Stratospheric Aerosols Measurements from a Compact Satellite Instrument

(ARGOS - Aerosol Radiometer for Global Observations of the Stratosphere)

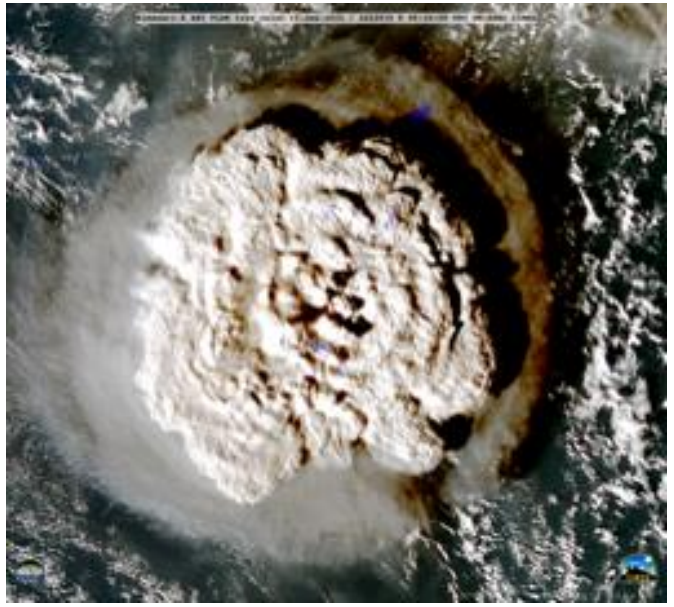
Matthew DeLand[1], Peter Colarco[2], Matthew Kowalewski[2],
Luis Ramos-Izquierdo[2] , Mary Grace Kalnay[3]

[1]Science Systems and Applications, Inc. (SSAI)
[2]NASA Goddard Space Flight Center
[3]Loft Orbital

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

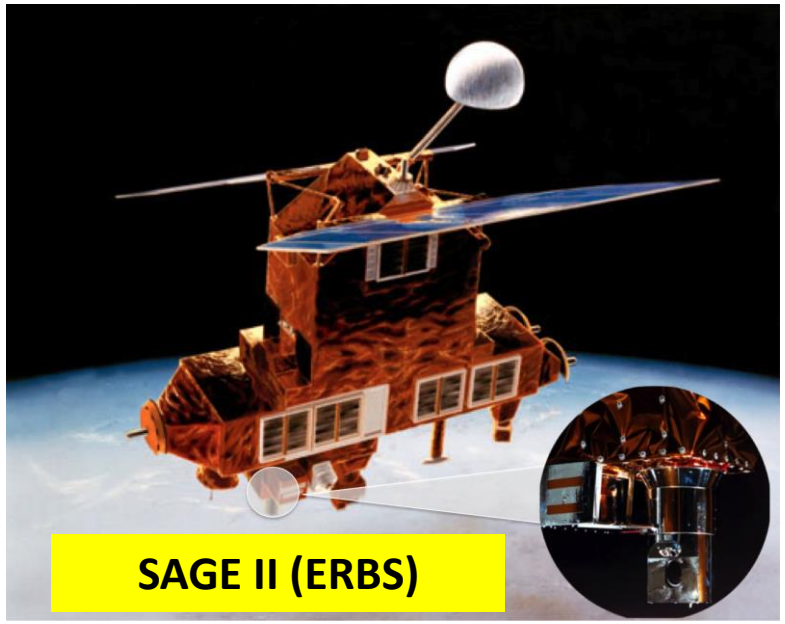
Science Rationale

- 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

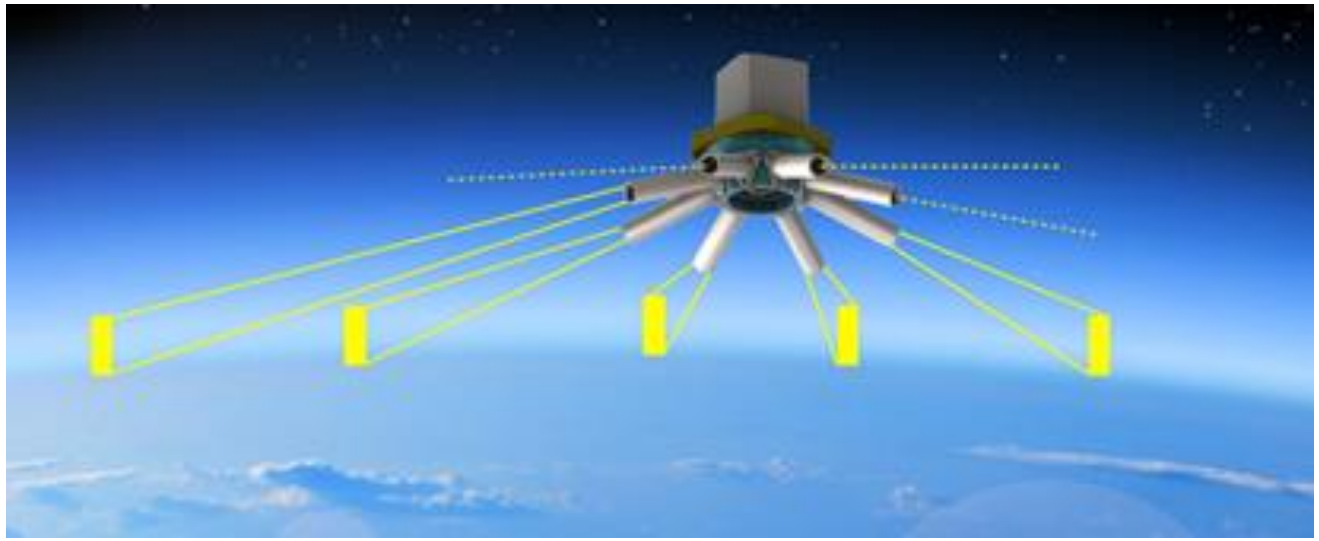
- High quality observations of stratospheric aerosols requires satellite measurements with good temporal sampling, spatial sampling, vertical resolution
- Occultation (e.g. SAGE II) – Self-calibrating measurement of extinction; Limited temporal and spatial sampling
- Lidar (e.g. CALIOP) – Good vertical 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



OSIRIS (Odin)

