National Aeronautics and
Space Administration

Sustainable Ozone and Aerosol Measurements from a 6U CubeSat: The Stratospheric Aerosol and Gas Experiment (SAGE) IV Pathfinder

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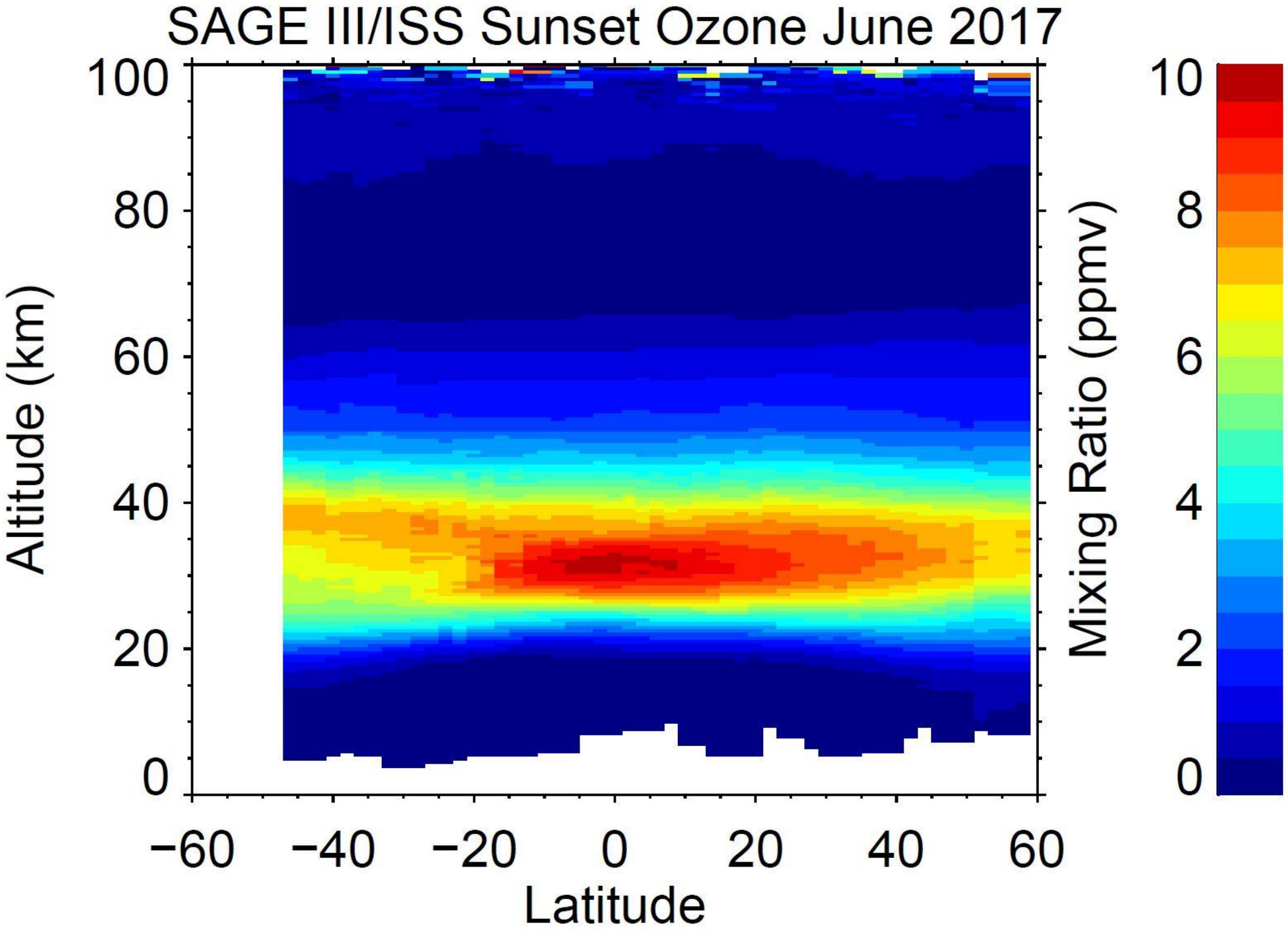

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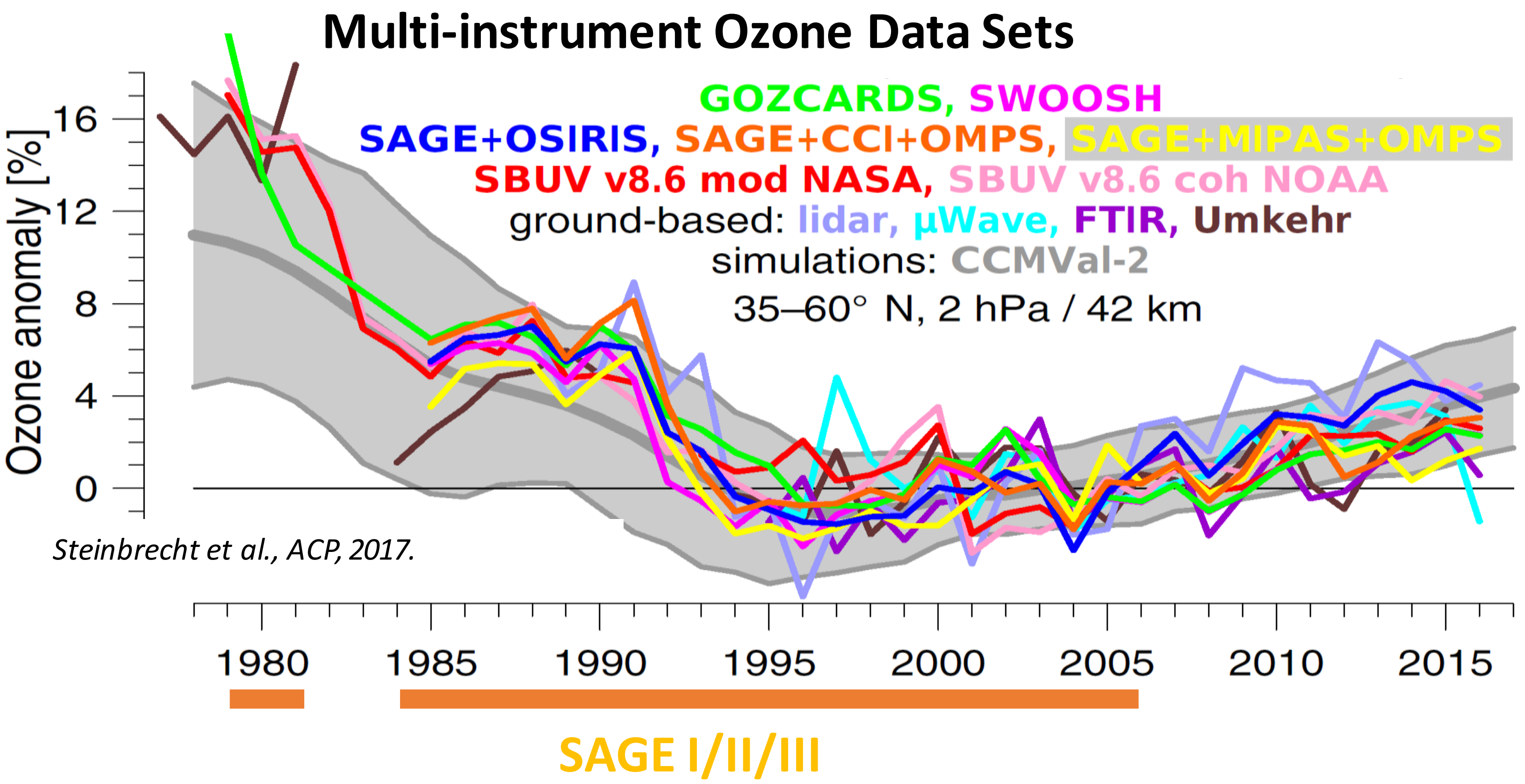

