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Evaluation of FLAASH atmospheric correction

Note

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Abstract

The FLAASH atmospheric correction module is evaluated. First, the user interface is considered. Then the performance of FLAASH is evaluated by testing it on images from four sensors with different properties: Landsat 7 ETM (medium spectral and spatial resolution), QuickBird (high spatial resolution, low spectral resolution), Worldview-2 (high spatial resolution, low spectral resolution) and MODIS (low spatial resolution, high spectral resolution).

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1 Executive summary

The FLAASH atmospheric correction module is evaluated. First, the user interface is considered. It is found that FLAASH takes a large number of inputs, adjustable to the conditions of the scene to be explored. However, a certain amount of the input data must be manually retrieved and entered by the user. Some pre-processing of the input data is also necessary. This makes usage a bit cumbersome.

A serious drawback of the FLAASH interface is that it is not possible to run as a batch job, but may only be used in GUI mode. This makes processing of large data sets practically impossible. Unless this is remedied, FLAASH will not be usable for any kind of automatic processing.

For sensors with the necessary bands, FLAASH normally retrieves aerosol and water vapour information from the image, providing well-adjusted input for the atmospheric correction. FLAASH does however, not accept any kind of ancillary data, containing ozone, surface pressure or water vapour in the cases when this may not be retrieved from the data. This limits the usability of FLAASH for some of our applications where we wish to use data from other satellites or models for, e.g., water vapour.

Then the performance of FLAASH is evaluated by testing it on images from four sensors with different properties: Landsat 7 ETM (medium spectral and spatial resolution), QuickBird (high spatial resolution, low spectral resolution), Worldview-2 (high spatial resolution, low spectral resolution) and MODIS (low spatial resolution, high spectral resolution).

In all cases the visible difference between the images are found to be very slight. Only around clouds there is occasionally found a visible difference. When studying the spectra, the improvements are clearer. For all sensors the spectrum is plotted for a pixel containing vegetation before (radiance) and after (surface reflectance) atmospheric correction with FLAASH. The radiance spectra show high values for blue and green wavelengths due to aerosol scattering, while in the surface reflectance spectra this is corrected. The blue and green values are much lower, and the chlorophyll peak in the green wavelength is visible. From the WorldView-2 and MODIS spectra it is also clear that FLAASH reduces the reflectance values of the near-infrared wavelengths.

In the Landsat and the QuickBird images some artefacts are introduced by FLAASH. Some discontinuities are visible, and in the case of Landsat a chequered pattern of squares of 12x12 pixels are occasionally seen. This is expected to originate from the adjacency correction, and by turning off this feature, the artefacts disappear. In the case of MODIS, adjacency correction is not possible, as it causes FLAASH to crash. For most applications the chequered pattern would not be acceptable. There is a need to get this functionality clarified; otherwise we cannot make use of it.

Along the side of the MODIS image, at extreme off-nadir angles, the image is visibly bluer. We expect this to be a result of the longer path-length through the atmosphere at these angles, and therefore more aerosol scattering. In the FLAASH corrected image, this blue colour along the side is still strongly visible. Apparently, FLAASH does not correct for this increased path length within the scene. This means that the atmospheric correction is only correct for angles close to nadir, limiting the usability of FLAASH for wide field-of-view sensors like MODIS.

2 FLAASH input data

FLAASH is managed by using a GUI, where all input parameters are set (Figure 1). The input files must contain calibrated radiance values. FLAASH does not calibrate the images, so in most cases a calibration must be performed first. FLAASH is also not able to process files in BIL format, so the input files must be converted to BSQ or BIP format before atmospheric correction. The input files must also contain information in the header on the wavelength of each band, or else a separate wavelength file must also be specified. In most cases this must be compiled manually. Finally, the units of the input file must be scaled to the same units as FLAASH ($\frac{\mu W}{cm^2} * nm * sr$), so a scale factor must be provided. This should be the number one needs to "divide" the data with in order to get the correct units.

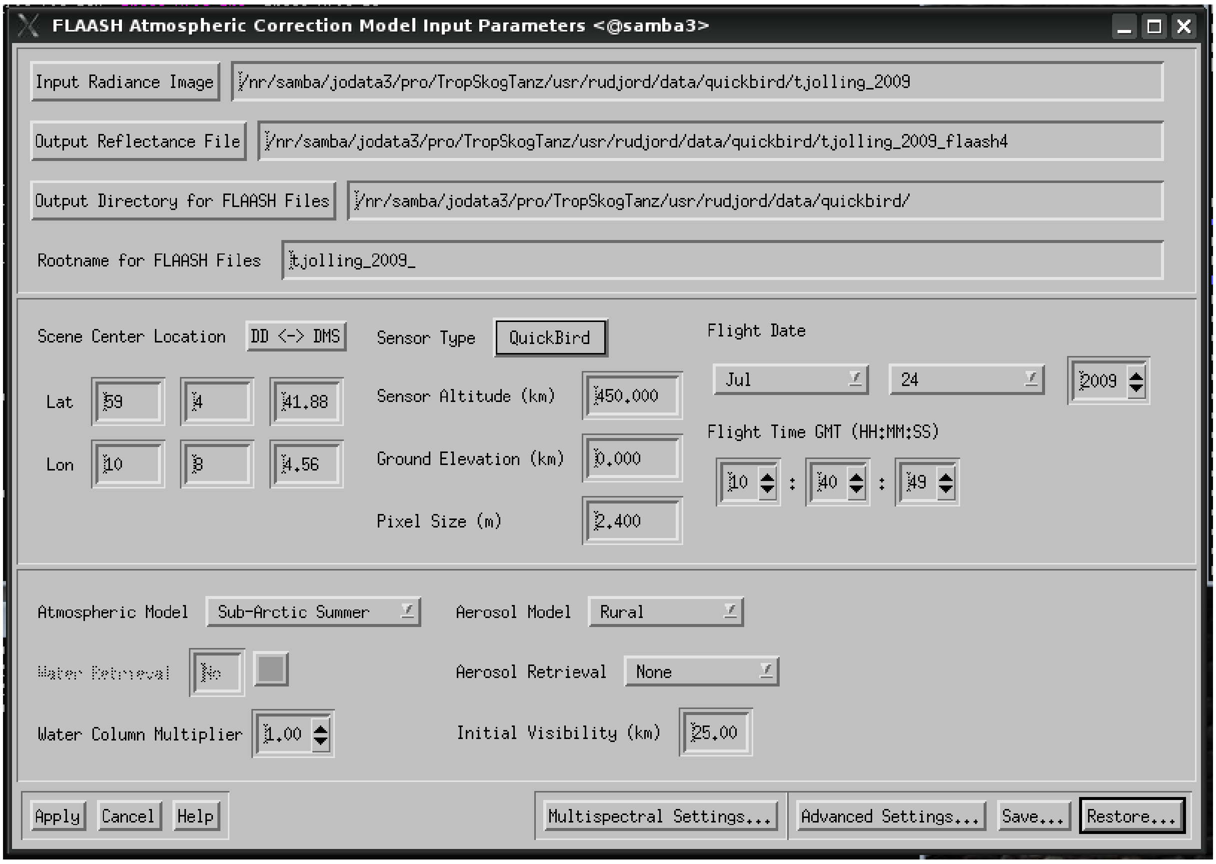

Figure 1. The FLAASH graphical user interface.

