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Path towards developing isotopically-enabled Lagrangian models of the stratosphere in conjunction with global models

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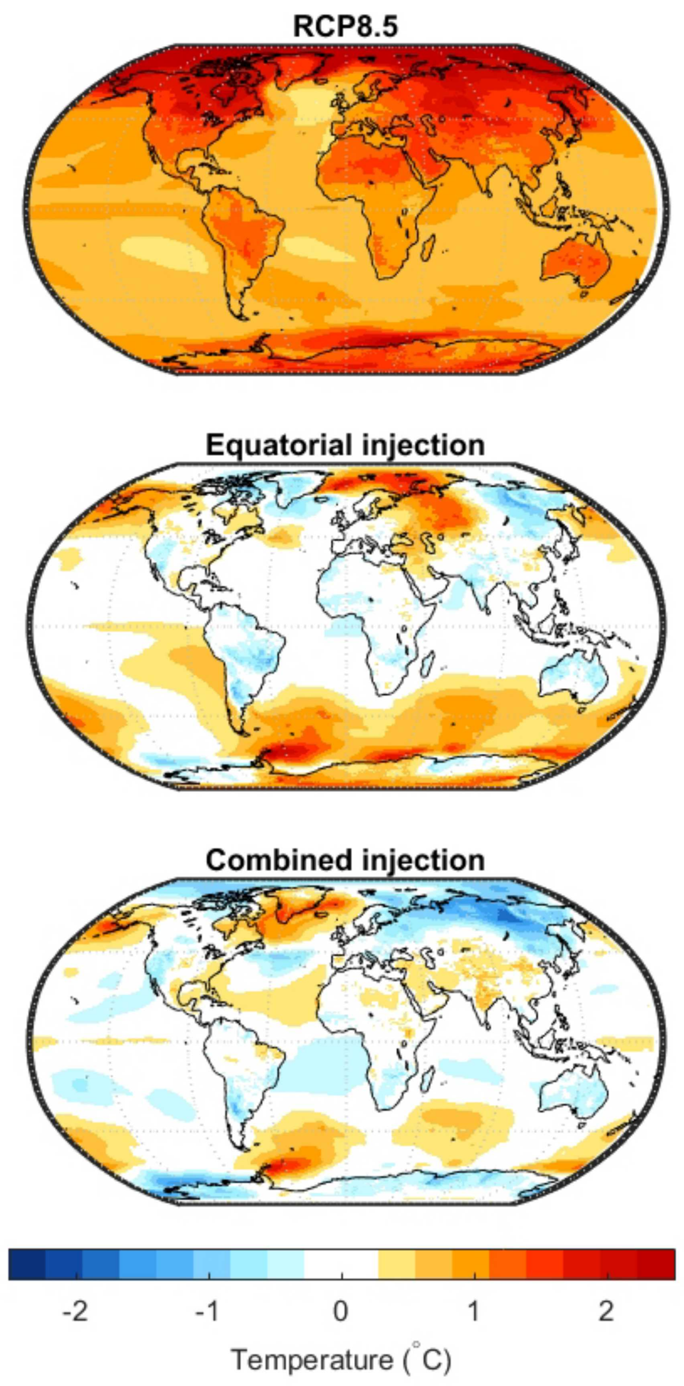
Motivation and Science Questions

There are significant gaps in our understanding of the stratosphere and the climate risks of solar radiation management are assessed almost exclusively from models. Stratospheric humidity has increased over the last 50 years (Rosenlof et al. 2001). Though, the stratosphere and troposphere exchange water vapor and energy regularly, the processes controlling stratospheric water vapor are not well understood. The isotopic composition of water vapor could be used to determine the dominant processes (e.g. relative influence of overshooting convection, large scale circulation, or in situ dehydration).

Through this project we aim to address questions such as:

- How will the changing dynamics of the atmosphere affect the ability of the stratosphere to maintain injected aerosols?
- Does water vapor exchange between the troposphere and stratosphere reduce the ability of the stratosphere to maintain injected aerosols?

By measuring the chemical composition of the lower stratosphere before and after these stratospheric events at seasonal intervals, we hypothesize that after these events, the ability of the stratosphere to maintain geoengineered particulate injections will greatly reduce. To begin testing this hypothesis, measurements of the lower stratosphere will be taken from Sandia's high altitude solar balloons.



