Worldview-2 High Resolution Remote Sensing Image Processing for the Monitoring of Coastal Areas

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Worldview-2 High Resolution Remote Sensing Image Processing for the Monitoring of Coastal Areas

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ABSTRACT

The spectral information provided by the multispectral Worldview-2 satellite increases the amount of spectral data available, thereby improving the quality of coastal environmental products. The atmospheric correction has proven to be a very important step in the processing of Worldview-2 high resolution images. On the other hand, specular reflection of solar radiation on non-flat water surfaces is a serious confounding factor for bathymetry and benthic remote sensing classification in shallow-water environments. This paper describes an optimal atmospheric correction model, as well as an improved algorithm for sun-glint removal based on combined physical and image processing techniques. This way, the atmospheric reflectance can be estimated and the effects from the apparent reflectance leaving from the water surface and the seafloor can be eliminated. Finally, using the corrected multispectral data, we have implemented an efficient physics-based method to obtain the remote bathymetry and a supervised classification for benthic mapping.

Index Terms— High resolution multispectral imagery, atmospheric model, sun-glint, bathymetry, benthic mapping.

1. INTRODUCTION

Remote spectral imaging of coastal areas can provide valuable information for characterizing and monitoring coastal waters. The use of multispectral imagery from satellite sensors such as Thematic Mapper, MODIS (Moderate Resolution Imaging Spectroradiometer), SeaWiFS (Sea-viewing Wide Field-of-view Sensor), and others has been established for many applications, including the estimation of chlorophyll concentrations, suspended matter and roughly water depth. With the advent of very high resolution multispectral imaging sensors such as the WordView 2 (WV2), there is the potential to retrieve much more information. Applications include water quality monitoring, benthic habitat mapping and remote bathymetry in coastal areas. However, achieving these goals requires overcoming a number of challenges.

Water-leaving radiance is very difficult to determine accurately, as it is often small compared to reflected radiance from sources such as atmospheric and water surface scattering, and it is subject to uncertainties in the sensor's radiometric calibration.

Thus, the atmospheric correction has proven to be a crucial aspect in the processing of high resolution images that can affect subsequent steps in remote sensing applications of satellite data. On the other hand, specular reflection of solar radiation on non-flat water surfaces is a serious confounding factor for bathymetry and, specially, for benthic remote sensing mapping in shallow-water environments.

This paper describes an optimal atmospheric correction model and an improved algorithm for sun-glint removal based on physical and image processing techniques. Those methods have been applied to the multispectral WorldView-2 (WV2 hereafter) channels to estimate atmospheric reflectance and to remove the effects from the apparent reflectance leaving from the water surface and the seafloor, respectively. Finally, we have implemented an efficient physics-based method to obtain the bathymetry of shallow coastal waters and a minimum distance supervised classification for benthic mapping, respectively.

2. IMAGE ACQUISITION AND MULTISPECTRAL ATMOSPHERIC PROCESSING

In order to make reliable estimates of water quality parameters, bathymetry and benthic mapping in the coastal areas, accurate retrievals of water leaving reflectances are required. In this context, the present operational atmospheric correction algorithms work reasonably well over clear ocean areas ('Case 1' waters), but gives inaccurate results over brighter coastal waters ('Case 2' waters). So, we have implemented a multi-channel atmospheric correction algorithm, specifically, the 6S (Second Simulation of a Satellite Signal in the Solar Spectrum) atmospheric correction method adapted to high resolution WorldView-2 multispectral satellite imagery.

2.1. WorldView-2 imagery

The WorldView-2 high-resolution commercial imaging satellite was launched on October 8, 2009. The satellite is in a nearly circular, sun-synchronous orbit with a period of 100.2 minutes at an altitude of approximately 770 km. WorldView-2 acquires 11-bit data in nine spectral bands covering panchromatic, coastal, blue, green, yellow, red, red edge, NIR1, and NIR2. The spectral response of each band is shown in Figure 1 [1].

