Global performance of the prognostic cloud droplet nucleation scheme and the effective aerosol hygroscopicity parameter in the EMAC model

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Motivation

Clouds play an important role in the climate system and are still the major uncertainty in general circulation models. Cloud properties are affected by atmospheric aerosol particles, which serve as cloud condensation nuclei(CCN), and so influence the climate by modifying the structure and dynamics of clouds. However, global models encounter challenges to account for these interactions between aerosol, cloud and climate due to the difficulty in parameterizing clouds. To reduce uncertainty in climate predictions there is a need to improve the large-scale cloud schemes and coupling within aerosol models.

Model description

EMAC (ECHAM -MESSy Atmospheric Chemistry) Model

The base general circulation model is the ECHAM5 (Roeckner et al., 2006) combined with the Modular Earth Submodel System (Jöckel et al., 2005, 2006). For a full description of the EMAC model and evaluation see Jöckel et al. (2005, 2006) or http://www.messy-interface.org.

Cloud droplet parameterization : Abdul Razzak & Ghan scheme

The ARG cloud droplet scheme prognostically determines the cloud droplet number concentration and mass from a prognostic aerosol model (GMXe, ISORROPIA) implemented in the EMAC model. This approach offers a more realistic treatment of the interactions between cloud, aerosols and chemistry as it explicitly calculates the aerosol activation and so prognostically derives the number of CCN and later on cloud droplet numbers. [Abdul-Razzak et al. (1998) and Abdul- Razzak and Ghan (2000, 2001)]

Aerosol activation scheme : K-Koehler theory

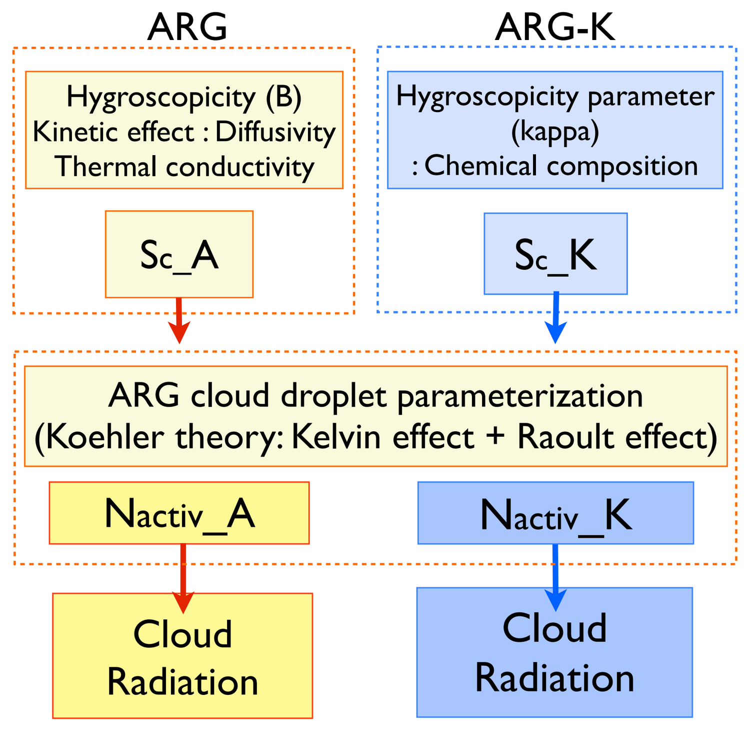
The effective hygroscopicity parameter kappa represents the relationship between particle compositions and CCN activity for aerosol activation in the EMAC model. This work presents the aerosol - cloud interaction with sensitivity simulations for aerosol parameterizations, chemical compositions and hygroscopicity. [Petters and Kreidenweis, (2007) and K. J. Pringle et al. (2010)]

Experiments

The model was run for a year with a spectral resolution of T42 degrees and with 19 levels in vertical. (2001,T42L19)

Hygroscopicity ?
: the absorption of water by soluble substance
: depends on its chemical composition (fraction of soluble components and their actual solubility)

Sc of CCN activation are primarily governed by the hygroscopicity and Raoult efficiency of the soluble substance.



