THE NEED FOR A GLOBAL OCEAN CHLOROPHYLL FLUORESCENCE PRODUCT FROM MERIS

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ABSTRACT

We discuss and show examples of solar-stimulated chlorophyll fluorescence images (Fluorescence Line Height, FLH) of coastal productivity and phytoplankton blooms. MODIS fluorescence products are made widely available through NASA Oceancolor and Giovanni web systems, but there are problems with interpreting data values, with normalization, and at cloud edges. The product does not appear to be widely used. MERIS has the technical advantage over MODIS of better band placing (including the additional 709 nm band) and of higher spatial resolution (300m compared to 1000m). More work needs to be done on the global MERIS FLH time series to demonstrate and refine future products from OLCI.

1. INTRODUCTION

In western Canada, we find that fluorescence images from both MERIS and MODIS provide more accurate mapping of bloom events than standard chlorophyll products based on blue and green wavelengths [1]. We have used fluorescence images to detect a new pattern of blooms indicating seeding of the spring bloom from deep, glacial inlets [1,2]. We note problems with some of the fluorescence products from MODIS, and suspect there are many undiscovered applications of satellite-measured fluorescence in ocean, and especially coastal, waters that could be demonstrated by a MERIS fluorescence product, and that could be further improved by OLCI.

2. FLH EXAMPLE: TYPICAL IMAGE

Fig. 1 compares typical MODIS Aqua data products recently produced by NASA, Oceancolor [3] for our area and distributed by real-time subscription. The top image is the standard chlorophyll product, showing high chlorophyll on the continental shelf west of Vancouver Island, extending in to the coast and throughout all coastal waters. The fluorescence product (middle image) matches many of the features of the chlorophyll image on the shelf, but fluorescence shows low values in many areas close to the coast and in coastal waters.

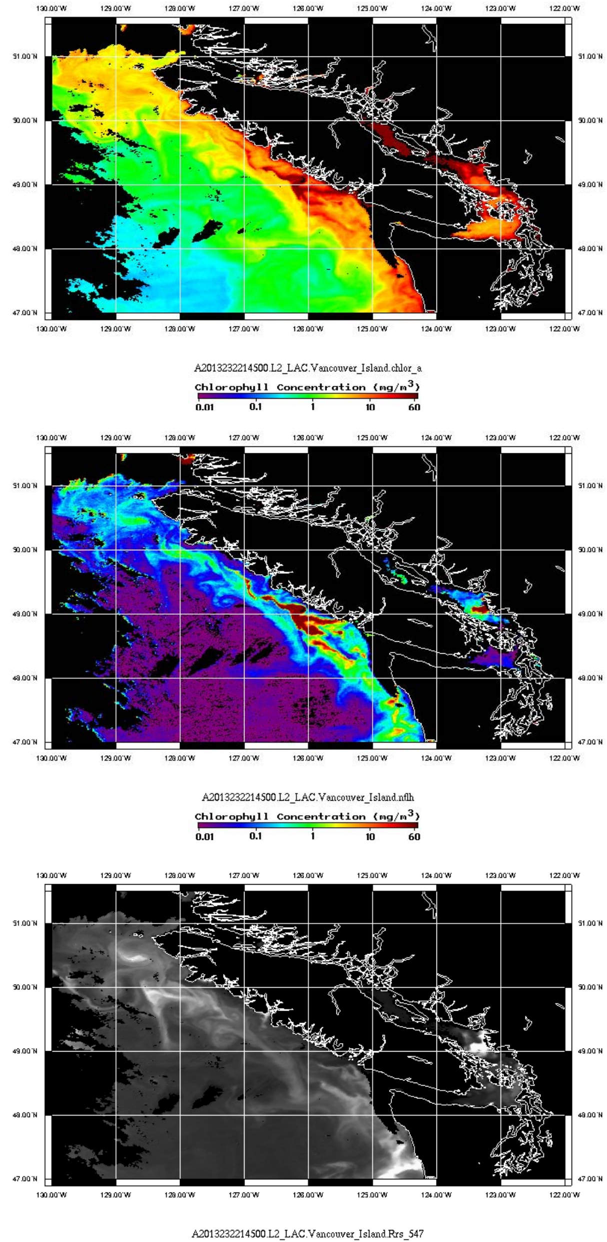

Figure 1. MODIS Aqua images of waters round Vancouver Island, BC, Canada, showing chlorophyll (top), fluorescence (middle) and brightness at 547nm (bottom) on 9 August 2013.

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The bottom image shows areas of bright water, probably due to blooms of Coccolithophores, which tend to concentrate along the edge of the continental shelf and are distributed differently to the chlorophyll and fluorescence patterns.

