Progress of the NASA Aerosol/Cloud/Ecosystems (ACE) Mission Polarimeter Working Group instrument inter-comparison

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The NASA Aerosol-Cloud-Ecosystem (ACE) mission is a US National Research Council Decadal Survey recommended mission that will contain an imaging polarimeter for remote sensing of aerosols and clouds. A variety of airborne polarimeter prototypes exist, so the ACE Polarimeter Working Group (ACEPWG) was formed to share information between groups and collectively work for improved measurement techniques, uncertainty characterization, and algorithm development. The initial focus has been on observations made during the Polarimeter Definition Experiment (PODEX), conducted in early 2013 in Southern California. Three ACE mission supported polarimeters were deployed on the high altitude ER-2 aircraft as it flew over a variety of targets. Two of those instruments to date have successfully produced Level 1 (geolocated radiance and polarization) data. Initial matched scene inter-comparisons found little radiometric, but significant polarimetric, bias. After improvement to geolocation in one instrument, and calibration in the other, polarimetric comparisons have improved significantly. We will describe these results, remaining unresolved issues, and future plans.

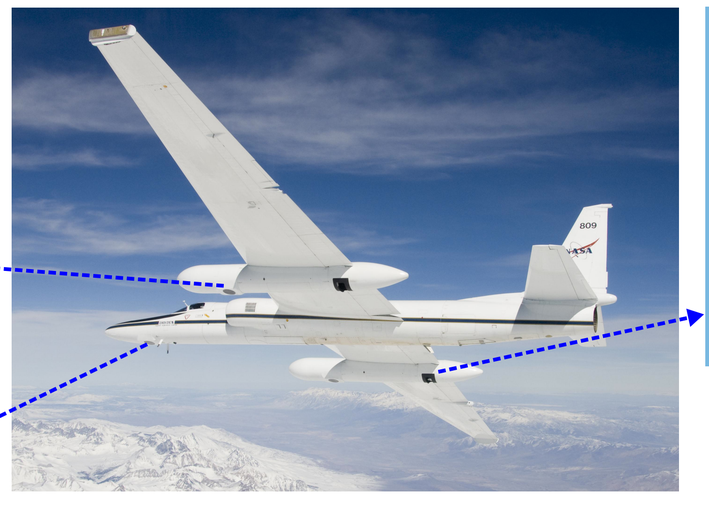
Dataset: PODEX (POlarimeter DEfinition EXperiment)

- **Ten NASA ER-2 flights** from NASA Armstrong, Palmdale, California.
- **Tested three** optical polarimeter instrument **airborne prototypes**.
  - **Instrument goals:** climate relevant properties of clouds, aerosols, ocean and land surfaces
  - **Heritage:** POLDER (CNES), APS-Glory (which failed during launch), MISR.
  - Airborne use informs development of future orbital instruments for ACE, PACE

First order question: do the instruments agree within uncertainty expectations?

Passive Aerosol and Cloud Suite (PACS): Imager that uses Philips prisms to split into polarized components. Principal Investigator is J. Vanderlei Martins, University of Maryland, Baltimore County.
Data are not yet availale for analysis

Airborne Multiangle SpectroPolarimetric Imager (AirMSPI): Pushbroom imager that uses a photoelastic modulator based technique. Principal Investigator is David J. Diner, Jet Propulsion Laboratory. See Diner et al. 2013a, 2013b.
Version 1, full dataset available, Version 2 (calibration updates) in progress
eosweb.larc.nasa.gov/project/airmspi/airmspi_table

