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2024 Sandia FORCEE Summer Research Symposium

Quantifying global atmospheric circulation changes in response to stratospheric volcanic aerosols

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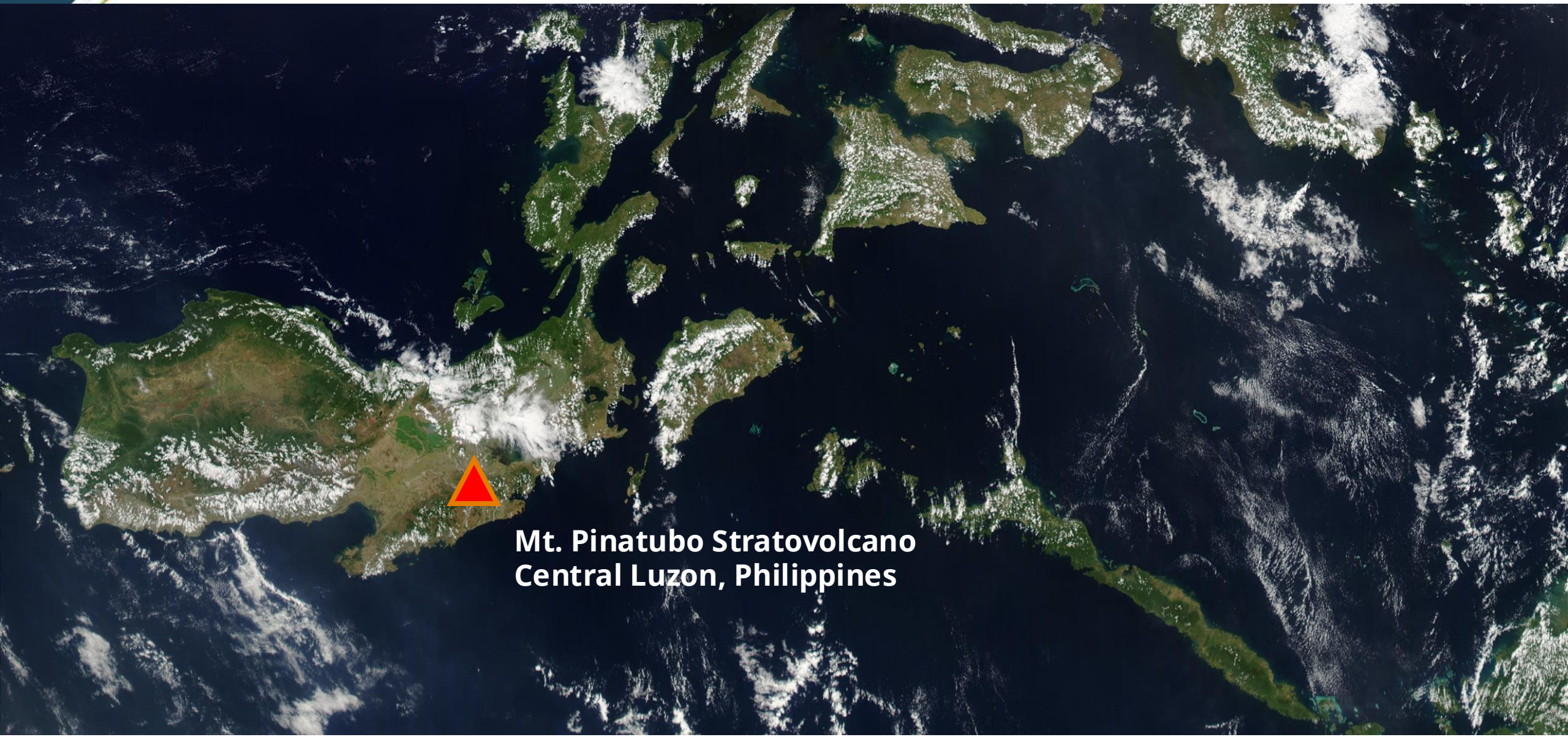
U.S. DEPARTMENT OF ENERGY

