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Bacteria and fungal spores in the global climate model ECHAM5-HAM

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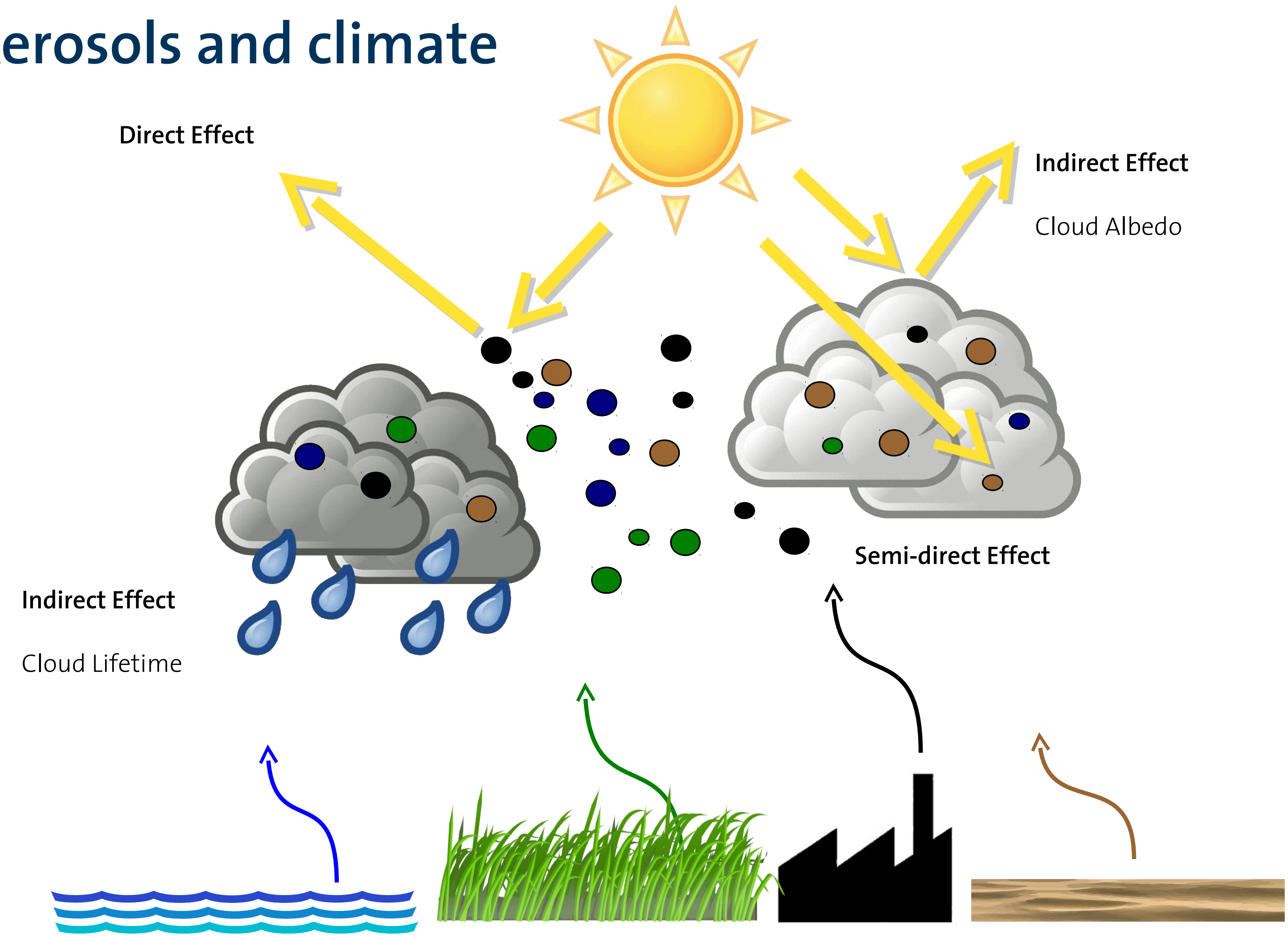
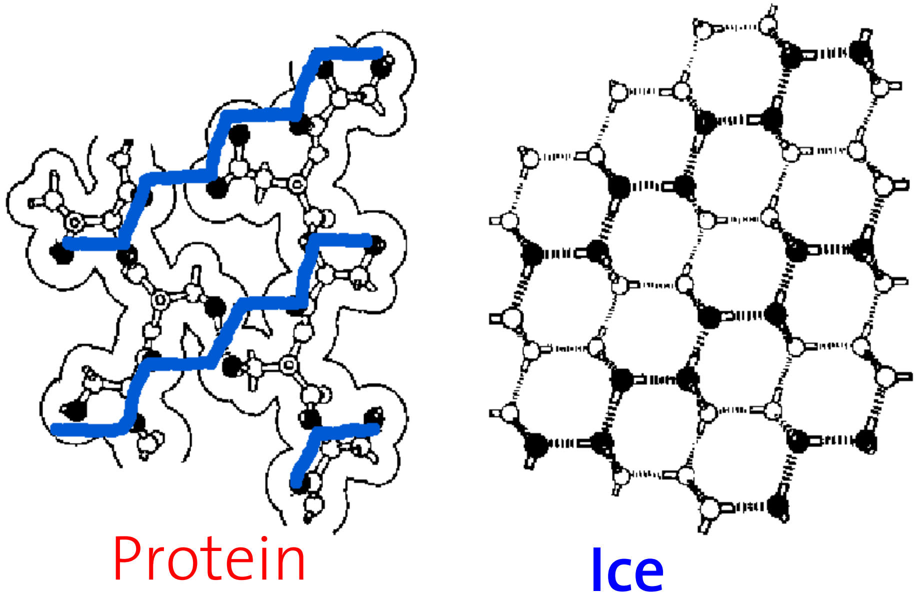
Aerosols and climate



