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Review

Challenges and opportunities for geostationary ocean colour remote sensing of regional seas: A review of recent results ☆

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ABSTRACT

Ocean colour remote sensing from sun-synchronous polar orbiting satellites has become well-established as a tool for extracting information on phytoplankton and suspended particulate matter and related processes in regional seas. New data is now becoming available from optical remote sensors on geostationary satellites and provides a much higher temporal resolution, typically an image once or more per hour during daylight compared to once per day. This higher temporal resolution opens up obvious opportunities for dramatically improving the data availability in periods of scattered clouds and for resolving fast processes such as tidal or diurnal variability of phytoplankton or suspended particulate matter. As the science community starts to explore this new data source, further new applications are likely to emerge. However, the geostationary orbit presents also new algorithmic challenges. The coverage of high latitudes is limited by the difficulties of atmospheric correction at very high sensor zenith angle and ultimately by the earth's curvature. Exploitation of the new possibilities of viewing the earth for a range of sun zenith angles over the day also stimulates a need to perform accurate atmospheric correction at high sun zenith angle. Traditional pixel-by-pixel data processing algorithms could be supplemented by information on the temporal coherency of data over the day thus potentially improving data quality, by adding constraints to the inversion problem, or data quality control, by a posteriori analysis of time series. This review assesses the challenges and opportunities of geostationary ocean colour, with emphasis on the data processing algorithms that will need to be improved or developed to fully exploit the potential of this data source. Examples are drawn from recent results using data from the GOCI and SEVIRI sensors.

Contents

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1. Introduction

Ocean colour remote sensing from polar orbiting sensors such as the Moderate Resolution Imaging Spectroradiometer (MODIS) and the MEdium Resolution Imaging Spectrometer (MERIS) has become well-established. Products for concentration of chlorophyll *a* and suspended particulate matter are widely used in marine science (McClain, 2009) and water quality monitoring (Bresciania, Stroppiana, Odermatt, Morabito, & Giardino, 2011). A single sun synchronous polar orbiting sensor (SSO) can provide global coverage. However, the sampling frequency, typically once per day, is too slow for resolving tidal and sub-diurnal processes, particularly in coastal waters, and the presence of clouds is a big limitation to data availability. A single geostationary orbiting sensor (GEO) provides coverage of only part of the earth but offers a vastly improved sampling frequency, typically one image per hour, and hence the possibility to resolve new processes from space. This is illustrated in Fig. 1 where the tidal variability of suspended particulate matter is captured by data from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) and is comparable to that found by in situ data, but is completely missed by the single image of MODIS-AQUA. The probability of obtaining data during periods of scattered clouds is also greatly enhanced, as shown in Fig. 1 (SEVIRI data for the North Sea) and Fig. 2 with data from the Geostationary Ocean Color Imager (GOCI) for the Bohai Sea. The difference between acquisition frequency for a typical SSO with overpass time at 12:30 UTC and a GEO is shown in Fig. 3, based on actual cloud-free observations of the Southern North Sea from SEVIRI. The simulated SSO sensor gives approximately 110 observation days per year compared to about 200 days/year for the GEO. Fig. 3 also shows the numbers of days/year, about 110 in this case, when four or more images would be available from a GEO with hourly acquisitions from 10:00 to 15:00, thus indicating the potential for resolving tidal processes.

However, the advantages go beyond simply obtaining more data. The exploitation of temporal coherency of natural processes offers entirely new ways of processing data — instead of pixel-by-pixel processing, information from adjacent pixels in time may allow better constraint of the ocean colour inversion problem or provide new opportunities for quality control via temporal outlier detection. Observation of a stable marine target over the day with different sun angles or the use of multiple geostationary sensors at different longitudes could give extra information on the bidirectional reflectance of the ocean–atmosphere system. Combination of high frequency geostationary data with empirical orthogonal function (EOF)-based multitemporal analyses methods, e.g. Beckers and Rixen (2003), can effectively fill gaps due to clouds and objectively identify outliers.

The objective of this paper is to present a review of the state of the art of geostationary ocean colour and to outline opportunities and challenges based on recent results from the GOCI and SEVIRI missions and analogous developments in other remote sensing fields (sea surface temperature, land and aerosols). This builds on the review made by the IOCCG (2012) and incorporates the findings of more recent studies in this fast-moving field. The particular focus of the present review is on coastal water applications, a priority niche for GEO exploitation as seen in the recent proliferation of studies of tidal variability of suspended particulate matter (Choi, Park, et al., 2014–this volume; Choi et al., 2012; Doxaran et al., 2014–this volume; He et al., 2013; Neukermans et al., 2009; Ruddick et al., 2012) and the related turbidity and diffuse attenuation (Neukermans, Ruddick, & Greenwood, 2012). The present review concentrates on aspects of data processing algorithms that are specific to GEO ocean colour.

A brief summary of the relevant SSO and GEO ocean colour satellite systems is given, highlighting the essential differences between the two orbits for data processing and exploitation. The impact of these differences on data processing algorithms is then assessed with some examples from new emerging methodologies. The new processes accessible to GEO are considered and the needs for corresponding new algorithms are outlined. The particular challenges of high zenith angle atmospheric correction are summarised. Multiscale algorithms, SSO/GEO synergy and algorithms using temporal coherency are addressed with reference either to early GEO ocean colour studies or to similar developments in other earth observation disciplines where GEO data exploitation is more mature. The challenges/opportunities regarding bidirectional effects are also summarised. Finally, the future perspectives for geostationary ocean colour are outlined.

2. Ocean colour remote sensing systems and orbits

In this section the satellite systems for ocean colour remote sensing are briefly described with a focus on the difference between the orbits for SSO and GEO. Table 1 gives some characteristics of two commonly-used SSO ocean colour sensors, MODIS and MERIS, and the first two GEO that have been used for ocean colour applications, SEVIRI (Schmetz et al., 2002) and GOCI (Ryu, Han, Cho, Park, & Ahn, 2012). Fuller details of these and many other past, present and future SSO ocean colour sensors, including the historically important Coastal Zone Color Scanner (CZCS) and Sea-viewing Wide Field of view Sensor (SeaWiFS), can be found at http://www.ioccg.org/sensors_ioccg.html. GOCI is the first (and, at the time of writing, the only) dedicated ocean colour sensor in geostationary orbit. SEVIRI is not designed for ocean colour applications, but has been included because of its demonstrated use for mapping suspended particulate matter and related quantities in turbid waters.

2.1. Near-polar sun synchronous orbits (SSO)

Near-polar sun synchronous orbits (SSO), sometimes termed "polar orbits", are a subset of the family of Low Earth Orbits (LEO), and have been adopted for nearly all ocean colour sensors to date, with the exception of the Hyperspectral Imager for the Coastal Ocean (HICO). SSO are typically 700–800 km above the earth's surface and a nadir-pointing SSO will cover approximately from pole to pole many times per day