Atmospheric correction models for high resolution WorldView-2 multispectral imagery: A case study in Canary Islands, Spain.

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The emergence of high-resolution satellites with new spectral channels and the ability to change its viewing angle has highlighted the importance of modeling the atmospheric effects. In this study we have proceeded to make the atmospheric correction of the eight multispectral bands of high resolution **WorldView-2 satellite** by three different atmospherics models (COST, DOS, 6S) defining the geometry of the satellite observation, viewing angle and setting the weather conditions more suited for the acquired images of the study area (Granadilla, Canary Islands). Specifically, the **6S atmospheric correction mode**l, based on radiative transfer theory, provides patterns which describe properly atmospheric conditions in this specific study area for monitoring turbid coastal environments. To check the proper functioning of the atmospheric correction comparison was performed between ground-based measurements and corresponding obtained by the eight multispectral satellite channels through the 6S atmospheric model, with similar date, weather and lighting conditions.

STUDY AREA AND MATERIAL

The study area is in the south part of Tenerife Island, near Granadilla City (Figure 1). The Port of Granadilla Environmental Monitoring Programme was established in 2010 in order to ensure sustained environmental quality across the wide range of natural and artificially created habitats within and immediately outside of the Port. So, turbid coastal environments and optically shallow waters need to be studied and regularly analyzed within a strategic plan for environmental monitoring.

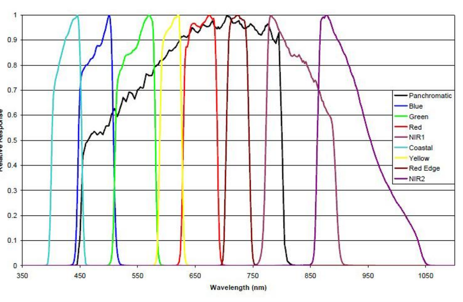
Location: Granadilla, Canary Islands

Figure 1. Study area. Location (28.07 N, 16.35 W) and Granadilla area WV2 image acquired on February 18, 2012 superposed in goggle map©..

In-situ measurements

- Water samples at fixed stations and samples collected by routine ships are analyzed weekly, monthly and seasonally now.
- The analysis result has provided water quality data regarding Chl-a, TSM, CDOM.
- To evaluate the results generated by the various atmospheric models, we used ground-based spectral data collected by the spectroradiometer Vis/NIR ASD FieldSpec 3 nearly coincident with WorldView-2 satellite over flight

WorldView-2 imagery



Bands	Center Wavelength	50% Band Pass	5% Band Pass
Panchromatic	0.632	0.464 – 0.801	0.447 – 0.808
Coastal	0.427	0.401 – 0.453	0.396 - 0.458
Blue	0.478	0.448 – 0.508	0.442 – 0.515
Green	0.546	0.511 – 0.581	0.506 – 0.586
Yellow	0.608	0.589 – 0.627	0.584 - 0.632
Red	0.659	0.629 – 0.689	0.624 – 0.694
Red Edge	0.724	0.704 – 0.744	0.699 - 0.749
NIR 1	0.831	0.772 – 0.890	0.765 – 0.901
NIR 2	0.908	0.862 – 0.954	0.856 - 1.043

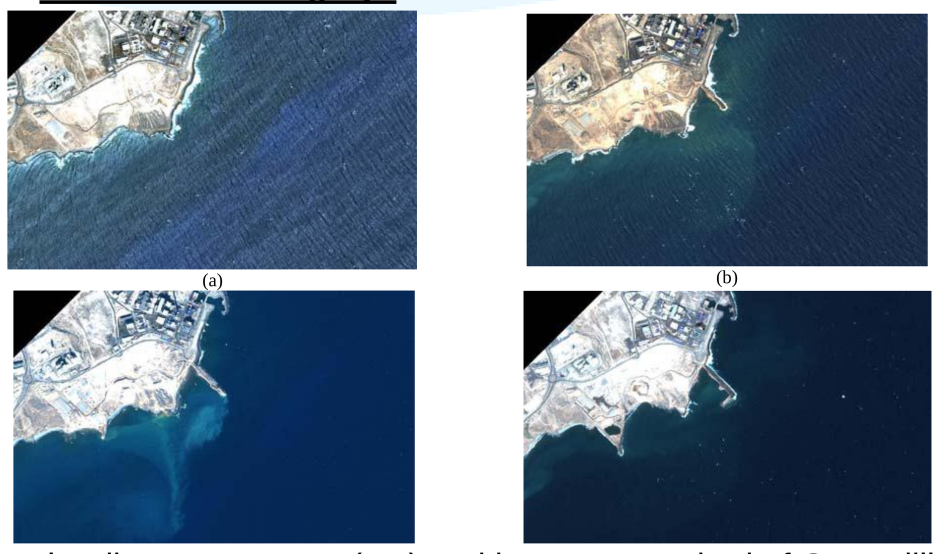


Figure 2. WorldView-2 Satellite: Relative spectral radiance response (nm) and imagery acquired of Granadilla Port area in different seasons.

