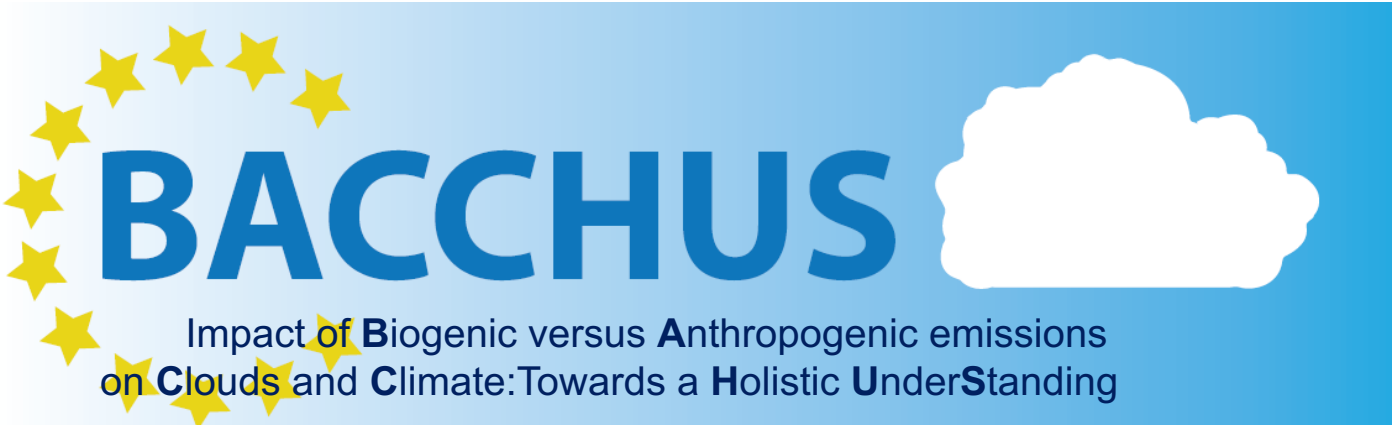


Highlights from the BACCHUS project

Natural aerosols and climate

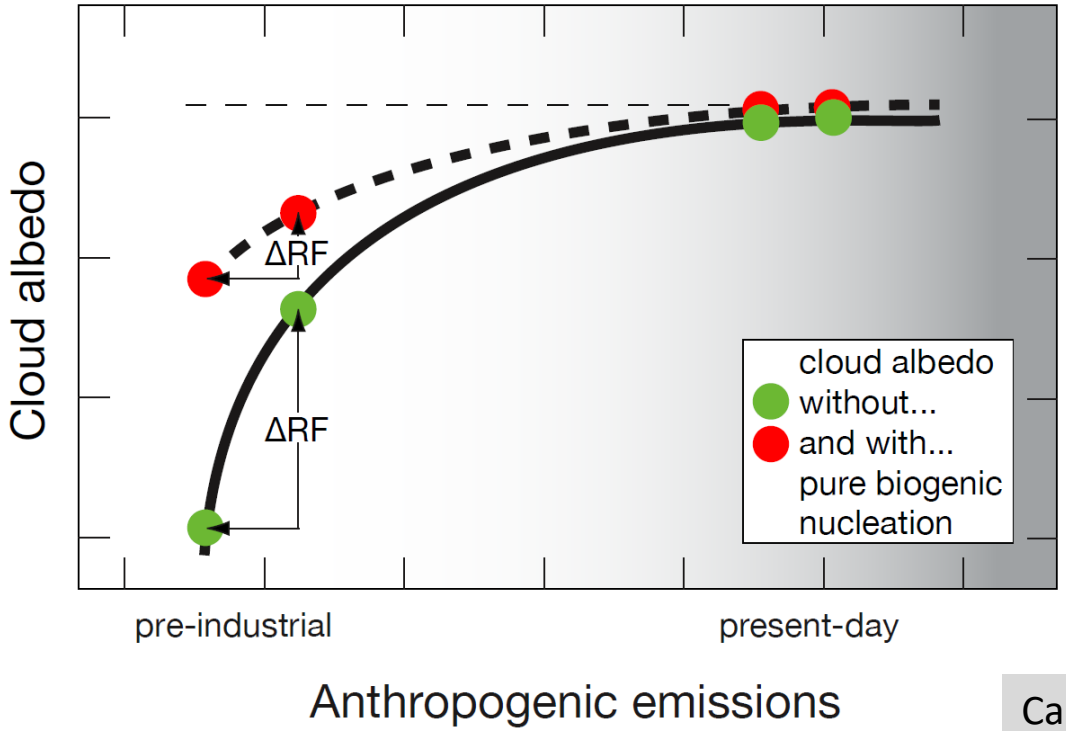
Ken Carslaw
University of Leeds
On behalf of the Bacchus consortium

SEVENTH FRAMEWORK PROGRAMME

Natural aerosols and climate

- **Fires**
  - Reassessment of pre-industrial fire emissions affects radiative forcing
- **Biogenic secondary organic aerosol**
  - Most new particle formation involves natural organic compounds
  - A new biogenic particle formation mechanism affects radiative forcing
  - Biogenic compounds could account for most of the multi-model spread in cloud condensation nuclei
- **Natural ice-nucleating particles**
  - New capability to simulate natural INP based on laboratory data
  - Very low natural concentrations over the Southern Ocean can account for radiative biases in climate models

