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One year in orbit of the first Geostationary Ocean Colour Imager (GOCI)

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Abstract—*Geostationary Ocean Colour Imager (GOCI) is the first Ocean Colour Imager to operate from a Geostationary Orbit. It was developed by Astrium SAS under KARI contract in about 3 years between mid 2005 and October 2008 and integrated on-board COMS satellite end 2008 aside the COMS Meteo Imager (MI). COMS satellite was launched in June 2010 and the in-orbit commissioning tests were completed in beginning of 2011.*

The mission is designed to significantly improve ocean observation in complement with low orbit service by providing high frequency coverage. The GOCI is designed to provide multi-spectral data to detect, monitor, quantify, and predict short-term changes of coastal ocean environment for marine science research and application purpose. Target area for the GOCI observation in the COMS satellite covers a large 2500 x 2500 km2 sea area around the Korean Peninsula, with an average Ground sampling distance (GSD) of 500m, corresponding to a NADIR GSD of 360m.

The presentation will shortly recall the mission objectives and major instrument requirements, and then present the results of in-orbit testing and validations. All functions and in particular the CMOS detector matrix operate nominally. Performances evaluated in orbit (SNR, MTF, etc.) show results above the requirements. Finally, in-orbit calibrations using the sun diffuser provide very satisfactory consistency with the ground characterisation. GOCI is now delivering operational products and proving the interest of Geo observation in the Ocean Colour applications

Index Terms— Geostationary, Ocean Colour

I. Introduction

With its successful launch on June 26, 2010, the Communication, Ocean, and Meteorological Satellite (COMS) is currently in normal operation for the service to the end users, exhibiting exciting and fruitful performances including the image data from the two on-board optical sensors, Meteorological Imager (MI) and Geostationary Ocean Color Imager (GOCI), and the experimental Ka-band telecommunication. This paper gives a comprehensive overview of the GOCI instrument in terms of its key design characteristics and current status of in-orbit performances.

II. COMS and GOCI overview

COMS is a multi-purpose, multi-mission, geostationary satellite. It has been designed and developed by the joint effort of EADS Astrium and Korea Aerospace Research Institute (KARI), and launched by Ariane 5 on June 26 2010. COMS is the first 3-axis stabilized geostationary satellite ever built in Europe for optical remote sensing.

COMS is a single geostationary satellite fulfilling 3 missions as follows:

- A meteorological mission by MI
- An ocean imager mission by GOCI
- An experimental Ka band telecommunication mission

MI is the common imager with the flight heritage from the later series of GOES and MTSAT satellites, and GOCI is the world' 1st ocean color imager to be operated in the geostationary orbit which has been newly developed for the COMS mission. The spacecraft launch mass is 2460 kg The orbital location is 128.2°E, design lifetime is 10 years.

Fig. 1 shows COMS in deployed configurations, where GOCI located on the earth looking satellite floor can be found.

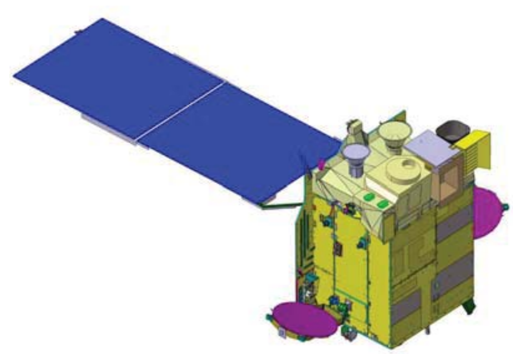

Fig. 1: COMS, in deployed configurations

Geostationary Ocean Color Imager (GOCI), the first Ocean Colour Imager to operate from geostationary orbit, is designed to provide multi-spectral data to detect, monitor, quantify, and predict short term changes of coastal ocean environment for marine science research and application purpose. GOCI has been developed to provide a monitoring of Ocean Color around the Korean Peninsula from geostationary platforms in a joint effort by Korea Aerospace Research Institute (KARI) and Astrium under the COMS contract.