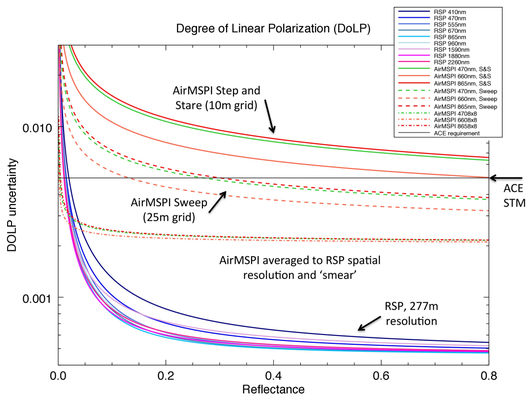


Research Scanning Polarimeter (RSP): Scanner that uses Wollaston prisms to split into polarized components. Was the airborne prototype for the Aerosol Polarimetry Sensor (APS) on the NASA Glory Mission. Principal Investigator is Brian Cairns, NASA Goddard Institute for Space Studies. See Cairns et al., 2003, Chowdhary et al, 2012 and Knobelspiesse et al., 2011.
Version 1, full dataset available, Version 2 (geolocation updates) available:
data.giss.nasa.gov/pub/rsp

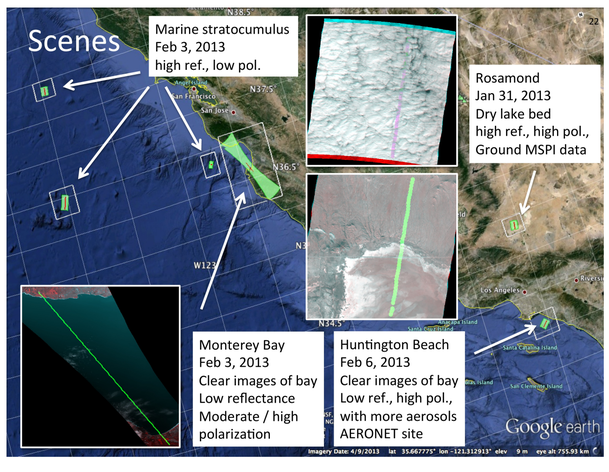
	Method	Imager?	Approximate polarimetric accuracy @reflectance=0.2	# view angles	Nadir ground resolution for ER-2 altitude	Channel center wavelength (nm): 355	380	410	445	470	550	555	660	670	766	865	870	935	960	1593	1880	2263	total # obs. per pixel
AirMSPI	Photoelastic modulation	Yes	1%: Step & Stare; 0.5%: sweep; 0.25%: averaged to RSP resolution	1 to 31	7m footprint, 9m along track 'smear'					1			2			3							up to 420
PACS	Philips prisms + linear polarizers	Yes	uncharacterized	Up to ~65	37m footprint, smear?																		up to 1170
RSP	Wollaston Prisms	No	0.075%	~152	277m footprint, 277m along track 'smear'					1				2		3							~4100

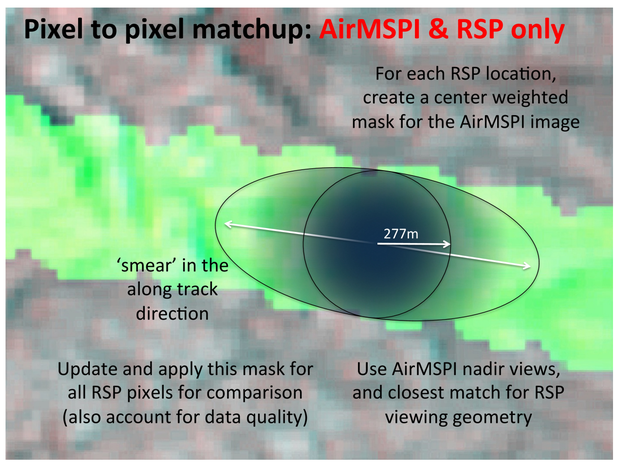
indicates no polarization sensitivty
1,2,3 indicates polarimetric comparison channels

Instrument uncertainties for Degree of Linear Polarization (DoLP, the ratio of linearly polarized to total light) are shown at right. AirMSPI has two targeting modes: "Step and Stare," (multiple captures of a specified ground area, gridded to 10m) and "Sweep" (continuous scanning, gridded to 25m). Because of the different spatial resolution scales, the contribution of random noise to uncertainty is different for each target mode. More uncertainty details can be found here: earthscience.arc.nasa.gov/sgg/ACEPWG/Uncertainty.html



