School of Earth and Environment
INSTITUTE FOR CLIMATE & ATMOSPHERIC SCIENCE
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Understanding the sources of uncertainty in global aerosol

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With input from Graham Mann Dom Spracklen, Philip Stier, Jeff Pierce, and others

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NERC AEROS project (2010-2013)

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AErosol model **RO**bustness and **S**ensitivity study for improved climate and air quality prediction (Leeds and Oxford)

Robustness: A prediction that doesn't change fundamentally in the face of model uncertainty

Use new statistical tools and uncertainty analysis techniques to quantify the sources of global aerosol model uncertainty at the process level.

Follow-up project NERC 2013-2016

Global **A**erosol **S**ynthesis and **S**cience project (GASSP!)

Leeds, Oxford, Manchester + 10 data partners + Met Office

What do we mean by “uncertainty” of the model?

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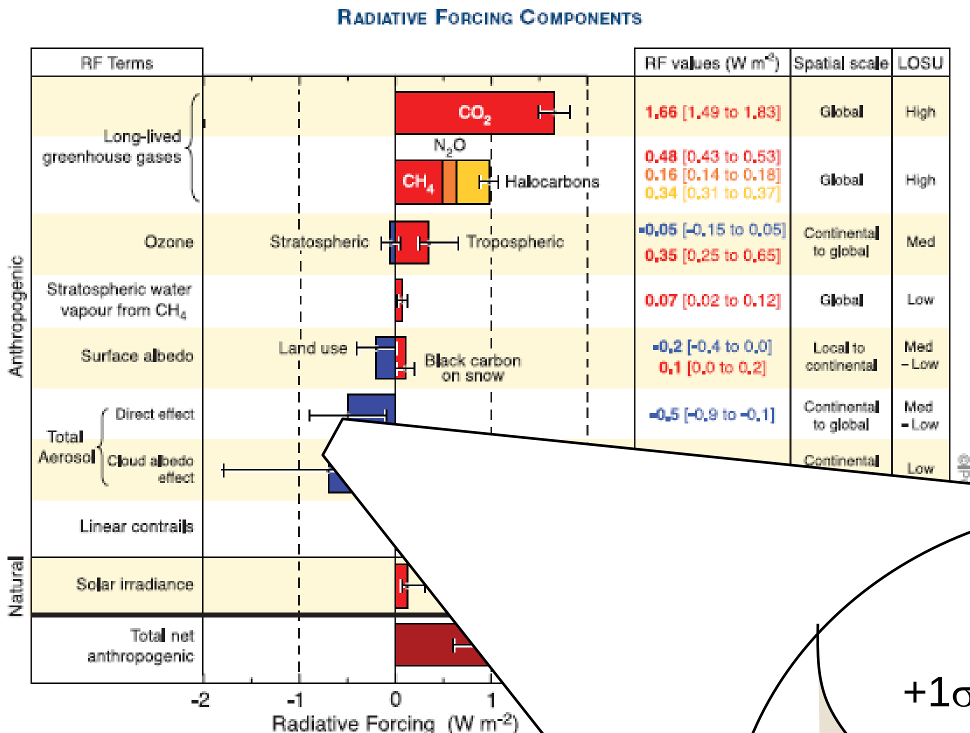
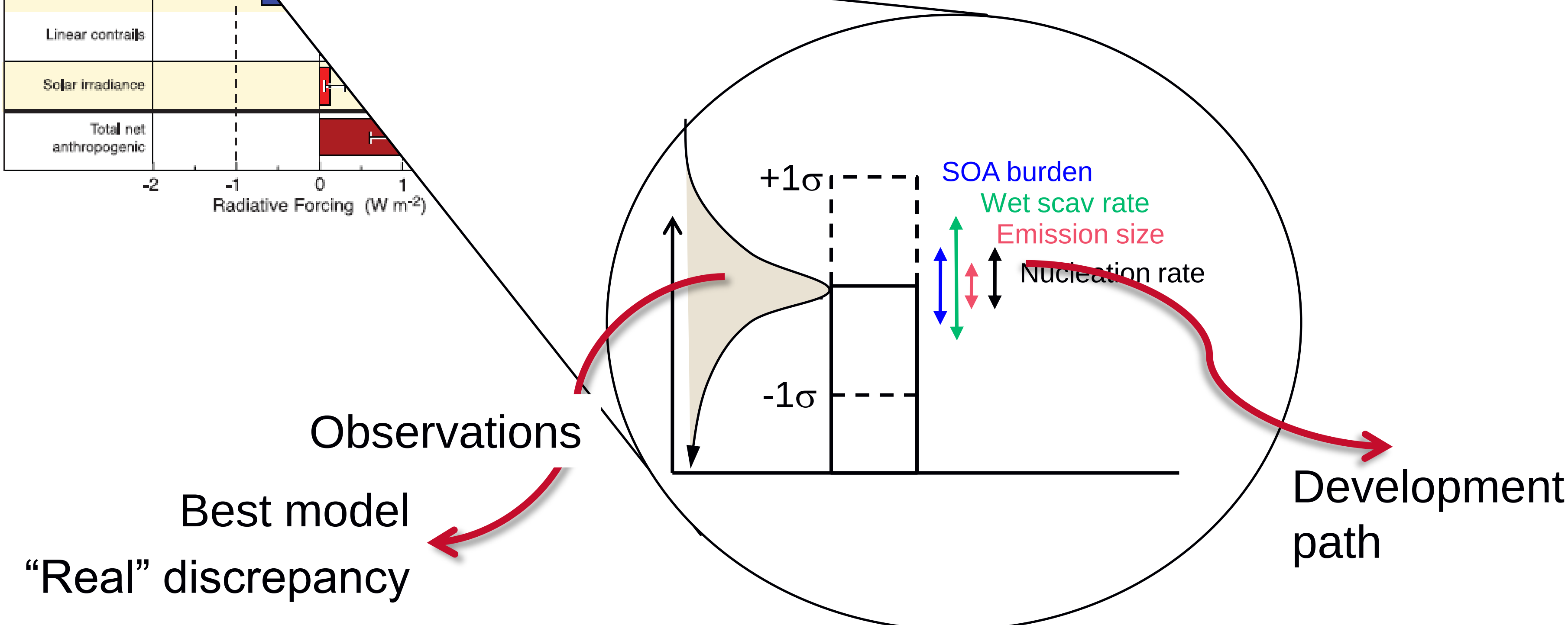


Model Intercomparison Projects focus on ***diversity***

Uncertainty attributable to processes would be a valuable addition



Using an emulator to do Monte Carlo on the cheap

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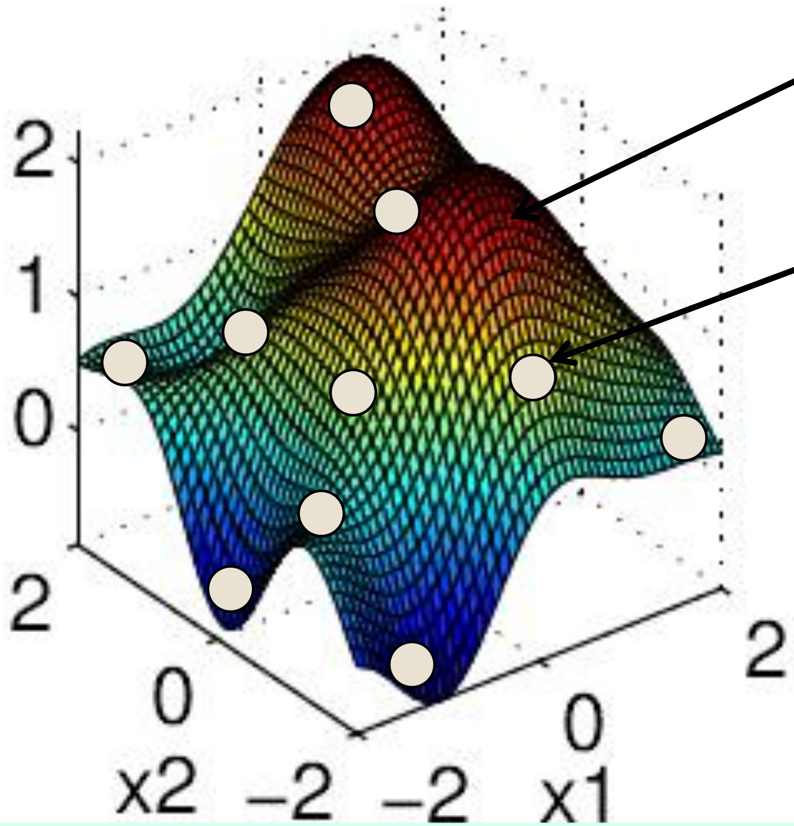
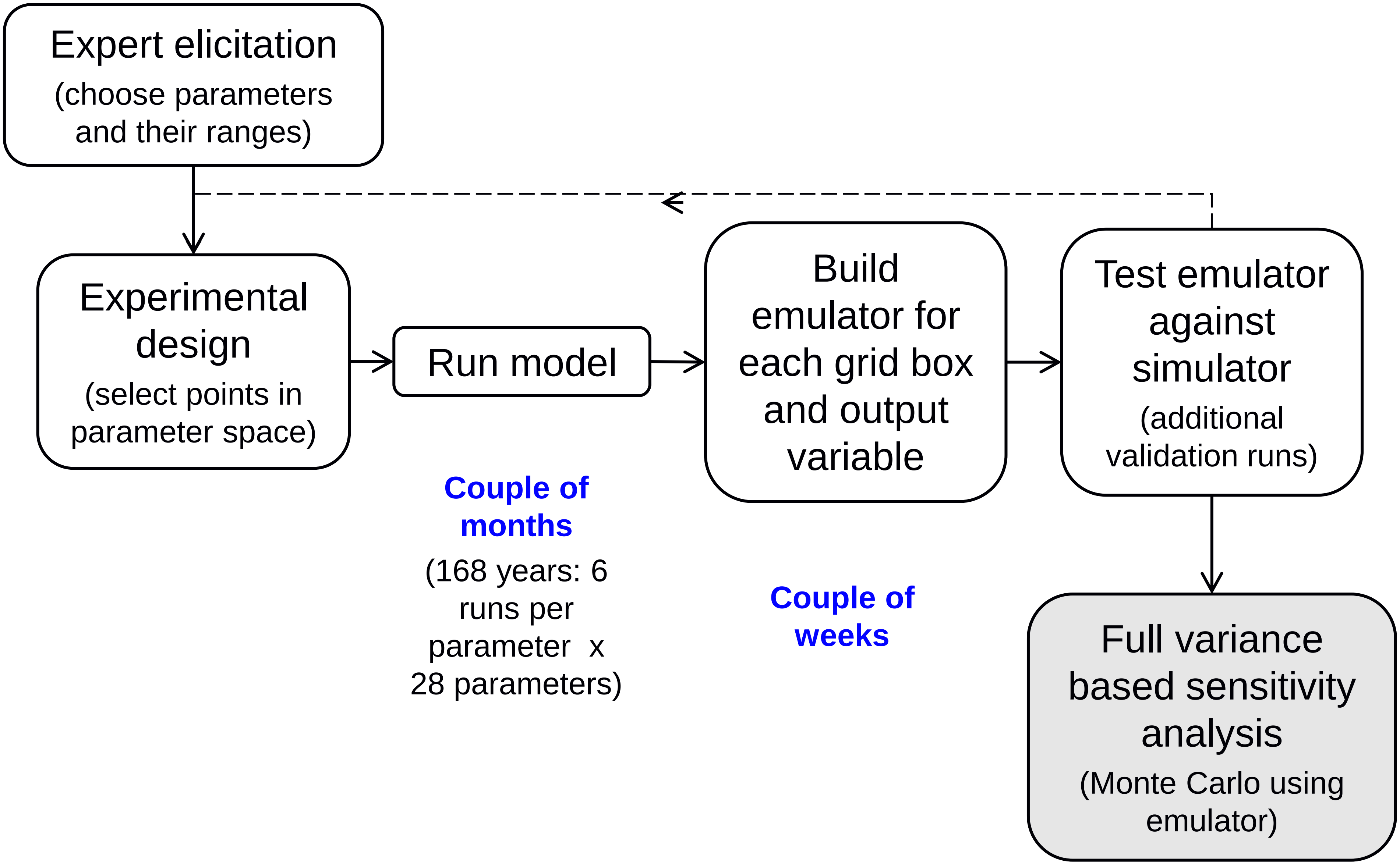


