EO-1 Ice-Sheet Investigations
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A series of investigations has validated the utility of EO-1's Advanced Land Imager (ALI) and Hyperion sensors for optical imagery in glaciological applications. These instruments have been used to investigate several ice-sheet phenomena that could not be investigated successfully with other remote imaging sensors. ALI multispectral bands were used to discriminate between clouds and snow and to measure flowstripe relief on ice shelves. The ALI panchromatic band was used to detect sastrugi (snow dunes). Hyperion hyperspectral capabilities were used to resolve and map snow grain size and determine albedo for ice sheets. Hyperion images of the Greenland ice sheet were also used to characterize errors in Hyperion's visible and near infrared (VNIR) and shortwave infrared (SWIR) detector arrays.

Cloud-Snow Discrimination

Discrimination between clouds and snow has been a problem with satellite optical imagery ever since the technology was first introduced because clouds and snow are both very bright and have similar spectral signatures. The problem is most acute over ice sheets where the surface provides little texture. ALI data were used to develop a methodology called "shadow matching" that can discriminate between clouds and snow. Shadow matching, which is available for any sensor with high enough resolution, detects a cloud's shadow, which appears darker than the cloud it borders. Areas of snow, although similar in brightness to clouds, do not have shadows. Other dark images, such as rocks, do not have shadows. Figure 1 depicts this methodology.

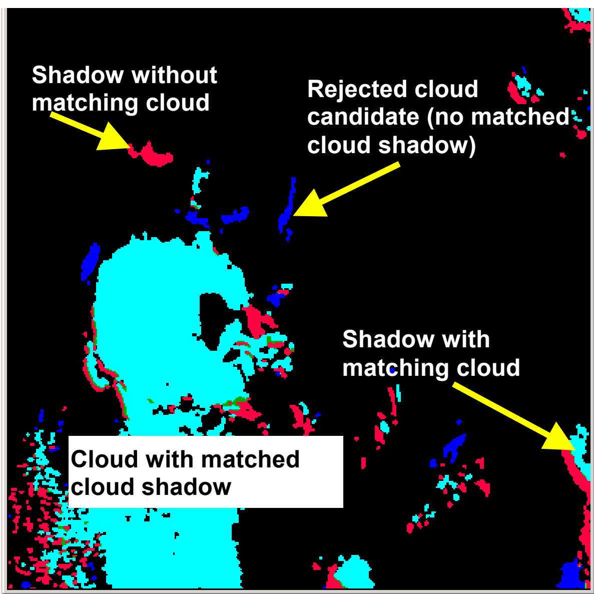


Figure 1. Cloud detection using shadow matching.

Flowstripe analysis
Flowstripes are topographic ridges generated by ice flow. The topographic relaxation of the flowstripes depends on its deformation and flow and is related to the length of time since the ice went afloat. The shape and trajectory of flowstripes offer clues to ice flow history. Photoclinometry applied to ALI images provides quantitative measurement of flowstripe relief (Figure 2).

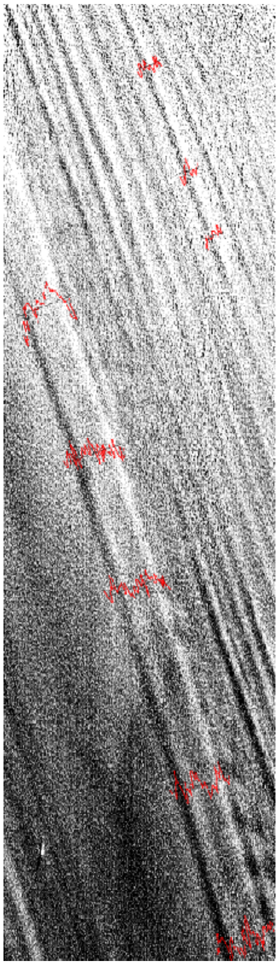


Figure 2. ALI flowstripe image. Profiles, shown in red, indicate brightness variations across the flowstripes.

This study analyzed flowstripes from the Amery Ice Shelf in Antarctica using ALI-derived measurements. When compared to similar data obtained through Landsat's Enhanced Thematic Mapper (ETM+) sensor, ALI permitted better discrimination of surface features that allowed for improved flow interpretation and velocity determination. This was due to ALI's improved radiometric resolution, which is approximately an order of magnitude better than that of ETM+.

Sastrugi Detection and Tracking
The ALI panchromatic band's ability to detect and track sastrugi was a newly discovered capability. Tracking sastrugi, which are windblown snow dunes typically less than 10 meters across and 1 meter in height (Figure 3), is valuable because it could greatly expand satellite measurements of ice-sheet surface motion.

