REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
26-02-2013	Conference Proceeding	

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Inter-Sensor Comparison of Satellite Ocean Color Products from GOCI and MODIS	
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER 0601153N
6. AUTHOR(S) Ruhul Amin, Richard Gould, Sherwin Ladner, Igor Shulman, Jason Jolliff, Peter Sakalaukus, Adam Lawson, Paul Martinolich and Robert Arnone	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER 73-9435-A2-5
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory Oceanography Division Stennis Space Center, MS 39529-5004	8. PERFORMING ORGANIZATION REPORT NUMBER NRL/PP/7330--12-1580
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research One Liberty Center 875 North Randolph Street, Suite 1425 Arlington, VA 22203-1995	10. SPONSOR/MONITOR'S ACRONYM(S) ONR
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution is unlimited.

20130422094

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Geostationary Ocean Color Imager (GOCI) is the first geostationary ocean color satellite sensor that collects images every hour during the day. This high temporal frequency can lead to improved understanding of short time scale optical and bio-optical variability in the ocean surface. However, such study can be complicated by the imperfect atmospheric corrections particularly in turbid coastal waters. In this study we use the Red Band Difference (RBD) & the Fluorescence Line Height (FLH) algorithms, which have been found to be less sensitive to atmospheric corrections & CDOM absorption, to separate waters with high algal & non-algal particles from the GOCI imagery and monitor their movement. The Moderate Resolution Imaging Spectroradiometer (MODIS) imagery is used as the ground truth and good agreement is found between the two sensors. The dynamics of the turbid waters observed by GOCI is consistent with currents predicted by the Navy Coastal Ocean Model (NCOM).

15. SUBJECT TERMS

satellite ocean color products, GOCI, MODIS, phytoplankton

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Ruhul Amin
					19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	Unclassified	UU	5	228-688-5000

Inter-Sensor Comparison of Satellite Ocean Color Products from GOCI and MODIS

Ruhul Amin[1], Richard Gould[1], Sherwin Ladner[1], Igor Shulman[1], Jason Jolliff[1], Peter Sakalaukus[1], Adam Lawson[1], Paul Martinolich[2], and Robert Arnone[1]

[1]Naval Research Laboratory, Code 7331, Stennis Space Center, Mississippi 39529, USA

[2]Qinetic North America, c/o Naval Research Laboratory, Code 7331, Stennis Space Center, Mississippi 39529, USA

Abstract: The Geostationary Ocean Color Imager (GOCI) was launched by the Republic of Korea on 27 June 2010 and is the first geostationary ocean color sensor in orbit that provides coastal bio-optical properties (such as chlorophyll concentration, absorption and backscattering coefficients) at unprecedented high spatial and temporal resolution. GOCI has 8 spectral bands covering 2,500 km × 2,500 km (centered 130E, 36N) at 500 m spatial resolution. Unlike polar-orbiting satellites which provide only one or two images of the same geographic area per day, GOCI collects images every hour from 9am to 4pm (eight images per day). This high temporal resolution can lead to improved understanding of short time scale optical and bio-optical variability in the ocean surface. However, retrieving ocean color products accurately can be challenging particularly in turbid coastal waters due to imperfect atmospheric correction. In this study, we process GOCI data through US Naval Research Lab's Automated Processing System (APS) and the standard GOCI Data Processing System (GDPS) distributed by the Korea Ocean Satellite Center (KOSC), and compare the retrieved ocean color products from the two processing systems. We use corresponding Moderate Resolution Imaging Spectroradiometer (MODIS) images as the ground truth to assess the performance of the two processing systems. Since these sensors can retrieve Fluorescence Line Height (FLH) which is less sensitive to atmospheric correction and colored dissolved organic matter (CDOM), we also compare the FLH products from these sensors, in addition to other ocean color products. Furthermore, we demonstrate the use of hourly GOCI images to detect and track features such as sediment plumes and algal blooms in the ocean surface.

