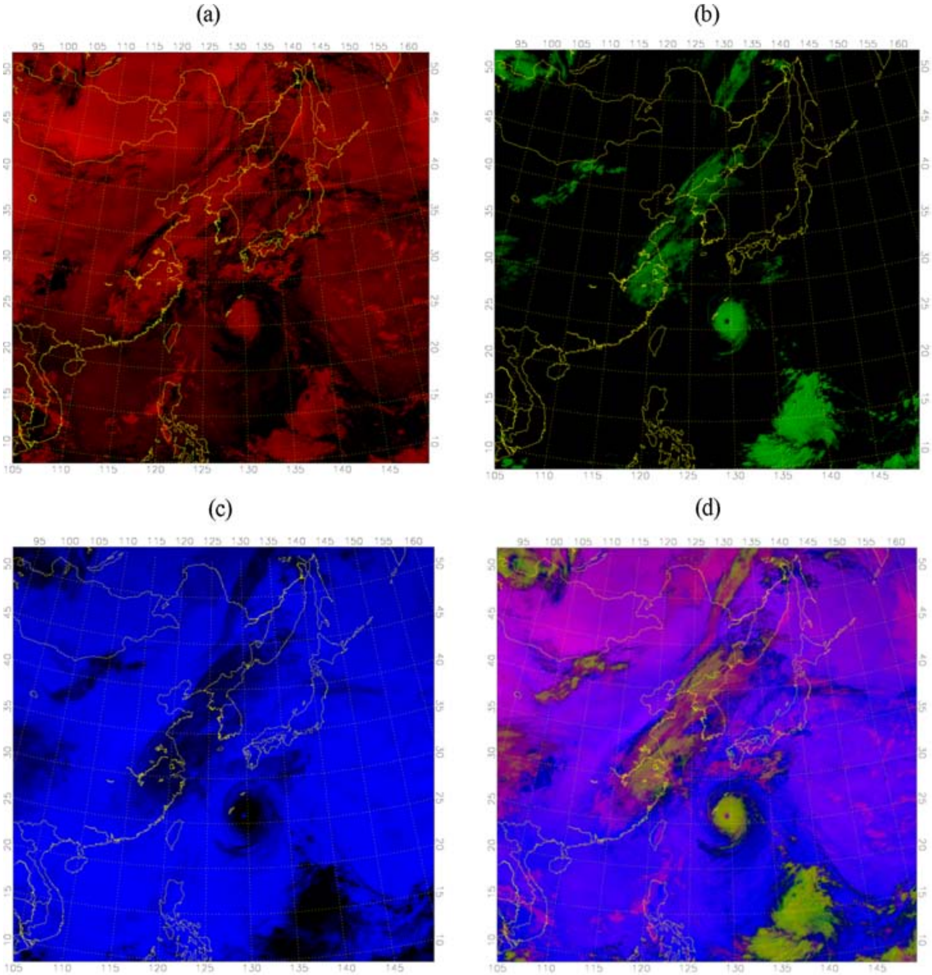

Fig. 2. COMS channel difference images using (a) IR2-IR1, (b) WV-IR1, (c) IR1, and (d) RGB composite. Data are from 02:00 UTC October 7, 2013, the period when Typhoon Danas was developing.

4. Discussion and Concluding Remarks

Recently, the advanced GEO meteorological satellites with 16 channels of meteorological imagers, such as GOES-R/ABI, Himawari-8/AHI, and Geo-KOPMSAT2A/AMI, has been operated for meteorological purposes. Compared with the previous operational meteorological satellites, the spectral, spatial, and temporal resolution are greatly improved. RGB image techniques are beneficial to forecasters because RGB images appear in natural colors, maintaining the textures of clouds without loss of satellite observations, and are easily made into an animation for better visualization.

In this study, we propose a unique convective cloud RGB product using brightness temperatures at IR2-IR1, WV-IR1, and IR1 of COMS satellite because these channels are useful for detecting clouds, convection, and surface, respectively. Such a convective cloud RGB product has not been developed in previous studies. This study estimated the threshold values of convective cloud RGB product. The threshold values of brightness temperature difference between COMS WV and IR1 bands for green color saturation were calculated from the comparison with KMA radar observation data from May to September in 2011 and 2012. The threshold values of brightness temperature difference between IR2 and IR1 for green color