In addition to the image file to be corrected, FLAASH also needs information on the geographical centre location of the image and the time it was captured. This information cannot be retrieved automatically from the data file, but must be entered by the user. The sensor may be specified from an extensive list of multispectral and hyper-spectral sensors for which the spectral response filter functions are known. Unknown sensor may also be selected, but then the filter functions must be provided separately. Sensors like AATSR and MERIS are missing from the list. The sensor altitude and pixel size are known for the sensors which FLAASH recognizes.

The ground elevation must be provided for each image, and must be found from some other source, for example Google Earth.

An atmospheric model must be selected depending on climate (latitude and time of year). If the image contains a water absorption band, FLAASH may estimate the water vapour column; else the water vapour is taken from the atmospheric model. An aerosol model must be selected depending on the expected type of aerosols present. For sensors with the necessary bands, FLAASH may perform aerosol retrieval from the image. Otherwise, default values from the aerosol model are used. In either case, an initial value for the visibility must be set. In most cases FLAASH provides default values for the bands to be used for water vapour and aerosol retrieval, but in some cases it must be specified by the user. The FLAASH manual provides some guidance to the choice of models and bands for aerosols and water vapour retrieval (http://www.exelisvis.com/portals/0/pdfs/envi/Flaash_Module.pdf).

If a non-nadir looking instrument is being used, the view direction of the sensor must be specified. FLAASH also uses adjacency correction as a default, correcting for light scattered to the neighbouring pixel.

Once all this information is provided, it is possible to save the settings to a file, for future reference, or for quickly adopting similar settings as before. A serious limitation, however is that it is impossible to run FLAASH as a batch job, from ENVI or otherwise, just by specifying such a settings file. As an absolute minimum it is necessary to open the FLAASH dialogue window and auto-fill the fields by loading a settings file. This makes it practically impossible to run FLAASH on large datasets.

2.1 A note on FLAASH vs. LEDAPS

For Landsat images, an alternative to using FLAASH is to use LEDAPS preprocessing. LEDAPS is provided free of charge by NASA as open source software. A limitation of LEDAPS is the poor resolution on the ancillary data (water vapour, ozone, surface pressure). For water vapour, FLAASH partially remedies this limitation for some sensors. For sensors with the required bands, water vapour is (in principle) found directly from the image, providing accurate and high resolution ancillary data. However for sensors with fewer bands (including Landsat, QuickBird and Worldview-2), this advantage is lost, as these values have to be set manually (or rather set by the model), as a single value for the entire image.

FLAASH also makes no mention of the ozone concentration or surface pressure, and we therefore assume model values are used in the place of these.

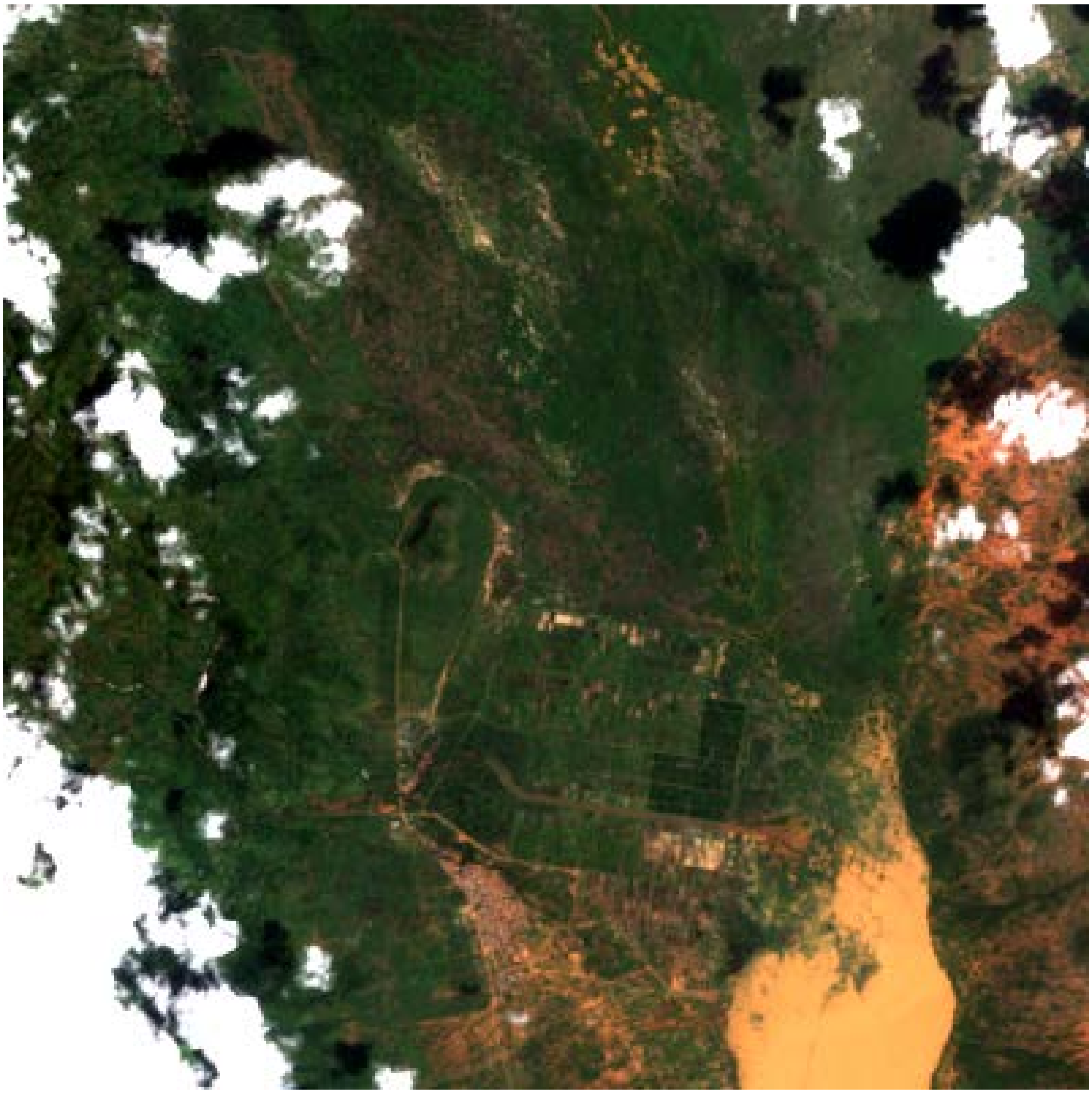

Figure 2. Original Landsat 7 ETM image from Tanzania on January 15, 2001.

