NOAA Earth’s Radiation Budget (ERB) Initiative and Stratospheric Aerosol Measurements

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Outline of this Talk
- Motivation
- Overview of NOAA Earth’s Radiation Budget initiative
- Stratospheric aerosol sampling with small balloons

***Acknowledgements:** David Fahey, Troy Thornberry, Dale Hurst, Elizabeth Asher, Karen Rosenlof, Daniel Murphy, Charles Brock, Graham Feingold*

Fiscal Year 2020 Congressional Funding to NOAA

(Commerce, Justice, Science & Related Agencies Appropriations Bill, approved 17 December 2019)

Earth's Radiation Budget. - In lieu of House language regarding Earth's radiation budget, the agreement provides no less than $4,000,000 for modeling, assessments, and, as possible, initial observations and monitoring of stratospheric conditions and the Earth's radiation budget, including the impact of the introduction of material into the stratosphere from changes in natural systems, increased air and space traffic, proposals to inject material to affect climate, and the assessment of solar climate interventions. Within these funds, the agreement further directs OAR to improve the understanding of the impact of atmospheric aerosols on radiative forcing, as well as on the formation of clouds, precipitation, and extreme weather.

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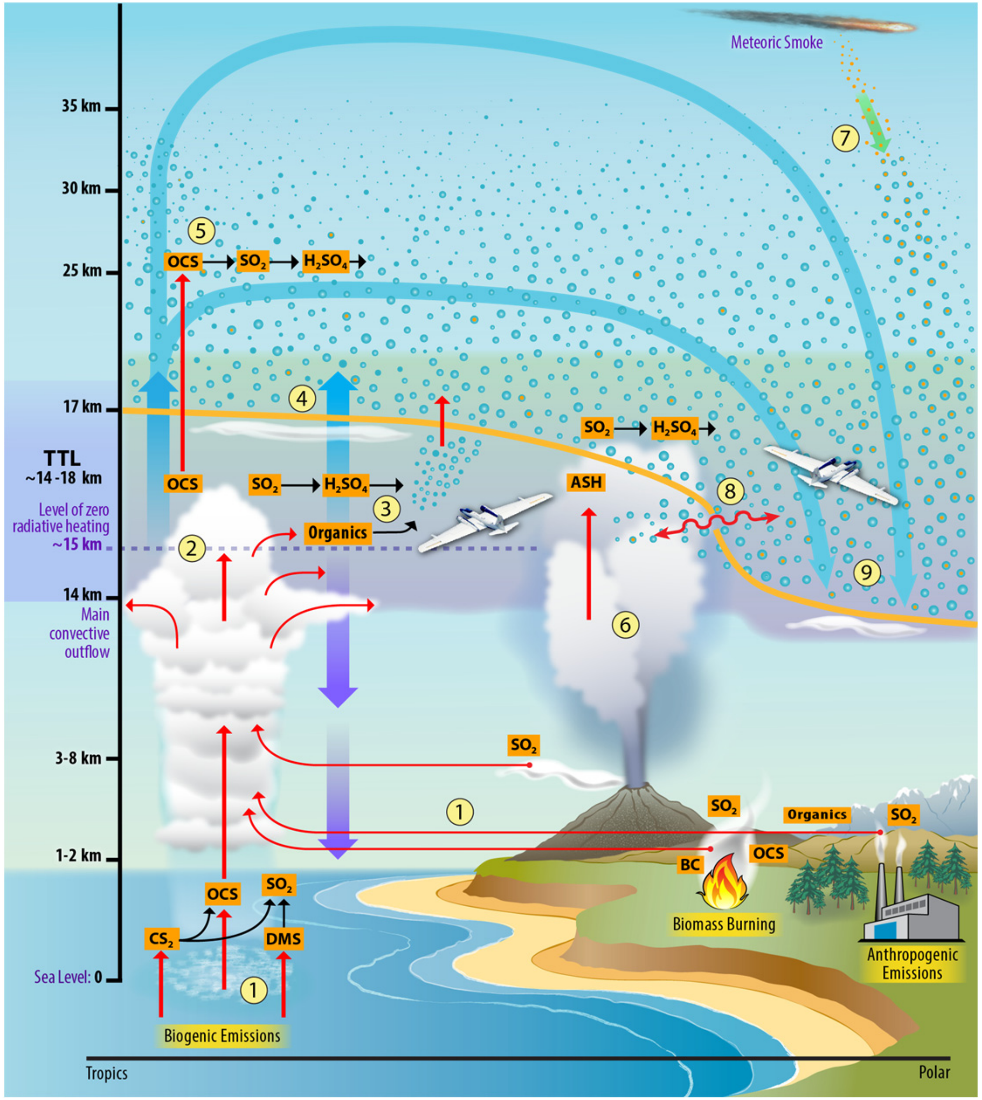
Stratospheric aerosol processes