Sc : Critical supersaturation
Nactive : the Fraction of activation

Result : Cloud Properties & AIE (Aerosol Indirect Effect)

Activation of aerosol in the cloud

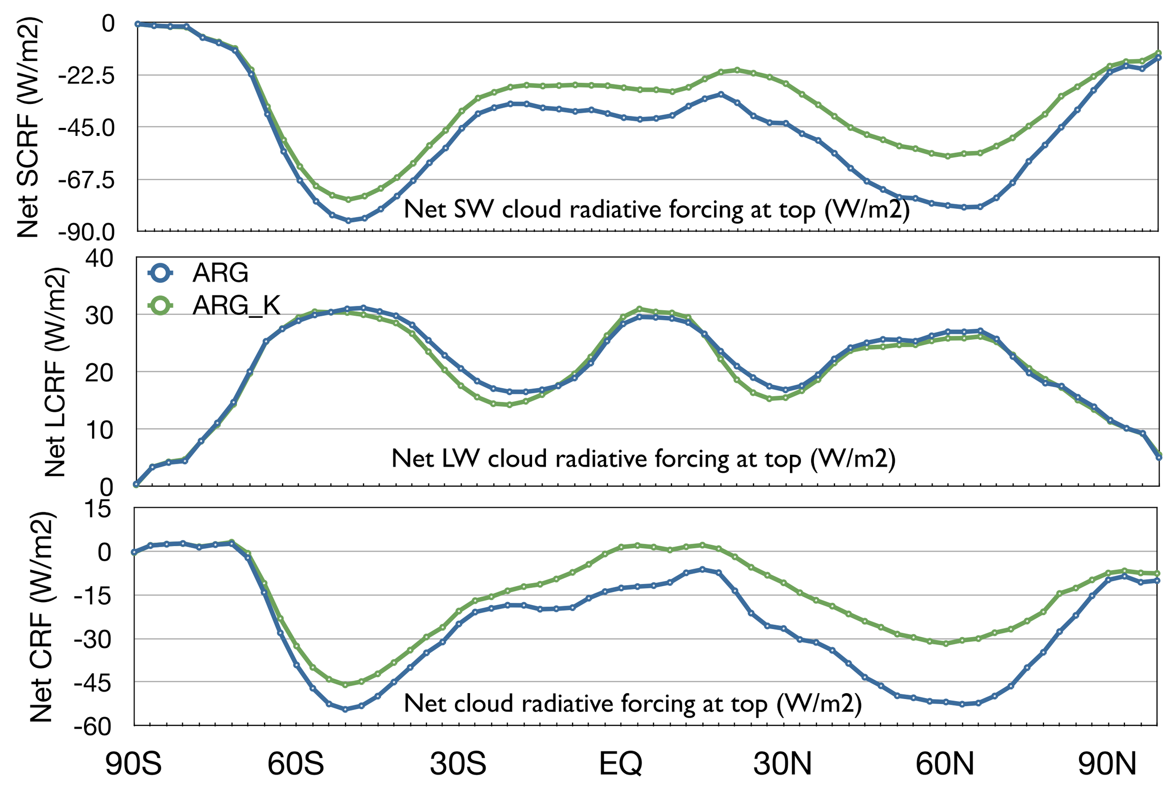
Global mean	NS	KS	AS	CS
ARG	0.02%	47.79%	99.47%	99.77%
ARG_K	0.01%	31.28%	99.44%	99.95%

The aerosol of AS and CS mode is almost all activated in both scheme. Main difference between ARG and ARG_K is in the KS mode. Chemical composition is more sensitive on small size of aerosol mode(Aitken). This small difference impacts on radiative forcing on climate directly and indirectly.

soluble modes	the range	
nucleation	< 5 nm	NS
Aitken	5 - 50 nm	KS
accumulation	50 - 500 nm	AS
coarse	> 500 nm	CS