Steinbrecht et al., ACP, 2017.

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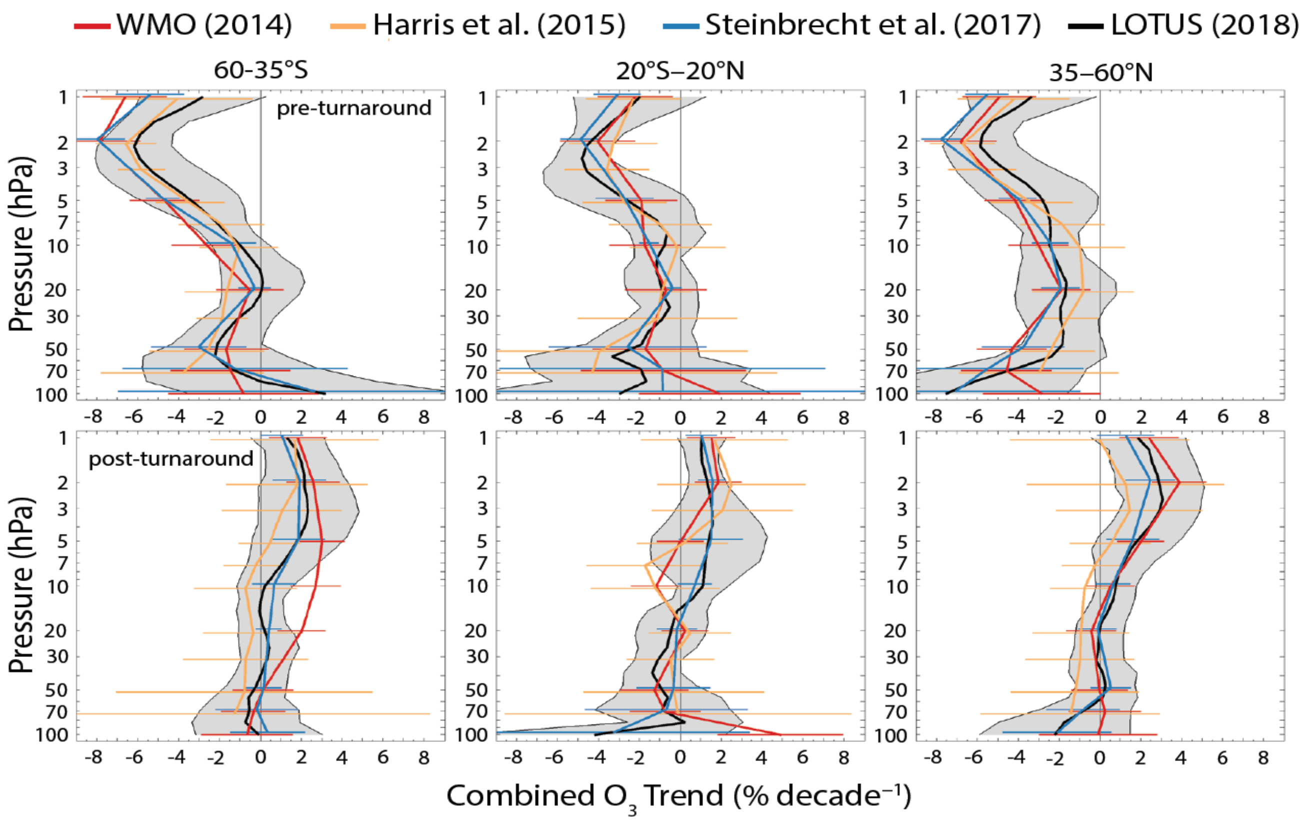