Top – RCP8.5 projected temperature change (no geoengineering)
Middle – Residual temperature response due to equatorial injection
Bottom – Residual temperature response due to injection at multiple latitudes
MacMartin et al. (2017)

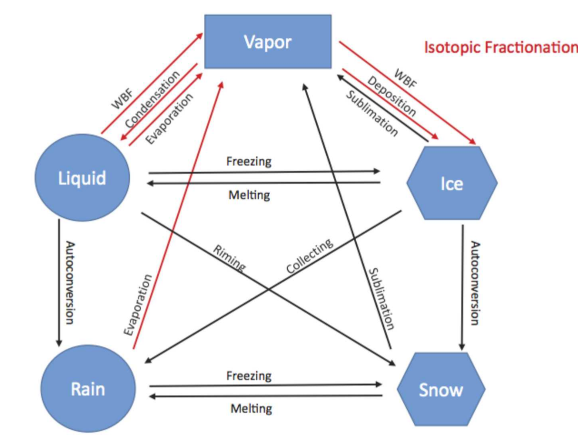
Model Overview: Isotopically-enabled Global Climate Models

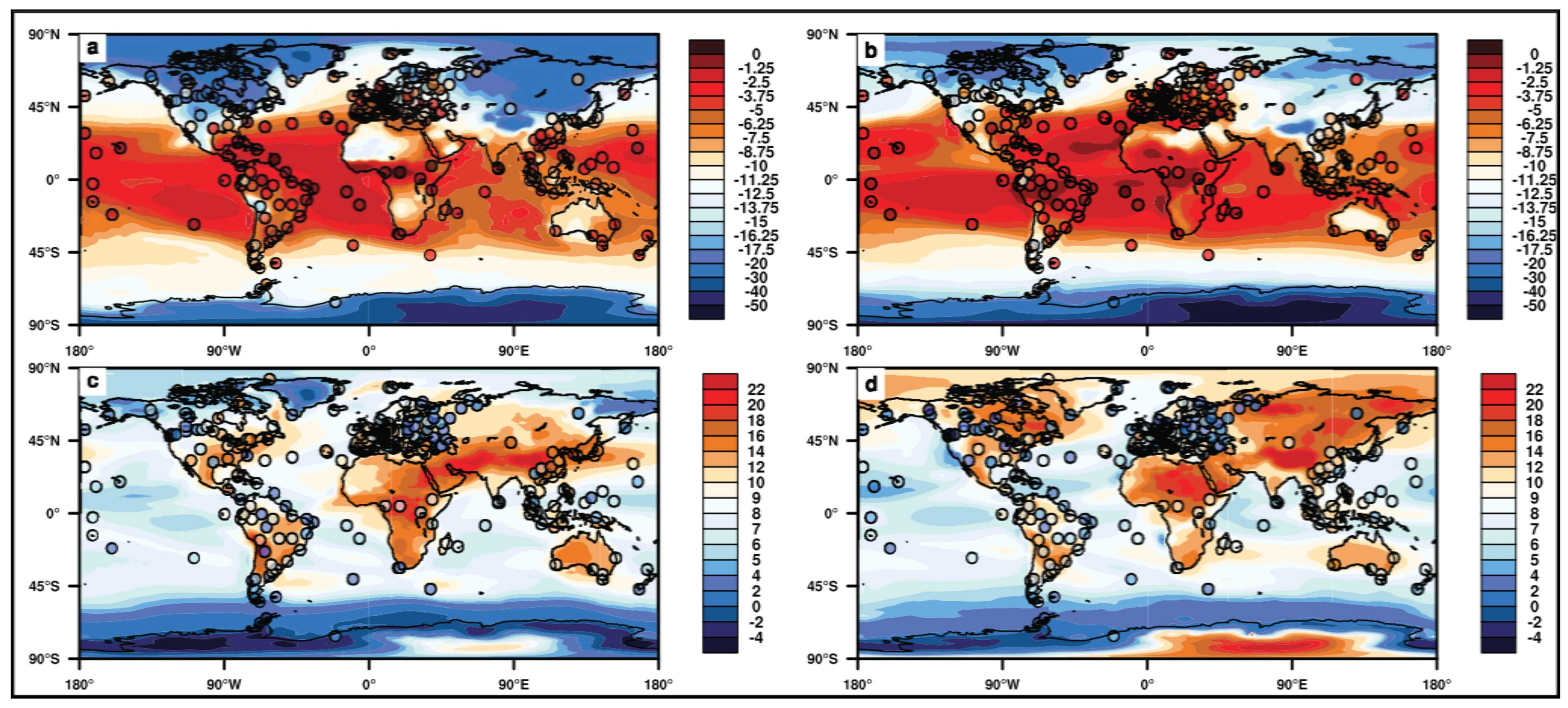
This work will be a basis for better understanding the impact of stratospheric intrusions using stable isotopes as atmospheric tracers.

