A TRIUMPH FOR MERIS: MONITORING OF BLOOMS AND VEGETATION USING THE GLOBAL MERIS MCI DATA SET

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ABSTRACT

The Maximum Chlorophyll Index (MCI) has successfully demonstrated a new way to monitor floating and near-surface vegetation and intense surface plankton blooms in coastal and ocean waters. MERIS MCI shows some blooms in which high radiance at 709 nm is the dominant feature of their optical spectrum. Such blooms would not be detectable without a band at this wavelength. The 10-year dataset is unique to MERIS in that the 709 nm band is not included in other wide-swath water-colour imagers such as MODIS, SeaWiFS or VIIRS. We have used the MERIS data to show patterns of pelagic *Sargassum* never before seen from space, an increasing trend of Antarctic "superblooms," and details of the global distribution of *Trichodesmium* and other blooms. In this paper we show examples from the full global MCI dataset compiled during a joint ESA (GPOD) and Canadian Space Agency project.

1. INTRODUCTION

The "Triumph" referred to in the title is the fact that MERIS brought the value of the 709 nm band for measuring water leaving radiance to the attention of the ocean remote sensing community, demonstrating its value for mapping blooms and pelagic vegetation. Further uses for mapping coastal vegetation and coral have still to be fully investigated. The magnitude of the 709 peak signal, as recorded by MCI, was mapped globally by MERIS and made available over the life-time of the mission, allowing detection of ocean targets not previously detected from space.

2. HETEROSIGMA BLOOMS

The 709 nm band of MERIS and the MCI derived from it, provide a robust and sensitive detector of photo-synthetic plant material against a water background. This responds to surface and near-surface slicks of phytoplankton bloom [1].

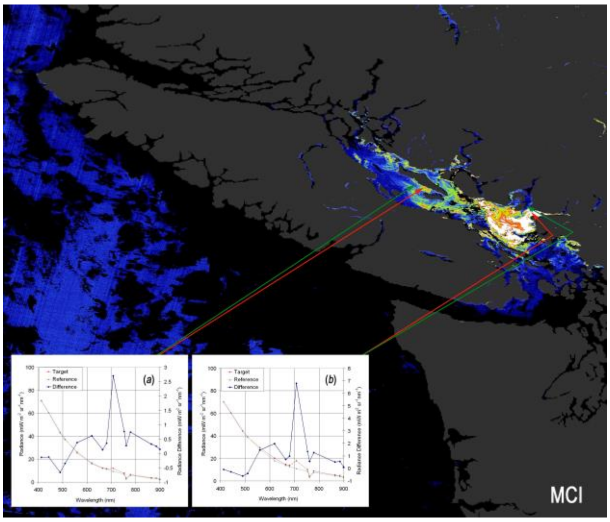

Figure 1. MERIS MCI image showing Heterosigma blooms in coastal waters of western Canada on 22 June 2011. Inset spectra show that the radiance signature of these blooms is predominantly a peak at 709 nm.

An example of a significant MCI image in waters local to the authors is shown in Fig. 1. Red and white colours indicate the strong response of MCI to high concentrations of phytoplankton in the coastal waters of the Strait of Georgia, near Vancouver, BC. Water offshore is cloud-covered (masked to black) or shows low MCI value (dark blue). Land is masked to dark grey.

Surface measurements near the time of the image suggests that the high MCI in this case was due to blooms of *Heterosigma*, a species of major concern to local shellfish harvesters. The spectra in inserts A and B in Fig. 1 show that the most significant feature of these blooms is the radiance peak at 709nm, which MERIS was almost uniquely equipped to detect, being the only sensor of MODIS, SeaWiFS or VIIRS to have a spectral band at or near this wavelength.

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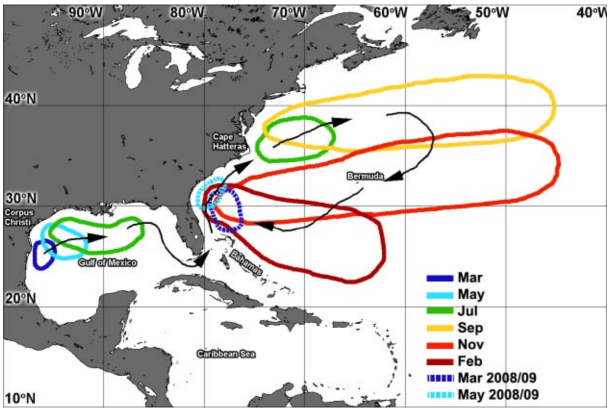

Figure 2. Sketch of average monthly distribution of Sargassum slicks observed by MERIS MCI over the period 2002 to 2009, showing annual circulation with growth in the Gulf of Mexico feeding a distribution in the subtropical north Atlantic.