The In Orbit Testing (IOT) of GOCI together with COMS was completed early part of 2011, and since then the instrument has been being successfully operated by KARI for the benefits of the Korea Ocean Research & Development Institute (KORDI).

III. GOCI Mission Overview

Main mission requirement for GOCI is to provide a multi-spectral ocean image of area around South Korea eight times per day as shown in Fig. 2. The imaging coverage area is 2500x2500 km2 and the ground pixel size is 500x500 m2 at centre of field, defined at (130°E - 36°N). Such resolution is equivalent to a Ground Sampling Distance (GSD) of 360 m in NADIR direction, on the equator. The GSD is varied over the target area because of the imaging geometry including the projection on Earth and the orbital position of the satellite, as shown on Figure 4. The GOCI spectral bands have been selected for their adequacy to the ocean colour observation, as shown in Table 2. The eight bands responses are shown in figure 3.

Band	Center	Bandwidth	Main Purpose
1	412 nm	20 nm	Yellow substance and turbidity extraction
2	443 nm	20 nm	Chlorophyll absorption maximum
3	490 nm	20 nm	Chlorophyll and other pigments
4	555 nm	20 nm	Turbidity, suspended sediment
5	660 nm	20 nm	Baseline of fluorescence signal, chlorophyll, suspended sediment
6	680 nm	10 nm	Atmospheric correction and fluorescence signal
7	745 nm	20 nm	Atmospheric correction and baseline of fluorescence signal
8	865 nm	40 nm	Aerosol optical thickness, vegetation, water vapor reference over the ocean

Table 2 : GOCI Spectral bands and main use

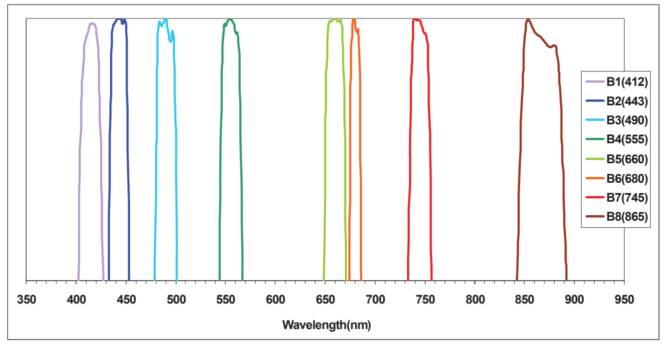

Fig. 3 : GOCI eight narrow bands profile

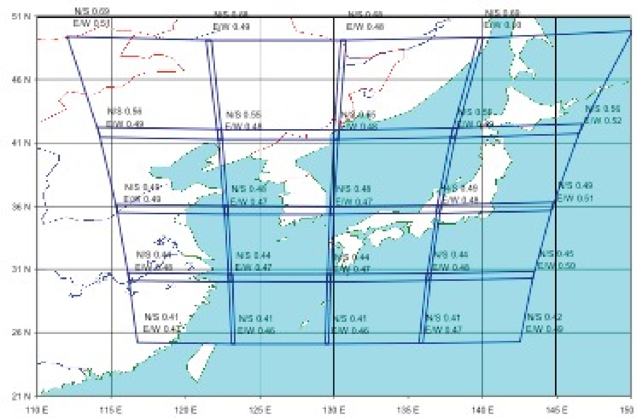

Fig. 4 - GOCI Target Area Around Korea

IV. Imaging Principle And Major Requirements

Imaging principle on GOCI is step-and-stare based on a dedicated 2Mpixels CMOS detector passively cooled and regulated around 10°C shown on Figure 6. The GOCI custom CMOS imaging sensor features rectangular pixel size to compensate for the Earth projection over Korea, and electro-optical characteristics matched to the specified instrument operations. It comes from the COBRA family, developed and qualified by ASTRIUM in cooperation with ISAE/CIMI for circuit design and with E2V for back-end manufacturing.

