Constraining aerosol radiative forcing using aerosol absorption

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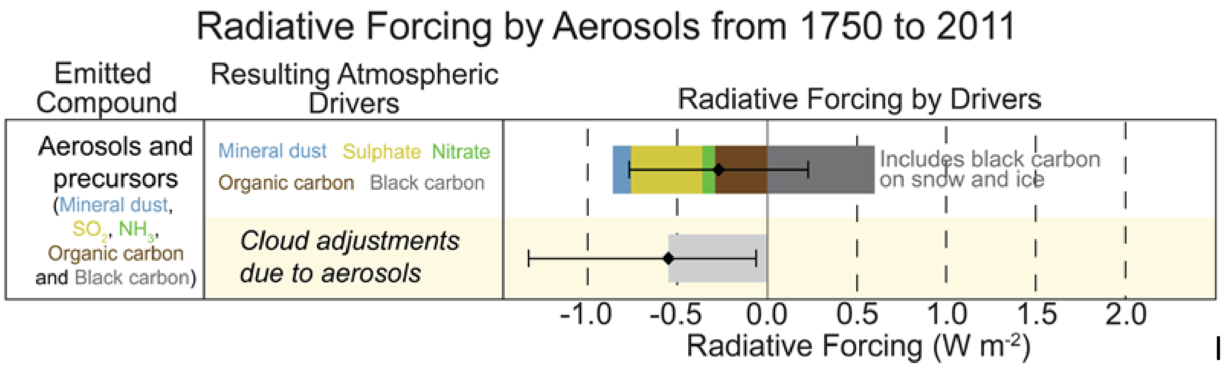
Climate Processes Group

Outlook

1. Introduction
2. AeroCom Black Carbon PPE setup
3. Constraining methodology
4. Multi-Model Black Carbon Experiment
5. Conclusions

Motivation



IPCC, 2013

The present day lack of good constraints on aerosol absorption can significantly affect the estimates of aerosol climate impact.

AeroCom Phase 2 multi-model:

- Annual mean total $AAOD_{550nm}$: 0.0042 ± 0.0019 (or ±50%)
- Min-max range total $AAOD_{550nm}$: 0.0021 to 0.0076

(Myhre et al. 2013)

DRF due to black carbon (BC) : +0.71 [+0.09, +1.26] W m^{-2}

(Bond et al., 2013)

Reducing uncertainty of aerosol ERF

Tuning a model will reduce uncertainty in aerosol radiative forcing ?

=> produce <u>one value</u> of forcing

We want all the model values that are observationally plausible …

How?

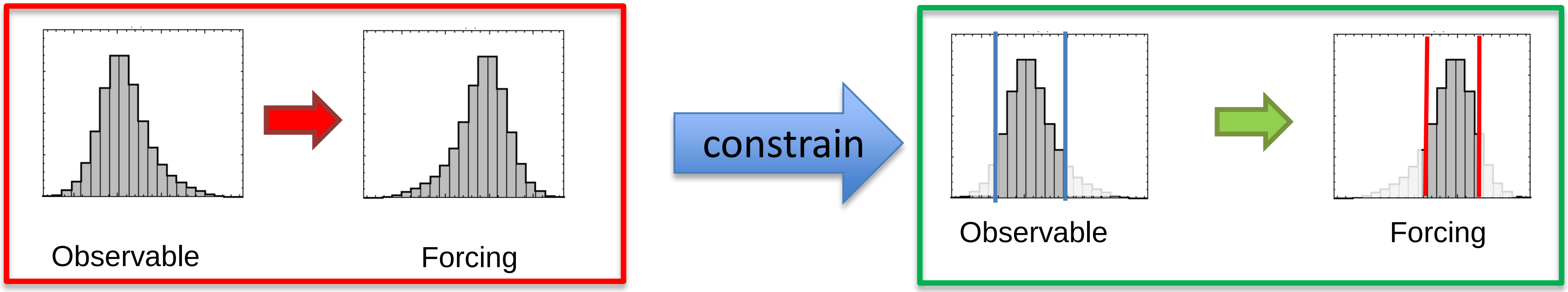
- sample uncertainty within a single model and challenge it with multiple observation types

Perturbed Parameter Ensemble (PPE)

AeroCom Black Carbon experiment (PPE)

Initial model variant and aerosol forcing

Constrained model variant and aerosol forcing



(Johnson et al., 2018)