Natural aerosols and climate

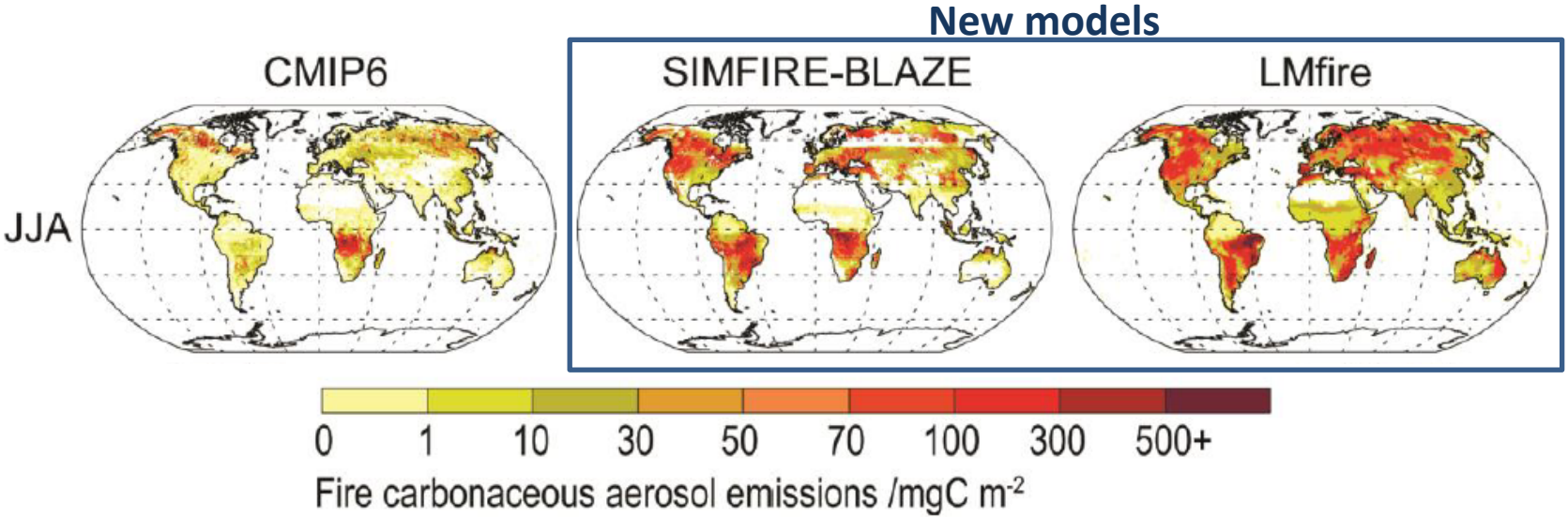


More natural aerosols → Reduced aerosol radiative forcing

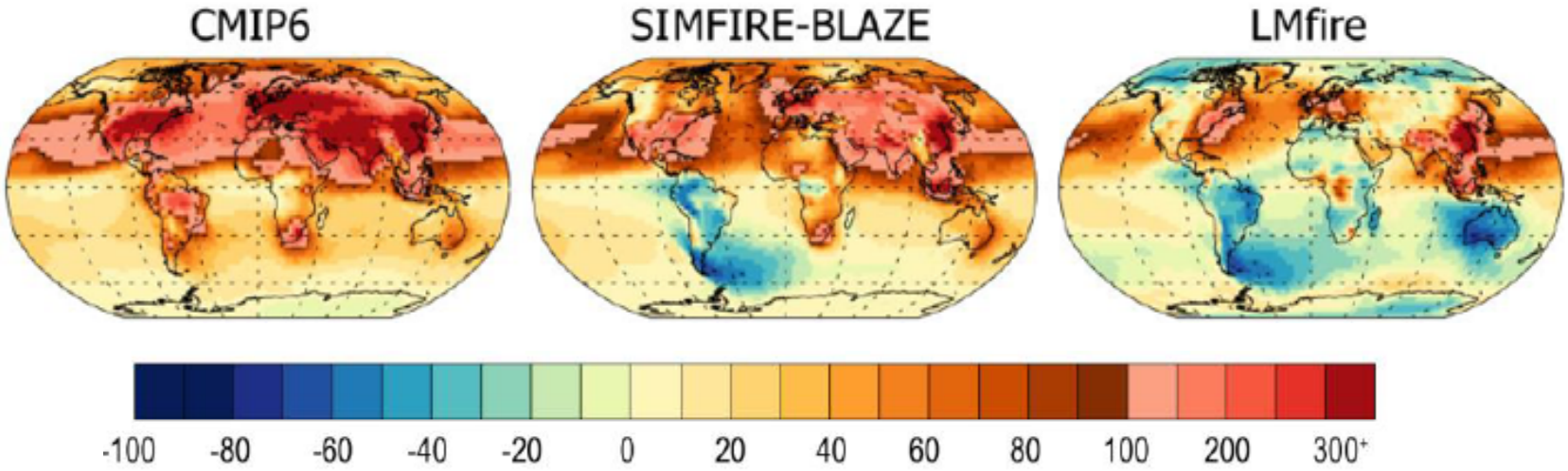
Carslaw et al. Large contribution of natural aerosols to uncertainty in indirect forcing, *Nature* (2013)

Pre-industrial fires: Emissions

- New models of pre-industrial fire emissions
- Tested the effect on aerosol radiative forcing