iCESM

- Includes fractionation processes for liquid-vapor, precipitation-vapor, and vapor-ice transitions

Below – Simulated DJF and JJA averages (1980–2014) for $\delta^{18}O$ and d-excess of precipitation from iCESM.
Right – CAM5 microphysical processes with the fractionation processes highlighted with red arrows.
Nusbaumer et al. (2017)





WACCM

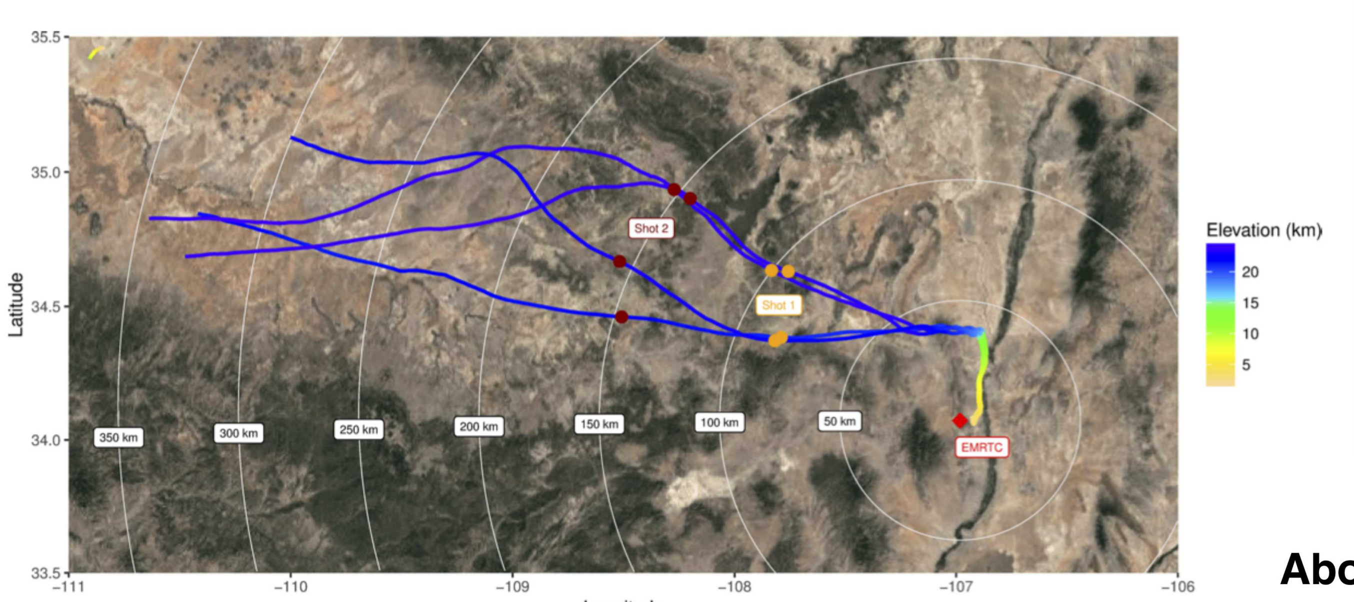
- "Go-to" model for stratospheric dynamics
- We seek to find out more about model capabilities for water isotopologues