Ice nucleation active protein



Adapted from Kajava & Lindow, *J. Mol. Bio.*, 1993

- Produced routinely by many leaf-dwelling bacteria when stressed:
  - Dry, cold, hungry
  - Tapping plant sap by destroying leaf cells through freezing to get nutrients and water

- Bacterial IN active at -2°C (Vali & Schnell, *JAS*, 1976)
- Fungal spores IN active at -2°C (Pouleur et al., *Appl. Environ. Microb.*, 1992)

Motivation

- Aerosol impact on clouds and precipitation is a big source of uncertainty in climate models
- Biological particles are excellent ice nuclei
  - Initiate freezing at higher temperatures (from -2°C on) than other aerosol acting as ice nuclei (dust and soot)
- Neglected in most climate models
  - Impact on clouds and precipitation?

Bioaerosols in ECHAM5-HAM

Model Setup

- ECHAM5.5-HAM GCM
- Bacteria and fungal spore emissions set in boundary conditions
  - Number emission flux from observations
  - Biomes: forest, grass, shrubs, crops, land ice (JSBACH)
- M7 aerosol module + bioaerosols
  - Emitted as insoluble particles, coagulation and transfer to other modes
- Return to ECHAM for microphysics calculation
  - Double-moment scheme (prognostic treatment of mass and number concentration of both cloud water and ice)
- 1yr (+3 month spin-up) simulations nudged for year 2000

Bioaerosol emission parameterisation

Bioaerosol emission depend on vegetation

(Lindow et al., Appl. Env. Microb., 1978)

$$F = \sum_{i=1}^{5} f_i F_i$$

f_i: fractional cover per ecosystem → JSBACH

F_i: number emission flux (yr^{-1}) → literature*

i: forests, grass, shrubs, crops, land ice

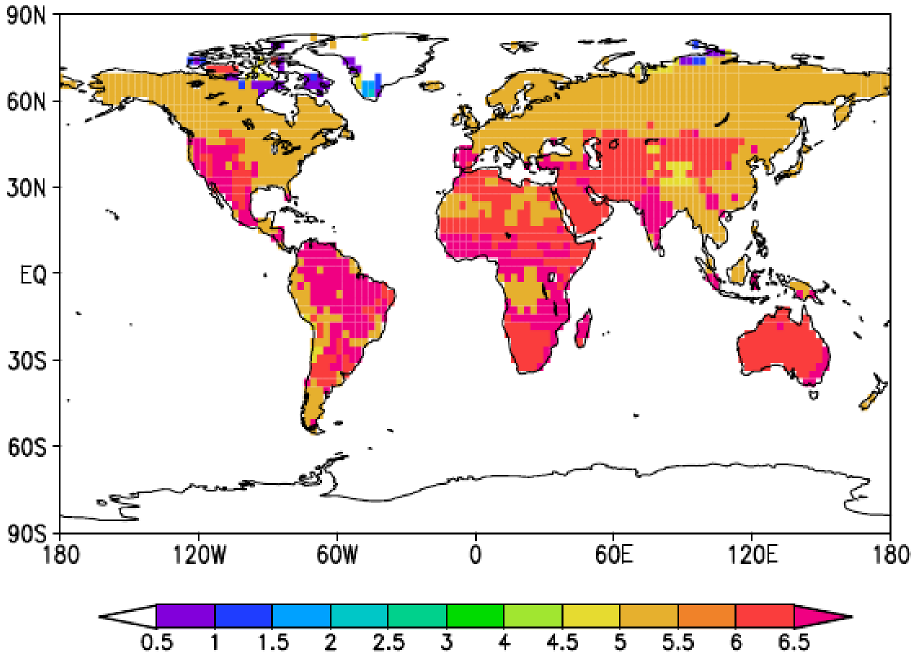
* Bacteria: Burrows et al., *ACP*, 2009a