COMPARISON OF ATMOSPHERIC CORRECTION METHODS

We have compared the effects of three atmospheric correction methods, specifically, DOS, COST and 6S techniques. These three represented a range of levels of sophistication in correction algorithms and were found to be the most often recommended by researchers and analysts.

- **The DOS method:** The dark object subtraction technique (DOS) is an image-based model that has been proposed to simplify atmospheric correction. The DOS model is based on the assumption that dark objects exist within an image and have zero reflectance. Consequently, the radiance resulting from corresponding pixels is proportional to the atmospheric path radiance, and can be used to account for the additive effects of atmospheric scattering. The minimum pixel values are selected for each individual band with the histogram method and subtracted from all pixel values for the corresponding band across an image. The following equation shows how the reflectance is calculated:

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

- **The COST method:** combines the assumption DOS method with the fact that very few objects on the earth's surface are quite dark. Thus, normally corresponds to 1% of the full reflectance image. The radiance of an object absolutely dark, when it is free of shade is as follows:

$$L_{1\%,\lambda} = \frac{0.01 \cdot E_\lambda \cdot \cos\theta_i}{d^2 \cdot \pi} \quad (2)$$

Then, the radiance is converted to reflectance of the objects at the Earth's surface using the equation:

$$\rho_\lambda = \frac{(L_{sen,\lambda} - (L_{haze,\lambda} - L_{1\%,\lambda})) \cdot d^2 \cdot \pi}{E_\lambda \cdot \cos\theta_i} \quad (3)$$

- **6S (Second Simulation of a Satellite Signal in the Solar Spectrum) method:** 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 conditions6. 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. This model predicts the reflectance ρ of objects at the top of atmosphere (TOA) using information about the surface reflectance and atmospheric conditions. This information is provided through a minimum of input data to the model and incorporated features. The TOA reflectance (ρ_(TOA,λ)) can be estimated using the following expression:

$$\rho_{TOA,\lambda} = \frac{L_{sen,\lambda} \cdot d^2 \cdot \pi}{E_\lambda \cdot \cos\theta_i} \quad (4)$$

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 6S model, defining the geometry of the satellite observation and viewing angle. The pass filters of the 9 bands have been defined and the weather conditions more suited to the study area (South of Tenerife, Canary Islands) were properly set. Using the input data and the embedded features, the model produces variables to assess the surface reflectance. The true reflectance value ρλ is obtained from the model output by the following expression,

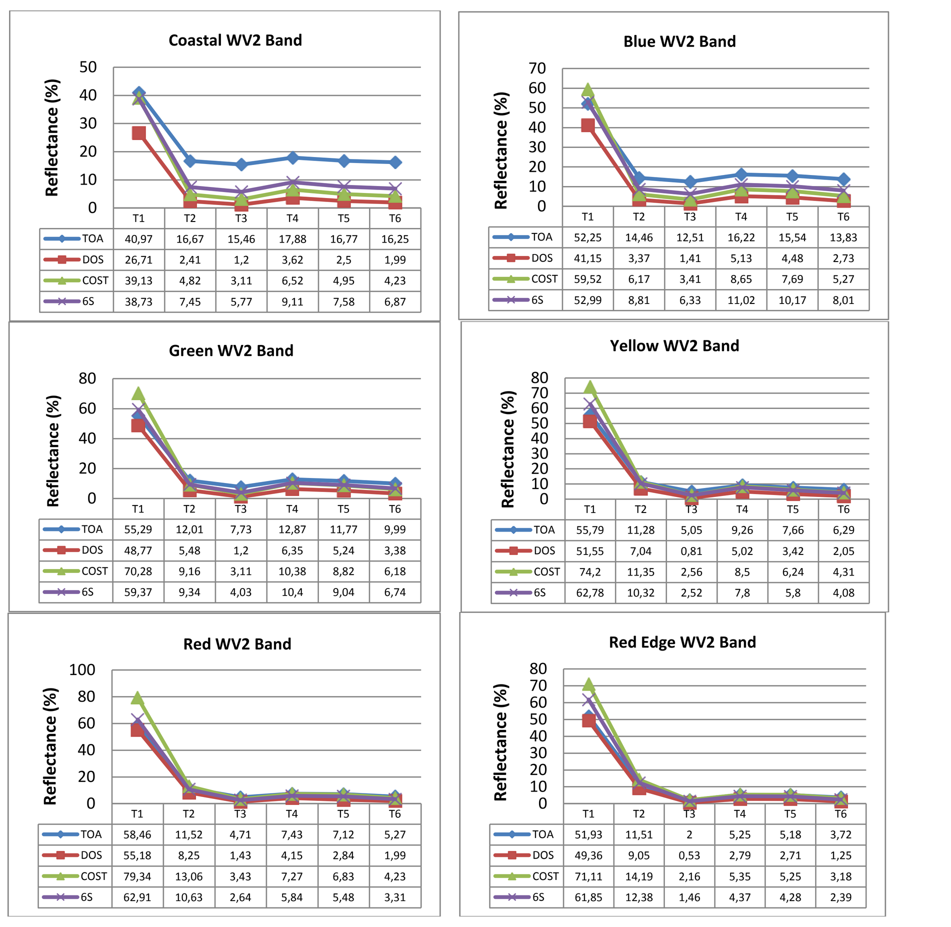
$$\rho_\lambda = \frac{y}{1 + (x_c * y)} \qquad y = (x_a * L_\lambda) - x_b \quad (5)$$