1. Constrain models using observations

PPE

2. Compare (constrained) models to each other

$\mathrm{M_{ulti}M_{odel}PPE}$

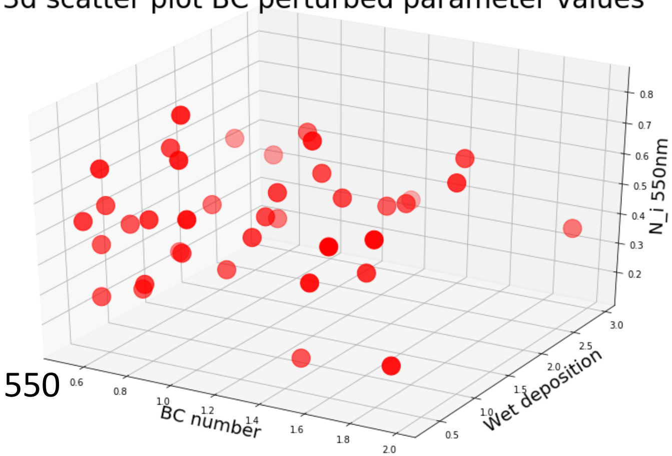
AeroCom Black Carbon PPE setup

ECHAM6-HAM BC PPE

Latin Hypercube sampling =>
parameter combination design

39 model runs

3d scatter plot BC perturbed parameter values



BC number/ Wet deposition /N_i 550 combinations

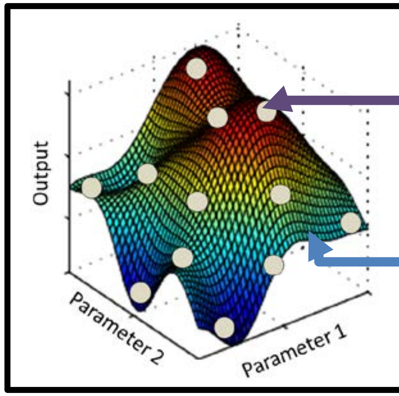
High time resolution output (3 hourly to monthly) for optimum comparison with measurements	Nudged to horizontal winds (identical throughout ensemble)
Aerosol RF	2017 meteorology
3 climate model parameters (BC emissions, wet deposition, BC imaginary part of RI)	2017 BC emissions
1850 and 2017 anthropogenic emissions	40 simulations per year (includes model baseline) + spin-up

1. Constrain models using observations

1. Model PPE (co-located on observations)

Observations

2. Gaussian Process Emulator



Model runs (40 simulations)

Model response surface

- 1 million points

(Watson-Parris et al., in preparation)

3. Implausibility metric

Observation

Model output [Prediction from emulator]

$$I(\boldsymbol{x}) = \frac{|z - E[\eta(\boldsymbol{x})]|}{\sqrt{[Var(\phi(\boldsymbol{x})) + Var(\epsilon) + Var(\delta)]}}$$

Emulator prediction uncertainty

Structural uncertainty

Observational uncertainty

$I(x)$ close to 0

=> model variant is more plausible.

Large $I(x)$

=> uncertainty terms are under-estimated (large structural error or poor representativeness).

=> parameters are implausible

(Johnson et al., in preparation)

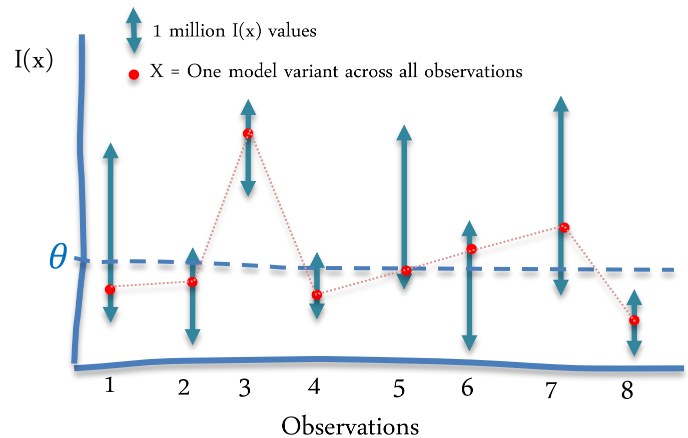
1. Constrain models using observations

4. Constraining process

(Johnson et al., in preparation)

