Impact of transient aerosol emissions on the European climate of the most recent decades

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Motivation

Trends in observed 20th century shortwave radiative fluxes are attributed to changes in anthropogenic aerosol emissions and clouds [1]

This is the first study to use a regional climate model equiped with sophisticated aerosol and cloud microphysics to investigate the recent solar brightening (reduction in surface shortwave radiation) over Europe.

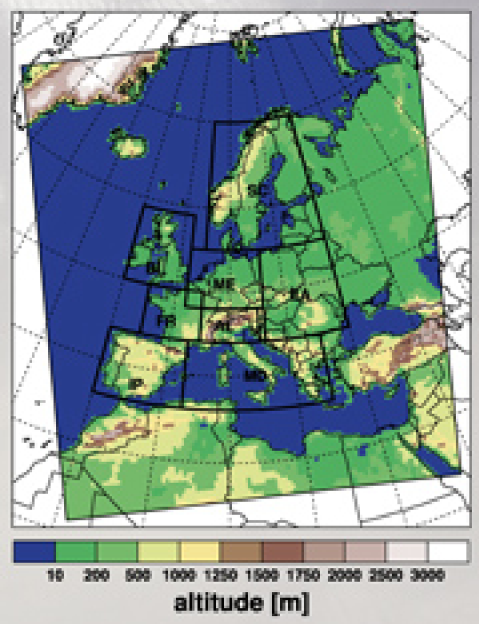
Model setup & simulation strategy

CCLM 4.0, 50 km hor. resolution, 32 levels, driven by ERA-40 reanalysis.

The model is fully coupled to an aerosol microphysics module and a sophisticated cloud scheme [2].

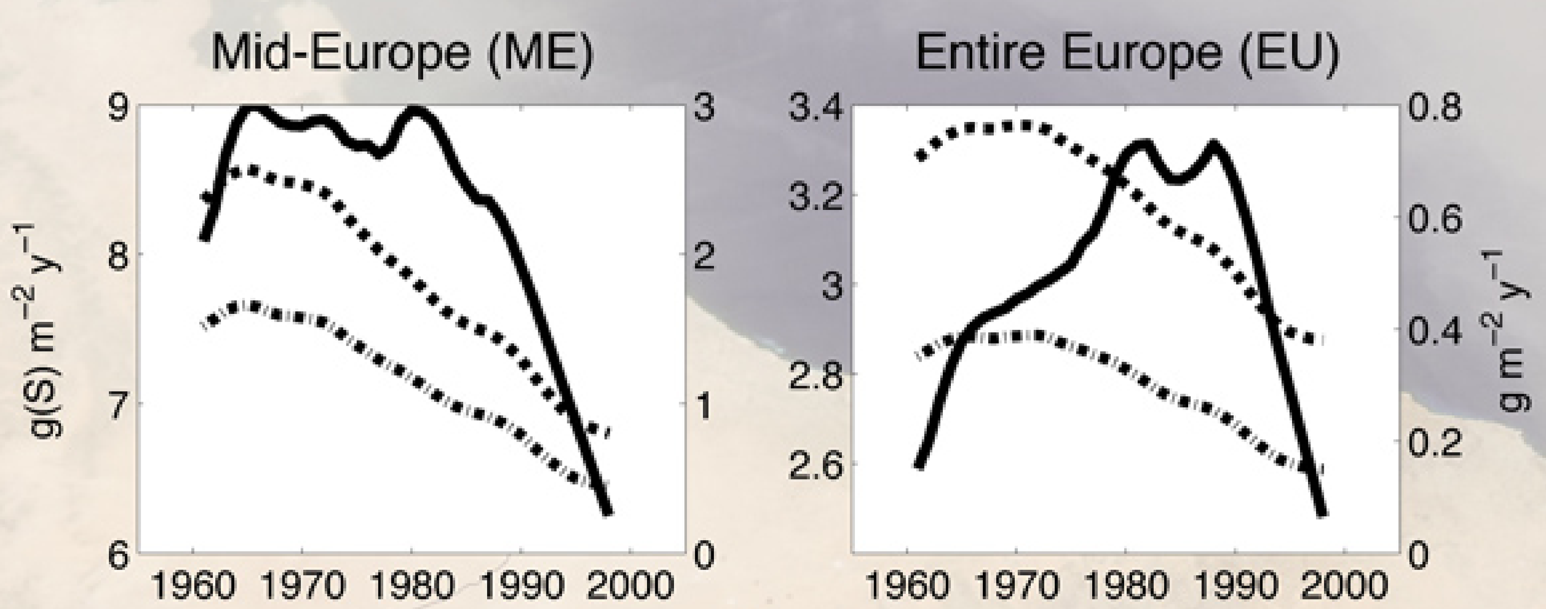
2 Simulations (1958-2001):