Pre-industrial fires:
Effect on changes in industrial-period aerosol



Pre-industrial to present-day % change in CCN

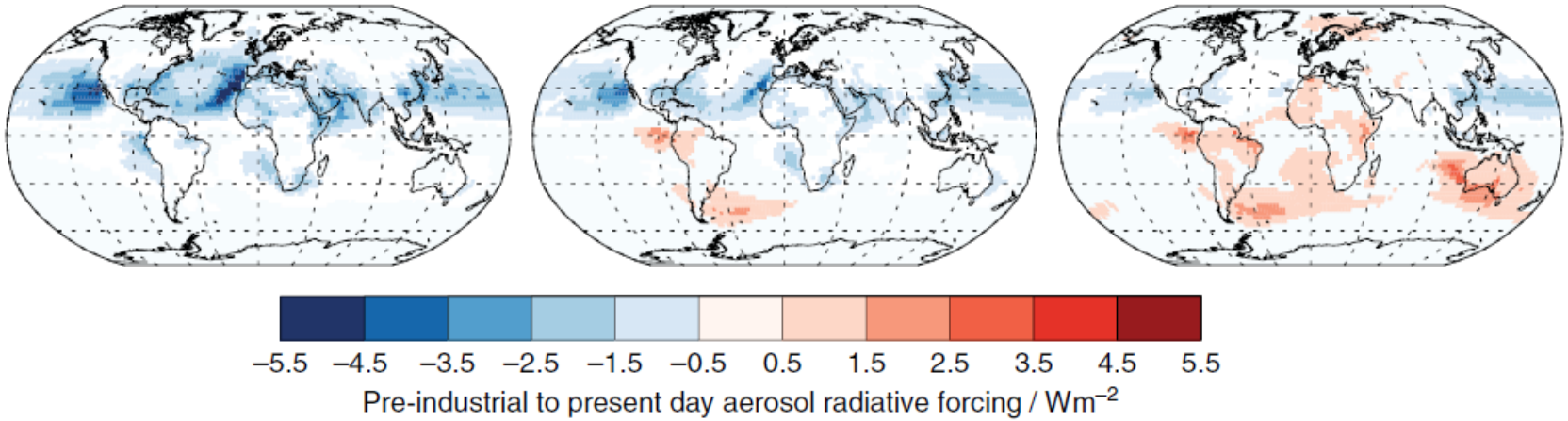
Hamilton et al. Reassessment of pre-industrial fire emissions strongly affects anthropogenic aerosol forcing, Nature Comms. (2018)

Pre-industrial fires: Effect on aerosol forcing

CMIP6 emissions
Global mean forcing = **-1.1 Wm^{-2}**

SIMFIRE-BLAZE emissions
Global mean forcing = **-0.7 Wm^{-2}**

LMFire emissions
Global mean forcing = **-0.1 Wm^{-2}**



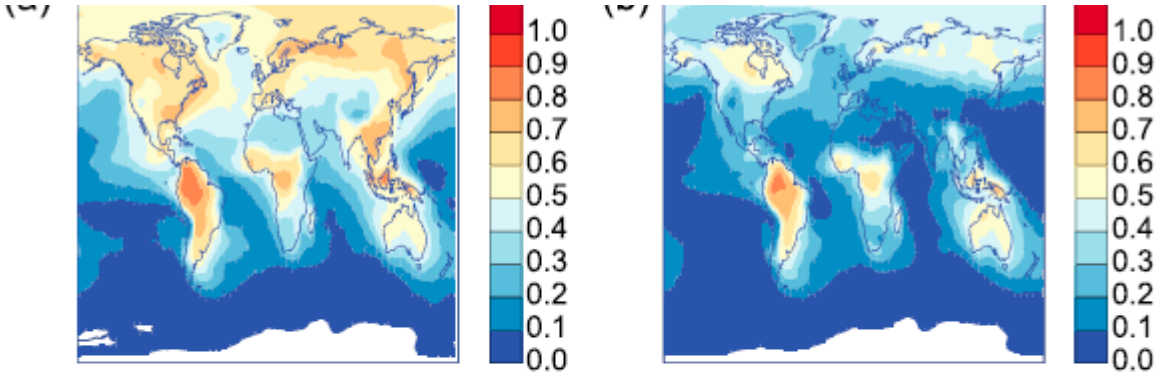
Hamilton et al. Reassessment of pre-industrial fire emissions strongly affects anthropogenic aerosol forcing, Nature Comms. (2018)

A 40-90% effect of fires on aerosol radiative forcing
Will affect climate sensitivity in ESMs
Will help development of next-generation ESMs

Contributions of biogenic emissions to CCN

Fraction of CCN from biogenic vapours

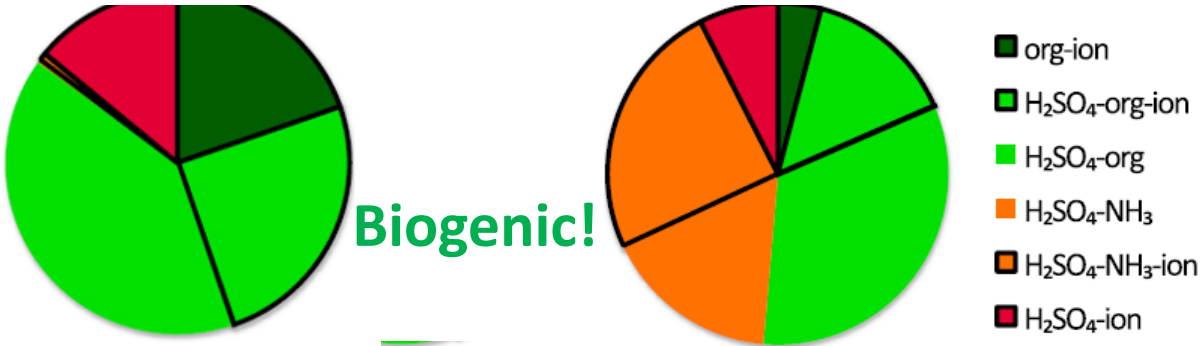
Pre-industrial **Present-day**



Very large influence of biogenic emissions on particle formation and CCN

Future ESMs will need to account for biogenic effects on particle formation and CCN