1. Emissions
2. Deep convection
3. Growth by oxidation, nucleation, & condensation
4. Large scale vertical advection
5. Additional oxidation
6. Volcanic eruptions and pyro-convection
7. Condensation on meteoric smoke particles
8. Stratosphere-troposphere exchange
9. Descent in Brewer-Dobson downwelling

Purple shaded region: operational NASA WB-57 altitude range

Key Goal of NOAA ERB Research: Explore and monitor stratospheric aerosol size distributions under baseline conditions, and following natural and anthropogenic injections of aerosols.

Figure adapted from Kremser et al., *Rev. Geophys.*, 2016.

Climate intervention proposals to reduce peak warming

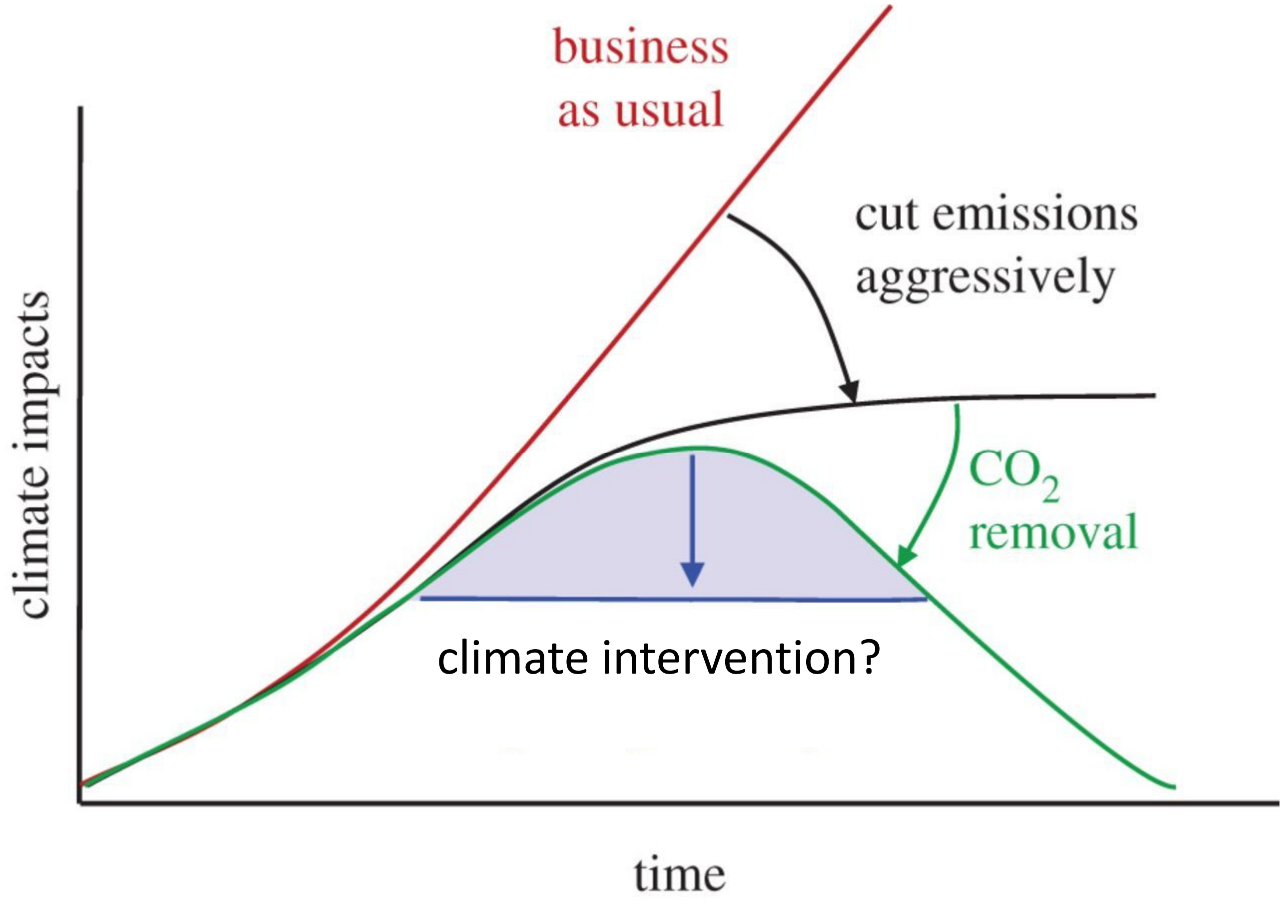
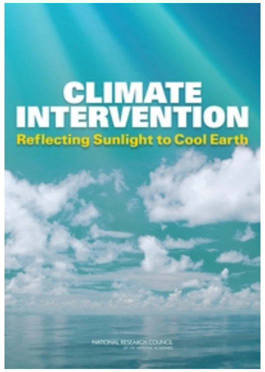