TRANS: transient aerosol emissions (NIES [3]), transient aerosol number and mass tracers at the lateral boundaries from ECHAM5-HAM [4].
CLIM: climatological mean emissions and tracers over the period 1958-2001.



Domain size, topography and outline of analysed regions.

Transient aerosol emissions



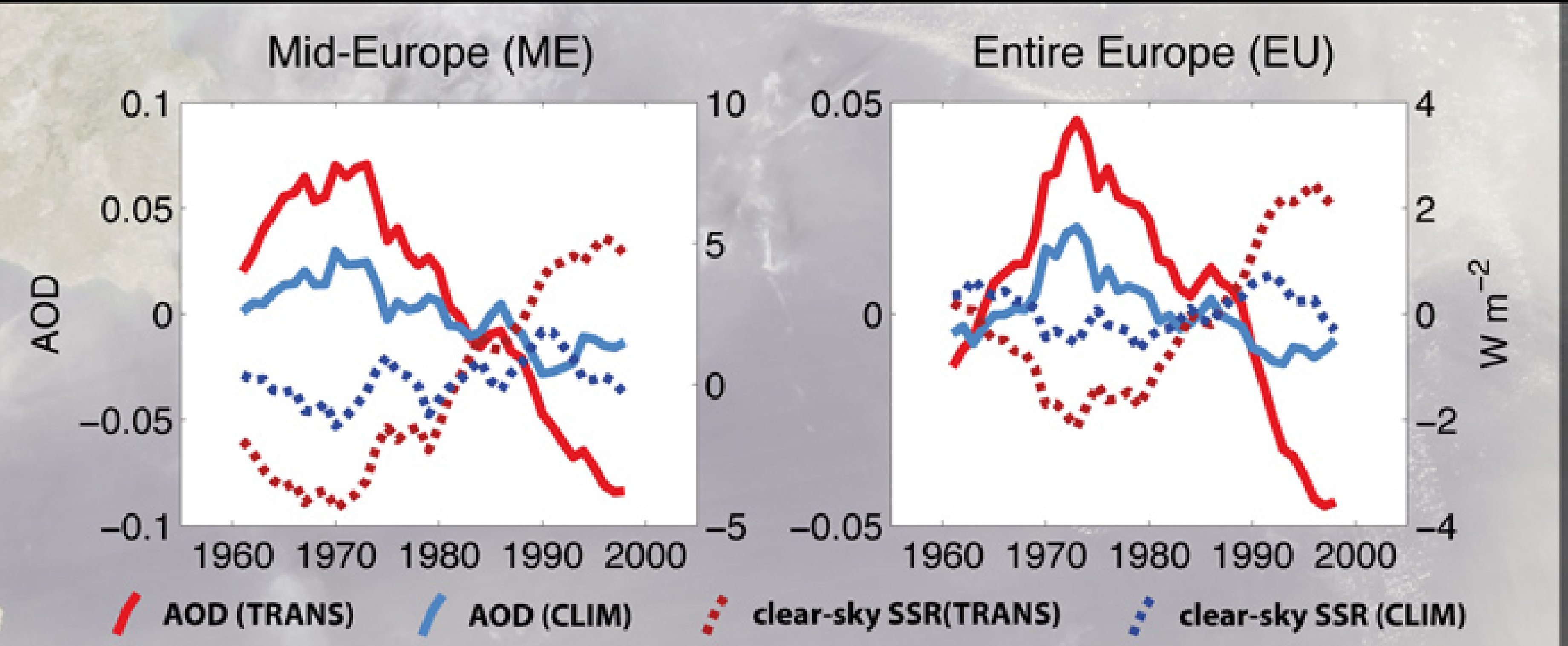
5-year running mean of emissions of sulfur dioxide [g(S) m^{-2} y^{-1}], black carbon and particulate organic matter [g m^{-2} y^{-1}]. Sulfur dioxide is a precursor gas for sulfate.