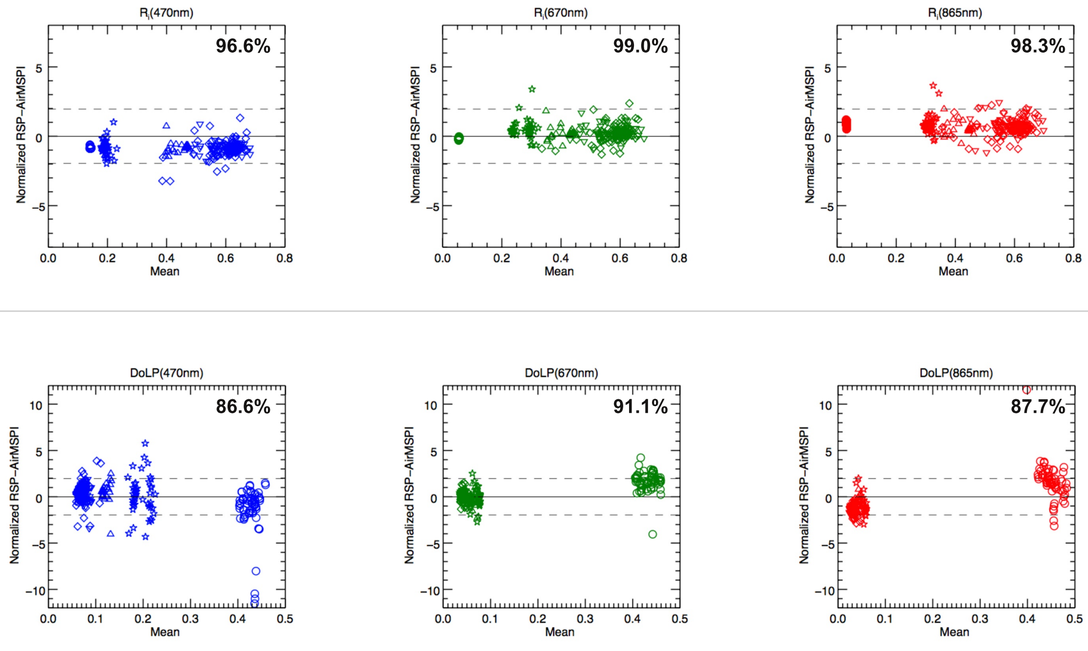
Comparison methodology & results





Seven PODEX scenes (above left) were chosen for intercomparison of AirMSPI and RSP reflectances and Degree of Linear Polarization (DoLP). Selections were made based on spatial homogeneity, high data quality, and variety of reflectance and DoLP values. Overall, more than 425 pixel-to-pixel matchups were performed, more details can be found here: earthscience.arc.nasa.gov/sgg/ACEPWG/Level1.html. The matchup procedure is described in the above right image, which is an AirMSPI image with an RSP ground track overlay in green. For the coordinates of each RSP pixel center, all AirMSPI pixels within a 277m radius were found. To account for staring time 'smear', this circle was stretched to be an ellipse in the along track direction. A center weighted version of this mask was used to determine the AirMSPI comparison data. Comparisons were made for nadir observations. Since RSP makes observations at more view angles than AirMSPI, the RSP data collected at the viewing angle closest to that of AirMSPI are selected for comparison. Finally, the uncertainty associated with each pixel and channel was determined with the analytical model for instrument uncertainty provided by each instrument PI (right-most figure in data section).

Matchups between AirMSPI and RSP are shown below. Biases between pairs of observations have been normalized by the sum of their one sigma uncertainties. If uncertainty is normally distributed and uncertainty estimates correct 95.4% of data normalized this way should fall within +/- 2. Actual percentages of matchups within this threshold are in the upper right of each figure. Reflectance machups are within the appropriate threshold, but this is not so for Degree of Linear Polarization (DoLP, ratio of linearly polarized to total reflectance). While the newly processed data is a dramatic improvement to the comparisons presented in the last AeroSAT workshop, problems remain.



