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Using Gaussian Process Emulator to Explore the Source-Receptor Relationships of Black Carbon

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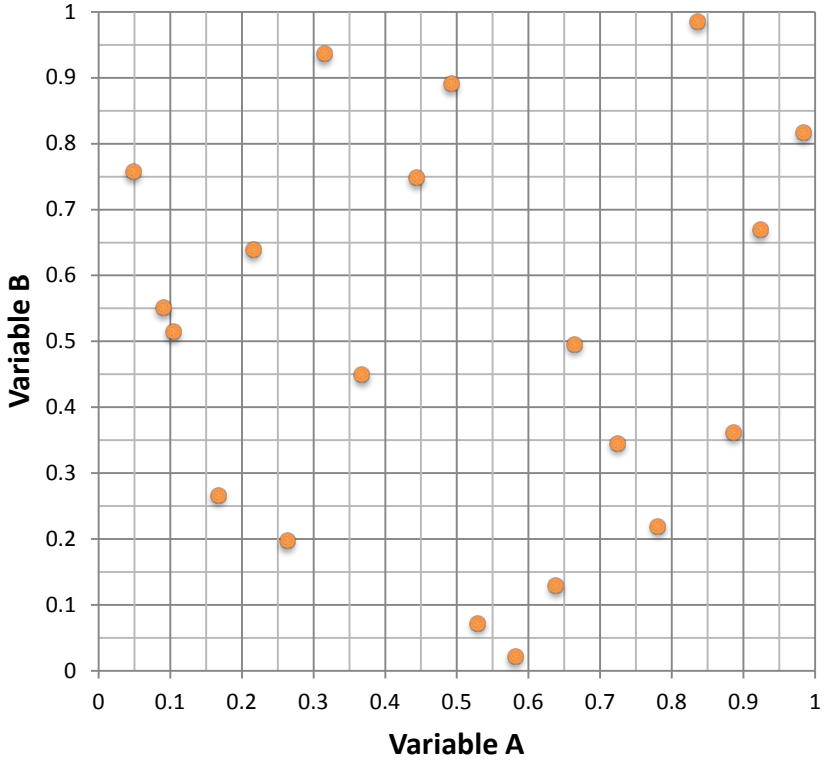
Source receptor relationship

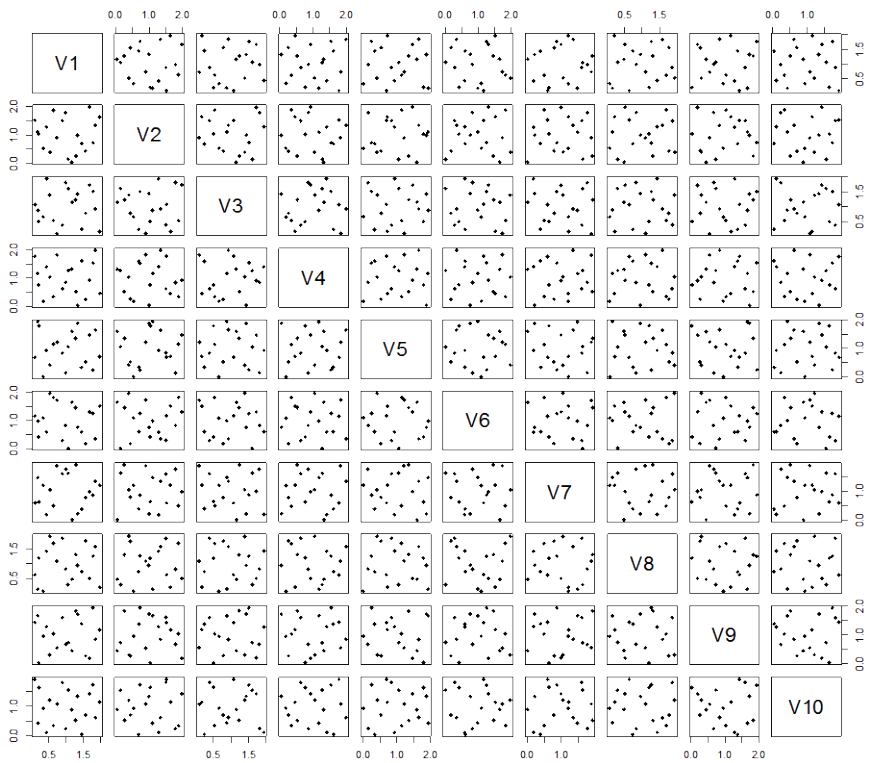
- simple sensitivity test
- tagging
- trajectory modeling
- chemical composition analysis
- inversion modeling
- ……

We are going to use a "UQ method" to explore this!