1. Introduction:

GOCI background and Sensor specification: The Geostationary Ocean Color Imager (GOCI) is one of the three payloads of the Korean Communication, Ocean and Meteorological Satellite (COMS) that was successfully launched in June 2010 from the Space Center in Kourou, French Guiana by Ariane 5 Launch Vehicle. GOCI is the world's first geostationary ocean color sensor designed with visible and near-infrared band that can measure radiance from the ocean surface. The advantage of GOCI is that it can obtain images every hour during the day and make it possible to monitor ocean in near real time. GOCI covers 2,500 × 2,500 km square around Korean peninsula centered at 36°N and 130°E with about 500 m pixel size and it is comprised of sixteen (4×4) slot images. It also has very high signal-to-noise ratio (over 1 thousand) which is advantageous for ocean color study since radiance from the ocean is very low. GOCI has six visible bands with band centered at 412 nm, 443 nm, 555 nm, 660 nm and 680 nm, and two near-infrared bands with band center at 745 nm and 865 nm. The life expectancy of GOCI mission is about seven years.

Capability of GOCI: over other sensor. Polar-orbiting satellite sensors such as MODIS and MERIS have been widely used for ocean color studies. However, those sensors have limitations in monitoring dynamic variation such as daily or hourly variation of the ocean surface. These sensors typically collect data at about 1km resolution and 1 image per day in cloud-free periods. While these sensors provide an enormous advantage in terms of spatial coverage, cloud coverage is a serious restriction for these sensors. Daily revisit time is another limitation for these sensors particularly in optically complex coastal waters which frequently changes due to tide, wind-driven advection, resuspension, etc. For these reasons, a geostationary sensor with high temporal frequency is ideal. Unlike polar-orbiting satellites which provide only one or two images of the same geographic area per day, GOCI collects images every hour from 00:00 GMT to 07:00 GMT (total eight images per day). This high frequency image acquisition makes it possible to study more detailed time-series analyses and movement of red tide, sediments, CDOM plume, etc. This also makes it a great tool for detecting, monitoring and predicting short term and long term biophysical phenomena and optical and bio-optical properties of the waters. It is a great tool for monitoring health of the marine ecosystem, coastal zone and resource management and marine fisheries information.
High frequency satellite observations are critical to studying and quantifying biological and physical processes within the coastal ocean.

Drawbacks of geo-sensors: Cost increases greatly for higher orbit geostationary platforms compare to polar-orbiting platforms and gives a reduction in spatial resolution for the same optical system.
Global constellations of geostationary atmospheric chemistry and coastal ocean color sensor are a possibility by 2020 [Fishman et al.,].

Previous ocean color study with geo-sensors: Although GOCI is the first geostationary ocean color sensor, geostationary platforms with the Spinning Enhanced Visible and InfraRed Image (SEVIRI) meteorological sensor has been used to map Total Suspended Matter (TSM) in turbid coastal waters [Neukermans et al., 2009]. GOCI also has been used to show sediment movement around the coastal region of Korean Peninsula [refs]. However, those studies used algorithms that are sensitive atmospheric correction. In this study we use algorithm that are less sensitive to atmospheric corrections [Amin et al., 2009].

Goal of this study: The objective of this study is to test the feasibility of separating algal and non-algal component from the turbidity map using GOCI sensor and to determine whether high frequency dynamics can be detected. We also track the features using hourly GOCI images. GOCI atmospherically corrected data is tested against MODIS data for validation then high frequency dynamic is presented. Our result suggest that (1) mapping of turbidity is feasible with FLH, (2) turbidity maps are well correlated with MODIS (3) high concentrations of algal and non-algal component separation is also possible and agreement between the two sensors are well. Finally, conclusions are drawn regarding feasibility of turbidity mapping, algal and non-algal component separation and recommendations are made for improving retrieval algorithm and atmospheric corrections. We qualitatively investigate daily variation in turbidity due to algal and non-algal particles in the coastal waters of Korean Peninsula. In this study, we only compare APS and GDPS results qualitatively and detect same bio-optical feature using both processing approaches.

