

Towards isotopically-enabled models of the stratosphere with implications for geoengineering

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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).

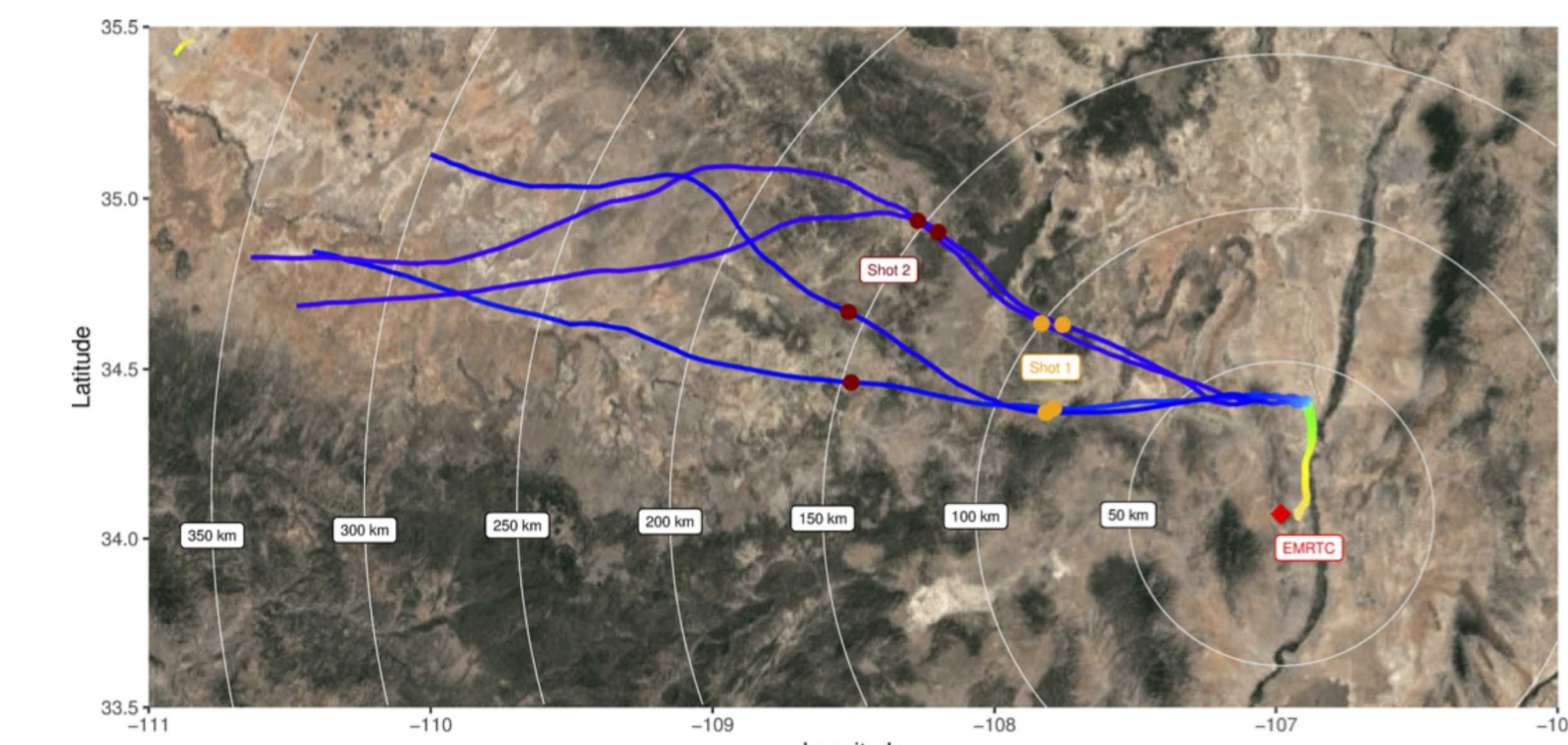
Through this project we aim to address questions such as:

- 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?