NNSA

Outline

1. Describe the Mt. Pinatubo Eruption
2. Basic Atmospheric Impacts
3. Tracer Impacts and Overturning Circulation
4. TEM?

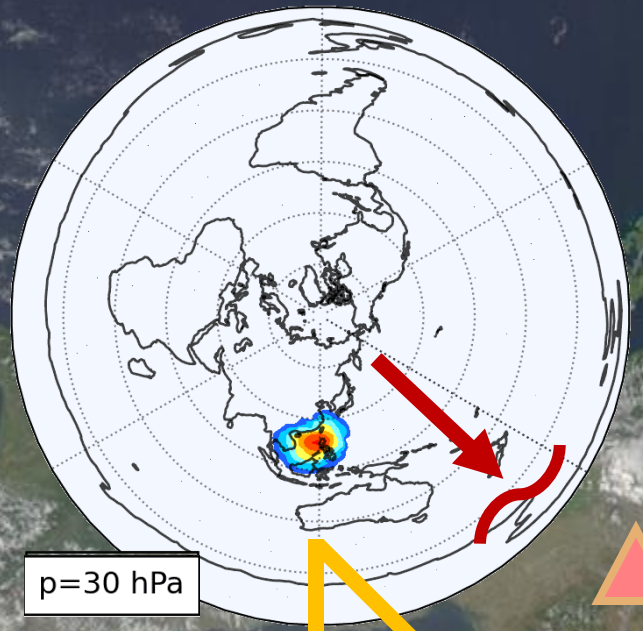
The 1991 Eruption of Mt. Pinatubo



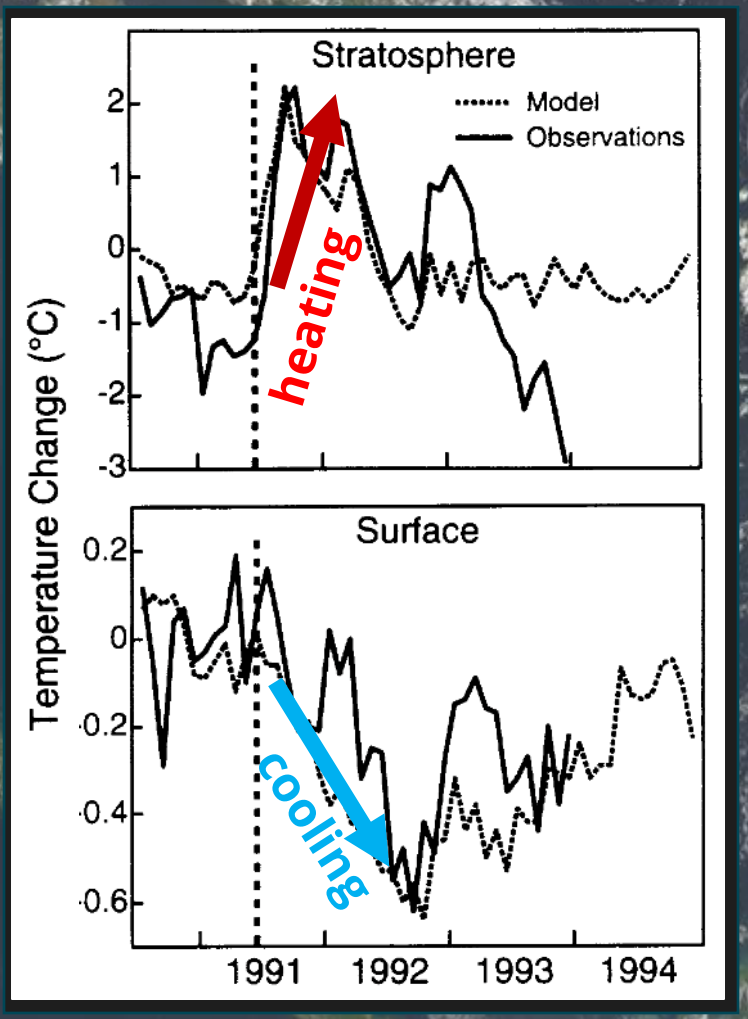
The 1991 Eruption of Mt. Pinatubo

The 1991 Eruption of Mt. Pinatubo

90-day Aerosol Plume



LW Absorption
SW Reflection



Self et al. 1993

Problem Statement

Question:

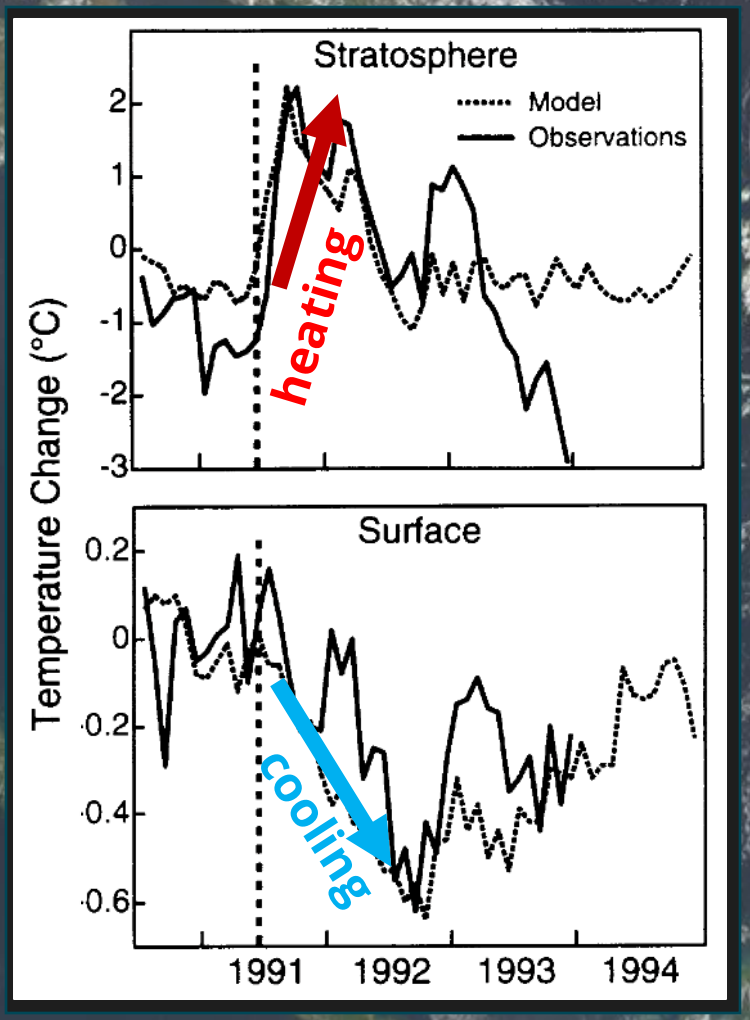
What happens to the general circulation of the atmosphere in response to this volcanic aerosol temperature signature?