This work relied on Ortho Ready Standard Worldview-2 images. Images were monthly taken from August 2011. At nadir, the collected nominal ground sample distance is 0.46 m (panchromatic) and 1.84 m (multispectral), however, commercially available products are resampled to 0.5 m and 2.0 m (outside U.S.). The nominal swath width is 16.4 km. The study area is in the south part of Tenerife Island (Canary Islands), as shown in Figure 2. Granadilla area has a water quality monitoring network in place for two years. To evaluate the results generated by the atmospheric model, we used ground-based spectral data collected by the spectroradiometer Vis/NIR ASD FieldSpec 3 nearly coincident with WorldView-2 satellite over flight (see Figure 3 (a)).

2.2 Atmospheric correction model for high resolution WorldView-2 multispectral imagery

The atmospheric correction algorithms to process remotely sensed data from low resolution sensors (p.e. MODIS, SeaWiFS, MERIS) were primarily designed for retrieving water-leaving radiances in the visible spectral region over deep ocean areas, where the water-leaving radiances are close to zero. For turbid coastal environments and optically shallow waters, water-leaving radiances may be significantly greater than zero because of backscattering by suspended materials in the water and bottom reflectance. Hence, applications of the Case 1 algorithm to satellite imagery acquired over turbid coastal waters often result in negative water-leaving radiances over extended areas. Therefore, improved atmospheric correction algorithms must be developed for the remote sensing of Case 2 waters.

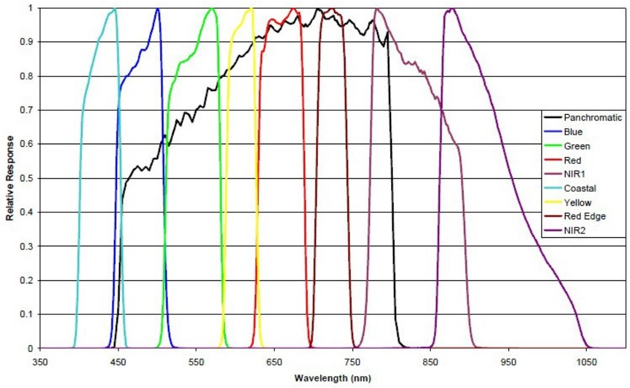


Figure 1. WV2 relative spectral radiance response (nm).

In this context, we decided to implement the 6S (Second Simulation of a Satellite Signal in the Solar Spectrum) atmospheric correction method adapted to high resolution WorldView-2 multispectral imagery of Granadilla area. 6S is an advanced radiative transfer code designed to simulate the reflection of solar radiation by a coupled atmosphere-surface system for a wide range of atmospheric, spectral and geometrical conditions [2]. It belongs to the group of procedures called atmospheric correction for the process of removing the effects of the atmosphere on the reflectance values of images taken by satellite sensors. The code operates on the basis of an SOS (successive orders of scattering) method and accounts for the polarization of radiation in the atmosphere through the calculation of the Q and U components of the Stokes vector.

This model predicts the reflectance ρ of objects at the top of atmosphere (TOA) using information about the surface reflectance and atmospheric conditions. The TOA reflectance ($\rho_{TOA,\lambda}$) can be estimated using the following expression:

$$\rho_{TOA,\lambda} = \frac{L_{sen,\lambda} \cdot d^2 \cdot \pi}{E_\lambda \cdot \cos\theta_i} \qquad (1)$$