ARGOS Measurement Concept

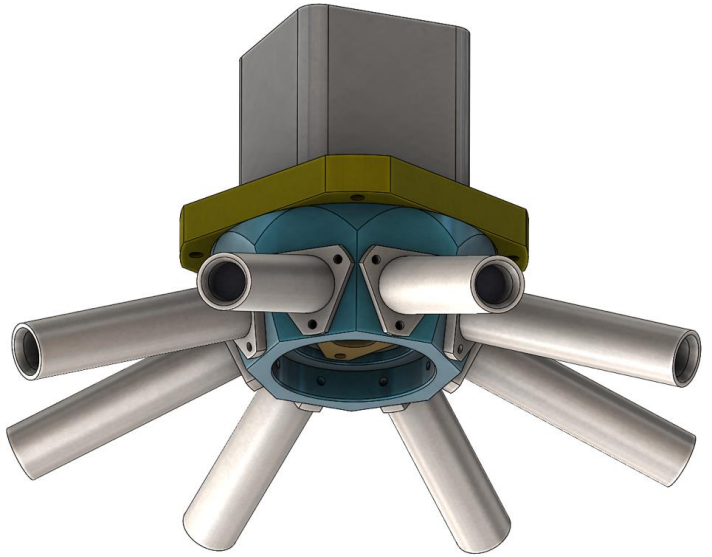
- Eight simultaneous viewing directions to atmospheric limb (forward and backward along orbit track, perpendicular to orbit, 45° azimuth between each of these directions)
- Each viewing direction measures simultaneous radiance profiles at 870 nm and 1550 nm
- All measurements captured on single focal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

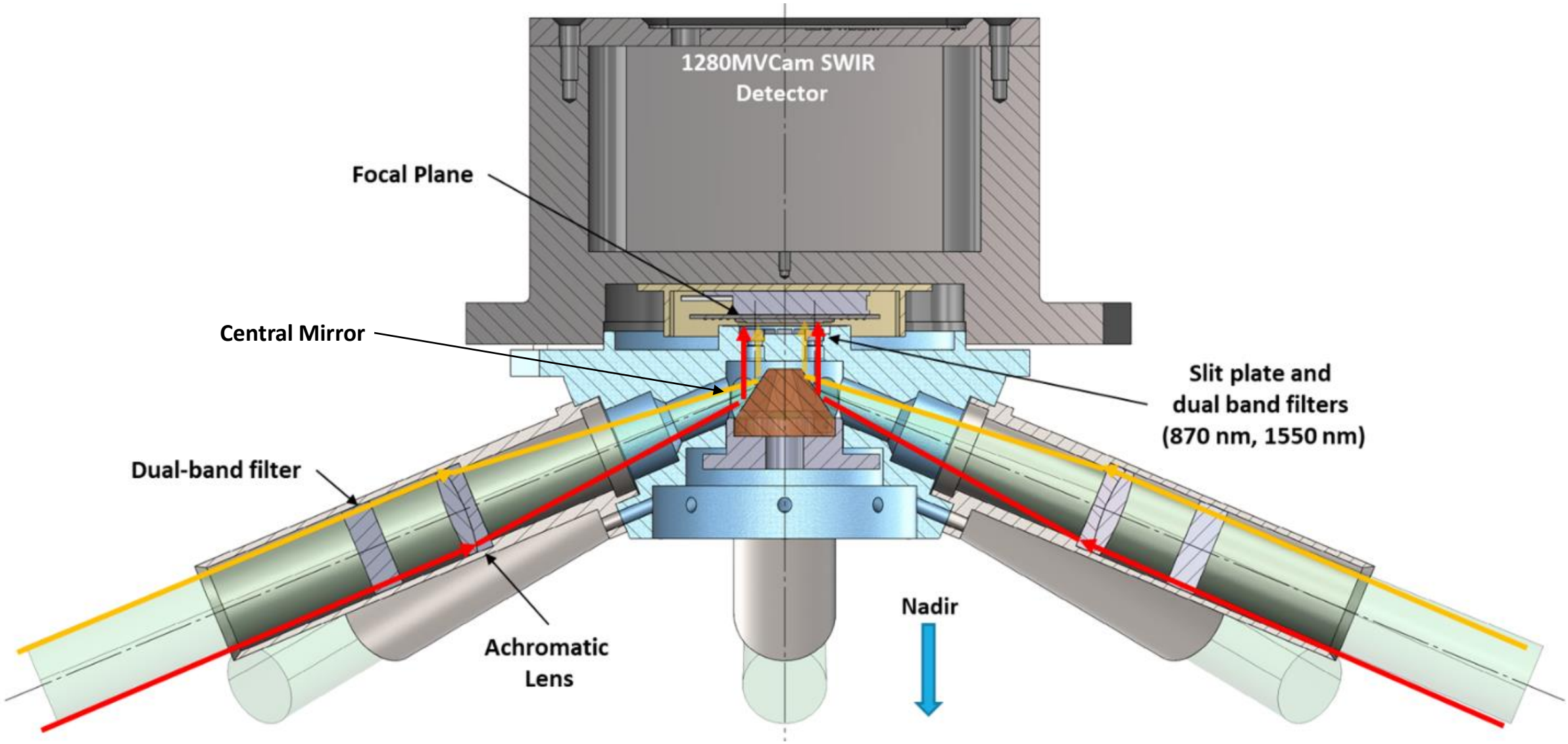
ARGOS Overview

- 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



PARAMETER	VALUE
Size	20 x 20 x 11.3 cm
Mass	4 kg
Power	15 W
Wavelengths	870(±5) nm, 1550(±20) nm
Camera	Princeton IR 1280MVCam
Data Rate	2.0 Mbits/second
Data Volume	~ 13 Gbytes/day

ARGOS Optical Design



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.