Figure adapted from MacMartin, Ricke, and Keith (2018) *Phil. Trans. R. Soc. A.*

"Should it ever become important for society to cool Earth rapidly, albedo modification approaches (in particular stratospheric aerosol injection (SAI) and possibly marine cloud brightening) are the only ways that have been suggested by which humans could potentially cool Earth within years after deployment."

US National Academies Press, 2015



Two proposed solar radiation management (SRM) approaches

Stratospheric Aerosol Injection (SAI)

- Simulate explosive volcanic eruption with injection or formation of stratospheric aerosol particles
- Default choice: sulfate aerosol particles produced in the stratosphere from SO_2 and H_2SO_4
- Other proposed materials: $CaCO_3$, diamond, titania
- Research needed:
  - Establishing baseline stratospheric conditions
  - Understanding stratospheric aerosol chemistry and microphysics
  - Modeling dynamical responses to stratospheric heating from enhanced aerosol loading
  - Modeling plume effects after aerosol injection
  - Identifying and modeling unintended consequences
  - Developing observations to evaluate implementation

Marine Cloud Brightening (MCB)

- Increase reflectivity of low-altitude marine clouds by injecting sea salt particles
  - Similar to the formation of ship tracks
- Example of Twomey Effect: more particles generate more drops of smaller size, resulting in more reflective clouds
- However, dynamic aerosol perturbations can yield counteracting effects:
  - Smaller drops tend to suppress rain formation and *increase* cloud amount
  - Smaller drops evaporate more readily and *reduce* cloud amount
- Research needed:
  - Quantifying the susceptibility of clouds to aerosol
  - Identifying where/when these conditions exist
  - Developing methods to inject sea salt aerosols
  - Understanding net local-to-global impacts of local aerosol-cloud perturbations
  - Identifying and modeling unintended consequences
  - Developing observations to evaluate implementation

2021 National Academy Report on Climate Intervention

The Board on Atmospheric Sciences and Climate; Division on Earth & Life Studies
The Committee on Science, Technology, and Law; Policy and Global Affairs Division
National Academies of Sciences, Engineering, and Medicine

Focus on stratospheric albedo modification and marine cloud brightening

Discuss research and research governance of these approaches

Sponsored by NOAA, NASA, DOE, and private funds

https://www.nationalacademies.org/our-work/developing-a-research-agenda-and-research-governance-approaches-for-climate-intervention-strategies-that-reflect-sunlight-to-cool-earth

NOAA Earth’s Radiation Budget Initiative

Research Goals

- Improve the understanding of the energy balance of the Earth system
- Establish a capability to observe and monitor stratospheric conditions
- Detect and accurately simulate the impacts of natural and human-caused aerosol injections in the stratosphere and troposphere.

