QUANTITATIVE DATA ANALYSIS FOR OCEAN OBSERVATIONS USING HYPERSPECTRAL AND MULTISPECTRAL DATA PROVIDED FROM A MULTI-SENSOR SYSTEM PACKAGE

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ABSTRACT

A feasibility study is presented which examined the application of a distributed sensor system package for ocean observations focusing the attention on the match-up of remotely sensed derived reflectances with *in situ* data. To verify the platform integration and data reliability for maritime missions, a field exercise was performed by NATO Research Centre (NURC) to build sensor integration, performance evaluation and data processing refinement. Our system incorporates an aircraft, satellites (Geo-Eye1, MODIS and MERIS) as well as a NATO research vessel (*N/RV Alliance*) that was used to perform both radiometric and bio-optical *in situ* measurements that were collected from 13th to 26th of March 2009, in the Ligurian Sea. These data were then used to calibrate and validate remote sensing reflectances. Once these data were reviewed and errors minimized, image processing (such as georectification and atmospheric corrections) were performed. To improve the aircraft data its images were rectified and geo-referenced to within 1-2 m accuracy generating water-leaving radiances maps that were compared with those available from the *in situ* and satellite measurements. The achieved performance was within published uncertainties [1] and the results showed that the aircraft imagery surpasses spatial and spectral resolution available from the satellites. On the basis of the methodology and algorithms tested here, our long term goal will be to retrieve high level oceanographic aircraft products such as Inherent and Apparent Optical Properties (IOP and AOP), diffuse attenuation coefficient (K) and chlorophyll-a concentration.

1. INTRODUCTION TO THE PROJECT

1.1. Background

The maritime zone is a highly dynamic region where hydrodynamic and morphodynamic processes may change on a wide range of spatial and temporal scales. Information regarding the variations of the littoral environment is critical for a large range of military and civilian missions [2]. Standard *in situ* surveying can provide this information but are typically very challenging because they require people and extended periods of time. Moreover, they may not be possible in denied areas. For these reasons, remote sensing of the shore is highly desirable. Satellites are an attractive solution but, for the nearshore-zone they typically have problems related to limited spatial resolution, a complete lack of temporal sampling on dynamical time scales and access limitations. Motivated by this fact, our idea consists is to utilize alternative observational platforms, such as aircrafts and Unmanned Aerial Vehicle-UAV [3]. The data presented here have been acquired during a cruise conducted by NURC and several international collaborating institutions. This experiment (BP09 – Battlespace Preparation 2009) addressed specific problems associated with remote sensing (RS) of denied areas, specifically to improve the quality of the optical properties derived from RS in marine coastal environments. This goal will be achieved integrating simultaneous aerial (aircraft and satellite) and *in situ* sensors to provide combined measurements that allow the nearshore characterization in spatial and spectral dimensions.

1.2. Objectives

The main objective is to improve the calibration and validation of large-scale ocean color sensors (such as MODIS, 1 km), medium scale sensors (e.g. MERIS, 300 m), and small scale sensors (GeoEye and AISA hyperspectral over-flight with 1-2 m of spatial resolution). In particular we have implemented a methodology for creating high-spatial and high-spectral resolution water-leaving imagery from aircraft acquisitions that were validate by using sea-truth data and were compared (uncertainties) with the imagery provided by the ocean color satellites, focussing the attention on ENVISAT-MERIS and AQUA-MODIS. In particular, the project objectives were:

- to test the logistics and operational use of the employed aircraft and its Imaging Spectrometer AISA-EAGLE hyperspectral sensor;
- to review the aircraft geolocation capabilities based on internal metadata and to verify the georectified imagery with resolution similar to that available

from the aircraft (1-2 meter of spatial resolution). For these reasons a high resolution commercial satellite image was acquired from GeoEye-1. This satellite sensor, launched on September 2008, is capable of acquiring image data at 0.41 m panchromatic (B&W) and 1.65 m multispectral resolution.

- to provide methodologies for atmospheric corrections and verify their performance using simultaneous *in situ* optical measurements.
- to compare variability between instrument calibrations and measurement protocols to compute uncertainties in retrieving *in situ* radiometric values and how these uncertainties are propagated in RS imagery, thus affecting geophysical derived products.
- to determine the intra/inter-pixel variability in optical and physical properties and how this affects the merging of low/medium/high spatial and spectral resolution of RS data for improving spectral and spatial resolution.

2. DATA AND INSTRUMENTS

In this paragraph we briefly describe the RS and *in situ* acquisitions that were used for this study. In particular we have focused the attention on two Tuscany coastal areas (in front of Carrara and Viareggio), as showed in Figure 1, where the aircraft AISA acquisitions (from the 17th of March) have been overlaid on the Geo-Eye-1 satellite image (the 22nd of March 2009) and on the *in situ* stations that were made from 13th to 26th of March 2009 with the NATO *N/RV Alliance*.