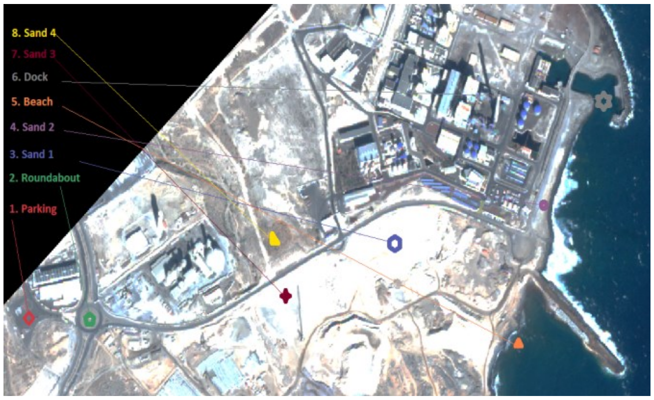
The minimum data set needed to run the 6S model is the meteorological visibility, type of sensor, sun zenith and azimuth angles, date and time of image acquisition, and latitude-longitude of scene center. In this study we have proceeded to correct the eight-band multispectral and panchromatic band of WV2 by means of the 6S model, defining the geometry of the satellite observation and viewing angle. The true reflectance value ρ_λ is obtained from the model output by the following expression,

$$\rho_\lambda = \frac{y}{1+(x_c * y)} \qquad y = (x_a * L_\lambda) - x_b \qquad (2)$$

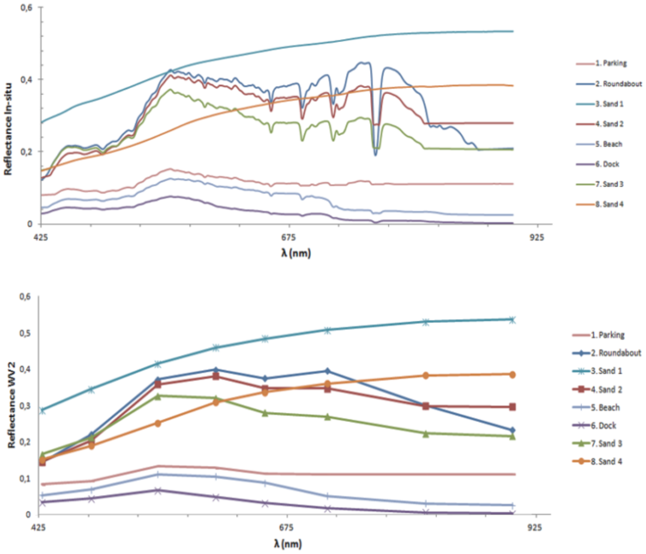
where ρ_λ is the corrected reflectance, L_λ is the sensed radiance, x_a, x_b, and x_c are the coefficients obtained from the model

Figure 2. WorldView-2 image of the Granadilla area (Canary Islands, Spain) acquired on February 18, 2012 and overlaid in goggle map$^{©}$.

Finally, in order to check the proper functioning of the selected 6S atmospheric correction algorithm, ground-based reflectance measurements were performed on a variety of locations, with similar weather and lighting conditions. Figure 3 (a) shows the WV2 image of Granadilla area where in-situ radiometric test points were obtained. The results achieved by 6S atmospheric correction techniques on WV2 image compared with ground-based reflectance measurements, are presented in Figure 3 (b). As it can be observed, the results show a great correlation between the reflectivity values obtained by in-situ measurements and the corresponding obtained by the eight multispectral satellite channels through the 6S atmospheric model.



(a)



(b)

Figure 3. (a) Location of the in-situ test points on WorldView-2 imagery of Granadilla area (February 2012) and, (b) ground-based reflectance measurements (top) and corresponding WorldView-2 multispectral 6S atmospheric corrected reflectance (bottom).

3. SUN-GLINT CORRECTION ALGORITHM

Specular reflection of solar radiation on non-flat water surfaces is a serious confounding factor for turbidity remote sensing in shallow-water environments. Therefore, the remote bathymetry and the mapping of benthic features can be seriously impeded by the state of the water.

