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Comparison of SeaWiFS, MODIS-Terra, MODIS-Aqua and MERIS satellites in the Southern Ocean

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Contemporary ocean color satellite radiometers provide an unprecedented insight into spatial distribution and temporal dynamics of oceanic chlorophyll-a. That information favors a deeper understanding of the atmospheric carbon dioxide sequestration by marine phytoplankton and, as a consequence, of the role of the Earth's oceans in the global carbon cycle. Nevertheless, radiometers data need to be accurate in order to be useful. In this study, the accuracy of SeaWiFS, MODIS-Terra, MODIS-Aqua and MERIS is tested both thanks to an intercomparison among those radiomers, and thanks a validation with a lidar fluorosensor. From one hand, the satellite radiometers monthly averages were in mutual agreement within their estimated accuracy (about 35%), from the other hand the mean difference between lidar fluorosensor measurements and satellite radiometers retrievals was less than 30%. In both cases larger deviations were possible in particular regions and short periods, suggesting that the chlorophyll-a bio-optical algorithms of the satellite radiometers should be calibrated in specific regions and limited periods.

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1. Introduction

The precise knowledge of primary production rates in the Southern Ocean has global importance for solving different ecological and climatological puzzles and, in particular, for understanding the processes of carbon exchange between ocean and atmosphere, a key factor in the global carbon cycle [Falkowski et al. 2000]. One of the main oceanic parameters, necessary for primary production calculations, is the surface chlorophyll-a (Chl-a) concentration [Behrenfeld and Falkowski 1997]. Although phytoplankton plays a major role in the global carbon cycle, its seasonal and spatial changes in the Southern Ocean are less known with respect to other oceanic provinces [Fargion et al. 2003]. Since 1997, an Italian group of researchers participated to oceanographic campaigns in Antarctica with the ENEA Lidar Fluorosensor (ELF), onboard the Research Vessel Italica, for in situ measurements of surface Chl-a concentrations based on laser-induced fluorescence (LIF) [Barbini et al. 2001]. Nearly at the same time, several satellite-based instruments began their operations. They measure ocean color from a near-polar orbit and calculate surface Chl-a concentrations thanks to bio-optical algorithms applied to the blue-to-green ratio [O'Reilly et al. 1998]. The more important are the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), onboard Orbview-2 [Hooker et al. 1992], the Moderate Resolution Imaging Spectroradiometer (MODIS), onboard Terra and Aqua [Esaias et al. 1998], and the Medium Resolution Imaging Spectrometer (MERIS), onboard ENVISAT [Huot et al. 2002]. Bio-optical algorithms used in these instruments for estimation of Chl-a concentrations are intended for mid-latitudes and are far from excellence [Barbini et al. 2003]. Thus their outputs need to be validated and corrected according to Southern Ocean specific taxonomic compositions [Alvain et al. 2004]. As a preliminary step, the data quality of those sensors has to be assessed. In order to contribute to this purpose, at least in the Southern Ocean, here we present a comparison of Chl-a imagery obtained by SeaWiFS, MODIS and MERIS during the 18th Italian Antarctic Oceanographic Campaign (January 5th – March 5th 2003), extending preceding results obtained only for SeaWiFS and MODIS [Barbini et al. 2005]. During that campaign, the data of those satellite radiometers span a Chl-a interval large enough to provide a good estimate of the overall accuracy of their Chl-a retrieval. Moreover, the satellite data are compared with the "sea truth" measurements performed by ELF, similarly to a study carried out in the Indian and Pacific Oceans [Barbini et al. 2004].

2. Methods

The instruments involved in this study have already been carefully described in the literature. The reader is referred to Barbini et al. [2001] for ELF, to Hooker et al. [1992] for SeaWiFS, to Esaias et al. [1998] for MODIS and to Huot et al. [2002] for MERIS.