2. Materials and methods:

Satellite Data: We acquired all eight GOCI L1B data from April 5, 2011 and processed them for comparison with MODIS image for qualitative validation purpose. Out of these eight GOCI images, we excluded first and last images from the study considering the intensity of illumination according to the sun angle. GOCI L1B data was processed through the standard GOCI Data Processing System (GDPS) and level-2 data was generated. GDPS have the atmospheric correction algorithms, as the spectral shape matching method (SSMM) and the sun glint correction algorithm (SGCA), and BRDF algorithm to solve bi-directional problem [Han H J et al., 2010 Proc. Of SPIE, 7861:786108-1-8]. GDPS is also capable of generating ocean color products such as chlorophyll concentration, suspended sediment, and CDOM. However, for this study we only used normalized water-leaving radiances (nLw) since FLH and RBD requires nLw or remote sensing reflectance (Rrs). We also processed same L1B data through NRL's APS system. Note that the APS is still under development to make it compatible for GOCI data processing. Thus APS results are preliminary and currently under investigation.

Modeled Data: We used relocatable NCOM model (Navy Coastal Ocean Model), which is physical model providing predictions of currents, Temperature (T) and Salinity (S). We set up the regional NCOM model for the area around Korea. The model is coupled to the global NCOM on open boundaries of the domain, and forced with atmospheric fluxes from the global atmospheric model NOGAPS. The NCODA (Navy Coupled Ocean Data Assimilation) system is used to assimilate satellite SST, glider data etc (what is available).

Algorithms:

The Red Band Difference (RBD) algorithm was developed by taking advantage of the chlorophyll fluorescence emission centered on 685nm (Amin et al., 2009). Since there is nothing else in the water that fluoresces in the red region, the RBD easily identifies chlorophyll rich regions from false chlorophyll-like features from CDOM plumes, sediment plumes, and bottom reflectance. The RBD algorithm is expressed as follows:

$$RBD = nLw(\lambda_2) - nLw(\lambda_1) \qquad (1)$$

where $nLw(\lambda)$ is the normalized water-leaving radiance which is defined as the upwelling radiance just above the sea surface, in the absence of an atmosphere, and with sun directly overhead. The λ_1 represents band 13 or GOCI band 5 and the λ_2 represents MODIS band 14 or GOCI band 6. The RBD approach has been used to detect blooms throughout world using MODIS and MERIS imagery (SPIE Europe paper). In this study, we use the RBD approach for first time on GOCI images to detect high concentration of chlorophyll region. The GOCI FLH products were generated using nLw at bands 5, 6 and 7.

3. Results and Discussion:

Phytoplankton blooms develop over the course of a few days to a week and the complete dynamics of the blooms are not captured by individual LEO sensors. The physiology of phytoplankton cells (chlorophyll content, nutrient uptake, etc.) varies on diel cycles, and this has a significant impact on their growth rate and hence primary production (PP) [Furnas 1990]. Therefore, multiple observations per day over several days would permit more robust satellite based estimates of PP. However, for such estimation, we need more reliable atmospheric correction particularly for the coastal ocean. In coastal waters, the standard NASA NIR atmospheric correction [ref] often fails due to higher turbidity and consequently significant higher radiance contributions in the NIR bands. Since the water-leaving radiance at NIR can no longer be considered negligible for the use of atmospheric correction for turbid waters [47, 57 OE], negative readings may result in the blue-green bands due to the over-correction of the atmosphere [58]. Algorithm that uses blue-green bands [18-20], have been found to perform poorly in coastal waters due to increased absorption of CDOM, increased particle scattering, inaccurate atmospheric correction and shallow bottom reflectance. Since atmospheric correction still remains a challenge in turbid waters, for this study we use algorithm that are less sensitive to atmospheric correction.