Design of experiments (DOE) vs. One-at-a-time (OAT)

Latin Hypercube DOE (20 samples, 10 variables)

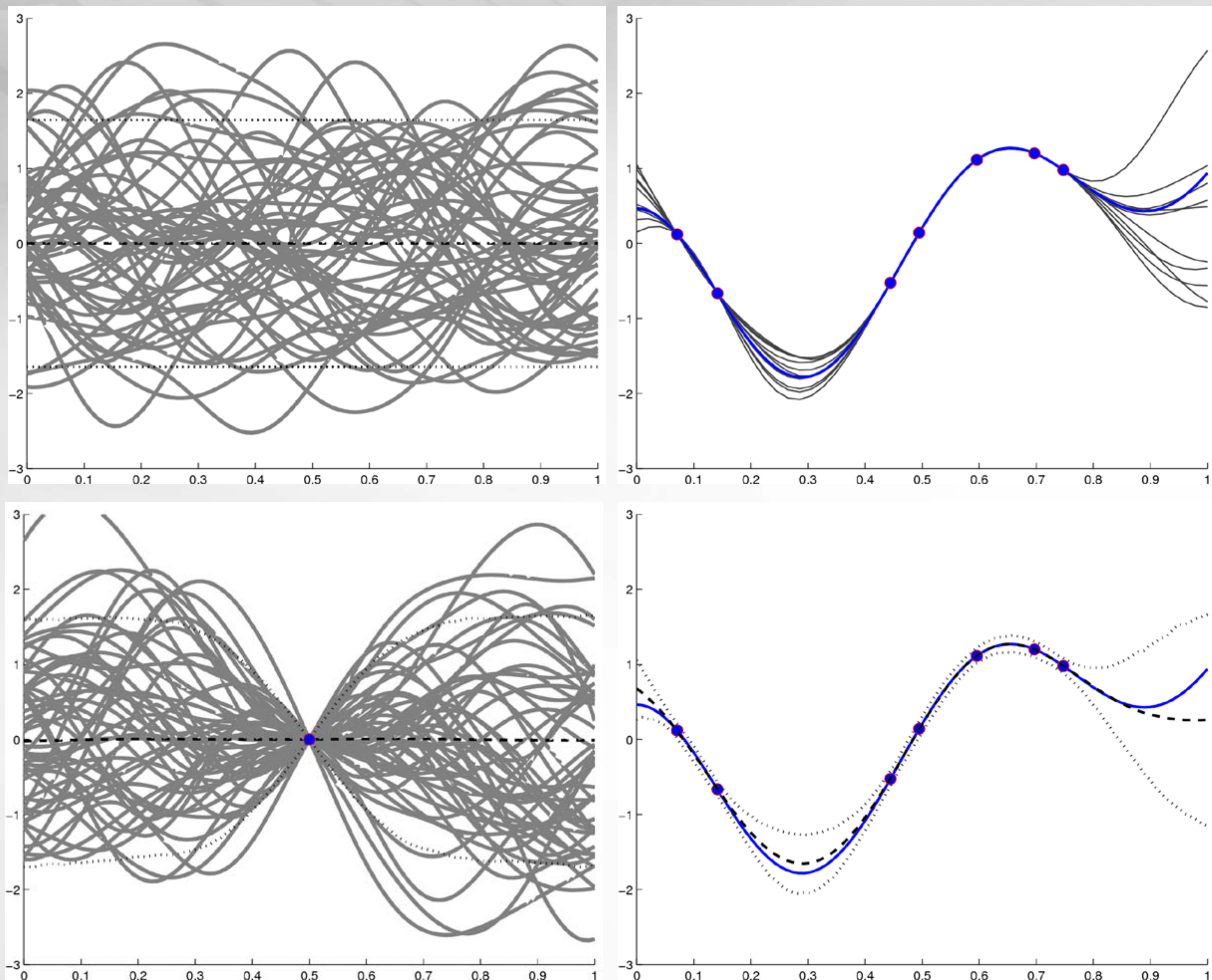




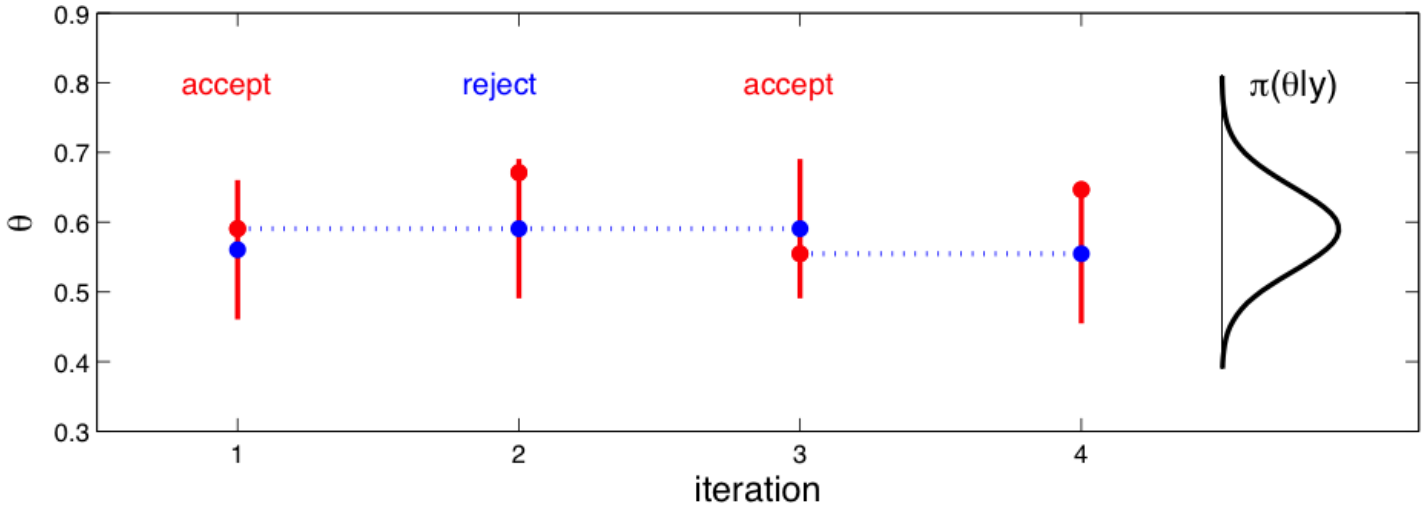
Advantage of DOE over OAT (Czitrom, 1999):

- Greatly **reduce** the number of experiments (**20** vs. 2 x 10, 20 x 10, or 20^{10} experiments)
- Provide more **precise** estimates of the effect of each parameter
- Give accurate estimates of the effect of the **interactions** between two factors
- Cover a **larger portion** of the parameter space

