HIGH SPATIAL RESOLUTION REMOTE SENSING OF THE PLYMOUTH COASTAL WATERS.

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ABSTRACT

CHRIS-PROBA has the potential to provide high spatial resolution satellite ocean colour imagery that is applicable to the mapping of estuarine and coastal waters. This paper outlines an appropriate atmospheric correction technique and preliminary results from its application to an example 06 March 2003 image acquired using mode 2 (water bandset). The results are encouraging and demonstrate that CHRIS-PROBA has the required radiometric sensitivity.

Further research will be carried out in 2004, including the continuing goal of acquiring contemporaneous airborne data and in-situ measurements.

1. INTRODUCTION

Remote sensing is a tool that can provide an increasing number of environmental properties over a range of spatial and temporal ranges. It can be used both in its own right (e.g. mapping of foam lines formed by fronts) and as a means of extrapolating in-situ surface measurements in space and time (e.g. mapping of sediment concentrations). Most spaceborne ocean colour sensors are of use for studying the coastal environment, but are of a limited value for estuaries. However, Compact High Resolution Imaging Spectrometer (CHRIS)-PROBA offers observing capabilities appropriate to estuarine monitoring. It has a spatial resolution of 25 metres and provides multi-look angle imagery, which can be used to improve the atmospheric correction (AC).

In the United Kingdom (UK), the Rame Head water test site is in the South West (see Fig. 1). The site includes the turbid Case II (dominated by suspended particulate matter, SPM, and coloured dissolved organic material, CDOM) waters of the Tamar estuary, less turbid waters of Plymouth Sound and summer Case I waters (dominated by phytoplankton) of the English Channel. These waters have therefore been the focus of many studies using remote sensing, including sensors such as the Natural Environment Research Council (NERC) Compact Airborne Spectrographic Imager (CASI), which has 15 configurable wavebands in its spatial mode.

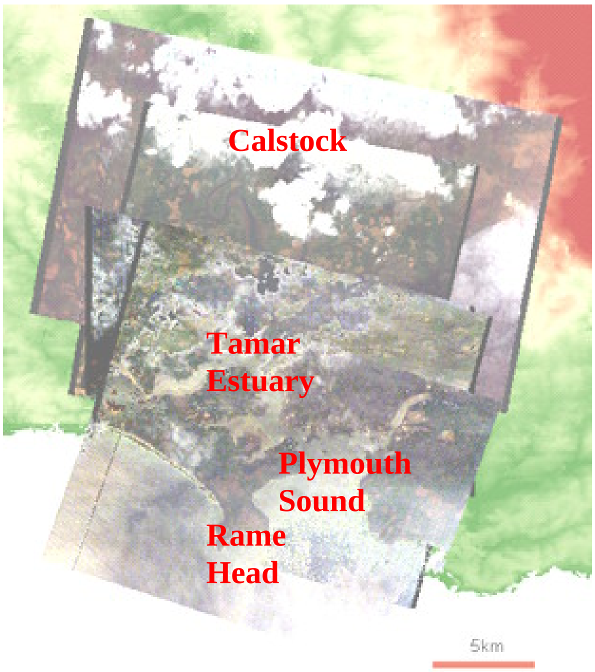

Fig. 1. CHRIS-PROBA quick-look imagery from the 12th and 14th April 2003 mosaiced over the top of a Landmap Digital Elevation Model, Copyright University Of Manchester/University College London Year 2001 [1].

Table 1 shows the CHRIS-PROBA 2003 imagery acquisitions and attempts at contemporaneous airborne (CASI) and in-situ campaigns. Truly contemporaneous data collection was not achieved due to the juggling of logistics and cloud conditions, but the datasets provide valuable information with the future prospect of qualitative comparisons.