Fig. 1a, shows MODIS Aqua chlorophyll image for April 5, 2011 over the Korean Peninsula. Since chlorophyll is retrieve using blue-green bands, it often fails in coastal water and usually over estimate chlorophyll concentrations. It can be seen that chlorophyll concentration is high in the coastal region particularly western and southern region. Fig. 1b, shows corresponding FLH images which show somewhat different features. Note that FLH uses red and NIR band where water absorption is significantly higher than the blue-green region. Thus FLH only sees first few meters of the surface waters. Although FLH can sometimes be used to detect blooms [29], it breaks down in highly scattering waters, where high red peak values in the reflectance are primarily due to contributions from elastic scattering modulated by chlorophyll absorption rather than the fluorescence, thus falsely indicating possible blooms. Thus, as the concentration of non-algal particles (NAP) increases, radiance generally increases as well, and the fluorescence peak becomes a less prominent component of the increased total signal. In contrast, the RBD technique is found to easily differentiate between the two effects, giving positive values under true bloom conditions and negative values in highly scattering waters. However, RBD approach is for high chlorophyll concentration (<1 mg/m3) and it depends on chlorophyll fluorescence quantum yield and the backscattering properties of the particles in the water [Amin et al., 2009]. Even though RBD correlates well with chlorophyll for relatively low backscattering blooms, it varies considerably with variation in the fluorescence quantum yield. Thus to relate RBD to chlorophyll concentration, fluorescence quantum yield is necessary. Fig. 1c shows the corresponding MODIS RBD image where sediment rich area detected by FLH disappears as expected and only true chlorophyll rich area can be seen. This result is consistent with our previous study based on the coastal waters of Florida (Amin et al., 2009). Fig.1d and Fig. 1e shows GOCI FLH and RBD images respectively that was acquired on April 5, 2011 at 04:16 UTC just 16 min after MODIS acquisition. This data was processed using the standard GOCI data processing system, GDPS. The agreement between MODIS and GOCI FLH and RBD images are reasonably good. This is probably due to the fact that these two algorithms are less sensitive to atmospheric correction uncertainties and CDOM absorptions. Fig. 1f shows the APS processed RBD image which agrees fairly well with the GDPS processed RBD image both showing similar biological features in the south eastern Korean coast.