Fungal spores: Dallafior & Sesartic, *BGD*, 2010

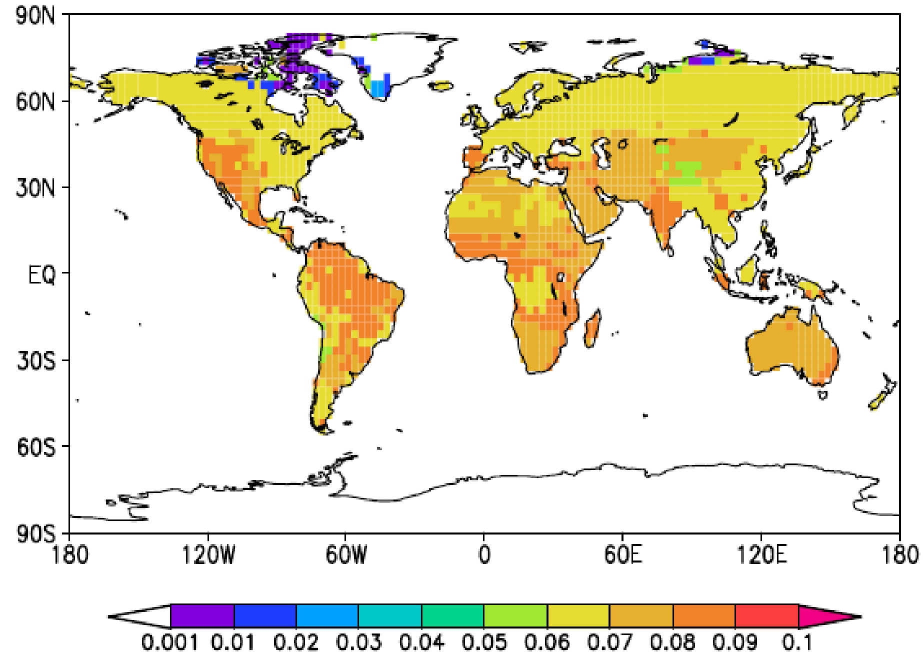
Bioaerosol transport

Bioaerosol emissions [g m^{-2} yr^{-1}]

