ECHAM6-CCN
and its climate sensitivity

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**ECHAM6 coupled to a CCN climatology**

- **Rationale:** can we account for aerosol effects using a simple aerosol/CCN climatology?
- Combine AERONET aerosol observations and AeroCom model results
- Assume that all coarse mode particles acts as cloud condensation nuclei (CCN)
- Assume that only a fraction of fine-mode particles acts as CCN by a cut-off size based on supersaturation and on chemical distribution
- Distinguish the fine-mode particles between anthropogenic and natural CCN based on the AeroCom model results
- Only the anthropogenic CCN vary with time
Description of the CCN climatology (1)

- CCN data are available as monthly means from 1850 to 2100, at 1km and 8km (pressure-driven decrease between these 2 extremes)

- 4 different CCN subsets with different supersaturation levels are used. The final CCN concentration is chosen based on local, current updraft velocity:

  \[ W \leq 0.01 \text{ m.s}^{-1} \quad \rightarrow \quad \text{CCN at 0.07\% supersaturation} \]

  \[ 0.01 \text{ m.s}^{-1} < W \leq 0.10 \text{ m.s}^{-1} \quad \rightarrow \quad \text{CCN at 0.10\% supersaturation} \]

  \[ 0.10 \text{ m.s}^{-1} < W \leq 1.00 \text{ m.s}^{-1} \quad \rightarrow \quad \text{CCN at 0.15\% supersaturation} \]

  \[ W > 1.00 \text{ m.s}^{-1} \quad \rightarrow \quad \text{CCN at 0.20\% supersaturation} \]
CCN (cm$^{-3}$) in 1km at 0.1% supersat.

all CCN in the year 2000

coarse mode CCN

fine mode natural CCN

anthropogenic CCN
Model differences

- Differences between ECHAM6-CCN and ECHAM6:
  - 2-moment vs 1-moment cloud microphysics
  - Autoconversion rate (rate of rain formation)
  - Aggregation rate (rate of snow formation)
  - Cirrus formation (the 2-moment scheme allows supersaturation with respect to ice)
  - Freezing and Bergeron-Findeisen process

- Differences between ECHAM6-CCN and ECHAM5.5-HAM:
  - Parameterizations of radiation, cloud optical properties and aggregation rate
  - CCN from aerosol climatology vs. HAM
  - Resolution: T63L47 (mid atm) vs. T42L19
Comparisons with observations

![Graphs showing ice water path, liquid water path, cloud droplet number concentration, and ice crystal number concentration across different latitudes.](image-url)
Mixed layer ocean simulations

\[ C_m \frac{\partial T_m}{\partial t} = H - Q \]

\[ Q \approx Q_{clim} \]

\[ Q_{clim} = H_{clim} - C_m \frac{\partial T_{clim}}{\partial t} \]
Climate sensitivity

Change in Precipitation (%) against Change in 2-meters Temperature (K).

- Humidity: 7% / K
- Precipitation: 1-3 % / K

Legend:
- echem5.5-ham
- echem6
- echem6-ccn

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$\Delta T = 2.8 \text{ K}$

$\Delta T = 2.9 \text{ K}$

$\Delta T = 3.8 \text{ K}$
Precipitation response

\[ \Delta P/P = 5.45\% \]

\[ \Delta P/P = 7.10\% \]

\[ \Delta P/P = 5.27\% \]
Different freezing mechanisms in ECHAM5.5-HAM and ECHAM6-CCN

Freezing rates [kg/kg]

- Contact freezing
- Immersion freezing
- Homogeneous freezing

ECHAM6-CCN
ECHAM5.5-HAM

CTRL
2xCO2
Different freezing mechanisms in
ECHAM5.5-HAM and ECHAM6-CCN

More cirrus clouds => More warming

More efficient mixed-phase cloud glaciation => More precipitation

Freezing rates [kg / kg]

CTRL

2xCO2

Contact freezing
Immersion freezing
Homogeneous freezing
ECHAM6-CCN
ECHAM5.5-HAM
Different CCN profiles in ECHAM5.5-HAM and ECHAM6-CCN

→ very low CCN concentrations in the case of ECHAM6-CCN may end up being a limiting factor for mixed-phase cloud formation, and therefore yield different regimes between ECHAM5.5-HAM and ECHAM6-CCN.
Conclusion

- **ECHAM6-CCN** presents a much higher climate sensitivity than ECHAM6 and ECHAM5.5-HAM

- The higher climate sensitivity as compared to ECHAM5.5-HAM is probably due to very different relative contributions from contact-, immersion- and homogeneous freezing

- Another likely source of differences is the very different CCN profiles (low CCN in upper troposphere in the case of ECHAM6-CCN)

- Still work-in-progress, further investigations to come soon!

- Possible surrogate for a CCN climatology: diagnostics from a full ECHAM6-HAM run
Annex
Time series

2xCO$_2$ – CTRL

- 2m Temperature (K)
- Precipitation (%)
- LWP (g.m$^{-2}$)
- IWP (g.m$^{-2}$)

ECHAM5.5–HAM2  
ECHAM6  
ECHAM6–CCN

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Convective vs stratiform precipitations

2xCO$_2$ – CTRL

![Graphs showing temperature, total precipitation, large-scale precipitation, and convective precipitation over time for different simulations.]

- **Black line**: ECHAM5.5–HAM2
- **Blue line**: ECHAM6
- **Red line**: ECHAM6–CCN

**Legend:**
- ECHAM5.5–HAM2
- ECHAM6
- ECHAM6–CCN

**Graph Details:**
- **X-axis**: Time (2000 to 2050)
- **Y-axis**: Temperature (K) for 2m Temperature, Precipitation (%) for Total Precipitation, Large-scale Precipitation, and Convective Precipitation

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Comparisons with observations

Shortwave cloud forcing [W m$^{-2}$]

Longwave cloud forcing [W m$^{-2}$]

Total cloud cover [%]

Total precipitation [mm/d]