- **direct effects?**
- **indirect (“downstream”) effects?**
- **physical mechanisms?**

Why we care:

In the an age of climate change and international consideration of geoengineering mitigation activities, it is crucial that we:

- **understand atmospheric ”side effects” of aerosol radiative heating**
- **identify mechanisms by which stratospheric heating can couple to surface conditions beyond temperature**



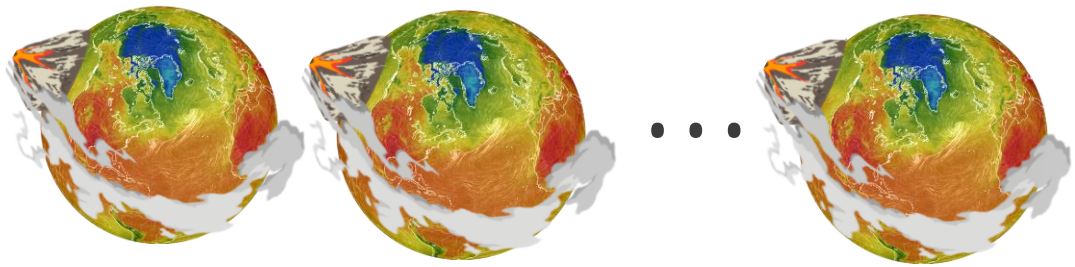
Self et al. 1993

Numerical Experiment Design

E3SM Energy Exascale Earth System Model