Current Research Partners

- NOAA Chemical Sciences Laboratory (CSL)
- NOAA Global Monitoring Laboratory (GML)
- NOAA Geophysical Fluid Dynamics Laboratory (GFDL)
- NOAA Climate Program Office (CPO)
- Cooperative Institute for Research in Environmental Sciences (CIRES)
- Cooperative Institute for Climate, Ocean and Ecosystem Studies (CICOES)
- National Center for Atmospheric Research (NCAR)

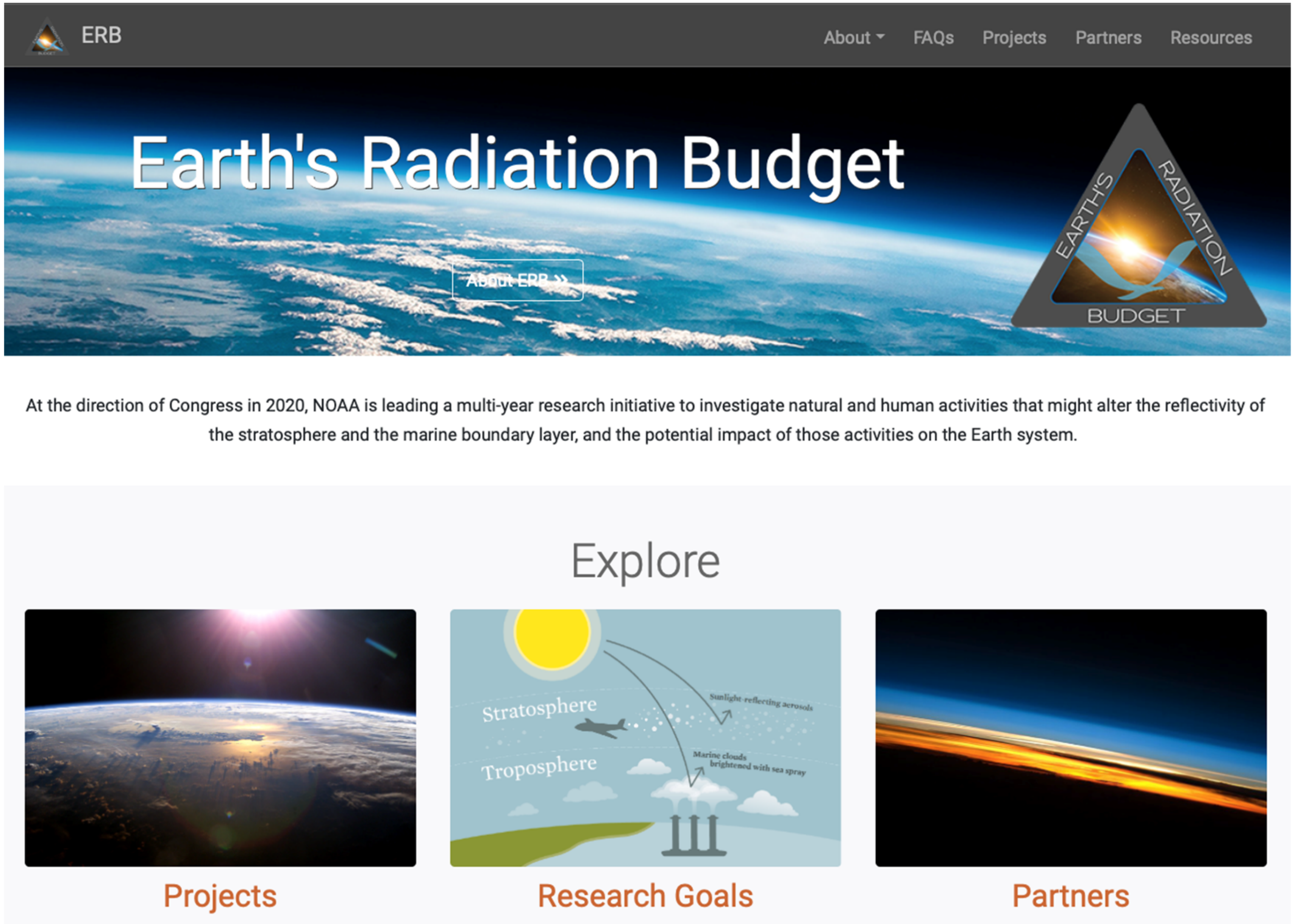
NOAA ERB FY20 Research Projects

1) Observations to understand baseline stratospheric aerosol conditions
   a) Small balloon observations
   b) Instrument development for future aircraft studies
   c) Laboratory studies
2) Modeling stratospheric and tropospheric responses to increased stratospheric aerosols
3) Modeling potential increases to reflectivity of low-altitude marine clouds by aerosol injection