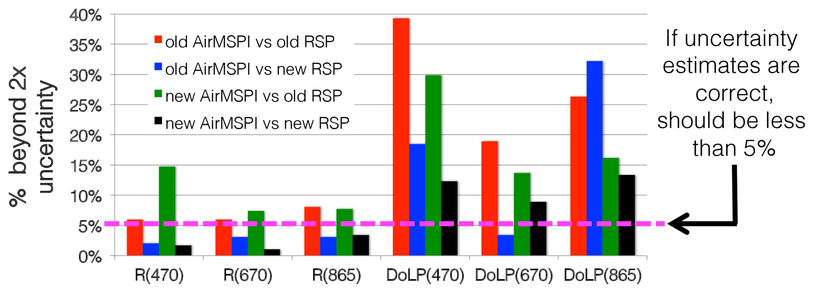
Conclusion & path forward

Level 1 instrument pixel to pixel intercomparison

- Only available for AirMSPI, RSP in 3 channels (470, 660/670, 865nm)
- Level 1 = calibrated, geolocated observables (Reflectance, R, Degree of Linear Polarization, DoLP)
- Previous results: Reflectances OK, Polarimetric comparisons larger than measurement uncertainty
- New RSP data has improvements to geolocation – available in version 2 data
- New AirMSPI data has improvements to calibration – but not yet publically available
- New comparison is better than before, but polarimetric biases are still too large
- Upcoming work: more scenes (currently pixel N~280), investigate view angle differences

Below: percentage of AirMSPI/RSP biases larger than 2x the joint uncertainty
For realistic uncertainty estimates, this should be less than 5%

Main message: polarimeters agree better than before, problems/work remains



Ongoing and upcoming activities

- Analysis so far has been for nadir or near nadir observations. Will be repeated for off nadir viewing angles.
- Add other scenes from PODEX, SEAC4RS and upcoming field campaigns (such as ORACLES).
- Polarimetric calibration intercomparison with respect to the JPL/University of Arizona Polarization State Generator (PSG). This is the AirMSPI reference.
- Construction/Inclusion of other polarimeters:
  - JPL team: AirMSPI-2, which has additional SWIR channels
  - UMBC team: HARP (cubesat), airHARP (cubesat instrument technique for use on aircraft), PACS-SWIR
  - SRON (new team!): SPEX-airborne, under construction and in the process of being integrated into the ER-2 aircraft.
- Regular (monthly) teleconferences of the ACE Polarimeter Working Group (ACEPWG)

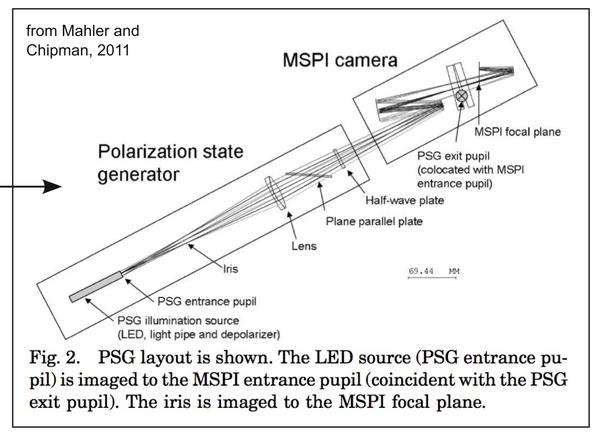


Fig. 2. PSG layout is shown. The LED source (PSG entrance pupil) is imaged to the MSPI entrance pupil (coincident with the PSG exit pupil). The iris is imaged to the MSPI focal plane.

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This work is ongoing, progress for the ACE mission Polarimetry Working Group (ACEPWG) can be found here:
earthscience.arc.nasa.gov/sgg/ACEPWG