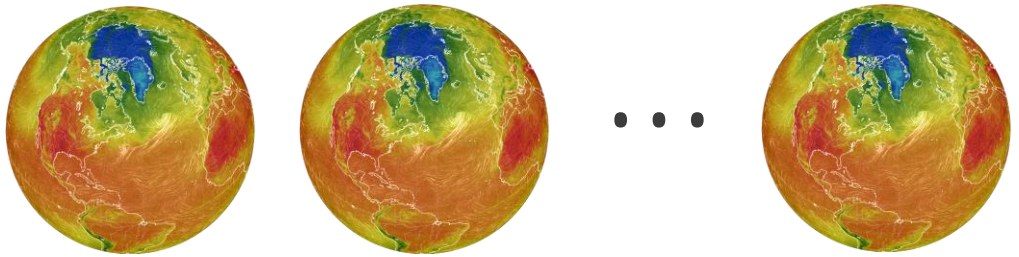
Pinatubo simulation ensemble

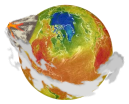
member 1 *member 2* ... *member N*



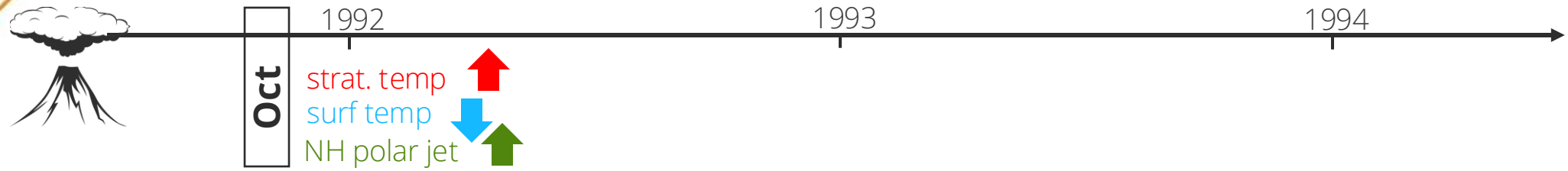
reference simulation ensemble

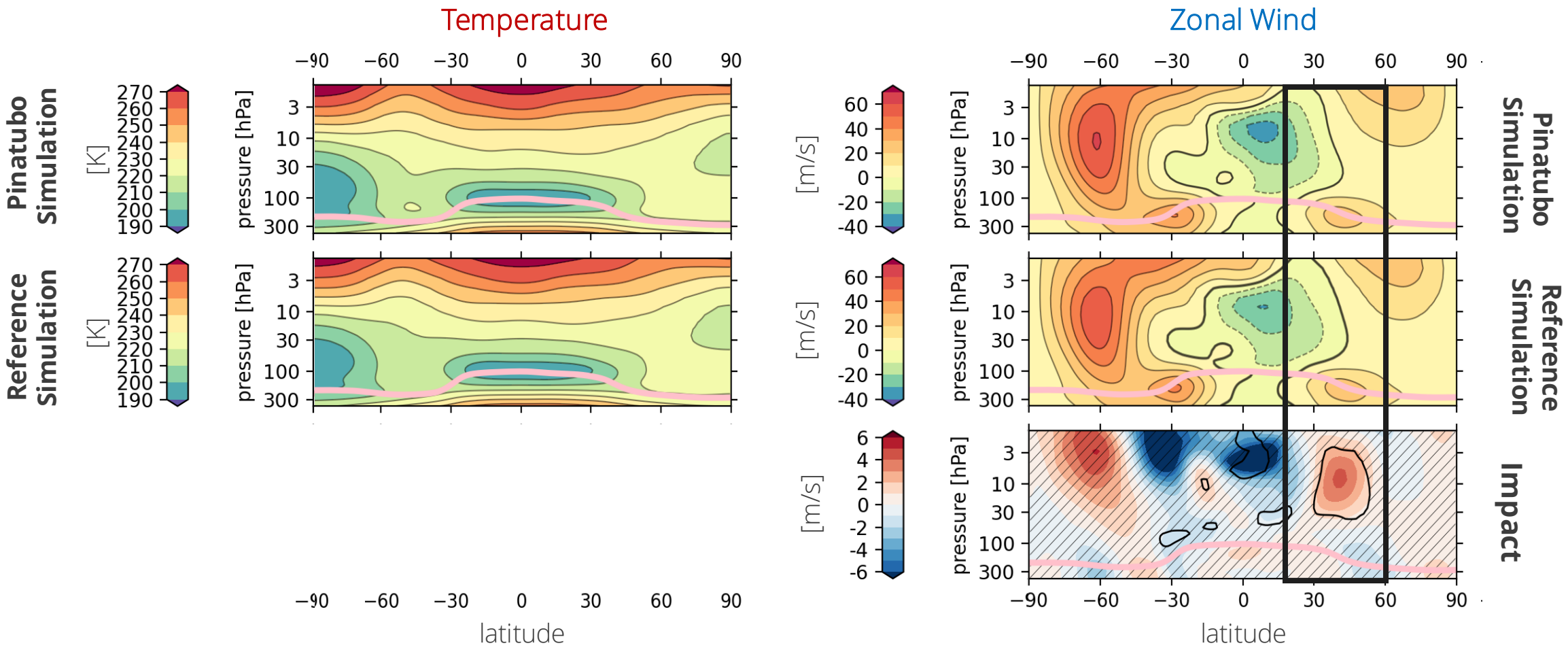
member 1 *member 2* ... *member N*



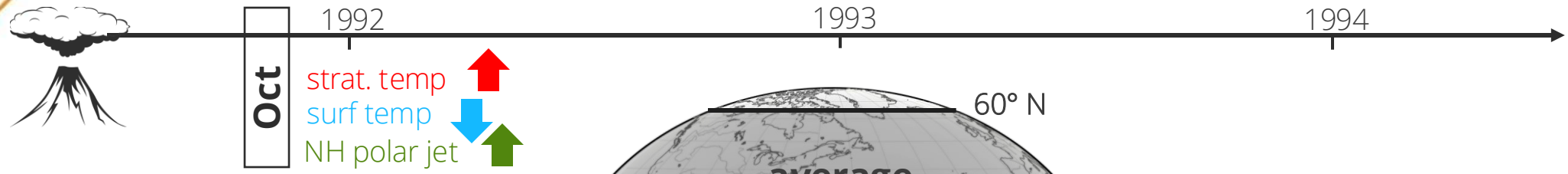
$\frac{1}{N}\sum$  (-) = $\frac{1}{N}\sum$ *impact significance*

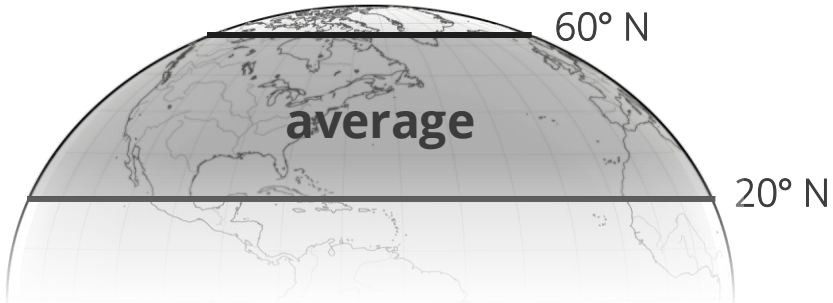
Experiment Results: modification of temperature and wind