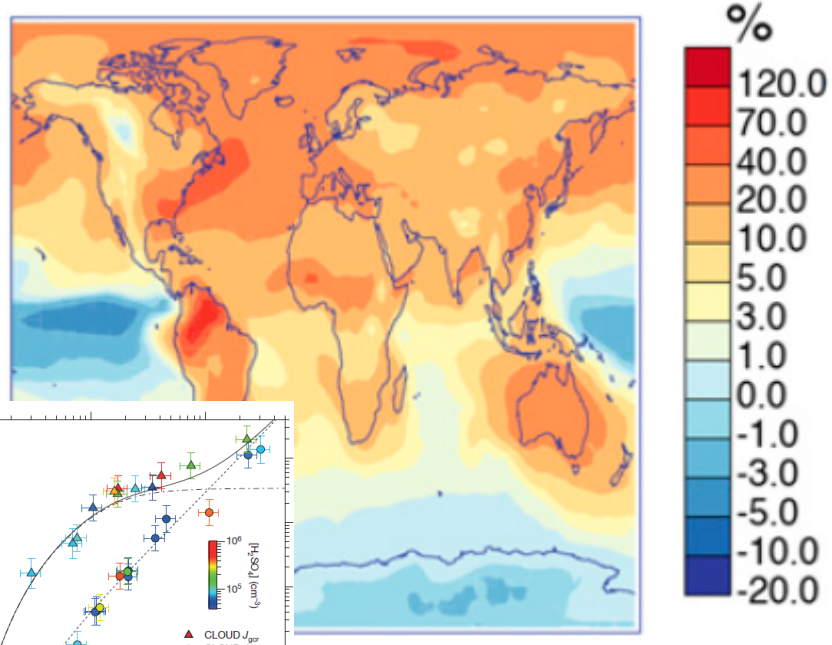
Fraction of new particle formation from biogenic vapours

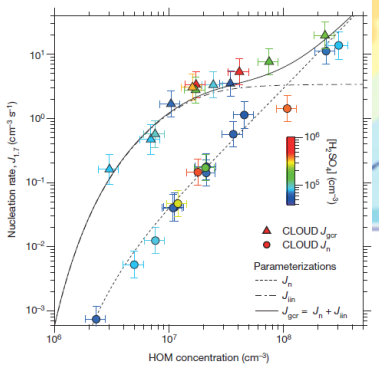


Gordon et al. Causes and importance of new particle formation in the present-day and pre-industrial atmospheres (JGR, 2018)

Biogenic new particle formation affects aerosol forcing

% change in preindustrial CCN





A new source of aerosol in the clean pre-industrial atmosphere from pure biogenic new particle formation

20-30% reduction in aerosol forcing.

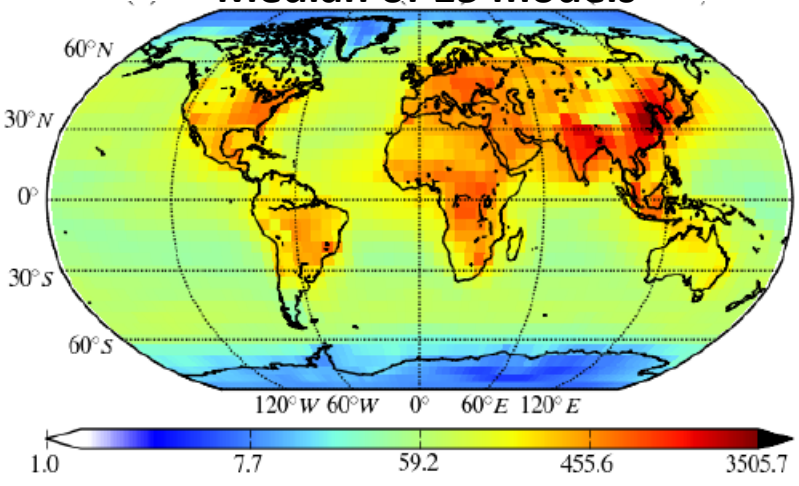
Future ESMs will need to account for biogenic effects on CCN

Kirkby et al. Ion-induced nucleation of pure biogenic particles (2016)
Gordon et al., Reduced anthropogenic aerosol radiative forcing caused by biogenic new particle formation PNAS (2016)