Essentially using the interpolated parameter space to extract as much information as Monte Carlo

Oakley, J. and O’Hagan, A.: Probabilistic sensitivity analysis of complex models: a Bayesian approach, J. Roy. Stat. Soc. B, 66, 751–769, 2004.

Lee, L.A. et al., Emulation of a complex global aerosol model to quantify sensitivity to uncertain parameters, ACP 2011.

The process of model emulation



The Global Model of Aerosol Processes (GLOMAP-mode)

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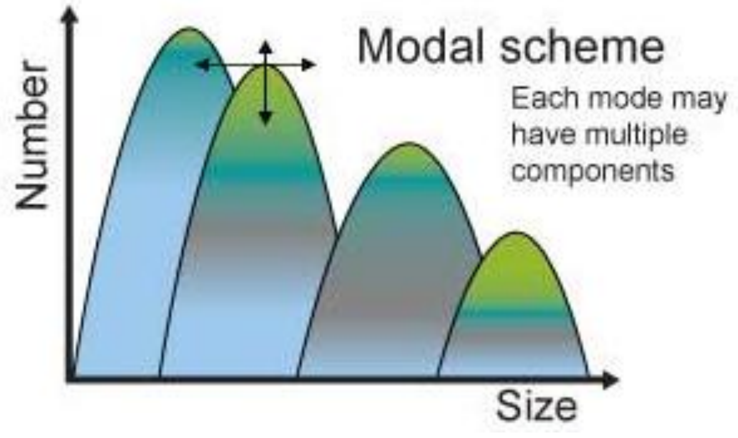

Global aerosol microphysics model within a 3D offline CTM forced by ECMWF winds

- Usually run at T42L31 (2.8°x2.8°) resolution
- Modal scheme: 7 log-normal modes
- Aerosol transport, new particle formation, gro by coagulation, condensation, cloud processing.
- Wet and dry deposition of gases & aerosol particles
- Chemistry can be driven by offline oxidants
- Emissions of DMS → SO_2 → H_2SO_4; monoterpenes → biogenic SOA
- Primary emissions of sea salt, dust, black & organic carbon (fossil/biofuel/biomass)

Not a GCM, so no aerosol feedbacks

Model description in Mann et al. (GMD, 2010)

Perturbed parameters 1/2

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Parameter	Lower	Upper
BCOC mass emission rate (fossil fuel)	0.5	2.0
BCOC mass emission rate (biomass burning)	0.25	4.0
BCOC mass emission rate (biofuel)	0.25	4.0
Sea spray mass flux (coarse/acc)	0.2x	5.0x
S02 emission flux (anthropogenic)	0.6x	1.5x
SO2 emission flux (volcanic)	0.5x	2.0x
Biogenic monoterpene production of SOA	5 Tg/a	360Tg/a
Anthropogenic VOC production of SOA	3Tg/a	160Tg/a
DMS mass flux	0.5x	3.0x
BCOC mode diameter (fossil fuel)	30 nm	80 nm
BCOC mode diameter (biomass burning)	50 nm	200 nm
BCOC mode diameter (biofuel)	50 nm	200 nm
Subgrid conversion of SO2 to SO4 ("primary SO4“)	0%	1%
Mode diameter of "primary SO4"	20 nm	100 nm

Particle and precursor gas emission rates

Properties of emitted particles

Perturbed parameters 2/2

Parameter	Lower	Upper	
BL nucleation rate k[H2SO4]	1E-10	2E-04	Microphysical rates
FT nucleation rate (BHN)	x0.01	X10	
Ageing "rate" from insol to sol (monolayer)	0.3	5	
Modal width (accumulation)	1.2	1.8	Model "structural choices"
Modal width (Aitken)	1.2	1.8	
Mode separation diameter (nucleation/Aitken)	9nm	20nm	
Mode separation diameter (Aitken/accumulation)	x1.5	x3	

Cloud drop activation dry diameter	30	100	Cloud processing
Reaction SO2 + O3 in cloud water (clean)	pH=4	pH=6.5	
Reaction SO2 + O3 in cloud water (polluted)	pH=3.5	pH=5	

Nucleation scavenging dry D (above activation)	0	100	Dry and wet deposition
Nucleation scavenging fraction (T> -15C)	0.2	0.99	
Dry deposition velocity (Aitken)	x0.5	X2.0	
Dry deposition velocity (accumulation)	X0.1	X10.0	

Raw model results in each grid box

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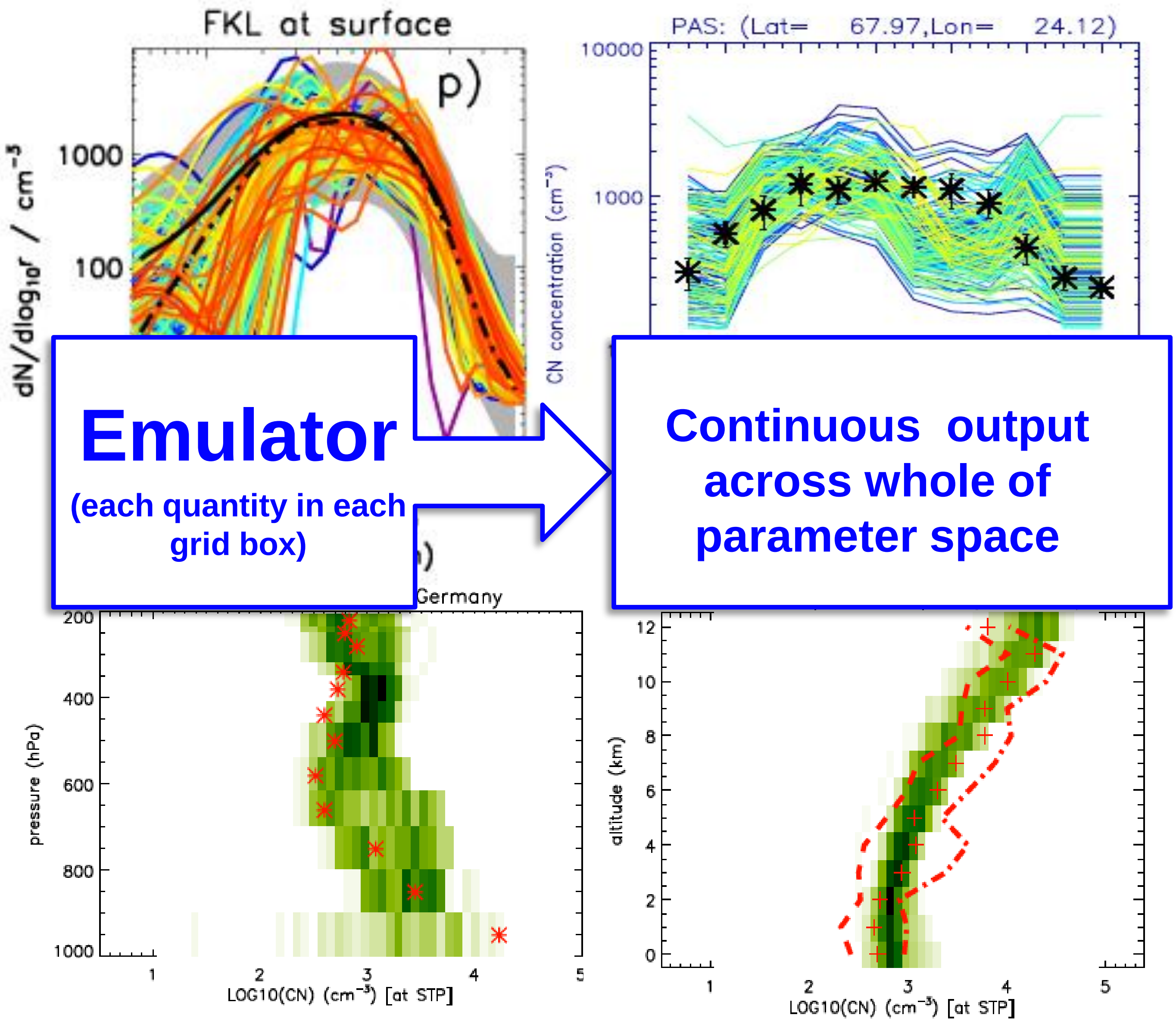