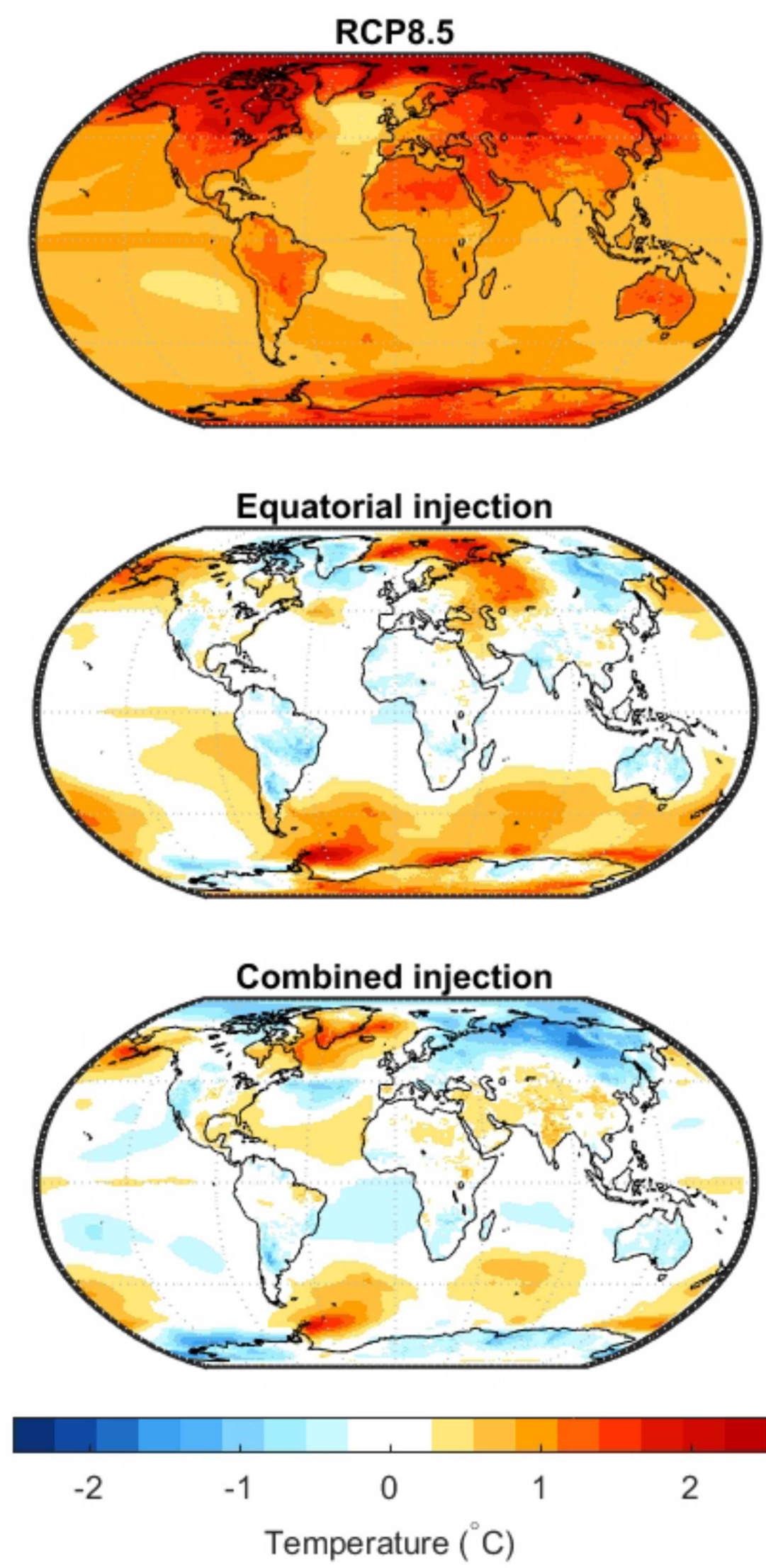
By measuring the chemical composition of the lower stratosphere before and after these stratospheric events at seasonal intervals, we hypothesize that after these events, the ability of the stratosphere to maintain geoengineered particulate injections will greatly reduce. To begin testing this hypothesis,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