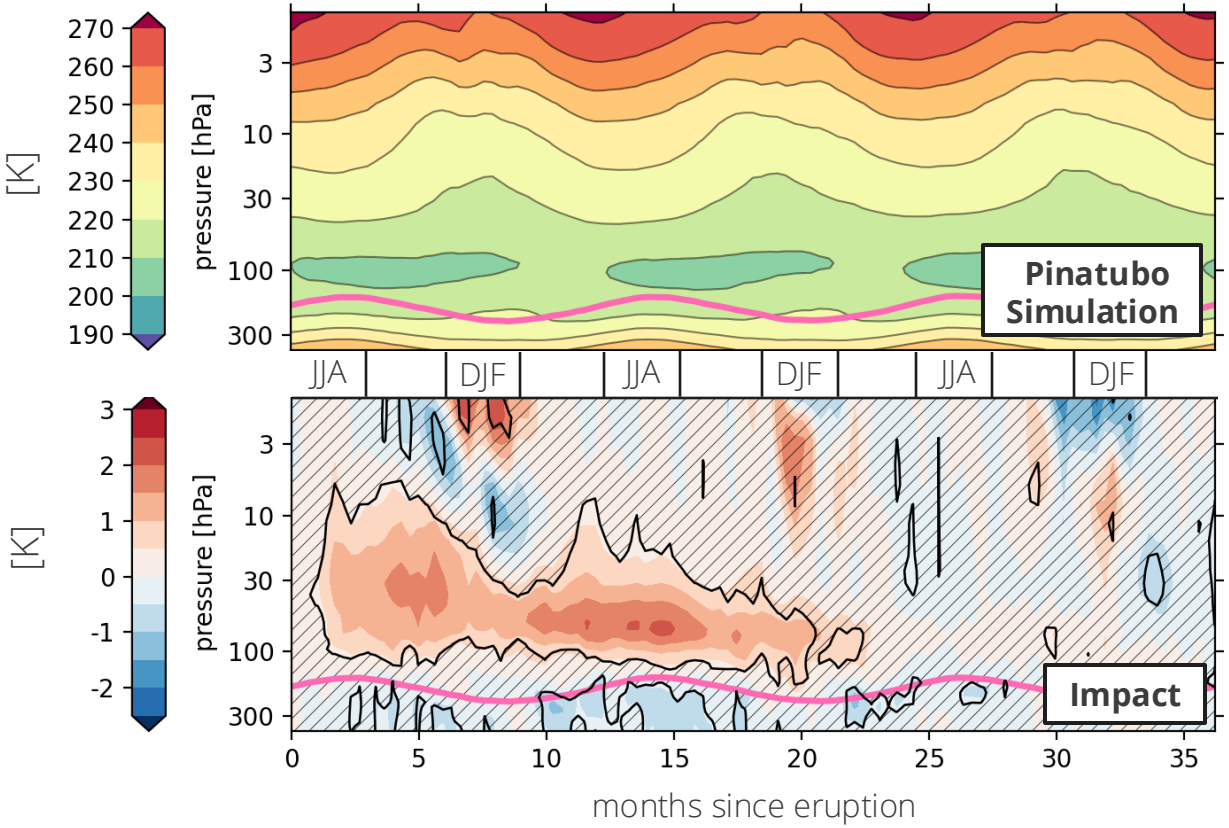


Experiment Results: modification of temperature and wind

