CLDERA – CLimate impact: Determining Etiology thRough pAthways

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sandia.gov/cldera

OVERVIEW

CLDERA will develop new methods to confidently attribute climate impacts to localized sources using a novel pathways approach built upon discovering and representing evolving chains of physical processes. CLDERA aims to improve climate risk assessments and decision-making through its transformation in approaches for climate attribution.

NEED

Climatic impacts (like drought, flooding, or crop yield) are driving national security, legislative and legal foci.

Modified from: http://www.thesourgrapevine.com/2019/11/the-ball-of-string-theory-for-learning.html

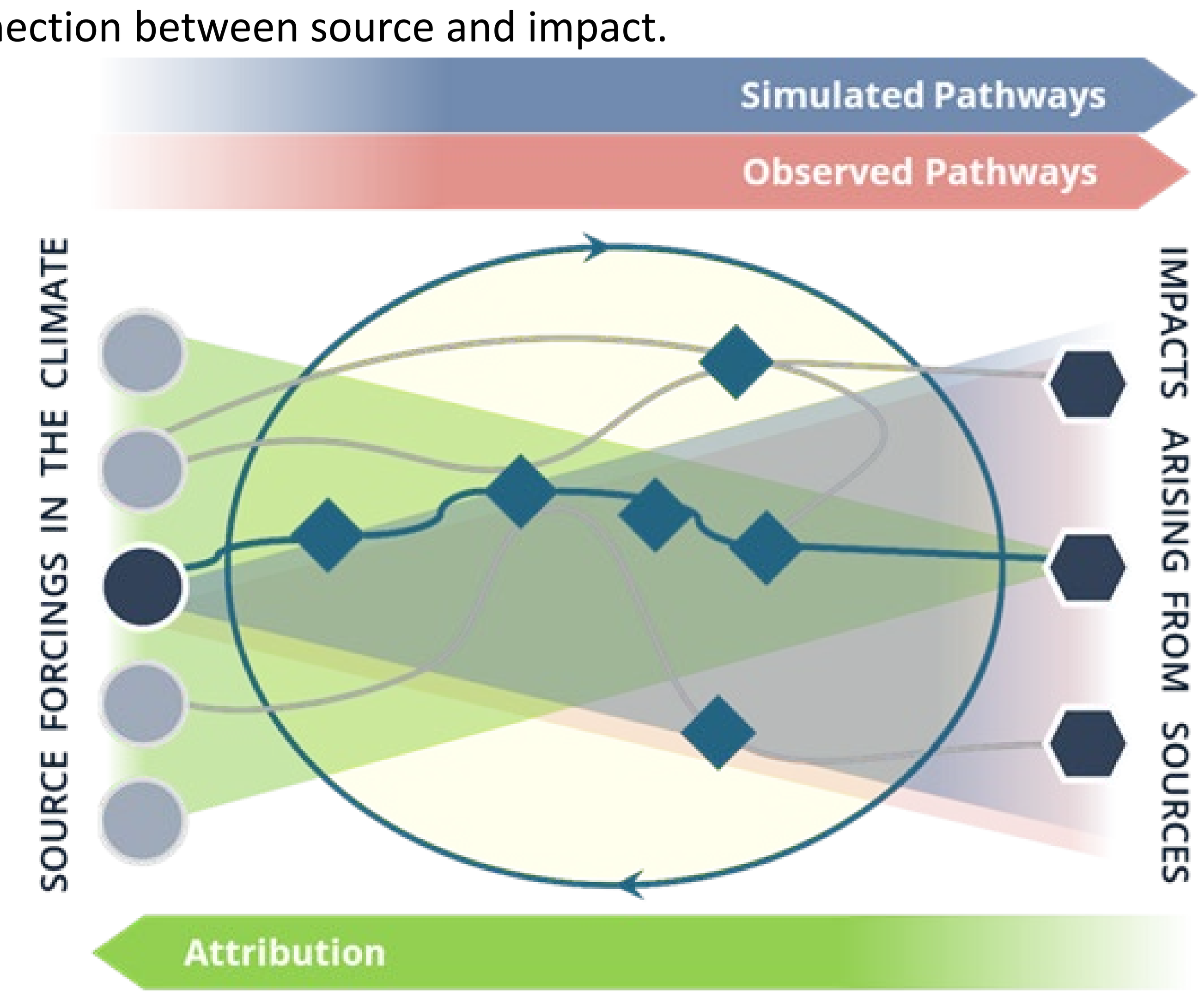
Complex coupling between processes obscure the **relationships** between **sources** and downstream **impacts.**

Traditional attribution connects a source to a primary climate variable in a **single step.**

The **technical challenge** is to draw quantitative relationships in a **multi-step attribution** framework.