The main message that we take from Fig. 1 is that the standard chlorophyll product is overestimating surface chlorophyll near the coast. This is expected where the standard "blue to green ratio" algorithm responds to absorption by CDOM as well as by chlorophyll. The fluorescence product probably shows a truer distribution of surface chlorophyll, but the absolute values shown by the present colour bar are in doubt. This is a duplicate of the colour bar used for the chlorophyll product, without allowance for details of the fluorescence mechanism.

Small areas of high fluorescence signal are also apparent at cloud edges on the left side of Fig 1, middle panel. This type of artefact is relatively easy to ignore in single images, but can lead to significant errors when images are combined in composites representing surface chlorophyll distributions over longer periods (e.g. monthly composites). This is a type of error which can be greatly reduced with further processing, masking areas near cloud, especially those relative to sun and scan directions where the error is observed to be especially large.

3. SPRING BLOOM IN THE STRAIT OF GEORGIA

MERIS provides a variety of chlorophyll product designed to track patterns and timing of coastal phytoplankton growth in coastal waters. In the Strait of Georgia, timing of the spring bloom is thought to be important for assessing the ocean survival (as opposed to river survival) of young salmon. However, presence of Coloured Dissolved Organic Matter (CDOM) and suspended inorganic material can confuse these products. We find that the simple, Level 1 (no atmospheric correction) FLH product provides the best indicator of these blooms [1,2].

The top centre panel of Fig. 2 shows the bloom as imaged in FLH. This bloom formed in early February in the waters of Jervis and Sechelt Inlets (north, centre of the area shown) and was tracked by Full Resolution (300m) MERIS FLH images (not shown). By the 18th of February the bloom had spread across the waters of the Strait. Its characteristic location and shape, also observed in two other years, has led to its being named the "Malaspina Dragon."

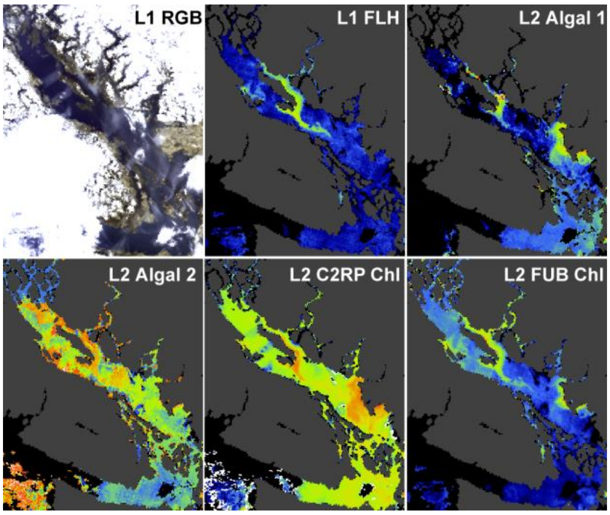

Figure 2. True colour (top left) and chlorophyll Reduced Resolution (RR, 1200m) products derived from MERIS for waters in the Strait of Georgia, BC, Canada on 18 February 2009.

The other panels of Fig. 2 show four chlorophyll products provided by MERIS. The L2 Algal 1 product is designed for ocean (Case 1) waters. This shows some of the bloom, with high values in the plume of the Fraser River (centre right of the area shown). Both the L2 Algal 2 and the L2 C2RP products are designed for coastal waters (Case 2). These show high values in many areas, including the Fraser plume, and hence show the "Malaspina Dragon" bloom much less clearly. The L2 FUB Chl product is derived through a neural net developed by the Free University of Berlin, Germany. This comes closest to the FLH product in defining the bloom, but gives less contrast, and high values in the Fraser River plume.

Some of the problems encountered by the standard products may also be due to the atmospheric correction procedure which has to deal with a more complex mixture of aerosols in coastal, as compared to oceanic, areas. As shown in Figure 2, we use L1 FLH, that is, FLH derived from Level 1 radiances with no atmospheric correction. We find that atmospheric correction provides few, if any, benefits especially for detecting and mapping blooms.

4. NORMALIZATION

Average values of water properties deduced from MODIS data are provided for all areas of the world's oceans and coastal waters by NASA'a Giovanni system [3]. This gives average images or time series of properties derived from global data at 4 and 9 km space resolution or 8-day or monthly time resolution.