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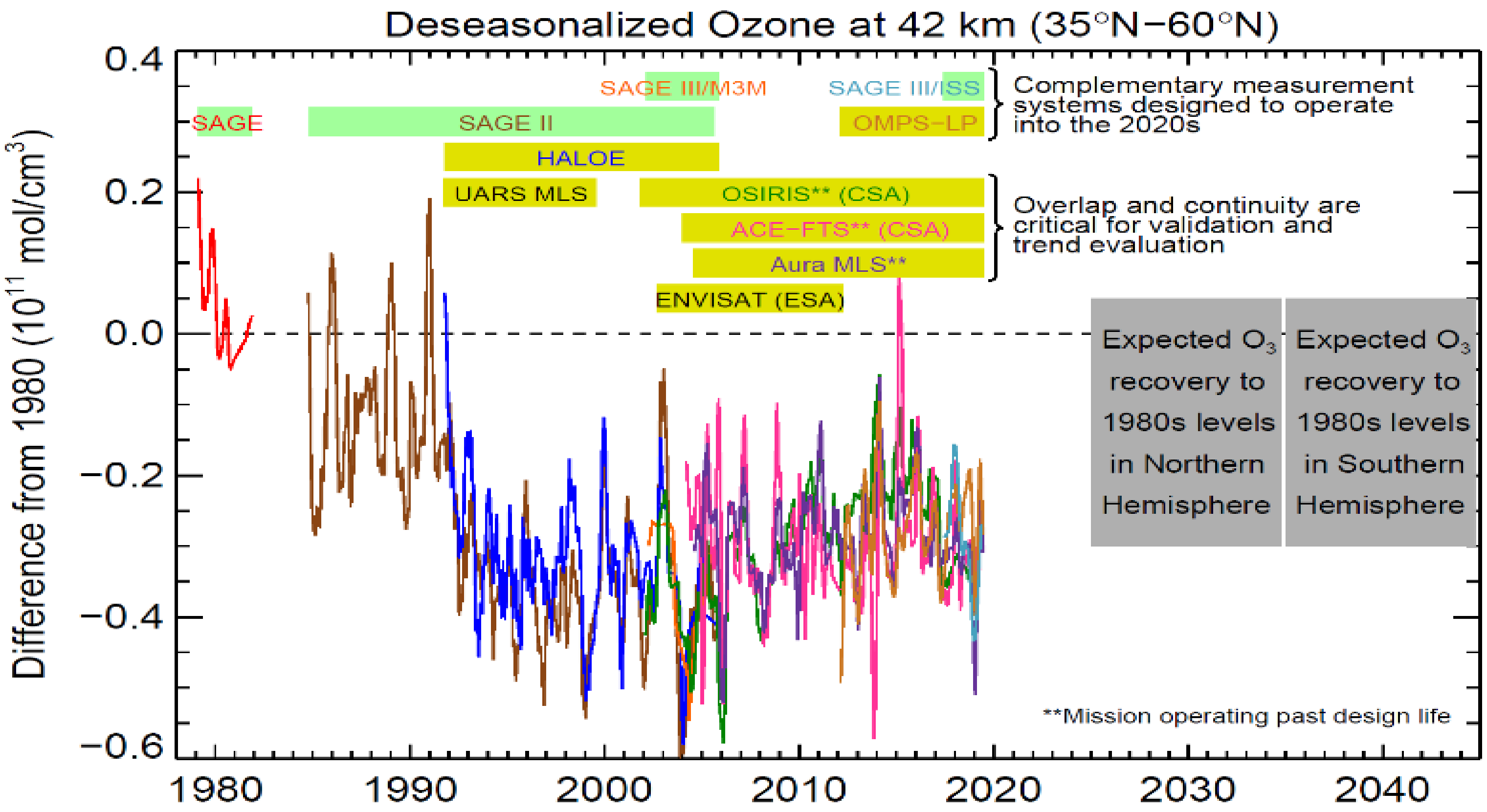

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SAGE III/ISS continues to be very successful but will not be around to see the recovery of stratospheric ozone to 1980s levels. The requirement to maintain data continuity for decades to come **requires a sustainable solution**.

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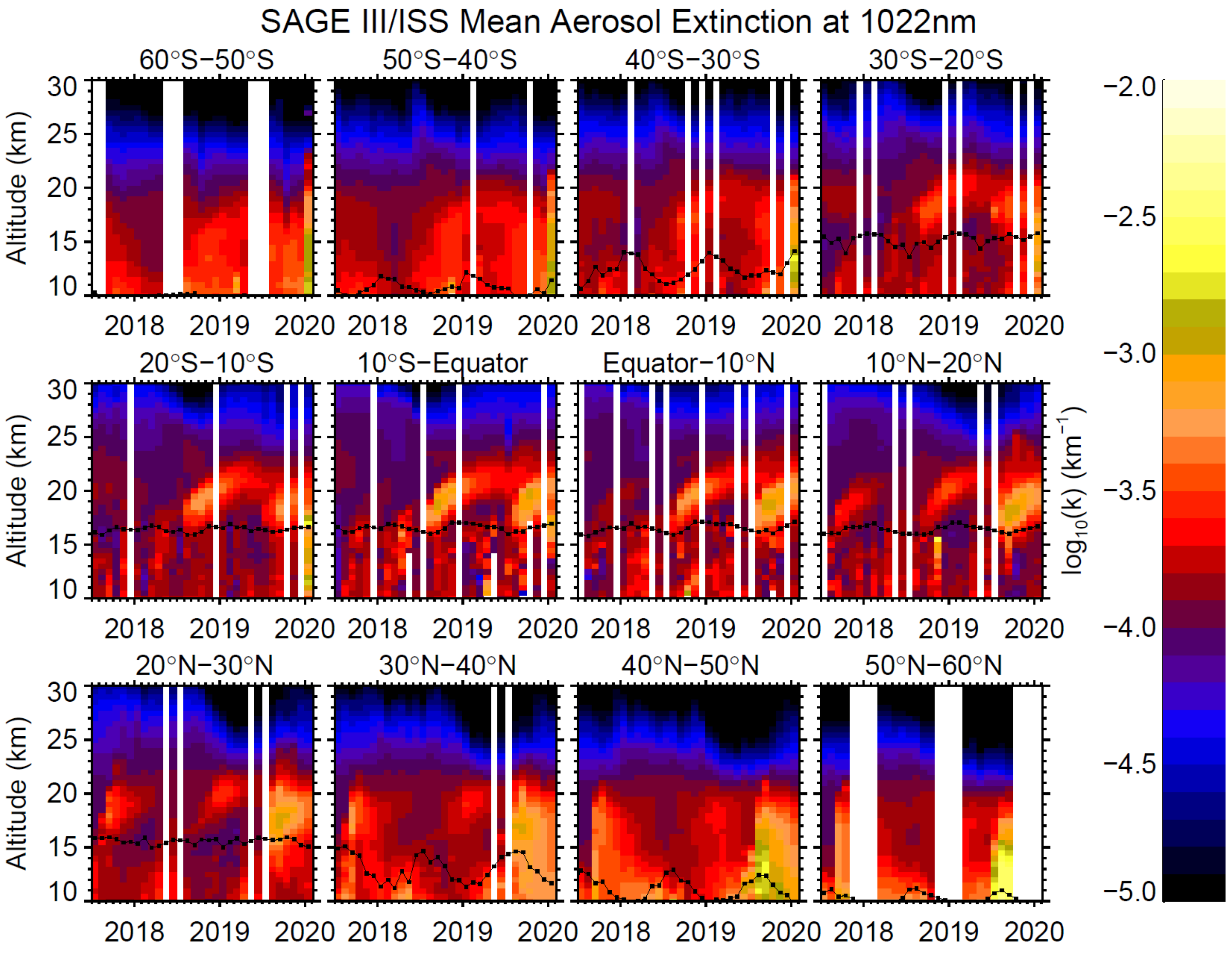