E3SM

- Department of Energy's climate model - Energy Exascale Earth System Model (E3SM)
- Improvements to the atmosphere: Updated microphysics, aerosols, and ozone photochemistry (see Golaz et al., 2019)
- Increased model vertical resolution (72L) and model top height (60 km) relative to CAM5

Stratospheric Sampling Overview

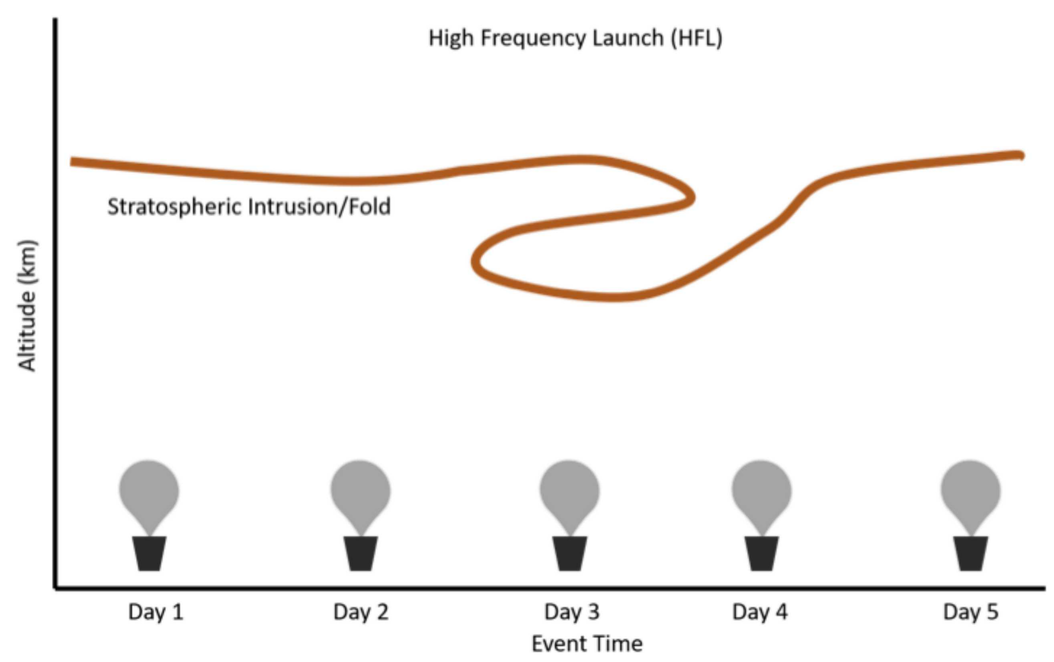
- Deploy recoverable high-latitude solar balloons to measure naturally-occurring gases with lightweight instrumentation including a micro-collection capsule and a miniature gas sampler.
- Use physical models to improve understanding of the samples obtained along the balloon path, stratospheric dynamics, and air exchanges before and after stratospheric weather events.

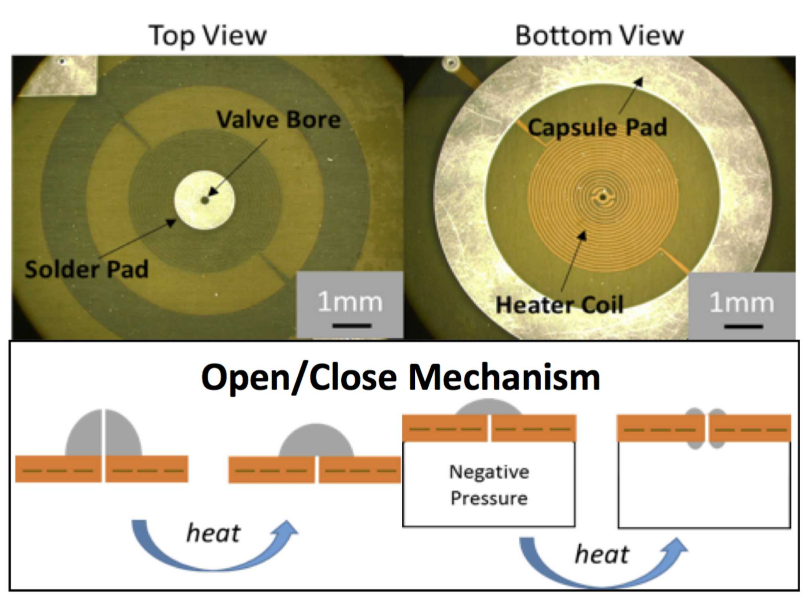


Above – Solar Balloon flight path and elevation deployed from EMRTC.