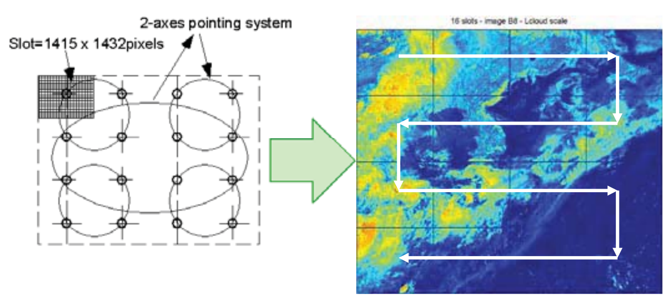

Fig. 5: Principle of GOCI image acquisition
32 Mpixels field of view is acquired in 16 slots

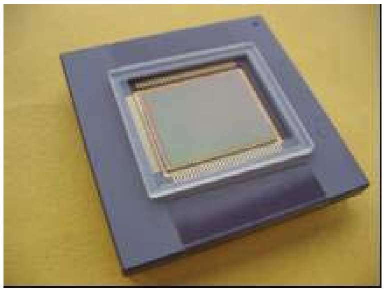

Fig. 6: GOCI CMOS Detector
2 Mpixels - 1415 x 1432
(shown with temporary window)

A pointing mirror supported by a 2-axis scan mechanism allows choosing the centre of the slot. The image is built by successively positioning the Line of Sight (LOS) at the centre of the 16 slots resulting in a 32 Mpixel images, as shown on Figure 5. A slot acquisition takes about 100 seconds for the 8 bands and dark signal acquisition. The complete image set in all bands is thus acquired and downloaded in less than 30 minutes.

The pointing mechanism is an assembly of two rotating actuators mounted together with a cant angle of about 1°, the double rotation allowing to position the LOS anywhere in the 4° cone with appropriate angles positions. The pointing law provides the relation between rotation of both actuators and the LOS. This high accuracy pointing assembly provides a pointing accuracy better than 150μrad and position knowledge better than 10μrad thanks to the use of optical encoders. The pointing mechanism is shown on Figure 7.

Fig. 7: GOCI Pointing Mechanism (w/o mirror)

V. GOCI – DESIGN OVERVIEW

The GOCI consists of a Main Unit and an Electronic Unit, with total Mass below 78 Kg. Power needed is about 40W for the electronics plus about 60W for thermal control. A Payload Interface Plate (PIP) supports a highly stable full SiC telescope, the two-dimensional Focal Plane Array (FPA) and a Front End Electronics (FEE), the pointing mirror mechanism, filter wheel mechanisms and shutter and calibration wheel. Fig. 8 shows the main unit, Fig 9 the Electrical unit.

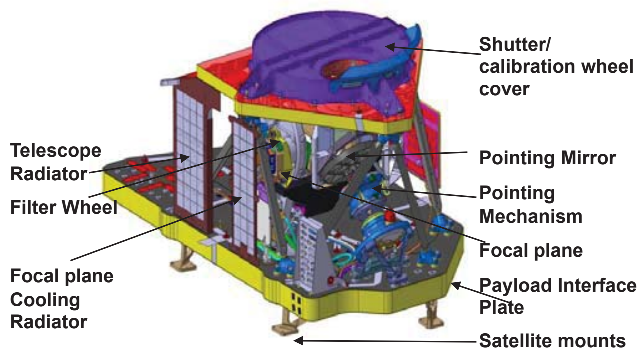

Fig 8: GOCI Main Unit, without MLI protection

Fig. 9: GOCI Electrical Unit

The 8 spectral channels are obtained by a filter wheel, which includes a dark plate in order to measure the system offset as well as 8 spectral filters. The filter wheel is shown on Fig. 10, with protective covers removed to show the 8 filters.

Fig. 10: GOCI filter wheel

Calibration is achieved by sunlight at night through a full pupil diffuser, made of fused Silica insensitive to radiation aging. A second diffuser of smaller size is used to verify the main diffuser stability. The full pupil solar diffuser (Fig 12) and diffuser monitoring (Fig 11) are both carried by the shutter wheel which also provides open or closed position in front of the optical aperture.
The radiometric calibration of the GOCI is performed for all pixels of the detector matrix by using the on-ground and in-orbit calibration data [3]. The GOCI operation concept is compatible with "every night" in-orbit calibration.