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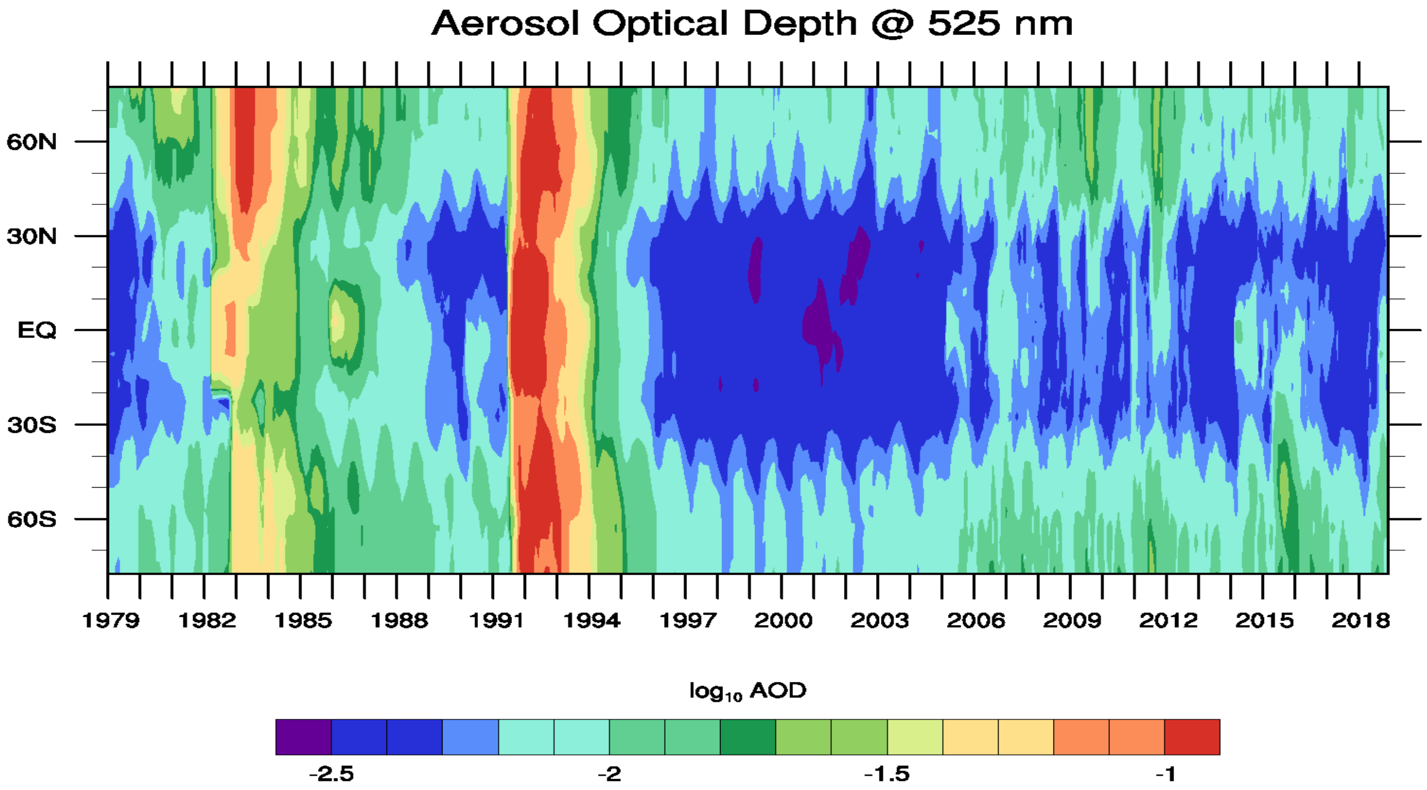

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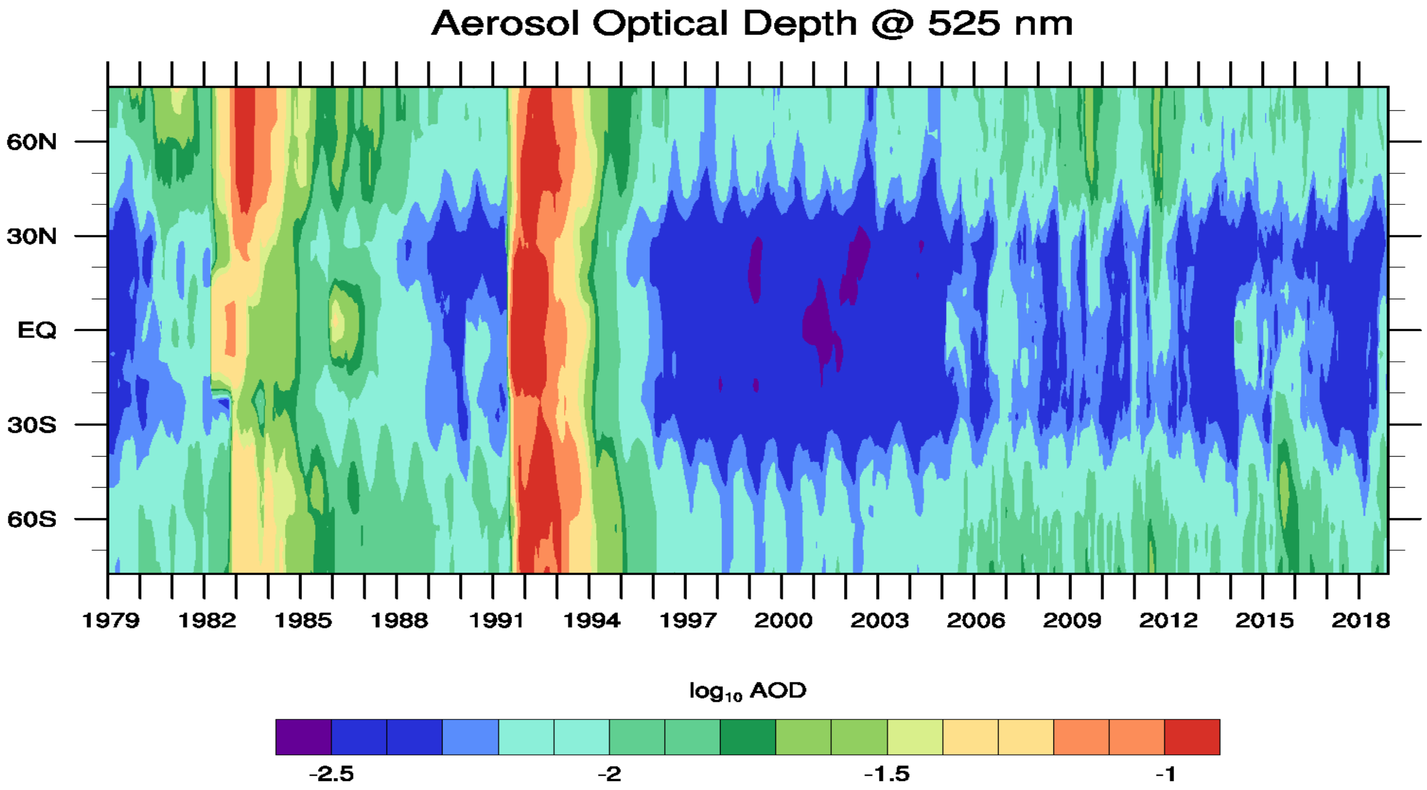