Fungal spores

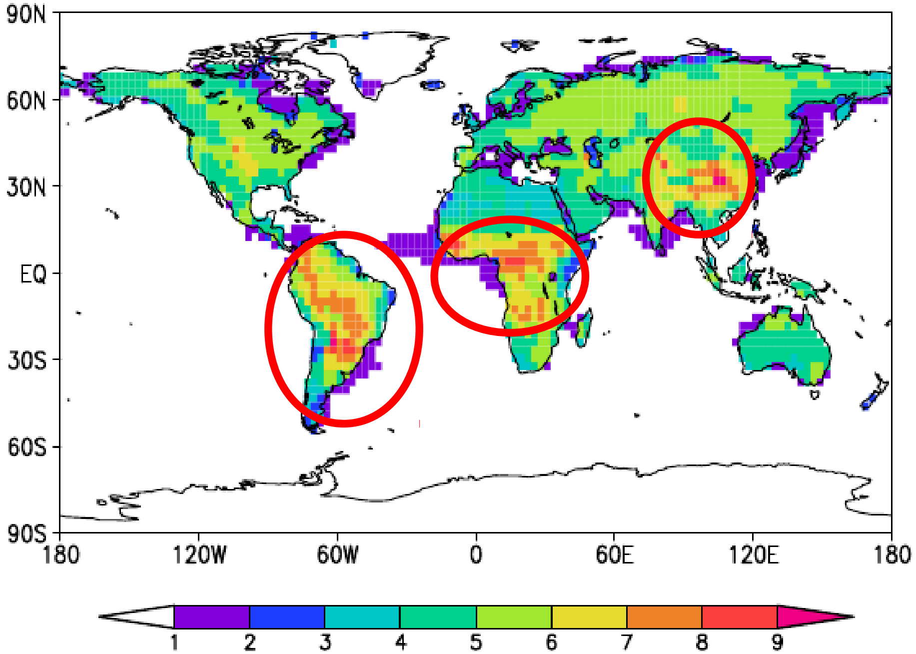


Bacteria

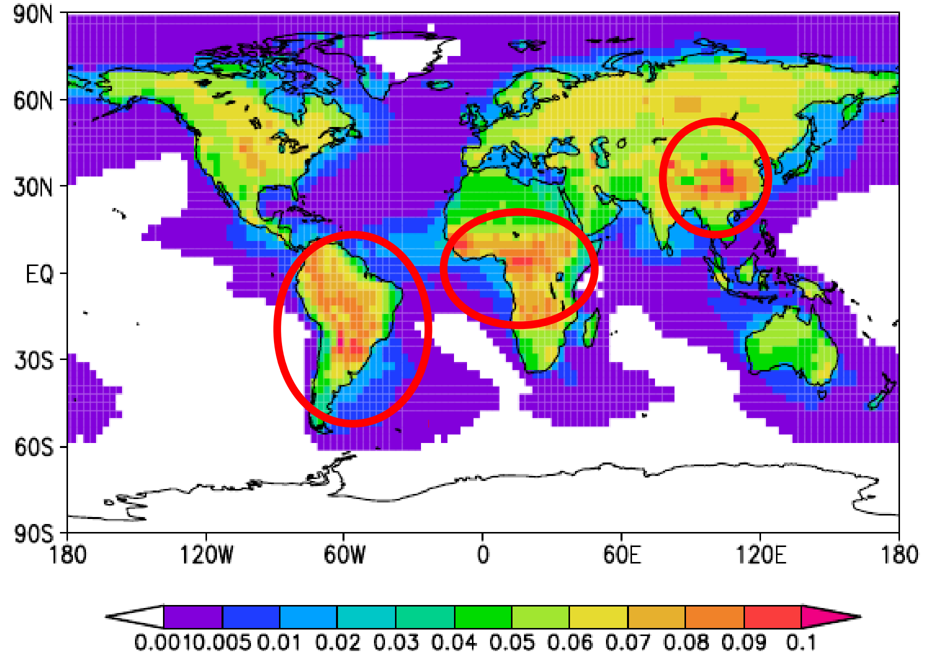


Bioaerosol deposition (dry+wet) [g m^{-2} yr^{-1}]

