In-situ polarization measurements for the Orbiting Carbon Observatory (OCO)

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The Jet Propulsion Laboratory (JPL) is developing the Orbiting Carbon Observatory (OCO), a polarization-sensitive sensor that will soon be launched. Calibration and validation for this instrument require the ability to account for polarization properties of various surfaces and atmospheres. In order to validate the OCO assumptions, it is necessary to have instrumentation that can measure atmospheric and surface properties. This paper evaluates several instruments that were on hand. Although these instruments were found to be lacking, this study has allowed us to define requirements for future instruments.

Background

JPL is building two space based sensors with polarization sensitivity: MSPI and OCO. A validation capability would benefit both of these programs.

1. Multiangle SpectroPolarimetric Imager (MSPI)

Multi-angle sensing: A Multi-angle Imaging SpectroRadiometer (MISR) is currently on-board NASA's Terra satellite. MISR has been in orbit since 1999 and generates images of the Earth at a 275 m resolution from nine different along-track view zenith angles (0º, 26º, 46º, 60º, and 70º fore and aft of nadir) in four spectral bands (446, 558, 672, 866 nm). Multi-Angle Observations allow for unique capabilities, unattainable by single-angle, typically nadir-viewing, imagers [1].

Multi-angle observations provide enhanced sensitivity to thin aerosols, including those over bright land. MISR is able to detect interferences from objects such as dust clouds or thin smoke. Detection of the same cloud from different angles even allows 3-D imaging of the aerosol plumes (Figure 1) [1].

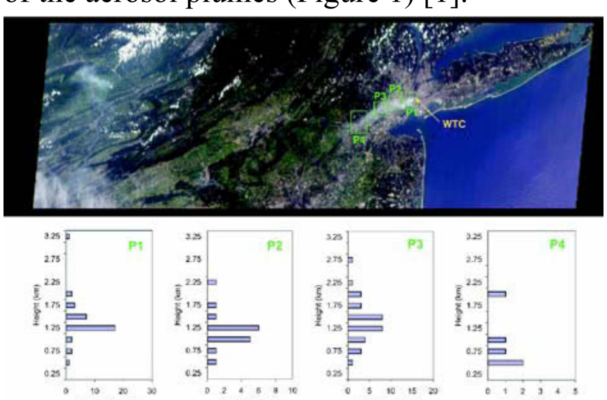

Figure 1: MISR analysis of the World Trade Center smoke plume on September 12, 2001.

Top: MISR image displaying the smoke plume prominently.

Bottom: Histograms of height generated using MISR data, for the four marked patches.

However, MSIR does not have Polarization Sensing capabilities. A polarization sensor would offer a new dimension to detection. Sometimes, items such as man-made materials are difficult to distinguish using multi-angle measurements; old MSIR data. A polarization sensor would be able to detect interferences much more accurately and clearly. This instrument would also yield data that would improve accuracy in the sensitivity of detection of aerosols. The new instrument is currently being constructed and has been given the name Multiangle SpectroPolarimetric Imager (MSPI). An example of the type of picture we could generate with MSPI is given in Figure 2.

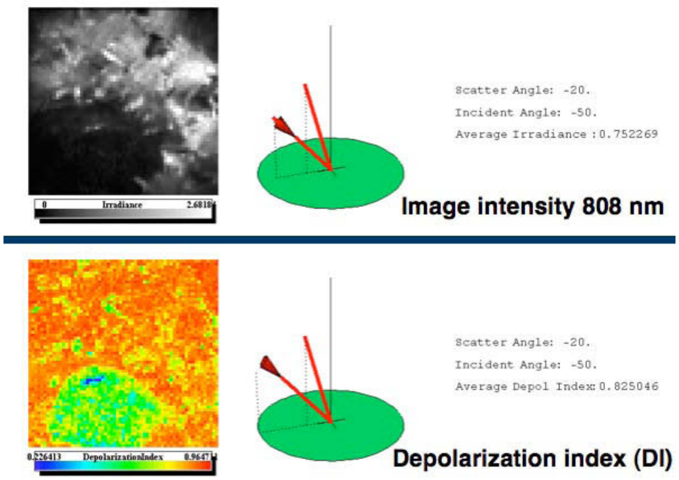

Figure 2:

Top: Intensity image of a piece of metal under a leafy shrub.

Bottom: Depolarization index image of the same scene.