To overcome this challenge, experts could refer to previous methods and models designed to take advantage of the glint to compute surface characteristics (e.g., wave height) or to remove glint contamination prior to estimating water column constituents and optical properties (e.g., mapping shallow-water benthos). However, these methods have been conceived for the open ocean, not for nearshore shallow environments. Because of nearshore topography, the assumption of monodirectionality of waves is generally not valid. Moreover, open ocean algorithms are designed for low-resolution data (1 km), where glint effects occur at a scale much smaller than pixel dimensions. In this paper, we propose a method based on combined physical principles and image processing techniques for removal of sea surface effects from high-resolution imagery in coastal environments.

Glint Removal: Following the procedure suggested by Hedley *et al.* (2005), one or more regions of the image are selected where a range of sun-glint is evident, but where the underlying spectral brightness would be expected to be consistent (i.e., areas of deep water) [4]. For each visible band all the selected pixels are included in a linear regression of NIR brightness against the visible band brightness. If the slope of this line for band *i* is *bi*, then the reflectance (*R)* of all the pixels in the image can be deglinted in band *i* by the application of the following equation:

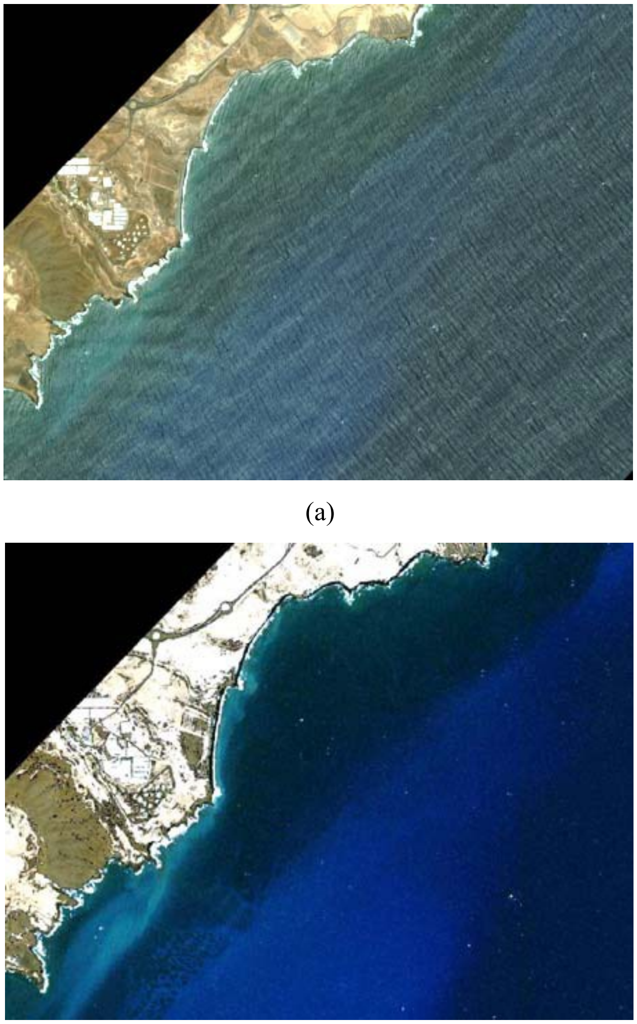
$$R_i' = R_i - b_i * (R_{NIR} - MIN_{NIR}) \qquad (3)$$

The deglinting procedure was carried out with atmospherically corrected WorldView2 multispectral imagery, and only on images that had glint pixels that would hinder the visibility of bottom features.

Unfortunately, the previous deglinting process, using the expression (3), affects to the spectral content of the image altering intensity and colors. To overcome this inconvenience, the Histogram Matching technique is applied to statistically equalize images after deglinting from the original water reflectivity for each channel.

Given that not all the sensor bands capture precisely the energy at the same time, a further improvement in the glint removal algorithm has been performed consisting on the use of an sliding window centered at singular points (foam of the waves) where template matching techniques have been applied over a reduced search area in order to eliminate the small spatial misalignments between the bands. After this improvement, the subtraction between the bands to be corrected and the near infrared band can be reliably performed. This new image processing technique removes most of the noise after the deglinting process. Finally, another improvement included is based on the elimination of pixels achieving reflectance values above a threshold adjusted for coastal waters. That way, the foam of the waves or "whitecaps" can be removed and such pixels filled by interpolation.