Fungal spores

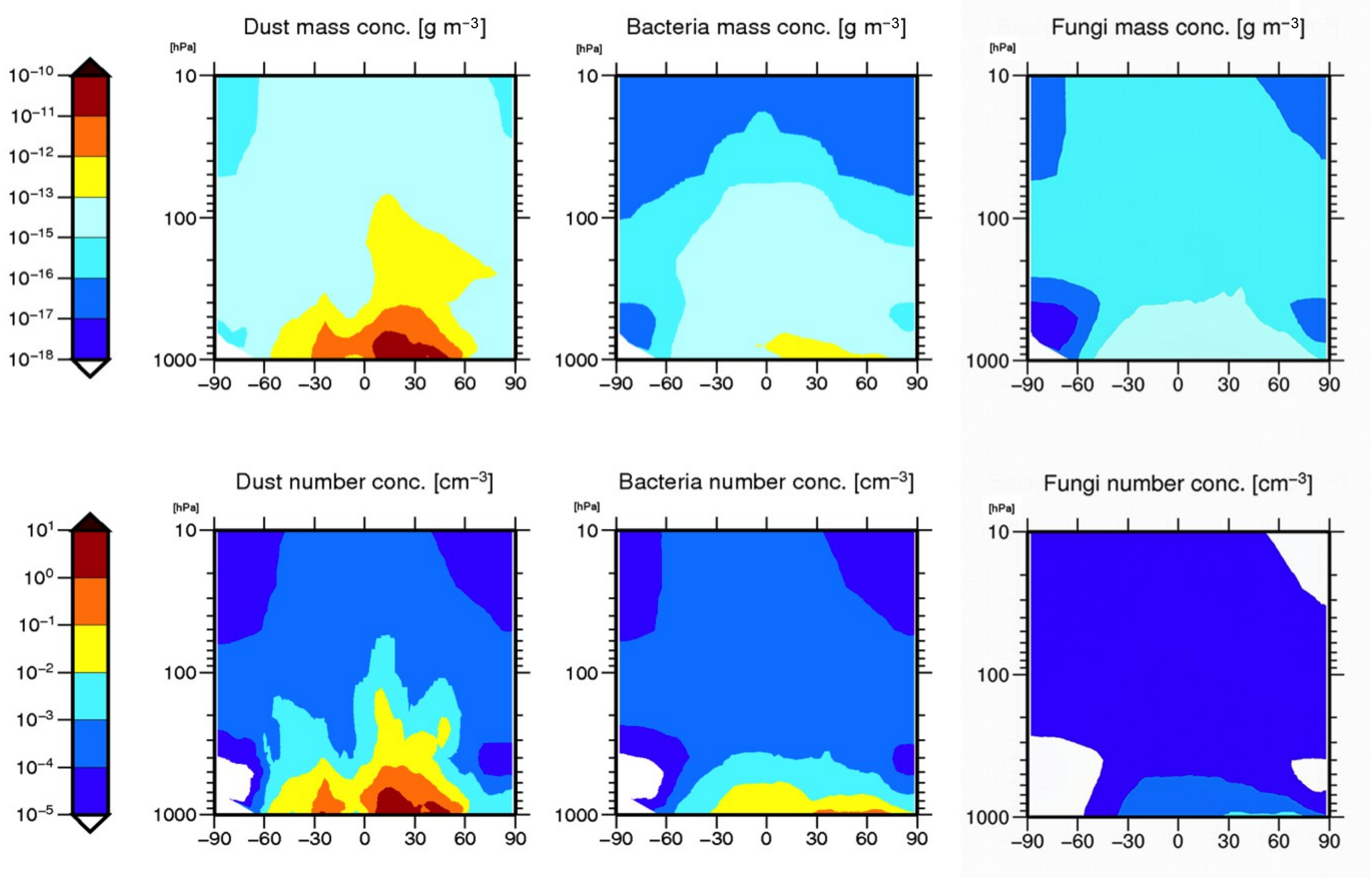


Bacteria



- Bioaerosol remain near their source of origin
- Enhanced deposition over regions with dense vegetation and high precipitation

Aerosol vertical distribution



- Bioaerosol reach heights relevant for cloud formation
- But much less bioaerosols than mineral dust available

Bacteria emission and deposition – model vs. observations [kg m^{-2} yr^{-1}]

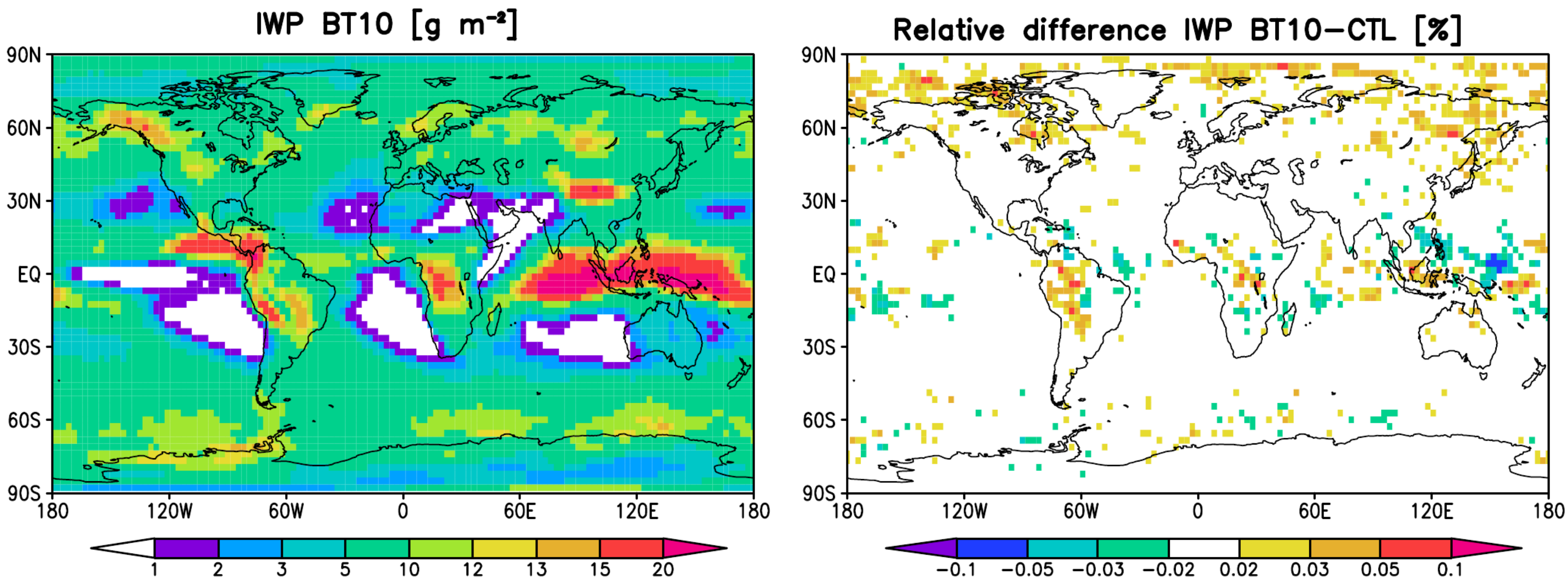
	Modelled	Observed
Emission	5.5×10^{-13}	1.02×10^{-13}
Dry deposition	1.7×10^{-13}	1.4×10^{-14} up to 2×10^{-11}
Wet deposition	3.8×10^{-13}	1.4×10^{-14} up to 1.7×10^{-9}

