Surface Reflectance Mapping Using Interferometric Spectral Imagery from a Remotely Piloted Aircraft

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BACKGROUND

During October 1997, NASA's Environmental Research Aircraft & Sensor Technology (ERAST) Program conducted flight tests of the Pathfinder Remotely Piloted Aircraft (RPA) out of the Pacific Missile Range Facility (PMRF), Kauai (Hawaii). The Pathfinder was a light-weight (≈500 lb), solar-powered RPA with an extremely limited (≈35 lb.) sensor payload capacity. One of the ERAST objectives was to evaluate the feasibility of using such RPA platforms to collect remotely sensed data in support of earth systems science. A key aspect of this objective was to make simultaneous spectral measurements of a common target using an airborne spectral imager and a ground-based spectrometer. Intercomparison of these results, together with modeling of atmospheric radiative effects, enable the establishment of ground-truth and the verification of the spectral imager's radiometric calibration. The outcome of this calibration exercise is a procedure for deriving the surface albedo for a variety of different regions of the overall scene containing the ground-truth target.

A Digital Array Scanned Interferometer (DASI) hyperspectral imager [1] jointly developed by NASA Ames Research Center and and Washington University was selected as the imaging spectrometer payload. Compactness, light weight, low power draw, rugged design and simplicity of operation made the DASI an ideal candidate for this mission. Observations using DASI were made over selected sites on the island of Kauai. The ground-truth exercise was done over the apron pavements PMRF.

SENSOR DESCRIPTION

DASI instruments achieve spectral discrimination using two-beam interference rather dispersion. This characteristic of DASIs sets them apart from conventional imaging spectrometers. The DASI's suitability for this mission as described above stem directly from this characteristic. The DASI developed for this mission acquired data in a "push-broom" mode, with a spectral range of 0.45 to 0.80 μm, a spectral resolution of about 250 cm^{-1} (10 nm at 0.65 μm) giving about 40 effective contiguous channels, and a cross-track full field-of-view of 11 deg with 240 spatial elements. The surface spatial resolution achieved was typically 5 m. Table I describes the DASI's characteristics.

EXPERIMENT DESCRIPTION

During the Pathfinder flight of Oct. 24, 1997, a DASI image cube was acquired over PMRF (22 deg 002' N, 159 deg 057' W) beginning 13:20 local time at an altitude of ≈25 kft. These flight conditions resulted in a spatial image range of 1.3 km cross track and 2 km along track. A spectrally averaged roll corrected view of this image is shown in Fig. 1. Designated regions of this image, were chosen for obtaining spatially averaged spectra. A large, spectrally flat concrete runway apron (regions 1, 2 and 3 of Fig. 1) had been selected as the target for our ground-truth and intercomparison study.

A Spectron SE590 spectroradiometer (Spectron Engineering, Denver, CO, USA) was used to measure surface reflectance of the apron located near region 1 of Fig. 1. The radiometer was mounted downward-looking on a boom-equipped tripod (Fig. 2), and was configured to view a spot size on the ground of ≈45 cm diameter. 71 spectral measurement sets were made during the period 12:19-13:37 local time, a period coinciding with airborne image acquisition. Sparse sampling over a surface area of about 1100 m^2 was achieved. Measurements were made of a level horizontal spectralon calibration panel approximately every ten minutes. Solar elevation above horizon ranged from 51-56 deg during the measurement period, with solar noon occurring at 12:25. Solar azimuth varied from 178-210 deg. The measurements were subsequently reduced to reflectances. All 71 measurements were averaged to estimate target mean reflectance and standard deviation (Fig. 3).

Radiosonde data from a station close to PMRF acquired at about the time of the DASI overflight served as input data for the atmospheric model, based on MODTRAN [2] with customized atmospheric parameter inputs.

ANALYSIS AND RESULTS

The data reduction process for DASI data involves treating systematic instrumental effects, obtaining spectra by Fourier transformation of the interferograms, and applying the results of laboratory measurements to obtain spatially, spectrally, and radiometrically calibrated spectral images in units of at-sensor radiance [3]. During the PMRF measurement, two unexpected circumstances occurred that required altering the original protocol established for the intercomparison study: 1) the remotely adjustable entrance slit of the DASI malfunctioned resulting in an overall multiplicative uncertainty of about a factor of two in the radiometric calibration, and 2) the onset of detector saturation occurred at the regions of the DASI image where the apron was located.

To overcome these problems, the following approach was taken: 1) a calibration method for treating the non-linear detector response at saturation onset was devised. The resulting treated interferograms had substantially reduced systematic error. 2) the ground albedo measurement together with the atmospheric model were used to derive an at-sensor radiance that was used as an in-flight radiometric calibration standard for the DASI. Fig. 4 shows the resulting comparison of DASI vs derived at-sensor radiance spectra, after a multiplying constant was applied to the original DASI radiance values. 3) This in-flight calibration was carried over to other regions of this scene to derive ground albedo spectra for all the designated regions. The numerical process involved developing a look-up table based on the model to transform corrected at-sensor DASI radiance values to surface albedo values. The resulting spectra are shown in Fig. 5.

