Measurements of Polarized Light Scattering by Atmospheric Particles with the Passive Aerosol and Cloud Suite (PACS)

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PACS – Passive Aerosol and Cloud Suite:
In preparation for NASA ACE Mission

- Multi-Angle Imaging Polarimeters for Aircraft and Space
  - UV, Hyperangular VIS, SWIR
- High resolution cameras
  - TIR
  - VIS-SWIR
- Aircraft in situ validation
  - PI-Neph (Polarized Imaging Nephelometer)
  - Open-Ineph (Open Path System)
PI-Neph: Measuring In situ Aerosols P11 and P12 from Aircraft

See Dolgos et al. presentation coming soon…
Removing the enclosure present in typical nephelometers and imaging a laser that traverses the exterior of an aircraft permits the entire phase matrix $P(\theta)$ of ice crystals and aerosols to be measured in their natural state.
PACS ER-2 Facts

Current VNIR system
- Ground Resolution = 37m
- Swath = 37km
- 470, 550, 670, 766, 870nm
- 1 K pixel X-track
- 65+ angles for all wavelengths
- 130 view angles for 670nm
- 110° FOV cross track
- +/- 55° FOV along track

SWIR Under construction:
- 1650, 1880, 2130, 2250nm
- 320x256 pixels
- Adjustable FOV
- Mounted together with PACS VNIR
PACS Observing Geometry:

Hyper Angular Coverage
100+ angles possible

Wide Angular Swath $\pm 155^\circ$

$110^\circ$ FOV

$\pm 55^\circ$ along track

Multiple simultaneous push-broom systems
PACS Observing Geometry:

- Selectable Aerosol angles
- Wide Angular Swath $\pm 55^\circ$
- $110^\circ$ FOV
- $\pm 55^\circ$ along track
- Multiple simultaneous push-broom systems
PACS

Three Polarized Images

Single View Pushbroom

These clouds represent real images of convective clouds projected through the front of the PACS flight prism.
Demonstration of the PACS Prism:

3 Simultaneous Polarized Images at 0, 45 and 90°

Example of Cross track nadir image of a cloud field over land
Examples of PACS Data from PODEX
Hyperangular Capability
Provides Cloudbow from small area (~2x2km from space)
PACS Wide FOV Lens and Prism

Calibration Challenges???
PACS Calibration Strategy

Intensities are measured in each port from known Stokes vector inputs

\[
\begin{bmatrix}
I_{\text{Port } A} \\
I_{\text{Port } B} \\
I_{\text{Port } C}
\end{bmatrix} =
\begin{bmatrix}
A_{11} & A_{12} & A_{13} \\
B_{11} & B_{12} & B_{13} \\
C_{11} & C_{12} & C_{13}
\end{bmatrix}
\begin{bmatrix}
S_{0 \text{ input}} \\
S_{1 \text{ input}} \\
S_{2 \text{ input}}
\end{bmatrix}
\]

A characteristic Matrix is determined to represent the PACS Optics at different FOVs

\[
\begin{bmatrix}
S_{0 \text{ input}} \\
S_{1 \text{ input}} \\
S_{2 \text{ input}}
\end{bmatrix} = \begin{bmatrix}
\text{Inv } C \\
I_0 \\
I_{45}
\end{bmatrix}
\begin{bmatrix}
I_0 \\
I_{45} \\
I_{90}
\end{bmatrix}
\]
Elements of the PACS Characteristic Matrix as a function of FOV

Term A11
\[ y = 2E-11x^2 - 3E-08x + 0.0004 \]
\[ R^2 = 0.4218 \]

Term A12
\[ y = 1E-10x^2 - 2E-07x + 0.0005 \]
\[ R^2 = 0.8319 \]

Term A13

Term B11
\[ y = 5E-10x^2 - 5E-07x + 0.0005 \]
\[ R^2 = 0.9587 \]

Term B12
\[ y = -5E-10x^2 + 5E-07x - 0.0005 \]
\[ R^2 = 0.9532 \]

Term B13
\[ y = -5E-10x^2 + 6E-07x - 0.0006 \]
\[ R^2 = 0.922 \]

Term C11
\[ y = 7E-11x^2 - 9E-08x + 5E-05 \]
\[ R^2 = 0.9072 \]

Term C12
\[ y = -8E-11x^2 + 1E-07x - 5E-05 \]
\[ R^2 = 0.9047 \]

Term C13
\[ y = 2E-10x^2 - 3E-07x + 0.0009 \]
\[ R^2 = 0.6577 \]
HARP CubeSat Mission

HyperAngular Rainbow Polarimeter – Funded by NASA InVEST Program
Planned for 2015

HARP Bus

Imaging arrays

Polarizers

Wide FOV lens

30 cm
The HARP payload is a wide FOV imager that splits three spatially identical images into three independent polarizers and detector arrays. This technique achieves simultaneous imagery of three polarization states and is the key innovation to achieve high polarimetric accuracy with no moving parts. The spacecraft consists of a 3U Cubesat with 3-axis stabilization designed to keep the imager pointing nadir. The hyper-angular capability is achieved by acquiring overlapping images at very fast speeds.

**Objectives:**
- Space validation of new technology required by the NASA Decadal Survey Aerosol-Cloud-Ecosystem (ACE) mission
- Prove the on-flight capabilities of a highly accurate wide FOV hyper-angle imaging polarimeter for characterizing aerosol and cloud properties
- Prove that cubesat technology can provide science-quality Earth Sciences data
Thank you.