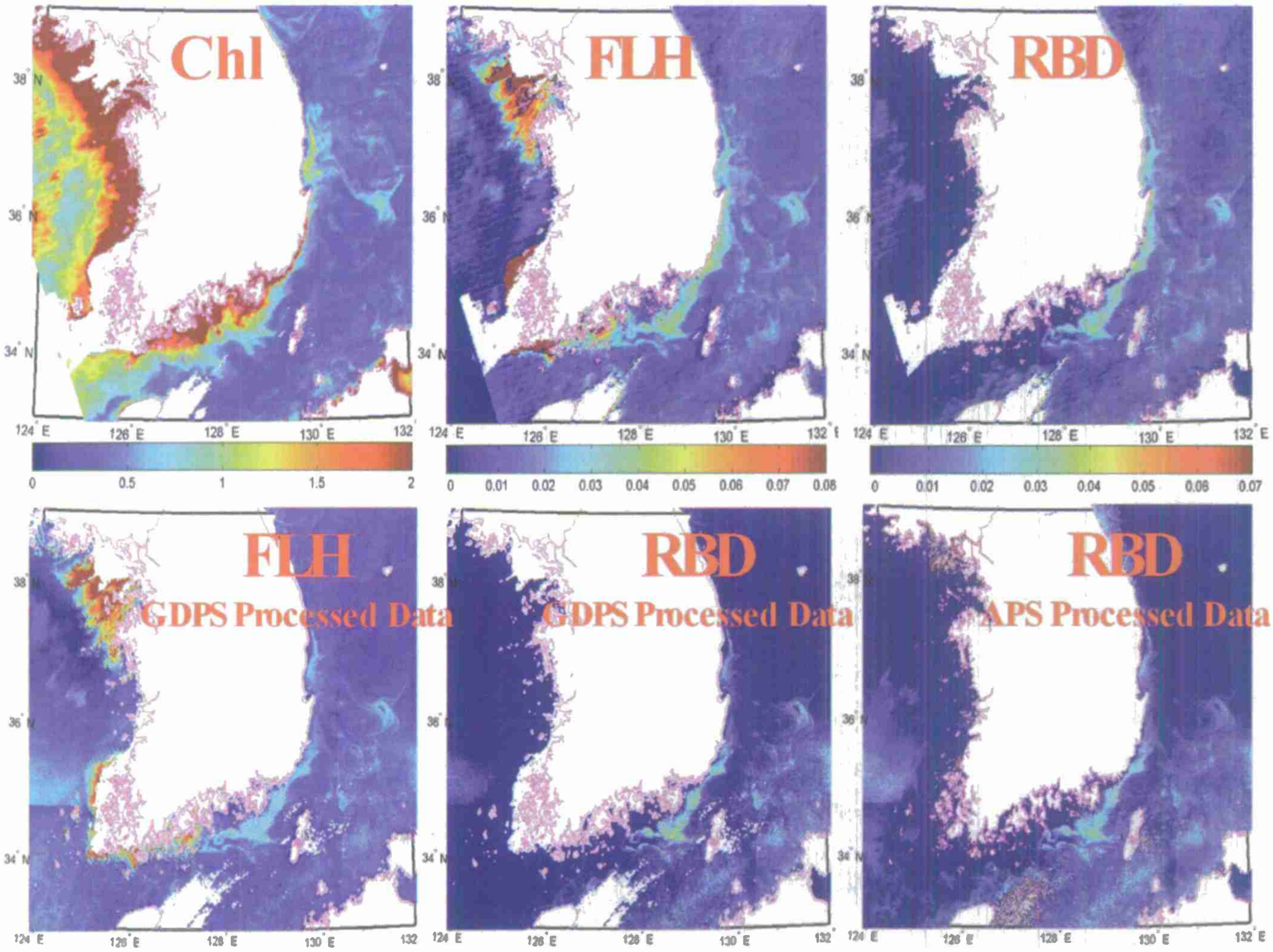

Fig. 1. Top panel showing MODIS ocean color products from April 5, 2011 acquired at 04:00 GMT: (a) Chlorophyll image, (b) FLH image, and (c) RBD image. Bottom panel showing GOCI image for April 5, 2011 that was acquired at 04:16 GMT: (d) GOCI FLH (data processed with GDPS), (e) GOCI RBD (data processed with GDPS), and (f) GOCI RBD (data processed with APS).

APS flag work pretty well compare to GDPS flags. GDPS removes most of the coastal pixels. Also APS does little better with the discontinuity of the quadrant (inter-slot discrepancy). Discontinuity in the GOCI quadrant is not as bad in the chlorophyll image compare to FLH. This is possibly due the fact that chlorophyll algorithm uses ratios which removes some of the discontinuity unlike the FLH which uses difference. Inter-slot discrepancy is significantly higher in fluorescence channel for the high slot.

Connecting chlorophyll fluorescence signal to biomass is complicated by the fact that the quantum yield is difficult to quantify [36] under natural light condition. Generally, it is assumed that the fluorescence quantum yield can vary widely, in a range of 0.3% to 10% [37-39]. Note that the RBD, which retrieves portion of the fluorescence signal from MODIS and MERIS measurements of bloom waters, is dependent on fluorescence quantum yield and correlates very well with the actual fluorescence amplitude for relatively low backscattering blooms such as *K. brevis*. To use fluorescence hence RBD as proxy of chlorophyll concentration requires a priori estimates of quantum yield, which is variable and know to be affected by a number of environmental factors and also species composition. *K. brevis* blooms quantification can be improved if the quantum yield is known.

Fig. 2a shows MODIS SST image for April 5, 2011 while Fig. 2b shows corresponding modeled SST and current using NAVY's NCOM model (ref). Good agreement between the measured and modeled data suggests that NOCOM is capable of generating reasonable SST and current data for the Korean Peninsula.