Emulator

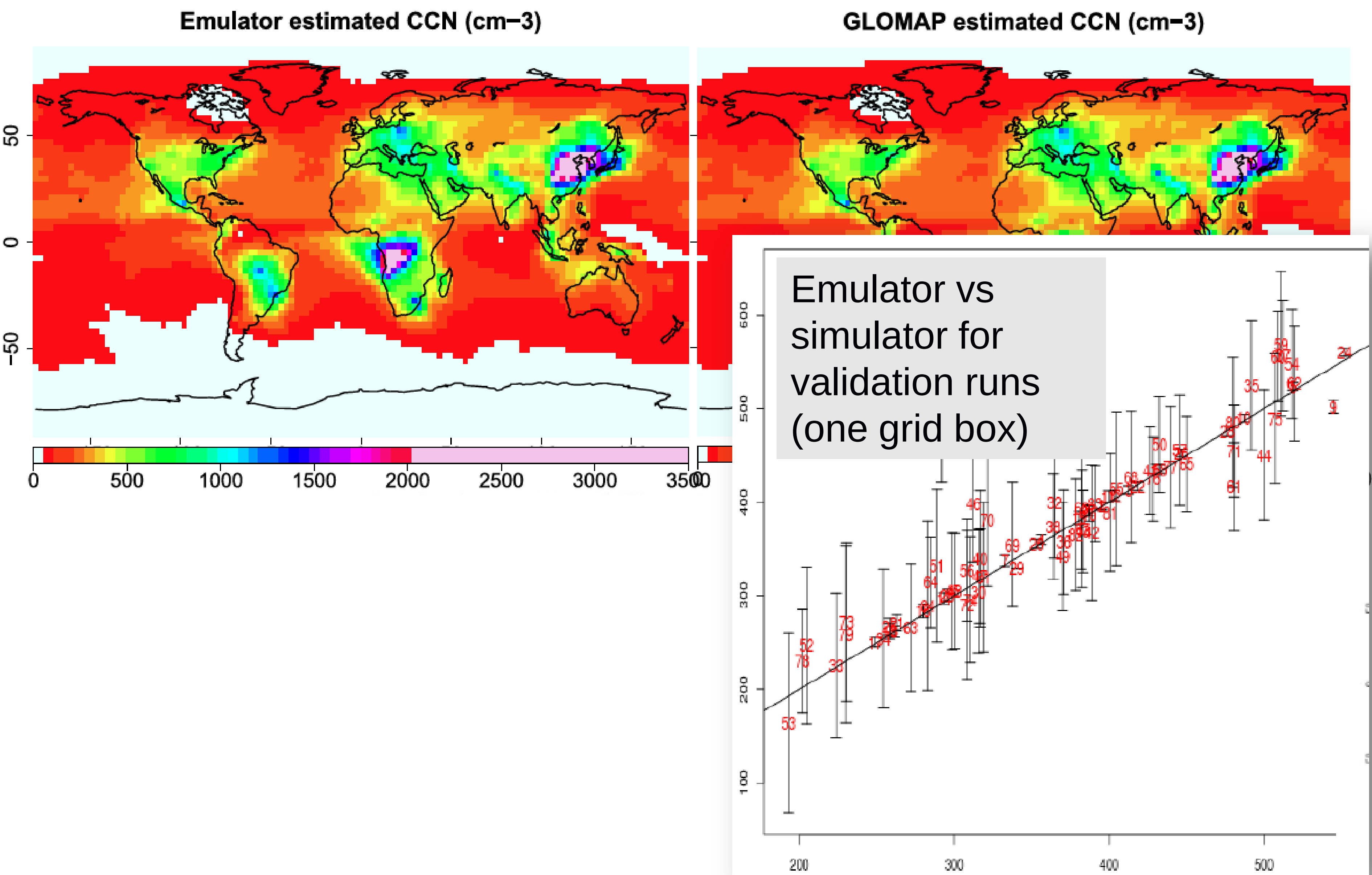
(each quantity in each grid box)

Continuous output across whole of parameter space

168 annual model runs covering 28-dimensional parameter space

Far from sufficient for Monte Carlo

Validate the emulator



How uncertain is global aerosol?

PDFs of CCN concentration in every grid box

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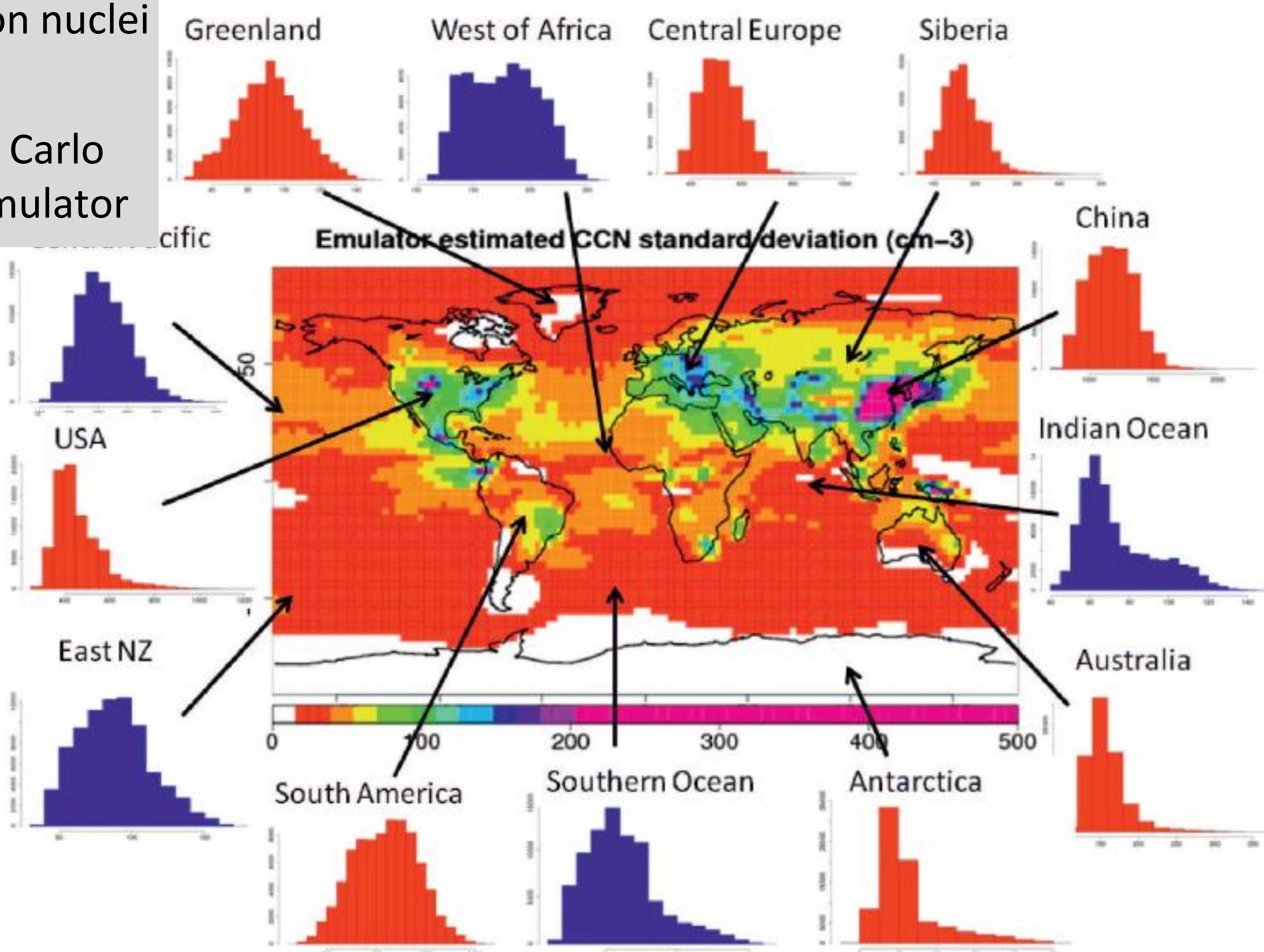
Cloud condensation nuclei (CCN)