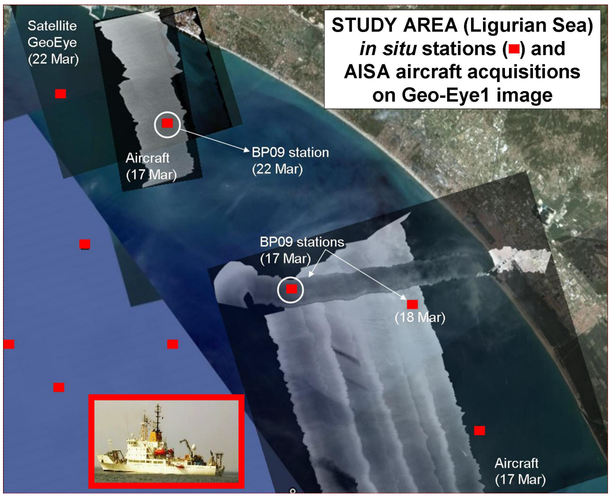

Figure 1. Geo-Eye (2009-03-22, 10:07 GMT), aircraft – AISA (2009-03-17, 12:07 GMT) acquisitions and N/RV Alliance in situ stations.

2.1. The *in situ* measurements

BP09 represents an important optical experiment performed by NURC as several types of optical sensors/platforms were used (such as ac-s, hypersepctral radiometers, radiance cameras, DOLPHIN tow vehicle, gliders, seabird ctd, Adcp, IOP sensors/frames, and micro-HyperPRO). This cruise was specifically designed to perform optical measurement to calibrate satellite and aircraft data, therefore the Alliance stations were scheduled day-by-day considering meteoreological (clouds, wind and currents) and physical (optical fronts) conditions. In this study we have focus the attention on the HyperPRO instrument that is a radiometer package able to provide the water-leaving radiances/reflectances. During the cruise two different HyperPRO instruments were used (14 stations by NURC and 27 stations by JRC). The combination of these *in situ* data in terms of time-space and quality criteria yields 9 match-up stations (the red box in figure 1) with satellite and aircraft that were used for this study. The profiling maximum depth was according to the water column condition and scientific interests but was limited to a maximum of 90 m determined by cable length. The water-leaving radiance at nadir has a bandwidth range from 300-1200 nm and a resolution of 10 nm and was obtained from the below surface radiance as:

$$L_w = L_u(0^-)\frac{1-\rho(\vartheta)}{n} \qquad (1).$$

Where $\rho(\vartheta)$ is the Fresnel reflection coefficient for the water-air interface and n is the refractive index of seawater. These values were used to perform comparisons with AISA data because it provides radiance products, while for the comparison with satellites there was a need to retrieve remote sensing reflectance with the formula:

$$R_{rs} = \frac{L_W}{E_S} \qquad (2).$$

The value obtained from equation 2 can be directly compared with the MODIS products, while to perform a comparison with the MERIS satellite products there was a need to multiply R_{rs} by π.

2.2. The satellite data and match-up procedures

Before showing the results, it is important to note that the satellite measurements used during our study are all level-2 data (that means water-leaving products such as radiances/reflectances, chlorophyll concentration, and K); this means that we were not able to operate on the atmospheric correction procedures. Fortunately, we had the possibility to use two different types of level 2 data, one processed by SeaDAS and the other processed by APS (by NRL-Stennis). On the basis of our comparison within *in situ* data, APS seems more appropriate for our areas (e.g. the pixels under low-clouds had NaN values in L2 SeaDAS products, while provided radiance information in the APS L2 products). For this reason comparison results have been made using Level 2 APS data. Therefore, we are working on the processing of top-of the atmosphere (TOA) Level 1 products in order to have the ability to change and/or assess the atmospheric corrections with our methodologies.

2.3. The AISA aircraft data processing

The AISA [4] acquisitions provide an important innovation to the development of our analysis because it offers a unique opportunity to test and evaluate atmospheric correction procedures. Moreover these products have a better spatial (2 m) and spectra resolution (63 channels) compared with those available from the standard optical RS instruments. The AISA data were radiometrically correct and georectified using an inertial navigation system mounted onboard the aircraft, final aircraft to satellite (GeoEye-1) image co-registration has been also applied. After georectification, the TOA radiances were atmospherically corrected in order to have water-leaving data comparable with those available. Initially these corrections were performed using standard methodologies, in particular the Research System Incorporated (RSI) ENVI software package was used to perform dark subtraction and thermal infrared correction. Once the path atmosphere and noise were removed, the resultant imagery was compared with *in situ* measurements. Therefore, because the retrieved performance was lower than expected, we decided to study alternative methods to improve the results. In particular, we had the possibility to implement and test the Tafkaa algorithm [5] that is a new methodology proposed by Marcos J. Montes and Bo-Cai Gao of Naval Research Laboratory, Washington, D.C. This methodology is based on Atmospheric REMoval (ATREM) 4.0 and uses Second Simulation of the Satellite Signal in the Solar Spectrum (6S) for scattering calculations. It is important to note that it cannot correct for the specular reflection of the air-water interface (sun glint, reflected sky and cloud light). Therefore, the above water reflectances were strongly contaminated from the surface reflectance and methodologies to estimate/remove these effects are required. Preliminarily, the removal of the "glint" contribution of the data was consider as a constant offset at longer wavelengths and was subtracted on the overall reflectance (only water pixels). We are working on an innovative correction scheme [6] that allows removal of surface-reflected sun glint and sky using *in situ* measurements (sky radiance, *in situ* absorption at 412 nm).