Fig. 11 : Diffuser monitoring (internal side)

Fig. 12: Full pupil Solar Diffuser (external side)

Major GOCI performance requirements are

- Dynamic of signal is coded on 12 bit per pixel
- Each image is acquired in two gains - High (for sea) and Low (for clouds) - to build a large dynamic and non saturated image. High gain images are averaged on-board by GOCI electronic unit, with a programmable image acquisition time between 3 and 6 sec
- Resulting SNRs is > 1000 on all bands
- System MTF is specified better than 0.3 on all bands after ground processing
- Nominal Life time is 7,7 years (7 years after commissioning), with 8 daytime images/day and possible calibration every night.

VI. GOCI PROJECT KEY DATES

GOCI Development started in July 2005 together with COMS satellite. The GOCI FM model was delivered to Korea in fall 2008 and integrated onto COMS satellite in December 2008.
COMS Launch was successful in June 2010 on an Ariane 5 launcher.
The in orbit commissioning was done in the first months of the satellite, from July 2010 until March 2011. The COMS satellite and GOCI have now been in their nominal operational life for more than one year.
Operational mission is foreseen for 7 years with KARI in charge of operations and KORDI/KOSC in charge of GOCI image processing.

VII. GOCI In-Orbit Performance Evaluation

Evaluation of GOCI in-orbit performance was done during commissioning of COMS satellite. GOCI commissioning was completed in January 2011, with all tests successful.

The main steps were:

- Functional tests: TM/TCs, mechanisms actuations, image acquisition, …
- Radiometric tests: dark signal, radiance response, S/N Ratio
- Calibrations using sun light at night time through the sun diffuser
- Geometric tests : GSD and image size, pointing law, slot overlap and MTF profile.
- GOCI Image Navigation and Registration (INR) processing was tested and tuned.

All tests were passed successfully in both nominal and redundant modes. In all cases, the GOCI instrument shows comparable results to ground when data can directly be compared.
The interesting topics from the in orbit tests are the MTF, SNR and calibration and also the INR tests as:

- GOCI 360 m NADIR GSD is new in Geostationary orbit
- Use of a full pupil solar diffuser in Geostationary orbit allowing to cross check ground characterisations with direct solar light is also a “first time”
- INR accuracy better than 2 pixels at 3 sigma corresponding to less than a 1km accuracy was challenging

VIII. GOCI In-Orbit MTF Evaluation

The Modulation Transfer Function (MTF), which depended both on GOCI but also on COMS platform stability, is at the end very satisfactory.

The quality of images taken by on-board optical instruments is indeed strongly dependent on the quality of the platform stabilisation. Strong requirements have been put on the COMS platform, all necessary to obtain the specified image quality.

Pointing accuracy (pitch and roll) : this specification is essential to a priori know where the instrument line of sight is aiming at. This is important for GOCI operation (due to further stitching of small images to construct the large imaging area).
Pointing knowledge (pitch and roll) : the pointing knowledge is mainly driven by the INR in order to start the landmark matching processing with a sufficient accuracy.
Pointing stability (pitch and roll) : this specification was mainly driven by the GOCI instrument, requesting integration times as long as 8 seconds, with a LOS stability within 10µrad.
Finally, specific attention was taken on micro-vibration coupling which would have resulted in non-recoverable loss of MTF in staring mode.

The first point is fulfilled by the heritage bus (E3000 platform), but the two last two points have necessitated the implementation of a high precision Fibre Optic Gyro (Astrium’s FOG Astrix 120 HR), implementation of passive dampers under wheels, various AOCS tuning (solar array natural mode damping, optimised wheel zero crossing management), optimized manoeuvres (reaction wheel off loading, EW and NS manoeuvres, etc.), and few operational constraints (stop solar array rotation during GOCI imaging period, etc.).

The resulting performances are better than expected providing a typical pointing knowledge of better than 0.003°, pointing accuracy of better than 0.05°, and the pointing stability of better than 7µrad/8s, all in roll and pitch. Fig. 13 shows the typical example of the performance on the platform stability.