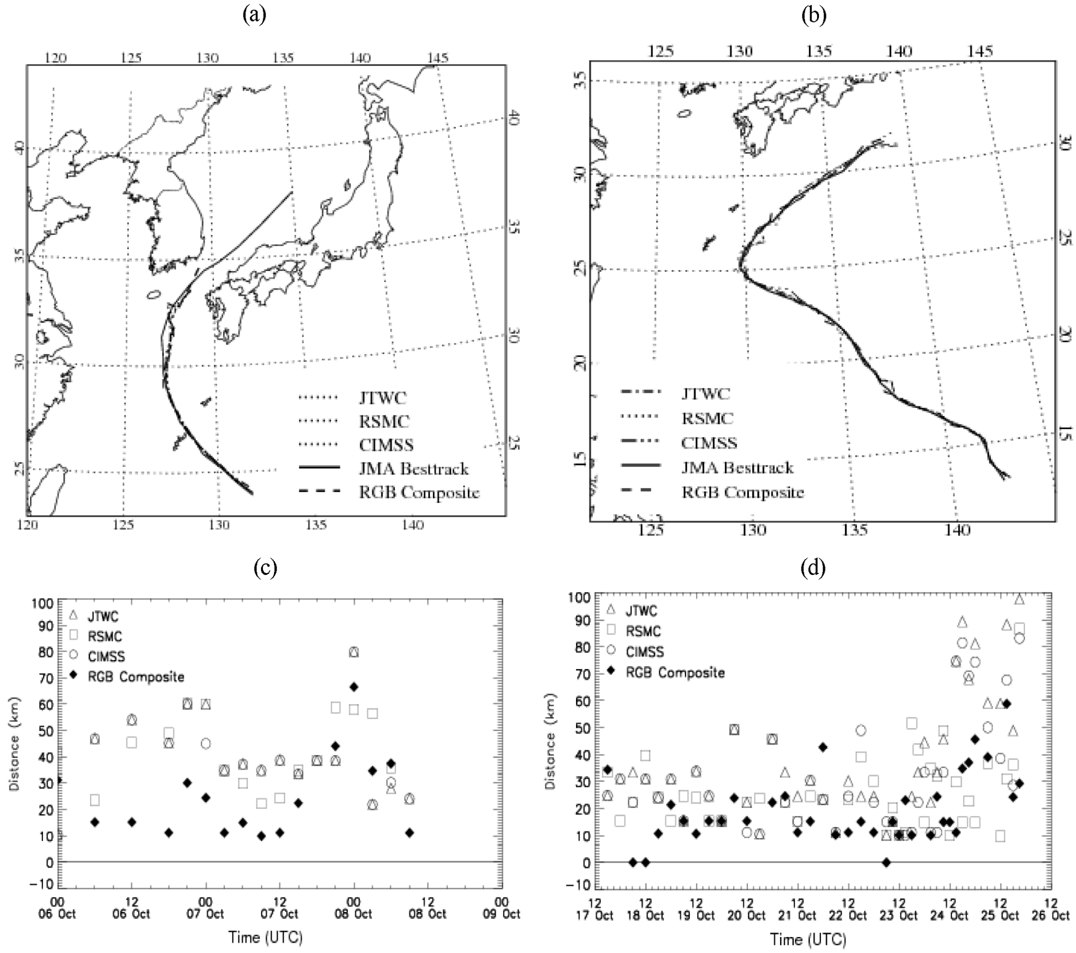

Fig. 3. Case study of Typhoons Danas and Francisco. Data for Danas are from 00:00 UTC on October 6 to 00:00 UTC on October 9, 2013; those for Francisco are from 18:00 UTC on October 17 to 21:00 UTC on October 25, 2013. Center positions of (a) Danas and (b) Francisco in 2013 analyzed by JTWC, JMA, CIMSS, RGB product, and RSMC best track. Time series of biases of the center position for (c) Danas and (d) Francisco between JTWC, JMA, CIMSS, RGB product, and RMSC best-track data.

saturation, and the brightness temperature at COMS IR1 for blue color saturation were determined using EUMETSAT RGB recipe and empirical tests, respectively.

Table 3. Bias and RMSE of center position analysis for typhoons Danas and Francisco from RSMC best-track data

Typhoon	Danas		Francisco	
	Bias (km)	RMSE (km)	Bias (km)	RMSE (km)
JTWC	40.405	43.478	38.060	46.056
JMA	47.475	53.721	26.610	60.682
CIMSS	39.647	42.484	33.667	41.139
RGB	22.969	27.889	17.352	22.133

We applied the presented convective cloud RGB image technique to analyzing the centers of Typhoons Danas and Francisco. Validation with the RSMC best-track data shows that the proposed RGB products produce relatively low uncertainty for analyzing the center of the two typhoons compared with JTWC, JMA, and CIMMS data. In addition, the RGB product is useful for reducing the time needed by forecasters for determining the center of the typhoon because of the heightened color contrast compared with the black and white satellite images. Consequently, the proposed RGB imagery is helpful for operational