GMXe model simulates the aerosol distribution: sulfate, black carbon, organic carbon, nitrate, ammonium, dust and sea salt

Cloud Radiative Forcing at top (unit :W/m2)



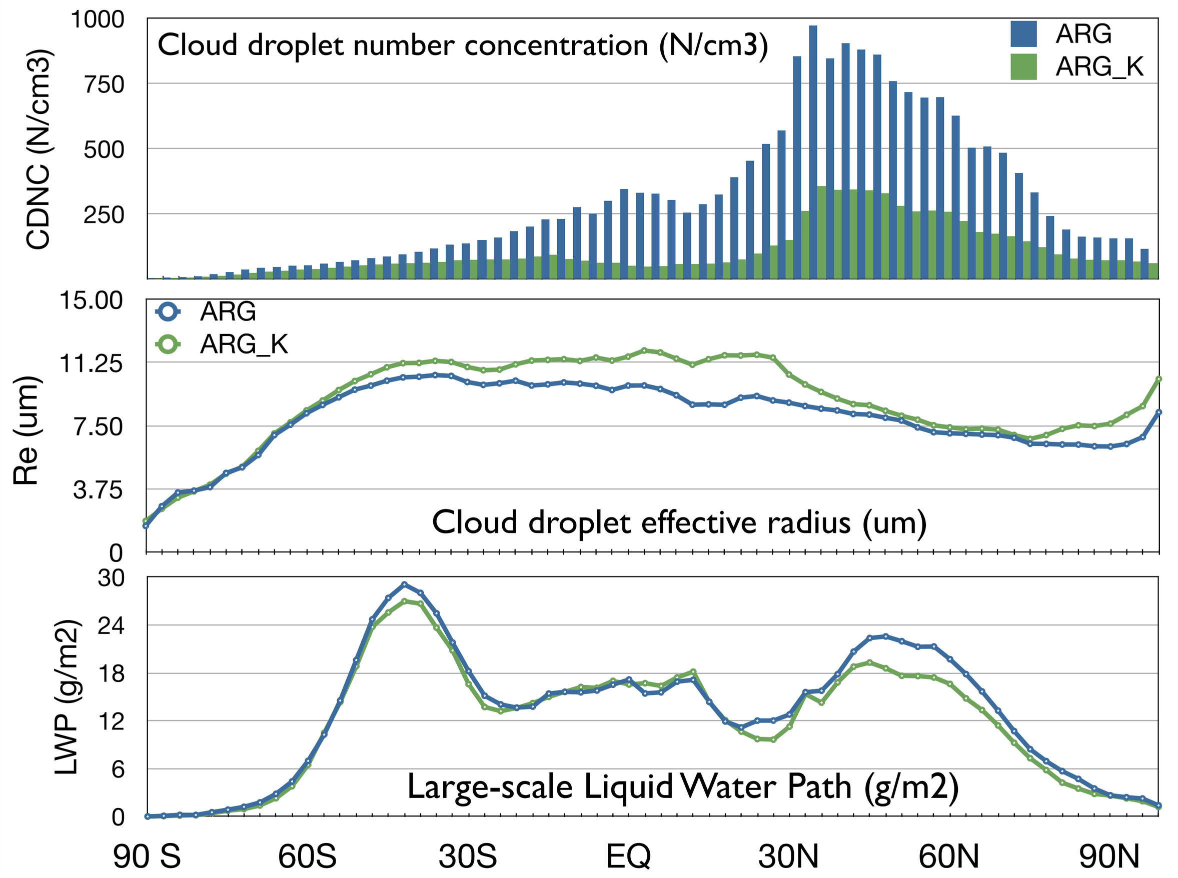
For small size aerosol(KS mode), the hygroscopicity of aerosol is more important to cloud formation, here shows a large impact on radiative forcing due to small changes in activated aerosol distribution.

Increasing aerosol has more potential CCNs, it leads more CDNs and so increasing cloud albedo. It reflects more solar radiation back into space. It might offset the anthropogenic CO2 and all other greenhouse gases.

