De-striping of MODIS Optical Bands for Ice Sheet Mapping and Topography

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Depletion of MODIS is a substantial improvement over AVHRR

From the late 1970s to the present, the operational MODIS High Resolution Radiometer (AVHRR) sensor with a spatial resolution of 1104 meters and a radiometric resolution of 16 bits (1 part in 65536) has been used to map both surface features and sea ice. MODIS has calculated on large regions of the earth’s ice sheets. The MODIS Imaging Spectroradiometer (MISR) imaging instrument flying on the Terra and Aqua satellites has even greater potential for these applications, due to its large field of view and high spatial resolution. Band 1: 520-530 nm red; Band 2: 665-715 nm near-infrared (near NIR); and Band 3: 841-876 nm (near-infrared) each have a spatial resolution of 250 meters per pixel and a radiometric resolution of 12 bits (1 part in 4096). Based on the success with AVHRR-based photogrammetry, MODIS should be capable of mapping ice sheet surface slopes as steep as 0.0025 vs. about 0.0007 for AVHRR.

Problem: MODIS artifacts (e.g. striping) limit its usefulness

Terra MODIS Level 2 MOS I (MOS1_0210) data have known inter-detector variations as large as 1% per cent, leading to distinct horizontal striping in contrast-enhanced ice sheet images. This primary striping pattern appears to be due to poor calibration among the 80 detectors that constitute a single scan of MODIS/AVHRR data. A secondary change-in-brightness pattern appears to alternate between successive 40-line-scans that is probably due to misaligned side effects in the double-sided MODIS scan mirror. The fact that the observed artifacts have regular patterns allows for their possible removal and the production of images having effective SNRs better than 1000. We describe here a series of empirical techniques for correcting the striping patterns that are present in the images.

Solution: Artifacts have periodicity which can aid in their removal

Although the design requirements for signal-to-noise ratios (SNRs) for bands 1 and 2 are stated to be only 128 and 201, respectively, the fact that the observed artifacts have regular patterns allows for their possible removal and the production of images having effective SNRs better than 1000. We describe here a series of empirical techniques for correcting the striping patterns that are present in the images.

Step 1: Extract swath images from HDF-EOS files

For this example we use the following Terra MODIS Level 2 data available at:

ftp://sidads.colorado.edu/pub/incoming/tharan/modis_adjust/

Step 2: Normalize with respect to solar illumination

We now divide each band 2 pixel by the cosine of the corresponding solar zenith angle pixel in order to minimize the solar illumination factors (essentially so that any remaining brightness gradients within a scan will be treated as a striping artifact which will be corrected). These images show the result of this normalization. Note that the anomaly now shows a reflectance of about 0.810, and that the horizontal striping now has an amplitude of about +0.025, still about +11% of the signal strength.

Step 3: Perform column regressions to correct the "fourth pixel" artifact

In attempting to correct the "fourth pixel" artifact, we will operate on 40 line detectors and 29 separately. For each detector, we assemble three vectors:

\[ l(d) \]
\[ r(d+1) \]
\[ m(d/2) \]

Then for each double scan detector, we construct a vector corresponding to each pair of adjacent double scan detectors.

\[ v'(d) = (v(d) - i(d) / s(d) \]

A scatterplot for double scan detector 0 in pass 5 is shown in the upper right. The results of this regression are scalars slope \( s \) and intercept \( i \) such that:

\[ t = s * m + i \]

We then perform a linear least squares regression using the resulting vector in the form of a MODIS band 2 image of a region of the Ronne Ice Shelf located between the Korff Ice Rise and the Institute Ice Stream.

Step 4: Normalize the mean of each "double-scan" detector with respect to the mean of the entire image

We now start attempting to correct the horizontal striping that is likely to have resulted from detector number 38 (838 mod 40). For each of these detector (bands 1 and 2) we first compute the mean reflectance of each detector number and then divide the reflectance of the given detector by the mean reflectance of all detector numbers. Each of these double scans will consist of 80 "double-scan detectors." The reason for this is so that we can simultaneously correct for "cross-talk" and detector calibration errors as well as inter-dECTOR calibration errors.

Step 5: Perform row regressions to correct residual striping

We then store the result, "back into" the image, and we repeat this operation for each of the 80 double-scan detectors. This effectively normalizes the mean of each double scan detector with respect to the mean of the entire image. The result of this operation can be seen in the images on the right. Clearly the amplitude of the striping has been reduced substantially, but there is a broad striping pattern corresponding to each double scan.

Step 6: Perform band regressions to "undone" the striping

We then perform a final set of row regressions in order to minimize the striping remaining after the previous step. This step consists of 8 passes. In each pass, linear regressions are performed, one for each double-scan detector.

This entire step is performed by the MODIS Swath-to-Grid Toolbox (MS2GT) available at:

http://nsidc.org/data/modis/ms2gt/

Examination of the images on the lower right indicate that the "fourth pixel" artifact has indeed been corrected.

m(d) = (v(d) + v(d+1)) / 2

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