Based on a Monte Carlo sampling of the emulator



CCN and associated uncertainty

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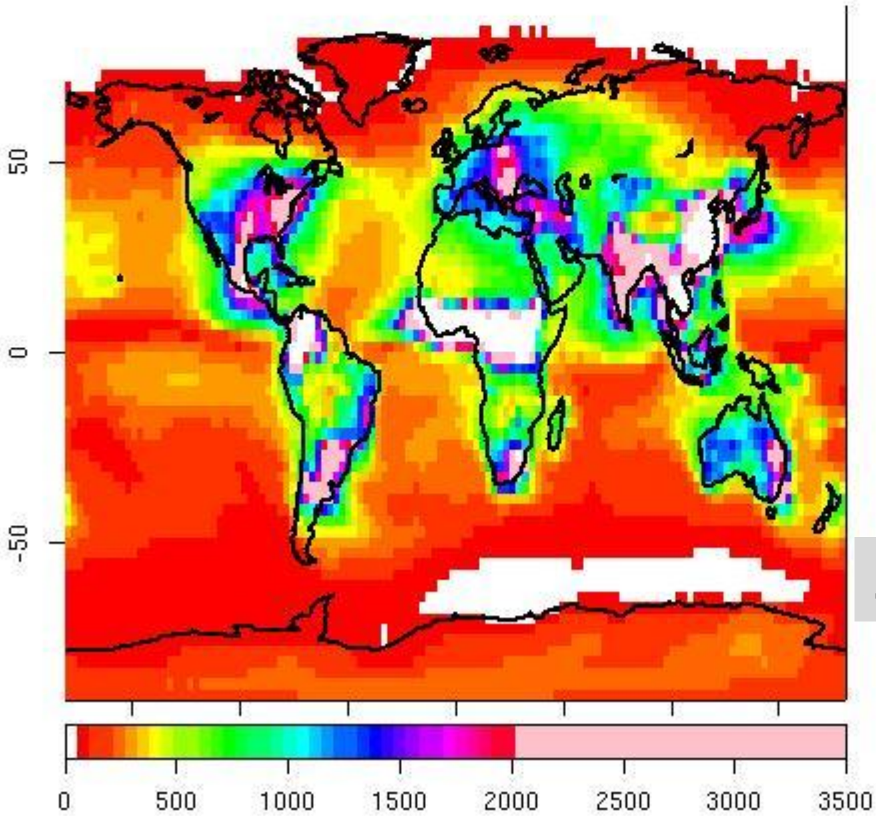
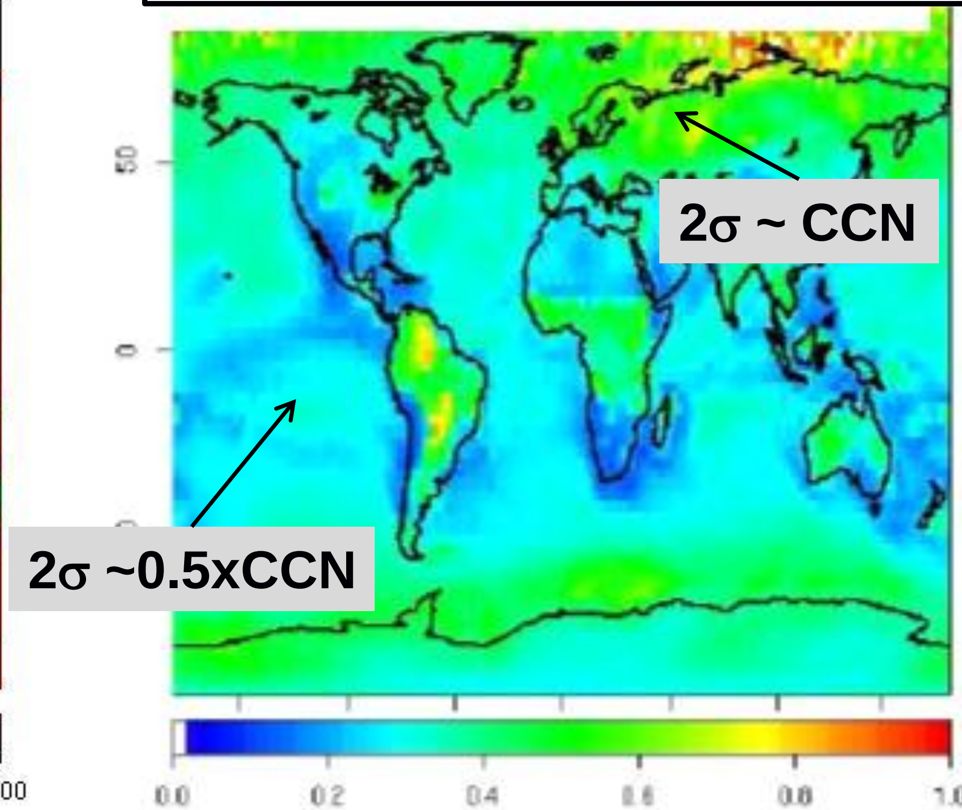
Emulator estimated CCN



CCN concentration / cm^{-3}

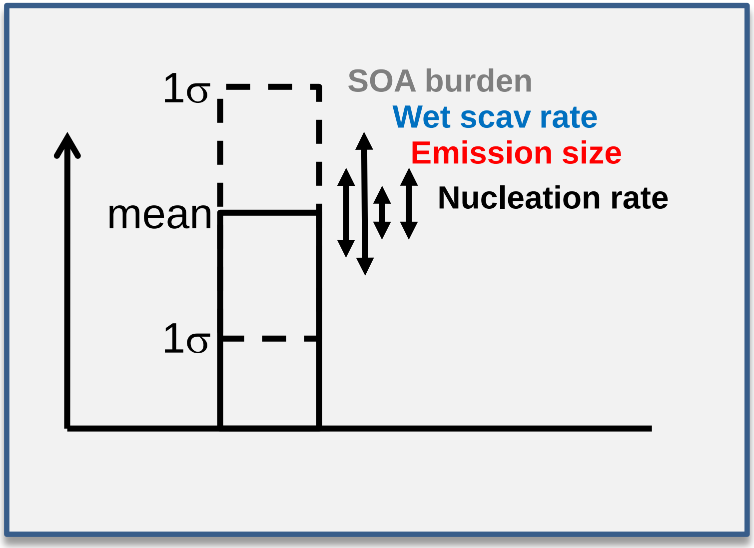
Emulator estimated coefficient of variation (σ/CCN)



(σ/CCN)

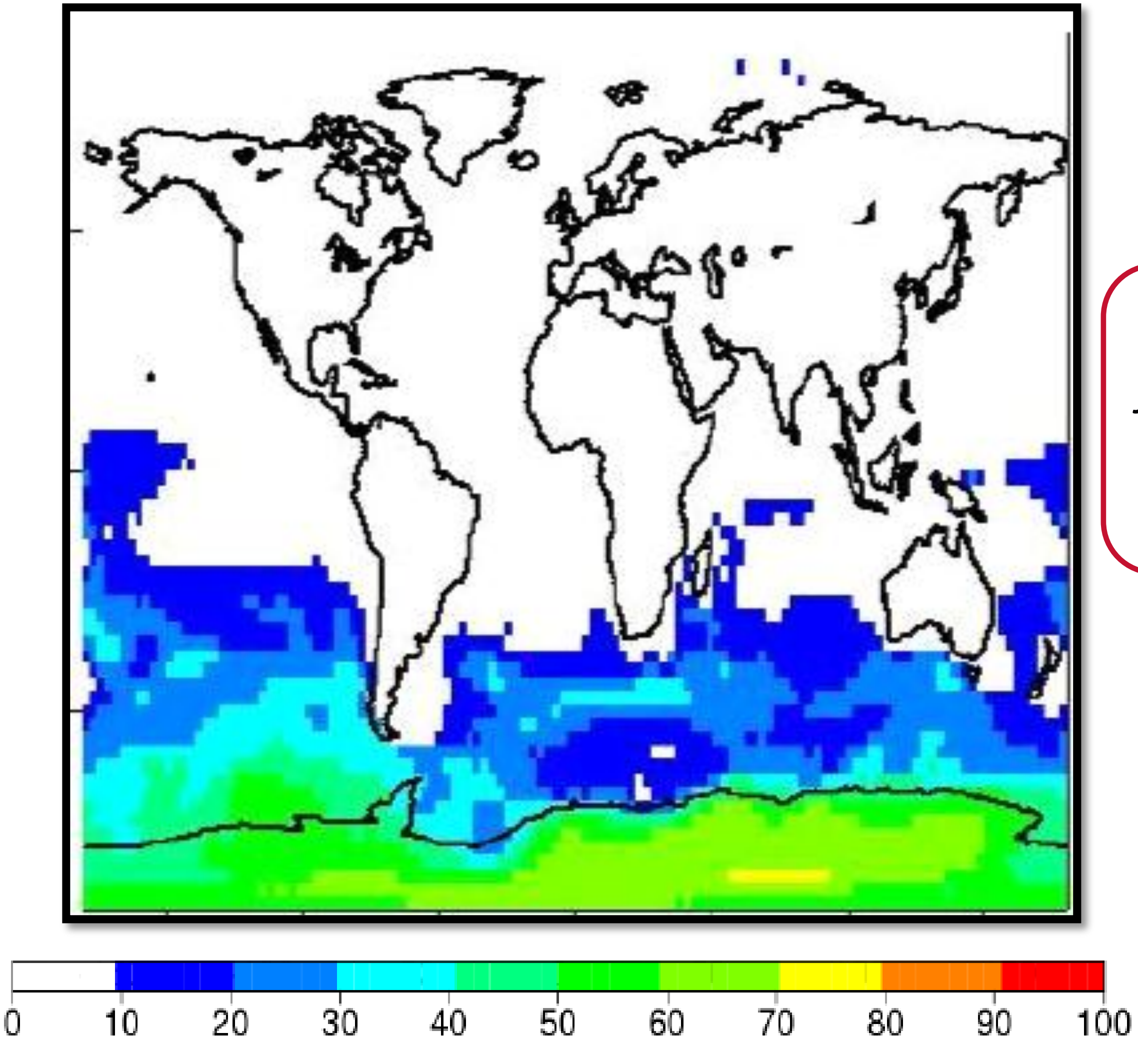
January

How much do the different parameters contribute to the uncertainty?