The uncorrected colour composite CASI imagery shown in Fig 2 is from April 2003 where four flightlines were flown over the same area, at height of 1 500 metres, to map changes in the turbidity throughout a tidal cycle. Sampling was carried out from a moored pontoon in the river at Calstock (Fig. 1) and included parameters such as reflectance, SPM and CDOM.

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Table 1. Fieldwork conducted in 2003.

Month	CHRIS-PROBA	CASI	In-situ
Feb 03	18 Feb: Lower estuary & Sound. Broken cloud.	None.	17 Feb: Sound.
Mar 03	6 Mar: Sound & offshore. Some cloud.	None.	None
Apr 03	12 & 14 Apr: Estuary & Sound. Cloud over upper reaches.	16 Apr: Upper estuary.	13, 14 & 16 Apr: Upper estuary. 14 Apr: Sound.
Jun 03		13 Jun: Sound & offshore. 24 Jun: Estuary. Clouds and shadow.	16 Jun: Breakwater. 23 & 24 Jun: Estuary. 25 & 27 Jun: Upper estuary.
Aug 03	24 Aug: Offshore. Glint	None.	22 Aug: Sound.
Sep 03	16 Sep: Offshore. Some cirrus.	None.	None
Nov 03	02 Nov: Sound & offshore. Some cloud.	None.	None

a)

b)

Fig. 2. Uncorrected colour composite CASI imagery from April 2003 with (a) the 4 flightlines taken over a tidal cycle and (b) zoomed in section showing the sampling pontoon at Calstock.

2. METHODOLOGY

A CASI atmospheric correction was developed [2] using the knowledge gained from the development and implementation of the SeaWiFS [3] and MERIS [4] processing code. This has been modified to take the CHRIS-PROBA imagery so that a preliminary validation of its ocean colour capabilities can be performed.

The AC takes the total sensor detected reflectance, $\rho_t(\lambda)$, and splits it into the total atmospheric path reflectance, $\rho_{atm}(\lambda)$, and desired water-leaving reflectance, $\rho_w(\lambda)$. Where $t(\lambda)$ is the diffuse transmittance.

$$\rho_t(\lambda) = \rho_{atm}(\lambda) + t(\lambda)\cdot\rho_w(\lambda) \qquad (1)$$

The atmospheric path reflectance is then split into the aerosol, $\rho_a(\lambda)$, and Rayleigh path reflectance, $\rho_r(\lambda)$, according to Eq. 2.

$$\rho_{atm}(\lambda) = \rho_a(\lambda) + \rho_r(\lambda) \qquad (2)$$

A non-water mask is then used to discard the land and cloud pixels. The mask is based on the threshold values at two near infrared (NIR) wavelengths [2]: wavebands 16 and 17 in Table 2. Any further computations are then only applied to the water pixels.

Table 2. CHRIS mode 2 water bands with the CASI bands indicated using an asterisk.

Waveband	Application	Waveband	Application
(1) 405.6 - 415.2*	MERIS	(10) 645.7 - 655.8*	MOS
(2) 438.0 - 446.8*	CIMEL / MERIS	(11) 666.3 - 677.2*	CIMEL / MERIS
(3) 485.6 - 494.8*	MERIS	(12) 677.2 - 682.8	MERIS / FLH
(4) 504.5 - 514.8*	MERIS	(13) 682.8 - 688.5	MERIS / FLH
(5) 525.6 - 534.2*	MODIS	(14) 700.2 - 712.4*	MERIS
(6) 556.1 - 566.3*	MERIS	(15) 751.9 - 758.9	Red Tide Index (RTI)
(7) 566.3 - 577.1*	SPM / Bathymetry	(16) 773.4 - 788.4*	MERIS
(8) 584.6 - 596.4*	SPM / Bathymetry	(17) 863.1 - 881.3*	CIMEL / MERIS
(9) 617.5 - 626.6*	MERIS	(18) 1002.7 - 1035.5	CIMEL

The Rayleigh scattering reflectance was computed using the well established theory [5]. At present the Rayleigh correction does not attempt to use actual meteorological values, but climatological values: atmospheric pressure of 1013.25 mbar; water vapour concentration of 2 g cm^{-2}; ozone concentration of 0.33 atm cm.

