Stratospheric Aerosols Measurements from a Compact Satellite Instrument
(ARGOS - Aerosol Radiometer for Global Observations of the Stratosphere)

Matthew DeLand\textsuperscript{1}, Peter Colarco\textsuperscript{2}, Matthew Kowalewski\textsuperscript{2}, Luis Ramos-Izquierdo\textsuperscript{2}, Mary Grace Kalnay\textsuperscript{3}

\textsuperscript{1}Science Systems and Applications, Inc. (SSAI)
\textsuperscript{2}NASA Goddard Space Flight Center
\textsuperscript{3}Loft Orbital

2023 Earth Science Technology Forum
20-22 June 2023, Pasadena, CA
Science Rationale

• Aerosols have an important and variable role in determining the energy balance of the climate system

• There continues to be significant uncertainty in aerosol distribution and composition

• Stratospheric aerosols (15-30 km) include a naturally occurring background component, transport of anthropogenic sources from the troposphere, and impulsive injections from volcanic eruptions and pyroCumulonimbus events

• Cooling caused by stratospheric aerosols (reflection of incident solar radiation) can offset some of the warming caused by increasing greenhouse gases
Measurement Options

- High quality observations of stratospheric aerosols requires satellite measurements with good temporal sampling, spatial sampling, vertical resolution.
- Occultation (e.g. SAGE II) – Self-calibrating measurement of extinction; Limited temporal and spatial sampling.
- Lidar (e.g. CALIOP) – Good vertical resolution; Measures scattering ratio; Less sensitive in stratosphere.
- Limb scattering (e.g. OSIRIS) – Good temporal and spatial sampling; Assume size distribution to derive extinction.
- We have chosen limb scattering to make comprehensive measurements at low cost.
ARGOS Measurement Concept

- Eight simultaneous viewing directions to atmospheric limb (forward and backward along orbit track, perpendicular to orbit, 45° azimuth between each of these directions)
- Each viewing direction measures simultaneous radiance profiles at 870 nm and 1550 nm
- All measurements captured on single focal plane

- 550 km altitude, Sun-synchronous orbit
- Vertical slits cover 0-60 km altitude at Earth limb with 0.5 km sampling
- Nominal along-track profile sampling is 45 km (6 second averaging)
ARGOS Overview

- Adapt OMPS LP concept for aerosol measurements in compact package
- Use bandpass filters at near-IR wavelengths for better altitude coverage into UT/LS and particle size information
- Add forward view for better aerosol sensitivity in Southern Hemisphere
- Add cross-track views for improved spatial coverage and information about short-term variations
- Collect short individual images (25 msec) to avoid saturation
- Co-add profiles for 6 seconds to improve SNR
- Fly technology demonstration with hosted payload provider to obtain better margins for size, mass, power requirements

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
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<tbody>
<tr>
<td>Size</td>
<td>20 x 20 x 11.3 cm</td>
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<tr>
<td>Mass</td>
<td>4 kg</td>
</tr>
<tr>
<td>Power</td>
<td>15 W</td>
</tr>
<tr>
<td>Wavelengths</td>
<td>870(±5) nm, 1550(±20) nm</td>
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<tr>
<td>Camera</td>
<td>Princeton IR 1280MVCam</td>
</tr>
<tr>
<td>Data Rate</td>
<td>2.0 Mbits/second</td>
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<tr>
<td>Data Volume</td>
<td>~ 13 Gbytes/day</td>
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</table>
ARGOS Optical Design

- Central Mirror
- Focal Plane
- 1280MVCam SWIR Detector
- Slit plate and dual band filters (870 nm, 1550 nm)
- Dual-band filter
- Achromatic Lens
- Nadir
ARGOS Sensitivity and Phase Function

- OMPS LP makes Southern Hemisphere measurements at high scattering angles, which represents low sensitivity (based on phase function) for typical stratospheric aerosol particles.
- **ARGOS** will add forward viewing measurements at low scattering angles to improve sensitivity in the SH.
- ARGOS will also measure the same approximate location along the orbit track within 15 minutes using both high and low scattering angles, which differ by a factor of 10 in phase function. This combined information will improve characterization of the aerosol phase function.
- Simultaneous measurements with broad wavelength separation will also improve characterization of size distribution.