For the comparison of Chl-a imagery obtained by SeaWiFS, MODIS and MERIS, level 3 monthly products, relative to January and February 2003, were downloaded in May 2005 (Table **Error! Bookmark not defined.**). In this way, the satellite data corresponded nearly exactly to 18th Italian Antarctic Oceanographic Campaign. For the comparison with ELF, level 3 daily (SeaWiFS and MODIS) and level 2 (MERIS) products, relative to the period from January 5th to March 5th 2003, were downloaded in May (SeaWiFS and MODIS) and April (MERIS) 2005 (Table 1). Level 3 daily products were not available for MERIS but this was not a problem because all the MERIS pixels falling in a SeaWiFS pixel on that day were averaged. This happened because, for both comparisons, SeaWiFS was chosen as reference instrument. In fact, standard mapped image products were used for SeaWiFS, corresponding to a resolution of 5’16”×5’16”, and all the MODIS pixels, the MERIS pixels and the ELF measurements falling in a SeaWiFS pixel were averaged. From now on those averages will be simply called “MODIS pixel”, “MERIS pixel” and “ELF measurement”, respectively. Two determinations (pixels of different satellites or pixel and ELF measurement) were considered concurrent if they coincided in space and were acquired on the same day.

Table 1. Download sites of the satellite radiometers data products.

Satellite radiometer	Site
SeaWiFS	ftp://disc1.gsfc.nasa.gov/
MODIS-Terra	ftp://g0dps01u.ecs.nasa.gov/
MODIS-Aqua	http://oceancolor.gsfc.nasa.gov/
MERIS	http://www.enviport.org/meris/ (level 3) http://141.4.215.11/merci/ (level 2)

The per cent difference (Δ) between the values of surface Chl-a concentration measured by two instruments (C and C’) was calculated as follows:

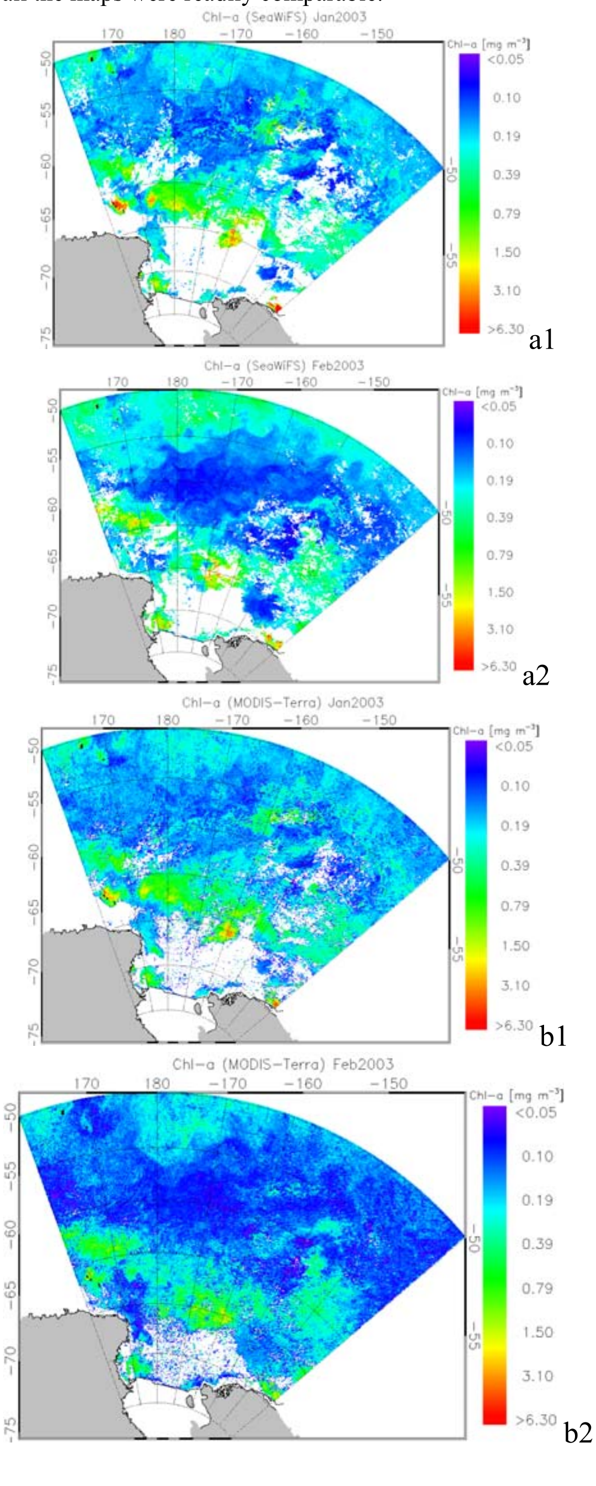
$$\Delta\ [\%] = 100 \times (C - C') / C$$

If two pixels of different satellites where considered, C was the SeaWiFS value, if a pixel and an ELF measurement where compared, C was the ELF determination.

