LEISA/Atmospheric Corrector (LAC) Summary

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The LEISA (Linear Etalon Imaging Spectral Array) Atmospheric Corrector (LAC or AC) on Earth Observing-1 (EO-1) is a hyperspectral imager providing 256-channel continuous spectra in the wavelength range from 0.89 to 1.58 microns. It has a single pixel spatial resolution of 250 meters, a 185-km swath-width, and a spectral resolving power ($\lambda/\Delta\lambda$) of 150 or greater ($\Delta\lambda < 10$ nm) throughout its spectral range. The imager employs a state-of-the-art wedged infrared (IR) filter, (a linear variable etalon or LVE) placed very close to a two-dimensional IR detector array to produce a two-dimensional spatial image. The LVE is a wedged dielectric film etalon whose transmission wavelength varies along one dimension to provide its spectral resolution.

A problem common to all measurements obtained by high spatial resolution multispectral (MS) imagers aboard satellites is the systematic errors in the apparent surface reflectances caused by atmospheric effects. Temporal and spatial variability in atmospheric scattering and absorption due to aerosols, clouds and molecular species, primarily water vapor, must be accounted for in the retrieval of accurate surface properties. The research team has developed the high-spectral/moderate-spatial resolution wedged filter hyperspectral imager, the LAC, to correct high-spatial, low-spectral resolution MS imagery for atmospheric effects.

The filter has a nearly linear dependence of wavenumber on position. It has a 0.45-cm section that covers the 1.2 to 1.6-μm spectral region at a resolution of ~35 cm^{-1}, and a 0.55-cm section covering the 0.9 to 1.2-μm spectral range at a resolution of ~55 cm^{-1}. The sections are bonded together to form a single filter assembly. This filter represents an advance in dielectric thin film technology.

A two-dimensional spatial image is formed on the detector array by a small, wide field of view (WFOV) lens. The filter is mounted within 200 μm of the array, so the image is formed simultaneously on the array and the filter. The spectrum of each point of the area imaged is obtained as the orbital motion of the spacecraft scans the image of that area along the focal plane in the variable wavelength dimension. This creates a three-dimensional spectral cube. The spatial resolution is determined by the angular resolution of the imaging optic, the image scan speed, and the readout rate of the array. The LAC uses three identical subassemblies to match the Landsat 7 swath width of 185 km (~15°). Each subassembly consists of a focal plane formed of a wedged filter mounted to a 256 x 256 pixel indium gallium arsenide (InGaAs) detector array placed behind a lens covering a 5° x 5° FOV.

The LAC is composed of two modules, the optics module and the electronics module. The optics module contains the lenses, focal planes, and electronics necessary to operate the arrays and to transfer the digitized pixel data to the electronics module. The electronics module contains the command and data interface to the spacecraft, the array timing and bias circuitry, the thermal electric cooler (TEC) control circuitry and the instrument power supply.

Figure 1 shows the interior detail of the optics module. In normal operation, light comes from the right through the triplet lens and is imaged onto the focal planes at the left. The cylinder directly above the focal plane is a stray light baffle. The baffles in the solar calibrators are evident, as is the spectralon reflector.

