Conceptual Study of GEO and LEO Sensors Characteristics for Monitoring Ocean Color around Korean Peninsula

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Abstract: Korea Aerospace Research Institute (KARI) has a plan to launch COMS for consistent monitoring of the Korean Peninsula. Korea Geostationary Ocean Color Imager (GOCI) is one of the main payloads of COMS which will provide a monitoring of ocean-colour around the Korean Peninsula from geostationary platforms. Ocean color observation from geostationary platform is required to achieve the proper spatial and temporal resolution for coastal observation mission. In this paper the characteristics of GOCI and LEO sensors are discussed. GOCI will provide the measurement data of 6 visible channels and 2 near-infrared channels (400nm ~ 900nm). The integration time and aperture diameter required to achieve the SNR specification of KGOCI are analyzed.

Keywords: Ocean Color Sensor, COMS, GOCI, Integration time, SNR.

1. Introduction

Space based observations of ocean color began with CZCS (Coastal Zone Color Scanner) which was launched in 1978. Since then many missions have been launched by various countries with increasing sophistication for ocean color monitoring: SeaWiFS (Sea Viewing Wide Field Sensor), OCTS (Ocean Color and Thermal Scanner), OCM (Ocean Color Monitor), MODIS (Moderate Resolution Imaging Spectro-Radiometer), MERIS (Medium Resolution Imaging Spectro-Radiometer). These ocean color sensors on low Earth orbiting satellites are capable of supplying highly accurate water-leaving spectral radiance with high spectral and spatial resolution at a global revisit period of approximately two to three days. Ocean color observation from geostationary platform is required to remedy the coverage constraints imposed by polar orbiting platforms. Unfortunately, no current geostationary platform possesses the ability to measure ocean color. Korea Aerospace Research Institute (KARI) has a plan to launch COMS for consistent monitoring of the Korean Peninsula and studying processes which can vary rapidly in time on land, oceans, and atmospheres. Geostationary Ocean Color Imager (GOCI) is one of the main payloads of COMS which will provide a monitoring of ocean-colour around the Korean Peninsula from geostationary platforms. In this paper the characteristics of GEO GOCI and LEO ocean color sensors are discussed.

2. GEO and LEO Sensors for Ocean Color Monitoring around Korean Peninsula

The relatively low frequency coverage of sun-synchronous, polar orbiting satellite sensors is inadequate to resolve processes operating at a shorter time scales. In addition, the current sun-synchronous polar orbiter observations along coasts are aliased with the tidal frequency [1]. High frequency observations are required in order to remove the effects of tidal aliasing and to validate tidal mixing terms in coastal ecosystem models. Geostationary satellites can provide high frequency observations of the environment over large geographic regions and permit the resolution of dynamic processes with time scales of hours to days. The "fixed view" of these platforms offers additional capabilities, such as providing a consistent viewing geometry to any given earth location, monitoring features that can only be detected by instruments capable of "staring", and increasing daily image coverage by compositing cloud-free areas of individual images collected during the same day. Furthermore, augmenting the continuous ocean-color observation of geostationary platforms with the high spectral and spatial resolution data from polar orbiters will allow the investigation of oceanic processes not possible with either platform separately.

1) Missions

The mission type designed for GEO and LEO ocean color sensors are different. The current sun-synchronous polar orbit ocean color sensors are used for global ocean observation and coastal monitoring. Science requirements for global- and local-scale ocean-color missions call for continuous, unbroken observations into the foreseeable future.