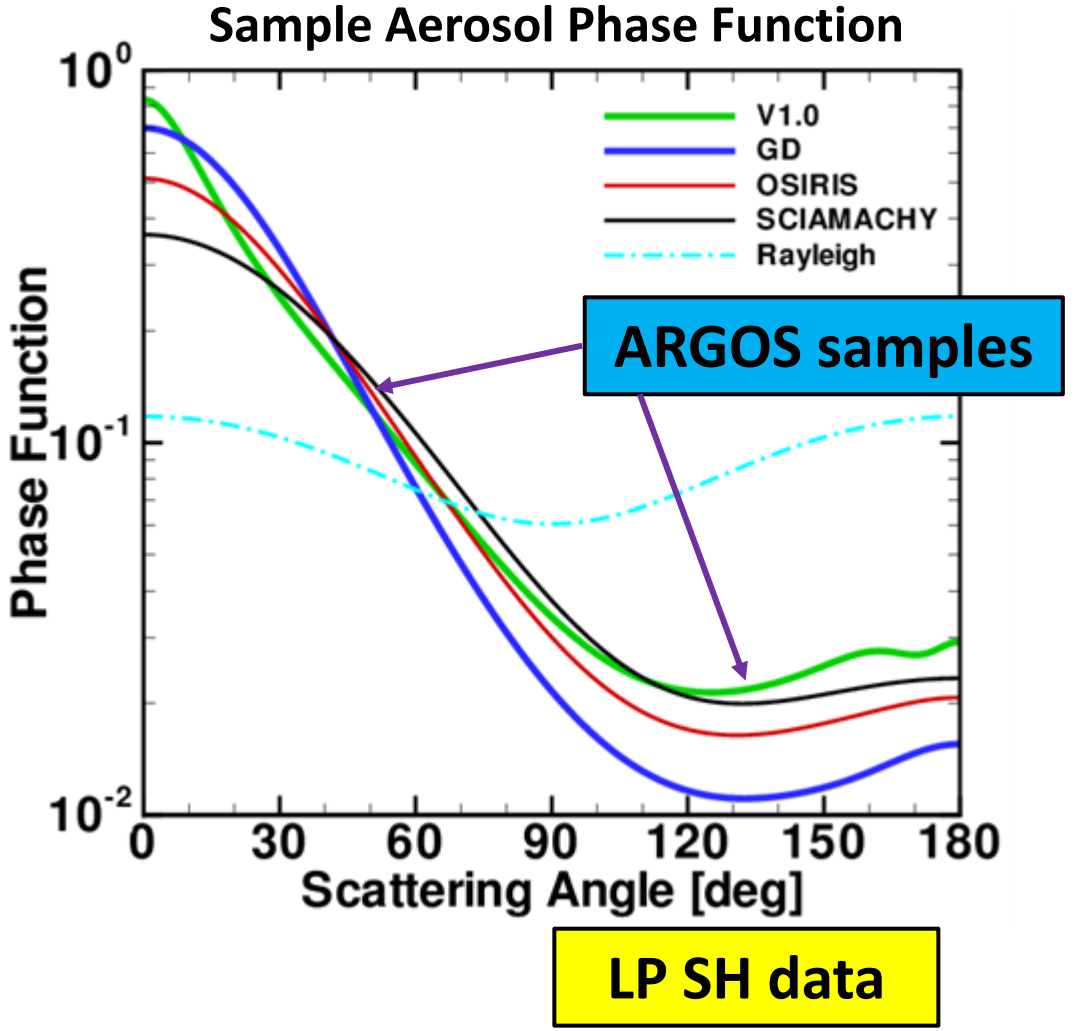
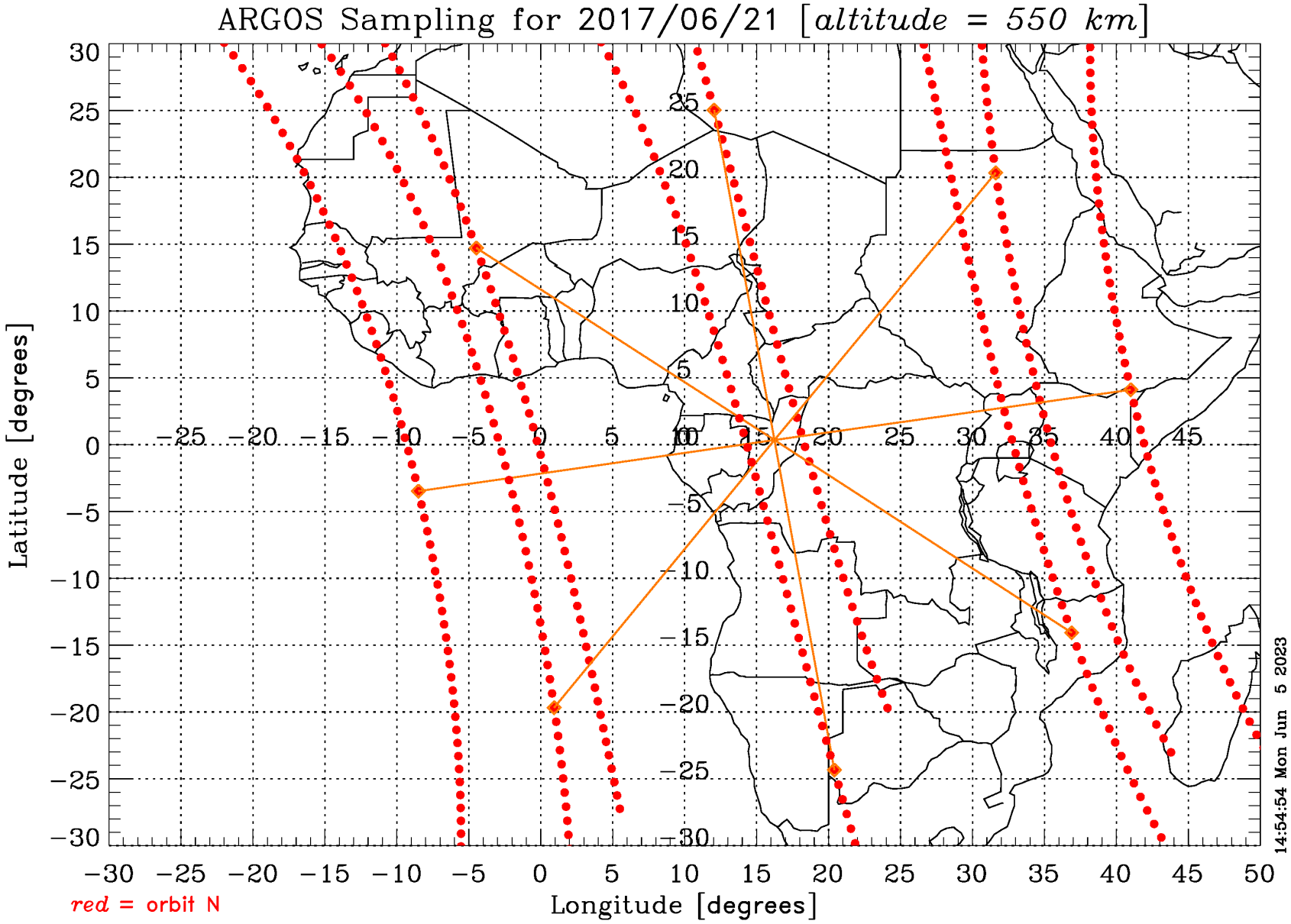


Figure from *Chen et al.* [2018]