2.2 Landsat

For the evaluation we investigated a Landsat 7 ETM image taken over Tanzania (Path 167, row 63) on January 15, 2001 (Figure 2).

Atmospheric correction using FLAASH was compared to using LEDAPS preprocessing. For the FLAASH correction, aerosols were retrieved from the images, but the Landsat bands do not allow water vapour retrieval. The water vapour was therefore taken from the atmospheric model. We assumed a tropical atmospheric model and a rural aerosol model with initial visibility 40 km.

The initial inspection revealed no significant visible changes after atmospheric correction, for neither FLAASH (Figure 3) nor LEDAPS (Figure 4). However, upon closer inspection it is revealed that in some places some linear discontinuities can be seen (Figure 5). These are not seen in the original image (nor in the LEDAPS corrected image), and must therefore have been introduced by FLAASH.

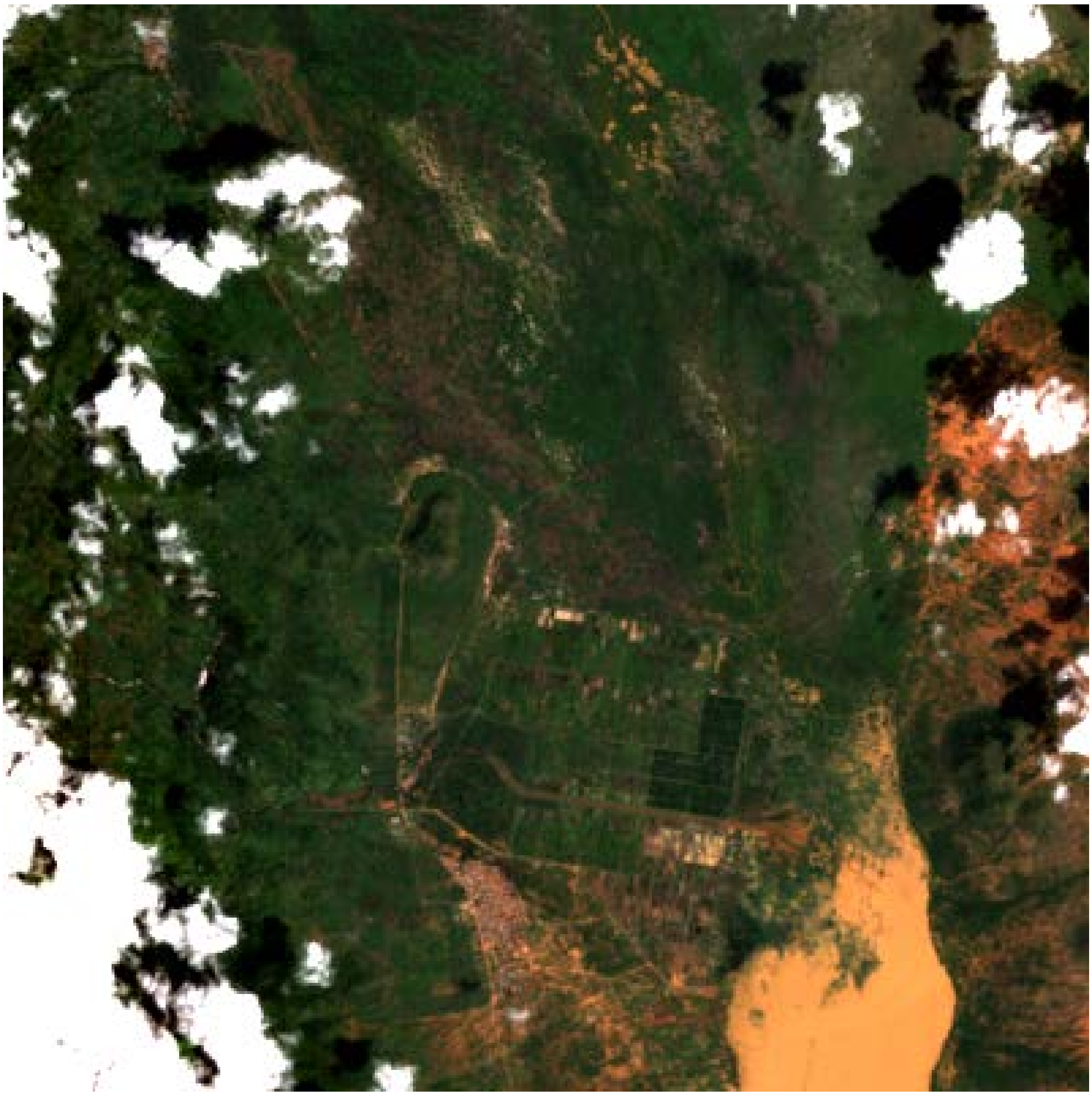

Figure 3, Same image as in Figure 2, but corrected with FLAASH.

When adjusting display parameters some squares (12x12 pixels) are visible in clouds of FLAASH corrected image (Figure 6). It is possible that these squares are related to the computational tiles that ENVI uses when analysing images.

These discontinuities indicate that some kind of averaging over 12x12 pixels is taking place. Therefore, the atmospheric correction was performed also with adjacency correction switched off. In this case the issue disappears (Figure 7), indicating that the discontinuities are related to an averaging scheme in the adjacency correction algorithm.