—— Sulfur dioxide -·-·- Black carbon ---- Organic matter

In most regions, sulfur dioxide emissions increase until the mid 1980s. The first country to reduce emissions drastically was Great Britain. A rapid decrease of sulfur emissions after 1985 suggests a steep increase in clear-sky fluxes and thus a brightening in Europe.

Black carbon and organic matter emissions were reduced earlier.

Results for clear-sky conditions

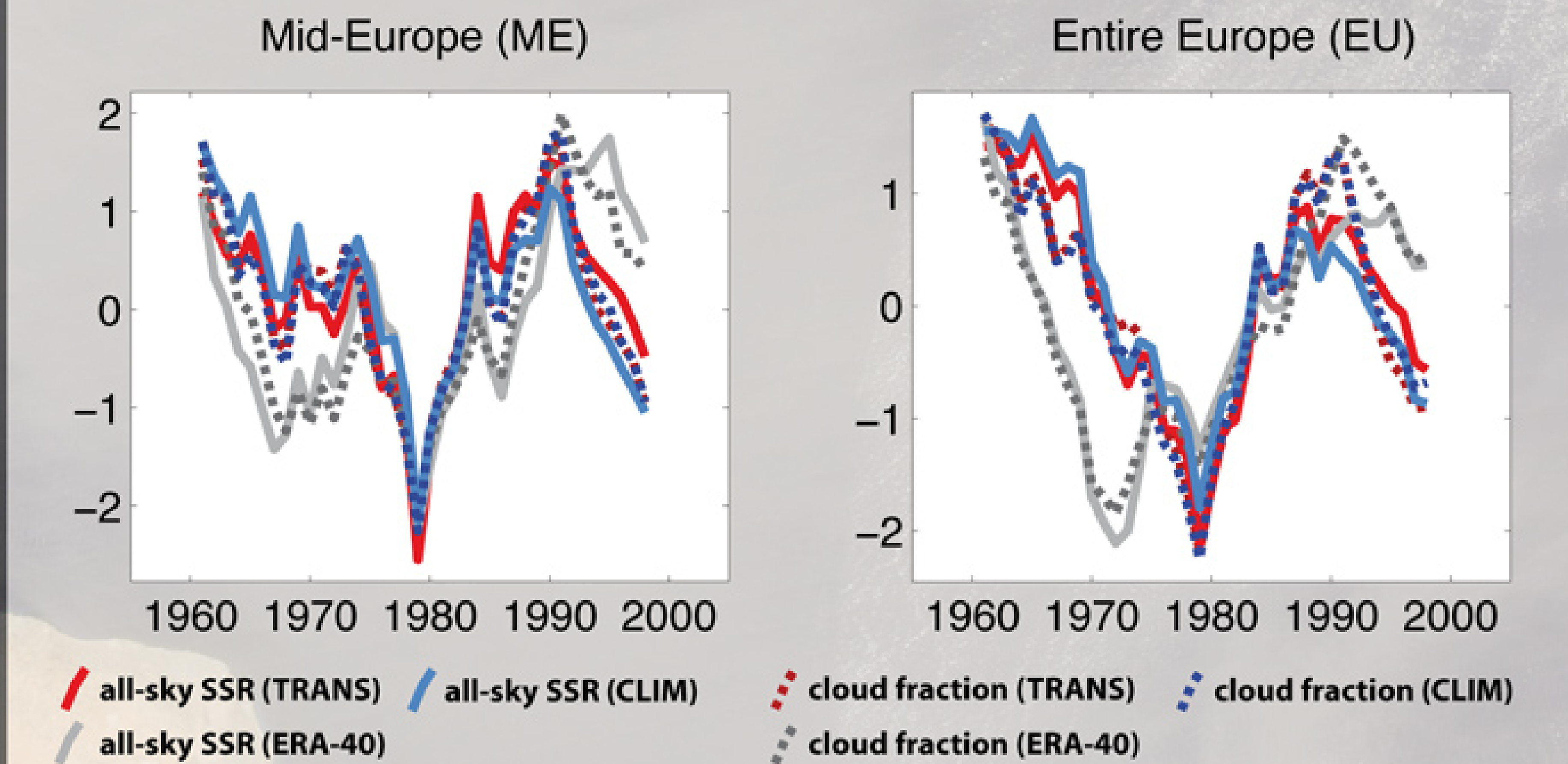


5-year running mean of aerosol optical depth (AOD, 550nm) and downward clear-sky surface shortwave radiation (SSR) anomaly [W m^{-2}].

A clear anti-correlation is found between the trend in aerosol optical depth (AOD) and downward clear-sky surface shortwave radiation (SSR). Thus, changes in anthropogenic aerosol emissions are responsible for the clear-sky trends.

The strongest effect appears in Mid-Europe (roughly 10 W m^{-2} brightening between 1970 - 2000) and the Mediterranean region (6 W m^{-2}), consistent with observations.