The region of interest, as in a preceding study, is the Ross Sea Sector (RSS) defined as the zone of Southern Ocean from the coast of Antarctica north to 50° S latitude in the 160° E – 130° W interval. In the imagery, provided in stereographic projection, white and gray zones correspond to missing values (clouds or ice) and land, respectively. Of course, the comparison between ELF and satellite radiometers is limited to the pixels along the ship track, although on many occasions ELF was able to carry out measurements when the satellite radiometers were not for the presence of clouds or ice debris.

3. Results

The satellite radiometers maps of surface Chl-a concentration are given in Fig. 1. The best coverage was obtained by MODIS-Terra. That of SeaWiFS and MODIS-Aqua was a bit lower and considerably higher than that of MERIS. This is not surprising because level 3 MERIS data were limited to case I water. Nevertheless, MODIS-Terra imagery was more fuzzier and fine structures were less visible. Conversely, MODIS-Aqua and MERIS seemed the best resolved instruments (a thorough comparison of the satellite radiometers resolution would have required to consider their original products and was beyond the scope of this paper). As far as Chl-a values were concerned, SeaWiFS showed the more intense algal blooms, while MERIS was rather lower in oligotrophic zones. Anyway, all the maps were readily comparable.



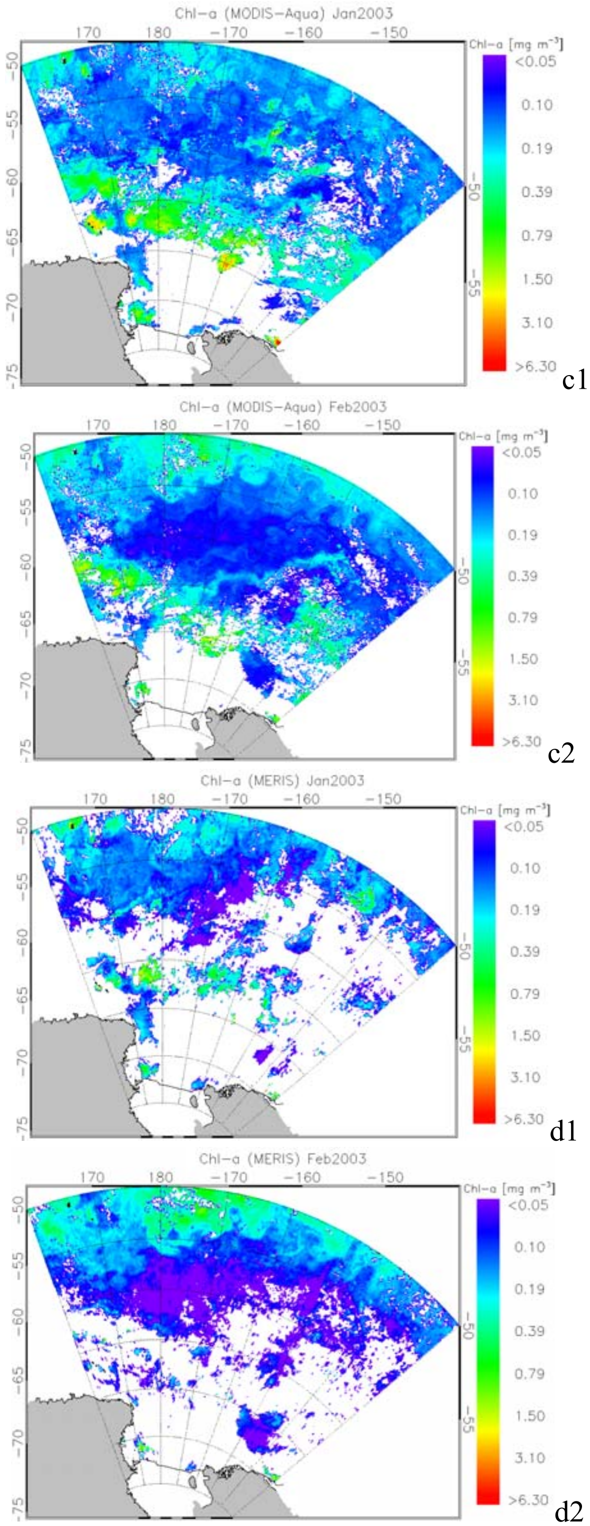
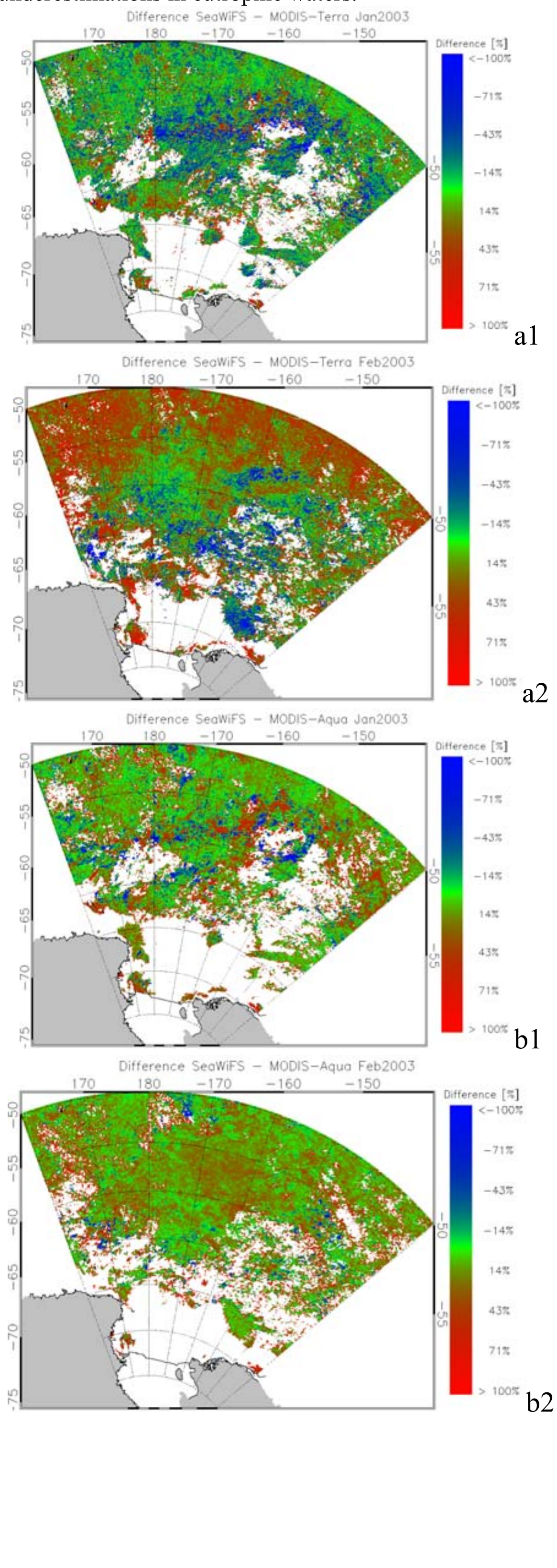