MTF in-orbit measures were evaluated on selected areas providing sharp edges in the images, such as coastlines. Several valid E→W, W→E, N→S and S→N transitions were averaged. Due to the bands selection, the process was applied with best success on the B7 and B8 bands showing a good earth-sea contrast.

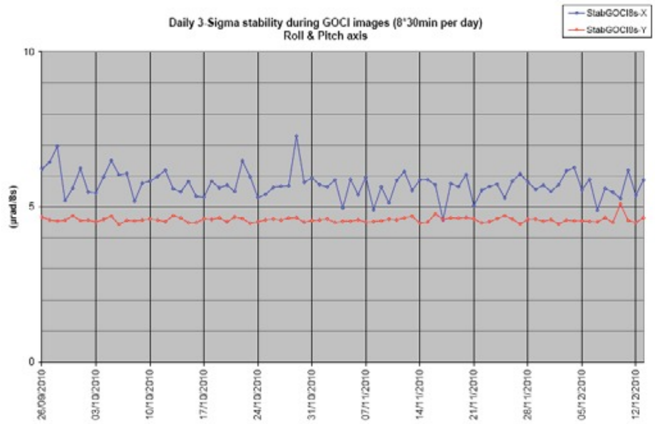

Fig. 13 : Typical LOS performance stability measured in orbit on COMS satellite

The results from this in-orbit evaluation per bands/directions are consistent with the ground measures done at instrument level during acceptance tests.

MTF is indeed better than specified, higher than 0,30 in both directions. This allows reaching MTF specifications at raw data level without the need for post-processing.
A typical example of edge analysis is shown on figure 14, with resulting MTF computation.
Figures 15 and 16 show example of GOCI in-orbit images demonstrating the geometrical quality.

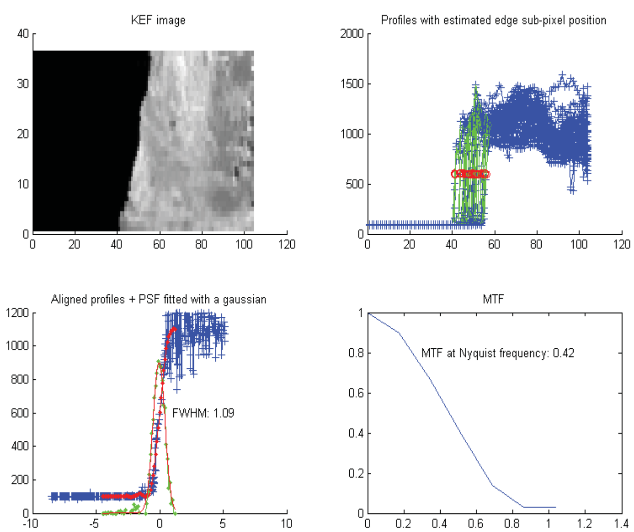

Fig. 14: example of MTF evaluation point on a transition edge within the GOCI image.

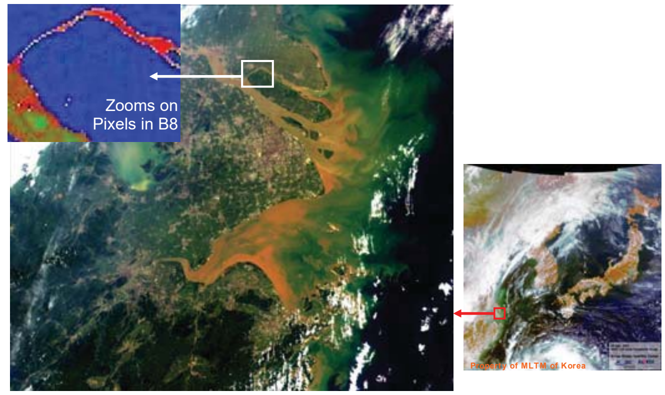

Fig. 15: Shangai Yangtze River, China, from raw data. The close-up on one slot shows streets detail (theoretical GOCI is resolution 500m at this latitude). An additional zoom shows the B8 pixels demonstrated the detection of sharp contrasts.