All-sky conditions

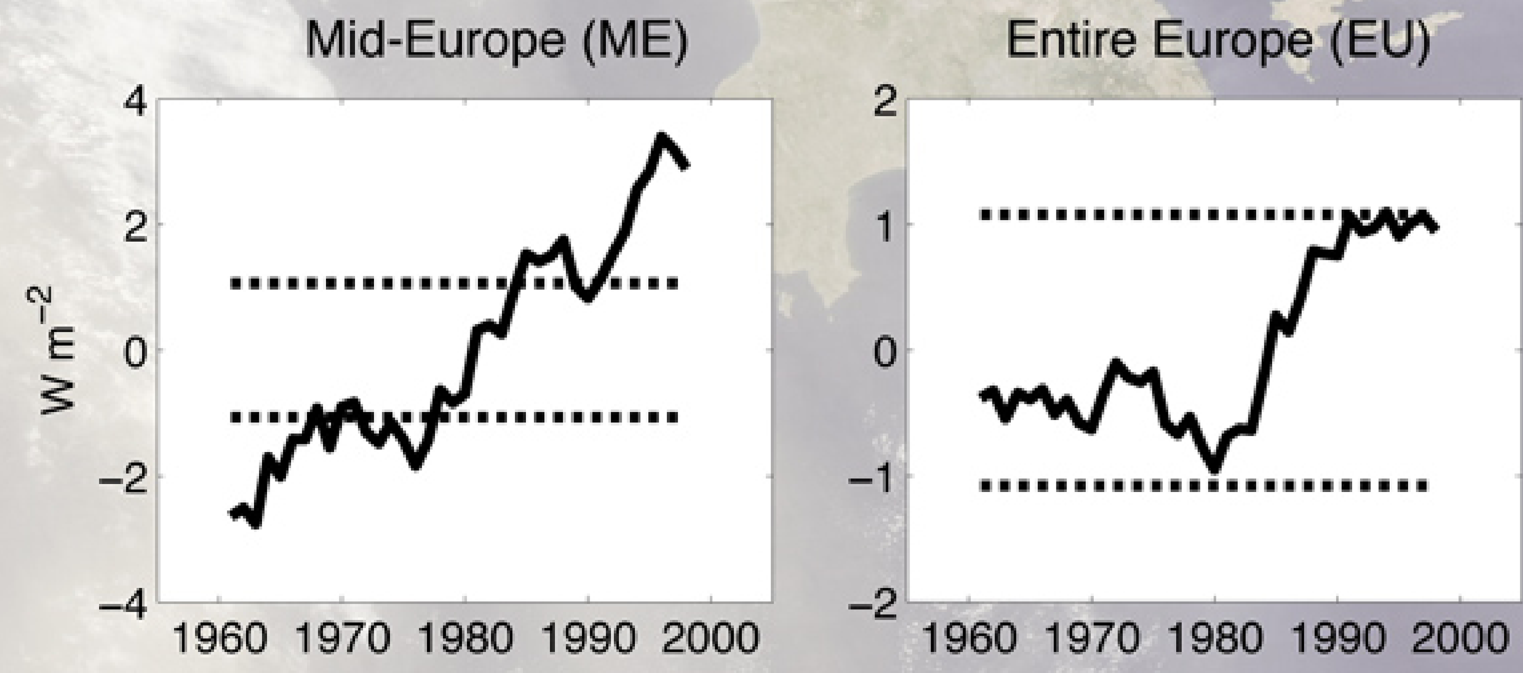


5-year running mean of the standardized anomalies of cloud fraction (inverted, multiplied with -1) and downward all-sky surface shortwave radiation (SSR).

Under all-sky conditions, aerosols play a minor role. Correlation coefficients R between cloud fraction and all-sky SSR are -0.94 for ME and EU. Long-term and interannual variability in all-sky SSR are thus determined by clouds.

The good agreement between the reanalysis and the two model simulations shows that the lateral boundary conditions and sea surface temperatures largely define the trends in all-sky radiative fluxes.

Transient emissions and internal variability



5-year running mean of the difference in all-sky downward surface shortwave radiation (SSR) [W m-2] between TRANS and CLIM (solid) and internal variability of the model based on the standard deviation of 4 ensemble simulations from [5] (dashed).

The difference (TRANS - CLIM) shows the effect of transient versus climatological aerosol emissions. Under all-sky conditions, this effect is largely insignificant as compared to the model's internal variability. Only in Mid-Europe, a significant brightening trend is found.

Therefore, the trends in all-sky SSR do not differ significantly for transient and climatological emissions.

Conclusions

Anthropogenic aerosols determine the trends in clear-sky radiation. On the other hand, clouds determine trends under all-sky conditions.

The model is strongly constrained by the lateral boundary conditions that define circulation patterns.

The effect of transient versus climatological emissions is insignificant in relation to the model's internal variability.

Observations suggest that regional climate models generally overestimate the role of clouds in defining all-sky trends to some degree (not shown).

[1] Wild, M., 2009: Global dimming and brightening: A review. J. Geophys. Res., 114, doi:10.1029/2008JD011470.
[2] Zubler et al., 2011: Implementation and evaluation of aerosol and cloud properties in COSMO-CLM. J. Geophys. Res., 116, doi:10.1029/2010JD014572.
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[4] Folini, D., and M. Wild, 2011: Aerosol Emissions and Dimming / Brightening in Europe: Sensitivity Studies with ECHAM5-HAM, in prep. J. Geophys. Res.
[5] Roesch, A., E. B. Jaeger, D. L. Lüthi, and S. Seneviratne, 2008: Analysis of CCLM model biases in relation to intra-ensemble model variability, Meteorol. Z., 17 (4), 369–382.

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