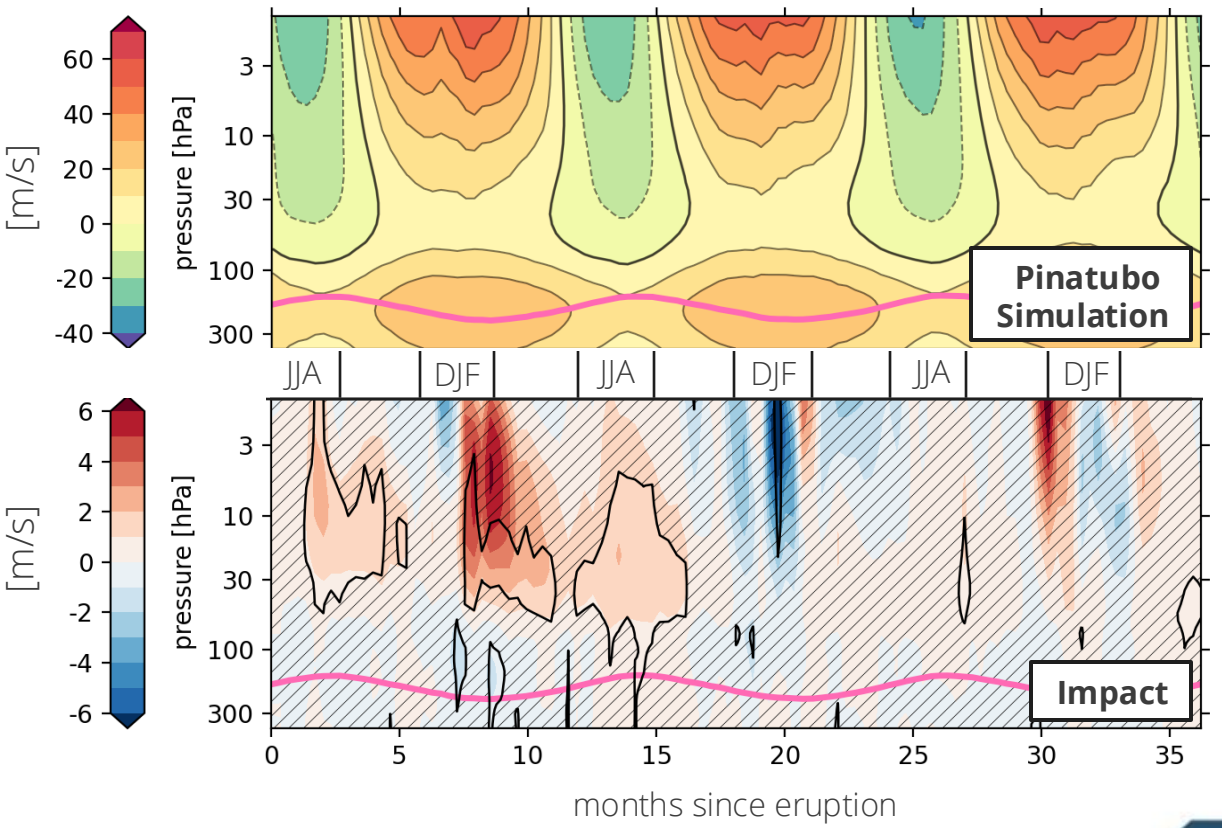




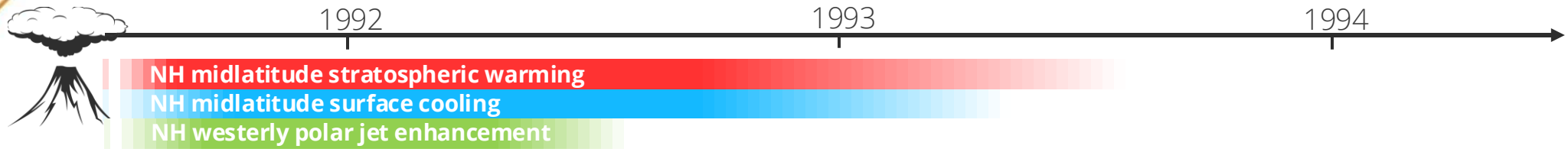
Temperature



Zonal Wind

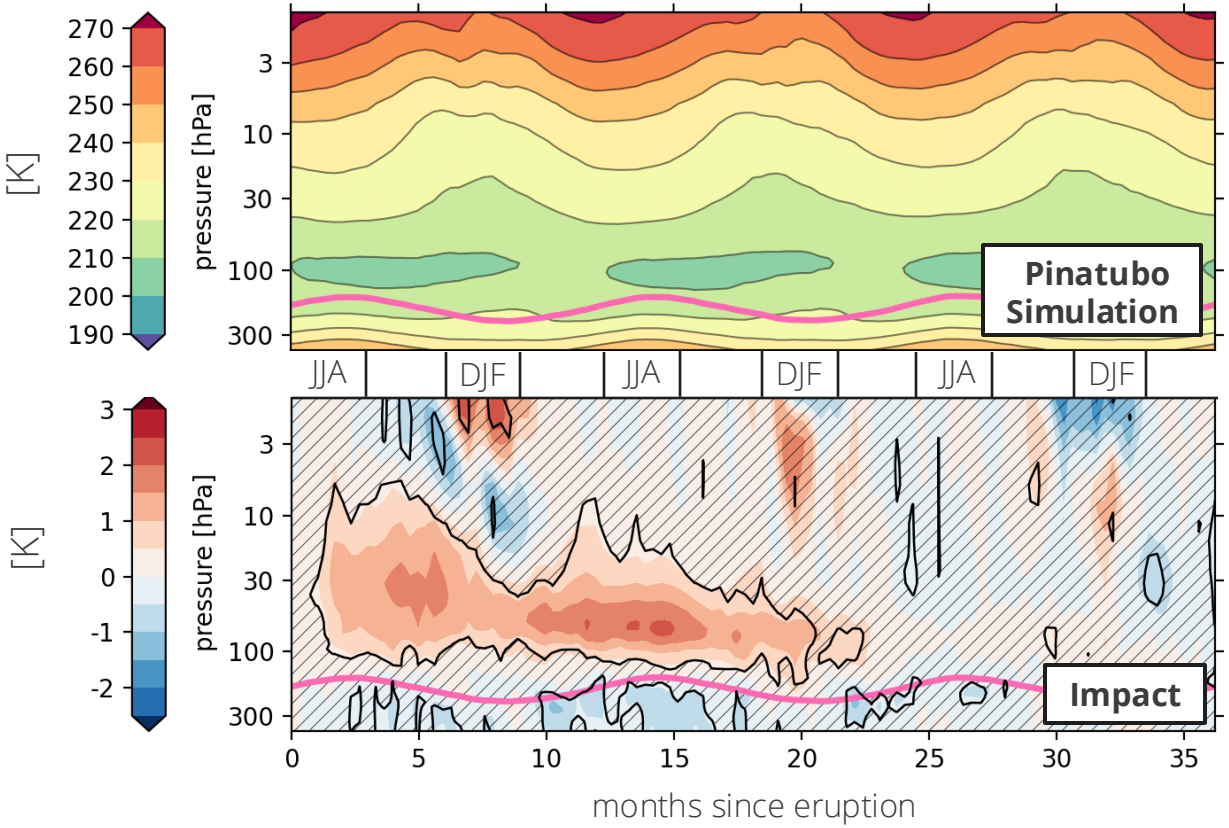