Stratospheric Sampling Overview

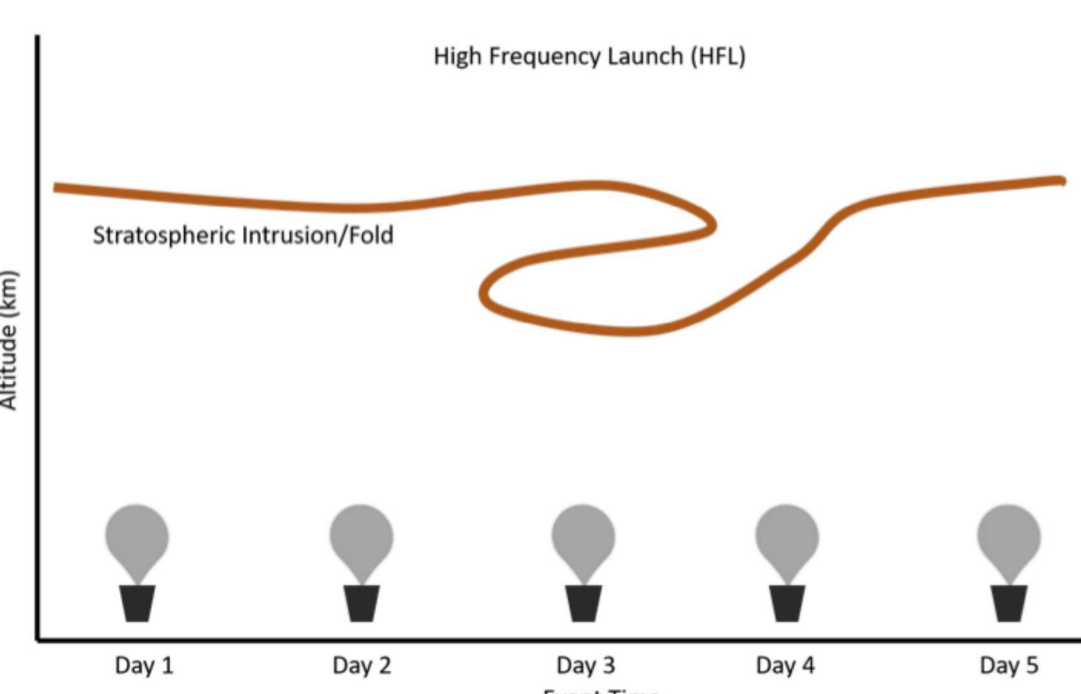
- Deploy recoverable high-latitude solar balloons to measure naturally-occurring gases with lightweight instrumentation including a micro-collection capsule and a miniature gas sampler.
- Use physical models to improve understanding of the samples obtained along the balloon path, stratospheric dynamics,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



Above – Solar Balloon flight path and elevation deployed from EMRTC.
Right Top – Team balloon build.