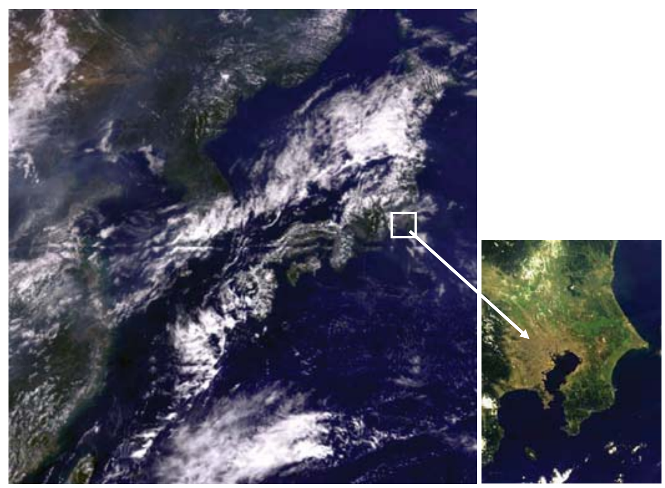

*Fig 16: Full GOCI 2500 * 2500 image, built with bands 1, 4 & 6 mixed raw data. The 16 slots are juxtaposed without removing overlap in this image. On right detail extracted from slot 5 showing Japan*

IX. GOCI IN-ORBIT SNR

The GOCI was turned on for the first time in orbit on July 12, 2010 and captured it first image the day after. Both sides (primary and redundant) were successfully tested during about two weeks. After the successful functional tests such as the mechanism movement, detector temperature control, and imaging chain validity, the radiometric performance tests and radiometric calibration tests have been performed. The radiometric performance test is aimed to verify the validity of performance measured on ground. In-orbit offset and dark signal shows a quite good correlation with the ground measurements. Also the radiometric gain matrix, which has been measured in-orbit, is very similar to the ground gain. The SNR test results in Table 17 show the performance exceeding the requirements in all 8 spectral bands by 25 to 40%. This is mainly due to the excellent quality of the CMOS matrix detector, and the design margin considered for worst-case analysis and EOL specifications.

Band	Mean SNR	SNR specification at GOCI level
B1	1476	1077
B2	1496	1199
B3	1716	1316
B4	1722	1223
B5	1586	1192
B6	1513	1093
B7	1449	1107
B8	1390	1009

Table 17: GOCI In-Orbit SNR test result

X. GOCI In-Orbit Calibration

GOCI first full radiometric calibrations were indeed done in orbit, as principle is to use the sun light when sun faces the satellite at night. Ground tests had validated the detection chain and the diffuser models.

GOCI in-orbit radiometric calibration relies on a full pupil Sun Diffuser (SD). The instrument is designed to allow a calibration every day. In practice, during IOT, two calibrations per week were performed. After IOT, the frequency of calibration was reduced to one per week. The potential aging of the SD is monitored by the second diffuser (Diffuser Aging Monitoring Device: DAMD) used less frequency than the SD, typically once per month since the end of the IOT. When not in used, both SD and DAMD are well protected by the shutter wheel cover to minimise their exposure to the space environment.

For IOT tests, 12 slots were acquired in a row within 30 min, providing 12 calibrations with large sun angle variation (from about 34° down to 29°) and large input radiance variations (around +50% from first to last calibration)

Results were very satisfactory and fully validated the calibration model. Difference between calibration results is very small (< 0.4% on mean gain) despite the large input radiance range and are most probably due to processing noise (small errors in the ephemerides and in the calibration time) and also possibly to short term variations of the sun irradiance. No dead pixel was found. SNR measured is better than 1300 on all channels with set parameters.

Gains from in-orbit calibration are very close to the on-ground estimated values (few % adjustments only).

Gains evolution on all bands since launch is shown on figure 18. Variation is very slow and small and consistent with EOL predictions with significant margins.

While calibration is possible every night, recommendation for calibration after IOT was limited to one Sun Diffuser calibration per week, and one monitoring diffuser check per month only.