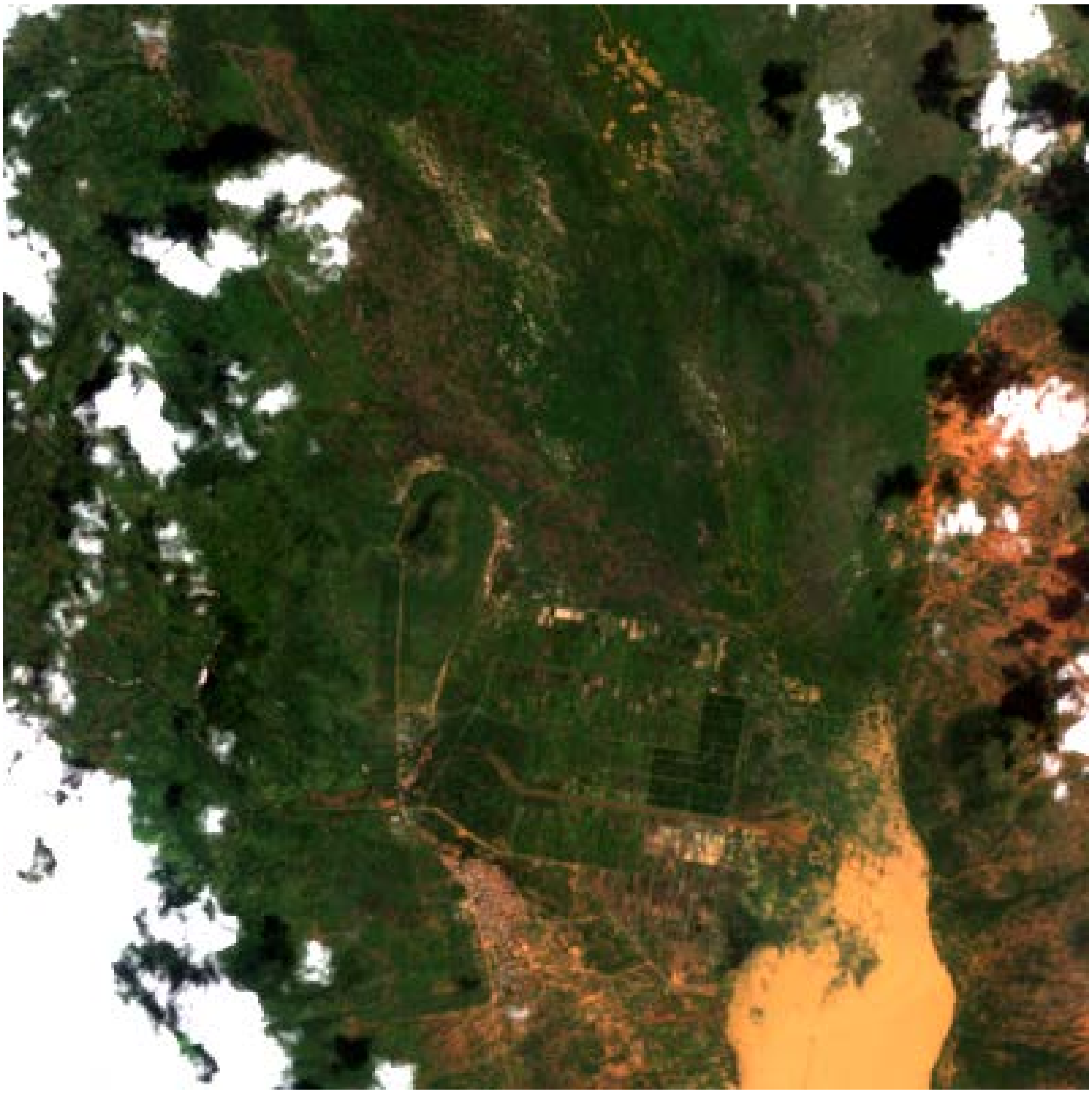

Figure 4. Same image as in Figure 2, but corrected with LEDAPS.

The shape of the spectrum was also investigated. We selected a pixel containing vegetation in the Landsat image and plotted the spectrum for the original radiance image as well as the surface reflectance images produced by FLAASH and LEDAPS. The original image shows relatively high values in the blue and green wavelengths (Figure 8), due to aerosol scattering. In the corrected images however, this effect is removed, and we see the characteristic small peak in the green wavelengths due to chlorophyll (Figure 9). The spectra produced from the two corrected images (FLAASH and LEDAPS) display no visible difference however.

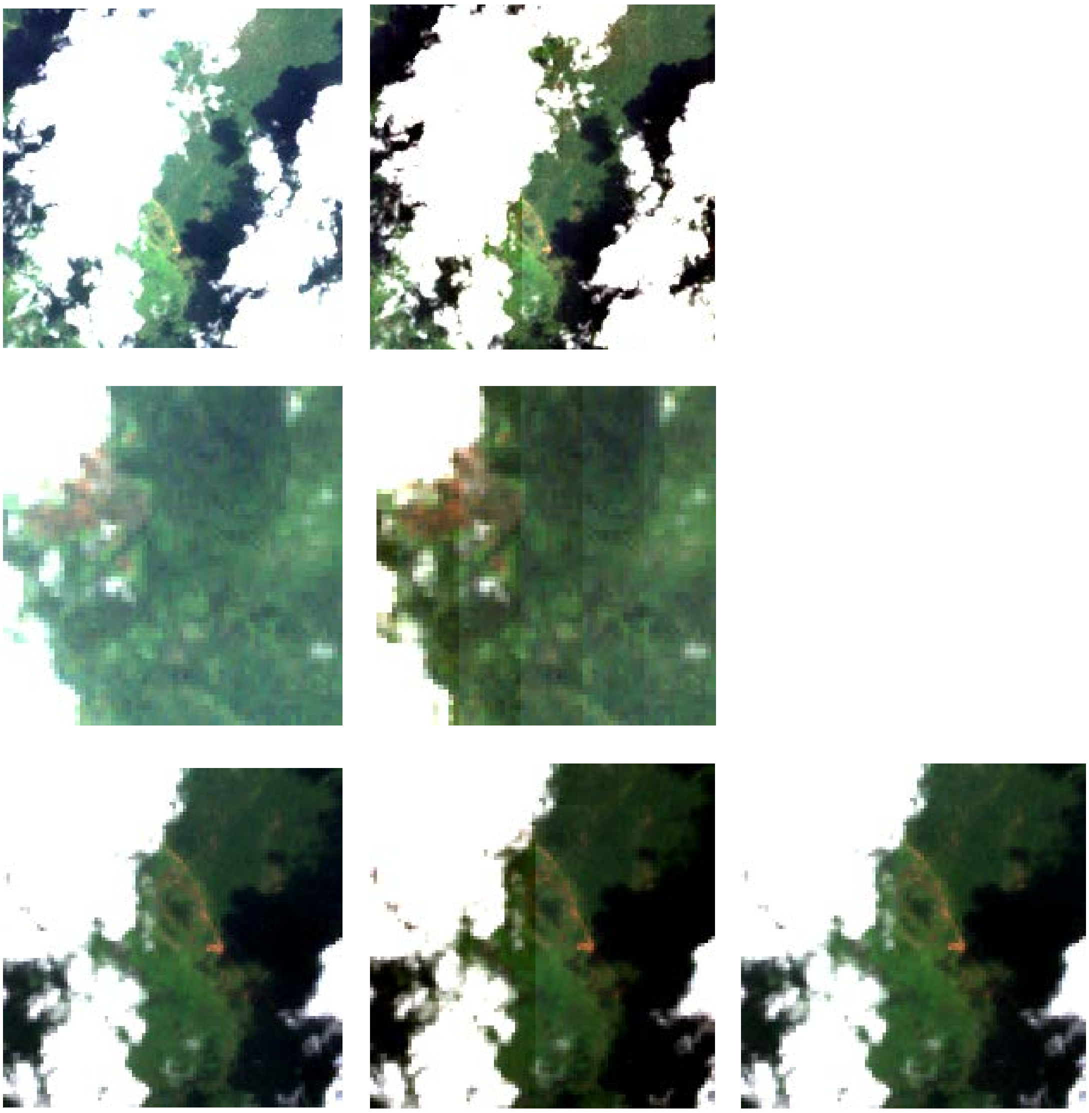

Figure 5. Details of a Landsat 7 ETM image over Tanzania on January 15, 2001. Left column: original radiance image. Middle column: surface reflectance image after atmospheric correction with FLAASH. Right column (only one image): surface reflectance image after atmospheric correction with FLAASH. Right column (only one image): surface reflectance image after atmospheric correction with LEDAPS.