Project Title	Principal Investigators (Orgs.)
Develop a climatology of stratospheric aerosol properties via in situ small balloon measurements	Troy Thornberry (NOAA CSL) Dale Hurst (NOAA GML)
Construct and integrate an airborne instrument suite for measuring a wide range of stratospheric aerosol size distributions	Charles Brock (NOAA CSL)
Develop capability for in-situ stratospheric measurements of OCS and CO	Andrew Rollins (NOAA CSL)
Develop a new CIMS instrument for stratospheric aircraft measurements	Patrick Veres (NOAA CSL) Andrew Rollins (NOAA CSL)
Add a counter-flow virtual impactor (CVI) to the PALMS aerosol instrument	Daniel Murphy (NOAA CSL)
Support laboratory study of the chemical transformations and kinetics of calcium carbonate ($CaCO_3$)	James Burkholder (NOAA CSL)
Improve representation of stratospheric sulfur aerosols in the GFDL Earth System Model version 4 (ESM4)	Vaishali Naik (NOAA GFDL)
Support development of the NCAR Community Earth System Model (CESM) for atmospheric aerosol studies	Simone Tilmes (NCAR)
Analyze NCAR model output (GLENS) to assess impacts of increased stratospheric aerosol on the climate system	Karen Rosenlof (NOAA CSL)
Conduct a model assessment of changes in stratospheric chemistry and circulation due to aerosols from volcanoes and rocket launches	Karen Rosenlof (NOAA CSL)
Conduct large eddy simulation (LES) modeling	Sarah Doherty (U WA/CICOES)
Assess marine cloud brightening (MCB) scenarios	Graham Feingold (NOAA CSL)
Improve representation of cloud brightening and aerosol-cloud interactions in the GFDL Coupled Atmosphere-Ocean Model version 4 (CM4)	Yi Ming (NOAA GFDL)

ERB Website

https://esrl.noaa.gov/csl/research/erb/



Future Directions of ERB Initiative

Current ERB projects are geared towards producing both immediate results and contributing to future research.

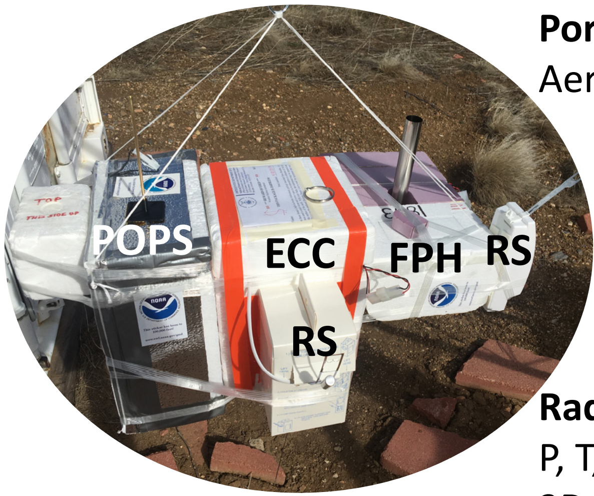
Potential work in subsequent years could include:

1) Geographic expansion of balloon observations
2) Field mission deployment of stratospheric aircraft instruments
3) Further lab testing of possible SRM materials
4) Model studies taking advantage of improvements in the representation of aerosols developed with FY20 funds

Balloon Baseline Stratospheric Aerosol Profiles (B2SAP)

Develop a climatology of stratospheric aerosol properties via *in situ* small balloon measurements

Troy Thornberry, Elizabeth Asher, Ru-Shan Gao (NOAA CSL)
Dale Hurst, Emrys Hall, Allen Jordan, Patrick Cullis (NOAA GML)