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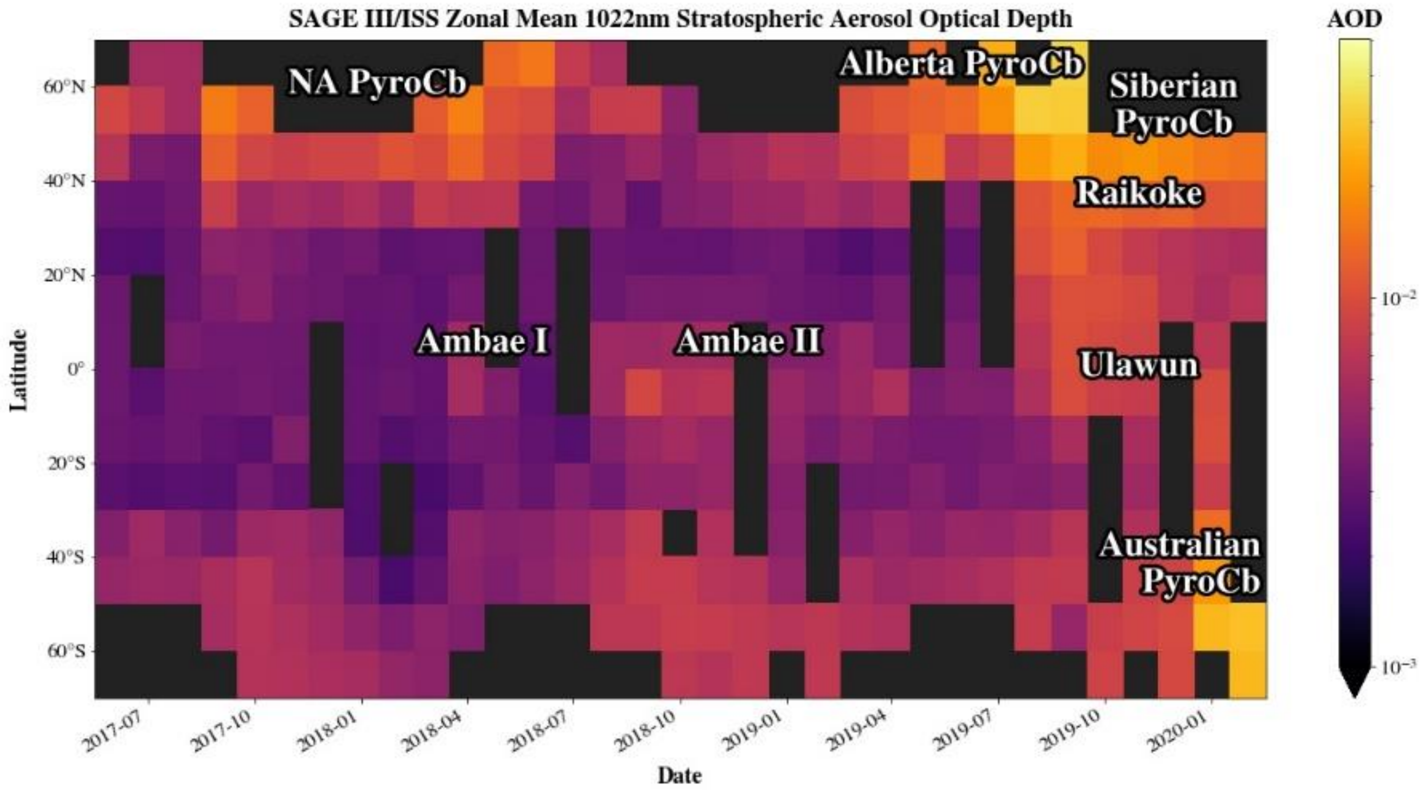