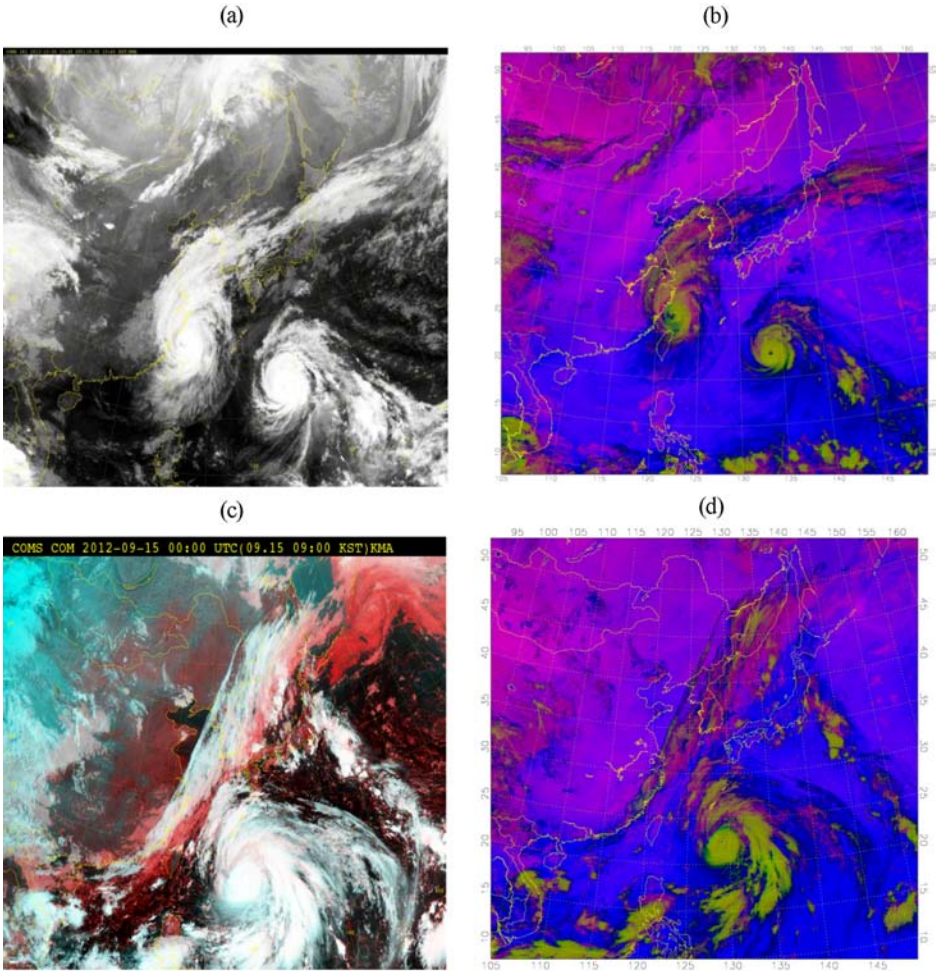

Fig. 4. (a) COMS IR1 observation image and (b) the proposed RGB image for Danas at 10:45 UTC on October 6, 2013. (c) The current 2-channel RGB composition using COMS visible and IR1 observations and (d) the proposed RGB image for Typhoon Sanba at 00:00 UTC on September 15, 2012.

purposes in detecting convective clouds and the centers of typhoons with less dependence on the experience and objectivity of the forecaster.

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References

Ban, H.-J., Kwon, Y.-J., Shin, H., Ryu, H.-S., and Hong, S., 2017, Flood monitoring using satellite-based RGB composite imagery and refractive index retrieval in visible and near-infrared bands. Remote Sensing, 9, 313.

Ford, A., and Roberts, A.,1998, Colour space conversions. Westminster University, London, United Kingdom, 1-31.

Kerkmann, J., 2005, RGB Composites with Channels 01-11 and their Interpretation. MSG Interpretation Guide. http://oiswww.eumetsat.org/WEBOPS/msg_interpretation/PowerPoints/Channels/rgbpart04_20050420.ppt (April 20th 2005).

Kim, Y., Kim, S., Sohn, E., Kim, K.-L., and Hong, S., 2013, Convective clouds detection using RGB composite imagery with COMS observation. 4th Asia-Oceania Meteorological Satellite Users Conference, Melbourne, Australia.

Kim, S., Sohn, E., Chung, S.-R., Choi, B.-C., 2012, Rainfall rate retrieval from COMS satellite for nowcasting in KMA/NMSC. EUMETSAT Meteorological Satellite Conference, Sopot, Poland.

Kurino, T., 1997, A satellite infrared technique for estimating "deep/shallow" precipitation. Advances in Space Research, 19, 511-514.

Satellite Application Facility on Support to Nowcasting and Very Short Range Forecasting (SAFNWC), 2009, Algorithm Theoretical Basis Document for "Convective Rainfall Rate" (CRRPGE05 v3.0).

World Meteorological Organization (WMO), 2012, WMO/ EUMETSAT workshop on RGB satellite products. Final Report. http://www.wmo.int/pages/prog/sat/documents/ RGB-WS-2012_FinalReport.pdf (September 17-19th 2012).

World Meteorological Organization (WMO), 2007, RGB Composite Satellite Imagery Workshop. Final Report. http://www.wmo.int/pages/prog/sat/documents/RGB-1_Final-Report.pdf (June 5-6th 2007).

Woo, H.-J., Park, K.-A., Li, X., and Lee, E.-Y., 2018, Sea surface temperature retrieval from the first korean geostationary satellite COMS data: validation and error assessment, Remote Sensing, 10, 1916.

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