Global multi-model CCN analysis

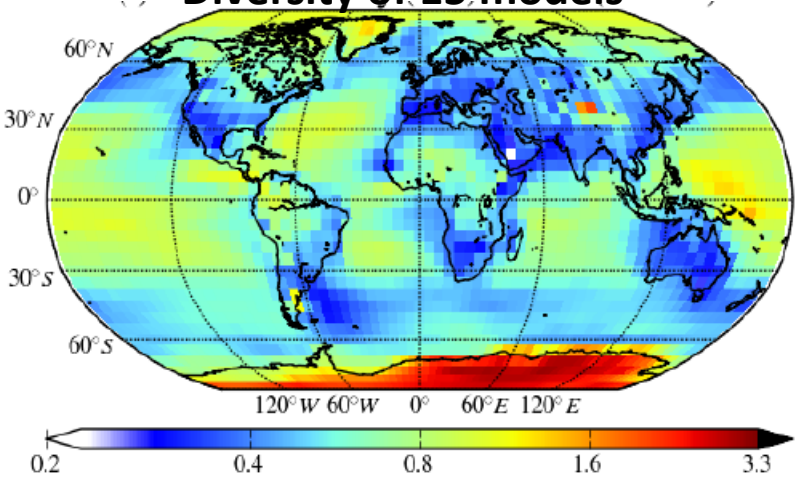
- Bacchus evaluation of CCN in 15 aerosol models

Median of 15 models



[CCN] / cm^{-3}

Diversity of 15 models



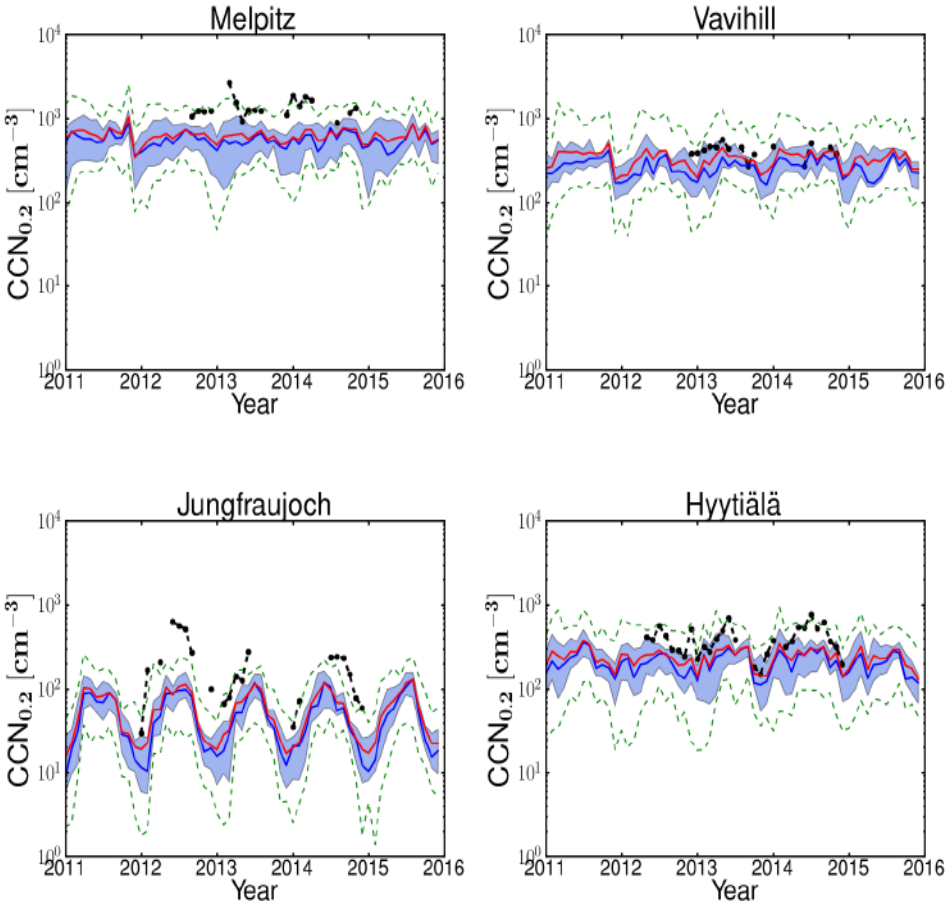
s.d./mean

Fanourgakis et al., Evaluation of global simulations of aerosol particle number and cloud condensation nuclei, and implications for cloud droplet formation, in preparation (2018)