1. Identify the model variants below a certain Threshold (θ)

2. Determine the Tolerance (T) as the % of observations for which the model variant is greater than θ

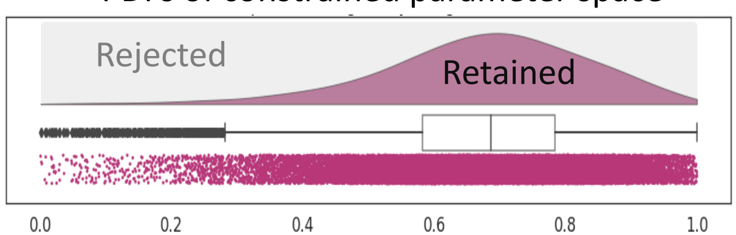


5. Retain/ Reject parameter space

PDFs of unconstrained parameter space

1 million points uniform distribution

PDFs of constrained parameter space



From the combination of θ and T

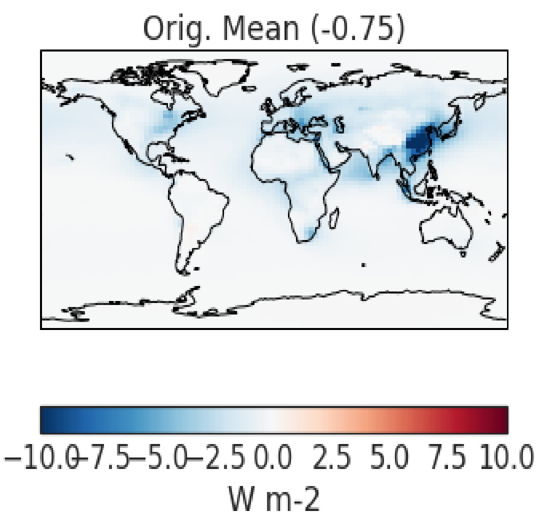
Results from GASSP PPE

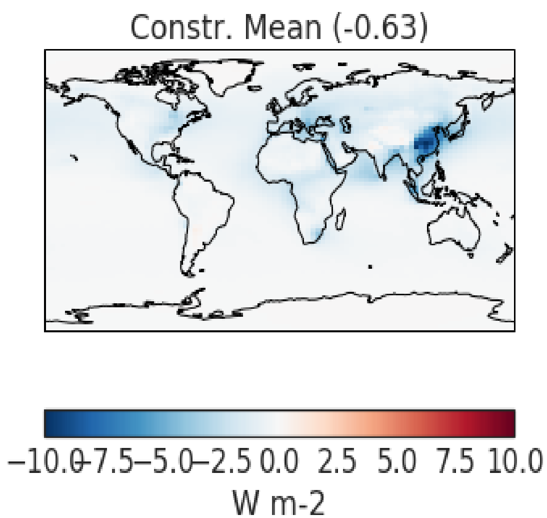
Global constraints - 2008

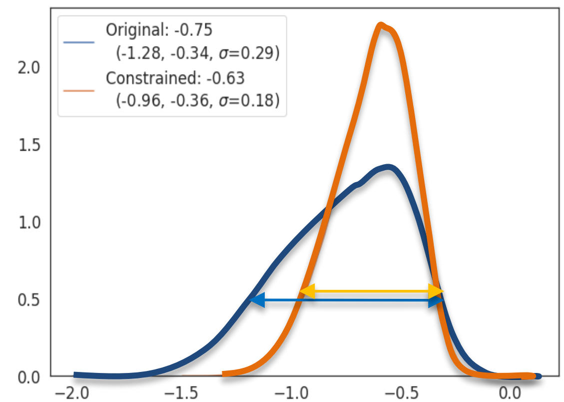
$\theta = 1$
$T = 0$

AERONET AOD (3 hourly model outputs collocated at each station)

ERF_{ari} constraint map







Constrained / Unconstrained
ERFari using AERONET AOD observations

(Masaru et al., in review)

Plausible combination of parameters
=> Plausible models
=> Reduction of model uncertainty and improved forcing estimates:
Effective Radiative Forcing (ERF) due to Aerosol Radiation Interaction (ari)