2. Orbiting Carbon Observatory (OCO)

The Orbiting Carbon Observatory (OCO) is a current mission sponsored by NASA's Earth System Science Pathfinder (ESSP) Program. OCO is a dedicated spacecraft that will acquire extremely precise measurements of CO_2 in the atmosphere from space. The OCO polarimetric spectrometers will measure sunlight reflected off the Earth's surface. This sunlight will pass through the atmosphere twice – once on the way down to earth from the sun, and again on the way back up to the OCO instrument. Each time it passes through the atmosphere, different aerosols will absorb light different specific wavelengths. The OCO instrument will then display diminished energy values at the characteristic wavelengths and allow scientists to identify aerosols in the atmosphere.

This instrument will be able to take data in three different modes – Nadir Mode, Glint Mode, and Target Mode. In Nadir Mode, the instrument will observe the ground directly beneath the spacecraft. In Glint Mode, it will track near the location where the sunlight is reflected off the Earth's surface. Finally in Target Mode, the Observatory will view a specified location continuously as the satellite passes over it.

Objective

OCO will need to make some assumptions on the polarimetric properties of the atmosphere and surface, in order to meet its objective of CO_2 retrieval. In order to validate these assumptions, instrumentation that measure these in-situ properties are required. We will use a handheld instrument, Microtops II, to measure aerosols. Surface pressure, also measured by the Microtops II, is used to determine the amount of molecular scattering within the atmosphere. Finally, we evaluate the ability of the LSpec detectors, and the ASD instrument, to measure surface polarization. These inputs are used along with a radiative transfer code, VLIDORT, in order to predict the top-of-atmosphere radiance that will be incident on OCO.

Polarization Methodology

Linear Polarizers can split light into linear components. These components can then be converted into Stokes Parameters, a set of values that describe the polarization state of electromagnetic radiation such as light. By convention, 0 degree polarization angle corresponds to the horizontal component of light and 90 degree polarization corresponds to the vertical component. Consequently, the first 3 stokes parameters for light – I, Q, and U can be represented by $I = I^0 + I^{90}$, $Q = I^0 - I^{90}$, $U = I^{45} - I^{135}$ where I^x is the intensity of the component of light at a polarization angle of x. The degree of linear polarization can further be calculated with the formula

$$DOLP = \frac{\sqrt{Q^2 + U^2}}{I}$$

Different surfaces are expected to polarize reflected light to different extents. Our ground based systems will mount linear polarizers on existing surface reflectance sensors in order to determine the upwelling stokes parameters from assorted surfaces.

OCO Simulation

VLIDORT is a linearized pseudo-spherical vector discrete ordinate radiative transfer code that can model light traveling through the atmosphere. Given information about the atmosphere through devices such as Microtops II (see atmospheric measurements) and information about surfaces, VLIDORT is capable of generating stokes parameters for light with respect to any atmospheric or surface properties. This will allow us to compare ground measurements with top of the atmosphere OCO data.

Atmospheric Measurements

Figure 3: Microtops II

Atmospheric measurements were done with an instrument called Microtops II, customized to take data at specific wavelengths (Figure 3). The device was operated by aligning the device with the sun using the targeting device, and scanning the aerosol optical depth. This device was used in conjunction with a GPS device and provided

- Latitude, Longitude, and Altitude
- Pressure & Temperature
- Aerosol Optical Thickness (AOT) at 440, 675, 870, 936, 1020 nm

The Solar Zenith Angle could then be calculated from the coordinates and the time using ephemeris, a table of values with astronomical object positions. The AOT would then be used by VLIDORT in its calculations.

<u>Surface Measurements</u>

<u>1. LSPec</u>

One of the sensors we tried was the LSpec. The LSpec utilized 8 separate LEDs at different wavelengths and represented the incoming intensity in terms of mV. This device was then mounted on a goniometer which allowed us to view surfaces from many different angles. A linear polarizer was attached in front of the device and could be freely rotated to change the polarization angle. (See Figure 4)

Figure 4:

Top Left: Wavelengths of the LEDs

Top Right: Frontal View of the Polarizer and Sensor

Bottom Right: Side View of the LSpec

Bottom Left: Goniometer (without the LSpec mounted)

Many surfaces were tested with the LSpec and linear polarizer combination. However, upon reviewing the data, it was discovered that noise interfered with the data to the extent of invalidating the results. Two surfaces worth noting were Spectralon and the simulated desert surface. Spectralon was intended to represent our lambertian surface and expected to have a degree of linear polarization close to 0 (Figure 5, Left). The desert surface was expected to slightly polarize light to different extents depending on the view angle and solar zenith angle (Figure 5, Right). Unfortunately, based on the Spectralon surface, the amount of noise vastly surpassed our expectations, which compounded the fact that our sensor's field of view (approximately 30 degrees) was much too large to obtain highly reliable data.