Fig. 1. Average surface Chl-a concentration measured by: SeaWiFS in January (a1) and February (a2) 2003; MODIS-Terra in January (b1) and February (b2) 2003; MODIS-Aqua in January (c1) and February (c2) 2003; MERIS in January (d1) and February (d2) 2003.

In order to better examine the disagreement among the satellite radiometers, the maps of per cent difference between the average surface Chl-a concentrations measured by SeaWiFS and another satellite radiometer are given in Fig. 2. MODIS-Terra behaved differently from January to February: in the first case high and low differences were present with a similar frequency, in the second one its retrieval was dominated by underestimations in eutrophic waters.



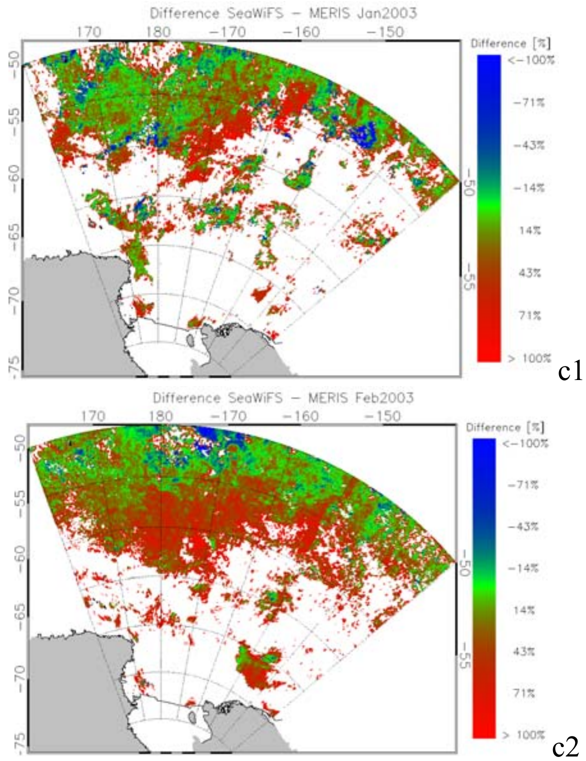


Fig. 2. Per cent difference between the average surface Chl-a concentrations measured by: SeaWiFS and MODIS-Terra in January (a1) and February (a2) 2003; SeaWiFS and MODIS-Aqua in January (b1) and February (b2) 2003; SeaWiFS and MERIS in January (c1) and February (c2) 2003.

For MODIS-Terra the areas of underestimation and overestimation seemed more uniformly distributed, although high differences were slightly more present. MERIS was even more discrepant from SeaWiFS and its underestimation was evident in oligotrophic waters. The monthly average in RSS of the per cent difference between the surface Chl-a concentrations retrieved by SeaWiFS and another satellite radiometer, given in Table 2, confirms those observations. In average, the satellite radiometers could be put in the following order, from the highest to the lowest surface Chl-a concentration: SeaWiFS, MODIS-Terra, MODIS-Aqua, MERIS.

Table 2. Monthly average in RSS of the per cent difference between the surface Chl-a concentrations retrieved by SeaWiFS and another satellite radiometer.

Satellite radiometers	January Δ [%]	February Δ [%]
SeaWiFS – Modis-Terra	-1.4	14
SeaWiFS – Modis-Aqua	15	20
SeaWiFS – MERIS	29	38

A priori, there is no reason to believe that SeaWiFS is more accurate than another satellite radiometer: this is why all the satellite radiometers were compared with the "sea truth" data provided by ELF along the ship track.

The surface Chl-a concentrations measured by ELF and retrieved by the satellite radiometers during the 18th Italian Antarctic Oceanographic Campaign are shown in Fig. 3. Unfortunately, only some general trends could be ascertained from Fig. 3: firstly, there was a general agreement between all the instruments; secondly, MODIS-Aqua was nearly ever lower than ELF; SeaWiFS and MERIS were often considerably higher than ELF (in eutrophic waters); MODIS-Terra seemed the satellite radiometer closest to ELF.

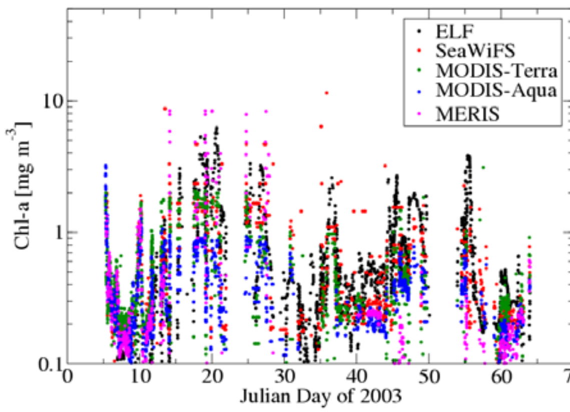


Fig. 3. Surface Chl-a concentration measured by ELF (black), SeaWiFS (red), MODIS-Terra (green), MODIS-Aqua (blue) and MERIS (pink).

In order to reveal the overall discrepancy among the instruments, the average along the ship track of the per cent difference between the surface Chl-a concentrations measured by ELF and retrieved by the satellite radiometers is given in Table 3.

Table 3. Average along the ship track of the per cent difference between the surface Chl-a concentrations measured by ELF and retrieved by the satellite radiometers.

Instruments	Δ [%]
ELF – SeaWiFS	-22
ELF – Modis-Terra	1.9
ELF – Modis-Aqua	29
ELF – MERIS	-15

The values were quite surprising: MODIS-Terra and ELF were near coincident, SeaWiFS and MERIS underestimated of about 20% and MODIS-Aqua overestimated of about 30%. In average, the satellite radiometers could be put in the following order (different from that above), from the highest to the lowest surface Chl-a concentration: SeaWiFS, MERIS, MODIS-Terra, MODIS-Aqua. Of course, those results refers to a specific region of the western Ross Sea: ELF measurements have been carried out near the coast from Cape Adare and Ross Island, except the few days of the New Zealand – Antarctica and Antarctica – New Zealand transects (at the beginning and at the end of the oceanographic campaign, see the low Chl-a of the first and last days, typical of oceanic waters). In particular, the high values of the Julian days from 18 to 27 were recorded near Terra Nova Bay.