Contributions to CCN variance

Percent variance due to DMS flux



Meaning: If we knew the *DMS flux* precisely, this is the reduction in CCN variance we would achieve

Contributions to CCN variance January

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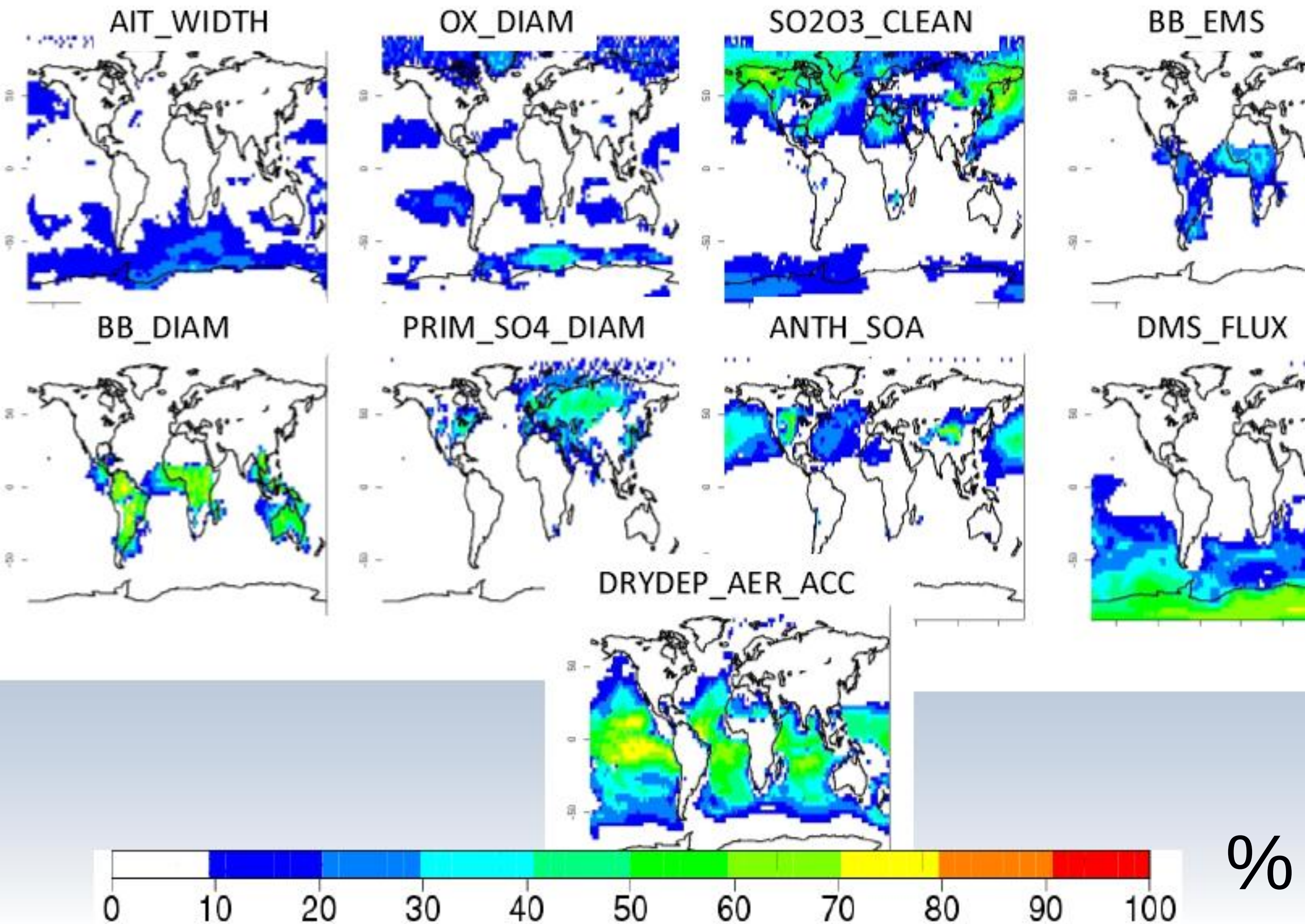
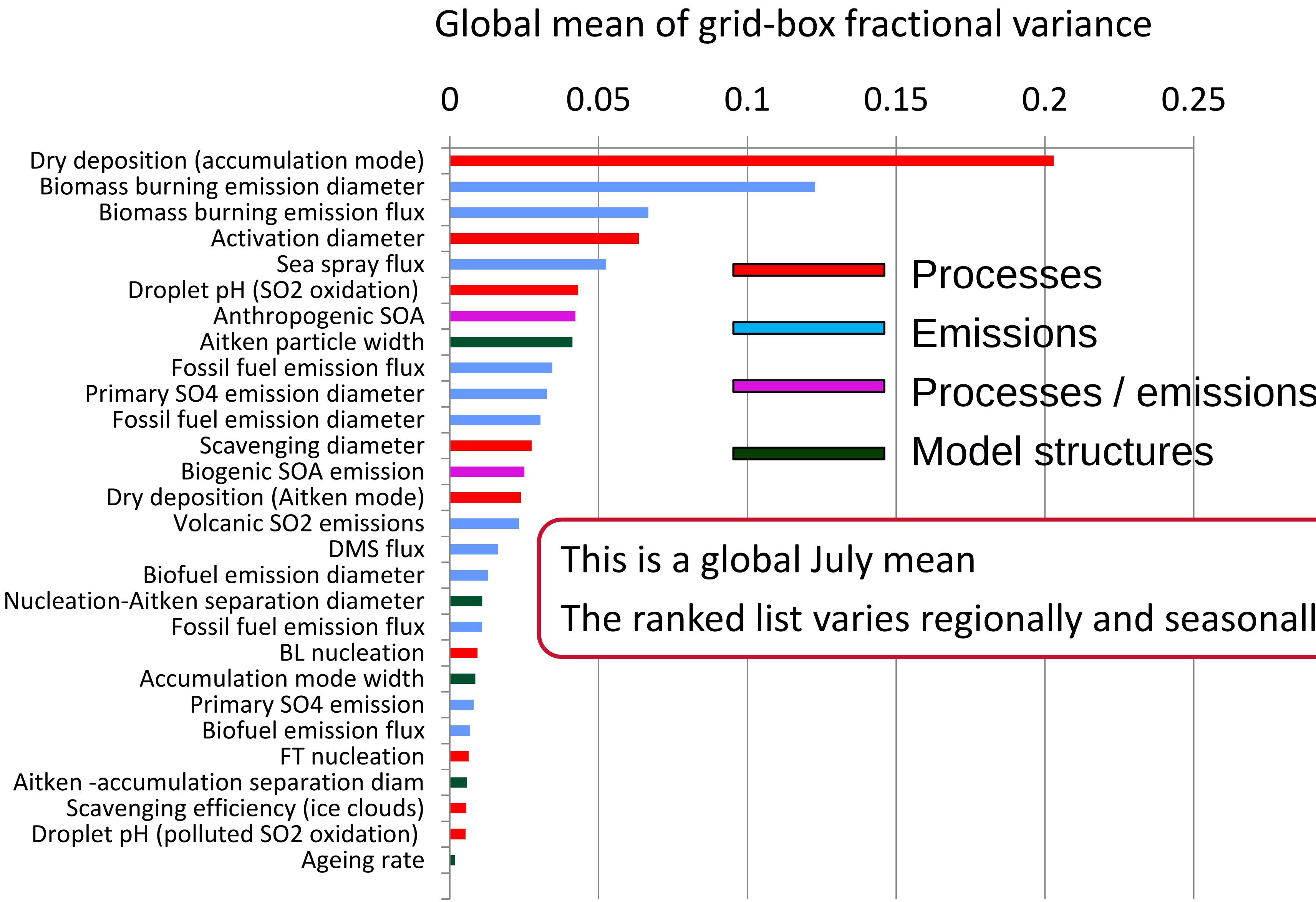