Perturbed parameters for AeroCom BC PPE

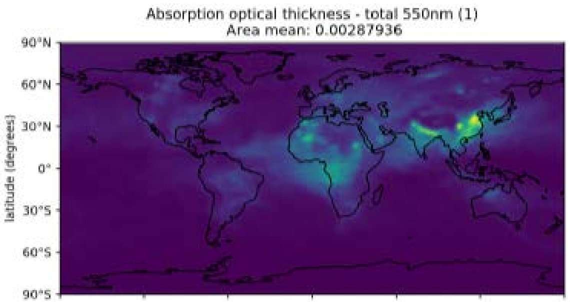
- Implementation test -

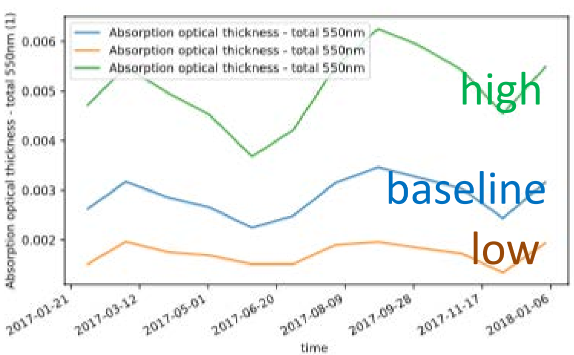
Atmospheric burden	**Aerosol number:** Scale mass flux of BC carbonaceous emission	**[X*0.5, X*2]**
	Wet deposition: Scale removal tendencies/change in droplet number	**[Y*0.3, Y*3]**
Radiative properties	**BC optical properties:** Scale the imaginary part of refractive index	**[0.0, 0.2, 0.8]**

Initial sensitivity test – ECHAM6-HAM

Atmospheric burden: BC emission flux

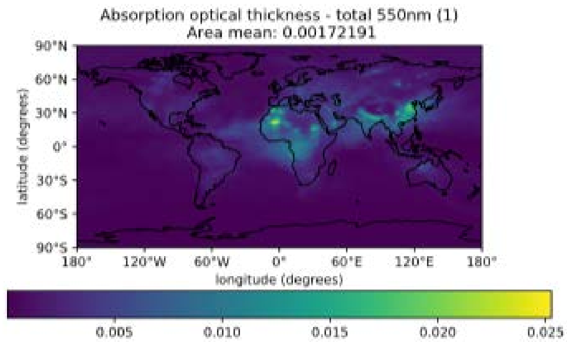
Baseline (X*1)