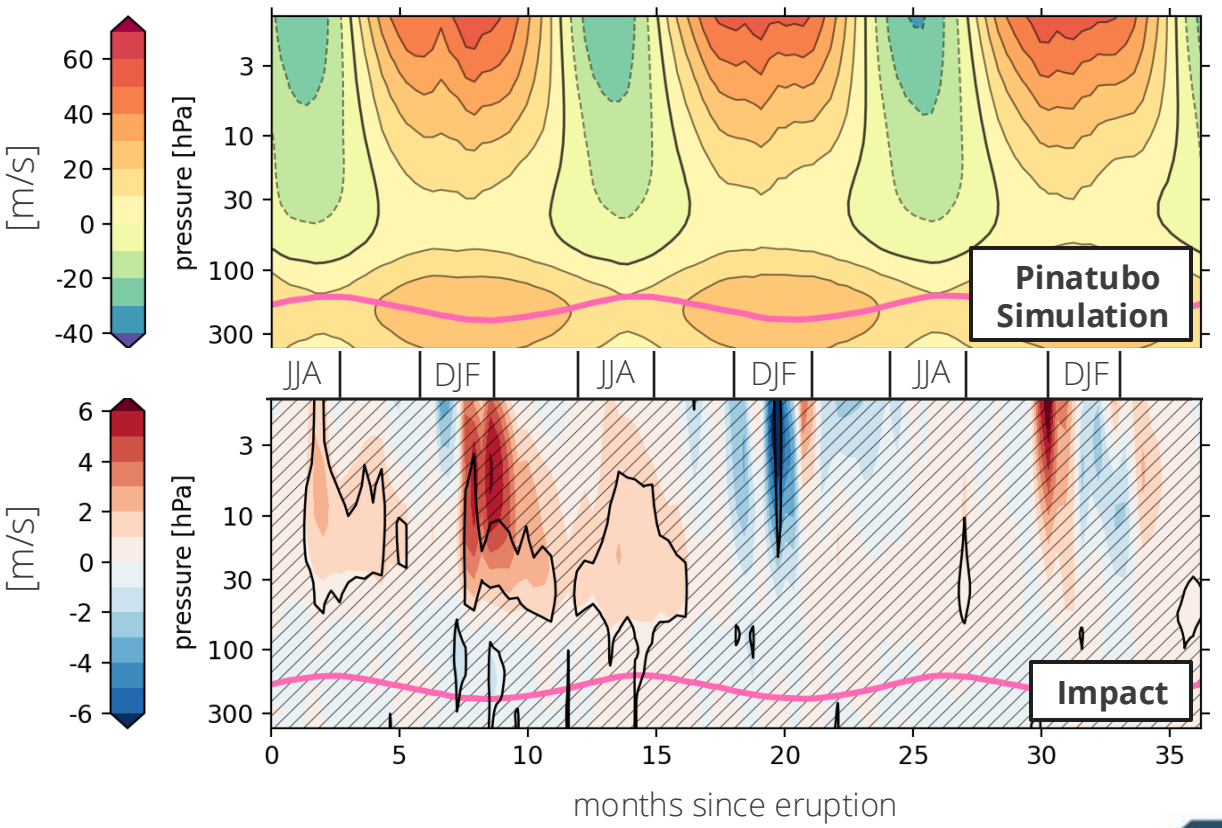
Experiment Results: modification of temperature and wind