Right Bottom – Schematic of potential stratospheric sampling strategy to measure temporal and spatial variation in a STE in the southwestern United States.



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 & Preliminary Results

Purpose: Inter-model comparison of known STE events in the NH and assess model fidelity and identify precursors to these events. This work will be a basis for better understanding the impact of stratospheric intrusions using stable isotopes as atmospheric tracers.

iCESM

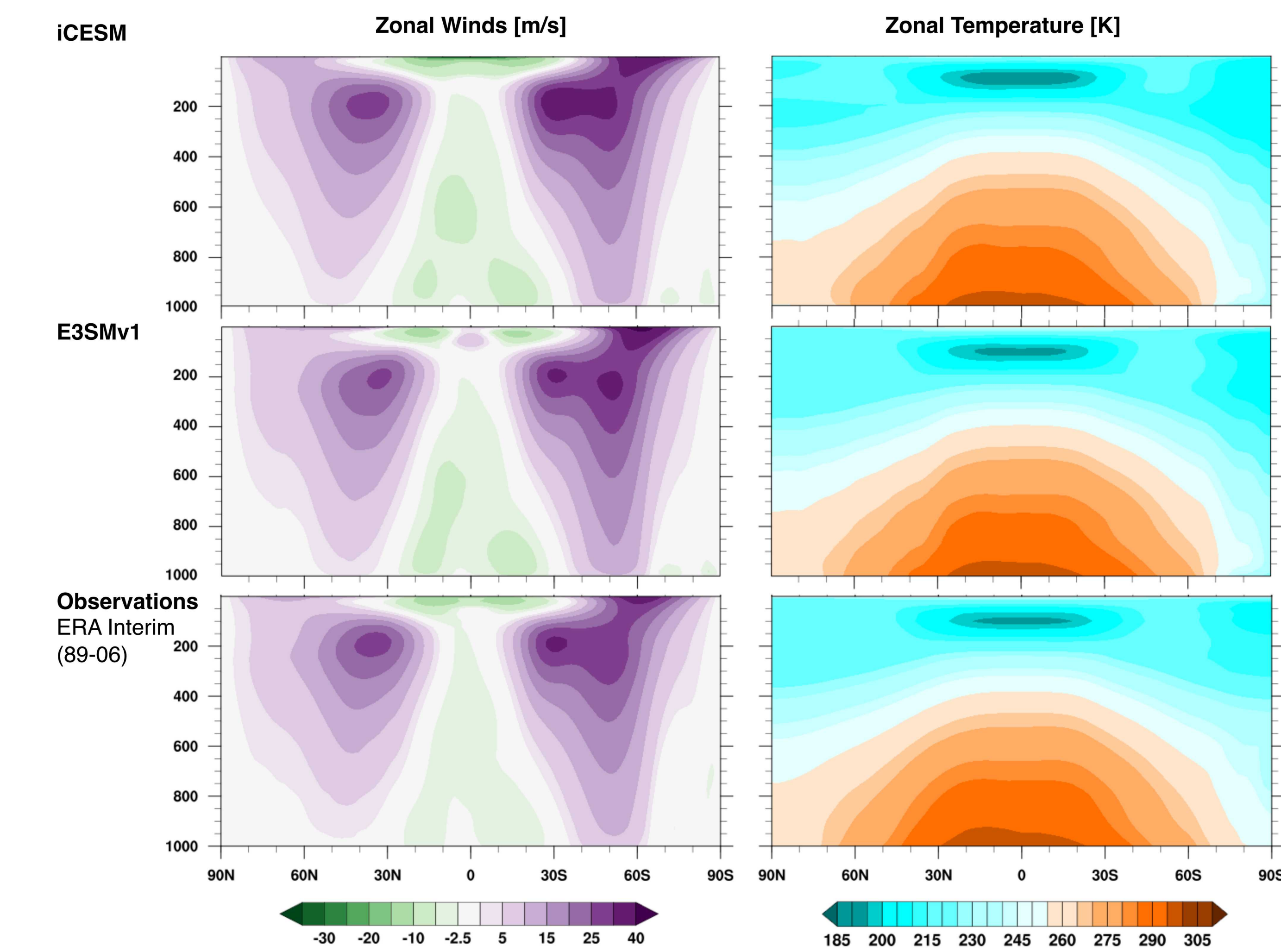
- Includes fractionation processes for liquid-vapor, precipitation-vapor, and vapor-ice transitions