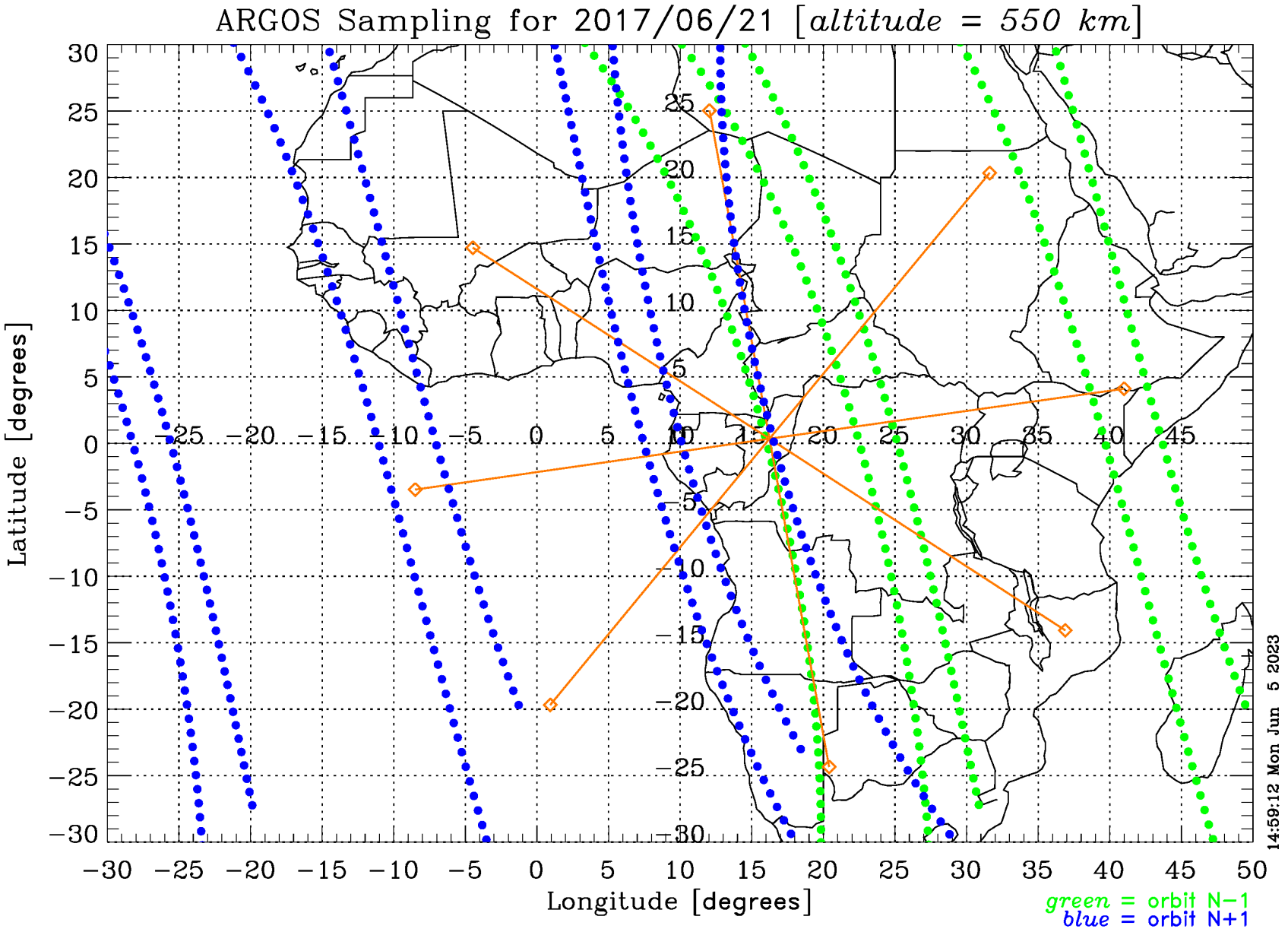
ARGOS Spatial Sampling – Single Orbit

- 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

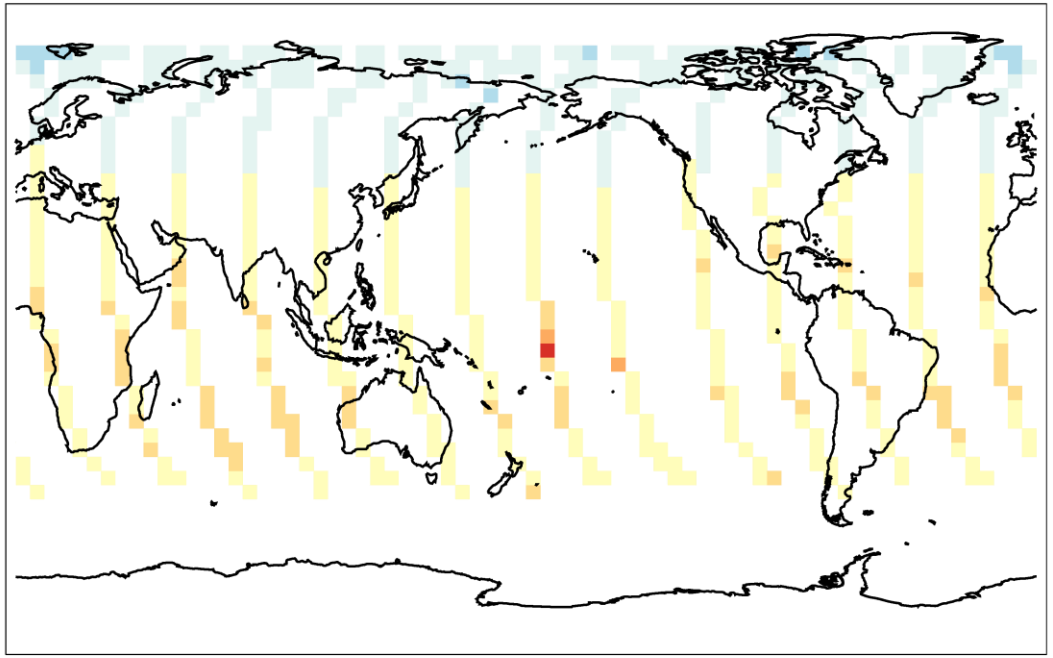
- ARGOS cross-track measurements from the preceding orbit ***(green)*** and following orbit ***(blue)*** provide additional samples near the same locations as the along-track measurements