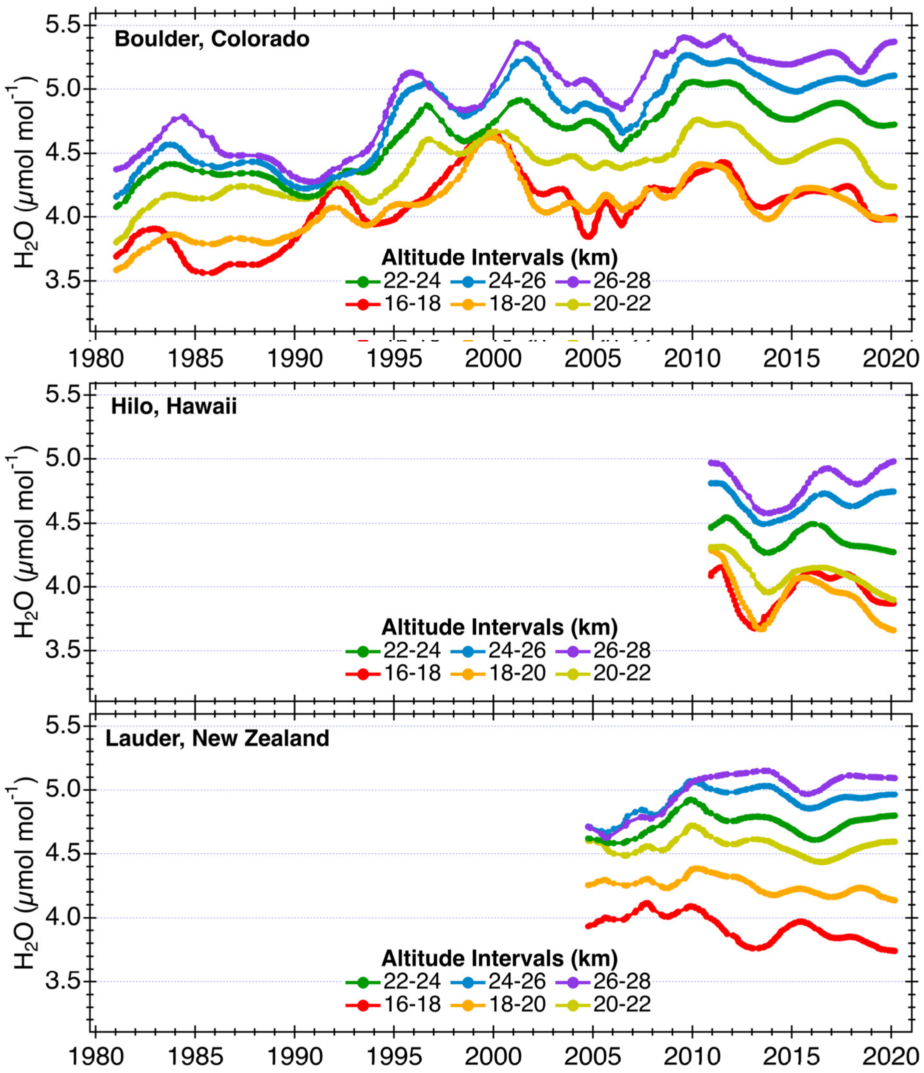


Portable Optical Particle Spectrometer (POPS)
Aerosol number and size distribution (140 nm – 2.5 µm)

Electrochemical Concentration Cell (ECC)
Ozone partial pressure, c_{O3}

NOAA Frost Point Hygrometer (FPH)
Water vapor partial pressure, c_{H2O}

Radiosondes (RS)
P, T, U <13 km, horizontal winds
3D GPS location, telemeters data



B^2SAP Goals

Initial (over the next year):

- Double the frequency of FPH+ECC+POPS soundings at Boulder (to 2+ monthly)

Future:

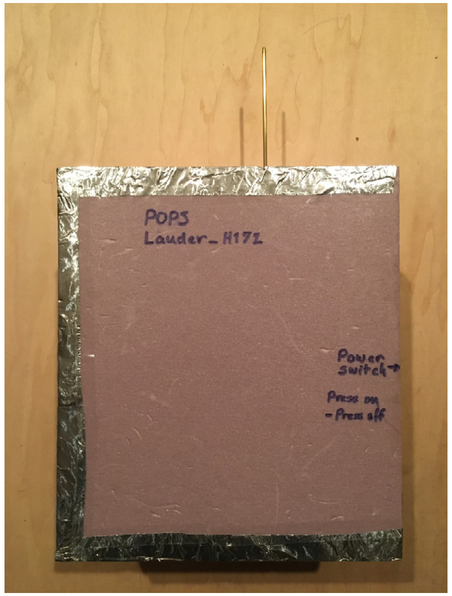
- Expand the addition of POPS to monthly FPH+ECC soundings at Lauder (45°S) (currently 4/year)
- Add POPS to soundings at Hilo (20°N)

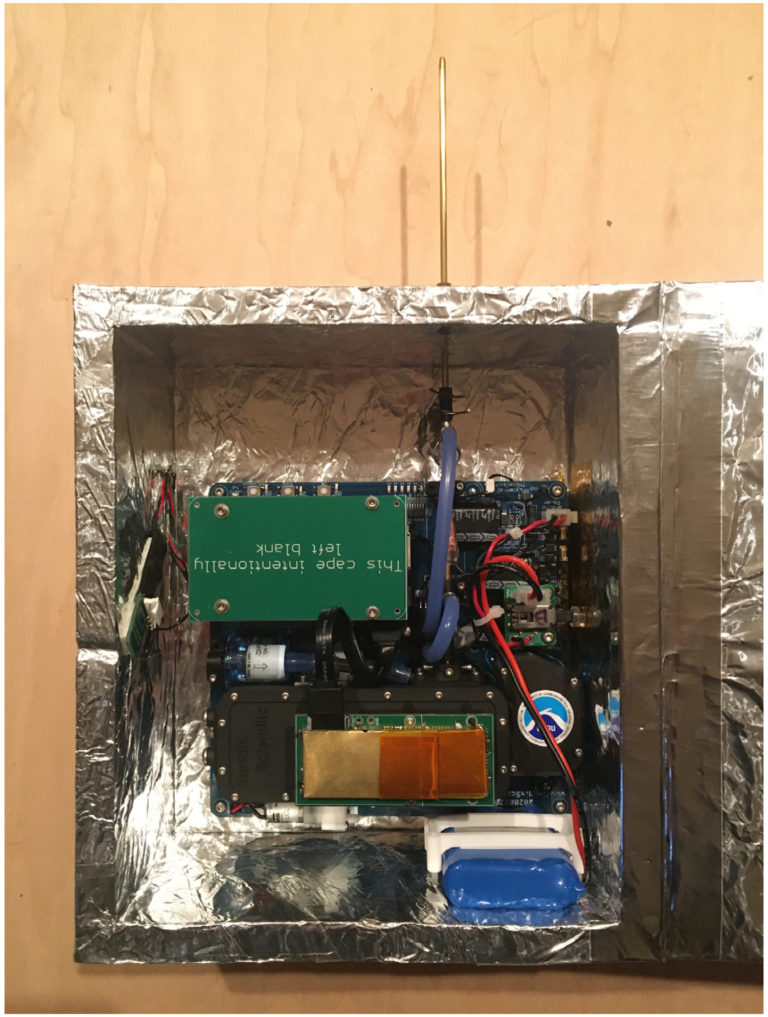
Current FPH record lengths at:

Lauder – 16 yrs

Hilo – 10 yrs

Printed Optical Particle Spectrometer



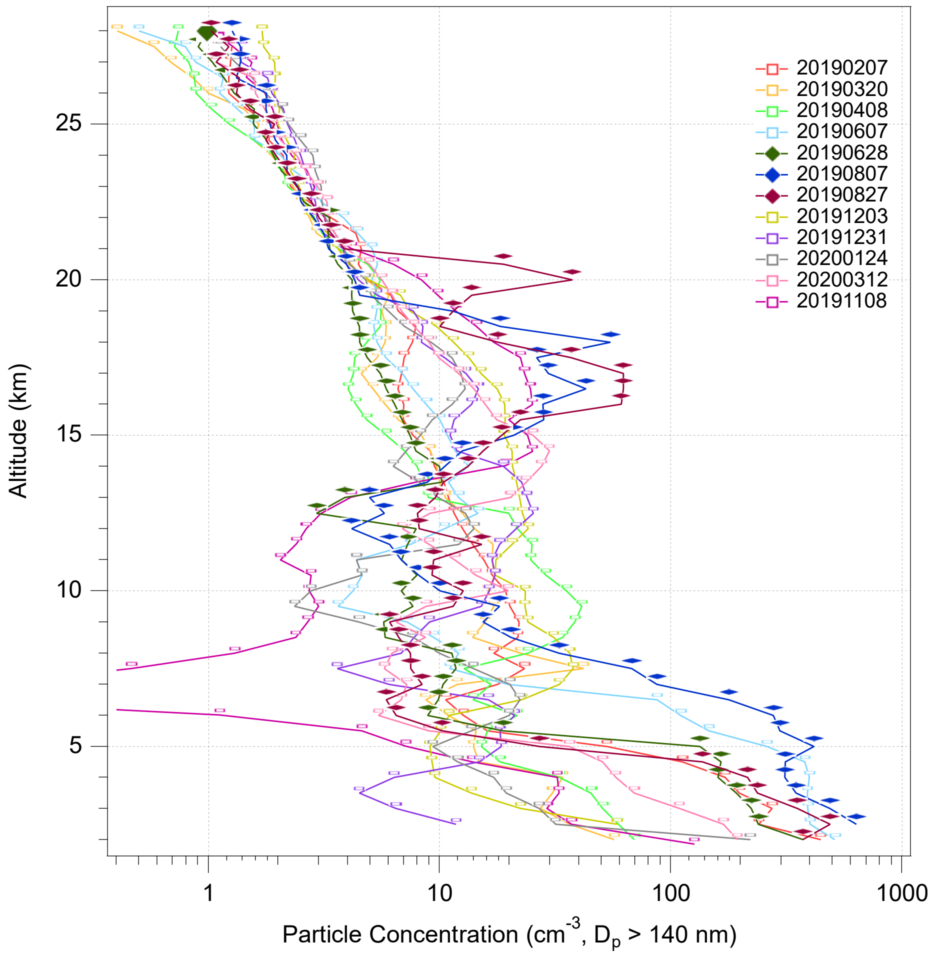


POPS specifications:

- 950 g
- 5 Watts
- Single-particle detection
- 140 – 2500 nm diameter range
- 3 - 5.5 $cm^3\ s^{-1}$ sample flow
- Altitude up to 28 km

Gao et al., AS&T 2016

POPS Aerosol Profiles over Boulder



Thornberry and Asher unpublished data

- NASA supports FPH, ECC, and POPS measurements of stratospheric water vapor, ozone, and aerosols for SAGE III-ISS water vapor, ozone, and aerosol retrieval validation. NASA support of POPS started in January 2019
- POPS sonde launches from Boulder (12/year) and Lauder, NZ (4/year), are timed to match SAGE III-ISS observations

➢ The NOAA ERB B^{2}SAP project will provide higher frequency launches to better capture variability and allow targeting of stratospheric aerosol perturbation events

Summary

- At the direction of Congress, NOAA is leading the Earth’s Radiation Budget (ERB) initiative
- Initial research goals of the ERB initiative:
  - Improving the understanding of the energy balance of the Earth system
  - Establishing a capability to observe and monitor stratospheric conditions
  - Detecting and accurately simulating the impacts of natural and human-caused aerosol injections in the stratosphere and troposphere on Earth’s radiation balance, weather, climate, and other Earth systems
- Current ERB projects include:
  - Initial observations of baseline aerosol conditions using instrumented balloons
  - Developing new instruments for future stratospheric aircraft campaigns
  - Performing laboratory studies on potential stratospheric solar radiation management materials
  - Developing and improving models of stratospheric and tropospheric responses to increases in stratospheric aerosol loading
  - Modeling potential aerosol injections to increase the reflectivity of low-altitude marine clouds
- The addition of an optical particle sensor to NOAA’s existing small-balloon sampling of ozone and water vapor is enabling the development of a stratospheric aerosol climatology, and providing a powerful combination of stratospheric ozone, water vapor and aerosol data for model validation.