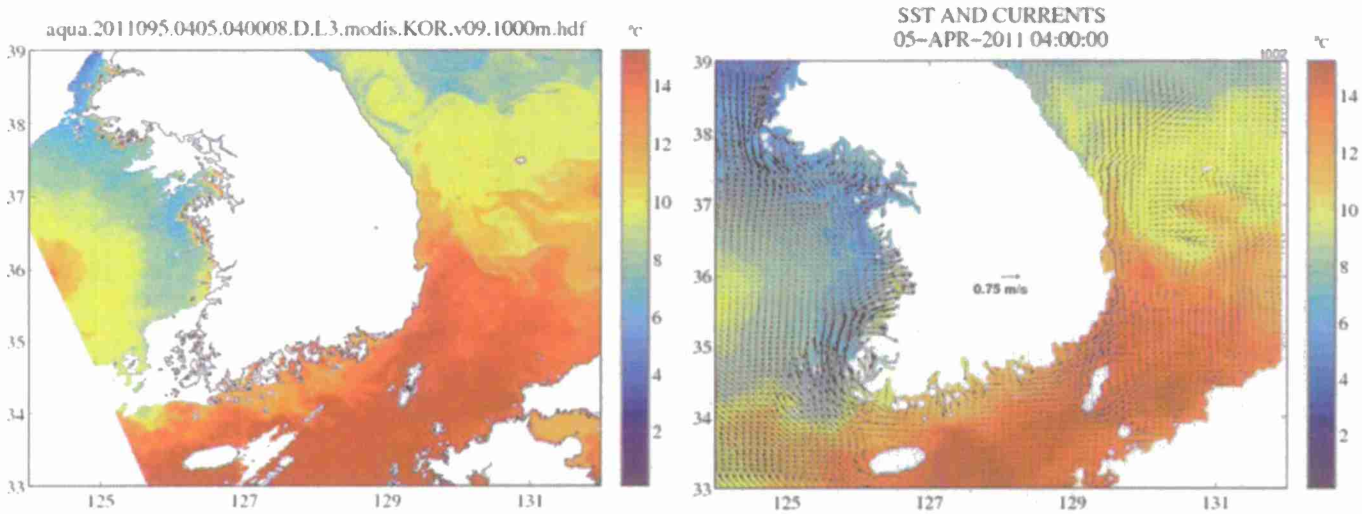

Fig. 2. (a) MODIS SST image for the April 5, 2011 and (b) corresponding NCOM modeled SST with current. Good agreement between the measured and modeled SST suggest that the NOCO is capable of generating good SST products and perhaps current products as well.

<u>Physics of the West Korean Peninsula</u>: The sedimentary environment of the west coast of Korea are influenced by the inland river systems and by the circulation of seawater because of the tidal cycle (Lee et al. 1998; Woo et al., 1998; Woo and Je, 2002). Therefore, a study of the temporal variations of suspended sediment (SS) concentration on the sea surface is important to understand the erosion or sedimentation pattern in coastal regions, especially in the environment of semidiurnal tides (Torres and Morelock, 2002; Zhang et al., 2010). … Water is shallow (<40 m) around Gyeonggi Bay (Ryu et al., 2011). This area has large tidal range (4-8 m) and strong tidal currents (1 – 2 m/s) [Kim and Lim, 2009].

Western tip of the Korean Peninsula, coastal zone adjacent to the city of Mokpo is characterized by shallow water depths (<50 m), relatively strong tidal currents (1 – 2 m/s), and a complicated coastline with numerous islands and extensive tidal flats [kang et al, 2009]. Tidal range (???).