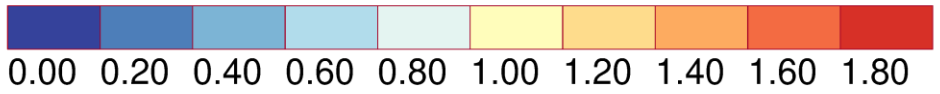


ARGOS Spatial Sampling Study

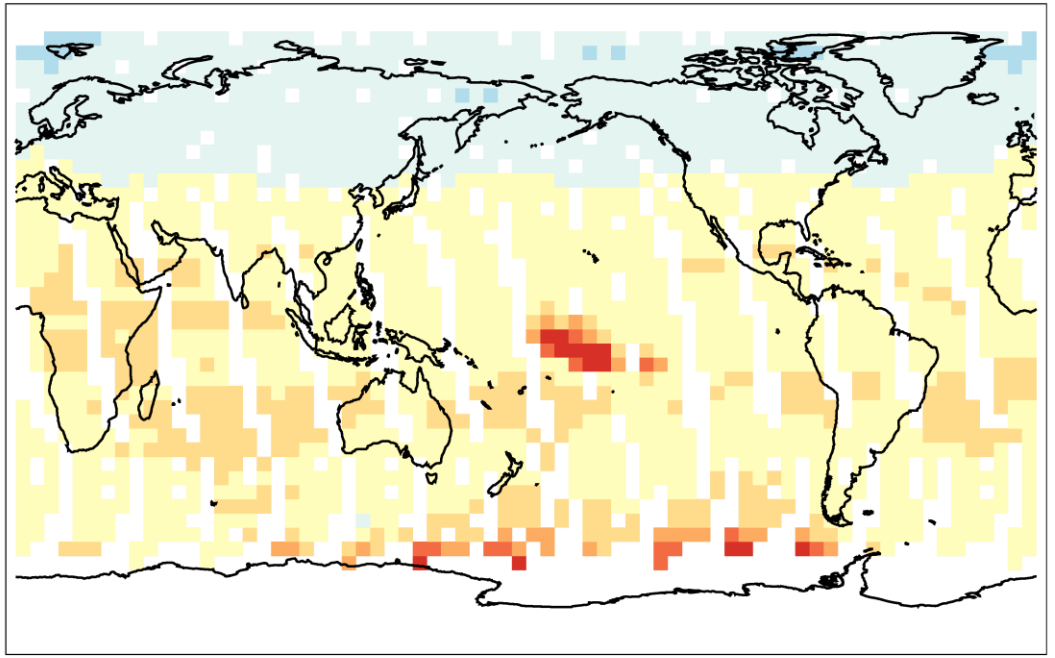
- Sample GEOS CCM output of 550 nm extinction at 20 km for single day shortly after Ulawun eruption in June 2019
- Single along-track view (*left panel*) captures piece of main plume near Equator
- Combining all ARGOS views (*right panel*) clearly defines spatial extent of main plume

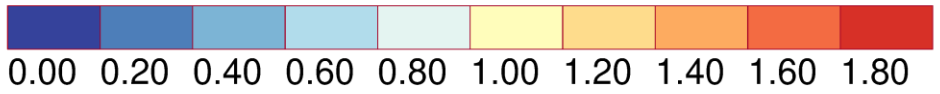
Single along-track view



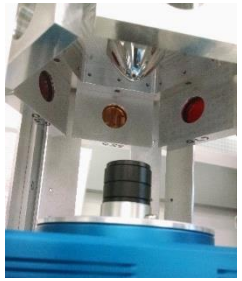


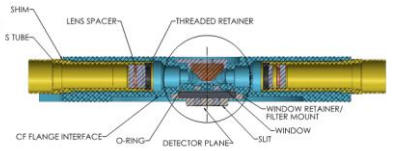
All ARGOS views

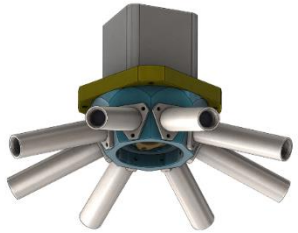




ARGOS Funding History – GSFC and ESTO Support



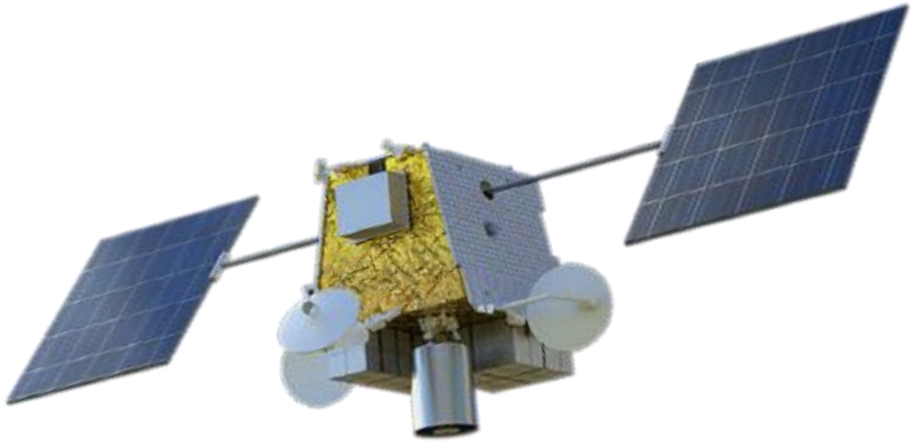




Parameter	IRAD 2016 (+610AT)	IIP 2018 (MASTAR)	IIP-Extension 2019	ESTO InVEST 2021
Azimuth Angles	6	8	8	8
#Wavelengths	2	3	3	2
Detector	Apogee (COTS)	Andor (COTS)	Andor (COTS)	Princeton Infrared 1280 MVCAM (mostly COTS)
Size (L x W x H)	8” x 8” x 15”	7” x 7” x 14”	6.5” x 6.5” x 8”	8” x 8” x 5”
Power	< 40 W	30 W	85 W	15 W (est)
TRL	3	4	5	6-7
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.

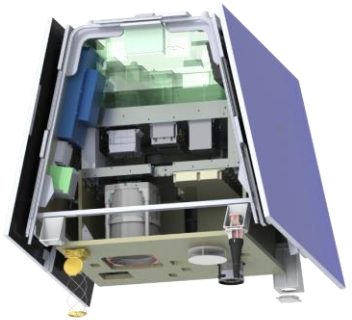
ARGOS InVEST launch (technology validation flight) planned for Spring 2024

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

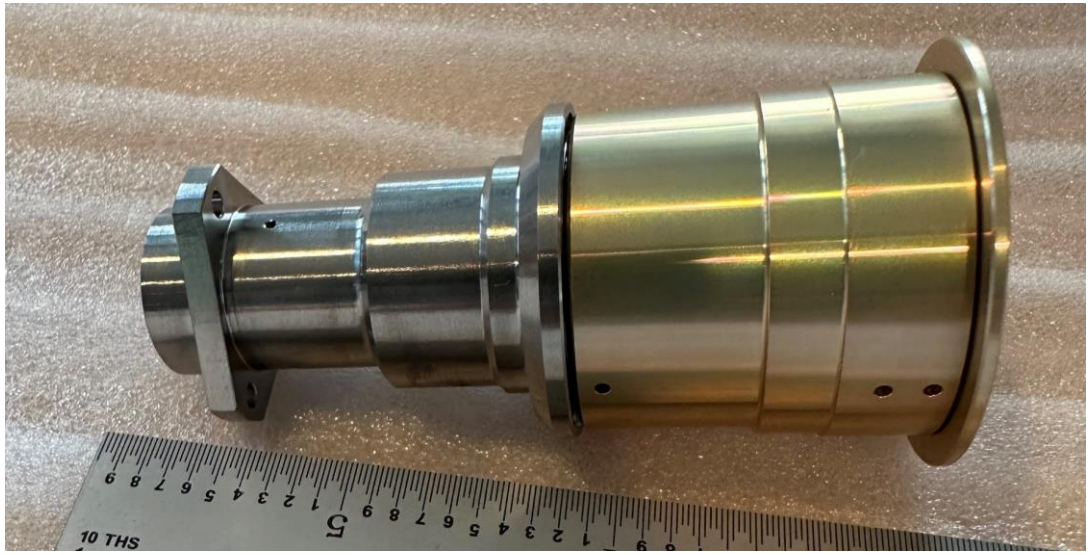
Cockpit:

- 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

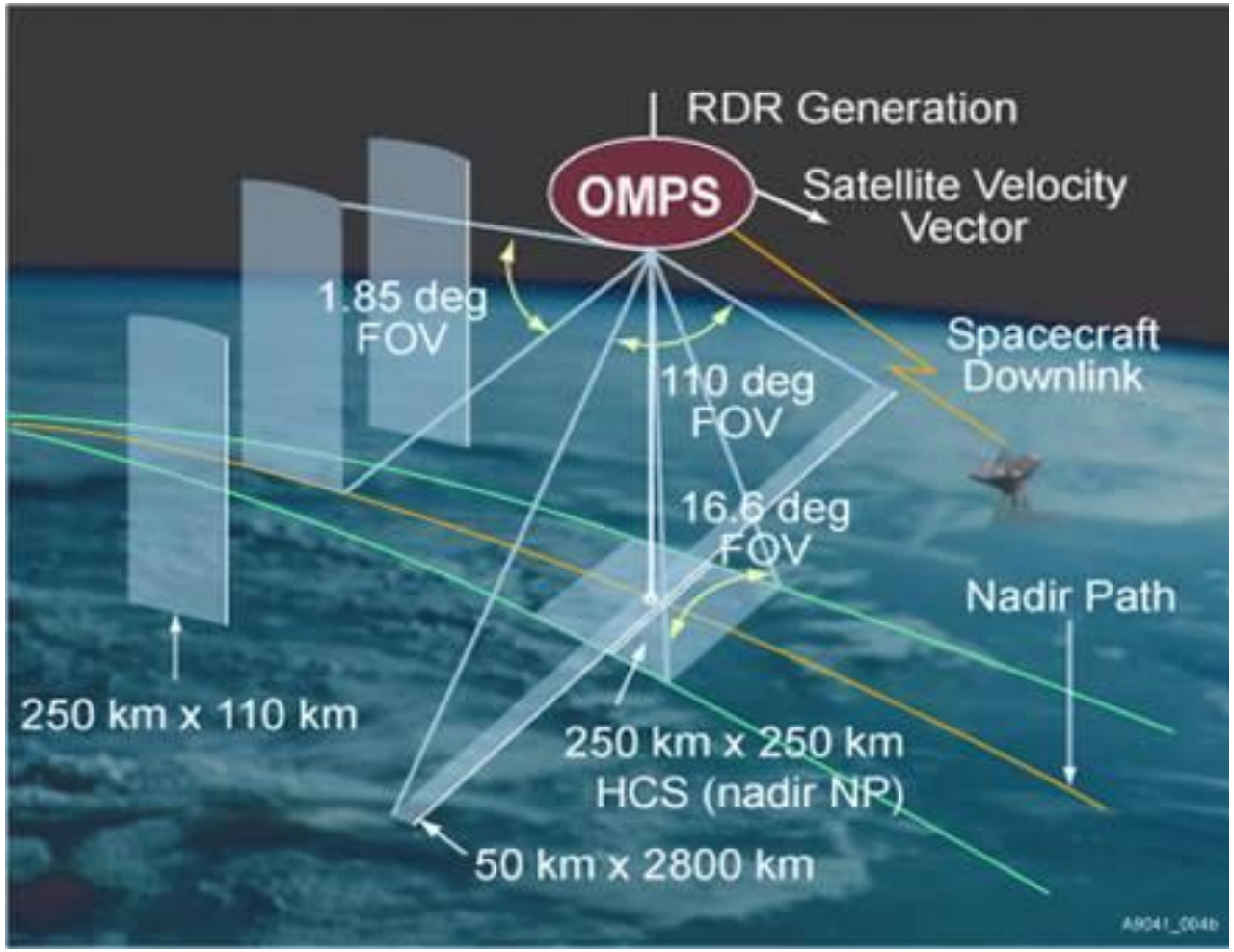
- Mechanical and optical components are in hand [top figure shows optical hub and central prism; bottom figure shows single aperture with baffle]
- COTS version of camera has passed flight-like vibration and thermal vacuum testing
- Integration is in progress
- Environmental and calibration testing with 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

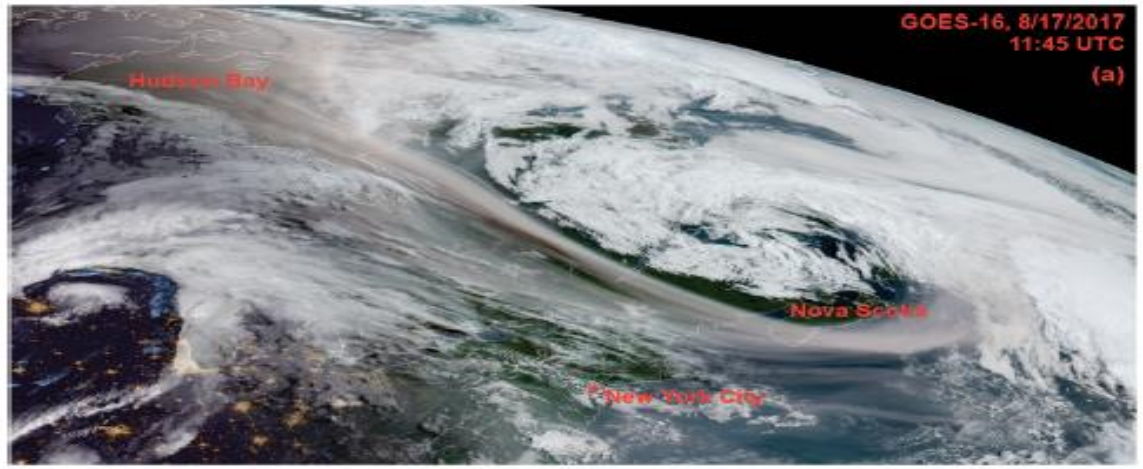
Concept Heritage - OMPS Limb Profiler (LP)