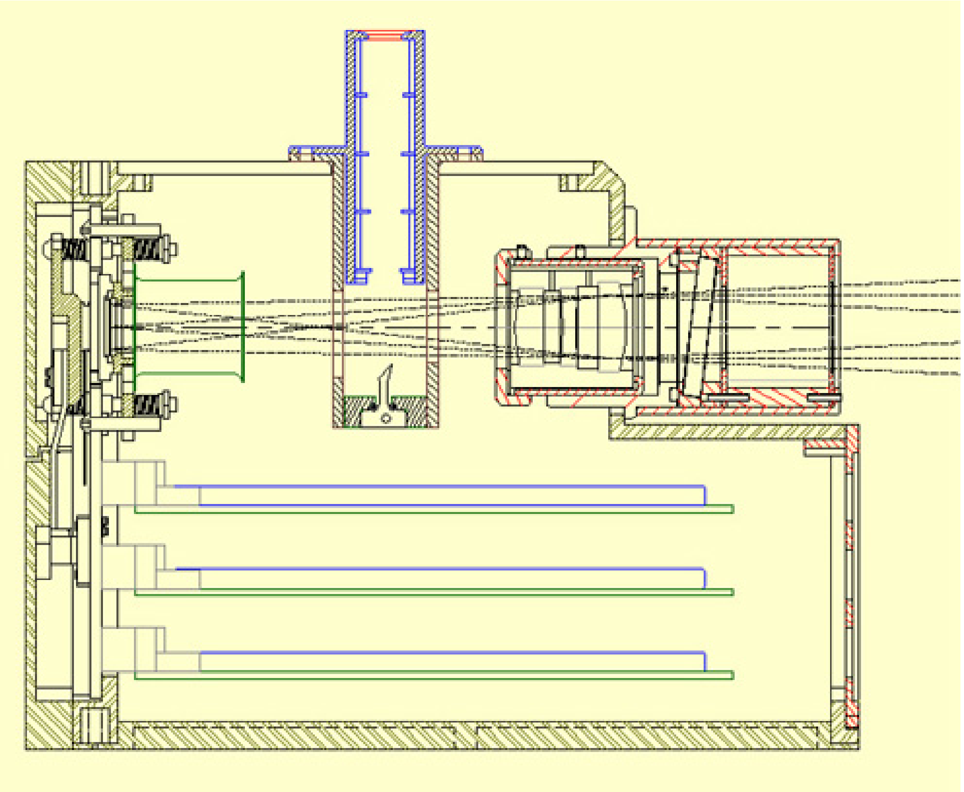

Figure 1. Optics module details. The array/LVE assembly is to the left while light from the scene enters to the right through an anti-reflective triplet lens. The spectralon target for the solar calibrations is at a 45° angle. The target is sized to approximate a 30% reflectance surface at 60° solar angle. The tilted element before the lens is a visible/ultraviolet reflector.

The LAC has a total mass of 10.5 kg: 4.4 kg for the electronics module, 3.9 kg for the optics module, and 2.2 kg for the cable connecting them. It uses a maximum power of 45 W on start-up, which decreases to about 35 W for a TEC temperature setting of 275 K once the temperature is stabilized. At the nominal fame rate of 28 Hz, which slightly oversamples the spatial dimension in the along-track dimension, the data rate is 95 Mbits/s (12-bit analog-to-digital (A/D) converters are used). A frame rate of 56 Hz allows double sampling in the along-track spatial dimension at the expense of reduced single-frame signal-to-noise ratios (SNRs).

The primary purpose of the LAC on EO-1, from an orbiting technology validation standpoint, is fourfold: 1) to validate the use of the wedged filter method for obtaining hyperspectral images, 2) to validate the use of a multi-array, multi-telescope system to synthesize a wide-field imager, 3) to validate the use of non-cryogenic InGaAs IR arrays for moderate resolution spectroscopy and, 4) to validate the use of lunar and solar measurements (in conjunction with ground-based measurement campaigns) to provide calibration. The science validation is to provide a demonstration of the ability of moderate resolution hyperspectral measurements to provide real-time atmospheric correction information to high spatial resolution multispectral sounders.

Prior to launch, the operational characteristics of the LAC, including dark current, read noise, radiometric sensitivity, central wavelength, bandwidth, and angular position, were measured for each pixel. For the most part, the characteristics measured prior to launch have not changed with two exceptions: the number of nonresponsive pixels has increased since launch, and a systematic noise source not apparent in pre-launch tests, and therefore presumably occurring after launch, has modified the radiometric calibration.

On-orbit validation includes: 1) determining the stability of the arrays under conditions of no illumination, 2) determining the instrumental noise characteristics under conditions of illumination, 3) determining the image quality, 4) determining the absolute radiometric calibration accuracy, 5) assessing the ability to obtain spectra, and 6) co-locating LAC images with Landsat 7 images. A typical on-orbit data collection event (DCE) lasts about 40 seconds during which ~1100 frames are obtained at the 28-Hz frame rate (2200 at 56 Hz) and produces a complete spectral image over an area of ~210 km x 185 km.

The limit on the SNR under most illumination conditions is determined by the Poisson distributed statistical variance of the photon flux from the source. The solar calibration DCEs are used to evaluate this limit for the LAC. The standard deviation of each pixel is measured over the 200 frames obtained during the calibration and the ratio of this to the average signal is used to determine the SNR. Figure 2 shows a wavelength dependent summary of the SNR obtained in this fashion. However, a systematic noise source that apparently occurred after launch limits the actual SNR to values lower than shown in Figure 2.

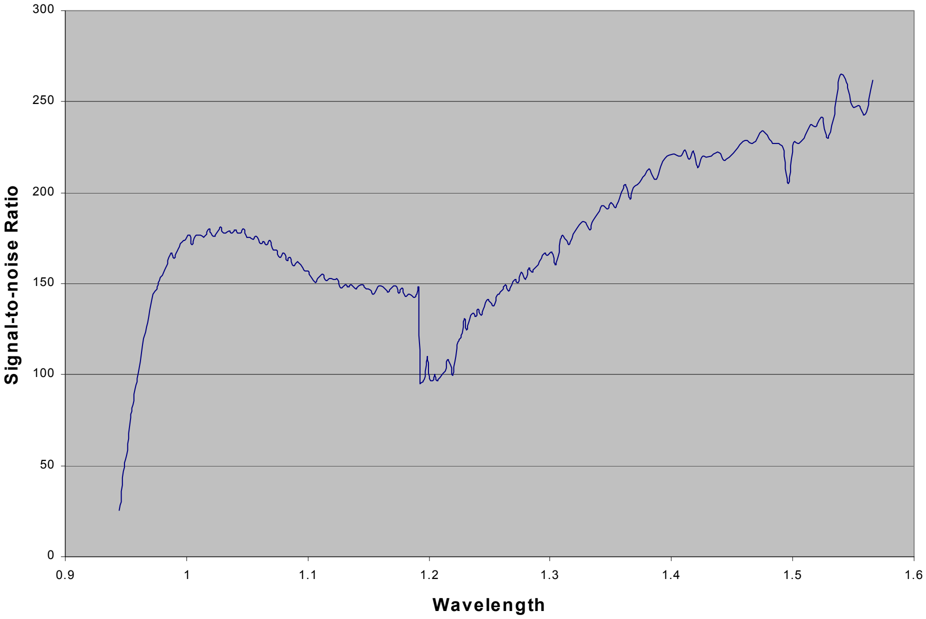

Figure 2. SNR ratio as a function of wavelength determined from a sole calibration DCE in the method described in the text. The rapid drop-off at wavelengths shorter than 0.97 µm is caused by loss of quantum efficiency in the InGaAs arrays.