APPROACH

Combine evidence from multiple nodes in the pathway to strengthen connection between source and impact.

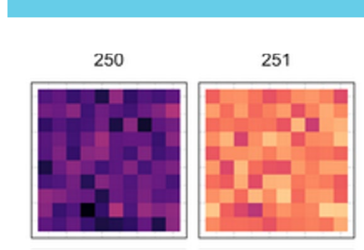


Tiered Verification

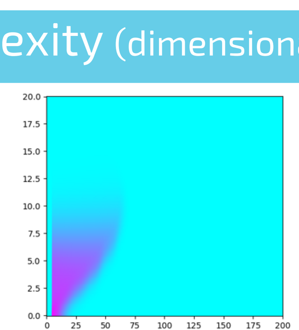
See Hollowed's A13C-01 on 12/12

Develop data sets of increasing complexity with key characteristics of the multi-step attribution problem to explore sensitivities, establish viability, and prove usefulness of advanced methods/tools.

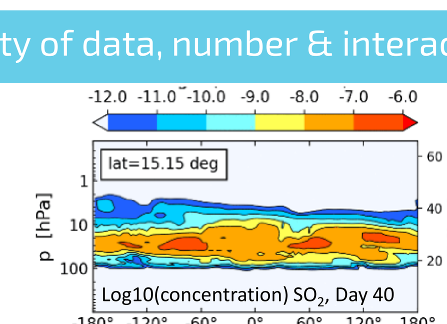
Data & Model complexity (dimensionality of data, number & interaction between processes, …)



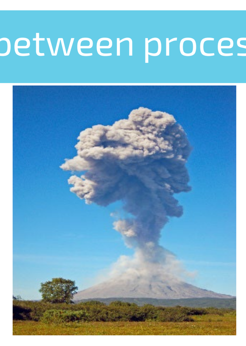
Synthetic Relationships



Gaussian Plume with prescribed winds



Idealized atm. + embedded pathways



Mt. Pinatubo in fully coupled climate model

OUTCOMES

Tools to discover and represent pathways, and analyses to establish pathway robustness to changing conditions.
Cross-validation using simulated and observational pathways will inform areas for model improvement and new measurements.

Contributory ranking of sources to specific impacts using pathways.
Capability enables robust risk analysis and offers the potential to guide future climate actions.

Attribution of source characteristics using inverse optimization methods.
Will provide credible methodology to deter unilateral implementation of climate interventions.

Beginning-to-end attribution in the climate system
Tracing evolving chains of physical processes to enable attribution of climate impacts from a localized source.

Energy Exascale Earth System Model (E3SM)

See Lin's A33F-08 on 12/14

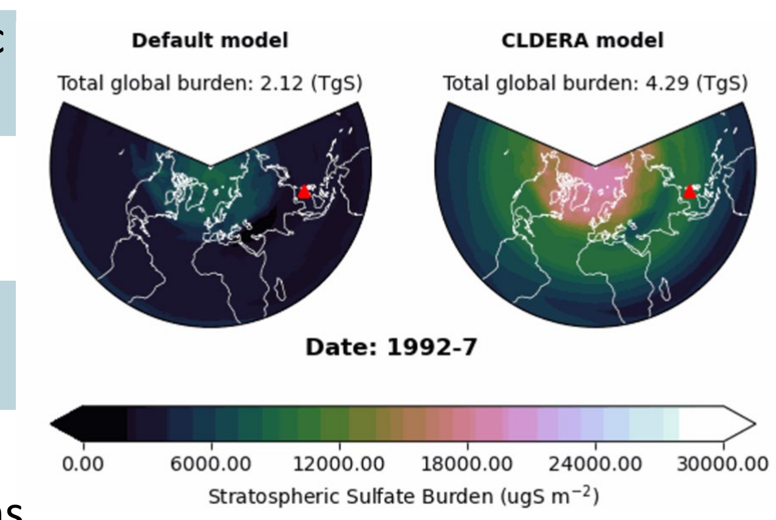
See Brown's A52Q-1203 on 12/16

Prognostic Aerosol Modeling: Simulate stratospheric volcanic aerosol in E3SM from SO_2 emissions.