Above – Solar Balloon in flight.

Right – Schematic of potential stratospheric sampling strategy to measure temporal and spatial variation in a STE in the southwestern United States.

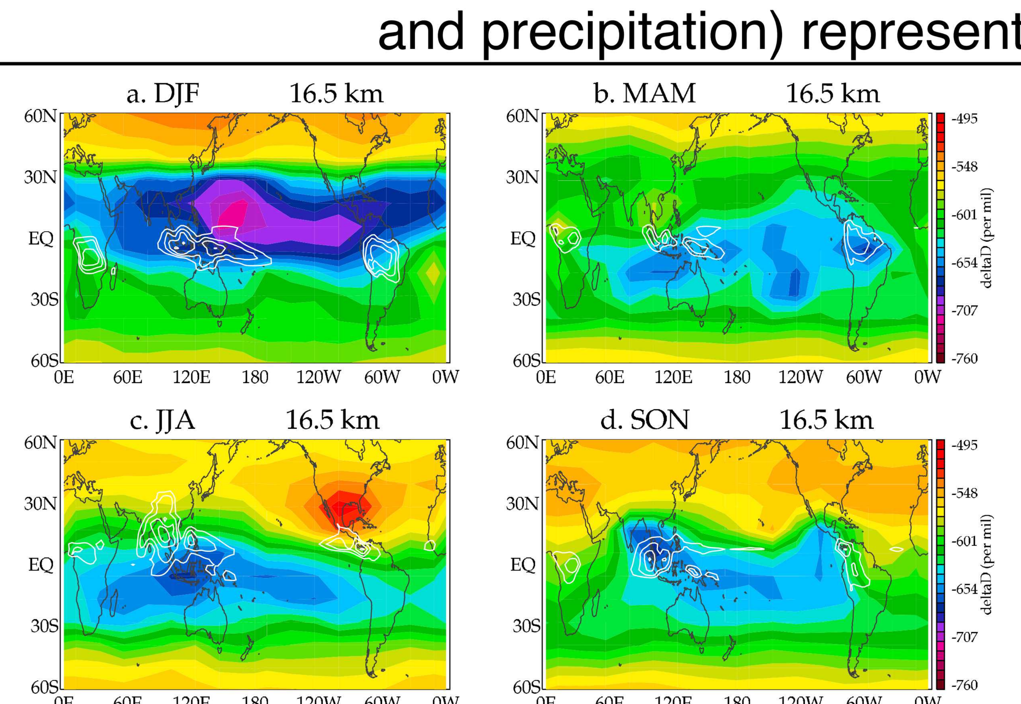




Left – Resistive heater solder valve/capsule designed for remote gas collection and transport for GCxGC/MS analysis.

Path Forward: Model Development & Evaluation

Model	Science Question
CLaMS	• Under what conditions do parcel model assumptions fail?
WACCM & E3SM & iCESM	• Does the global model capture STE? • What is the magnitude of mixing in the UTLS? • How well is the measured isotopic composition (vapor and precipitation) represented in the model?



Left – Cross sections of δD at 16.5 km for DJF, MAM, JJA, and SON from gridded ACE-FTS measurements (2004-2009).
Randel et al. (2012)

- Gather observations of δD and $\delta^{18}O$ of vapor and precipitation for model validation (e.g. satellite observations, precipitation surface measurements)
- Run simulations in a nudged configuration for iCESM, E3SM, and WACCM
  - Purpose: Inter-model comparison of known STE events in the NH and assess model fidelity and identify precursors to these events.
  - Use the simulation results to identify which model to use going forward.
- If E3SM compares well, develop iE3SM
- Run simulations in nudged configuration in iE3SM
  - How does the higher model top, improved vertical resolution, and microphysics of iE3SM and compare to iCESM output and observations of the isotopic composition of water vapor and precipitation?

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