Evaluation of multi-model CCN against measurements

- Median model-observation bias of 37%
- Highest bias of factor 5-10

ESMs need improvements in processes

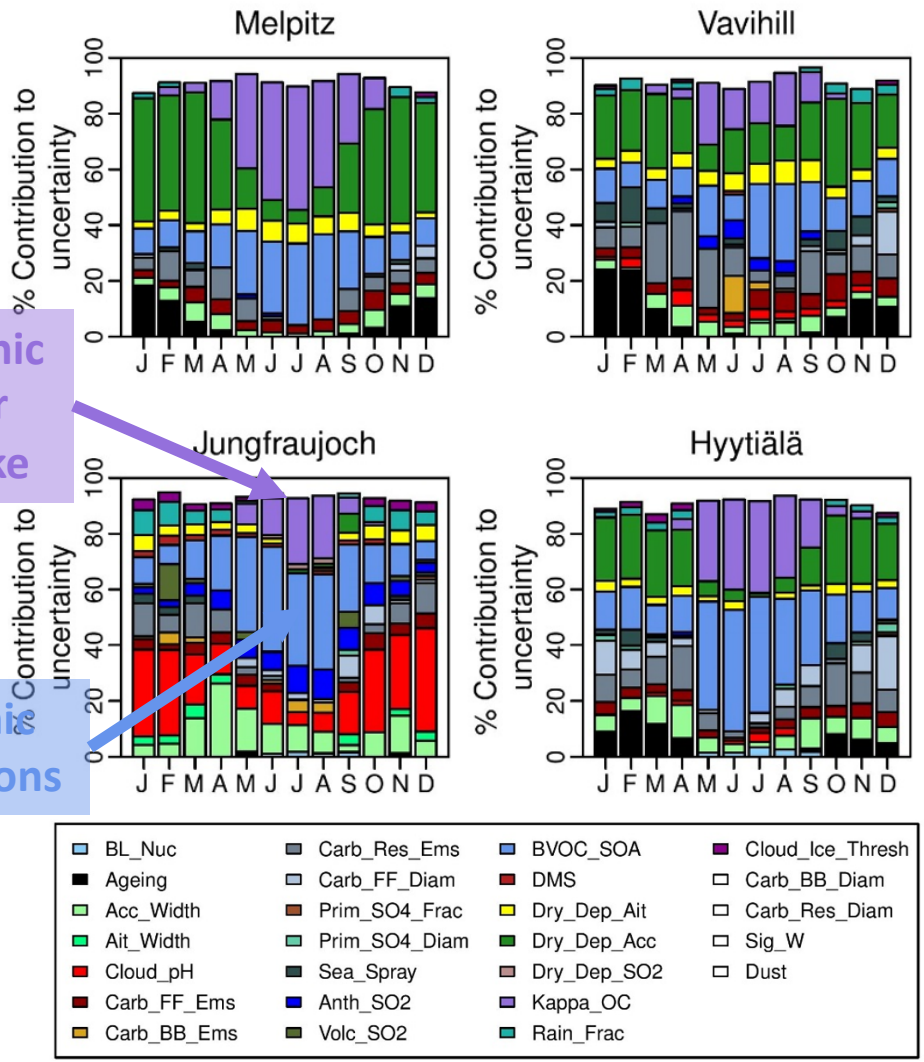


Fanourgakis et al., Evaluation of global simulations of aerosol particle number and cloud condensation nuclei, and implications for cloud droplet formation, in preparation (2018)

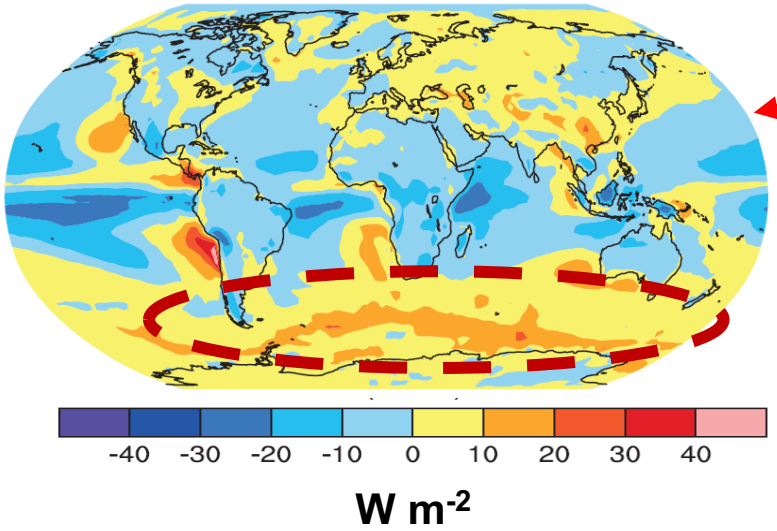
Importance of biogenic compounds for CCN uncertainty

- A large global model sensitivity analysis of one model
  - (26 parameters, 190 simulations)
- 50-80% of CCN uncertainty in summer is related to the biosphere

The biosphere strongly controls climate-relevant aerosol even in polluted environments