Statistical surrogate model, or "emulator": Gaussian process model



Metropolis recipe for MCMC



Initialize chain at θ^0

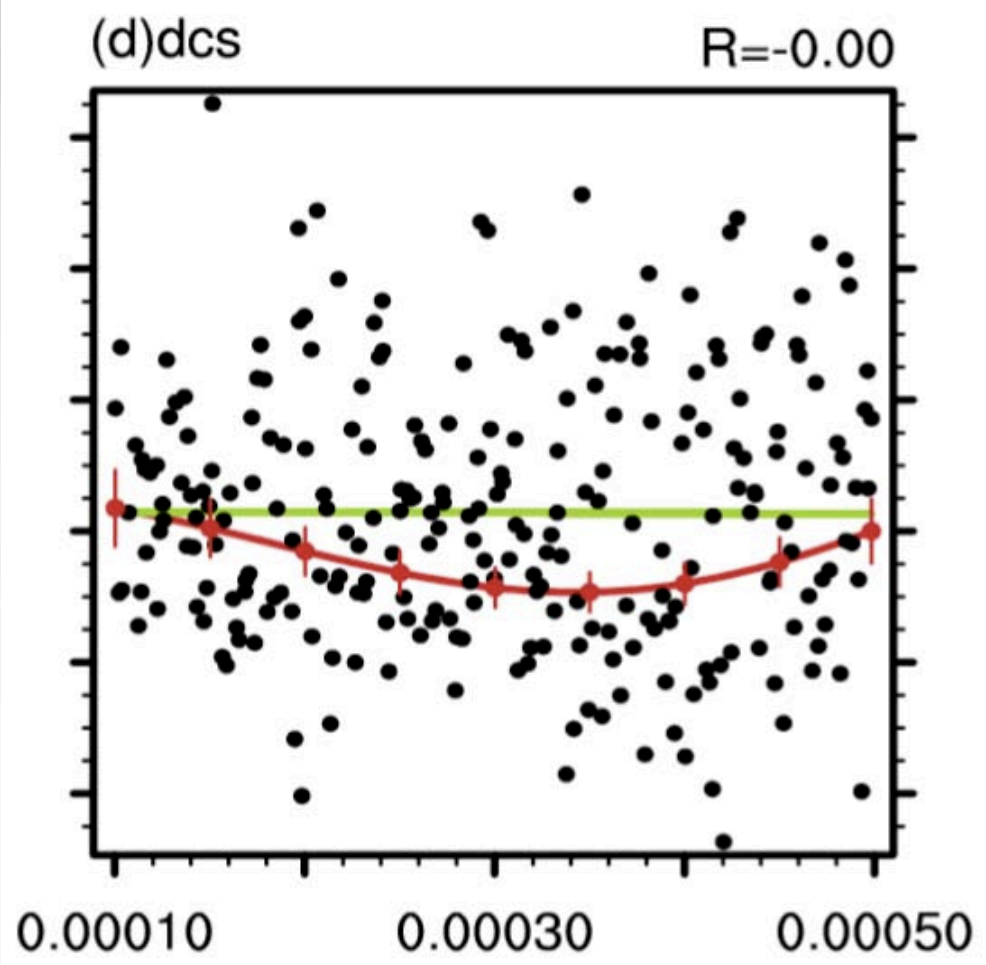
1. Given current realization θ^t, generate θ^* from a symmetric kernel $q(\theta^t \to \theta^*)$

   i.e. $q(\theta^t \to \theta^*) = q(\theta^* \to \theta^t)$

2. Compute acceptance probability $\alpha = \min\left\{1, \frac{\pi(\theta^*|y)}{\pi(\theta^t|y)}\right\}$
3. Set $\theta^{t+1} = \theta^*$ with probability α, otherwise $\theta^{t+1} = \theta^t$
4. Iterate steps 1 – 3