4. Conclusions

The comparison among SeaWiFS, MODIS-Terra, MODIS-Aqua and MERIS in the Southern Ocean during the 18th Italian Antarctic Oceanographic Campaign showed that the satellite radiometers were in agreement within their estimated accuracy (about 35%). Nevertheless, discrepancies were larger in specific regions. During this research, SeaWiFS and MODIS-Terra values of surface Chl-a concentration were the closest. MODIS-Terra offered also the best coverage.

If the surface Chl-a concentration retrieved by the satellite radiometers was compared to that measured by ELF, the average difference was less than 30%. Although this suggested that also in the sea region spanned by ELF the satellite radiometers were in agreement within their estimated accuracy, their behavior was different than in the Southern Ocean: SeaWiFS and MERIS values were the more similar. Regarding ELF measurements as “sea truth”, it can be concluded that MODIS-Terra was the more accurate satellite radiometer in the western Ross Sea in the period from January 5th to March 5th 2003. Those results suggest that the bio-optical algorithms of each ocean color satellite radiometer should be calibrated in limited sea regions and specific year periods.

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References

[1] S. Alvain, C. Moulin, H. Loisel, Y. Dandonneau, E-proceedings of Ocean Optics XVII. ONR, Fremantle, Australia, CD-ROM, 2004.
[2] R. Barbini, F. Colao, L. De Dominicis, R. Fantoni, L. Fiorani, A. Palucci, E. S. Artamonov, International Journal of Remote Sensing **25**, 2095 (2004).
[3] R. Barbini, F. Colao, R. Fantoni, L. Fiorani, I. G. Okladnikov, A. Palucci, International Journal of Remote Sensing, **26**, 2471 (2005).
[4] R. Barbini, F. Colao, R. Fantoni, L. Fiorani, A. Palucci, J. Optoelectron. Adv. Mater. **3**(4) 817 (2001).
[5] R. Barbini, F. Colao, R. Fantoni, L. Fiorani, A. Palucci, International Journal of Remote Sensing **24**, 3205 (2003).
[6] M. J. Behrenfeld, P. G. Falkowski, Limnology and Oceanography **42**, 1479 (1997).
[7] W. E. Esaias, M. R. Abbott, I. Barton, O. B. Brown, J. W. Campbell, K. L. Carder, D. K. Clark, R. H. Evans, F. E. Hoge, H. R. Gordon, W. M. Balch, R. Letelier, P. J. Minnett, IEEE Transactions on Geoscience and Remote Sensing **36,** 1250 (1998).
[8] P. G. Falkowski, R. J. Scholes, E. Boyle, J. Canadell, D. Canfield, J. Elser, N. Gruber, K. Hibbard, P. Högberg, S. Linder, F. T. Mackenzie, B. Moore III, T. Pedersen, Y. Rosenthal, S. Seitzinger, V. Smetacek, W. Steffen, Science, 290: 291 (2000).
[9] G. Fargion, B. Franz, E. Kwiatkowska, C. Pietras, S. Bailey, J. Gales, G. Meister, K. Knobelspiesse, J. Werdell, C. McClain, Proceedings of SPIE, **5155**, 49 (2003).
[10] S. B. Hooker, W. E. Esaias, G. C. Feldman, W. W. Gregg, C. R. McClain, In: Hooker, S. B. and Firestone, E. R. (Eds.), SeaWiFS Technical Report Series. NASA, Greenbelt, US, **1**, 1992.
[11] J.-P. Huot, H. Tait, M. Rast, S. Delwart, J.-L. Bézy, G. Levrini AATSR and MERIS. ESA Bulletin **106**, 56 (2002).
[12] J. E. O'Reilly, S. Maritorena, B. G. Mitchell, D. A. Siegel, K. L. Carder, S. A. Garver, M. Kahru, C. McClain, Ocean color chlorophyll algorithms for SeaWiFS. Journal of Geophysical Research C **103,** 24937 (1998).

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