- 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



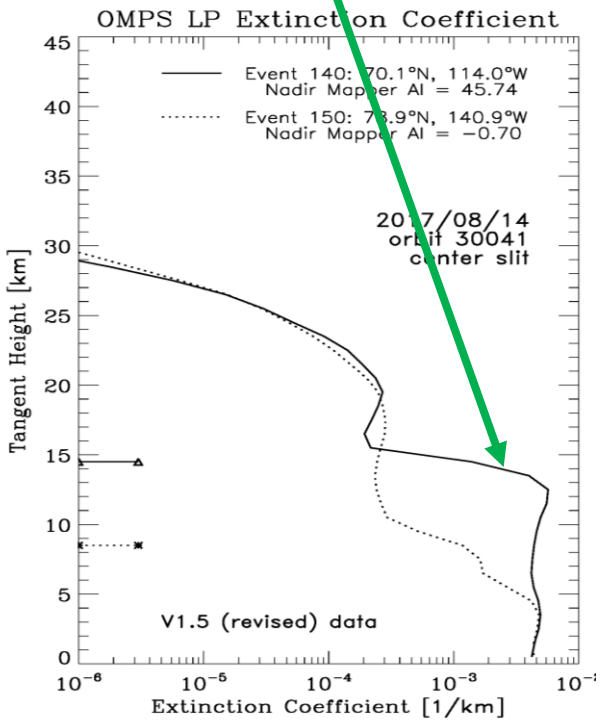
Aerosols from pyroCb Events

- 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

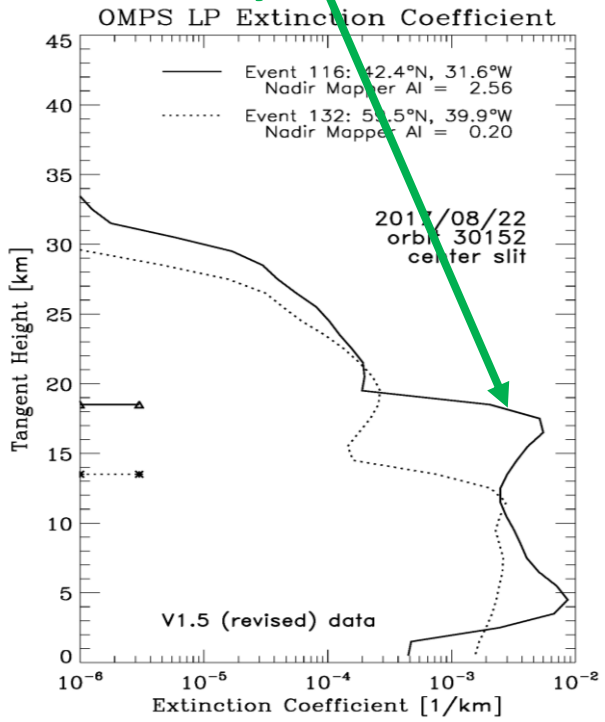


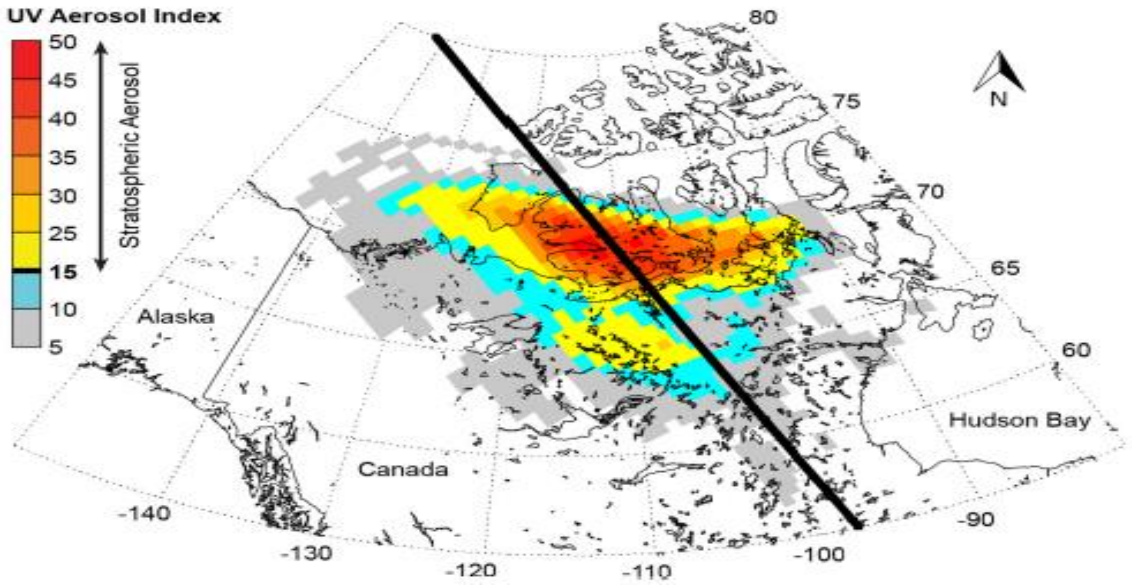
Peterson et al. [2018], *Nature Climate Atmo. Sci.*