Ranked CCN uncertainty



This is a global July mean

The ranked list varies regionally and seasonally

Regional/seasonal sensitivities

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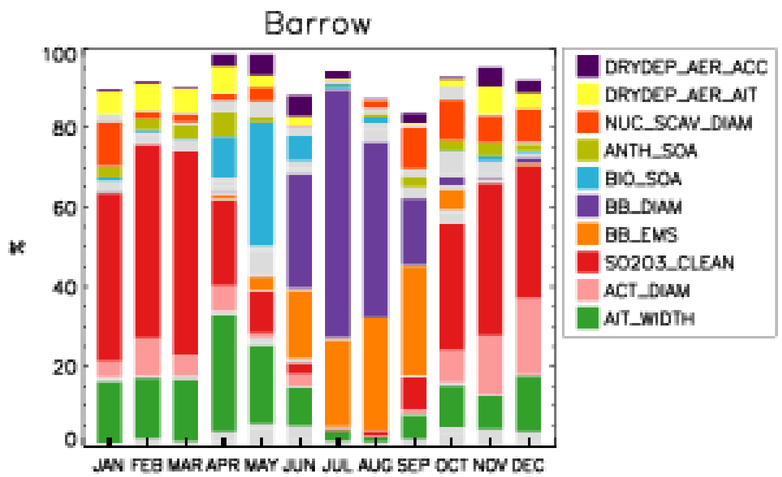
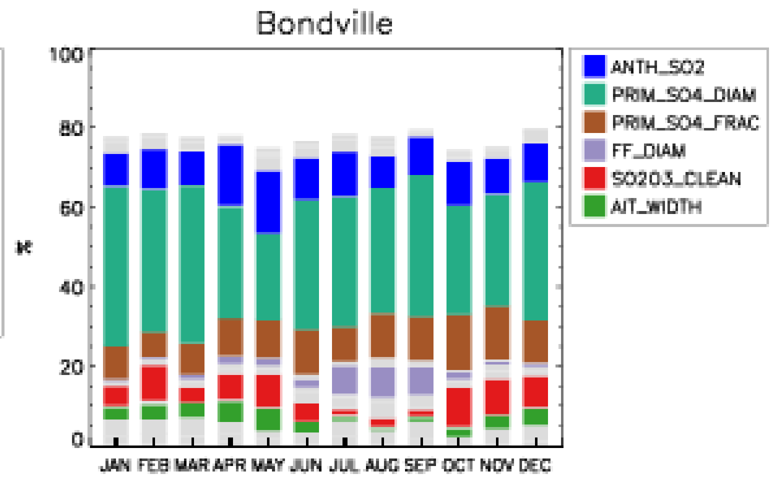
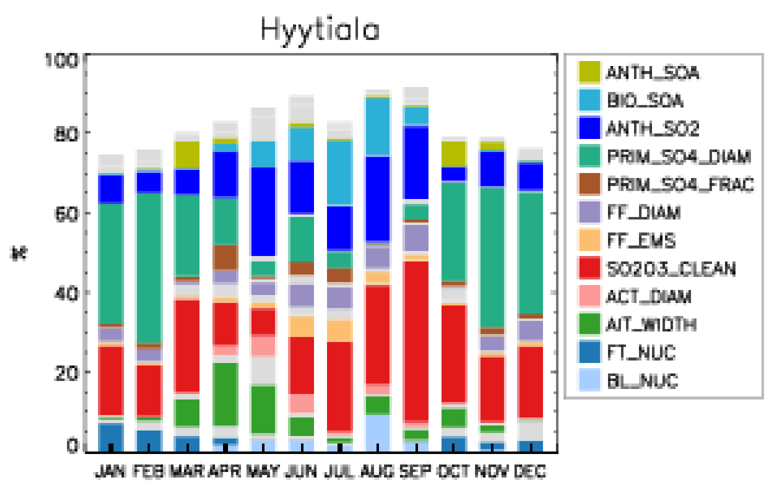
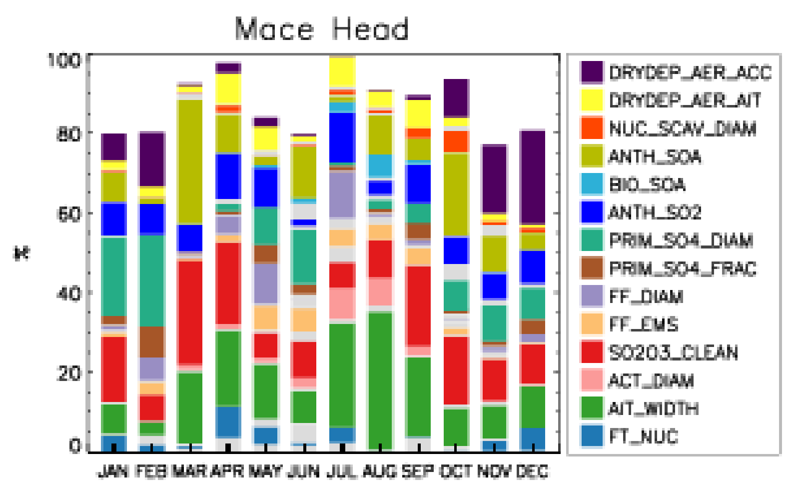








Indirect forcing

Forcing depends on the ***change*** in aerosol properties between pre-industrial and present day

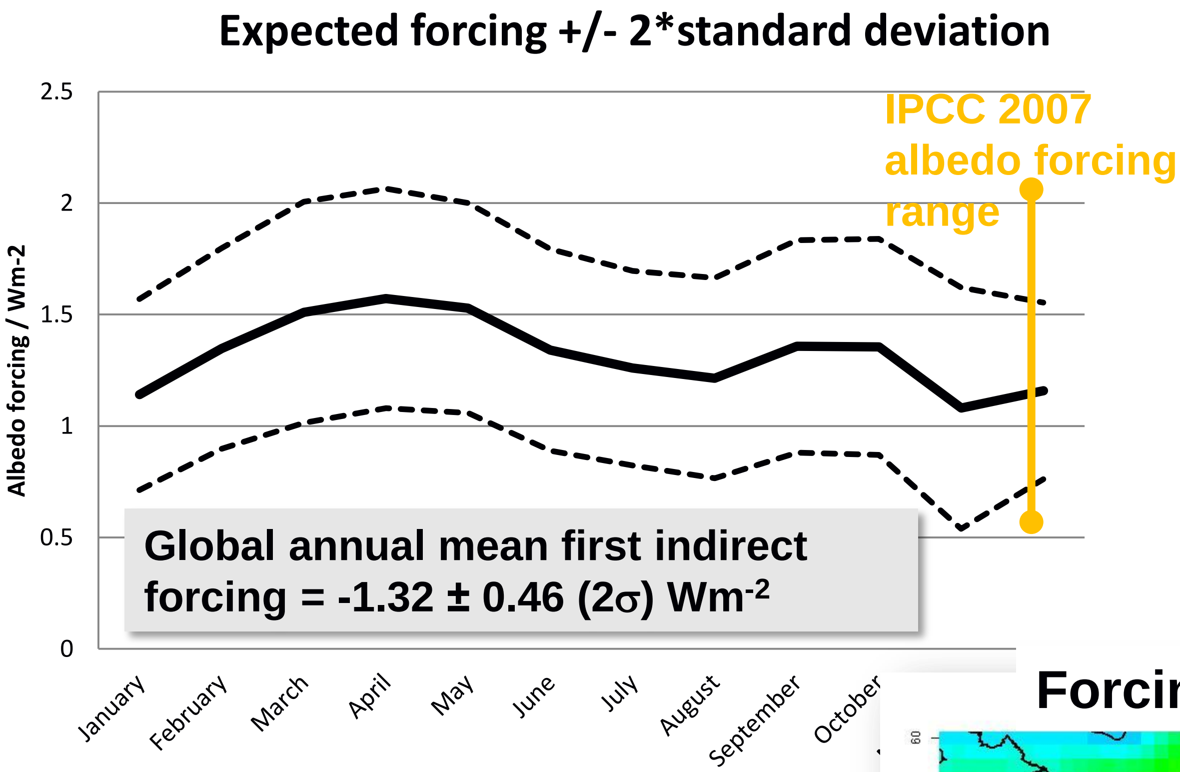
Some factors may “cancel out”

Forcing depends non-linearly on CCN

Repeat the 168 runs with pre-industrial emissions but same meteorology

Emulate change in effective radius → forcing

Uncertainty in indirect forcing



Global annual mean first indirect forcing = -1.32 ± 0.46 (2σ) Wm^{-2}

Top 5 contributions to albedo forcing uncertainty (variance)

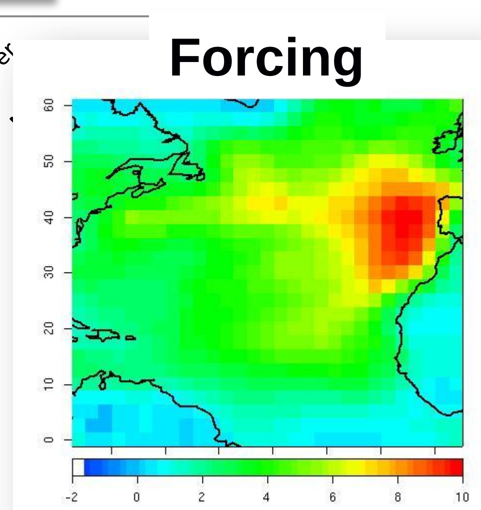
24.3% Degassing volcanic SO_2

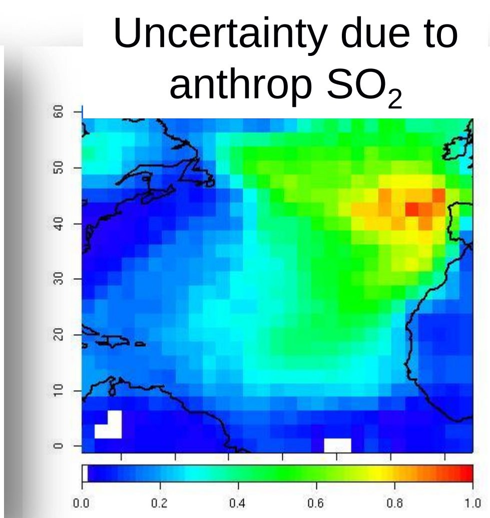
18.1% Anthropogenic SO_2

12.3% DMS flux

11.2% Anthropogenic SOA

10.8% Accumulation mode width





Future work

Global Aerosol Synthesis and Science Project (GASSP!)

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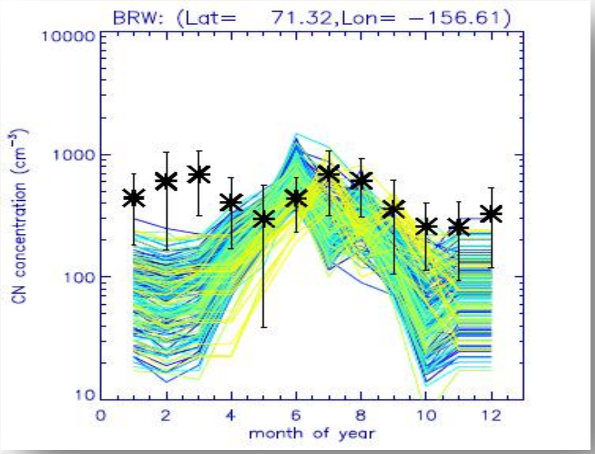
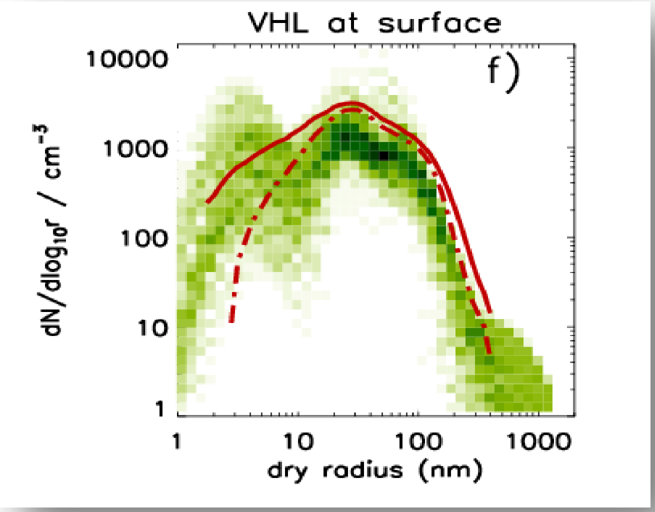
Leeds/Oxford + 10 data partners