The primary mission of GEO GOCI is to provide the remote sensing data of open sea and coastal water environment around the Korean Peninsular. The missions of GOCI are followed:

- Detecting, monitoring and predicting short term biophysical phenomena
- Studies on biogeochemical variables and cycle

- Detecting, monitoring and predicting noxious or toxic algal blooms of notable extension
- Monitoring the health of marine ecosystem
- Coastal zone and resource management
- Producing an improved marine fisheries information to the fisherman communities

The coastal monitoring mission of GOCI is established to satisfy the requirements of GOCI user community. Increased concerns about the rapid and negative changes of coastal areas have high-lighted the necessity for the development of integrated systems for research and operational use in monitoring the resources and processes in coastal waters. More than 98% of the world's catch of marine species is taken within 300 km of the coastline, and more than half of the total biological production of the ocean takes place in that zone [2]. In many coastal areas, a considerable increase in the concentration of nutrients in coastal waters has been recorded. Nutrient enrichment of the waters stimulates the growth of phytoplankton, leading, in certain circumstances, to the phenomenon of algal blooms and to anoxia in the lower part of the water column with destruction of the benthic fauna and flora.

2) Technical Requirements for Ocean Color Sensors

The requirements for ocean-color sensor, such as spectral and temporal resolution, are different according to the mission type. The requirements for global ocean observations are as follows [2]: (1) global spatial coverage at a resolution of 4 to 8 km; (2) three to five day temporal resolution; and (3) a minimum band set that includes three channels in the visible and two in the near infrared with adequate spectral resolution and signal-to-noise ratio. No single instrument operated on its own is capable of meeting the temporal resolution requirement. A single ocean-color satellite can observe only about 40% in four days [2].

The requirements for coastal monitoring are evolving and the combination of high spectral resolution, high spatial resolution (0.1 to 0.5 km) and frequent revisit are very difficult requirements to meet. The community has not had experience with satellite sensors designed specifically for coastal ocean-color applications. Most proposed coastal ocean-color products are experimental, and development to date has been based on airborne missions. MODIS, MERIS has been provide major advances in coastal water imaging and satisfied many of the spectral and spatial requirements for coastal application, but the temporal resolution requirement is not satisfied.

• Spectral and temporal requirements

The requirements for spectral resolution and the number of spectral band of ocean color sensor are depend on the mission type. The spectral characteristics of LEO ocean sensors are summarized in reference [1].

The GOCI is designed to provide information multi-spectral data to detect, monitor, quantify, and predict short term changes of coastal ocean environment for marine science research and application purpose. Table I summarizes the central wavelength of measurement channels and their primary use. The eight channels of GOCI cover spectral range from 400nm to 880 nm. The channel positions of spectral bands are optimized for monitoring of ocean color. In the visible, the majority of the light flux at the top of the atmosphere comes from the atmosphere itself. Therefore the removal of the atmospheric radiance from that measured at the top of the atmosphere is an essential part of ocean-color processing For KGOCI, the two channels are selected for atmospheric correction.

Table 1. Spectral channels of GOCI.

Ch.	Band Center	Primary use
B1	412 nm	Yellow substance and turbidity
B2	443 nm	Chlorophyll absorption maximum
B3	490 nm	Chlorophyll and other pigments
B4	555 nm	Turbidity, suspended sediment
B5	660 nm	Baseline of fluorescence signal, Chlorophyll, suspended sediment
B6	680 nm	Atmospheric correction and fluorescence signal,
B7	745 nm	Atmospheric correction and base line of fluorescence signal.
B8	865 nm	Aerosol optical thickness, vegetation, water vapor reference over the ocean

Effective imaging of coastal waters generally requires more rigorous temporal and spatial coverage than is necessary for the global ocean. Thus, coastal requirements are only partially met by the current generation of satellites. One-day coverage is a minimum requirement for resolving the "events" occurring every two to ten days, generally in response to wind forcing. Table II shows the ground resolution and recurrent period of LEO ocean color sensors

Table 2. Ground resolutions of LEO ocean color sensors.

Sensor	Ground resolution @ nadir [km]	Recurrent period of satellite	Global Coverage [days]
CZCS	0.825	6 days	No global coverage
MOS	0.520	24 days	No global coverage
OCTS	0.70	41 days	3
SeaWiFS	1.13	16 days	2
POLDER	6	41 days	1
MODIS	1.0	16 days	1-2
MERIS	1.2/0.3	35 days	3

The primary mission of GOCI is to monitor of ocean around the Korean peninsula, not global ocean monitoring. It will provide the temporal and spatial requirements for coastal application. The ground resolution of GOCI shall be designed 500m × 500m at the center of field of regard (FOR) for successful mission. This high spatial resolution will enable to map and monitor small scale oceanic biophysical variables in the coastal water environments.