From Dave Higdon

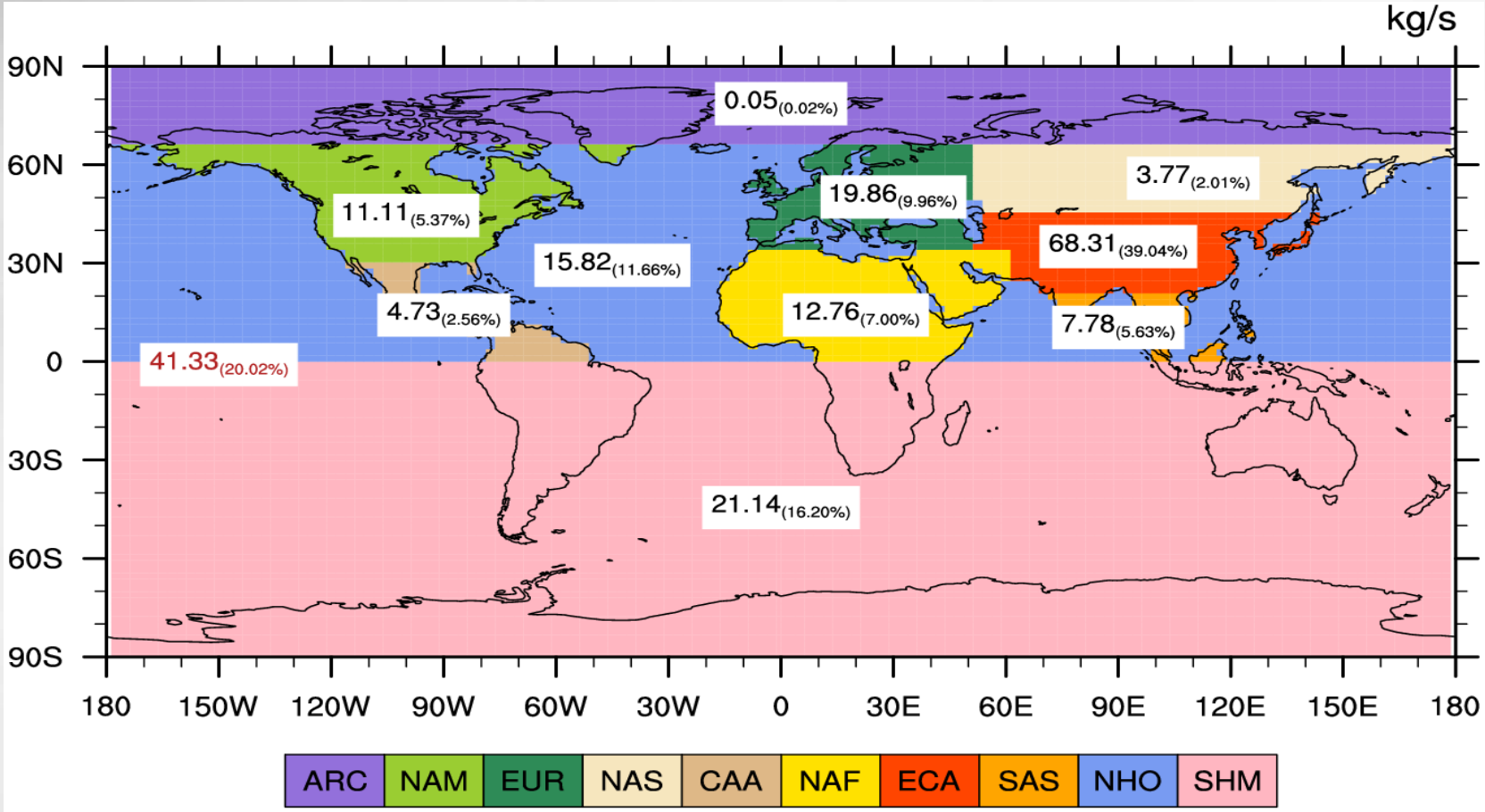
Example (global cloud forcing vs. dcs)