For the Case I assumption, the NIR water-leaving reflectance was assumed to be near zero [6], which is termed a Dark Pixel (DP) atmospheric correction. Eq. 1 can then be rewritten to give Eq. 3 when the Rayleigh reflectance is subtracted. The aerosol path reflectance can then be calculated for NIR wavelengths (greater than 700 nm) using an exponential relationship for the spectral behaviour of aerosol optical depth [7].

$$\rho_{rc}(\lambda > 700nm) = \rho_a(\lambda) \qquad (3)$$

The Case II (or bright pixel, BP) atmospheric correction uses several sensor look-up-tables, which hold standard values such as the NIR inherent optical properties. The NIR water reflectance at a given wavelength is a function of the optical properties of seawater, the optically active water constituents and the solar and viewing geometry. The optical effects of CDOM and phytoplankton are assumed to be negligible in the NIR, which gives Eq. 4 [3].

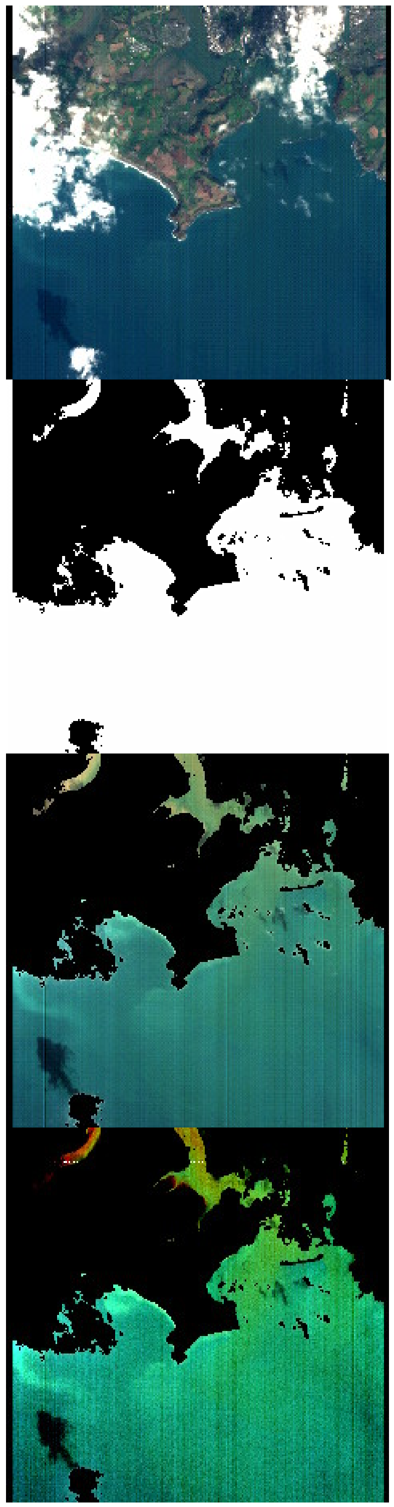
$$\rho_{rc}(\lambda) = \rho_t(\lambda) - \rho_r(\lambda) = \rho'_a + t(\lambda)\cdot f(\lambda, SPM, \theta_0, \theta, \phi) \qquad (4)$$

Eq. 4 is then solved for the two NIR wavebands using a non-linear, least squares, Newton-Raphson minimisation. The SPM NIR reflectance is subtracted from the Rayleigh corrected reflectance values to give aerosol reflectance in the NIR. The DP atmospheric correction method is re-applied to extrapolate this NIR aerosol radiance to the visible bands.