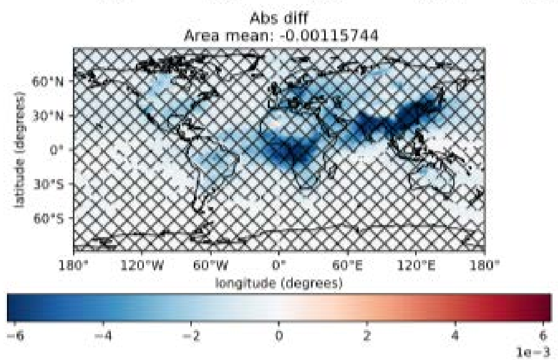




Absorbing AOD

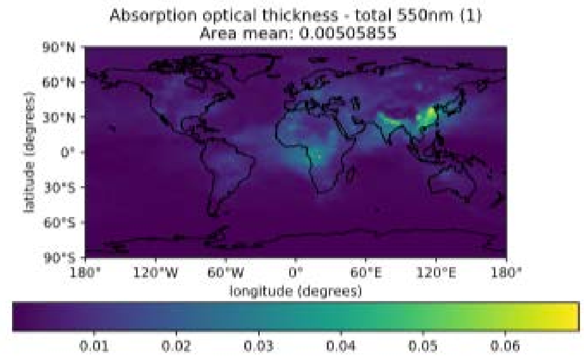
Low: X*0.5

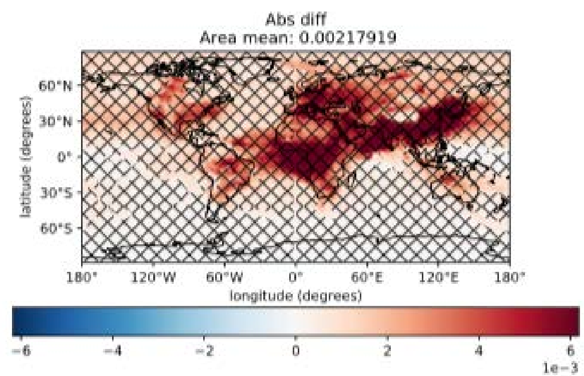




Diff AAOD

High: X*2



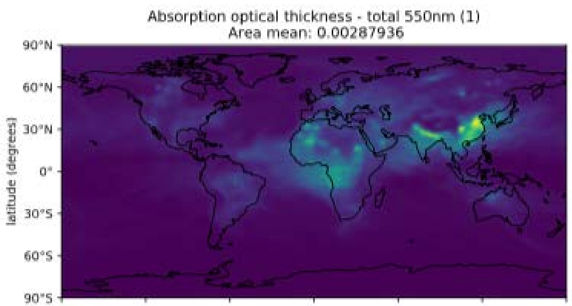


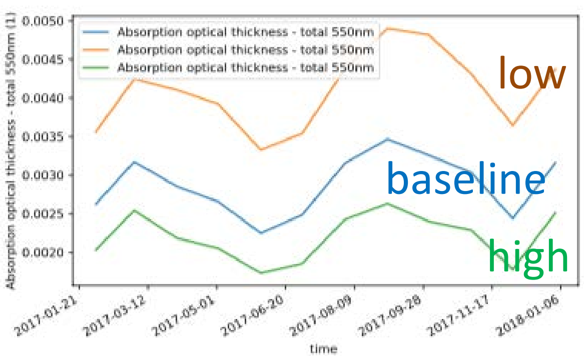
Diff AAOD

Initial sensitivity test – ECHAM6-HAM

Atmospheric burden: Scale wet deposition

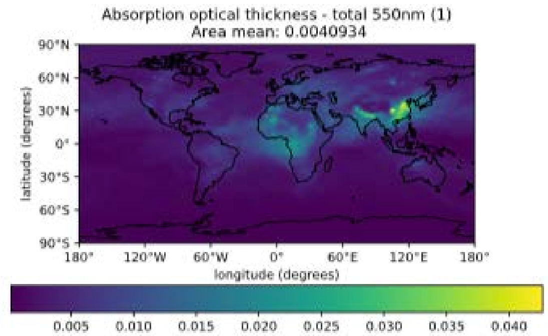
Baseline (X*1)