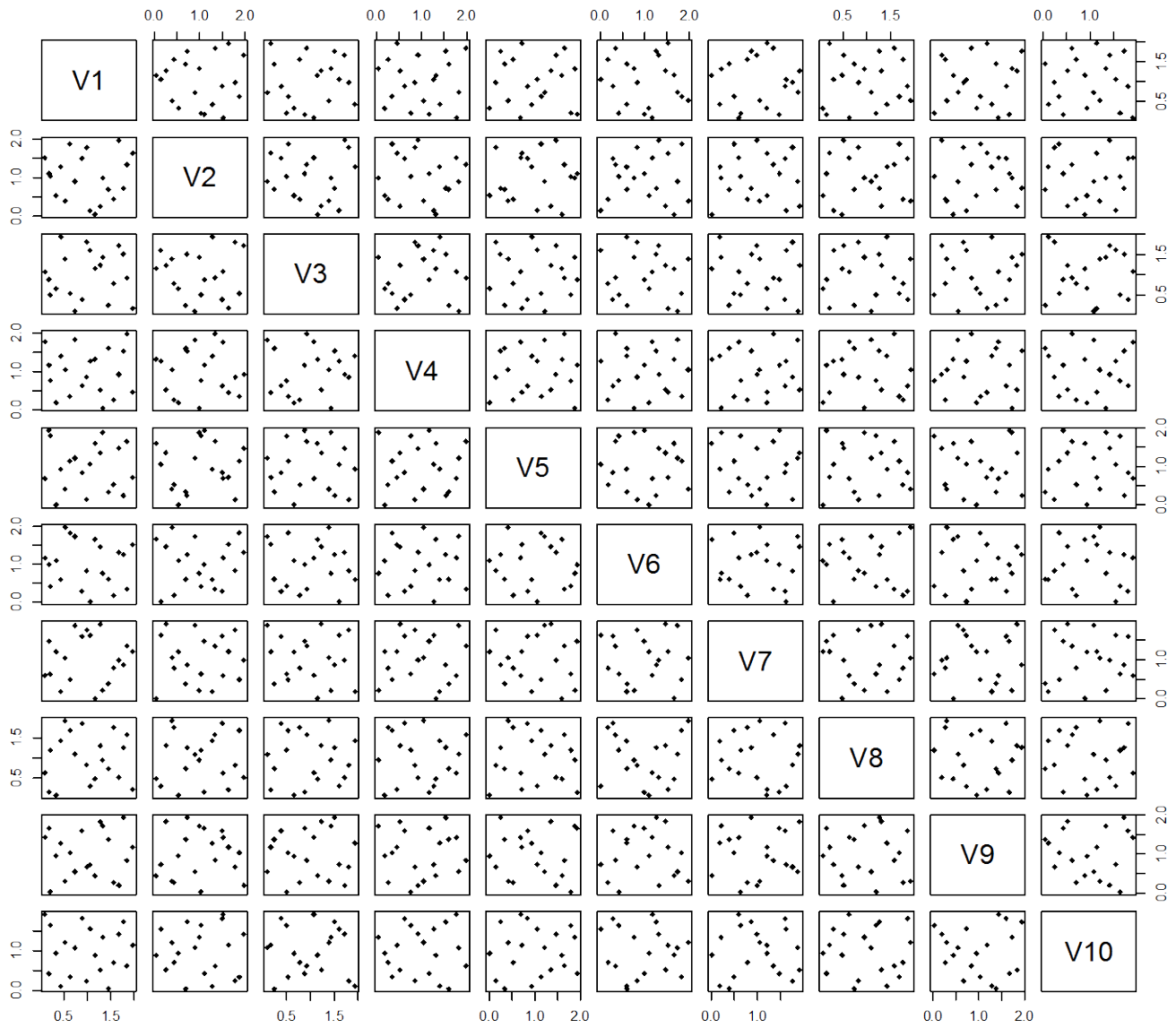
Liu et al. *in preparation*.

Design of Experiment

- Latin Hypercube DOE of 20 simulations
- Regional emission perturbation 0-10% of global emission
- Only anthropogenic emissions are perturbed
- CAM-driven and ERAI-driven simulations



Latin Hypercube DOE (20 samples, 10 variables)