The results of a full deglinted image are shown in Figure 4. This example presents a glinty Worldview-2 image from the Granadilla area, with a poor signal to noise ratio in shallow waters, as shown in Figure 4 (a). Before incorporating the glint removal procedure, glint was a major problem when trying to classify the bottom. After the glint was removed, the bottom features became pronounced and classification algorithms could be applied successfully (Figure 4 (b)).



(a)

(b)

Figure 4. Results obtained after deglinting process: (a) original WorldView-2 image of the Granadilla area and, (b) image after deglinting using equation (3).

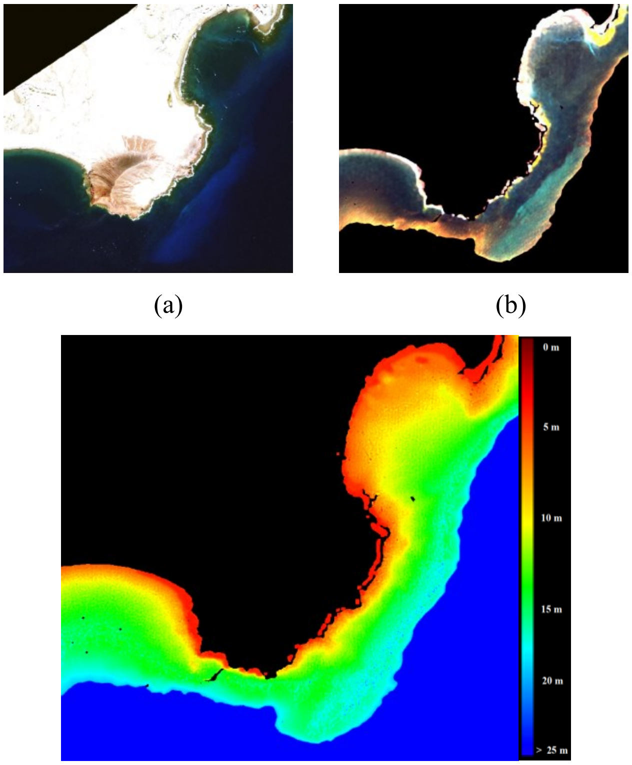
4. BATHYMETRY AND BENTHIC MAPPING

After atmospheric and glinting corrections of WorldView-2 multispectral imagery of Granadilla area, remote bathymetry and benthic mapping of shallow-water environments can be obtained with high resolution and precision. For bathymetry, an efficient multichannel physics-based algorithm has been implemented, capable of solving the radiative transfer physical model equation of seawater.

Using the radiative model to compute bathymetry has yielded good results as it considers the physical phenomena of water absorption and the relationship between the albedo of the seafloor and the reflectivity of the shallow waters. Thus, the radiative modeling allows us to calculate the albedo of the seafloor [5]. This achievement is of fundamental importance for the classification of benthic species. The model is given by equation,

$$R(0-,\lambda) = R_\infty(0-,\lambda) + \left(R_b(0-,\lambda) - R_\infty(0-,\lambda)\right)e^{-2k_d * Z} \quad (4)$$

where $R(0\text{-},\lambda)$ is the reflectivity of the water inner surface. R_∞ $(0\text{-},\lambda)$ is the reflectivity of the deep water inner surface. R_b $(0\text{-},\lambda)$ is the seafloor albedo or reflectivity. Kd is the diffuse attenuation coefficient and Z is the depth. The results for Granadilla region are displayed in Figure 5.