Figure 3. Sastrugi have an eerie beauty.

Tracking sastrugi requires that the sastrugi features, which are individually smaller than a pixel, produce unique patterns at a macro-pixel scale. It also requires that these patterns persist over "meaningful" time scales.

ALI's increased radiometric resolution provides a signal-to-noise ratio (SNR) sufficient to detect the unique patterns produced by sastrugi fields. The unique patterns that persist over time allow investigators to track the movement of the sastrugi. ETM+, on the other hand, has a poorer SNR, leaving the sensor unable to detect subtle patterns of reflectance variation and thus unable to track the movement of sastrugi fields.

Figure 4 below shows ALI images of sastrugi fields for February 20 and October 2, 2001. The majority of the region is covered with sastrugi adjacent to the crevassed margin of an Antarctic ice stream (upper left). The three images at the right show the cross-correlation results between the two ALI images using correlation chips of different sizes. The leftmost correlation image uses the smallest chip size and has poor results except for the crevassed ice stream margin. The middle correlation image uses a larger correlation chip size, resulting in better cross-correlation. The rightmost image uses the largest correlation chip size, and the increased number of bright pixels in this image indicates that it is possible to track sastrugi over many months.

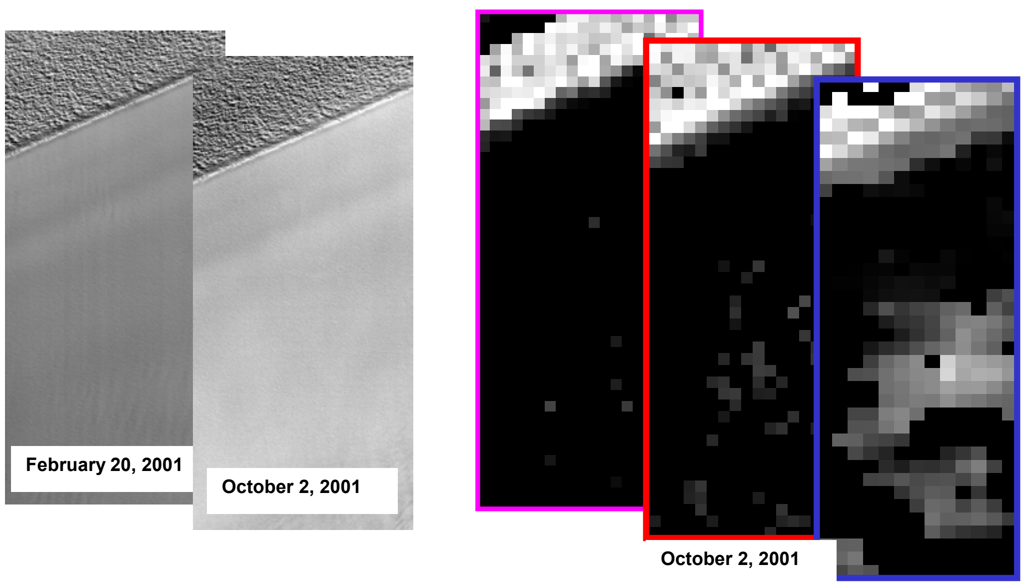
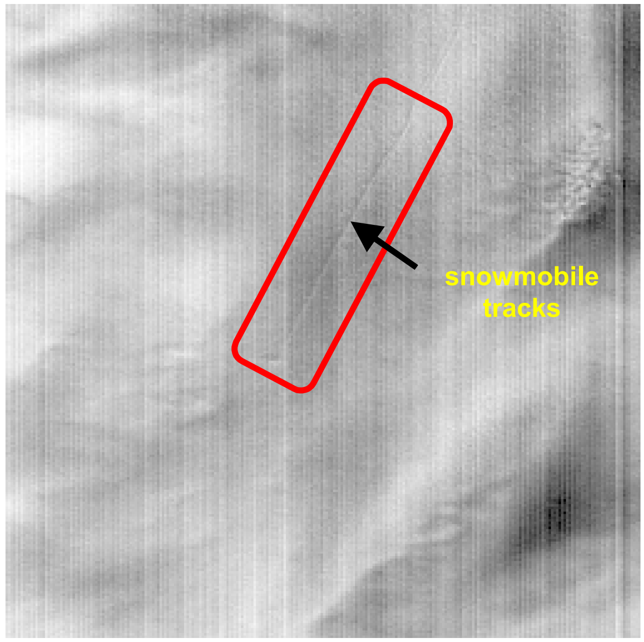


Figure 4. Sastrugi image cross-correlation with sub-image areas of varying-sizes.