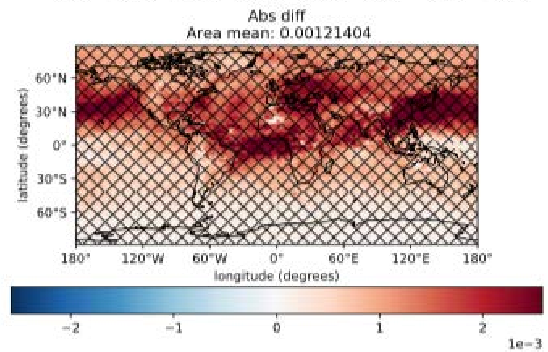




Absorbing AOD

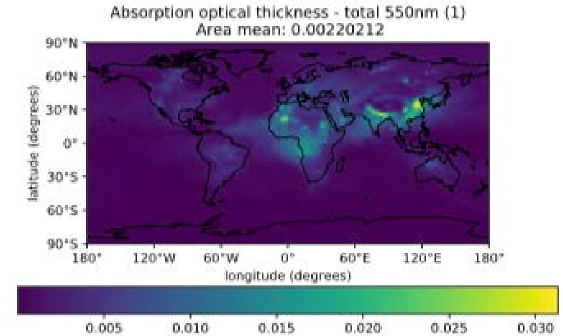
Low: X*0.3

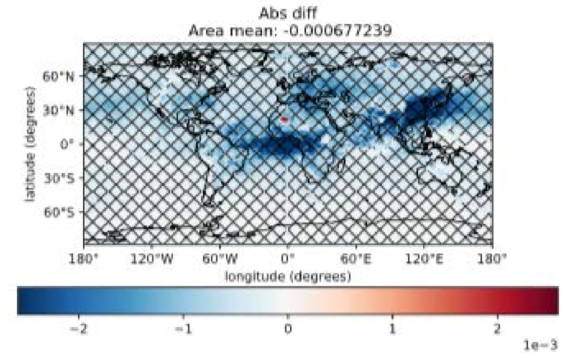




Diff AAOD

High: X*3



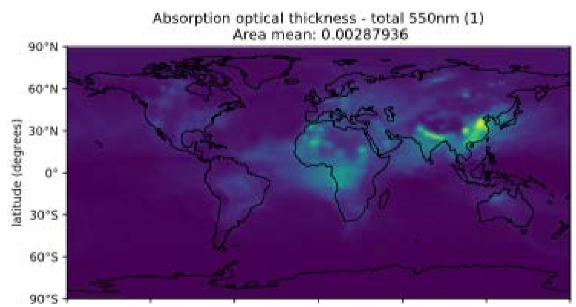


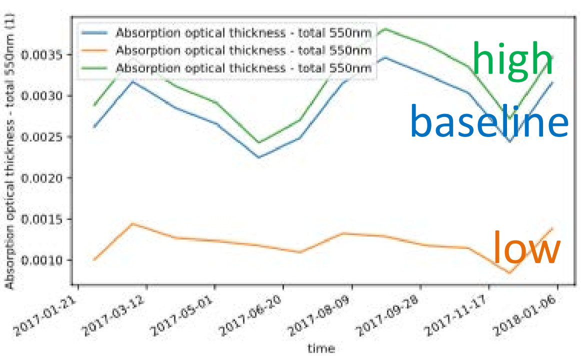
Diff AAOD

Initial sensitivity test – ECHAM6-HAM

Radiative properties: BC optical properties

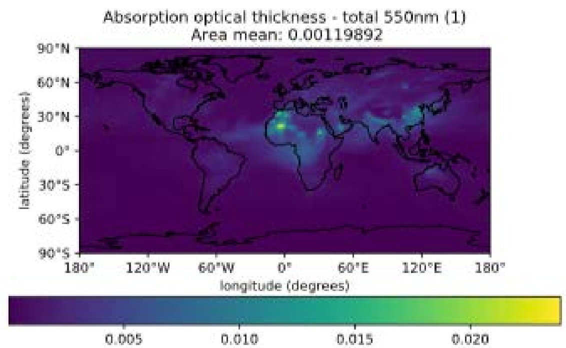
Baseline (N_i = 0.71)

