Novel airborne imaging polarimeter undergoes high-altitude flight testing

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Optical and signal processing technologies for high-accuracy polarimetric imaging, aimed at studying the impact of atmospheric haze and clouds on Earth's climate, have been demonstrated on checkout flights aboard NASA's ER-2 aircraft

Tiny particles floating in the air—haze and pollution layers, smoke and dust plumes, water and ice clouds—are major players in the Earth's climate system. Many of these particles efficiently reflect incoming sunlight back to space, cooling our planet. Others have a warming effect. The diversity of particle compositions, sizes and shapes, and high degree of spatial and temporal variability, make accurate determination of their global climate impacts a challenging task.

Remote sensing from orbiting satellites, in which measurements of the spectral, directional, and polarimetric character of reflected sunlight are used to derive information about particle properties, is the most effective means of rapidly covering large areas of the Earth. Current spaceborne aerosol sensors typically measure intensity at moderately high spatial resolution (< 1 kilometer) and polarization at coarser resolution (> 6 km). To study aerosol particle properties near cloud boundaries, climate scientists are interested in measuring both intensity and polarization at a spatial resolution of 1 kilometer or finer over a broad swath. To obtain particle properties such as refractive index and size distribution with high sensitivity, polarimetric imaging with an uncertainty of 0.5% or better in degree of linear polarization (DOLP) is required.

In collaboration with colleagues at the Jet Propulsion Laboratory (JPL) and the University of Arizona (UofA), we have developed a novel polarimetric imaging approach capable of meeting this observational challenge. We envision a future satellite instrument containing several polarimetric cameras pointed at different angles of view, which we call the Multiangle SpectroPolarimetric Imager (MSPI). An airborne prototype, known as AirMSPI, flies aboard NASA's high-altitude Earth Resources (ER)-2 aircraft. AirMSPI is a single polarimetric camera on a pointable gimbal. The camera includes spectral channels at 355, 380, 445, 470, 555, 660, 865, and 935 nm. Polarimetry at 470, 660, and 865 nm is provided by wire-grid polarizers at 0º and 45º orientation. Figure 1 shows example imagery acquired by AirMSPI during its maiden flight on October 7, 2010.

At the heart of the AirMSPI camera is a retardance modulator consisting of a pair of photoelastic modulators (PEMs) sandwiched between two achromatic, athermalized quarter wave plates. Each PEM consists of a fused silica element coupled to a quartz piezoelectric transducer (PZT). The PZT induces stress birefringence in the fused silica with a resonant oscillation frequency of about 40,000 cycles per second. In order to obtain a modulation frequency closer to the camera's frame rate (about 25 frames per second), tandem PEMs with slightly difference resonant frequencies are used, resulting in a beat modulation pattern. For each pixel in the focal plane detector array, this modulation encodes information about intensity I as well as one of the linear Stokes parameters (Q or U, depending on whether the array is overlain by a polarization analyzer at 0º or 45º, respectively). The key to obtaining high polarimetric accuracy is that the ratios Q/I and U/I detected in this manner are independent of optical transmittance or

detector gain. These relative measurements are then combined to produce DOLP.[1,2] We developed several technologies to implement this imaging approach, including high reflectance/low diattenuation mirror coatings,[3] fabrication methodologies for producing broadband quarter wave retarders[4] and integrated filter/polarizer assemblies,[2] and detector readout circuitry synchronized to the PEM oscillations.[2]

Processing of the sampled modulation patterns to generate the DOLP image in Figure 1 was implemented in ground data processing. AirMSPI contains sufficient on-board storage to record the required raw data. Because the large data volume would result in an impractically high downlink data rate for a future satellite instrument, we have also developed technology to process the modulated data on the fly in a field programmable gate array (FPGA).[5] High polarimetric performance requires accurate knowledge of the amplitude and phase of the PEM oscillations, so an optical probe consisting of a polarized light beam and a high speed detector was also developed to interrogate the PEMs during flight. These two technology upgrades have been recently implemented on AirMSPI and were tested successfully in flight aboard the ER-2 on August 31, 2011.