The fine scale differences between regions 1, 2, and 3 evident in Fig. 5a are primarily attributable to the saturation onset effects described above. As a consequence, only a limited assessment of the atmospheric model effectiveness can be made from Fig. 4. The discrepancies between the curves of Fig. 4 between 13500 and 19500 cm^{-1} can be explained by these effects. Outside this spectral region, diminishing sensor response is the main cause of degradation. Regions 7 and 9 are better indicators of the atmospheric model effectiveness: these spectrally flat, low-albedo spectra reveal very little residuals for those atmospheric features annotated in Fig. 4. It is unlikely that these surfaces might have spectral features that precisely cancel these residuals. Also, there is little evidence of such residuals in the regions having vegetation, all of which have no saturation effects. The spectral features of the later regions are consistent with typical reflectance spectra of vegetation found in the literature.

CONCLUSION

The assessment criteria used for the intercomparison study are 1) the accuracy of the overall radiometric calibration for the DASI, 2) the effectiveness of the atmospheric model in deriving accurate surface albedo spectra, and 3) the quality of the DASI spectra (i.e. signal-to-noise, and magnitude of artifacts). Because of the instrument slit malfunction described above, assessment of absolute radiometric calibration was not possible. However, all indications are that the atmospheric model was successful for deriving surface albedo spectra under non-saturated, linear detector conditions. Overall the DASI sensor performed well under these circumstances. The regions having vegetation reveal spectral features that are consistent with typical reflectance spectra of vegetation.

ACKNOWLEDGMENTS

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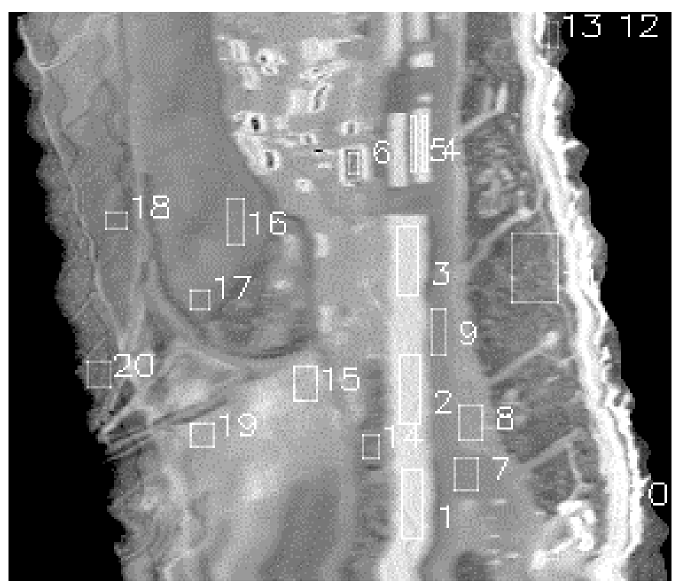

Fig. 1 - Spectral averaged image obtained by the DASI sensor flying aboard the ERAST Pathfinder over PMRF at Kauai on Oct. 24, 1997. Designated regions are marked by overlayed numbered boxes.

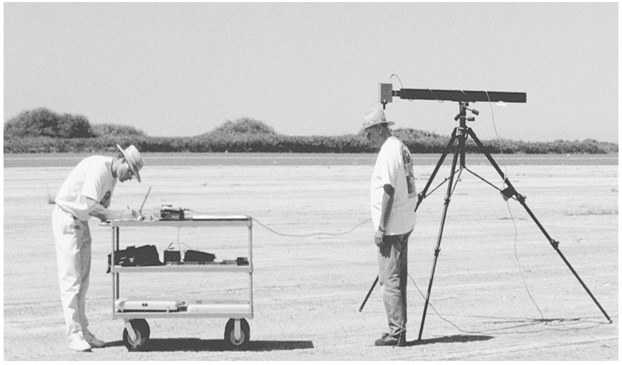

Fig. 2 - Photograph of ground crew during the measurement of surface albedos. This site is close to region 1 of Fig. 1.

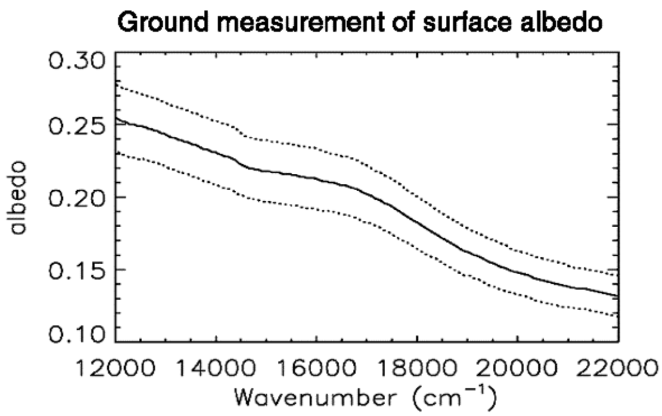

Fig. 3 - Results of surface albedo measurement of designated region 1 in Fig. 1. The standard measurement error (dotted curves) is shown about the mean value (solid curve).