3. PELAGIC *SARGASSUM*

In 2005 we used MERIS MCI to map the distribution of intense, sinuous slicks of free-floating (pelagic) *Sargassum* in the Gulf of Mexico [2]. This was the first time that *Sargassum* had been detected from space, in spite of its wide distribution in the northern sub-tropical Atlantic, which had led to a large area, roughly 20 to 40N, 80 to 40W, being named the Sargasso Sea. Floating mats of *Sargassum* sometimes cover large areas, and show strong contrast to water especially in the near infrared, but it took the additional sensitivity provided by the 709nm band of MERIS to make *Sargassum* easily detectable. We were then able to show that SeaWiFS and MODIS also provide some capability for its detection [2].

With analysis of MERIS data for the years 2002 to 2010, we were able to show a seasonal cycle of the apparent distribution (Fig. 2), indicating a fairly consistent, annual circulation covering a large area of the Gulf of Mexico and the Sargasso Sea [3]. We were aware of a probable bias in the MERIS observations towards cases where surface slicks had aggregated to be large enough to be easily visible to the 1200 m spatial resolution data that we were using. However, the distributions shown in Fig. 2 are consistent with historical ship surveys, many from 1880 to 1940, although these never covered large enough areas or long enough periods to show a consistent annual pattern.

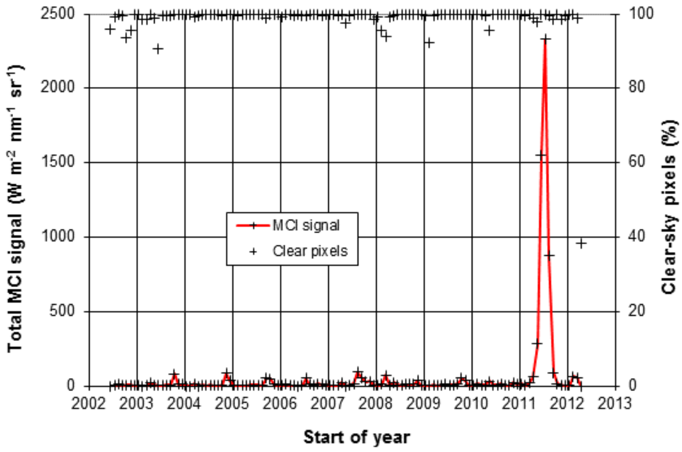

Figure 3. Monthly MCI signal indicating total surface Sargassum amount in the area 5 to 9N, 35 to 50W, in the tropical Atlantic. The percentage of clear-sky pixels for each monthly composite is close to 100% except for the final month in which MERIS failed.

In 2011 we were surprised to see a completely different distribution of *Sargassum*, dominated by growth in an area of the tropical Atlantic about 600km north east of the mouth of the Amazon River in Brazil [4]. This area is just below the bottom right of Fig. 2 and is outside any area of reports in historical surveys. MERIS satellite observations were confirmed by widespread reports from southern Caribbean islands, such as Barbados, near the bottom of Fig. 2, and from Sierra Leone in Africa where no pelagic *Sargassum* had been previously reported.

Satellite observations showed signal extending to both these areas, but with most signal in the peak month of July 2011, in the area enclosed by 5 to 9N, 35 to 50W (Fig. 3). A possible link with the Amazon River flow rate is suggested by the anomalous dip in global sea level centred in early 2011, which GRACE satellite observations suggested was partly due to water stored on land, partly in the Amazon basin [5]. However, the nature of the link is unexplained.

Fig. 3 shows the peak concentration in July 2011, with lower, but still significant amounts in June and August 2011. In earlier years the MCI signal is much less, and may in fact be due to cosmic ray hits on the MERIS detectors, which affect observations near Brazil, in the area known as the South Atlantic Anomaly [6].

Such large variations in the spatial distribution of pelagic *Sargassum* remind us how hard it is to determine and understand the long-term distribution of many marine ecosystems, and also of the essential contribution that satellite observations can make.

