An Operational Ocean Color Approach with *Végétation/SPOT-4*

Atmospheric Correction and Temporal Merging

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Abstract— **Demand for near-real-time (NRT) satellite ocean observations is rapidly increasing with the development of operational oceanography and its applications such as ocean monitoring for offshore oil exploitation, fish resources management or detection of surface pollution. This paper demonstrates that useful NRT ocean color measurements can be deducted from the blue, red, near-infrared and SWIR bands of *VEGETATION* on-board the SPOT satellites. The data processing is based on a very simple and primary algorithm. In particular, the atmospheric correction algorithm described in [1] is based on the use of the near-infrared B3 band to estimate aerosol amount and, assuming a unique maritime model, to extrapolate the aerosol signal to the B0 blue spectral band, the only one that is sensitive to marine reflectance. In order to increase the spatial coverage which can be sometimes very limited due to cloud coverage, a dedicated merging algorithm is used. An operational product, based on these processing algorithms is currently distributed on a commercial basis as the ocean color component into the Catsat package [2]. Some algorithmic improvements have been studied to improve the atmospheric correction using 2 spectral bands for the selection of the aerosol model among nine. They are illustrated by results obtained using acquisitions over the Canal of Mozambique in June 2000.**

Keywords : oceancolor, near-real-time, algorithm, datamerging

I. Description of the Végétation System

The *Végétation* instrument, launched in April 1998 on-board the SPOT-4 satellite, is fully described in [3]. The total field-of-view is 101° cross track leading to a ground swath of 2250 km with a ground resolution of about 1km at nadir. The four complementary spectral bands are the blue band (B0 from 0.43 to 0.57 µm), the red band (B2 from 0.61 to 0.68 µm), the near-infrared band (B3 from 0.79 to 0.89 µm), and the short-wave infrared band (SWIR from 1.58 to 1.75 µm). The spectral bands B2, B3, and SWIR were designed for the vegetation monitoring and an additional blue band was defined for atmospheric correction. The *Végétation* calibration methods, detailed in [4] and [5], allow a high level of quality of products. Consequently, as if *Végétation* is not designed for ocean color studies, it appears that the calibration accuracy and radiometric performances are quite consistent with ocean color requirements for open ocean as written in [6]. Only one spectral band is sensitive to ocean reflectance but in theory, it is sufficient to retrieve some information from the surface pigment concentration as described in [7], the objective with *Végétation* being not presently to retrieve accurate surface pigment concentration but mainly to draw ocean color maps from regions of interest.

Végétation is a complete system with a specific ground segment for data programming, processing and distribution as described in [8]. It allows the delivery of images acquired all over the world in a very short time, typically 2 to 4 days after acquisition date : the service is fully operational. The VGT-P products, related to one image acquisition, are composed by top of the atmosphere (TOA) reflectances in the four *Végétation* spectral bands in a Plate Carrée geographic projection of 1 km resolution, and ancillary data (geometry of acquisition and exogenous atmosphere information).

II. Atmospheric Correction Algorithm

The marine reflectance in the blue band is derived from TOA reflectances through an atmospheric correction algorithm which is completely described in [1]. The main steps of this algorithm are :

- Cloud mask – Because atmospheric molecules and ocean surface are optically black in this spectral band, the signal observed in the SWIR band is only due to clouds, aerosol or sun glint, components that we want to detect and eliminate (or furthermore correct). The first approach used was to apply a single threshold : pixels with corresponding SWIR TOA reflectance greater than 0.0125 were declared cloudy. We intend to implement a complementary cloud mask by using a second threshold on the B3 reflectance multiplied by cosines of solar zenith angle and viewing zenith angle in order to consider the influence of the airmass.

For pixels that are declared "clears", the TOA reflectance, ρ_{toa}, observed by the sensor can be expressed as :

$$\rho_{toa} = \left\{ \rho_r + \rho_a + \rho_w \frac{T_s^{tot} \cdot T_v^{tot}}{(1-\rho_w.\omega)} \right\} .t_g \qquad (1)$$

where ρ_r is the reflectance due to molecular scattering, ρ_a is the reflectance due to aerosol scattering including coupling terms with molecules, ω is the atmospheric albedo, T_s^{tot} and T_v^{tot} are total atmospheric transmittances (sum of direct and diffuse components) respectively for the solar and viewing zenith angles, t_g is the transmission due to gaseous absorption (ozone plus water vapor) and ρ_w is the marine reflectance. We ignore here the surface foam reflectance which is negligible for surface wind speed under 5-7 m.s^{-1} but this term should be considered is a more general algorithm simply using the surface wind speed from meteorological data set. The objective is thus to retrieve marine reflectance ρ_w in the blue band B0 which represents only about 10 to 20% of the TOA reflectance.