where ρλ is the corrected reflectance, Xa, Xb, and Xc are the coefficients obtained from the model (Xa is the inverse of the transmittance, Xb is the scattering term of the atmosphere and, Xc is the reflectance of the atmosphere for isotropic light), and Lλ is the observed radiance (w/m2*sr*µm).

RESULTS

- **In order to perform appropriate comparisons of the atmospherically corrected images, six representative targets locations were selected within the test site (Figure 3). The results obtained by COST, DOS and 6S atmospheric correction techniques (% reflectivity units) on WorldView-2 image, compared with the Top of Atmosphere (TOA) reflectance, are presented in Figure 4.**

Figure 3. Location of land and coastal targets on WorldView-2 imagery in Granadilla area..



Coastal WV2 Band

	T1	T2	T3	T4	T5	T6
TOA	40,97	16,67	15,46	17,88	16,77	16,25
DOS	26,71	2,41	1,2	3,62	2,5	1,99
COST	39,13	4,82	3,11	6,52	4,95	4,23
6S	38,73	7,45	5,77	9,11	7,58	6,87

Blue WV2 Band

	T1	T2	T3	T4	T5	T6
TOA	52,25	14,46	12,51	16,22	15,54	13,83
DOS	41,15	3,37	1,41	5,13	4,48	2,73
COST	59,52	6,17	3,41	8,65	7,69	5,27
6S	52,99	8,81	6,33	11,02	10,17	8,01

Green WV2 Band

	T1	T2	T3	T4	T5	T6
TOA	55,29	12,01	7,73	12,87	11,77	9,99
DOS	48,77	5,48	1,2	6,35	5,24	3,38
COST	70,28	9,16	3,11	10,38	8,82	6,18
6S	59,37	9,34	4,03	10,4	9,04	6,74

Yellow WV2 Band

	T1	T2	T3	T4	T5	T6
TOA	55,79	11,28	5,05	9,26	7,66	6,29
DOS	51,55	7,04	0,81	5,02	3,42	2,05
COST	74,2	11,35	2,56	8,5	6,24	4,31
6S	62,78	10,32	2,52	7,8	5,8	4,08

Red WV2 Band

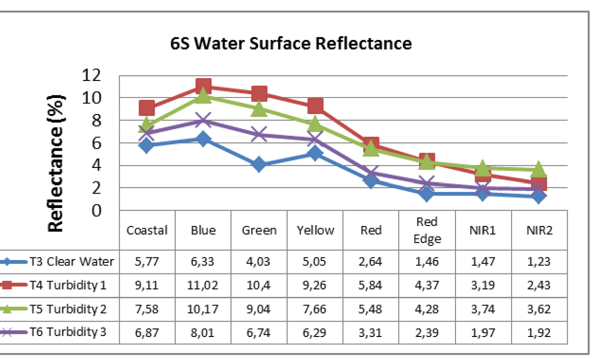
	T1	T2	T3	T4	T5	T6
TOA	58,46	11,52	4,71	7,43	7,12	5,27
DOS	55,18	8,25	1,43	4,15	2,84	1,99
COST	79,34	13,06	3,43	7,27	6,83	4,23
6S	62,91	10,63	2,64	5,84	5,48	3,31