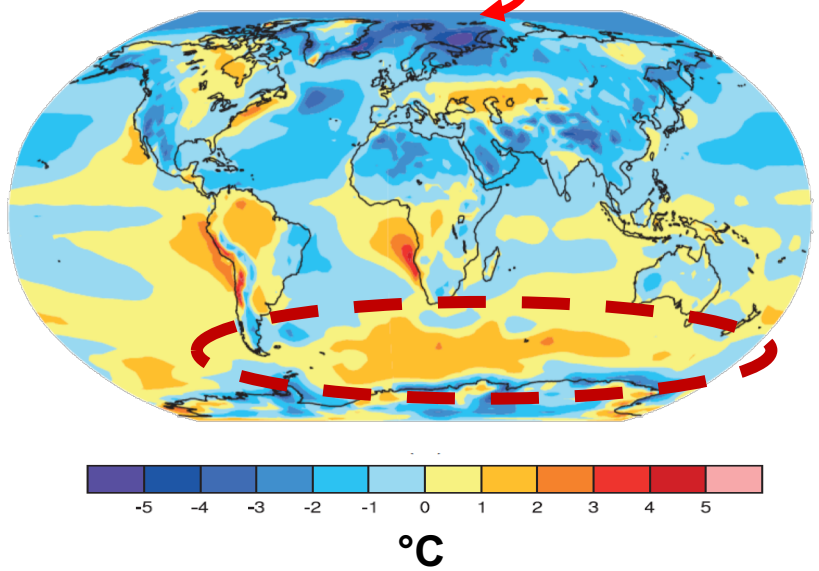
Natural ice-nucleating particles



Surface solar radiation bias in climate models

Resulting sea-surface temperature bias

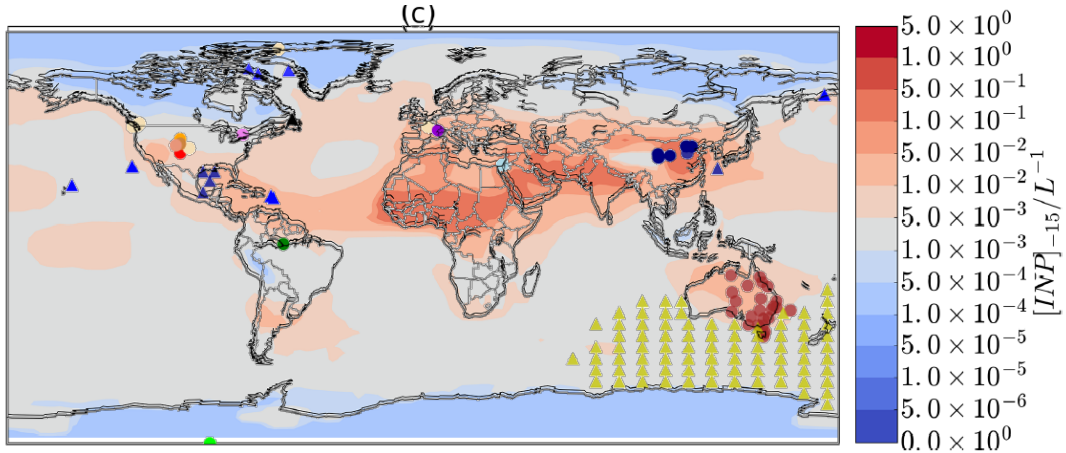
Flato et al. (2013)



Bias affects whole Earth system:

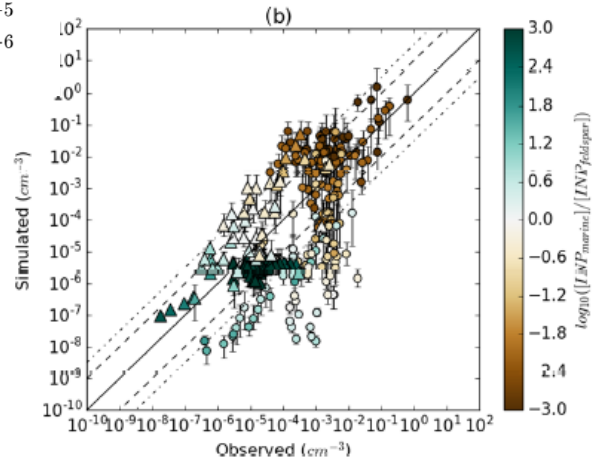
- Sea ice
- Surface pressure
- Large-scale circulation