- Gazeous absorption – The gazeous transmission t_g is calculated according to [9] with for input, gas amount from ancillary meteorological data.

- Rayleigh scattering – The molecular contribution ρ_r can be accurately computed using a radiative transfert code (thereafter called SOS code) based on the Successive Order of Scattering method developed in [10]. For this, the main input parameter are molecular optical thickness computed according to [11] and surface pressure.

- Aerosol amount – For the B3 band, the ocean being black, it is possible to directly estimate the aerosol reflectance ρ_{toa}(B3) using Eq. (1), reflectance which characterizes the aerosol amount.

- Aerosol model – In [1], our first approach was to consider a unique aerosol model (Maritime 98% used in [12]) to extrapolate the aerosol reflectance estimated at B3 to the shorter band B0 and B2. This extrapolation coefficient, which includes coupling terms with the molecular contribution, is taken from a look-up table generated using the SOS code [10]. If preliminary results were satisfying, this rough assumption needed to be improved by a better determination of the aerosol model and so spectral behavior. For this, the aerosol contribution was calculated for 9 models used for the SeaWiFS data processing (see [12]) and a determination of the aerosol model was implemented on the algorithm, selecting the ones that provides the smaller marine reflectances at B2, band for which the marine reflectance can usually be assumed to zero (in case-1 waters). Consequently, as shown in Fig. 1, the major improvement in the atmospheric algorithm described in [1] is here the determination of an aerosol model map.

- Bidirectionnal effects – *Végétation* being a wide field-of-view sensor, marine reflectance estimations are made for various viewing conditions over all its 2200 km swath. As described in [13] bi-directionality of marine reflectance exist (with effects of typically 10 to 20%). In our algorithm, marine reflectances were normalized to a standard condition according to [13] which is helpful when comparing or merging acquisitions made for 3 or more successive days (and so different viewing conditions).

After these successive corrections, each VGT-P images provides for a given area a daily marine reflectance image as the example shown in Fig. 2 for the Mozambique Channel. These maps were compared in [1] to SeaWiFS derived images and to altimetry data from Topex-Poseïdon and a high coherence was evidenced.

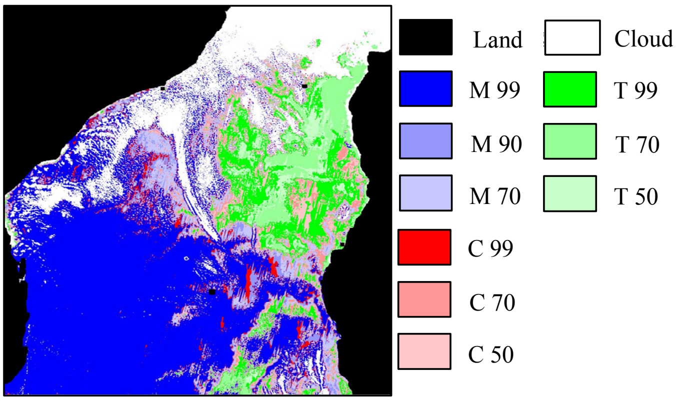

Figure 1. Aerosol models derived from the algorithm over the Mozambique Channel and for the 16th June 2001. The predominant model is Maritime (99%) while some Tropospheric models appear on the North-East and East.

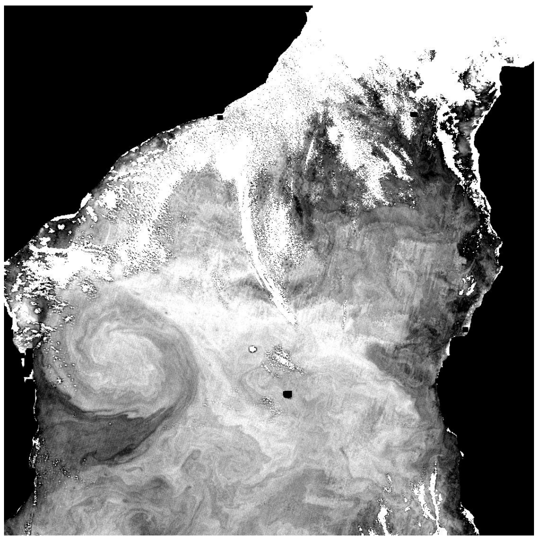

Figure 2. Marine structures derived from VÉGÉTATION acquisitions over the Mozambique Channel, the 16th June 2001. Mozambique coast appears black on the left, Madagascar coast appears black on the right, and clouds are white. A large whirlpool is visible on the west (diameter ~ 300km).