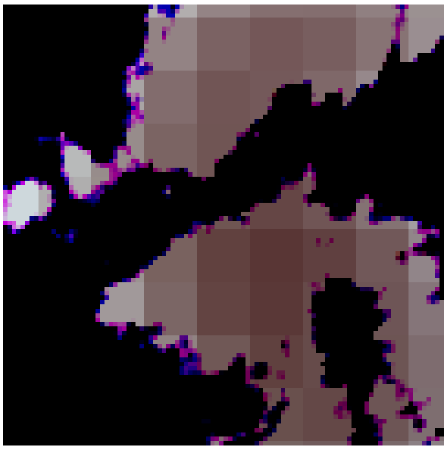

Figure 6. Details of clouds in a Landsat 7 ETM image over Tanzania on January 15, 2001, after atmospheric correction with FLAASH. Colors have been adjusted to enhance the pattern in the clouds.

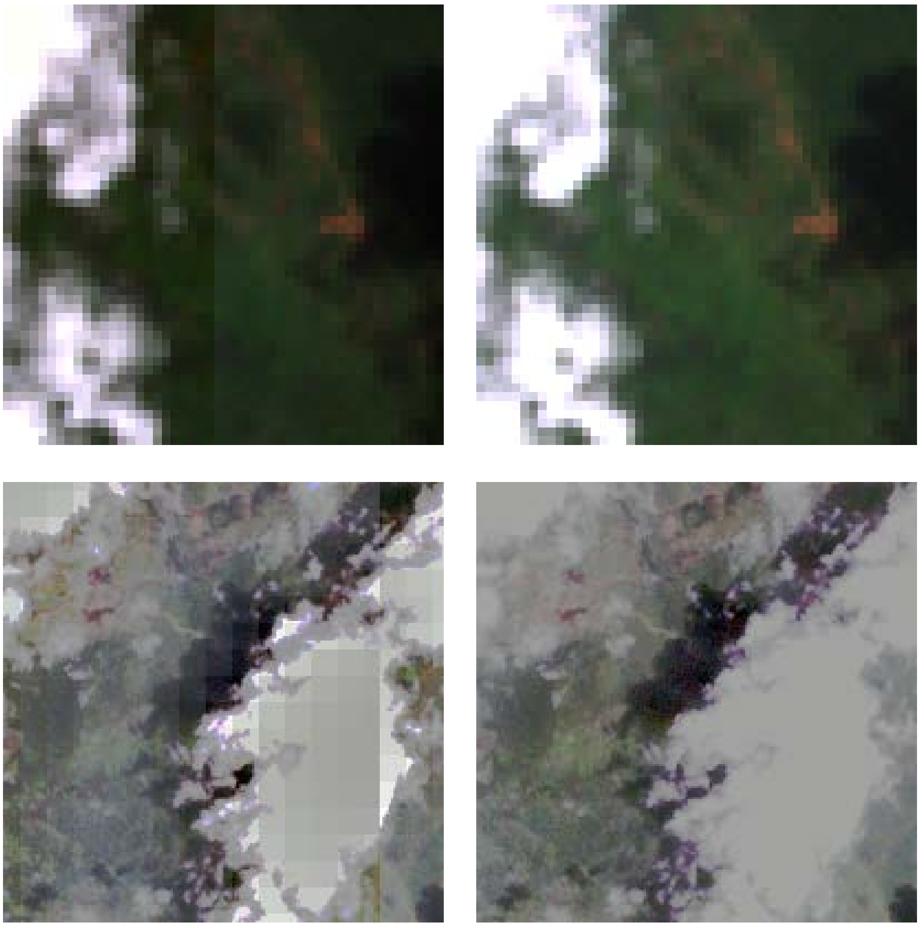

Figure 7. The same Landsat 7 ETM image as previously, after atmospheric correction with FLAASH, with adjacency effect turned on (left) and turned off (right). The stripes and squares disappear when adjacency correction is disabled.

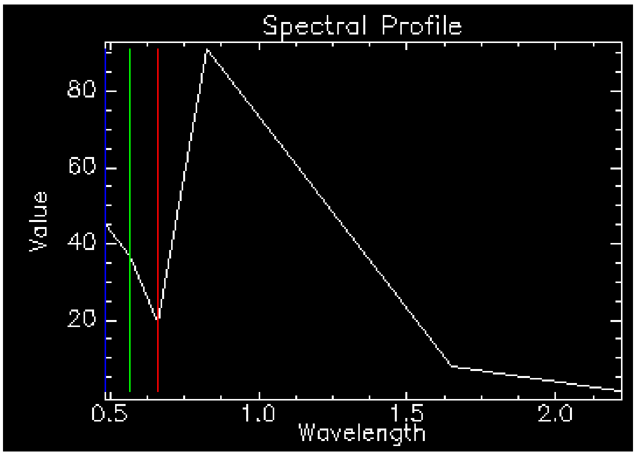

Figure 8. Spectrum of vegetation covered pixel in original Landsat radiance image. Note high values in blue and green due to aerosol scattering in the atmosphere.

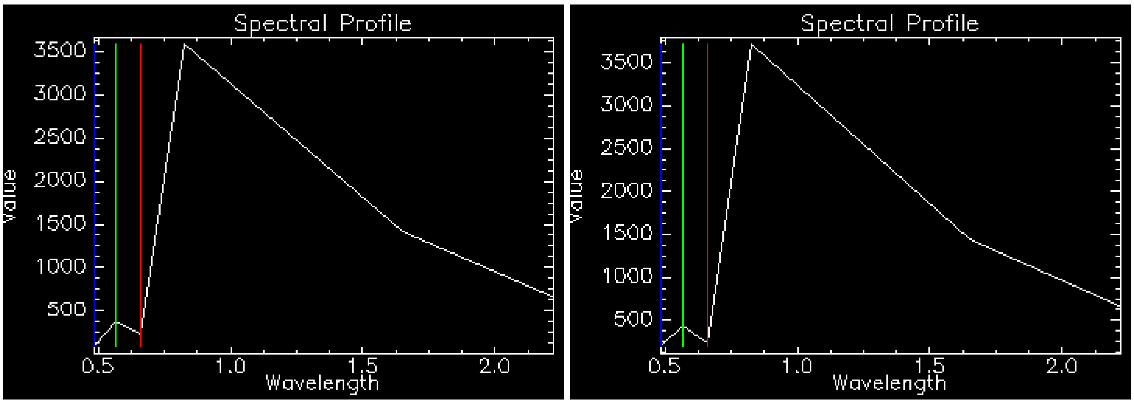

Figure 9. Spectra of the same vegetation covered pixel in the Landsat surface reflectance image, with atmospheric correction performed using FLAASH (left) and LEDAPS (right). Note the characteristic shape of vegetation: a peak in the green band due to chlorophyll, and the "red edge", with high reflectance values in the near infrared.