(well known as the 1st AIE or Twomey effect)

W/m2	ARG	ARG_K
SCF	-46.28	-35.77
LCF	20.74	20.19
Net CRF	-25.53	-15.58

Aerosol Indirect Effect (2nd) : CDNC , Re, LWP



z=17	ARG	ARG_K
CDNC(mean)	306 /cm3	107 /cm3
CDNC(max)	973 /cm3	357 /cm3
Re (mean)	7.633 um	8.355 um
Re (max)	10.817 um	12.232um

- AIEs are consequences of modified cloud properties by aerosol. That highly dependent on the aerosol species and meteorological conditions (Lohmann and Feichter, 2005)
- The 2nd AIE shows Re distribution corresponding to the distribution of global mean of CDNC. Increasing CDNC has smaller size cloud droplet radius and more liquid water contents from more cloud droplets.
- Increasing cloud droplets are getting smaller and unifying size. It directly impacts on cloud microphysics such as less collision and coalescence in warm clouds.

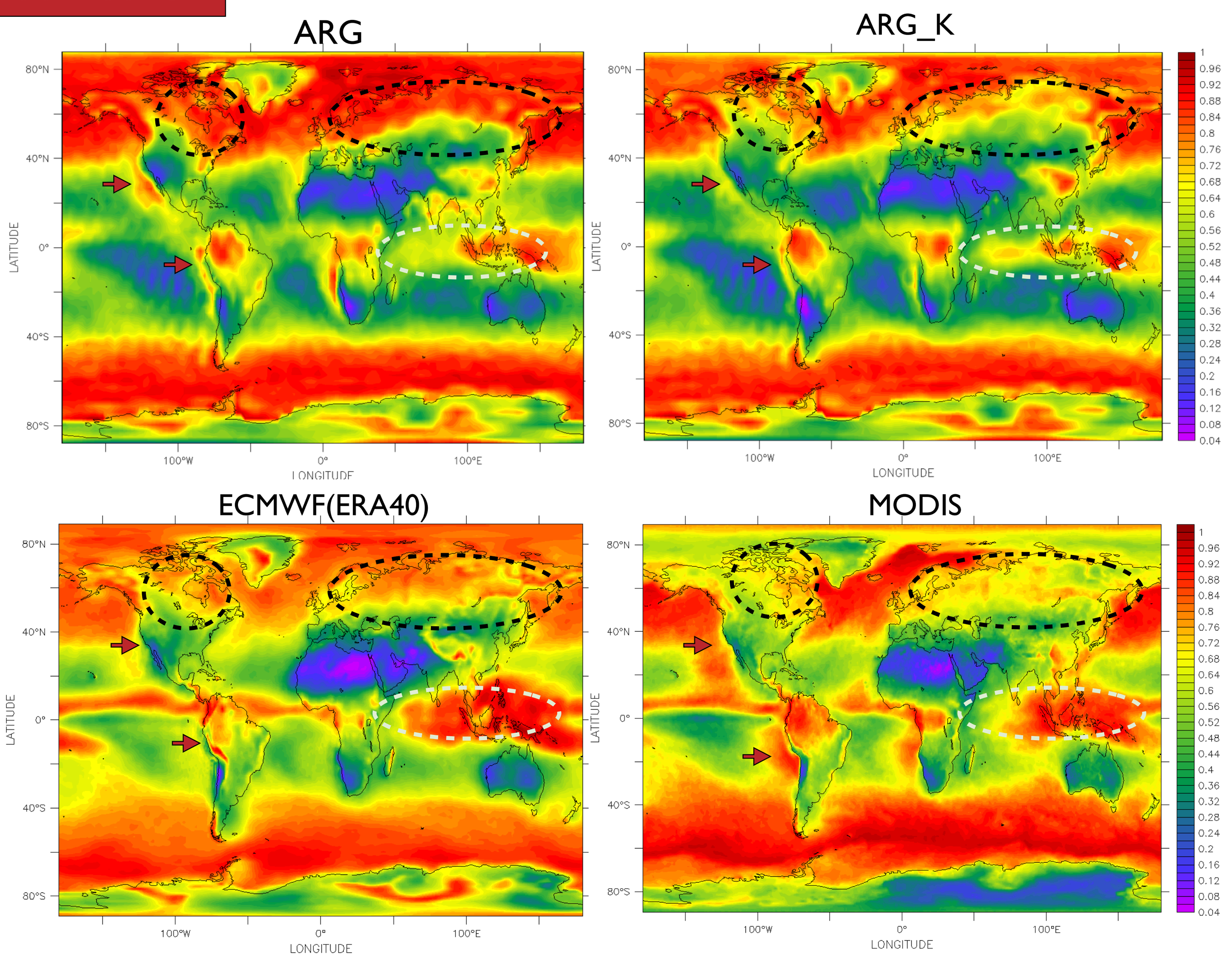
Global distribution of total cloud cover