Synthesis of global aerosol microphysics data

Use model sensitivity and uncertainty statistics to:

- Identify plausible, implausible and **best models**
- Identify **structural weaknesses** from remaining bias and inconsistencies between datasets
- Inform **observational strategies**
- **Indirect forcing** most consistent with modern aerosol measurements





Parametric uncertainty versus multi-model diversity

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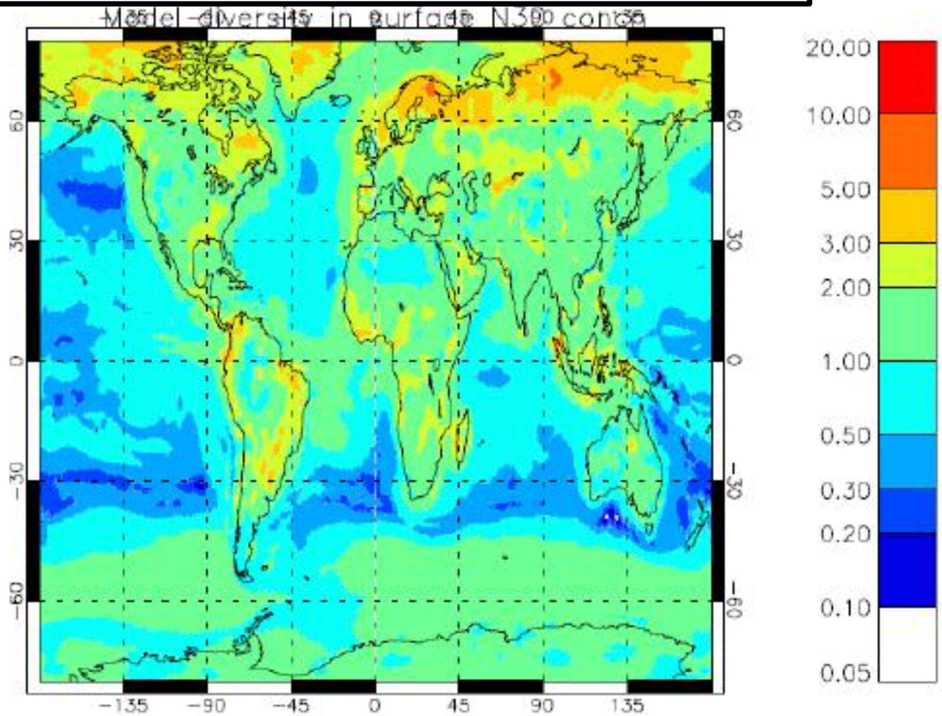
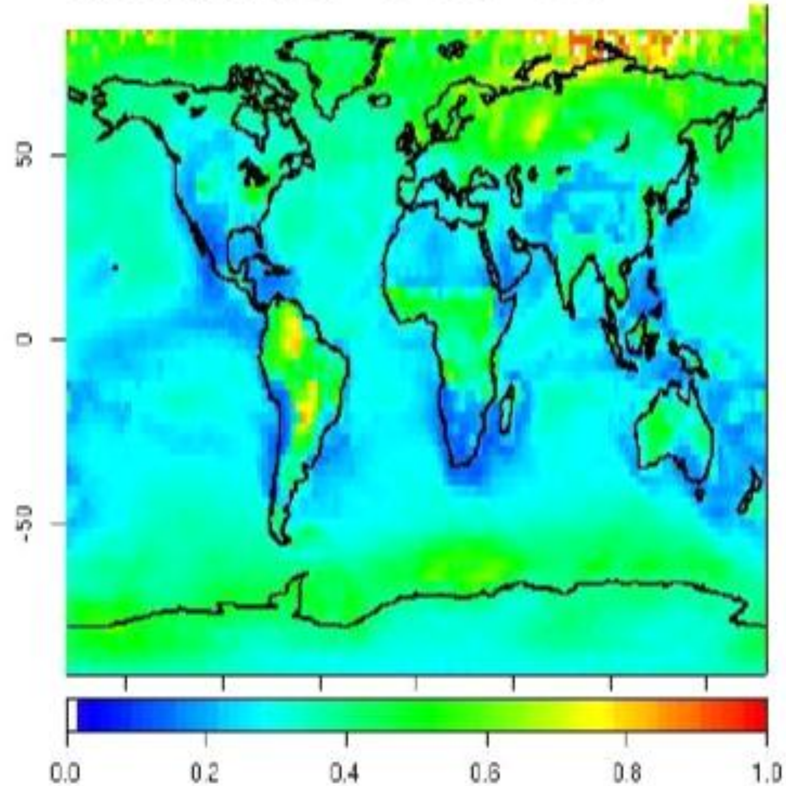
AEROCOM 12-model diversity in N30 = (P75-P25)/P50



GLOMAP coefficient of variation (σ/CCN)



AEROCOM data from Graham Mann

Summary

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- Can use model emulation to calculate a Monte Carlo-level of information: global 3-D fields of ***aerosol variance***, ***variance contributions***, and ***probability distributions*** for all parameters
- CCN parametric uncertainty 1σ varies between 30 and 80%
- Uncertainty in BC is similar to CCN, but fewer important parameters
- Parametric uncertainty in indirect effect (due to emissions and aerosol processes) is **-1.32 ± 0.46 (2σ) Wm^{-2}** (vs IPCC 0.3-1.8 Wm^{-2} range)
- Parameters controlling indirect forcing are not the same ones controlling present day CCN $\Rightarrow$ new strategy for model evaluation
- ~40% of parametric uncertainty in indirect effect from natural emissions

Happy to initiate collaborations to exploit all the data!

Lee, L.A. et al., Emulation of a complex global aerosol model to quantify sensitivity to uncertain parameters, ACP 2011.

Lee L.A. et al., Mapping the uncertainty in global CCN using emulation, ACPD, 2012.

Black carbon

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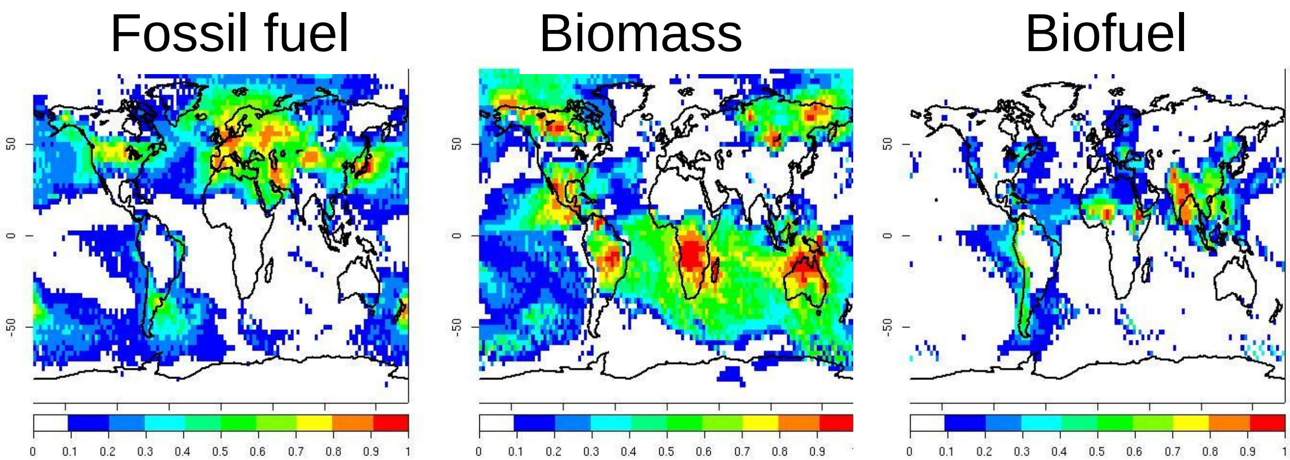

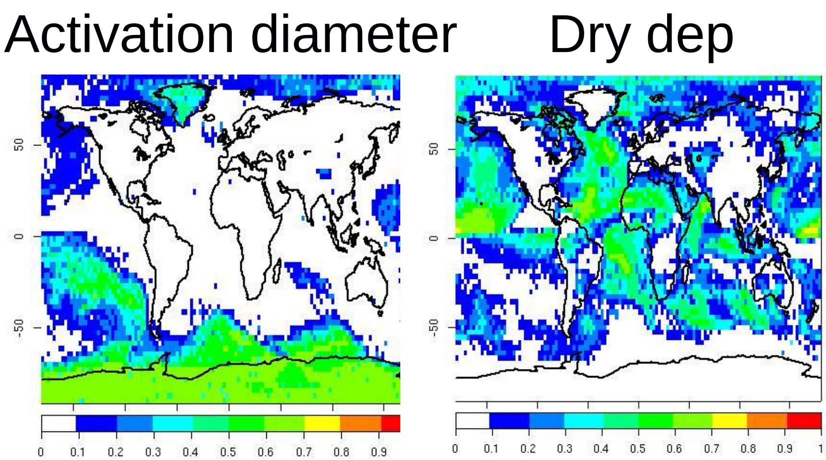

BC mass is much simpler to model than CCN

Uncertainty dominated by 5 parameters: *emission factors and removal processes*

North Atlantic forcing variances (February)