Natural ice-nucleating particle simulations



Vergara-Temprado et al., ACP, 2017

New capability to simulate ice-nucleating particles on a global scale

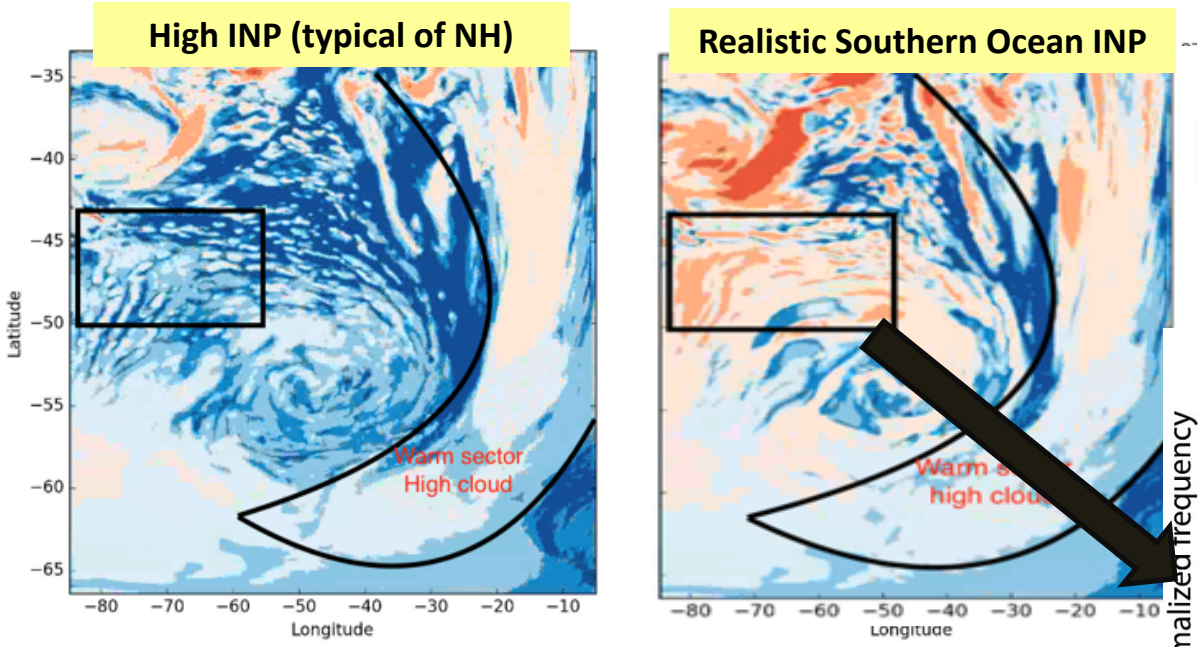


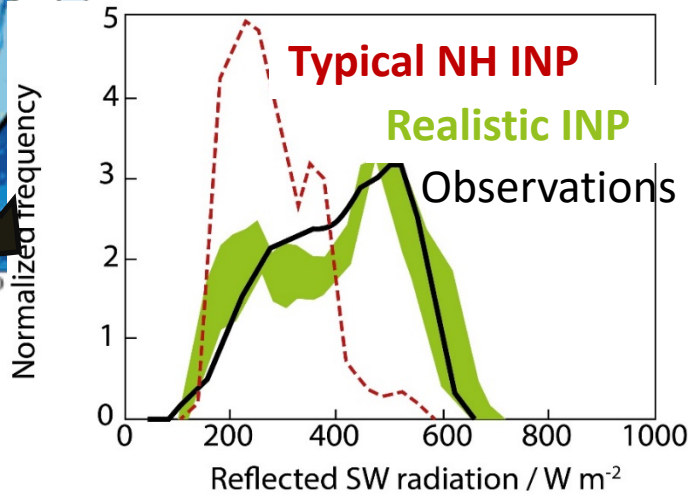
Natural ice-nucleating particles: Effect on radiative biases

Very low natural INP concentrations make Southern Ocean clouds much more reflective

May affect climate sensitivity.

Implications for model complexity

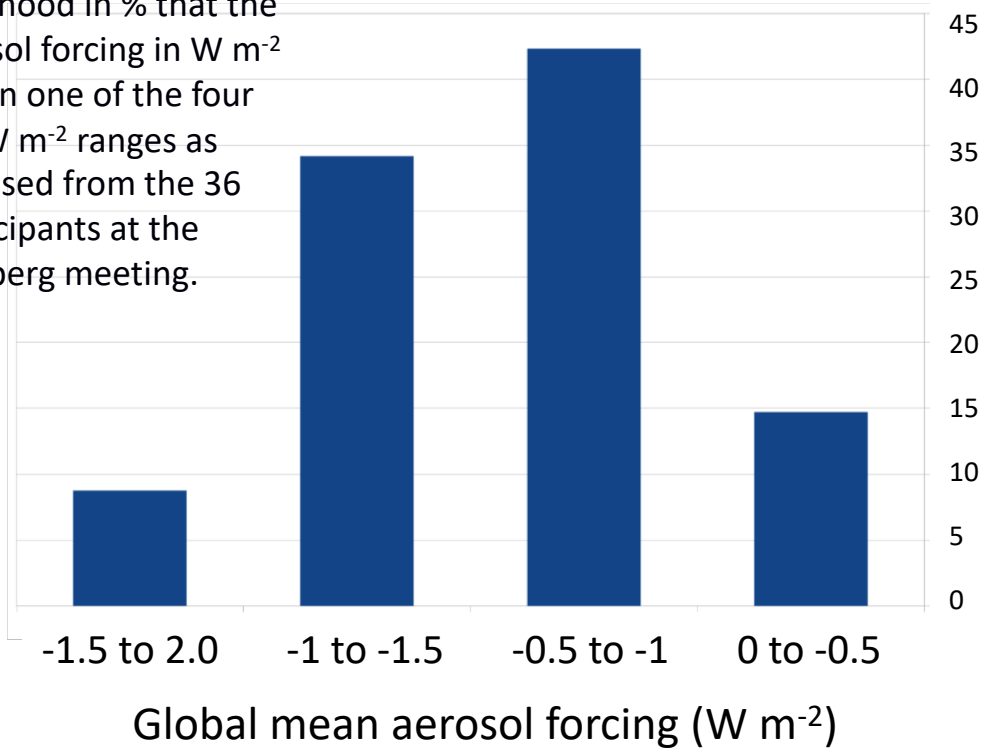




Vergara-Temprado et al., Strong control of Southern Ocean cloud reflectivity by ice-nucleating particles PNAS 2017

Anthropogenic aerosol radiative forcing: Results from the Ringberg meeting

Likelihood in % that the aerosol forcing in W m^{-2} falls in one of the four 0.5 W m^{-2} ranges as assessed from the 36 participants at the Ringberg meeting.



Bacchus contributed to the ***"Bounding aerosol forcing"*** WCRP meeting in January 2018

Bacchus findings re natural aerosol may reduce likelihood of most-negative forcings

Bacchus outcomes related to natural aerosols and climate

Bacchus has revealed and quantified very large effects of natural aerosols on aerosol radiative forcing

- **Fire emissions** strongly affect anthropogenic radiative forcing
- **Biogenic compounds** make a major contribution to cloud condensation nuclei
- **Biogenic compounds** strongly control CCN even in polluted environments
- Very low natural concentrations of **ice-nucleating particles** over the Southern Ocean can account for radiative biases in climate models

→ **Several clear opportunities for improving other ESMs**

Bacchus policy-relevant outcomes

- Aerosol concentrations in the pre-industrial era were higher than previously thought
  - **Implementation in new ESMs is likely to lead to a *smaller anthropogenic aerosol forcing* and, consequently, a *smaller climate sensitivity.***
- Aerosols in polluted environments are strongly controlled by biosphere emissions
  - **Policies related to air pollutants should account for pollutant-biosphere interactions**
- Ice formation affects radiative biases in climate models
  - **Correcting these biases in ESMs may affect climate sensitivity**
  - **Treating the processes robustly is complicated. We need to enable more-complex ESMs to be developed and run in Europe**
- Several areas for ESM development have been identified
  - **Bacchus outcomes provide a clearer path towards more-accurate ESMs**