Overall, simulated annual total cloud cover distributions of EMAC(ARG and ARG_K) and ECMWF(ERA40) are over estimated arctic regions(than MODIS); EMAC underestimated on ITCZ compared to both ECMWF and MODIS.

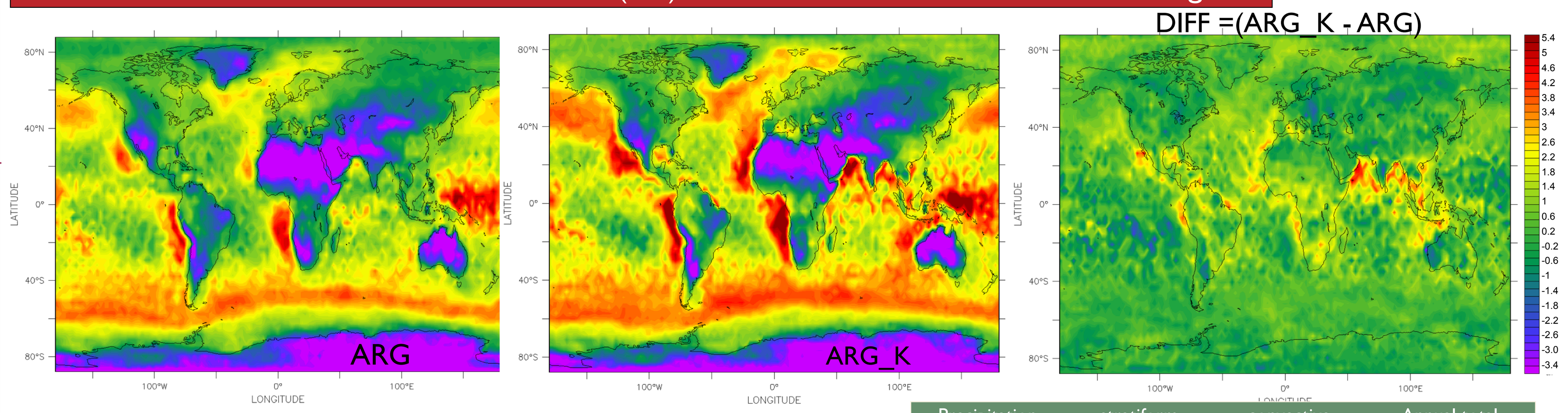
To evaluate ARG and ARG_K scheme (in EMAC) with ECMWF and MODIS
: Two black circled regions, ARG_K is closer than others, seems improved some continental regions which are usually overestimated in old version of EMAC.