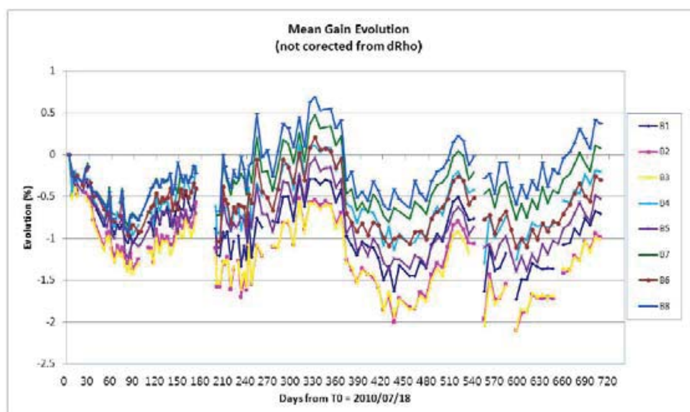

Fig. 18: Evolution of gain computed through GOCI in-orbit calibrations during the first 2 years.

All the variations observed in orbit up to now are within 1 to 2% which is very low and very satisfactory. Some evolutions seem to be correlated with the longitudinal solar incident angle. This opens the way to further improvement of the calibration model if necessary.

XI. GOCI In-Orbit INR tests

The INR performance is evaluated on the basis of landmarks residuals (statistical error after landmark best fit). In order to verify the validity of this approach, the coastline from the images is checked against an absolute coast line (based on known databases). The table 19 illustrates the typical performances of COMS-GOCI INR as observed during the IOT: two-pixel accuracy is reached with margin.

Figure 20 shows an example of shoreline identification on GOCI images.

	Navigation		Within Frame Reg.		Frame-to-Frame		Band-to-Band	
	EW	NS	EW	NS	EW	NS	EW	NS
Specification	**28.0**	**28.0**	**28.0**	**28.0**	**28.0**	**28.0**	**7.0**	**7.0**
Spec + Allocation VIS only	31.3	31.3	34.3	34.3	34.3	34.3	21.0	21.0
Jan 2011	17.5	15.5	22.9	21.2	7.7	7.3	<10.0	<9.6

Table 19: Typical Peformances for GOCI INR

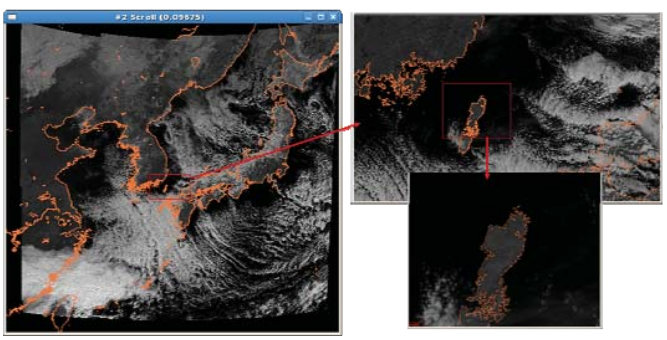

Fig. 20: Example of shore line matching on typical images shows good geo-localisation achieved by the Image Navigation & Registration SW on bands B7 & B8 (which provide best earth/water contrast)

XII. Conclusion

Advantages of GEO orbit in OCI application is now demonstrated in orbit through the real case of the GOCI instrument.

GOCI is an ideal complement to LEO orbit observations taking advantage of the geostationary orbit:

- High availability of images : 1 image/ hour for COMS-GOCI.
- Significantly better cloud free conditions with elimination of cloud due to continuous observations on one day.
- Diurnal phenomenon observable (8 images per day), with different angles of sun illumination.
- Sun glint by nature less constraining due to lower field angle of observation
- On the opposite it is to be noted that SNR, MTF and straylight control were more demanding in GEO and particular attention was indeed paid to BRDF and ghost control in the GOCI development.

GOCI performances demonstrated already during in-orbit commissioning prove that the specified targets were reached and often exceeded, paving the way to geostationary observation in the Ocean Color applications.

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