Evaluate E3SM's Stratosphere: Characterize biases and understand what physical processes can be captured.

Establish climate variability surrounding Mt. Pinatubo: Characterize signal-to-noise for detection & attribution.

Sensitivity Analyses: Determine pathway robustness to altered: eruption characteristics and model parameterizations.



Simulated Pathways

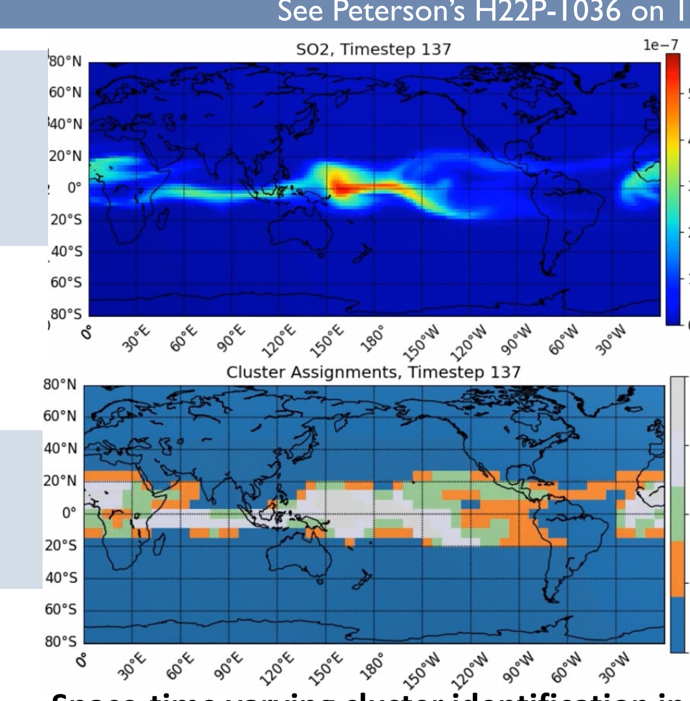
See Peterson's H22P-1036 on 12/13

Random Forest Regression (RFR): Generate feature pathway networks using multi-variate RFR (full pairwise analysis of input features).

Profiling: Dynamically trace pathways through the E3SM software as the software executes (in-situ).

Tracing: Add active and passive tracers to E3SM to enable model evaluation and pathway identification.

Signature-Based Clustering: Find & track non-stationary variable clusters for use as features in pathway identification.



Space-time varying cluster identification in response to Mt. Pinatubo source.

Observed Pathways

See Li's IN22A-07 on 12/13

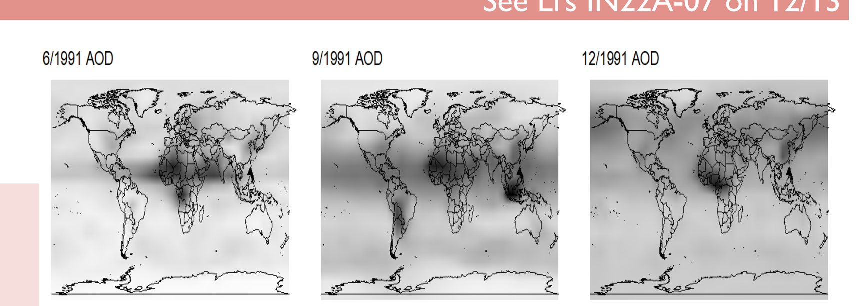
Data Fusion: Fuse observational datasets to obtain near-real time measurements over complete space-time grid.