Temperature

Zonal Wind

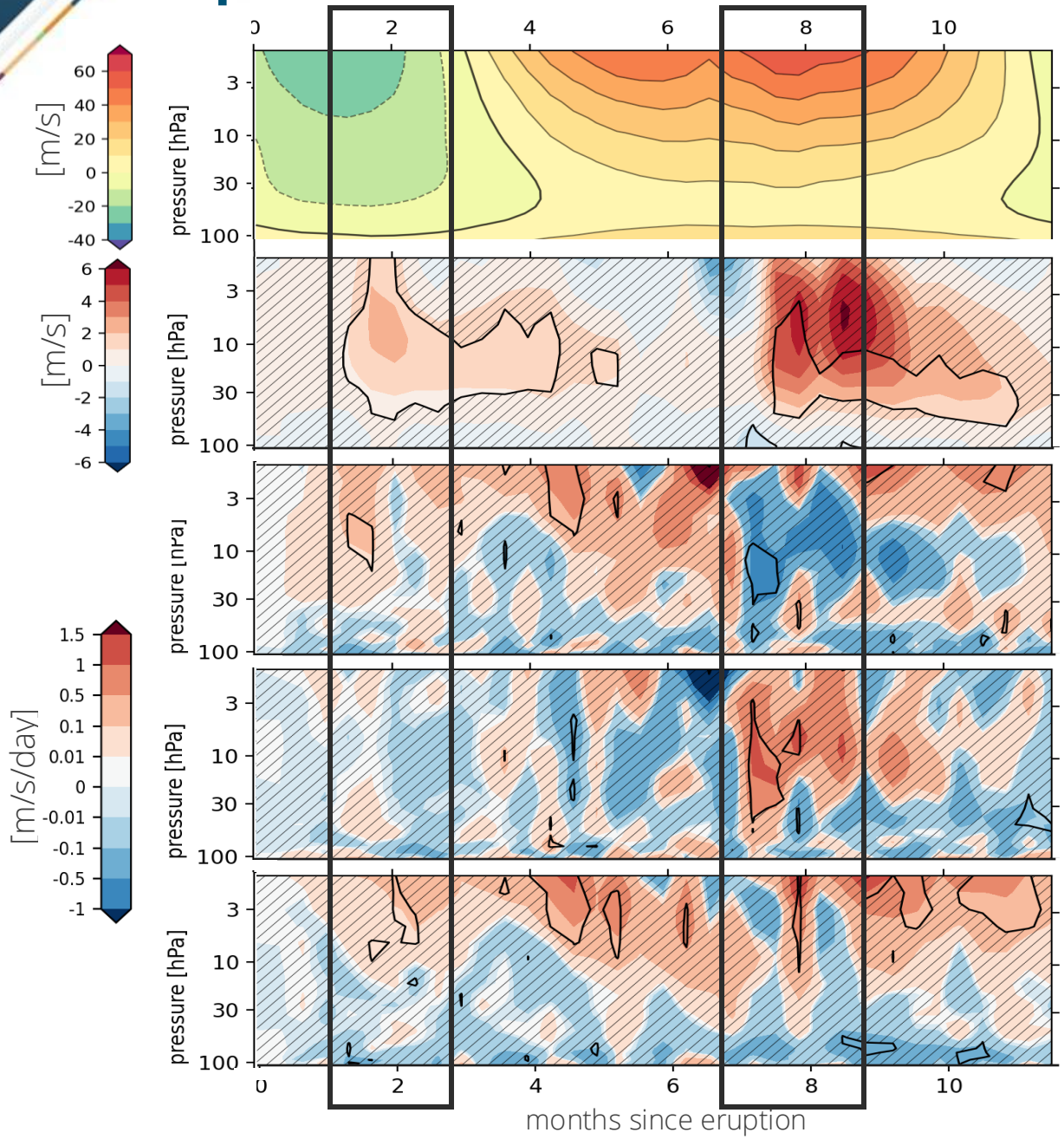




Experiment Results: TEM momentum budget

$$\frac{\partial \overline{u}}{\partial t} = \left(f - \frac{\partial \overline{u}}{\partial y} \right) \overline{v}^* - \frac{\partial \overline{u}}{\partial z} \overline{w}^* + \rho_0^{-1} \nabla \cdot \mathbf{F} + \overline{X}$$

Experiment Results: TEM momentum budget



Zonal Wind (U)

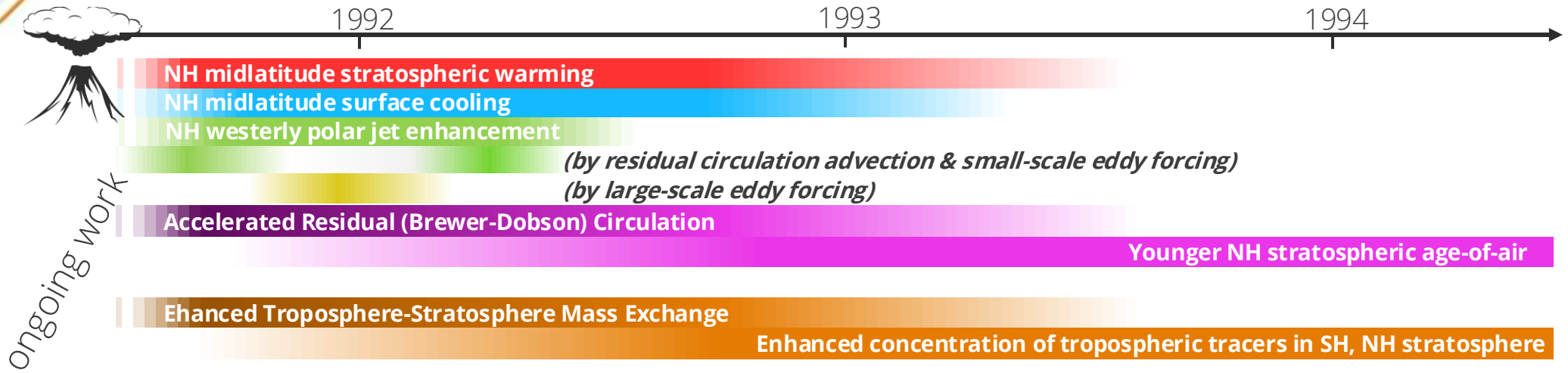
Zonal Wind (U)
Impact

dU/dt *Impact*
(residual circulation)

dU/dt *Impact*
(eddy forcing)

dU/dt *Impact*
(gravity wave forcing
& diffusion)

Experiment Results: TEM momentum budget



Concluding Remarks

- Stratospheric aerosol forcing affects the Earth's climate in complex ways
- Specific physical mechanisms giving rise to observed impacts are subtle and difficult to identify
- However, our simulation and analysis methodology seem to be allowing us to find these highly nonlinear climate impacts of large volcanic eruptions

Future Work

- We have begun to develop sound tools and methodology, but have not yet answered the question; *what happens to the general circulation in response to stratospheric aerosol forcing, and by what mechanisms?*
  To make progress toward this goal:

- Statistical significance of some of the findings is lacking; more ensemble members are in production

- Impact analysis is being done on many more variables, and with regional focus beyond the NH midlatitudes

- TEM Budget methods are being extended to an analogous framework for tracer concentrations

- We need to conceive of simple metrics for quantifying climate impacts in further reduced datasets (e.g. 1-D expressions of impact strength)

- Finally, we will be searching for trends in the presented measures, with respect to total injected mass for size-varying volcanic events. The datasets to enable this have been produced.

Acknowledgements

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Thank you for your attention!

Questions? Email me at hollowed@umich.edu