2 days - Canada



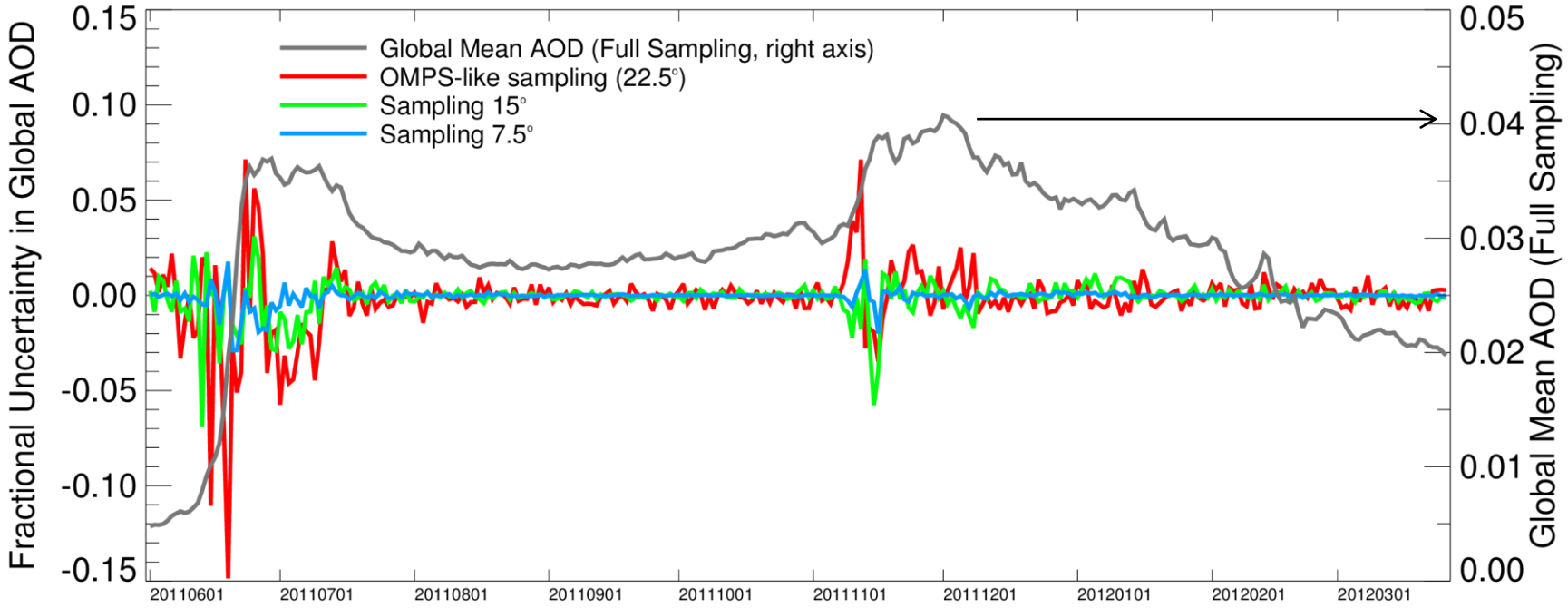
9 days - Atlantic





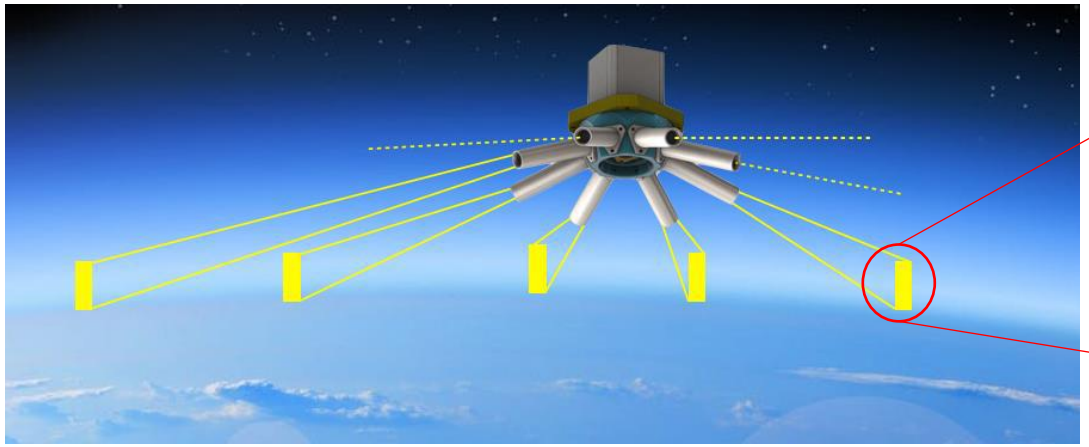
ARGOS Spatial Sampling Study - 1

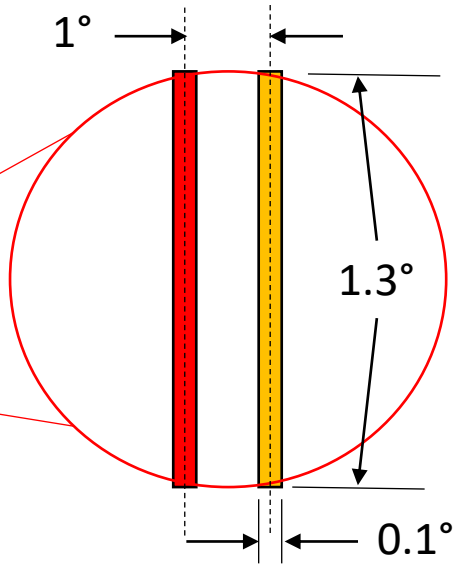
- We conducted a spatial sampling study using output from the GEOS-5 atmospheric model. GEOS-5 included a representation of stratospherically produced aerosols and perturbations from large volcanic eruptions in 2011 (Nabro, Nyamuragira).



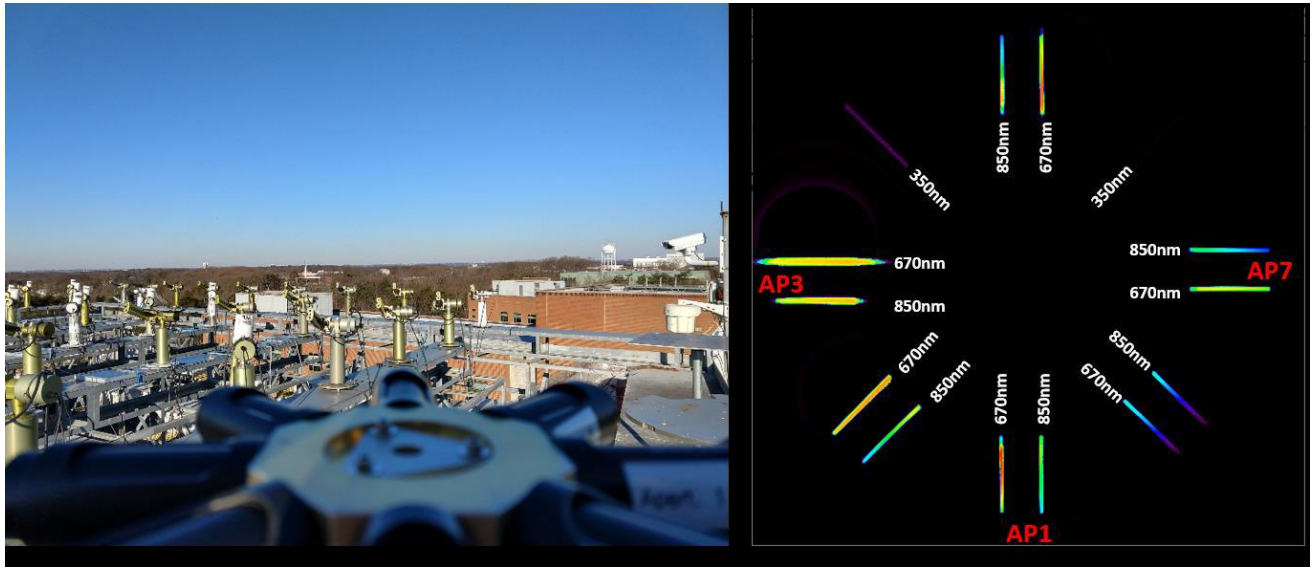
Aerosol loading *(gray)* increases by a factor of 3–4 following a volcanic perturbation. The uncertainty in estimated global mean aerosol loading decreases from 15% for OMPS-LP like sampling ***(red)*** to 3–5% for ARGOS sampling (3x denser in longitude) ***(blue)*****.**

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