3. RESULTS

The AC was carried out on an example CHRIS-PROBA image from the 06 March 2003 with a combination of wavebands 11, 6 and 3 used to produce colour composites. Fig. 3 shows the various stages of the AC as the imagery was processed, the final BP AC is not shown as it was very similar to Fig 3d. The uncorrected image shows cloud contamination and cloud shadows (Fig. 3a). Most of the cloud and land was successfully removed by the non-water mask (Fig. 3b), where black represents the masked pixels. However, the Rayleigh corrected image (Fig. 3c) still shows the influence of cloud shadow in the bottom left corner and just outside of the Plymouth Sound.

a)
b)
c)
d)



(5)

Fig. 3. CHRIS-PROBA imagery for the 06 March 2003. The coloured images represent composites of wavebands 11, 6 and 3 as red, green and blue.

a) Uncorrected image
b) Non-water mask
c) Rayleigh corrected image
d) Aerosol corrected image.

The aerosol (DP) corrected image (Fig 3c) shows over-correction of Case II pixels in the top left corner, due to the removal of too much reflectance since the water reflectance in the NIR was treated as atmospheric scattering. This can be corrected when a full atmospheric correction, with the BP method, is applied. The BP AC was switched on, but the AC process needs further tuning as several aspects (including the geometry) were roughly approximated for this preliminary analysis.

Fig. 4a shows a series of above water reflectance spectra for different concentrations of SPM measured in the Tamar, which highlights the significant reflectance in the NIR that must be accounted for in a successful atmospheric correction. Most of the spectra also tend to peak in the green (500 to 600 nm). Fig. 4b shows the different stages of the AC process being applied to a pixel from the example image; it was located off Rame Head and so in low SPM concentration waters. The first two wavelengths have very high reflectance values, which is a recognised problem with the calibration, but generally the corrected spectra show a similar shape to that of Fig 4a with a peak in the green.

a)

b)

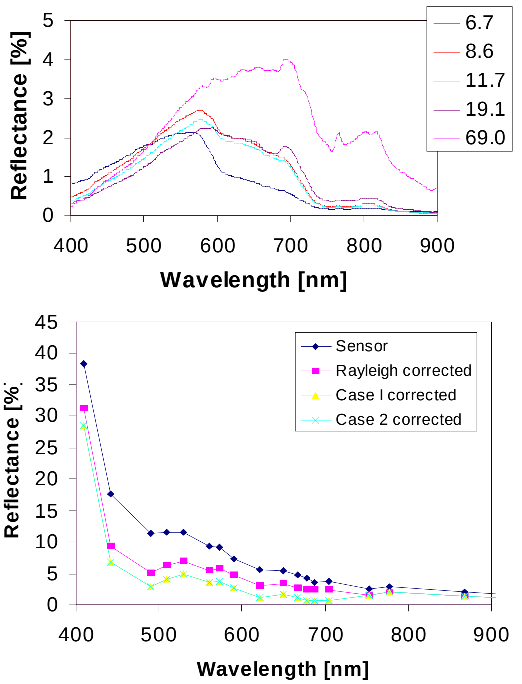


Fig. 4. Spectral curves a) measured in the Tamar and b) extracted from a 6th March 2003 CHRIS-PROBA pixel off Rame Head.

4. CONCLUSION AND DISCUSSION

The AC shows promising results, but needs further refinement. To validate the atmospheric correction we also need to compare the derived above water reflectance to concurrent *in-situ* reflectance measurements. In 2004 the fieldwork will be repeated in an attempt to get contemporaneous in-situ, CASI and CHRIS-PROBA data. However, the existing 2003 dataset will be further processed to provide an analysis of both the satellite and airborne imagery in terms of SPM, chlorophyll and CDOM concentrations.

Further work will continue on the processing of the satellite (CHRIS-PROBA) and aircraft (CASI) imagery, and there will also be enhanced biological sampling as previous research has indicated a summer bloom in the upper reaches of the Tamar.

5. REFERENCES

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6. ACKNOWLEDGEMENTS

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