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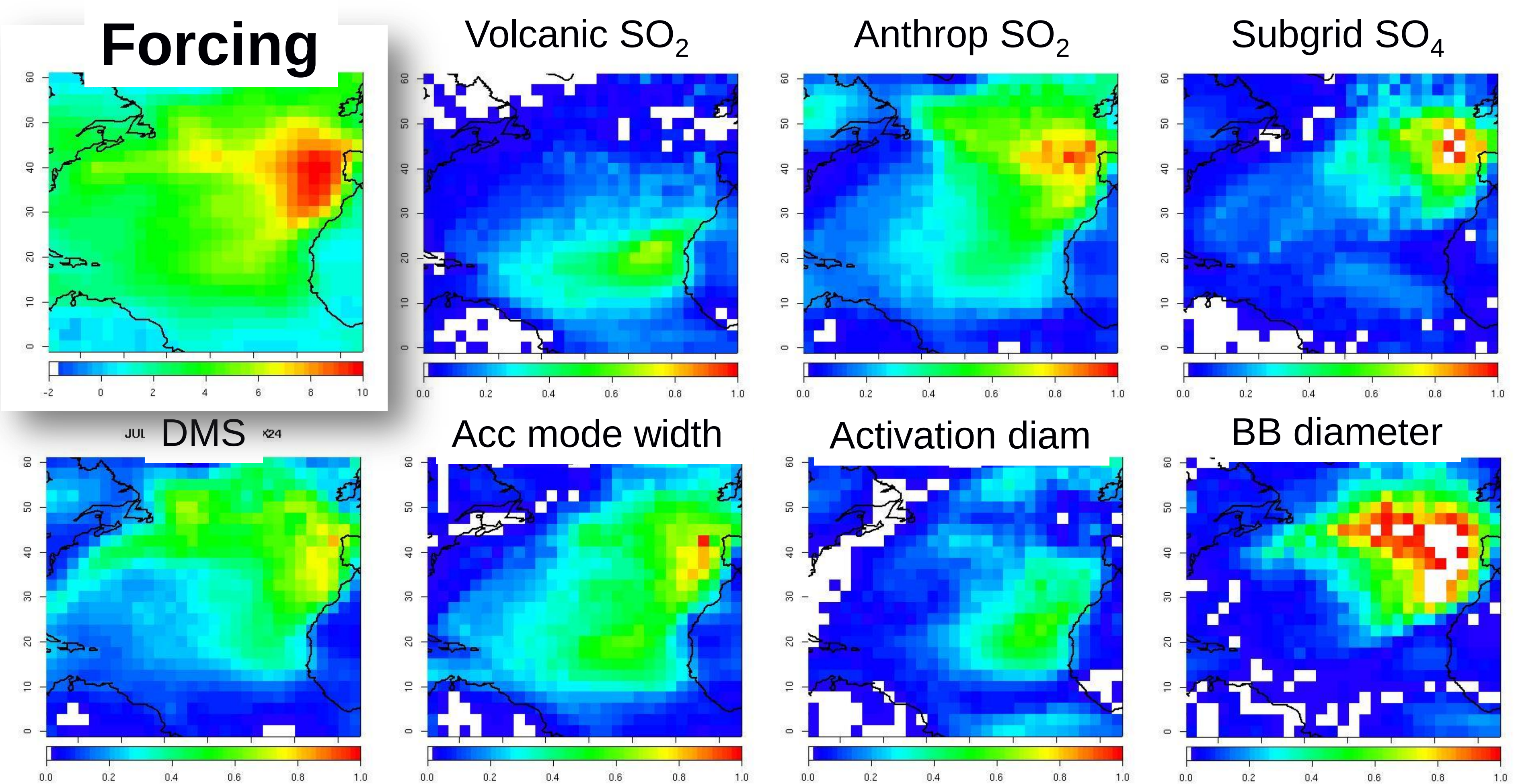

Why do natural emissions contribute to uncertainty in forcing?

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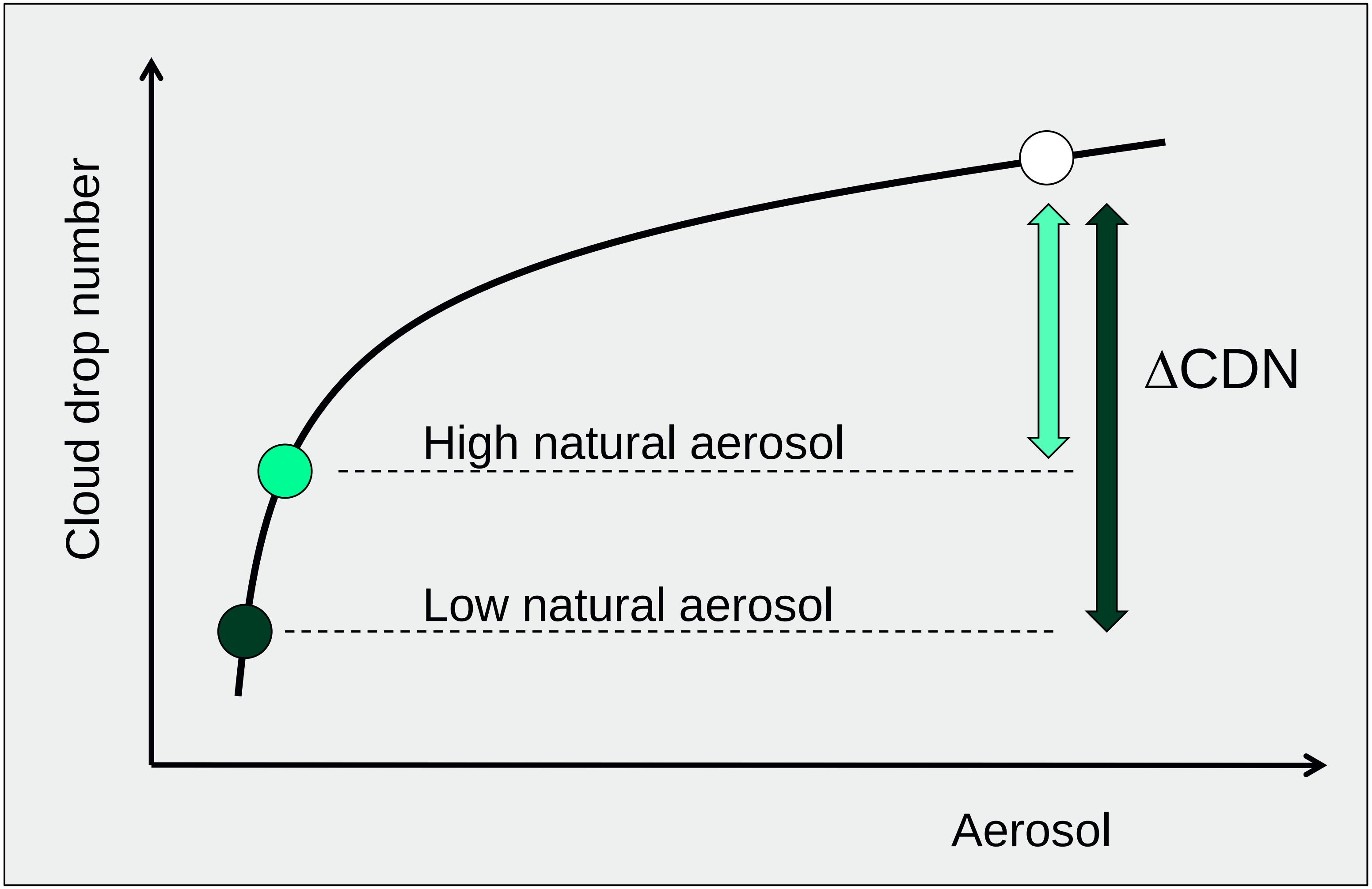
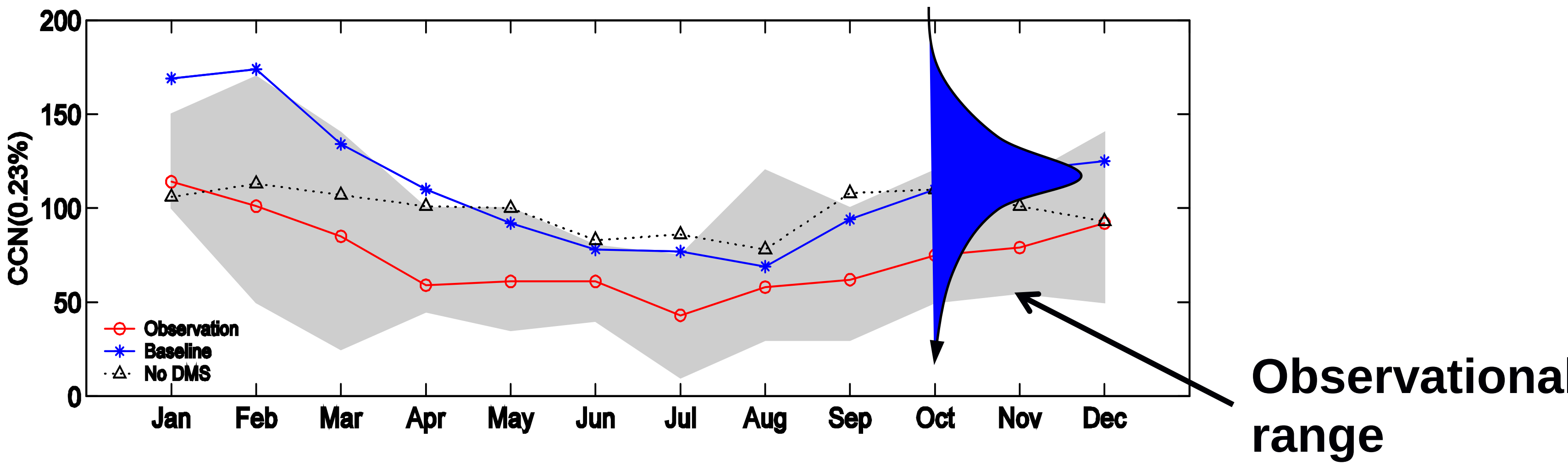


Importance of tropospheric volcanic aerosol for indirect radiative forcing of climate, A. Schmidt et al., Atmos. Chem. Phys. Discuss., 12, 8009-8051, 2012

Sensitivity and uncertainty "one at a time"

GLOMAP predictions of CCN at Cape Grim using "one-at-a-time" sensitivity tests



- One-at-a-time tests sample only a tiny fraction of parameter space
- They don't provide any statistical information