STSM scientific report

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Task 1 Using hyperspectral remote sensing data for benthic habitat mapping.

The first and the most important task of the current STSM was to discuss possible pre-processing methods and their application to the hyperspectral data in order to be able to extract good quality reflectance information for the benthic habitat mapping purposes. Our aim was to apply different pre-processing steps to the Estonian Marine Institute (EMI) Hyspex hyperspectral data from the Estonian coastal environment and provide an initial evaluation of the results.

HySpex VNIR-1024 airborne hyperspectral camera (Norsk Elektro Optikk, NEO) covers the spectral range from 410 to 988 nm at a sampling interval of 2.7 nm providing spectral information in 216 spectral bands. The radiometric and geo-correction of the Hyspex raw data was performed in Estonia by EMI. The raw Hyspex data were converted into units of spectral radiance using software developed by the NEO. Geometrical correction was performed using PARGE geo-coding software. The geometrically resampled image resulted in a pixel size of 1 meter.

First of all the quality of the Hyspex at sensor radiance was tested using Modtran® MODO radiative transfer code. MODO allows simulating *in situ* measured spectral signal to the at-sensor radiance using standard atmospheric parameters (water vapour, aerosol type etc.). *In situ* spectral measurements from the two stations of our study area performed by the Trios Ramses spectrometers were used for the MODO forward modelling. Figure 1 shows the MODO modelled at-sensor radiance spectra for two different field stations in Estonian coastal waters. Modelled at-sensor radiance spectra were associated with the pixel in the Hyspex image in which *in situ* Ramses measurements were performed and compared with the measured Hyspex at-sensor radiance spectra.

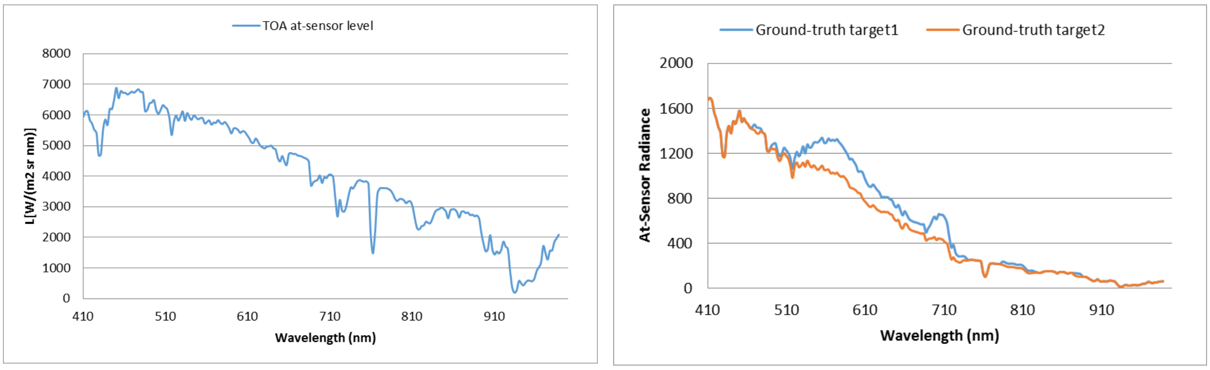

Figure 1. MODO modelling results. First image shows the top-of-atmosphere radiance without introduced ground through spectra. Second image shows the MODO modelled at-sensor radiance spectra for two different field stations.

Figure 2 shows the comparison of MODO modelled at-sensor radiance and Hyspex measured at-sensor radiance in the first field station. As some differences occurred between modelled and measured radiance spectra, the correction factors were retrieved in order to recalibrate the Hyspex radiance image. The most evident differences occurred in the blue part of the spectrum (400-530 nm), where modelled spectra showed significantly higher radiance values. 3rd order polynomial coefficients were considered the best option for the recalibration of Hyspex radiometric images.

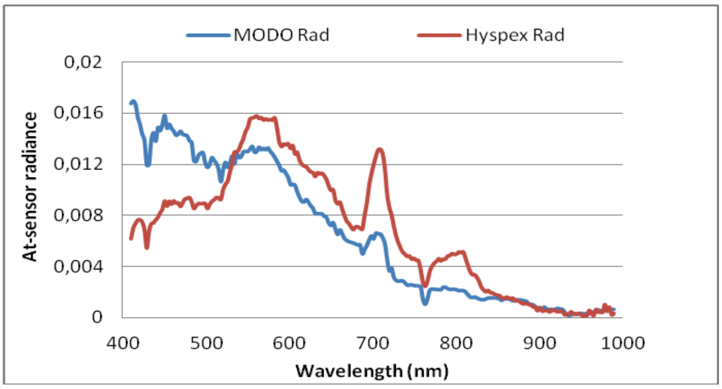

Figure 2. Comparison of MODO modelled at-sensor radiance and Hyspex measured at-sensor radiance in the first field station.