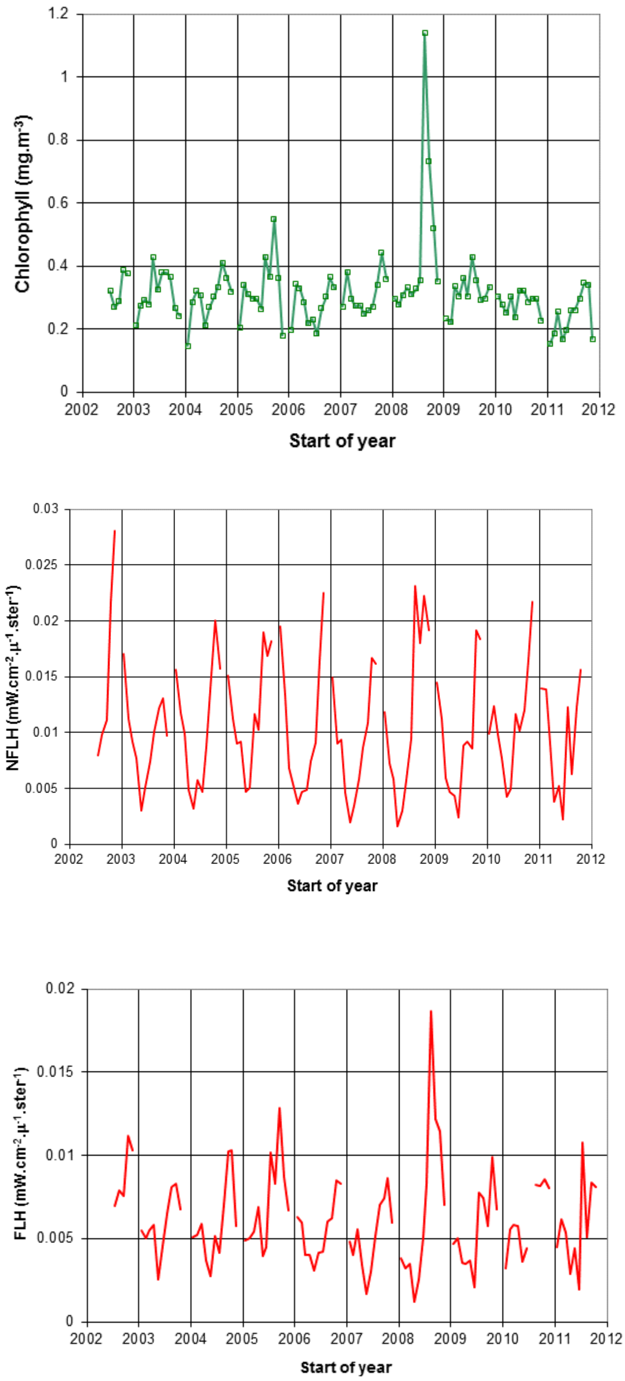

Figure 3. Monthly time series of MODIS Aqua values averaged by Giovanni over a 2-degree square centred on 50N, 145W in the NE Pacific, showing chlorophyll (top), and normalized fluorescence (middle). The bottom plot shows fluorescence with normalization removed.

Fig. 3 shows monthly time series averaged over a 2-degree square, centred on Station Papa in the north-east Pacific. The chlorophyll values derived from satellite data using the standard algorithm (top panel) are expected to be correct in these ocean waters. The series shows the nearly constant value of 0.3 $\pm$ 0.1 mg.m^{-3} typical of chlorophyll in this area, with little or no seasonal cycle. The time series clearly shows the high value caused by the eruption of Mount Kasatochi in August 2008, when injection of iron increased chlorophyll values over a large area of the north Pacific. The centre panel of Fig 3. shows the time series of fluorescence as presented by Giovanni. This is normalized to allow for variations in solar irradiance due to changes in average sun elevation during each month of the year. One would hope that the fluorescence product would provide an alternate estimate of chlorophyll concentration and would appear similar to the top panel. However, the middle panel shows a strong annual cycle, which almost completely masks the peak in August 2008.

The problem here is that the fluorescence data should not be normalized. Studies of the fluorescence mechanism e.g. [4] show that for a given chlorophyll concentration, the fluorescence signal rises to a constant value as sun elevation increases above about 20 degrees. Thus, when insolation is sufficient for ocean colour satellites to produce reliable results (sun elevation above 20 degrees), fluorescence is fully stimulated, and the fluorescence signal is independent of the value of solar irradiance. This means that FLH, the fluorescence radiance as detected, is the appropriate indicator of chlorophyll concentration. Fig. 3 shows no values for December in each year, when sun elevations are less than 20 degrees.

Removing the normalization (by multiplying NFLH by the cosine of the average sun zenith angle for each month, to produce the original FLH values) gives the time series shown in the bottom panel of Fig. 3. The annual cycle is now greatly suppressed and the peak in August 2008 is clearly visible, suggesting that FLH provides a viable alternate estimate of surface chlorophyll. This bottom panel shows an annual cycle with minima in spring, and peaks in fall each year, suggesting a possible annual variation in fluorescence efficiency. This would complicate estimation of chlorophyll concentration, but might lead to new knowledge of phytoplankton physiological state.