Observational data: Lindemann et al. (1982), Lindemann and Upper (1985), Lindow and Andersen (1996), Jones et al. (2008)

- Modelled emissions and depositions are in the observed order of magnitude

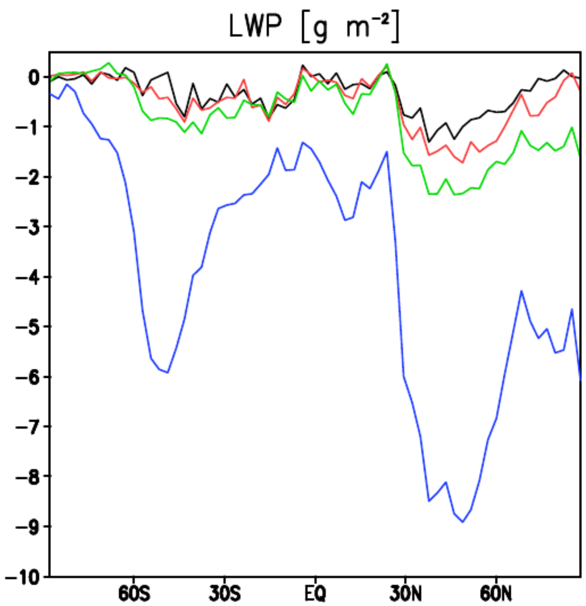
Bioaerosol impact on clouds and precipitation

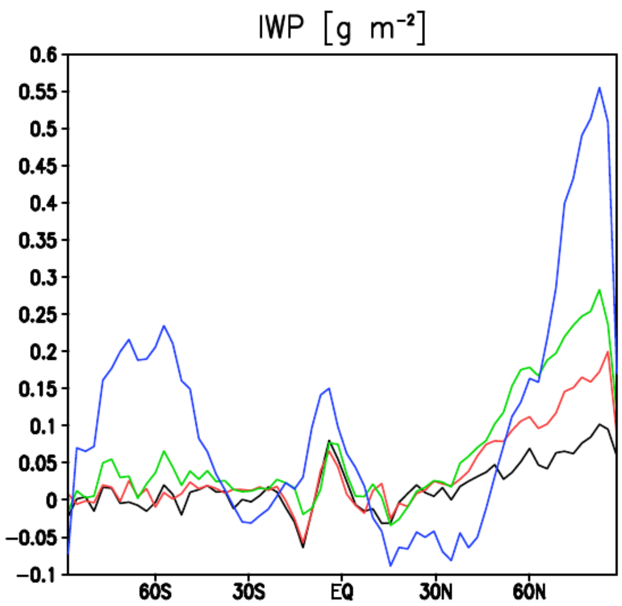
Ice water path



- Surface temperatures in the Artic are in the range of mixed-phase-clouds (0°C to -35°C) → bioaerosol can have an impact on this region even without being transported to higher altitudes
- Tropical and boreal forests act as bioaerosol sources

Ice and liquid water path (annual zonal mean)





Difference to control simulation for:

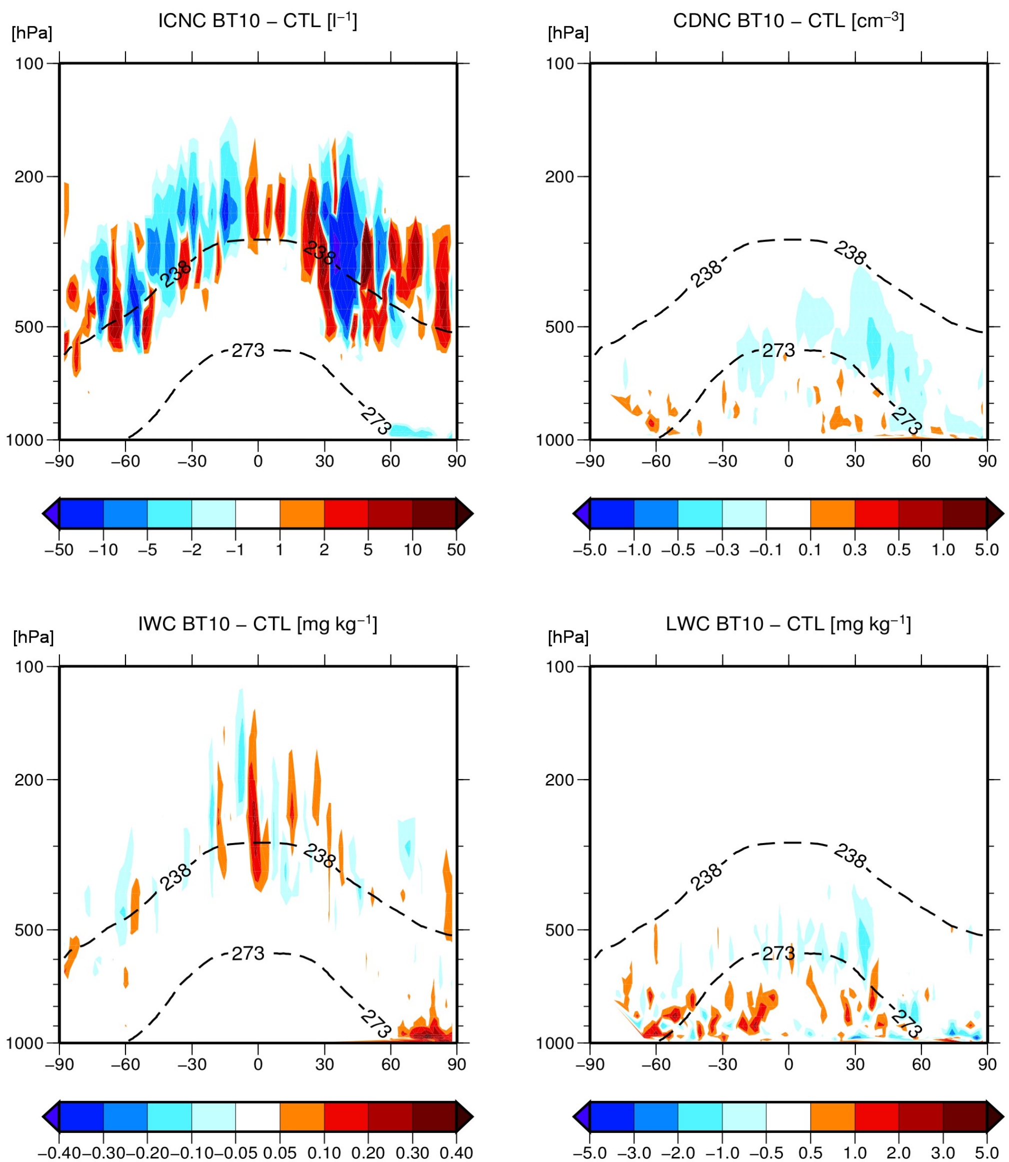
1% bacteria IN active

10% bacteria IN active

100% bacteria IN active

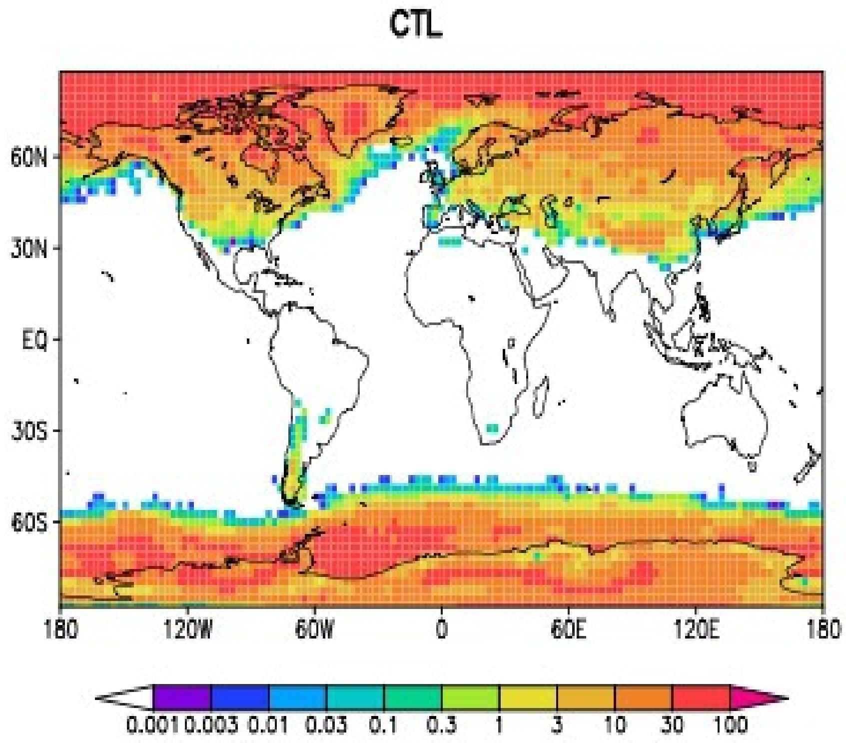
100% bacteria IN active, 100-fold emissions

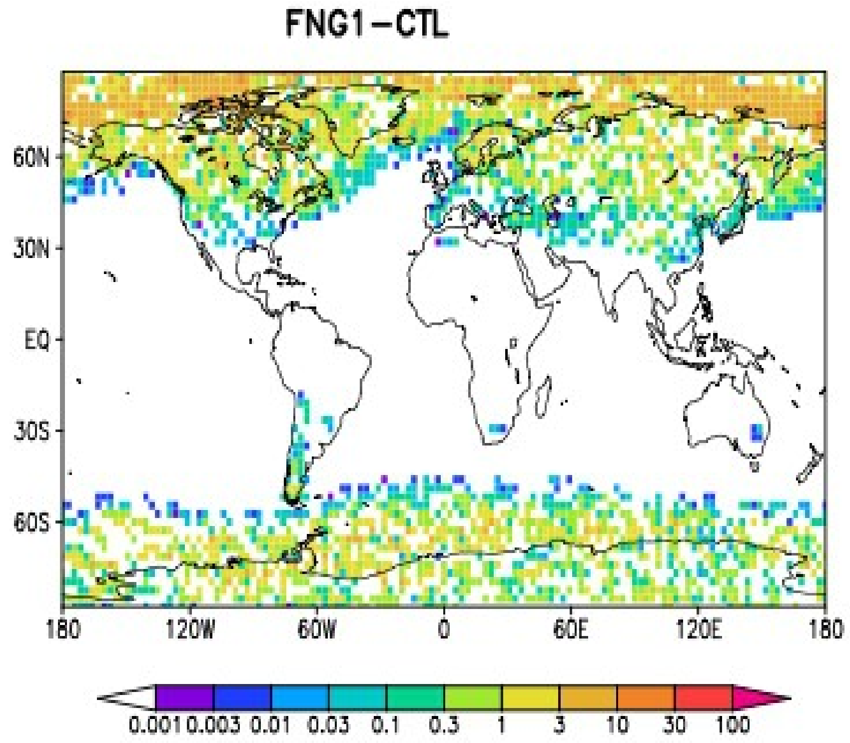
- Ice water path increases over tropical and boreal regions
- Corresponding reduction of liquid water path; pronounced in the storm-tracks due to more efficient precipitation release
- Forests and tundra as bacterial ice nuclei sources
- Signal consistent for different bacteria concentrations and IN activity



- Bacteria induce freezing at warmer temperatures
- Fewer but larger ice crystals formed
- Larger ice-water-content, lower liquid-water-content
  → Bergeron-Findeisen

Effective ice crystal radius [µm]





- Effect of fungal spores on clouds negligible
- Larger ice crystals

Conclusions

- Bacteria and fungal spores acting as ice nuclei introduced into ECHAM5-HAM
- Emission and deposition of bioaerosols comparable to observations
- Better observational data for bioaerosols needed to improve model results and validation
- Inclusion of bioaerosol leads to no significant changes in cloud formation and precipitation on a global scale however, they affect the liquid and ice water content of the atmosphere, as well as the ice crystal radius at higher latitudes