Figure from *Chen et al.* [2018]
ARGOS Spatial Sampling – Single Orbit

• ARGOS along-track and cross-track measurements from a single orbit (red) cover a wide geographic swath
• Orange lines indicate location of each sample for one measurement
ARGOS Spatial Sampling – Multiple Orbits

- ARGOS cross-track measurements from the preceding orbit (green) and following orbit (blue) provide additional samples near the same locations as the along-track measurements.
ARGOS Spatial Sampling Study

- Sample GEOS CCM output of 550 nm extinction at 20 km for single day shortly after Ulawun eruption in June 2019
- Single along-track view (left panel) captures piece of main plume near Equator
- Combining all ARGOS views (right panel) clearly defines spatial extent of main plume
# ARGOS Funding History – GSFC and ESTO Support

ARGOS InVEST launch (technology validation flight) planned for Spring 2024

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IRAD 2016 (+610AT)</th>
<th>IIP 2018 (MASTAR)</th>
<th>IIP-Extension 2019</th>
<th>ESTO InVEST 2021</th>
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<tbody>
<tr>
<td>Azimuth Angles</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>8</td>
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<tr>
<td>#Wavelengths</td>
<td>2</td>
<td>3</td>
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<tr>
<td>Detector</td>
<td>Apogee (COTS)</td>
<td>Andor (COTS)</td>
<td>Andor (COTS)</td>
<td>Princeton Infrared 1280 MVCAM (mostly COTS)</td>
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<tr>
<td>Size (L x W x H)</td>
<td>8” x 8” x 15”</td>
<td>7” x 7” x 14”</td>
<td>6.5” x 6.5” x 8”</td>
<td>8” x 8” x 5”</td>
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<tr>
<td>Power</td>
<td>&lt; 40 W</td>
<td>30 W</td>
<td>85 W</td>
<td>15 W (est)</td>
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<tr>
<td>TRL</td>
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<td>4</td>
<td>5</td>
<td>6-7</td>
</tr>
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**Capability**

- Concept demonstration.
- Single wavelength per aperture angle.
- Lab operations only.
- Breadboard validation in lab environment.
- Two IR science wavelengths in 6 of 8 apertures.
- Single UV channel in 2 of 8 apertures for RSAS altitude registration.
- Lab and roof operations only.
- System prototype demo in relevant environment.
- Size reduction, improved stray light performance.
- Autonomous operations.
- Configured for high altitude balloon flight attempt in Fall 2021.
- System (prototype) flight qualified/demo in space.
- Size reduction with custom detector.
- Increased TRL with prelaunch testing, flight heritage control electronics.
- Space flight capable.
A Fast and Simple Ride to Orbit with Loft

Longbow Satellite Platform:
• Derived from the Airbus OneWeb bus
• Onboard data storage and processing, command management, communications
• Procured in bulk

The Hub:
• Universal payload adapter
• Provides interface for mechanical, thermal, electrical, and software

Cockpit:
• Mission operations software

ARGOS will fly on Longbow, Loft’s next generation satellite platform
Loft abstracts away mission complexity to enable customers to focus on their payload and data
Frequent flight opportunities available with flights manifested through 2026
Current Status and Future Plans

- Mechanical and optical components are in hand [top figure shows optical hub and central prism; bottom figure shows single aperture with baffle]
- COTS version of camera has passed flight-like vibration and thermal vacuum testing
- Integration is in progress
- Environmental and calibration testing with fully assembled instrument planned for Fall 2023
- Delivery to Loft in January 2024
- Launch target is Spring 2024
- Plan to adapt current OMPS LP aerosol algorithm to retrieve extinction profiles
Backup Slides
Ozone Mapping and Profiling Suite (OMPS) Limb Profiler (LP) launched on Suomi NPP satellite on 28 October 2011

- **Limb scatter** measurements look backward along the orbit track with three slits (center, ±4.25° to each side = 250 km horizontal separation at tangent point)
- Hyperspectral CCD collects simultaneous data over 0-80 km altitude (1 km sampling) and 290-1000 nm (spectral resolution = 1-35 nm)
- Retrieval products include ozone profile, aerosol extinction coefficient profile, cloud top altitude
Aerosols from pyroCb Events

- Large forest fires in Canada in August 2017 injected smoke into the stratosphere (pyroCb)
- Record aerosol index (AI) values observed
- OMPS LP and other instruments (e.g., CALIPSO, SAGE III) tracked the rise and spread of the plumes for months after the initial event

Peterson et al. [2018], Nature Climate Atmo. Sci.
We conducted a spatial sampling study using output from the GEOS-5 atmospheric model. GEOS-5 included a representation of stratospherically produced aerosols and perturbations from large volcanic eruptions in 2011 (Nabro, Nyamuragira).

Aerosol loading (gray) increases by a factor of 3–4 following a volcanic perturbation. The uncertainty in estimated global mean aerosol loading decreases from 15% for OMPS-LP like sampling (red) to 3–5% for ARGOS sampling (3x denser in longitude) (blue).
ARGOS Viewing Geometry

- 8 simultaneous directions (45° apart)
- 2 slits in each aperture direction
  - 2 wavelengths: 870 nm, 1550 nm
  - 1.3° slit elevation field of regard (FOR)
  - 0.1° slit width FOR
  - 1° separation between slits
- Altitude coverage = 0-60 km

Ground Testing (March 2019)
- Predecessor instrument (MASTAR) operated on building roof at NASA GSFC
- Measurements towards Sun (AP3), away from Sun (AP7) show expected variation in signal strength
- Faint stray light signals (arcs) guided improvements in optical design for ARGOS instrument