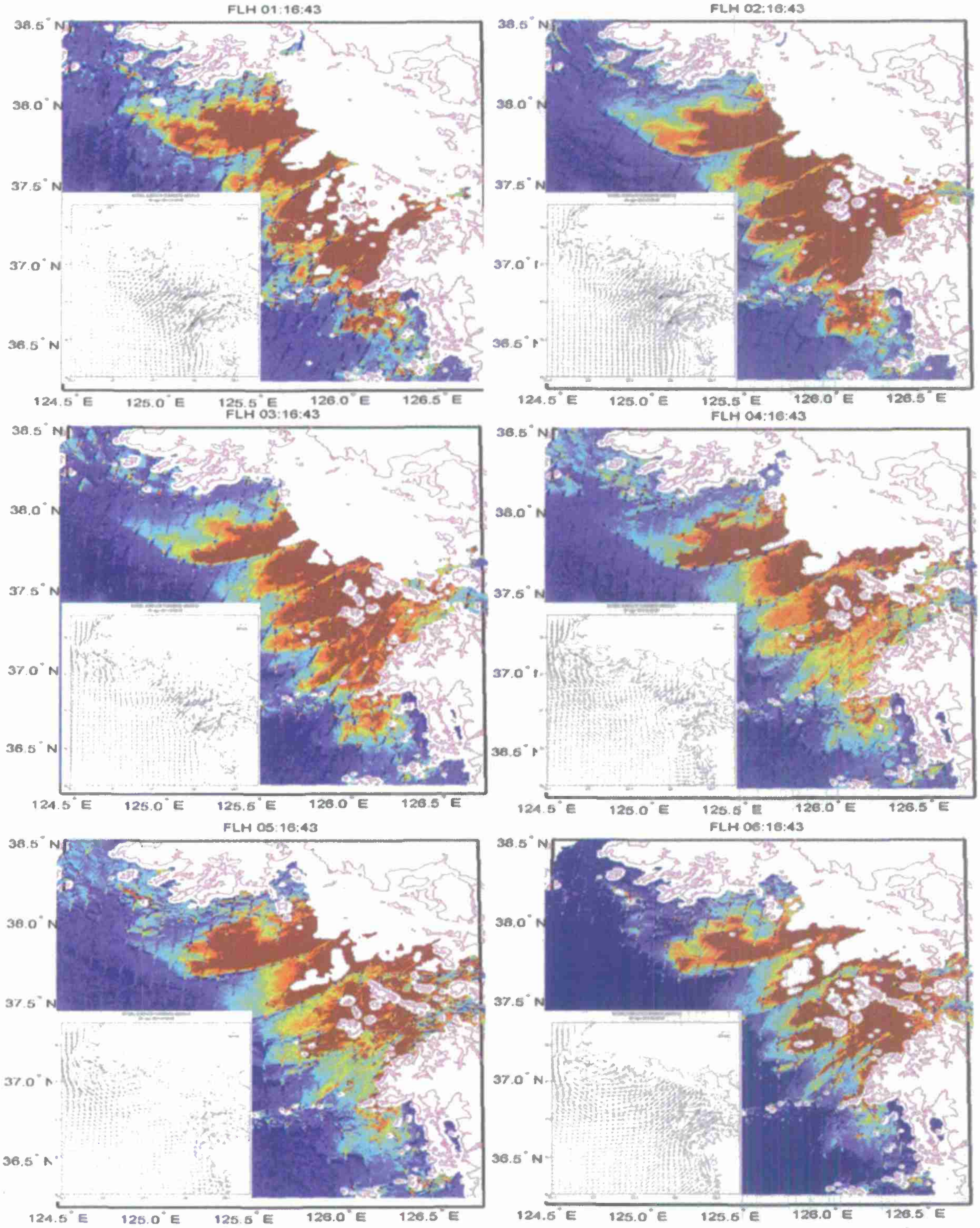

Fig. 3. GOCI FLH images for 6 consecutive hours starting from 01:16 GMT to 06:16 GMT showing the movement of the sediment due to strong tidal forces. Inset shows the corresponding current map predicted by NOCOM.

4. Conclusion:

GOCI can be used effectively to monitor the temporal dynamics of the turbidity due to algal and non-algal particles in the coastal and open waters. This study successfully separate algal and non-algal particles from GOCI and use MODIS as ground truth to validate the results. Good agreement between GOCI and MODIS suggest that GOCI sensor is capable of producing quality ocean color products. Also the sediment movement due to tidal observed particularly on the west coast of the Korean Peninsula suggest that NOCOM is capable of predicting reasonable SST and current map for this region. However the NOCOM modeled and GOCI measured data need to be validate using in-situ measurements.