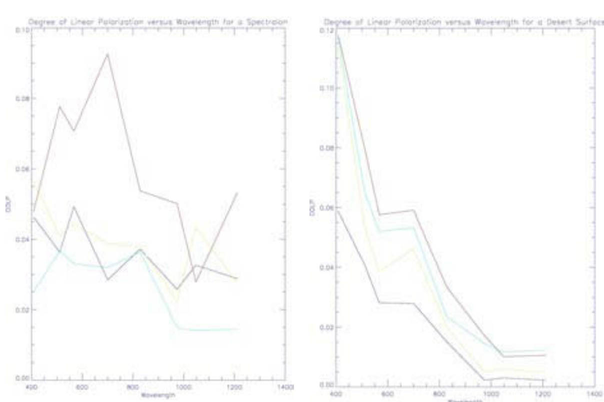

Figure 5:

Left: Polarized Surface reflectance for Spectralon

Right: Polarized Surface Reflectance for a desert surface

2. Field Spec Pro

We then mounted the same polarizer onto a Field Spec sensor. This device is an excellent field capable, surface reflectance sensor that has been tested and validated for non-polarization sensitive data (Figure 6).

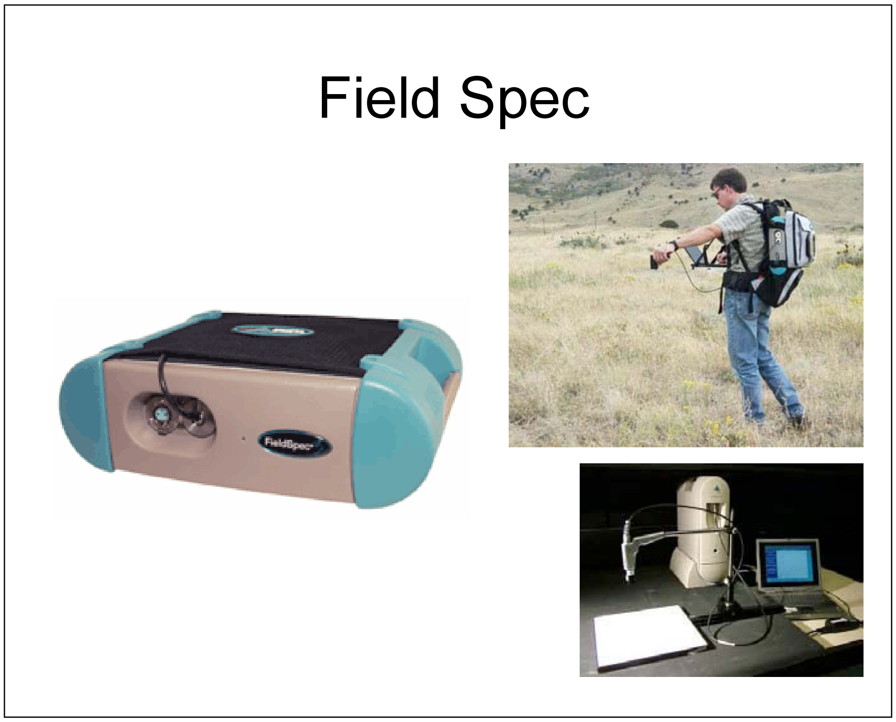

Figure 6:
Left: Side View of an actual Field Spec
Top Right: Field Spec in use in a field
Bottom Right: Field Spec in use in a lab

Using the Field Spec and polarizer combination, the field of view could be set to 1, 5, or 8 degrees and noise was significantly reduced when compared to the LSpec. The Field Spec operates with an optical fiber that transmits incoming light to the sensor. However, we discovered that no combination of polarizer or half wave plates could negate the fact that each time we moved the fiber, the data would change (Figure 7). The fiber makes this device extremely unreliable for our objective, as the extent to which the data could be changed exceeds the total expected polarization values for many surfaces and thus invalidates using this instrument for polarization sensitive data.

Beyond this, we attempted to clamp the optical fiber in place and obtain a set of polarization data for potential further studies. We noticed a significant sine wave appeared in the irradiance as the polarization sensor rotated 360 degrees that surprised us. (Figure 8) Any potential pattern we expected to occur with a 180 frequency due to the nature of polarization (for example the horizontal polarization angle occurs twice in a 360 degree sweep). We hypothesized that this might be because the optical fiber is circularly polarizing the light, but no conclusive tests on this idea have been run.