Red Edge WV2 Band

	T1	T2	T3	T4	T5	T6
TOA	51,93	11,51	2	5,25	5,18	3,72
DOS	49,36	9,05	0,53	2,79	2,71	1,25
COST	71,11	14,19	2,16	5,35	5,25	3,18
6S	61,85	12,38	1,46	4,37	4,28	2,39

Figure 4. Results of atmospheric corrections models COST, DOS, 6S and TOA reflectivity for land-sea targets in the area under study.

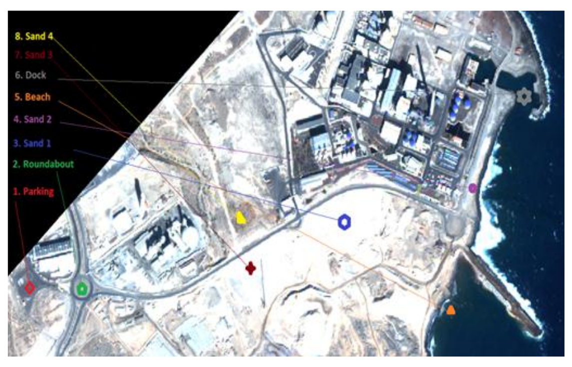
- **Case of study: Water turbidity.**



	Coastal	Blue	Green	Yellow	Red	Red Edge	NIR1	NIR2
T3 Clear Water	5,77	6,33	4,03	5,05	2,64	1,46	1,47	1,23
T4 Turbidity 1	9,11	11,02	10,4	9,26	5,84	4,37	3,19	2,43
T5 Turbidity 2	7,58	10,17	9,04	7,66	5,48	4,28	3,74	3,62
T6 Turbidity 3	6,87	8,01	6,74	6,29	3,31	2,39	1,97	1,92

Figure 5. Variation of water surface reflectivity, obtained by 6S atmospheric model, due the turbidity in coastal waters.

- **Results obtained by 6S compared with ground-based reflectance measurements:**



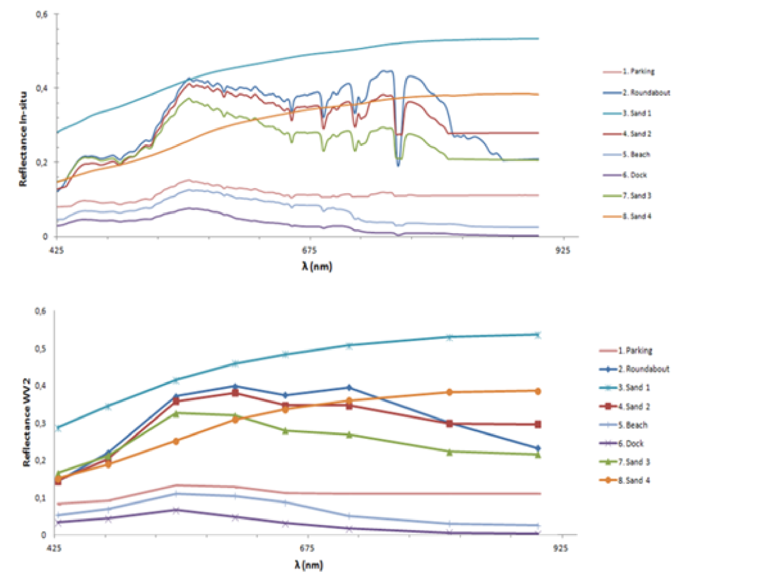


Figure 6. (a) Location of in-situ test points on WV2 imagery in Granadilla area (February 2012) and, (b) ground-based reflectance measurements (top) and corresponding WV2 multispectral 6S atmospheric correction reflectance (bottom).

CONCLUSIONS

- ✓Atmospheric correction has proven to be a crucial point in the pre-processing of images in remote sensing applications. During the study, it is proposed to compare and evaluate the success of three different atmospheric corrections for WorldView-2 multispectral data beyond the scope of turbid coastal environments mapping within a strategic plan for Granadilla Port environmental monitoring.
- ✓We chose to compare the effects of DOS, COST and 6S atmospheric correction methods and it was found that all algorithms performed successful the overall evaluation but 6S is found to be a better corrector algorithm for turbid coastal environments and optically shallow waters.
- ✓We compared the RT 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.

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