Three different atmospheric correction modules were tested on the Hyspex image: FLAASH (**F**ast **L**ine-of-sight **A**tmospheric **A**nalysis of **S**pectral **H**ypercubes), ATCOR (**AT**mospheric **COR**ection) and ACORN (**A**tmospheric **COR**rection **N**ow). All of them are commercially-available atmospheric model-based softwares that use licensed MODTRAN-4 technology that allow to remove atmospheric effects in remote sensing imagery and generate a reflectance image at ground level. FLAASH atmospheric correction was performed already in the EMI as it is a plug-in available in the ENVI image processing software. Other two atmospheric correction procedures were performed during the STSM at the University of Haifa.

Each of the model-based atmospheric correction methods was applied to the one single Hyspex flight line collected over the Estonian coastal waters. ATCOR4 and ACORN5 were applied to the both - original and recalibrated Hyspex at-sensor radiance data. The retrieved atmospherically corrected ground reflectance spectra were compared with the *in situ* Ramses spectral data acquired from the same location, but unfortunately not at the same time. The airborne Hyspex image was collected on the 22.07.2014, but Ramses measurements were carried out between 04.07.2011-11.07.2011. Therefore the comparison of these data sets needs to be treated with some caution.

Figure 3 and figure 4 show comparison of the results of different atmospheric correction procedures and Ramses *in situ* spectra in two field stations in the Haapsalu Bay area in Estonian coastal waters. The station HA2 is located in the 0.5m water depth and it is characterized by the soft sandy bottom, 60% of which is vegetated by charophytes. The station LF050 is located in the 1.0m water depth and it is densely vegetated by the higher order vegetation.

Figure 3 shows the absolute reflectance spectra of atmospherically corrected and *in situ* measured Ramses spectra. It is seen that ATCOR produced consistently low corrected reflectance values compared to the field measurements, whereas those originating from FLAASH and ACORN show more similar absolute values to field spectra between 450-750 nm. The wavelength range between 450-750 nm has the utmost value in the relatively dark and CDOM rich Baltic Sea. CDOM absorbs light strongly in the shorter wavelengths (less than 450 nm) precluding those wavelengths from benthic habitat mapping. Water itself absorbs light strongly in the red and near-infrared region of the spectrum and therefore wavelengths greater than 750 nm do not contain usable information for the benthic habitat mapping.

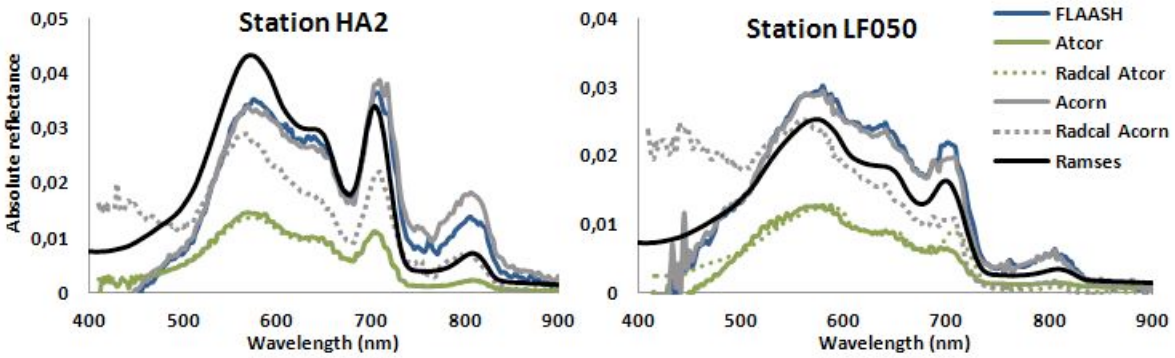

Figure 3. Direct comparison between the atmospherically corrected absolute reflectance spectra and ground reflectance spectra obtained using Ramses field spectrometer in two field stations in the Haapsalu Bay.