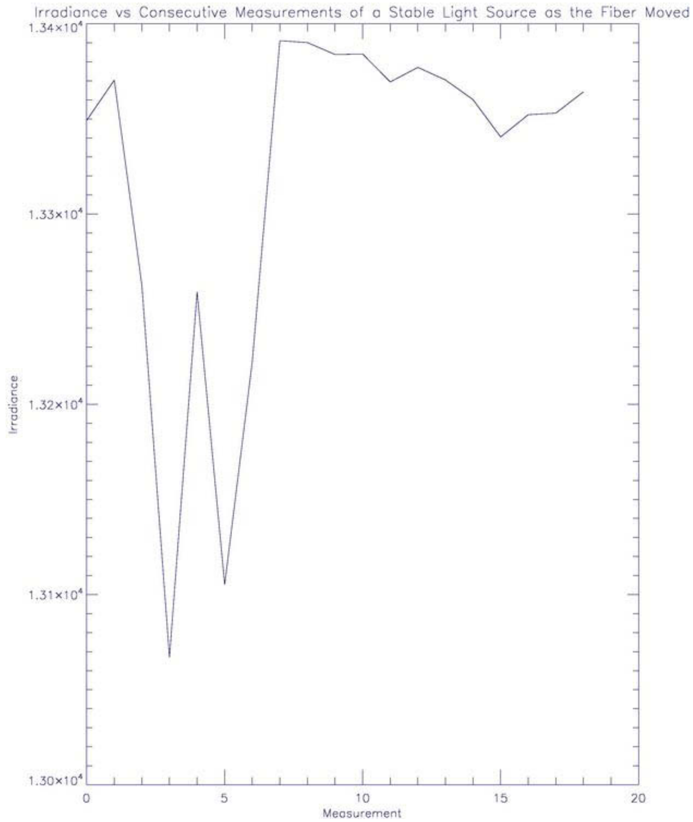

Figure 7:

Irradiances of a constant non-polarized light source as measured by a Field Spec with polarizer

The two early dips are where the testers are disturbing the wire

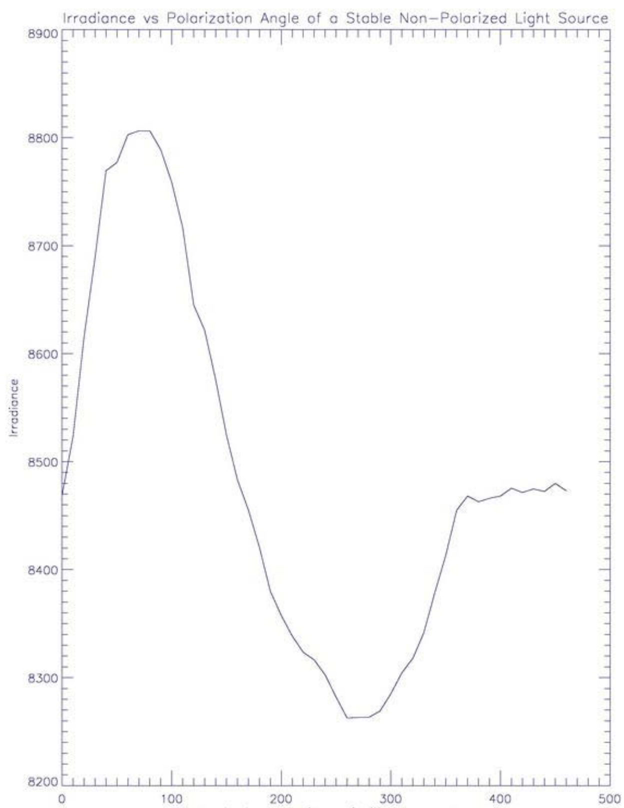

Figure 8:

Irradiances of a constant non-polarized light source as measured by a Field Spec with polarizer

The Sine wave occurs over a 360 degree period. The values from 370 to 460 are for a Polarization Angle of 0 and represent the effect of noise (control group)

Future Plans

We believe that it is necessary to continue exploring design plans for an in-situ polarization sensor for the space instrument MSPI. We have learned several key properties that our in-situ sensor requires in order to be successful.

Properties

- Narrow field of view
  - Preferably less than 5 degrees – 1 degree is ideal
- Signal-to-noise needs to exceed 200:1
- Sensor needs to be insensitive to polarization to 0.1%
  - A good method to determine polarization sensitivity of a sensor is to use the device to record data for a non-polarizing light source at various polarization angles – these values should be constant
- Range: needs to measure reflectance values between 0 and 1.5

The results of this project will assist in future attempts at in-situ polarization sensors and definitely warrants further study.

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