• ***SNR and Aperture Size Requirements***

Since ocean color sensor measures very small water leaving radiance signal immersed in large atmospheric path radiance, one of the challenges of the ocean sensor is to carry out measurements with high precision. This demands a very high signal to noise ratio (SNR) performance. The SNR is specified by

$$\frac{S}{N} = \frac{L_\lambda}{NEdR} \quad (1).$$

where L_λ means typical input radiance and NEdR, the minimum differential radiance that can be measured by the system with SNR at the specified input radiance level, specifies precision of radiometric measurement.

The SNR specifications for GEO and LEO sensors are based on the user requirements according to main application not the orbit. The SNR specification of GOCI ranges from 750 to 1000 for 8 channels. The NEdR specification of GOCI is compared with LEO ocean color sensors in Fig. 1. The NEdR radiance values are in $Wm^{-2}\mu m^{-1}sr^{-1}$. The NEdR of GOCI is similar to values of SeaWiFS.

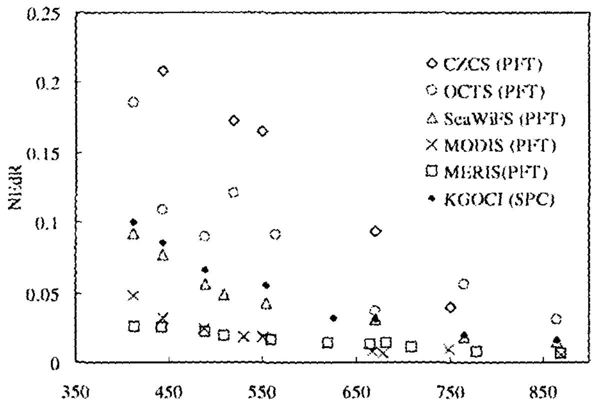

Fig. 1. NEdR of GOCI and LEO ocean color sensors

The system sensitivity (SNR or NEdR) depends on the received input radiance, integration time and aperture diameter. Radiance level measured by ocean color sensor depends on instantaneous field of view (IFOV) of the sensor, spectral bandwidth, optical aperture and integration time. While collected energy increases with square of the IFOV and aperture diameter, it varies linearly with spectral bandwidth and integration time. IFOV of GEO GOCI is 25 ~ 125 times smaller than other sensors onboard at LEO platform. This is mainly due to the fact all other sensors operate from a LEO platforms which are about 40 ~ 50 times closer to earth. Since spectral bandwidth is determined by other considerations, the options to compensate for the reduced IFOV are to increase the optical aperture and/or integration time. In case of GEO sensor, the available integration times is longer than LEO sensors because of its staring function.

The integration time T_{int} required to collect the minimum optical energy for achieving the NEdR performance is calculated by [3]

$$T_{int} = \frac{n_s \cdot hv}{\Phi \cdot A \cdot \eta} \quad (2)$$

where n_s is the number of signal electrons required to satisfy the SNR specification resulted from Eq. (1)

hv is photon energy Ws

Φ is light power W/m^2

A is pixel area m^2

η is quantum efficiency.

If the photon noise is dominant in comparison with noise electrons due to CCD image sensor, the n_s can be calculated from SNR specification by

$$n_s = \left(\frac{S}{N}\right)^2 \quad (3).$$

The integration time needed to achieve the SNR specification of KGOCI is estimated as a function of optical aperture for all spectral channels by Eq. 2 and plotted in Fig. 2. The estimation is done assuming values of optical efficiency and quantum efficiency as 0.5. The integration time is directly proportional to area of aperture in Fig. 2.