Fig.4 shows a time series derived from Giovanni for an area in the southern hemisphere at latitudes 30 to 40S. The top panel shows the standard chlorophyll values, again probably correct in these largely oceanic waters. There are minima at the start of many years, and maxima in about April and September. The centre panel shows the spurious peaks in NFLH, here centred in June of each year, which is again at minima of noon sun elevation. With normalization removed, FLH (lower panel) shows a pattern more similar to chlorophyll, with maxima near April and September but with more distinct minima at the start of each year.

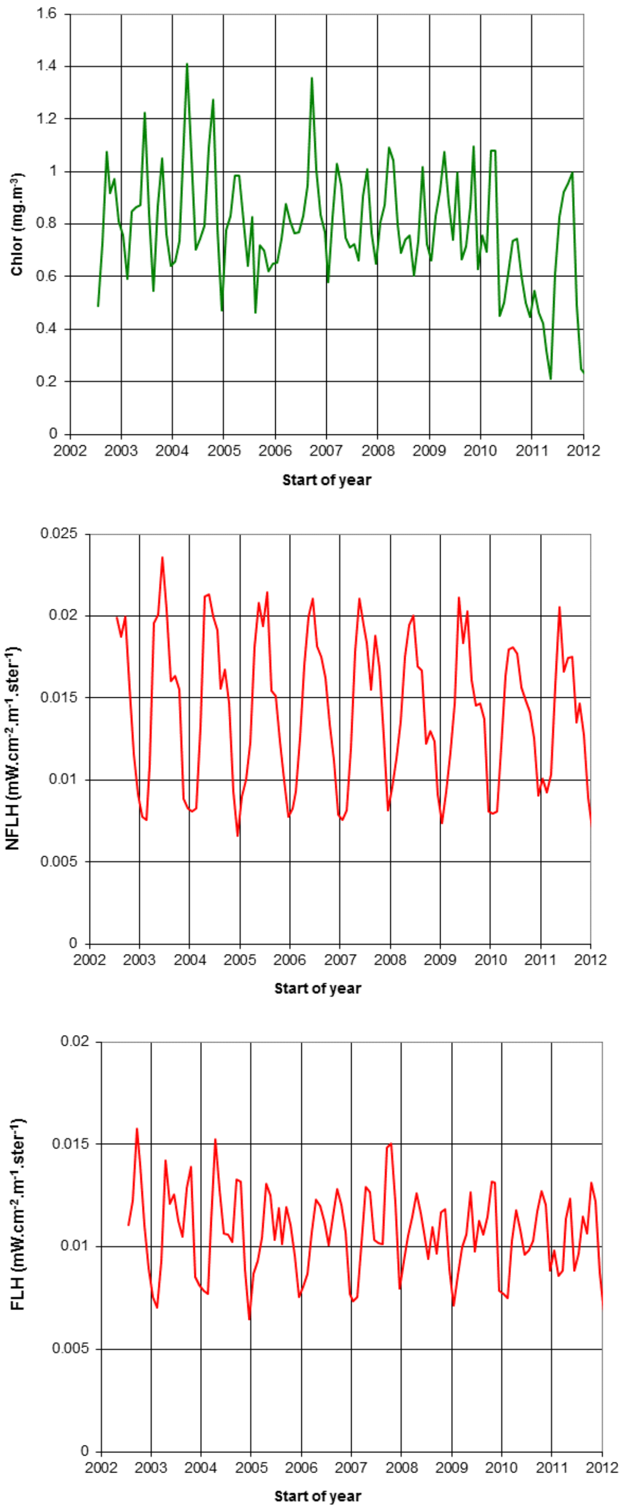

Figure 4. Monthly time series of MODIS Aqua values averaged by Giovanni over the area 30 to 40S, 15 to 25E, covering water off the south coast of South Africa, showing chlorophyll (top), and normalized fluorescence (middle). The bottom plot shows fluorescence with normalization removed.

Many other similar examples to Figs. 3 and 4 show conclusively that the fluorescence product should not be normalized. The present version of Giovanni needs to be corrected to provide the non-normalized FLH product as the alternative indicator of surface chlorophyll concentration.

5. CONCLUSIONS

We are finding successful applications of FLH data and believe that with improvements to data quality, more users and more successes would appear. We have found problems with the way fluorescence data are currently handled by NASA Giovanni, and believe that these are limiting their use. We note that MERIS data are not distributed using a simple, widely accessible web tool similar to Giovanni. MERIS fluorescence data need to be made more widely available in this way. It would greatly improve international acceptance of OLCI data if such a system were tested with MERIS fluorescence and other data, and in place before launch of Sentinel 3.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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