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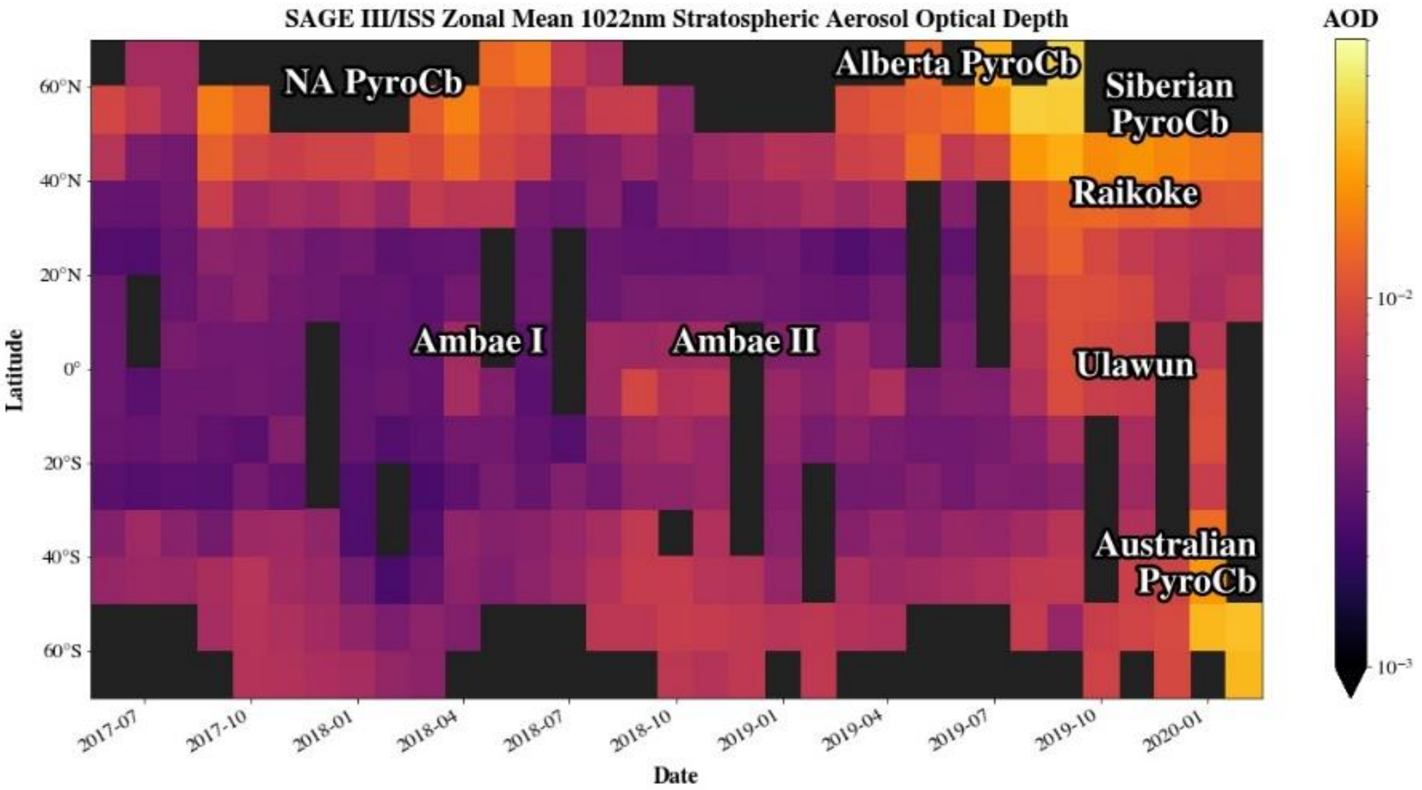

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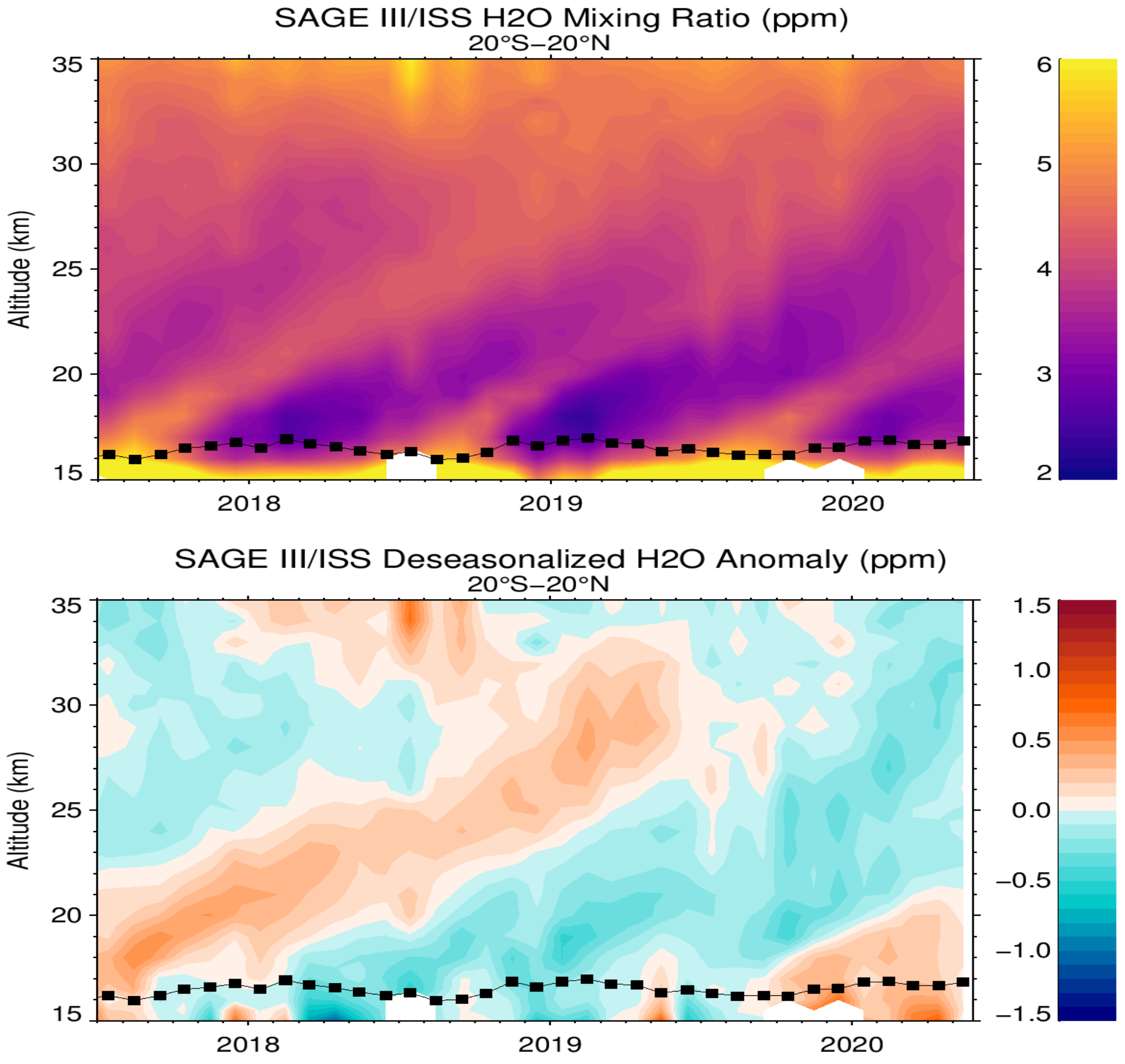
The importance on climate models and the uncertainty of events requires **continuity in the aerosol record**.

Stratospheric Water Vapor

Water vapor plays important roles in stratospheric chemistry and Earth's radiation budget and is a useful transport tracer.

SAGE data is a core component of the combined satellite record of water vapor such as the Stratospheric Water and OzOne Satellite Homogenized (SWOOSH) data set.

SAGE III/ISS is the only instrument under 15 years old currently providing measurements of stratospheric water vapor.