Surface albedo calculations

The EO-1 Hyperion has been used to resolve and map variations in snow grain size over large regions of the East Antarctic Plateau. This contributes to improved calculations of broadband surface albedo for ice sheets, an important component of surface energy balance. The Hyperion was also used to map snow grain size over Greenland and to compute spectral albedo using the ice absorption feature from the Hyperion image and the Radiative Transfer Model (Figure 5). This results in a more accurate determination of albedo (±2%) than previously available.

Figure 5. Hyperion image of Greenland, May 20, 2001.



Hyperion detector array errors

Investigators used Hyperion images of the Greenland ice sheet to characterize errors in the Hyperion VNIR and SWIR detector arrays. The homogeneous character of the ice sheet over time underscored the usefulness of ice sheets as targets for on-orbit sensor characterization. The ice sheet's uniformity and stability in terms of surface slope and surface reflectivity allowed spatial variations to legitimately be attributed to detector variability of the Hyperion instrument rather than to variations in the landscape.

The analysis of two images of an extremely homogeneous region, taken on July 7, 2001, and August 8, 2001, revealed variability of the Hyperion detector arrays across the swath direction, in the spectral dimension, and in the temporal dimension. This variability caused striping in the images. The striping could be almost completely removed by applying appropriate corrections to the specific scenes that were available from another image that was taken either very soon before or after the scene requiring correction. Figure 6 shows images of ice sheets derived from Hyperion data used to determine detector errors for three Hyperion bands.

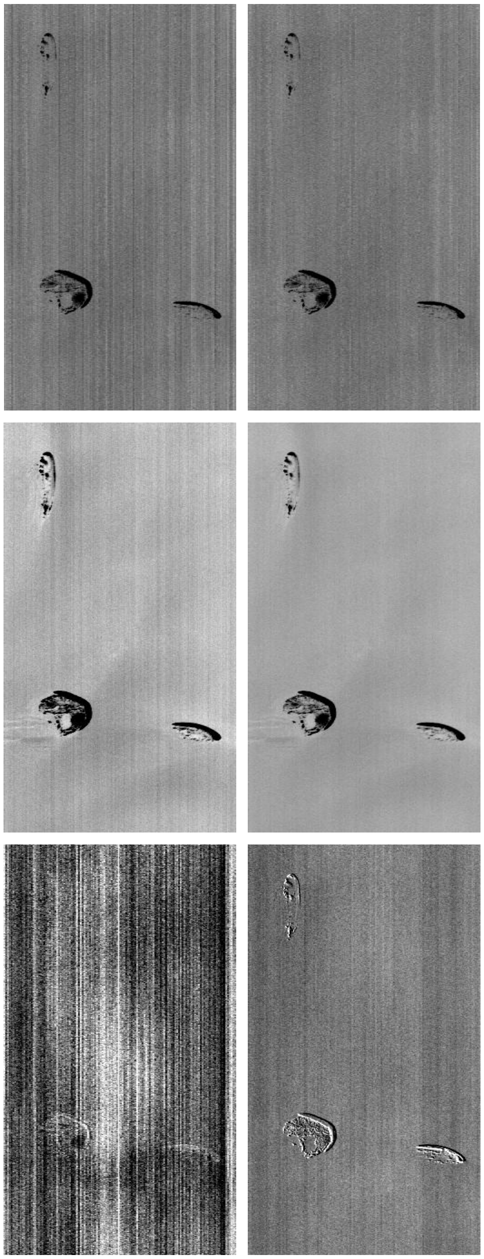


Figure 6. Correction of a short (526-line) portion of Hyperion data of the ice sheet near to the region used in the determination of detector errors. Band 80 (942.8 nm) is shown. The upper pair is the uncorrected (left) and corrected image (right); middle pair is MNF band 4; lower pair is MNF band 11.

Conclusions

The ALI and Hyperion sensors aboard the EO-1 have proven useful a variety of glaciological applications. These instruments have successfully investigated several ice-sheet phenomena that could not be examined effectively with other remote imaging sensors. ALI multispectral bands discriminated between clouds and snow and measured flowstripe relief on ice shelves. The ALI panchromatic band detected sastrugi. Hyperion hyperspectral capabilities resolved and mapped snow grain size and determined albedo for ice sheets. Hyperion images of the Greenland ice sheet characterized errors in Hyperion’s visible and near infrared (VNIR) and shortwave infrared (SWIR) detector arrays. Methods were devised to correct the errors.