2.3 QuickBird

Two QuickBird images were corrected, one taken over Oslo on May 5, 2006 and one taken over Tjølling on July 24, 2009. The QuickBird bands do not allow for the retrieval of water vapour or aerosols from the image, so we assumed model parameters. For the image over Oslo we assumed an atmospheric model for mid-latitude winter and an urban aerosol model with a visibility of 40 km. For the image over Tjølling we assumed an atmospheric model of sub-arctic summer and a rural atmospheric model. Since the image contained a lot of hazy clouds we set the visibility to 25km.

For the image over Oslo the visible change is very slight (Figure 10). Only the shape of the spectrum reveals a change (Figure 11). The spectral profile shows a significant reduction of the blue and green components, but maintaining the chlorophyll peak in the green band.

Figure 10. Oslo, May 5, 2006. RGB composite using QuickBird bands 3, 2 and 1. Left: Original calibrated radiance image. Right: Surface reflectance image after FLAASH atmospheric correction.

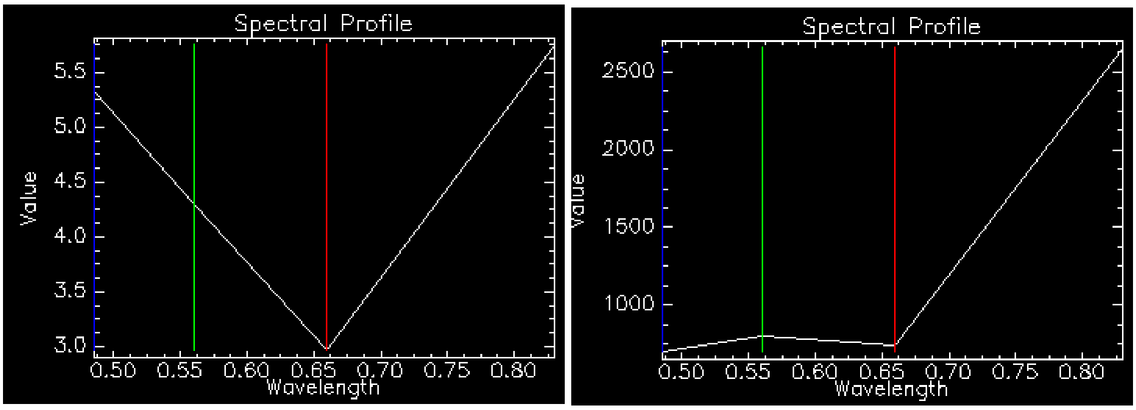

Figure 11. Spectral profile of a grassland pixel in Oslo, May 5, 2006 with QuickBird. Left: Original calibrated radiance. Right: Surface reflectance after FLAASH atmospheric correction.

In the image of Tjølling some slight changes are visible around the clouds after atmospheric correction. However, upon visual inspection it is hard to evaluate if it is an improvement (Figure 12). In some places an artefact is seen. A weak discontinuity is visible in the clouds (Figure 13), suggesting that two areas have been processed separately. This discontinuity does not exist in the original QuickBird calibrated radiance image, and must therefore have been introduced by FLAASH. The computational tile size in FLAASH was increased, but the discontinuity remained. We also tried to change the visibility to 40 km, but this only served to strengthen the discontinuity. As with the Landsat image, we turned off adjacency correction, and this removed the discontinuity.

Figure 12. Tjølling, July 24, 2009. RGB composite using QuickBird bands 3, 2 and 1. Left: Original calibrated radiance image. Right: Surface reflectance image after FLAASH atmospheric correction.

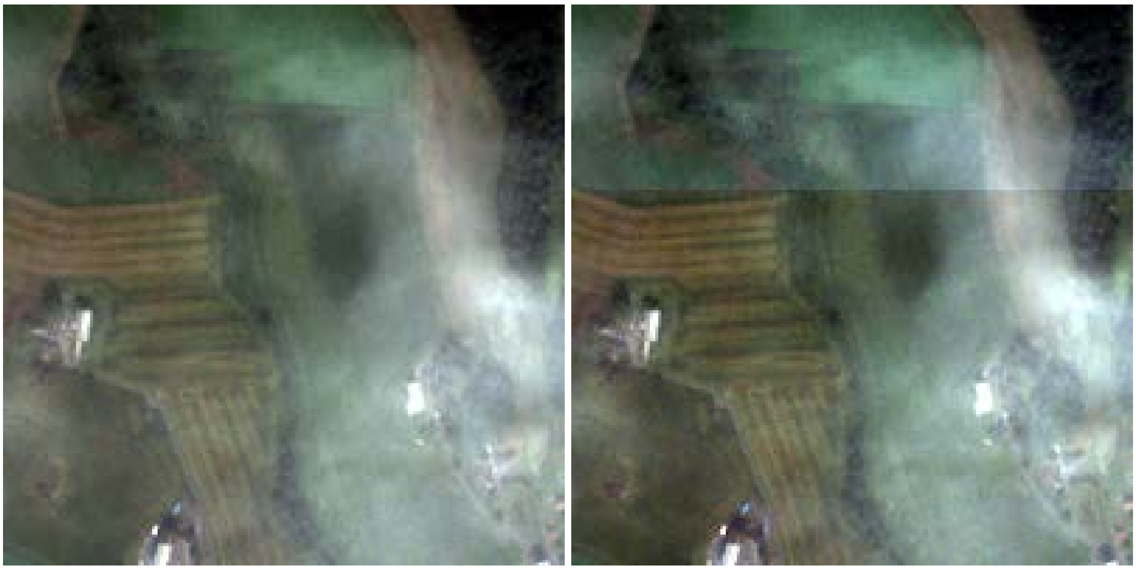

Figure 13. Tjølling, July 24, 2009. RGB composite using QuickBird bands 3, 2 and 1. Left: Original calibrated radiance image. Right: Surface reflectance image after FLAASH atmospheric correction. Note the discontinuity introduced during the atmospheric correction.

The spectral profile of a forested pixel in the image from Tjølling was investigated (Figure 14). Also here we see high values of blue and green in the original radiance image, which is significantly reduced in the corrected image. However, the green peak due to chlorophyll is less pronounced here.

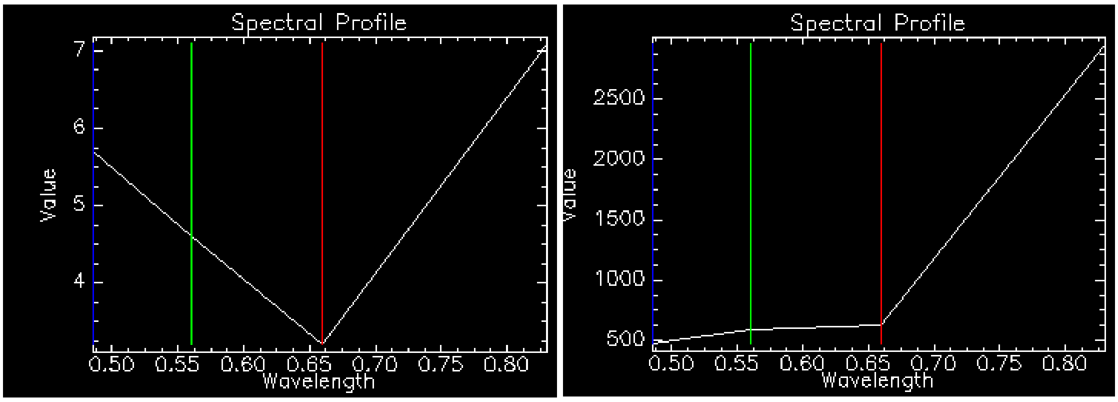

Figure 14. Spectral profile of a forested pixel in Tjølling, July 24, 2009 with QuickBird. Left: Original calibrated radiance. Right: Surface reflectance after FLAASH atmospheric correction.