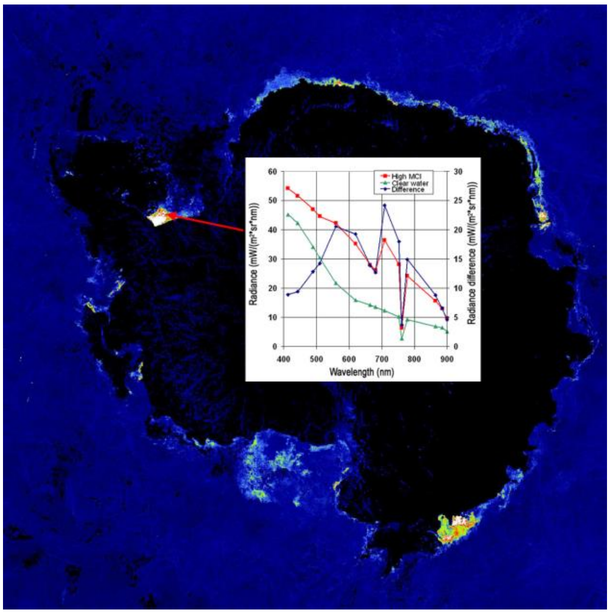

Figure 4. A composite MCI image for February 2007 showing the Antarctic (polar stereographic projection) with areas of high MCI close to the summer ice edge. Black areas are land, ice or persistent cloud. Inset shows a bloom spectrum (red) with absorption giving low radiances at 665 and 681 nm (suggesting the presence of chlorophyll a) and a radiance peak measured by MCI at 709 nm.

4. ANTARCTIC BLOOMS

In 2007 we noted high MCI signal along the coasts of Antarctica in late Austral summer (February and March) of each year [5]. Fig. 4 shows the monthly composite for February 2007 in which especially high signal is measured in the south west Weddell Sea (upper left of Fig. 4) where Smetacek et al., [8] reported "superblooms" among ice in the 1980s. In this type of bloom, large areas of a mixture of sea water and small ice crystals also contain sufficiently high concentrations of phytoplankton to be visibly discoloured to yellow or even brown or red. Such blooms have been reported by observers on ice-breakers, but have not previously been observed with satellite sensors.

The spectra in the inset in the centre of Fig. 4 show relatively low radiance in MERIS bands at 665 and 681 nm suggesting absorption by chlorophyll a, with relatively high radiance at 709 nm suggesting presence of a "red edge" increase in reflectance, again suggesting presence of high concentrations of chlorophyll a.

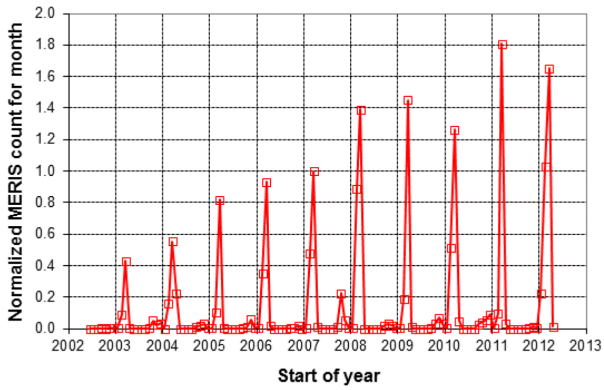

Figure 5. Total MCI signal showing Antarctic bloom signal summed over all longitudes for the latitude range 60S to 80S.

Fig. 5 shows the result of summing the total MCI signal for all coastal waters of Antarctica (all longitudes, latitudes 60 to 80S). The time series peaks in March of each year with the amplitude of the peak increasing over the lifetime of MERIS. The plot shows values normalized to the total signal in March 2007. The continuing increase of peak signal in March of each year does not appear to be an artefact of MERIS and is unexplained [9]. With the demise of MERIS in April 2012, we are unable to say whether the increase continued in 2013. Launch of OLCI in mid-2014 should allow measurements to recommence for March 2015.

5. CONCLUSIONS

We have described some of the new results provided by the MERIS MCI signal in mapping one type of coastal plankton bloom, pelagic Sargassum and blooms near Antarctica. We have also made use of the data to study blooms of *Trichodesmium* and other species, and to monitor coral reefs and coastal vegetation. As shown in the spectra in Fig. 1, the spectral band at 709 nm is essential for defining the signature of some blooms, which are dominated by a peak radiance at this wavelength. Even in Fig. 4, the peak at 709 nm, though less dominant, is essential in defining the apparent absorption by chlorophyll a in the spectrum shown. Because of the demonstrated importance of this band, we feel justified in referring to MCI as a "triumph for MERIS."

6. ACKNOWLEDGEMENTS

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