Besides providing technology demonstrations, these test flights have advanced AirMSPI's readiness for participation in scientific field campaigns focused on aerosols and clouds. As a next step on the pathway to space, a new airborne prototype that extends the spectral range into the shortwave infrared, AirMSPI-2, is currently in development.

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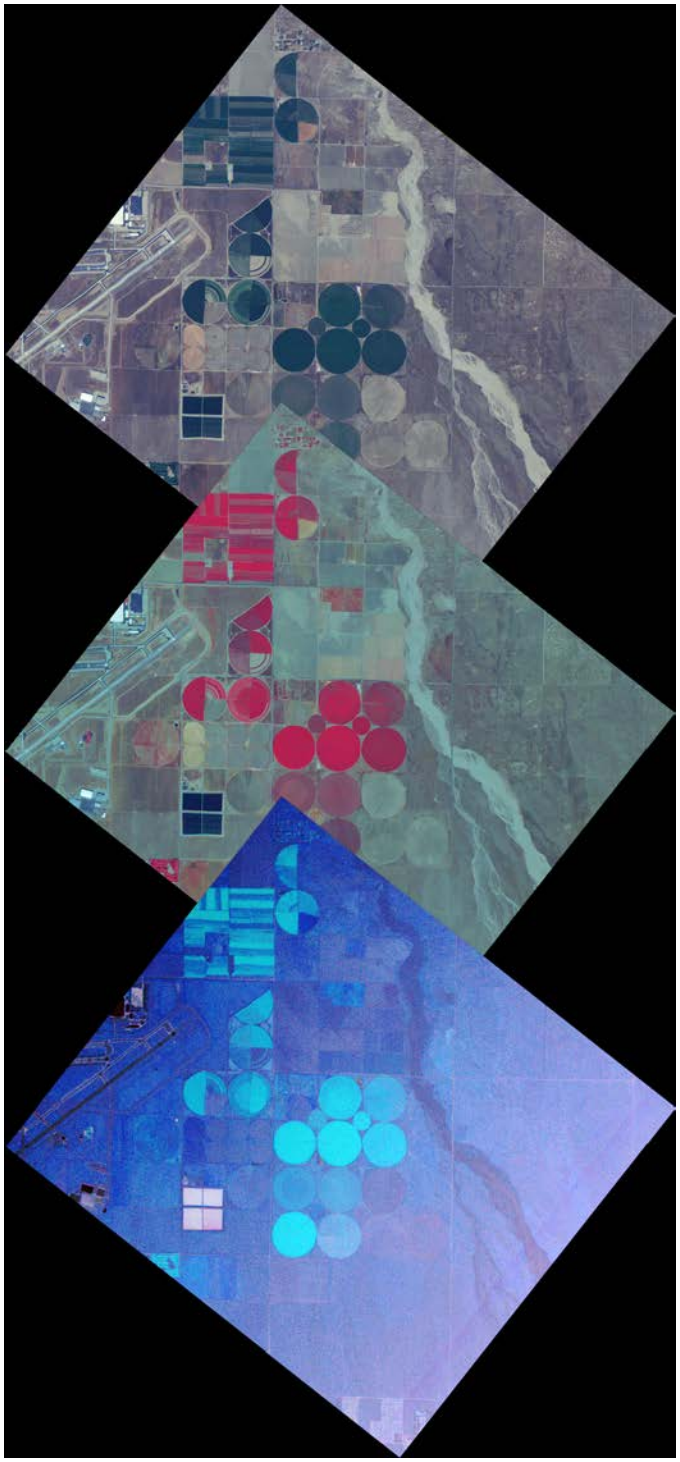

Figure 1. These AirMSPI images show views of Palmdale, CA acquired on October 7, 2010. The Palmdale Airport, where the ER-2 is based, is at left. The top image is a natural color view produced using intensity data at 445, 555, and 660 nm for the blue, green, and red display. The middle image shows intensity at 470, 660, and 865 nm; vegetated areas appear red due to the high reflectance of leaves in the near-infrared. The bottom image is DOLP at 470, 660, and 865 nm. The highly polarized square feature near lower left is a wastewater treatment facility.

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