Prior to launch, the image quality was checked by imaging a simulated source at infinity onto a single pixel. The on-orbit terrestrial surface images indicate that the focus has remained good after launch. As a further test, images of the moon obtained during the lunar calibration scans have been used to determine the rise distance of a sharp boundary. The results show a rise from 5% illumination to 95% illumination in approximately 1 pixel, again indicating excellent focus and image quality.

The ability to create spectra is illustrated in Figure 3, which shows two spectra obtained in regions near the Suez Canal. The differing water vapor absorption is clearly visible here.

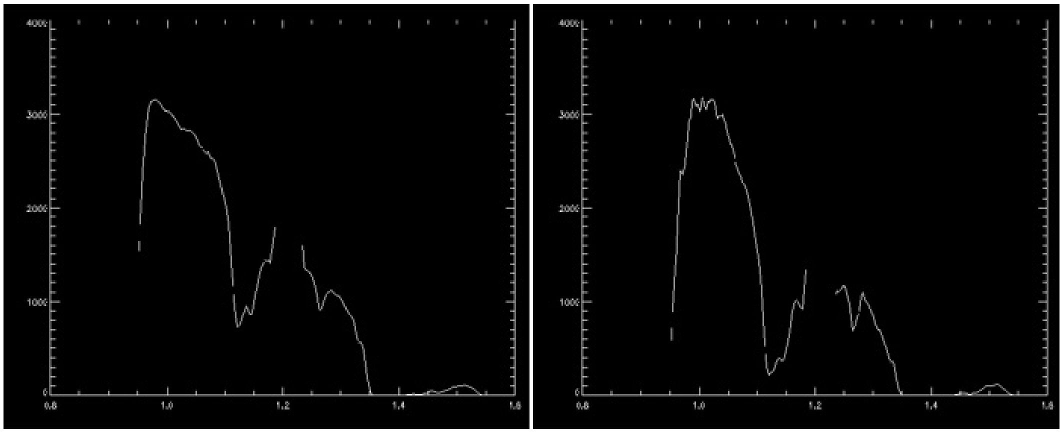

Figure 3. Two spectra obtained in different regions near the Suez Canal. Note the much deeper absorption at 1.13 μm in the right panel, indicative of greater atmospheric water vapor.

As part of the data processing, single wavelength LAC spectral images are placed on a latitude-longitude grid for comparison with Landsat 7 multispectral data. As shown in Figure 4, this process produces accurately positioned maps, further verifying the pre-launch angular measurements. The potential utility of the LAC for correcting Landsat 7 data is illustrated here, since the real-time atmospheric features are the same in both data sets.

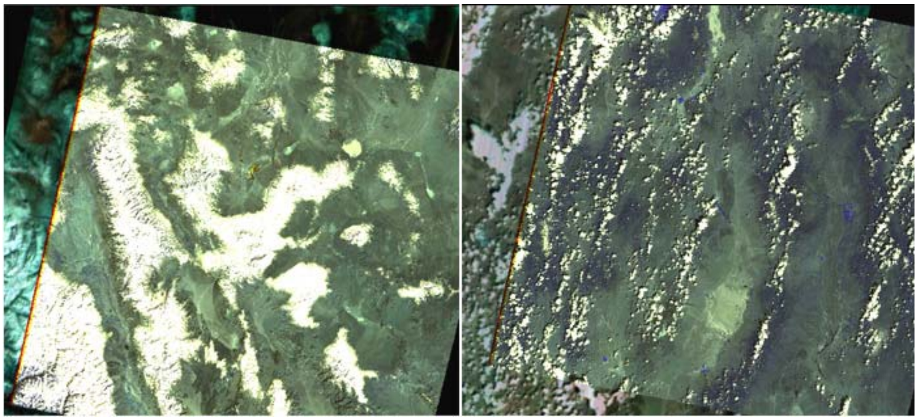

Figure 4. Overlay of Landsat 7 image on LAC image taken within 1 minute. Railroad Valley, Nevada (left) and Cuprite, California, (right) are used as calibration areas for these instruments. The features in the images are well correlated.

The LAC on EO-1 has successfully demonstrated a wedged filter hyperspectral imager on a space-based platform. This technology is highly desirable because of its inherent mechanical, electrical, and optical simplicity, its low mass, and its robust nature because of the total avoidance of moving parts. The wedged filter system may be used for any application requiring low to moderate spatial resolution hyperspectral imaging data, except for those with a rapid temporal variation (i.e., variability on a time scale shorter than that required to scan the spectrum).