(a) (b)

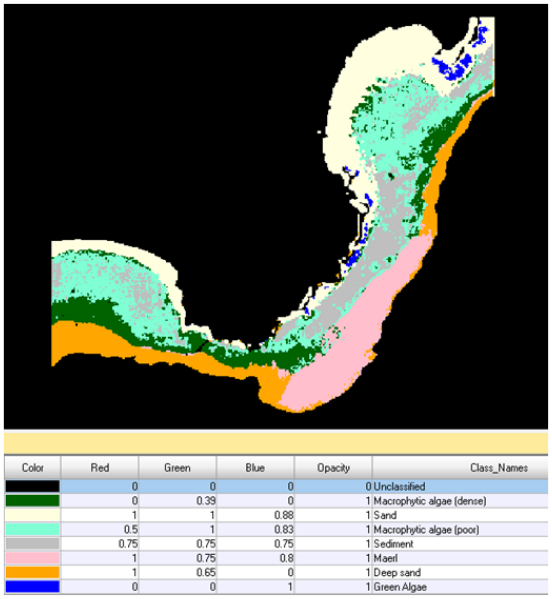
(c)

Figure 5. (a) WorldView-2 atmospheric and sun-glint corrected imagery, (b) seafloor albedo and, (c) map of estimated depth (bathymetry) for the Granadilla area.

For the mapping of benthic features, a supervised classification of benthic indexes has been carried out. The training classes were clearly defined (see bottom of Fig. 5) and a detailed separability assessment was conducted using the Jeffries-Matusita and the Transformed Divergence metrics. In our context the supervised classification methods used was the minimum distance. This technique uses the mean vectors for each class and calculates the Euclidean distance from each unknown pixel to the mean vector for each class [6]. The pixels are classified to the nearest class,

$$D_i(x) = \sqrt{(x - m_i)^T (x - m_i)} \qquad (5)$$

where D is the Euclidean distance; *i* the *ith* class; *x* is the n-dimensional data (where n is the number of bands) and m_i is the mean vector of a class. Figure 6 provides the results of the benthic classification. Results were validated and are consistent with available bionomic profiles.



Color	Red	Green	Blue	Opacity	Class_Names
⬛	0	0	0	0	Unclassified
🟩	0	0.39	0	1	Macrophytic algae (dense)
⬜	1	1	0.88	1	Sand
🟩	0.5	1	0.83	1	Macrophytic algae (poor)
⬜	0.75	0.75	0.75	1	Sediment
🟥	1	0.75	0.8	1	Maerl
🟧	1	0.65	0	1	Deep sand
🟦	0	0	1	1	Green Algae

Figure 6. Classification map of shallow-water benthos of the Granadilla area, obtained by minimun distance supervised classification.

5. CONCLUSIONS

Coastlines, shoals and reefs are some of the most dynamic and constantly changing regions of the globe. Monitoring and measuring these changes is critical to marine navigation and an important tool in understanding our environment.

This work has demonstrated the application of very high resolution multispectral imagery to remote bathymetry and benthic mapping in the shallow-water environments. The results include depth maps and bottom visualizations. As part of this effort, atmospheric correction in the littoral zone was advanced through new capabilities added to the 6S atmospheric correction method. For evaluating atmospheric correction we compared the 6S model with coincident ground-based reflectance measurements in the area under study areas obtaining a very good correlation between the reflectivity values obtained by in-situ measurements and the corresponding acquired by atmospheric processing of the eight multispectral satellite channels.

Specular reflection of solar radiation on non-flat water surfaces is a serious factor that impedes the proper estimation of water quality parameters, as well as the bathymetry and the mapping of benthic features. Therefore, an improved and robust methodology to remove glint contamination has been included. This procedure exploits physical information but it is also relies on image processing algorithms to achieve the maximum performance.

After atmospheric and glinting corrections of WorldView-2 multispectral imagery, bathymetry and benthic mapping of shallow-water environments can be obtained with high resolution and precision. For bathymetry, an efficient multichannel physics-based algorithm has been implemented while for the mapping of benthic features, a supervised classification of benthic indexes has been carried out. Results have been validated with in-situ data providing an excellent accuracy.

ACKNOWLEDGEMENTS

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