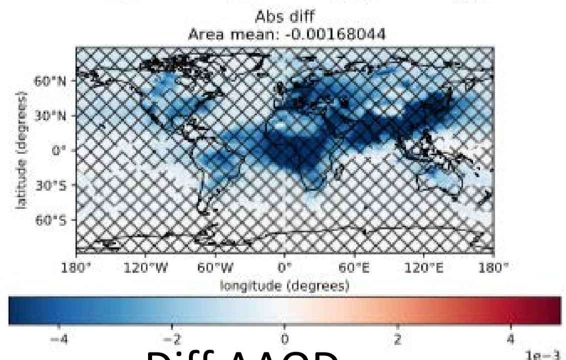




Absorbing AOD

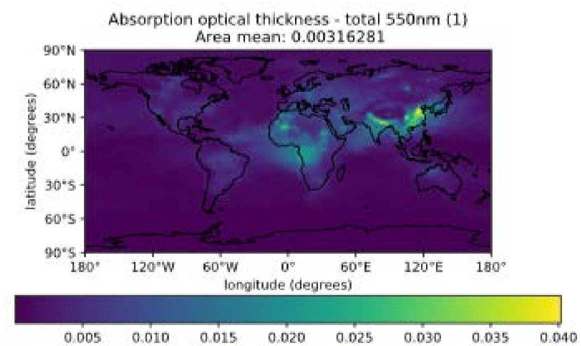
Low: N_i = 0.2

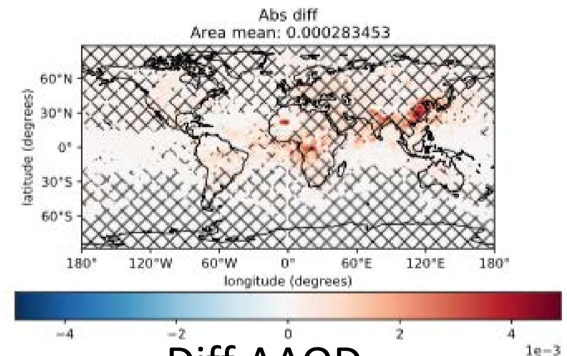




Diff AAOD

High: N_i = 0.8





Diff AAOD

2. Compare models to each other

Multi-Model AeroCom BC PPE setup

Latin Hypercube sampling => parameter combination design

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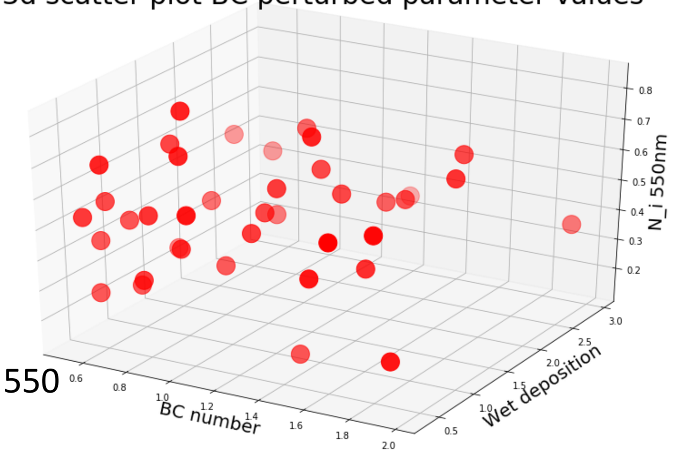
3d scatter plot BC perturbed parameter values



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Collecting diagnostics

Diagnostic	Domain	Structure	Time scale	Observation source
TOA fluxes	Global	2d field	Monthly	
AOD (440 and 870nm)	Station	Station	3hr	Aeronet
AOD (550nm)	Global	2d field	Monthly	MODIS
AAOD	Station	Station	3hr	Aeronet
BC mass mixing ratio	Flight track simulator	Defined points	3hrly	GASSP + CLARIFY database
BC mass mixing ratio	Global	3d field	Monthly	GASSP database
BC dry deposition flux	Global	2d field	Monthly	
BC wet deposition flux	Global	2d field	Monthly	
BC burden	Global	2d field	Monthly	
BC emissions flux	Global	3d field	Monthly	
All species (except BC) emission flux	Global	3d field	Monthly	
Aerosol number (in each mode)	Global	3d field	Monthly	

Conclusions and Perspectives

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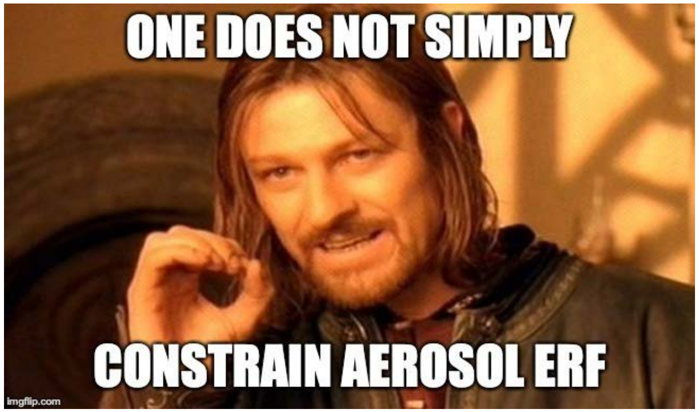

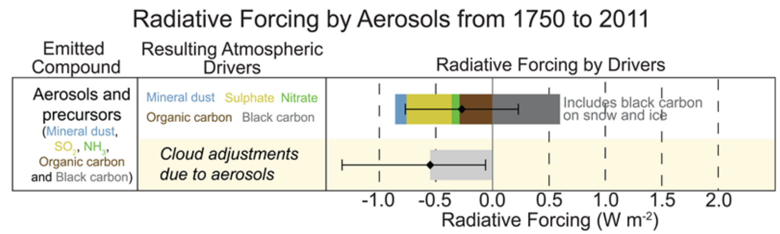

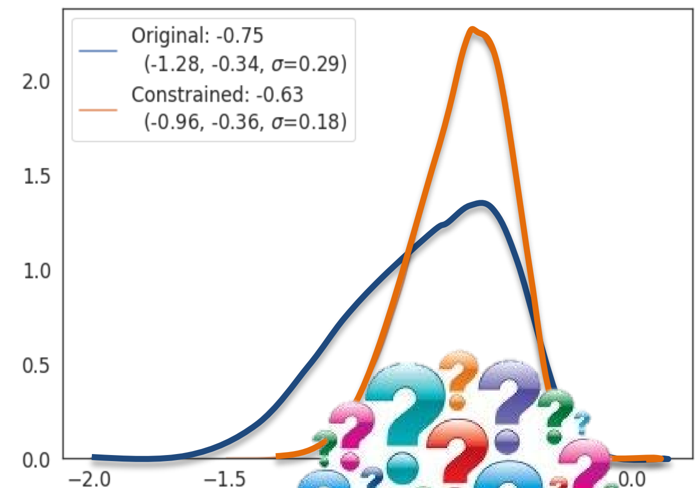

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PPE

2. Compare (constrained) models to each other

$M_{ulti}M_{odel}PPE$