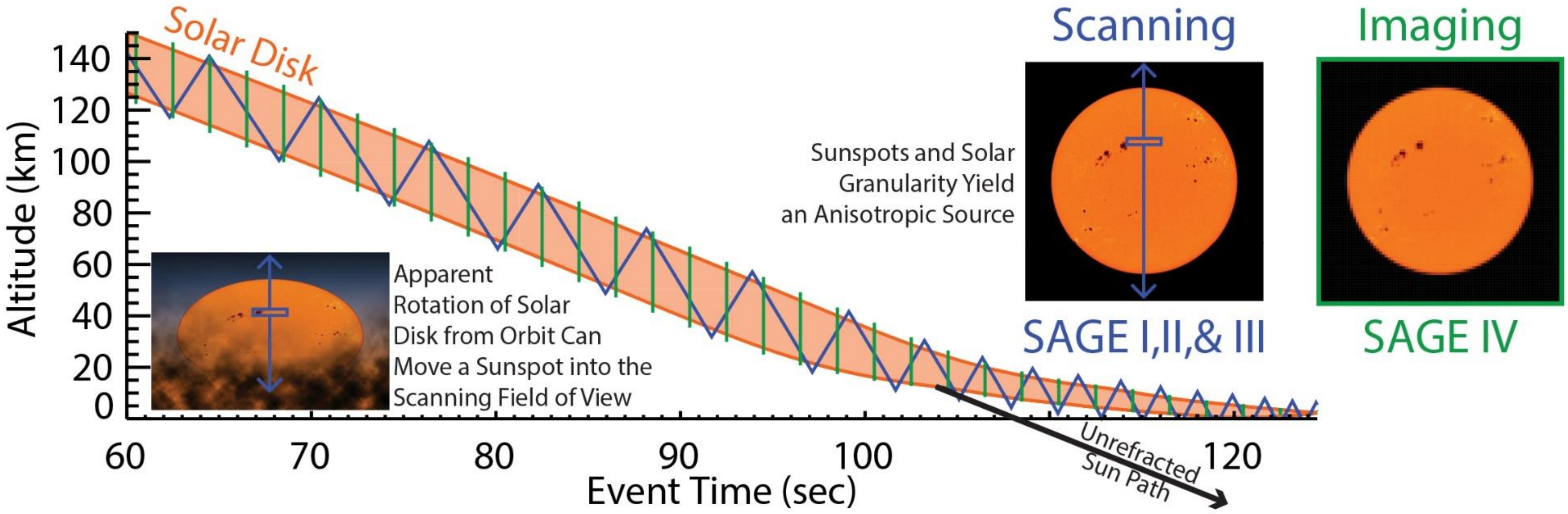
What have we learned from SAGE so far?

Over four decades of experience with solar occultation have taught us how to optimize the measurement for the next generation system.

Lessons learned from SAGE I/II/III Scanning Technique:

- When using a scanning spectrometer, pointing knowledge becomes critical and subsequently requires heavy (~350 kg) and expensive mechanisms.
- Assumptions must be made about the instrument's mechanical stability during an event.
  - Linearity of scan mirror motion
  - Azimuthal tracking expects a uniform image
  - Non-orthogonal transient behaviors
- External meteorological data are required to compute refraction for tropospheric and lower stratospheric pointing.
- Radiometric symmetry of the solar disk must be assumed while scanning.

What are we doing different?: Solar Imaging



- Absolute pointing is intrinsic to solar imaging
- No assumptions are required for tracking mechanisms
- Atmospheric refraction information is independently retrievable
- Anisotropy of the solar disk (e.g., sunspots and granularity) is measured

SAGE IV Science

Ozone Concentration:

- Precision (≤1%) and vertical resolution (≤1 km) required for trend assessments
- Necessary stability derives from measurement technique and on-board instrument characterization (SAGE II was ≤2%/dec)

Aerosol Extinction:

- Unique data product intrinsic to solar occultation that does not require modeling of particle size or type
- Precision (≤5%) and vertical resolution (≤1 km) same as previous SAGE instruments (exceeds other non-SAGE instruments)
- Multi-wavelength measurements can be used to infer aerosol properties (e.g., size and type) and can improve other instrument retrievals (e.g., OMPS-LP)

Water Vapor & NO2 Concentrations:

- Precision (≤10%) and vertical resolution (≤2 km) same as previous SAGE instruments

Neutral Density / Temperature:

- Imaging offers intrinsic measurement of refraction and inference of neutral density and temperature

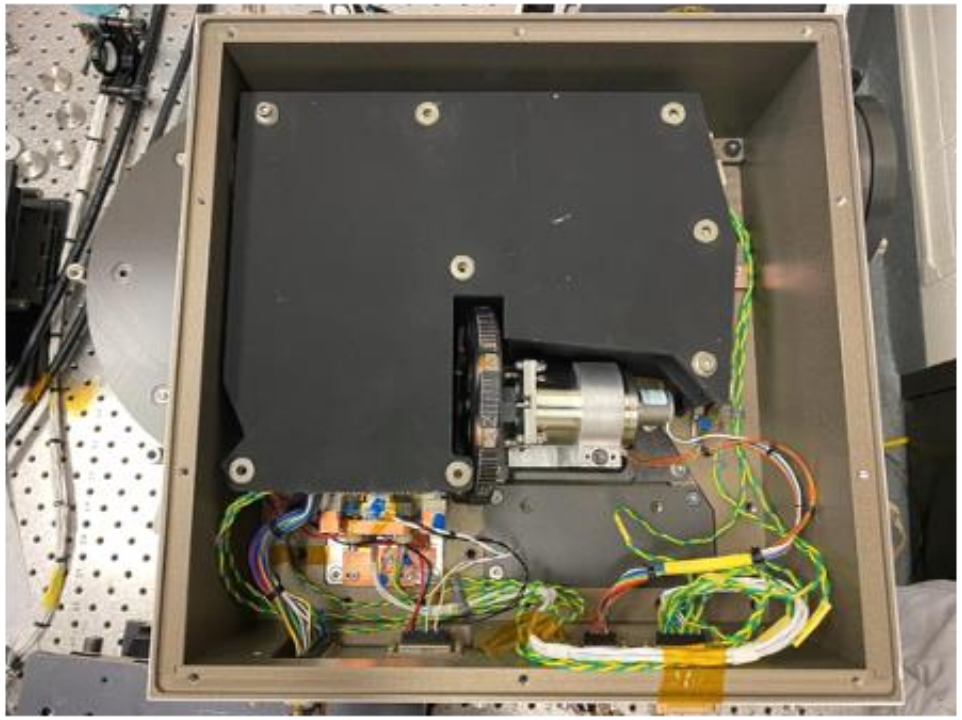
Spectral Channel	Target
Light Block	Dark Current
Diffuser	Flat-Fielding
448 ± 1 nm	NO2 / Aerosol
452 ± 1 nm	NO2 / Aerosol
525 ± 5 nm	Aerosol
600 ± 10 nm	Ozone
676 ± 5 nm	Aerosol
945 ± 15 nm	Water Vapor
1020 ± 10 nm	Aerosol
Possible Additions	**Purpose**
Split H2O into 2	Better Water Vapor
756 / 868 nm	Better Aerosol
385 nm	Density in Mid-Atm.
O2 A-band	Better Dens/Temp