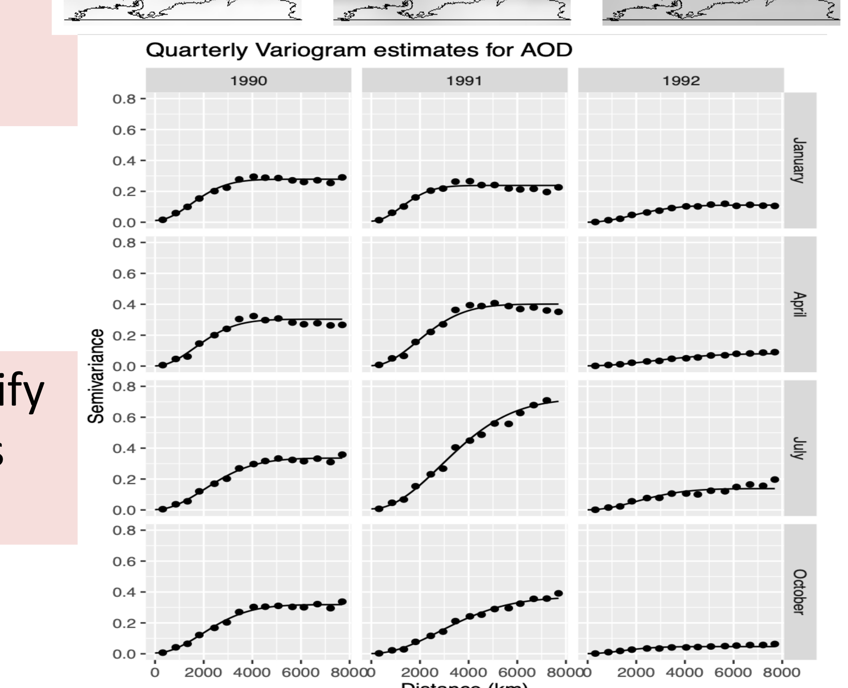
Dynamic space-time models: Adopt space-time dynamic models to incorporate multiple nodes and establish correlations between nodes.

Spatially-varying changepoint methods: Establish dependence between local climate shifts and distance from source.

Elastic Functional Warping changepoint methods: Identify climate shifts using functional time series methodologies accounting for phase variability.

Explainable Echo State Networks (ESNs): Develop explainable (permutation feature importance) and interpretable methods to quantify relationships between pathway nodes as modeled by recurrent neural networks.



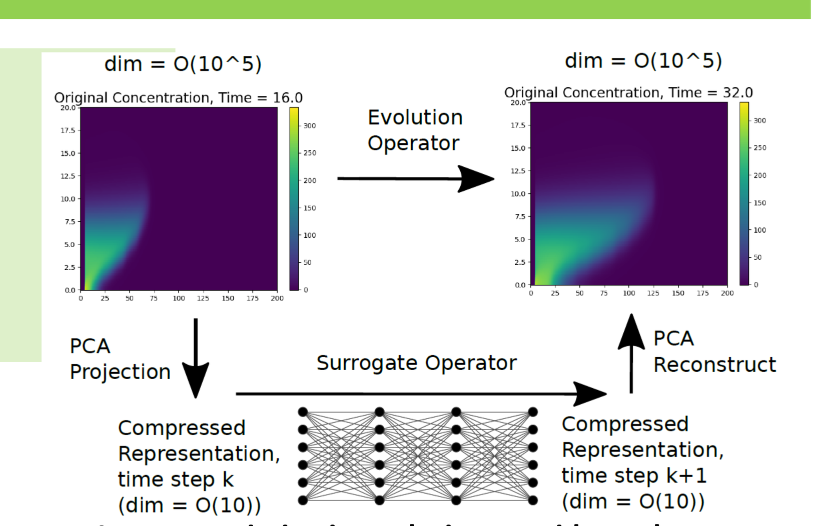


Spatial characteristics are time varying in response to Mt. Pinatubo source.

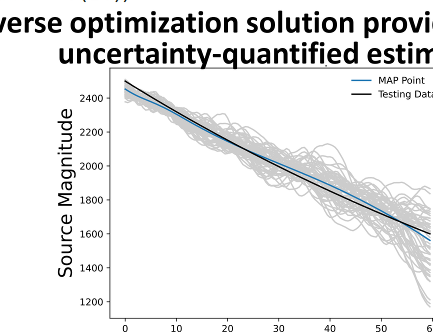
Attribution

Enhanced Fingerprinting: Investigate advanced principal component analyses (tensor based, non-negative, etc.) and employ multiple nodes in the pathway to sharpen the signal-to-noise ratios and enable downstream impact attribution.

Inverse Optimization: Identify source characteristics by developing deep operator neural networks (DONNs) to model parts of E3SM for PDE-constrained optimization.



Inverse optimization solution provides a close, uncertainty-quantified estimate.



Causal Modeling: Develop causal discovery method for spatially nonstationary and transient relationships; use directed graphs to represent causal networks.

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