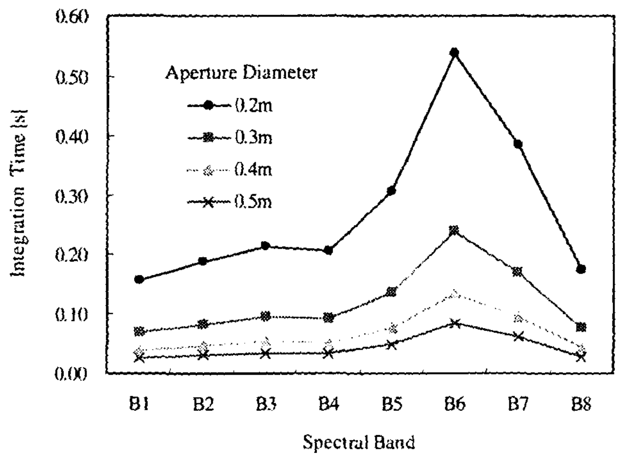

Fig. 2. Trade-off of integration time and aperture size

For B6 channel, the longest integration is required because of its narrow bandwidth. If an aperture of 0.5m diameter is used, the required integration time is shorter than 100 ms for each channel. Increasing optical aperture has the penalty of increasing the weight and size of the payload. The available integration time is limited by four factors: full well capacity of the detector, dark current, attitude stability of the platform during data acquisition and time available for imaging the required region.

• ***Calibration Requirement***

The physical interpretation of the GOCI data needs an accurate sensor calibration. In general, an accuracy of few percents is required for the radiometric calibration of ocean color missions [4][5]. For the GOCI, the absolute radiometric accuracy shall be less than 4% over the range of the saturation radiance.

Most common technology for on-board calibration of ocean color sensor is to use a solar diffuser. Most of the ocean color instruments that are currently operated at LEO are calibrated by observing a diffuser plate, inserted in front of the aperture of the system and illuminated by direct sunlight. This technique has also been proposed for future geosynchronous imagers. The diffuser plate calibration technique has a number of beneficial features, but the major problem with the diffuser plate is the progressive degradation of its diffusely reflective surface in the space environment. To mitigate this problem, an independent monitoring sensor, designed for high stability, may also have to be flown onboard the spacecraft. It is also necessary to minimize sun glints on the deployed the diffuser plate. This constraint is particularly important for imagers in geosynchronous orbit, where reflective baffles and thermal control surfaces are often used to minimize the effects of solar intrusion.

An alternative to the diffuser plate has been proposed [6]. It uses the sun directly through an attenuator fabricated by drilling a large array of holes with diameters in the 50-100 μm range into an opaque plate. This perforated plate technique is capable of providing a well-characterized, uniform radiance source at a high albedo level for full-aperture, end-to-end calibration. When the perforated plate is normal to the sun line, the diffracted radiation is unpolarized and insensitive to tilt. The perforated plate's throughput depends only upon its geometry, giving it greater long-term stability than the reflectivity of a diffuser plate. Since the perforated plate calibration technique requires that the sun lie within the FOR of the instrument, its availability may be more restricted than that of a diffuser plate technique. Since attitude maneuvers are very undesirable for an operational geostationary satellite, the perforated plate calibration can only be performed when the sun passes through the FOR of the instruments. The GOCI will be calibrated by both of transmitted sun light from diffuser and direct sun light through the perforated plate.

3. Conclusions

The primary mission of GOCI is to provide a monitoring of ocean-color around the Korean Peninsula from geostationary platforms. It is planned to be loaded on Communication, Ocean, and Meteorological Satellite (COMS) of Korea. The GOCI will provide the remote sensing data of 6 visible channels and 2 near-infrared channels (400nm ~ 900nm) for observation of ocean color. These channels nearly coincide with the SeaWiFS bands. The integration time and aperture diameter required to achieve the SNR specification of GOCI is analyzed. The high spatial resolution of GOCI will enable to map and monitor small scale oceanic biophysical variables in the coastal water environments. At the same time, the wide area coverage of the COMS will be capable of studying the meso-scale oceanic changes.

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