2.4 WorldView-2

A Worlview-2 image from Tjølling in Norway taken on September 9, 2011, was corrected for atmospheric effects using FLAASH. The WorldView-2 bands do not allow water vapour or aerosol retrieval, so we assumed values from an atmospheric model of sub-arctic summer and a rural aerosol model. We set the visibility to 40 km.

For most parts of the image, there are no visible differences between the original and the corrected image (for example as in Figure 15). However, in areas with clouds, some improvement may be seen as the strong blue component from aerosol scattering is reduced (Figure 16).

Figure 15. RGB composite of Worldview-2 bands 5, 3 and 1. Left: original image. Right: image after atmospheric correction with FLAASH.

Figure 16. RGB composite of Worldview-2 bands 5, 3 and 1. Left: original image. Right: image after atmospheric correction with FLAASH.

The spectra were also compared. Figure 17 shows the spectral profile of a green grass field in the image before and after correction. The corrected image has a clearly lower blue component, and clearly shows the expected chlorophyll peak in the green band. The near infrared band with the highest wavelength (0.95 μm) also shows a clear reduction after atmospheric correction with FLAASH.

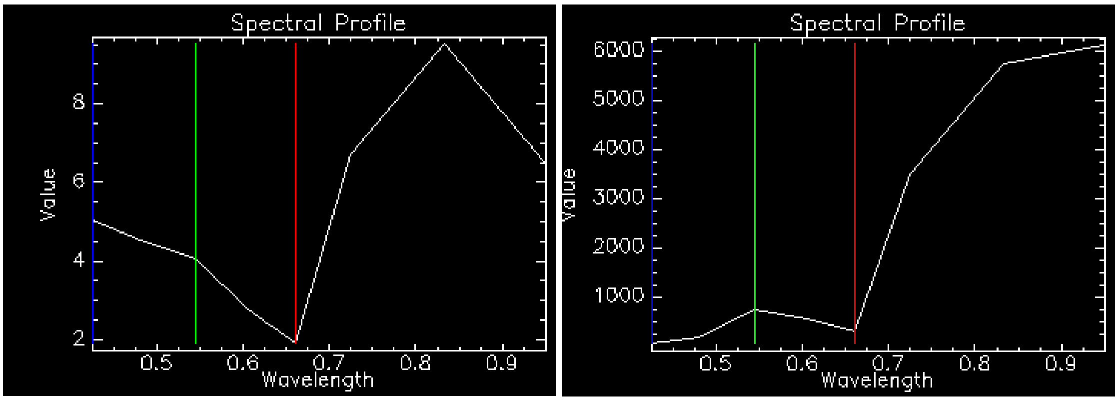

Figure 17. Spectral profile of a grassland pixel in a Worldview-2 image. Left: calibrated radiance of the original image. Right: surface reflectance of image after atmospheric correction with FLAASH.

2.5 MODIS

A MODIS image from January 15, 2001, taken over Tanzania was investigated. For this test we used 1km resolution, in order to take advantage of the many spectral bands of MODIS. We performed atmospheric correction of the image using FLAASH. The atmospheric model was set to tropical. We used aerosol retrieval with default variables and a rural aerosol model. We set initial visibility to 30 km.

In principle, the MODIS bands also allow for water vapour retrieval, using the 940nm water feature. However, band 16, which should be used as a reference band (just outside the water vapour spectral region), has the majority of the pixels set to -1. Therefore we performed the atmospheric correction without water vapour retrieval to begin with.

At the first of atmospheric correction, the FLAASH module crashed with the error message "ACC_LSMOOTH2: Cannot continue with smoothing calculation". We decided to turn the adjacency correction feature off. The MODIS pixels are relatively large, so it is possible that this makes the adjacency correction impossible. The size of the pixels also makes the adjacency effect small, since only a relatively small amount of light scatter out of the pixel. This change allowed FLAASH to run to its conclusion.

As with the previous tests, the visual difference between the images before and after the correction, is small (Figure 18). One notable feature is the radiometric disturbance along the side edges of the image. Far away from nadir the image appears bluer (Figure 19). This is mostly visible in the left part of the image. We suppose this effect comes from far off-nadir view angles, and therefore longer path length though the atmosphere causes more atmospheric scattering, increasing the blue and green wavelength. This effect is still present in the corrected image. FLAASH does not seem to correct for this increased path-length. This means that the atmospheric correction is only correct for angles close to nadir, which would be a significant limitation for wide field-of-view sensors, like MODIS.

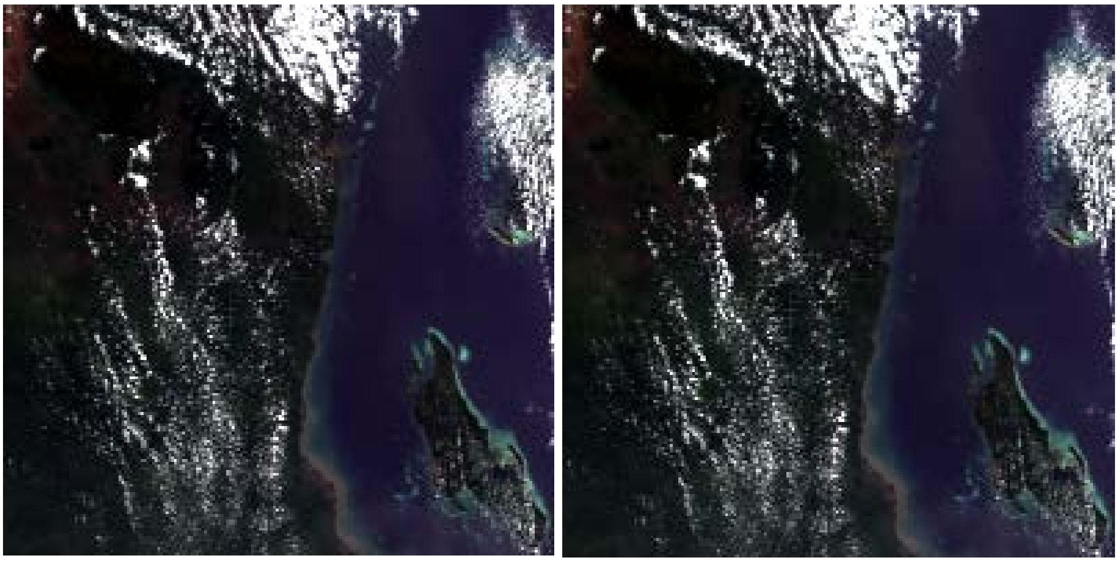

Figure 18. Terra MODIS image of Tanzania from January 15, 2001. Left: TOA reflectance. Right: Surface reflectance after atmospheric correction with FLAASH.