III. Data Merging and Ocean Color Product

Because daily images are sometimes highly contaminated by the presence of clouds, a dedicated algorithm was defined in order to merge several days of observation and therefore to assess a more complete coverage of enlarged zones. This algorithm considers 2 important aspects :

- the age of data which is an important aspect for near-real-time applications that require the most recent data as possible;

- the quality of data quantified by a "quality index" based on the importance of clouds on the vicinity of the considered pixel;

The number of days used to generate a temporal merging is initally 3-4 days. Figure 3 illustrates the quasi-complete coverage of marine structures obtained for 15-16-17th June 2001. The resolution was degraded to 0.04° (about 4 km) in order to decrease the volume of images. The other advantage is that this resolution ignores the high-frequency information, which can be considered as non-pertinent for near-real-time applications interested by more or less stable events.

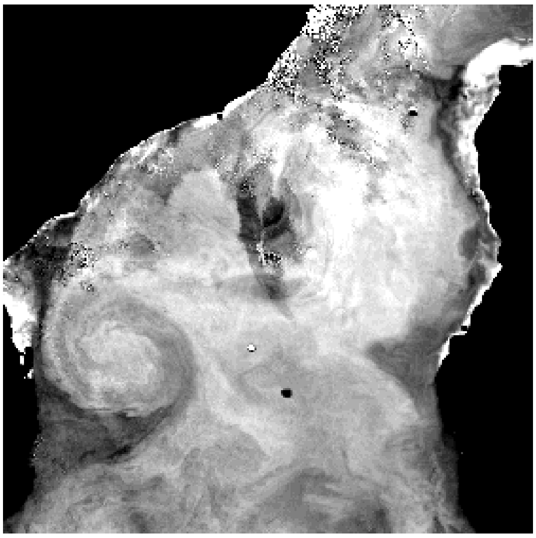

Figure 3. Marine structure resulting from the temporal merging of 3 days of acquisitions, 15th, 16th, and 17th June 2001. A quasi-complete coverage is assessed as if some residual artifacts are still visible.

IV. Operational Product

An operational ocean color product, based on these processing algorithms is currently distributed on a commercial basis as the ocean color component into the Catsat package (see [2]), a worldwide satellite system to support fishing activities. At the present time, the ocean color products are available for a large area illustrated Fig. 4 on which usual marine structure of oceans (Atlantic, Pacific and Indian) and seas (North and Mediterranean) can be easily identified.

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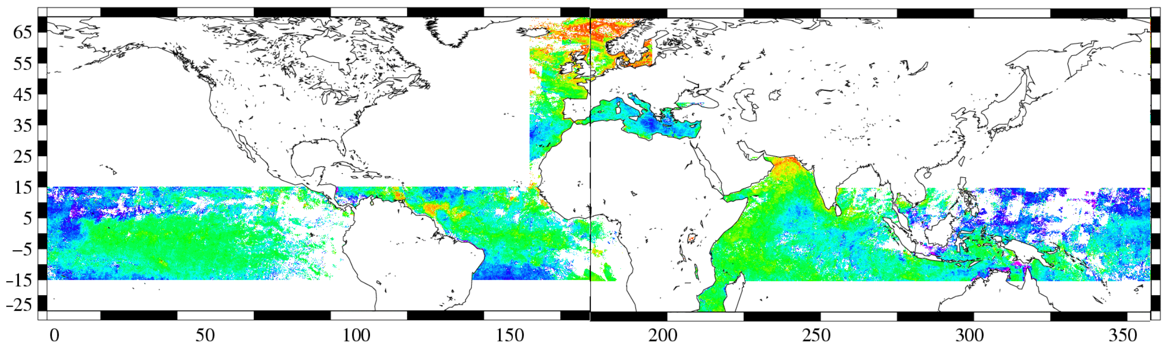

Figure 4. Gobal coverage of the operational ocean color acquisitions with Végétation/SPOT-4 (example of programmation valide for 2001). Oceans around the equator (from +15 to –15° latitude), mediterranean and North seas and a part of the Atlantic ocean are regularly covered. The map illustrates oligotrophic waters in blue and eutrophic waters in green, and mesotrophic waters in red.