Global BC burden change due to regional emission perturbation

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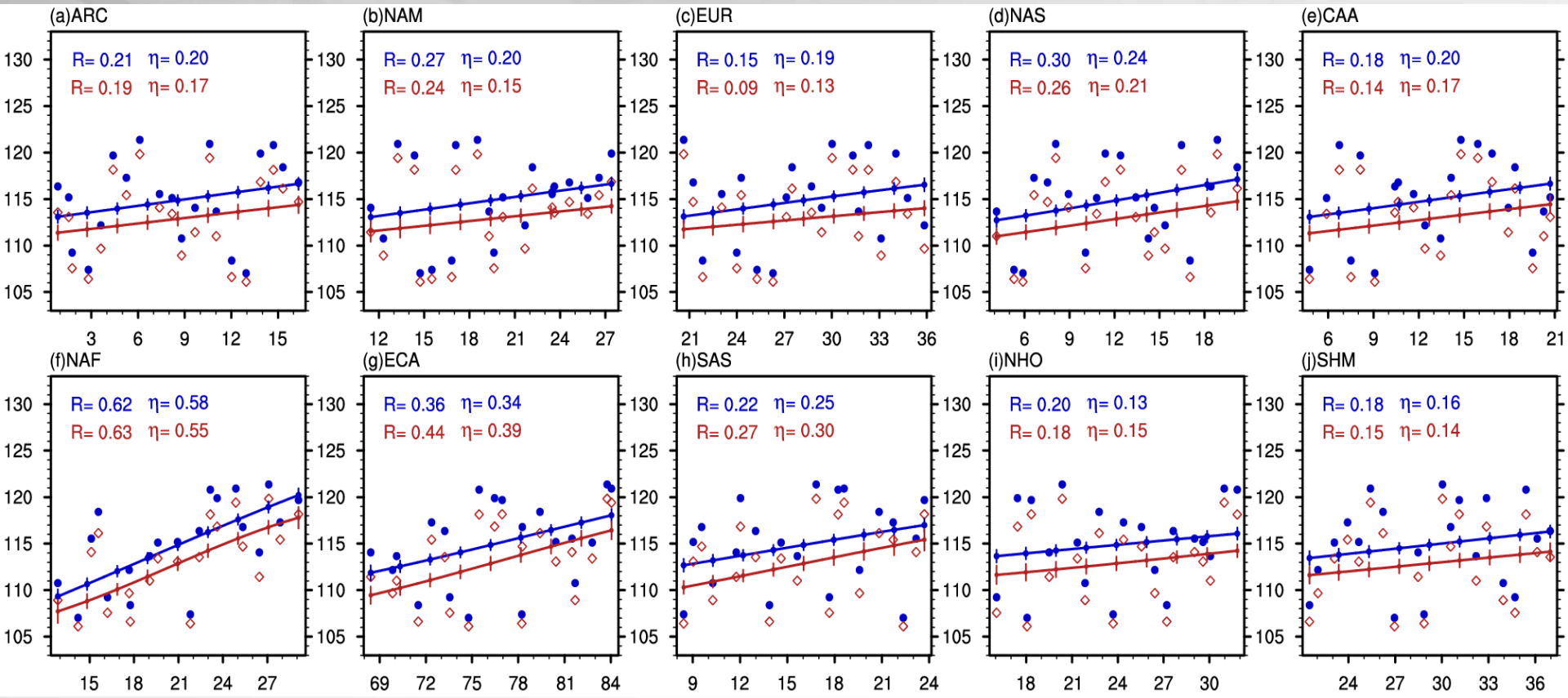

Variance of Global BC burden explained by main and interactive (2-variable) effects