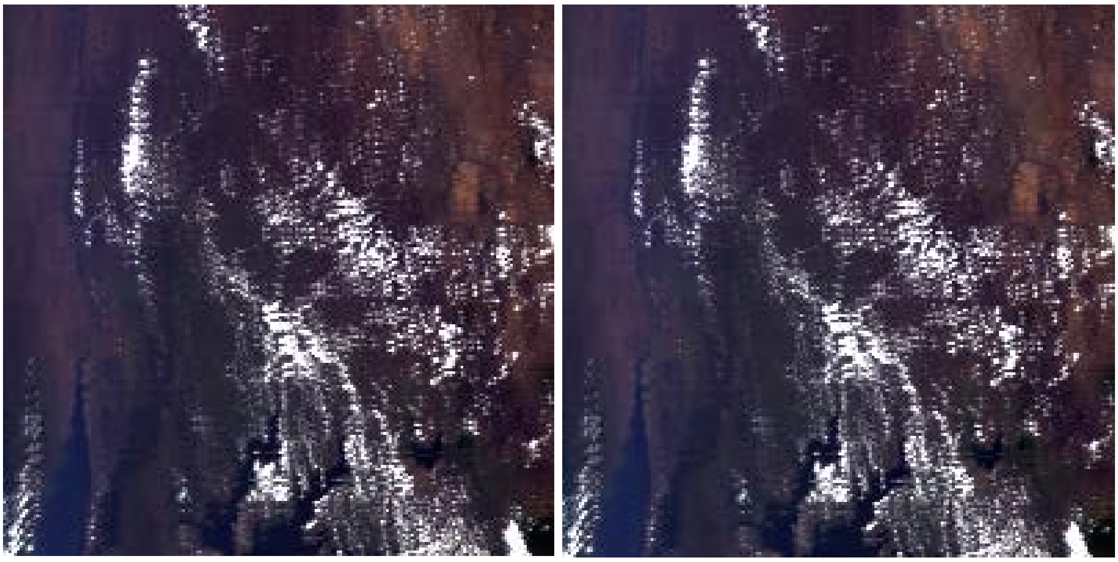

Figure 19. Terra MODIS image of Tanzania from January 15, 2001. Left: TOA reflectance. Right: Surface reflectance after atmospheric correction with FLAASH. Note the “blue tint” on the left part of both images.

The spectrum was found for a pixel containing vegetation, located near nadir (Figure 20), before and after atmospheric correction. When comparing the surface reflectance spectrum to the TOA reflectance spectrum of the same pixel we see that the blue-green part of the spectrum has been reduced, and the infrared part of the spectrum has increased. As before, the “chlorophyll-peak” is visible in the corrected spectrum.

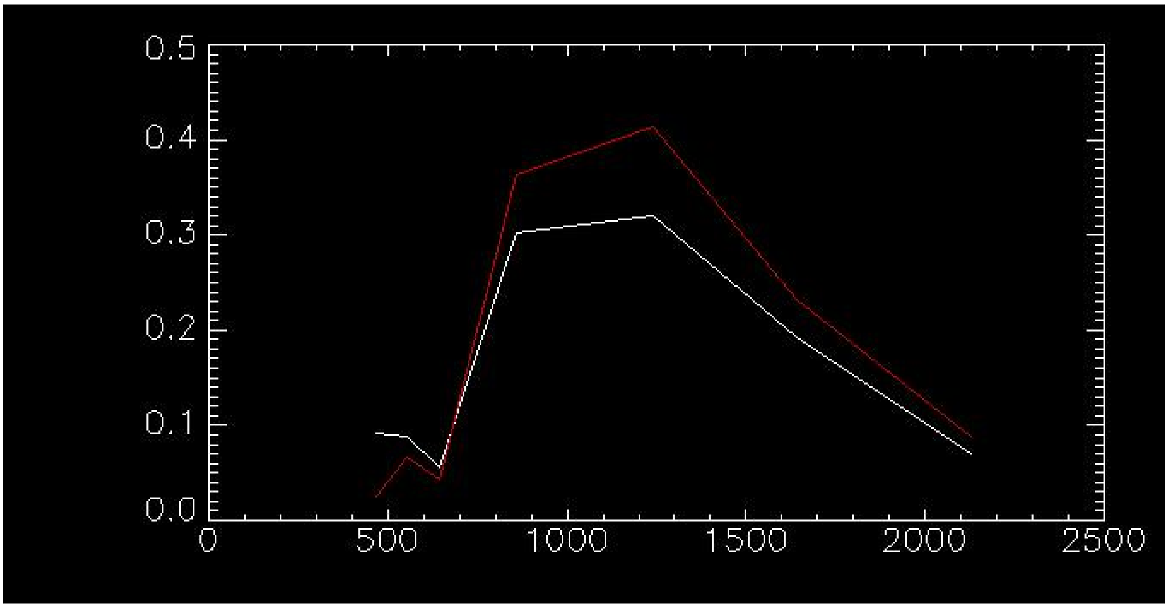

Figure 20. Spectrum of the first 7 bands of MODIS. The plot shows TOA reflectance spectrum (white) and surface reflectance after atmospheric correction with FLAASH (red).

Finally, we performed atmospheric correction on the same image again, and this time we used water vapour retrieval. We used water absorption feature of band 19. As a water reference channel we used MODIS band 2. The water reference channel should lie just outside the spectral range for water absorption. It is recommended to use a channel in the range 870-890nm. MODIS band 2 covers the spectral range 841-876nm. When comparing this result with the previous atmospheric correction (without water vapour retrieval) no visible difference was found.

3 Conclusions

FLAASH performs atmospheric correction for a wide range of sensors. By visual inspection, the differences in the image are very small, but the spectra reveal significant changes, in particular for the green and blue wavelengths. However FLAASH is found to suffer from the following limitations.

- FLAASH is unable to automatically perform elementary operations on the data, making cumbersome manual pre-processing necessary (calibration, BIL-to-BIP conversion, scaling, writing wavelengths to header).

- No batch processing, making atmospheric correction of large datasets practically impossible.

- Adjacency correction is not possible for MODIS, and introduces artefacts for the other sensors.

- For MODIS: aerosol scattering for far off-nadir angles are not corrected.

- Water vapour retrieval is normally not possible for multispectral sensors and model values are used instead.

- For QuickBird and Worldview-2, aerosol retrieval is not possible and model values are used.

- FLAASH is (in contrary to LEDAPS) unable to adjust for variations in several atmospheric parameters, e.g. ozone, surface pressure and water vapour (except for sensors where water vapour retrieval is possible). Preferably, it should be possible to read this type of ancillary data from external sources, in order to account for spatial variation within a scene.