WACCM

- “Go-to” model for stratospheric dynamics

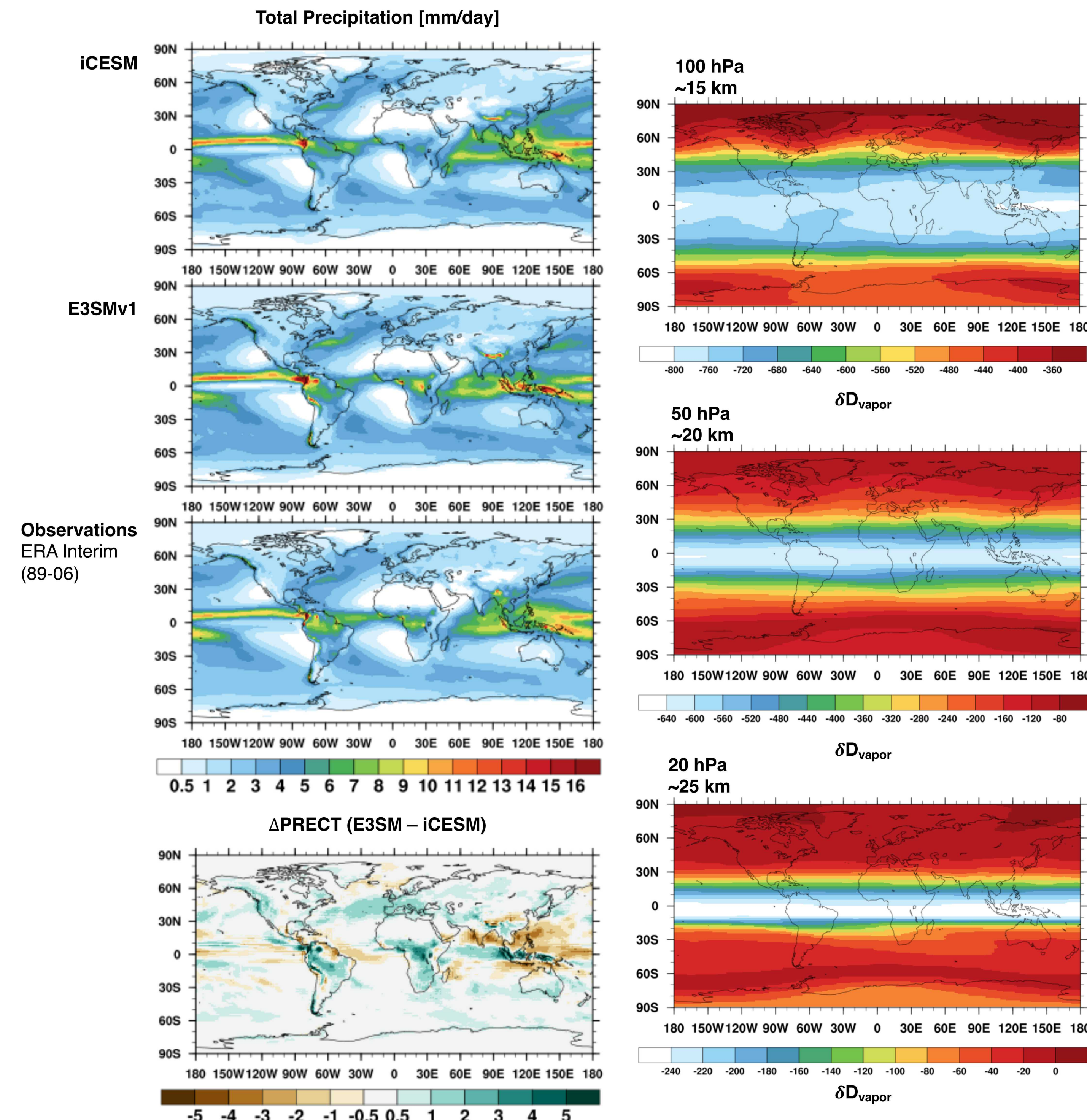
E3SM

- 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



Path Forward: Model Development & Evaluation

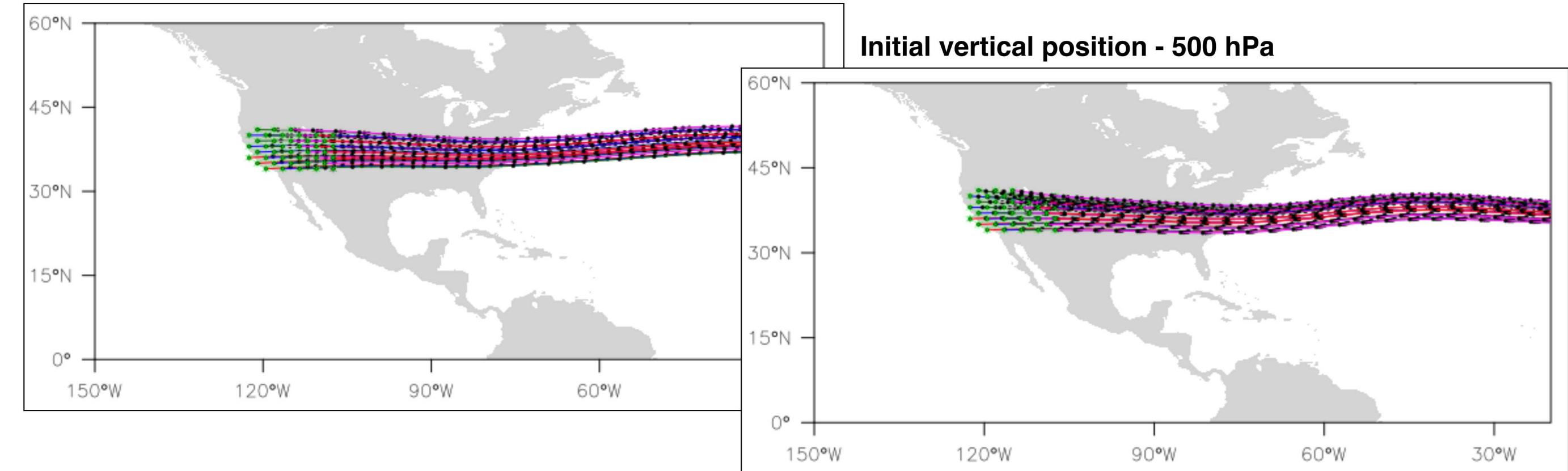
- Gather observations of δD and $\delta^{18}O$ of vapor and precipitation for model validation (e.g. satellite observations, precipitation surface measurements)
- Run simulations in a nudged configuration for iCESM and E3SM
- Following the methodology of Skerlak et al. (2014), do the models reproduce the climatology of STEs?
- Use the simulation results to identify which model to use going forward.
- If E3SM compares well, consider the development of 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?



Preliminary CLaMS results for 3D iCESM trajectories over the Southwest

CLaMS will be used to quantify mass exchanges between the troposphere and stratosphere after the work of Skerlak et al. (2014)

Initial vertical position - 100 hPa



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?



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