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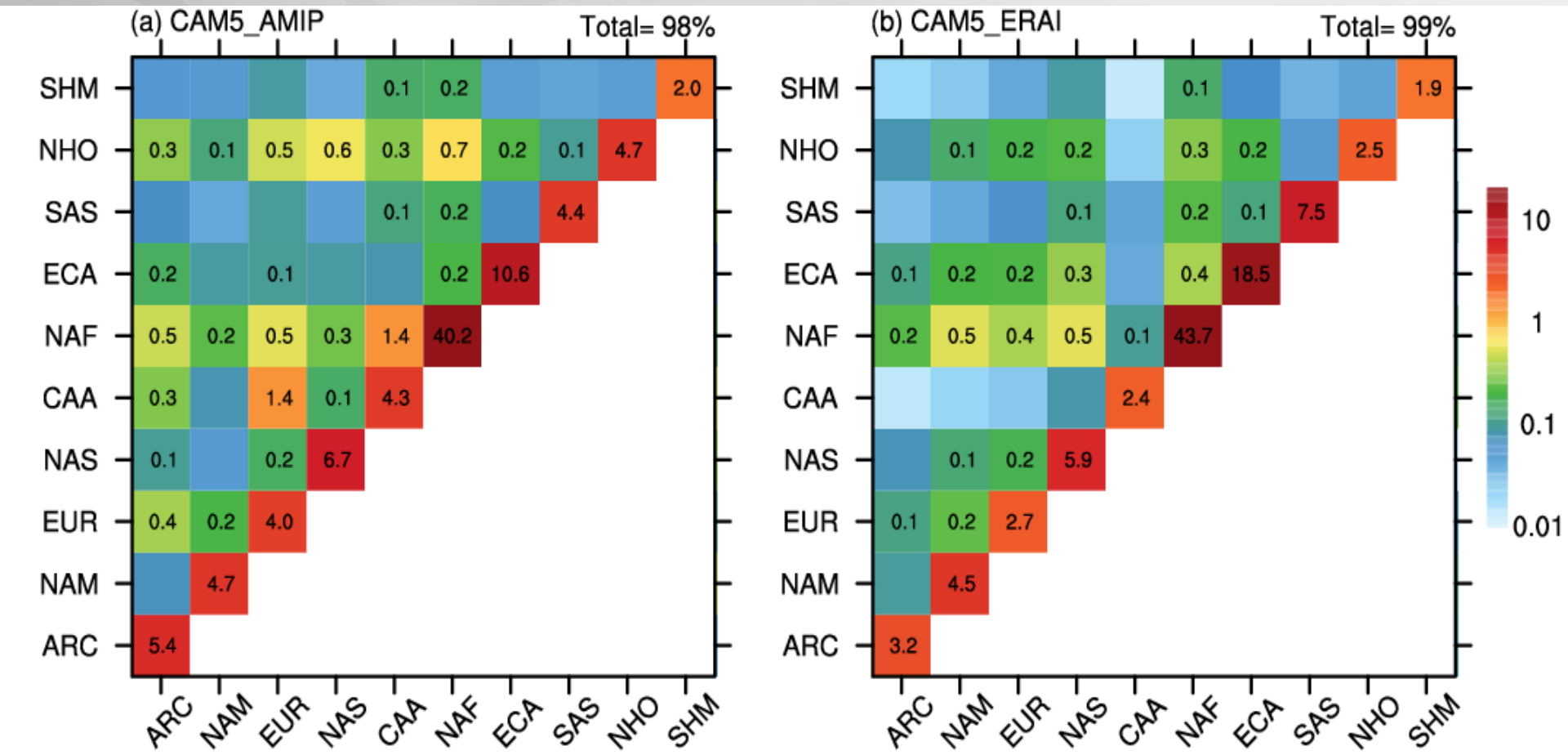
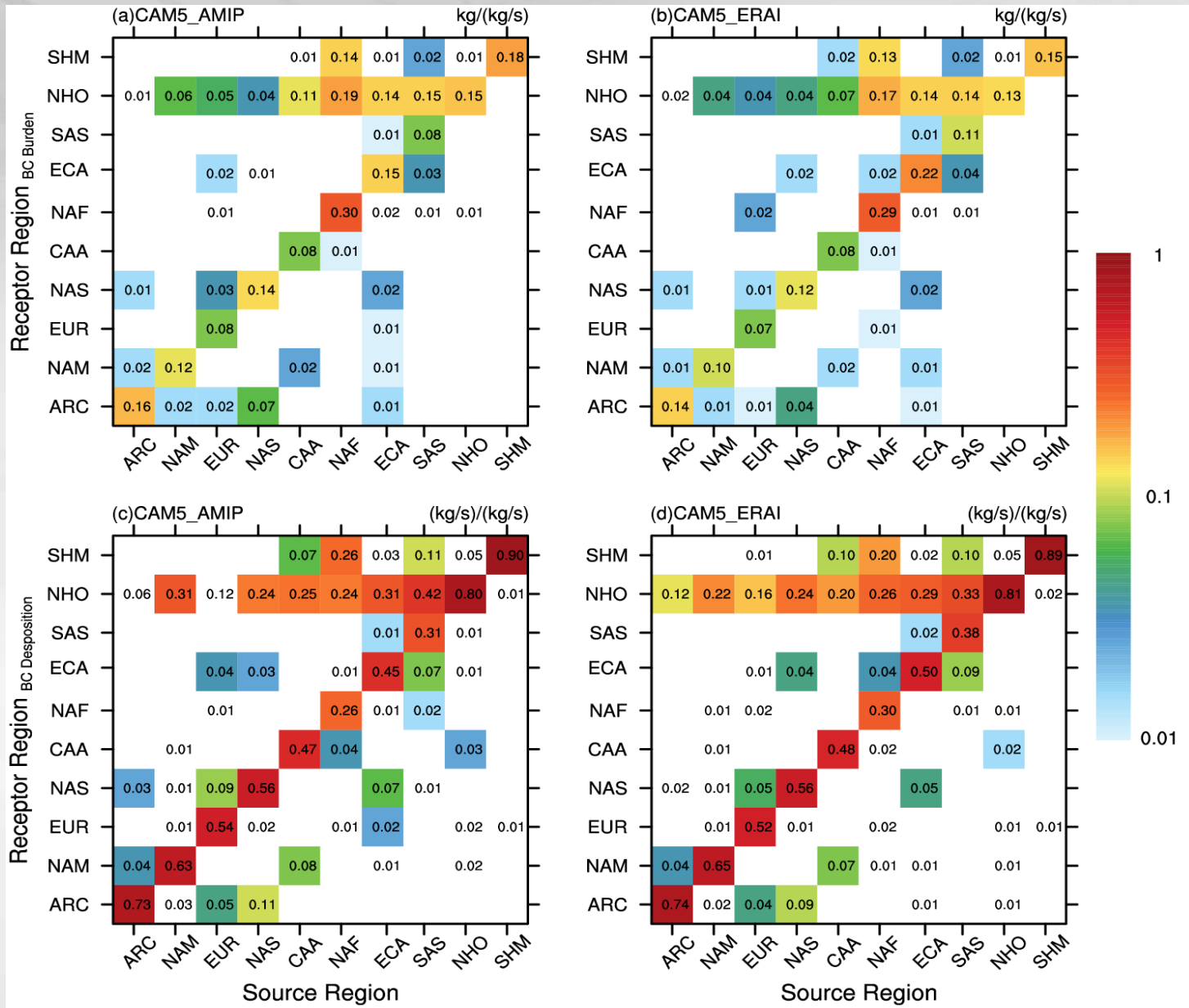
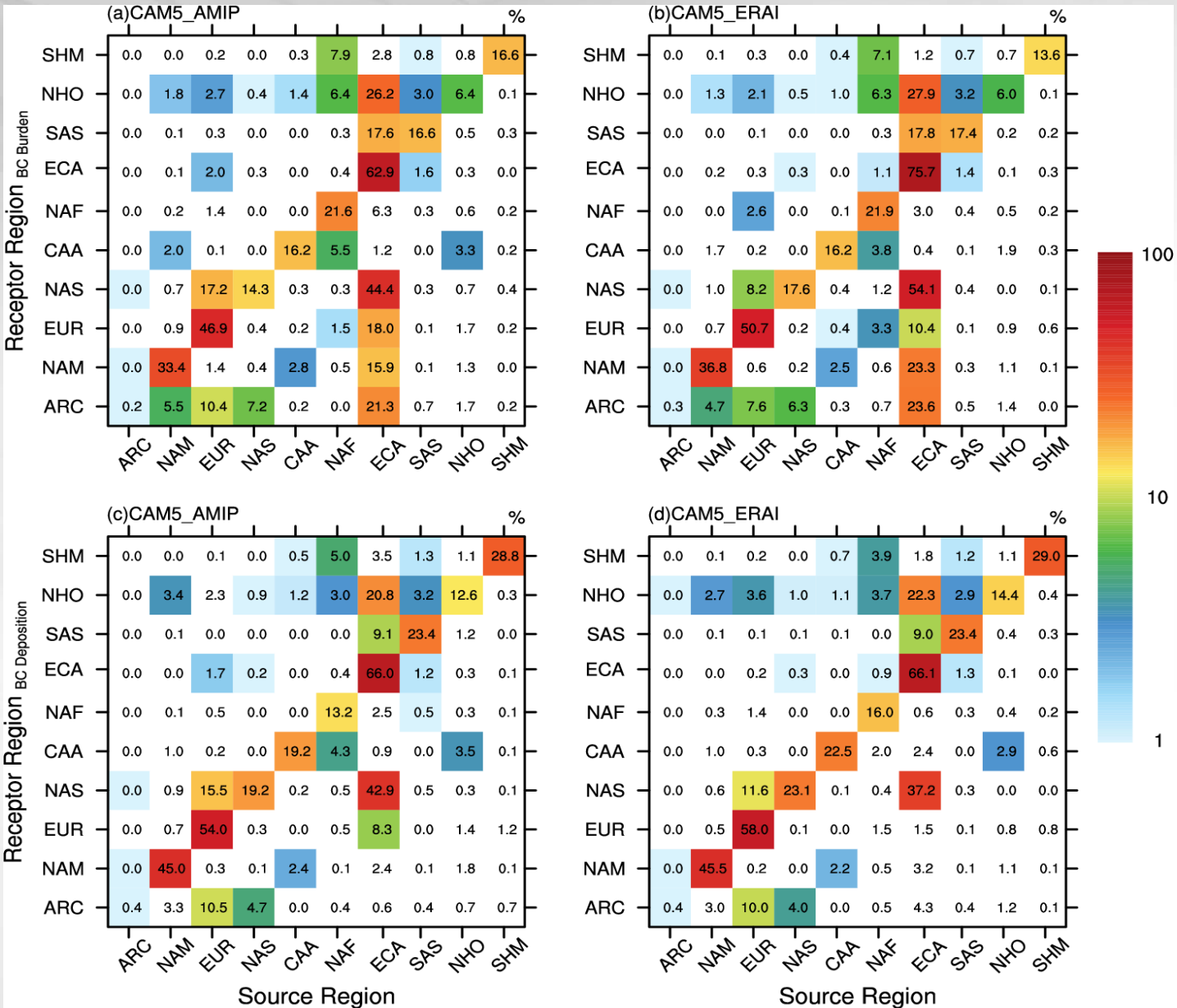


Contribution Efficiency



Source-Receptor Relationship



Concluding Remarks

- Owing to the complexity and nonlinearity of the climate system, it is computationally expensive to systematically identify the cause-and-effect of multiple factors in climate models. With an appropriate design of experiment and emulations, sensitivity studies can be achieved with relatively little computational cost.

- In this study, we have demonstrated that the free-running model CAM5 and the reanalysis-driven offline model produce similar results.

- BC source-receptor relationship is found approximately linear.

- The burden and surface deposition rates in every region are the most vulnerable to the increase of local emissions.

- Due to the large emission, Asia contributes a significant portion of BC burden and deposition over many regions in the North Hemisphere.