Current Goals: SAGE IV Pathfinder IIP

Objectives:

Develop a laboratory SAGE IV prototype enabling a follow-on transition to a low-risk flight mission

- Demonstrate the radiometric performance of the system through laboratory and Sunlook testing
- Utilize commercially available parts to the extent possible (i.e., no R&D) with a clear path to flight



Three Year Plan ending in 2020:

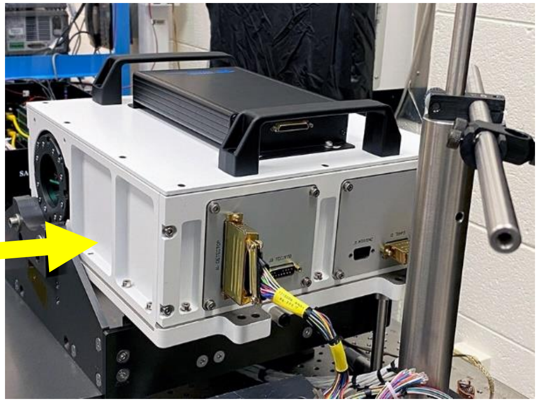
PY1: Finalize requirements, process major procurements, build and test telescope

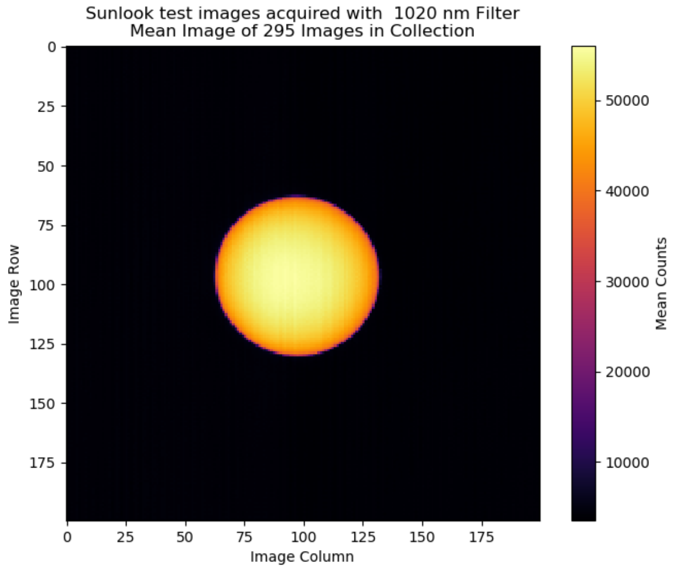
PY2: Test subsystems, finalize firmware and software, begin integration

PY3: Finish integration, test fully integrated system ← We are here!

Instrument Testing

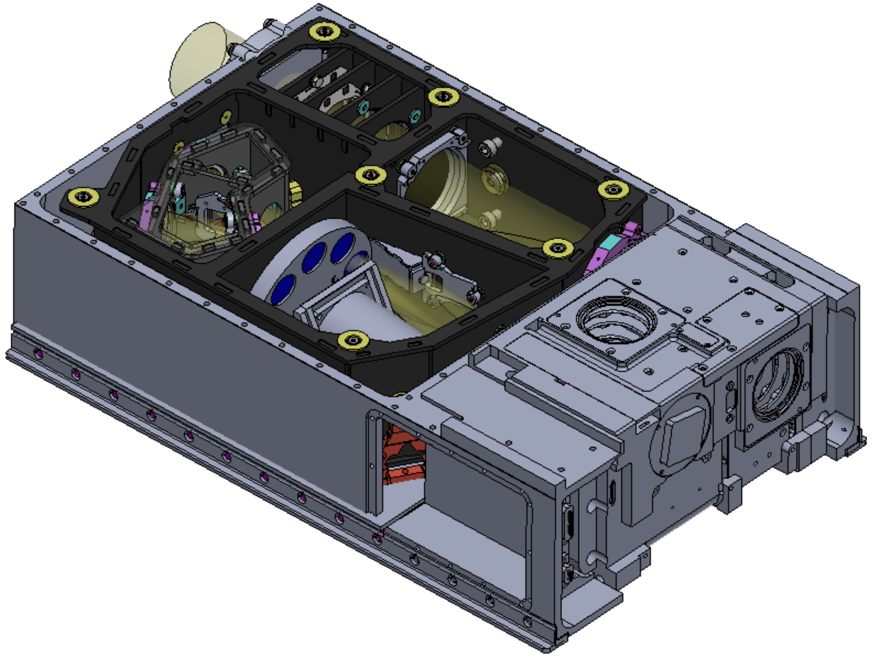
- SAGE IV prototype integrated into surrogate chassis for testing.
- Extensive system testing and characterization performed in laboratory clean room with calibrated light source.
- Sunlook testing occurred outdoors with instrument surrogate chassis positioned on equatorial mount.
- Closed-loop control of the system maintained the Sun in the instrument FOV.
- Sunlook testing successfully assessed the integrated system performance.
- Testing interrupted by COVID-19 restrictions, and completion is underway again.





Future Goals: SAGE IV Flight Mission

- SAGE IV is a solar occultation imager capable of meeting or exceeding SAGE-quality ozone, aerosol, and water vapor measurements
- Instrument and spacecraft small enough to fit in a 6U CubeSat form factor for a significant size and cost reduction
- Enables cost-effective sustainability of measurements
- Accelerated schedule that ensures measurement validation by operating concurrently with SAGE III
- Simple design offers extensibility for greater utility:
  - Constellation for better coverage
  - IR extensibility for better H_2O, gain CH_4 & CO_2
  - Expansion to 12U to include spectrometer
  - Solar occultation at Venus or Mars



SAGE IV is a pathfinder for affordable science continuity