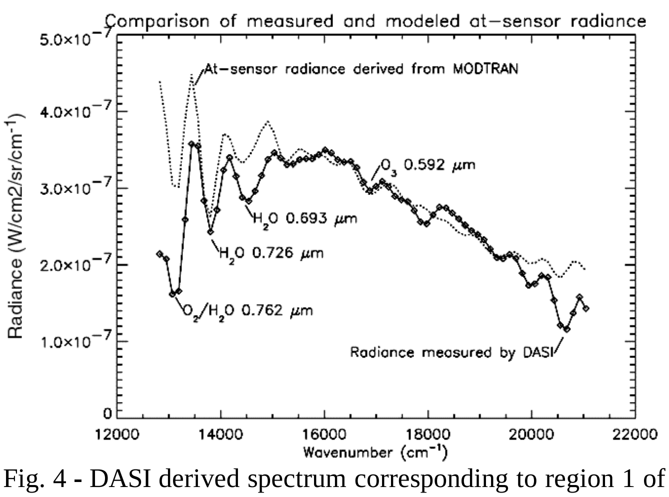

Fig. 4 - DASI derived spectrum corresponding to region 1 of Fig. 1 (solid curve with symbols) together with a modeled spectrum derived from MODTRAN and the surface albedo measurement of Fig. 3 (dashed line).

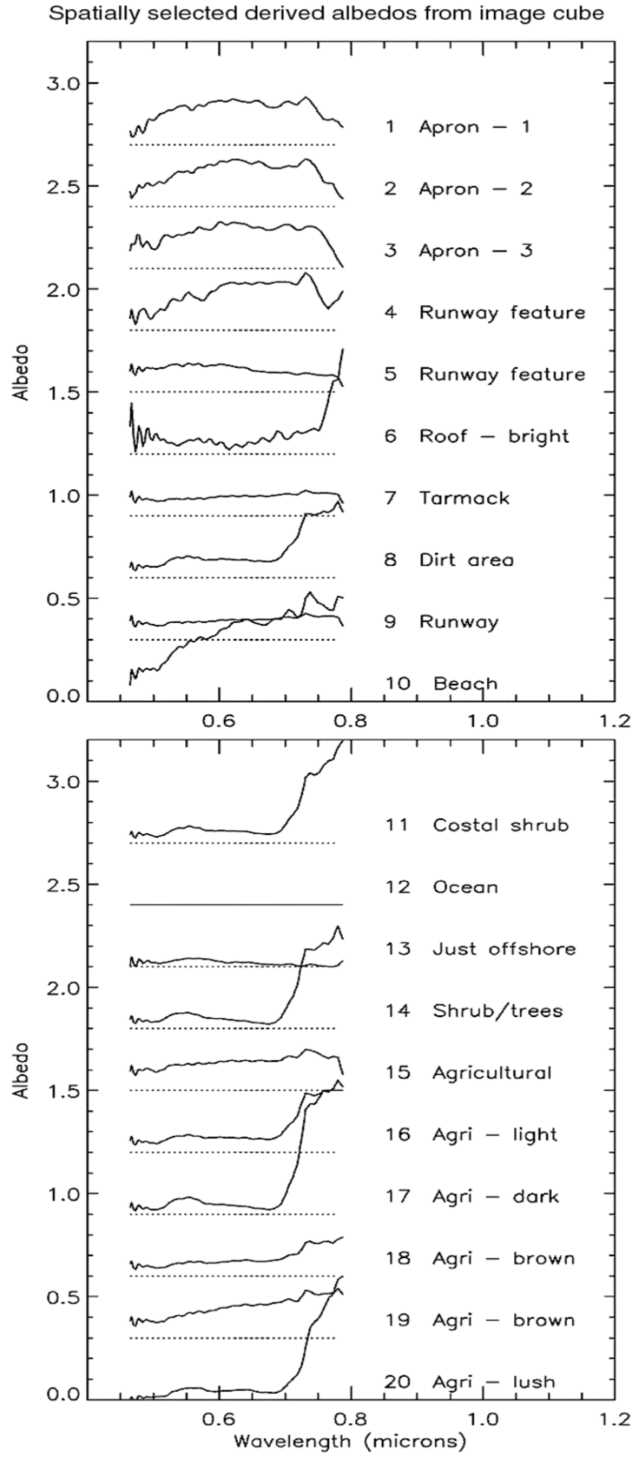

Fig. 5 - Surface albedo spectra derived from DASI measurements for each of the designated regions of Fig. 1. The dotted lines indicate the albedo scale origin for each region. Identification was aided by color aerial photographs of the scene. Regions 11, 14, 16, 17, and 20 reveal the vegetation red-edge feature caused by chlorophyll. The spectra of regions 6 and 10 are badly distorted due to detection saturation.