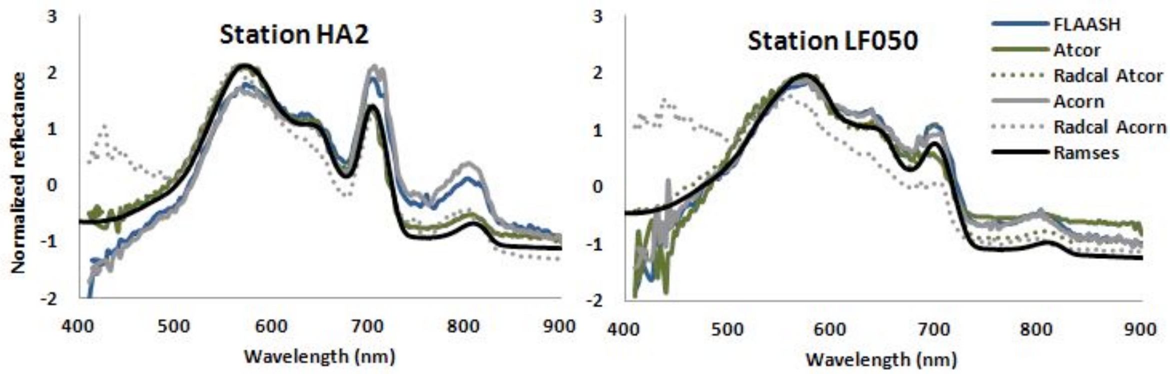

Figure 4. Direct comparison between the atmospherically corrected normalized reflectance spectra and ground reflectance spectra obtained using Ramses field spectrometer in two field stations in the Haapsalu Bay.

It's interesting to note that while based on slightly different atmospheric models and procedures, ACORN and FLAASH produced very similar results. Applying ATCOR and ACORN to the recalibrated Hyspex image (Radcal ATCOR, Radcal ACORN) showed the increase of spectral values in the shorter wavelengths (less than 500nm), whereas the recalibration had greater influence on ACORN results. It is seen that the corrected reflectance spectra of Radcal ACORN differs greatly from the corrected ACORN spectra, while Radcal ATCOR shows comparatively similar results with ATCOR.

Figure 4 shows the normalized reflectance spectra of atmospherically corrected and *in situ* measured spectra. Normalized spectra allow better comparison of spectral shapes of each of the corrected spectra. As a general observation, the shapes of all spectra (except the Radcal ACORN spectra) are in a good conformity with the data from the ground measurements. **Still, ATCOR showed the closest comparison with the shapes of the field spectra and**

outperformed other modules in the specific case. Retrieving the correct spectral shapes is of utmost importance while using classification methods like the Spectral Angle Mapper (SAM) in benthic habitat mapping purposes. SAM is relatively insensitive to illumination effects, since it is invariant to absolute values of reflectance. Reflectance spectra are normalized in SAM before comparison to each other.

Those different atmospheric correction methods were applied to the one single Hyspex flight line during the current STSM due to the large file sizes and resulting very long processing time. Although only four *in situ* measurement points were located on that single flight line, it gave important indications about the performance of different atmospheric correction modules on the Hyspex remote sensing data. In our further collaboration with Dr. Brook the rest of the Hyspex flight lines from the given study area will be processed. The entire study area contains 12 field measurement points, which should give us better basis for the assessment of different atmospheric correction modules and allow finding coefficients for correcting the absolute values of ATCOR results.

Task 2 Radiometric field campaigns.

Radiative transfer models used in the current STSM demonstrated efficiency in simulating ground spectral data. Nevertheless their performance was influenced from their dependence on assumptions of standard atmospheric parameters over the entire scene. Accurate radiometric values are the key factor in the extraction of quantitative information based on spectral reflectance from at-sensor radiance. The atmospheric conditions must be measured in the field at the time of image acquisition in order to obtain the inputs needed to compute the atmospheric path radiance for each pixel.

Current STSM allowed observing the performance of atmospheric measurements in the Haifa University. AISA hyperspectral imagers were set up for the data collection up to 4 times in a day for two weeks in order to characterize temporal variability of the atmospheric properties. Such ground based radiation measurements allow analysing the properties and distribution of the atmosphere with regard to its constituents, such as aerosols, water vapour, ozone, etc. Given information can be introduced in a radiative transfer models while correcting remote sensing images from atmospheric effects. Thereby the exact atmospheric properties are used in atmospheric models, instead of standard values.

Unfortunately, as the atmospheric measurements had just started in the Haifa University, the data were not processed and it was not possible to follow the methods of retrieving atmospheric parameters from the radiation measurements. However, given information will be distributed to EMI by the Haifa University when the measurements are processed.

Task 3 Performing close-range hyperspectral measurements

Current STSM allowed participating in several field studies organised by the Haifa University, where close-range hyperspectral measurements were performed with different radiometric sensors. During the field studies sensor calibration and radiometric point measurements were performed.

EMI has purchased a laboratory rack for our hyperspectral Hyspex sensor, which allows scanning the sample area with millimetres scale pixel size for reflectance measurements. The first tests for performing laboratory measurements with such a scanning device will start in the spring of 2016. Although such a laboratory rack was not present in the Haifa University, we are interested in proceeding the collaboration with Dr. Brook as she has lot of experiences working with different ground radiometric measurement devices and different spectral analysis tools.