3. RESULTS

We present our preliminary analysis with the below quote used to evaluate these preliminary results.

"The goal of modern ocean color sensors is to provide the water-leaving radiance with a 5% accuracy over oligotrophic, chlorophyll depleted, waters [7] which can also be expressed as an uncertainty of 0.002 in terms of reflectances [1]."

We are working on a more complete statistical analysis (increasing the time at more that 1 day). Table 1 summarises the results from two HyperPRO stations of the 17th March during a very clear day in which all MODIS, MERIS and AISA imagery were available (without clouds). These stations was performed at 9:47 GMT and 12:32 GMT and are very close to the MERIS and MODIS overpasses, respectively 9:40 GMT and 12:52 GMT.

λ [nm]	***In situ***	**MODIS L2**	**MERIS L2**	**Uncert_ ainty**
412	0.011283	0.002276	-	0.009007
412	0.011283	-	0.012408	0.001125
442	0.012167	-	0.013965	0.001798
443	0.012167	0.011534	-	0.000633
488	0.013348	0.013112	-	0.000236
489	0.013348	-	0.016345	0.002997
509	0.010836	-	0.013653	0.002793
531	0.008445	0.011948	-	0.003503
551	0.008445	0.007796	-	0.000649
559	0.006119	-	0.007226	0.001107
619	0.001052	-	0.000708	0.000344
664	0.000507	-	0.000506	0.000001
667	0.006581	0.002178	-	0.004403
678	0.000507	0.000184	-	0.000323
680	0.000492	-	0.000781	0.000289
708	0.000163	-	0.000030	0.000133

Table 1. Comparison between in situ and satellite Level 2 products.

The comparison shows poor performance for the bluest band (412 nm) and performance within requirements at 443 – 708 nm. Moreover, it is important to note that it is influenced from the following problems:

- Lower satellite spatial resolution (MODIS-1Km, MERIS 300 m) in respect to the *in situ* stations. Indeed the size of the box area of the 17th March area was about 3x2 kilometres that means only 3 pixels of MODIS match-up the 9 *in situ* stations.
- Calibration
- Poor atmospheric correction.

After these considerations, we can understand how the aircraft data provides an innovative contribution to the development of optical information and assessments as well as coastal forecasting.
Figure 2 show the results of the comparison between the *in situ* water-leaving radiances (in red) and the aircraft

radiance, before (black) and after the Tafkaa_6S implementation.

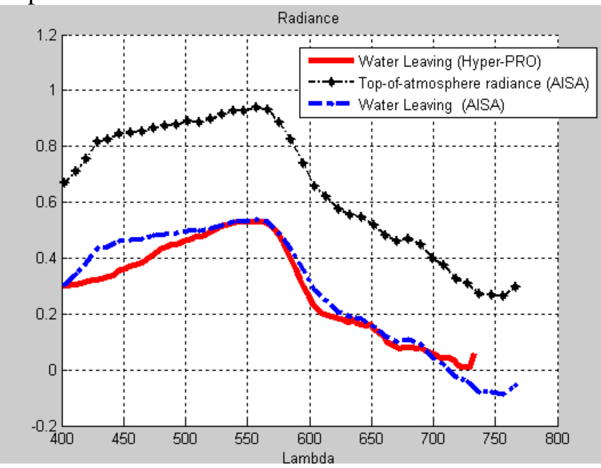

Figure 2. Comparison between in situ and AISA measurements before (TOA radiances) and after (water leaving radiances) the Tafkaa6s atmospheric correction.

The comparison shows, as for MODIS and MERIS, low performance for the bluest band but it definitely increased at 443 – 708 nm. Moreover the resolution of the aircraft data will be used for our statistical analysis because their have more spatial and spectral resolution in to respect MODIS and MERIS data.

4. CONCLUSION

This study present an approach for analyzing surf zone imagery from a distribute sensor system, emphasizing the role that the aircraft platform can provide. On the basis of the results we found that the accuracy of AISA products surpassed the quality of those created by satellite systems.

4.1. Work in progress

Our long term goal is to implement algorithms to estimate IOP and AOP from this type of aerial sensors; in particular we are working on a multiband quasi-analytical algorithm to retrieve IOP (absorption and backscattering coefficients) and AOP (absorption coefficients of phytoplankton pigments and gelbstoff). This algorithm [8] is based on remote-sensing reflectance models derived from the radiative transfer equation, and values of total absorption and backscattering coefficients are analytically calculated from remote-sensing reflectance.

4.2. Acknowledgements

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