Cloud directly influence on the radiation budget of the Earth-ocean-atmosphere system

Limitation of comparison with ECMWF
: different resolutions (T42L19 vs T159L60)
High resolution might over estimated LWP, Cloud cover, precipitation
Limitation of comparison with MODIS
: MODIS produces limited variables

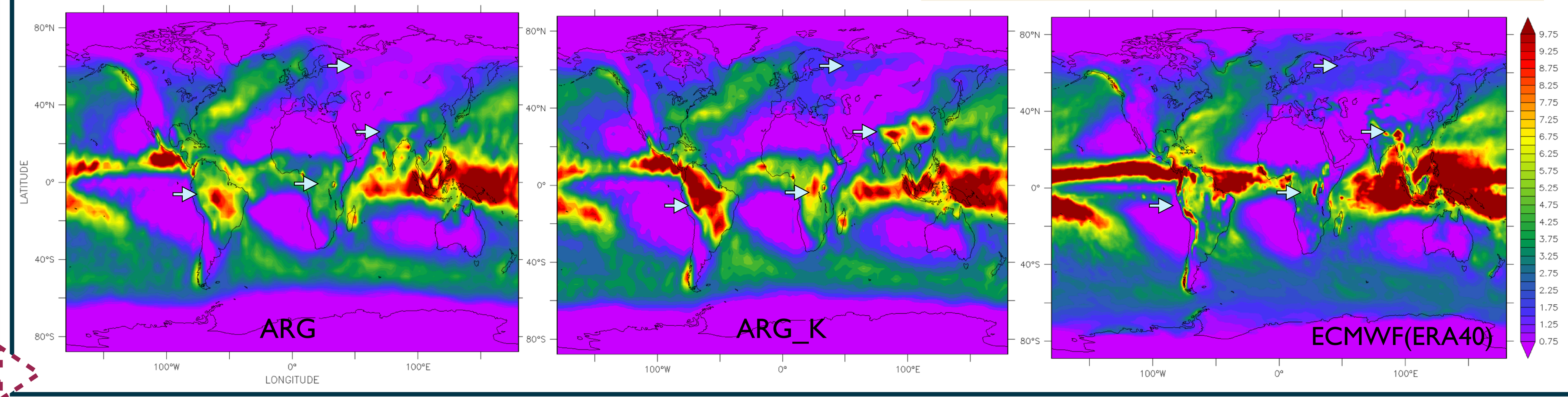


Global distribution of Cloud effective radius (um) : sea salt effect on oean and coastal regions



Global distribution of total daily precipitation (mm/day)

Precipitation	stratiform	convective	Annual total
ARG	1.007 mm/day	1.776 mm/day	1016 mm/yr
ARG_K	1.051 mm/day	1.776 mm/day	1032 mm/yr
ERA40	1.753 mm/day	1.728 mm/day	1271 mm/yr



Conclusion

- This work presents the aerosol - cloud interaction with sensitivity simulations for aerosol parameterizations, chemical compositions and hygroscopicity.
- A prognostic treatment of CCN activation of aerosol together with a two-moment cloud droplet scheme allows more sophisticated and improved coupling between aerosols and clouds.

: This approach offers a more realistic treatment of the interactions between cloud, aerosols and chemistry as it explicitly calculates the aerosol activation and so prognostically derives the number of CCN and later on cloud droplet numbers.

- This study shows the importance of the effective hygroscopicity parameter kappa (which represents the relationship between particle compositions and CCN activity) for aerosol activation in the EMAC model.

: Chemical components modify activated aerosol size distributions, particularly large differences in critical supersaturation in Aitken size. These changes significantly influence the distribution of cloud droplet formation, precipitation, and total cloud cover. Concerning cloud radiative forcing on climate, it has a quite large impact, the so-called first aerosol indirect effect or Twomey effect.

OUTLOOK

Limitations

Hard to evaluate these parameterizations with the quantity of the global annual average values. : inter-comparison of selected regions with observation data

Several uncertainties due to description of individual microphysical and chemical processes remain.

: Some well-known aerosol species are comparatively well understood, major uncertainties still exist regrading organic carbon (OC), dust, black carbon (BC) and etc. which are the dominant emissions in atmosphere.

Further studies

- Investigating the atmospheric chemistry on aerosol effects in GCMs and potentially improving the cloud parameterization scheme.
- Closer investigation of sensitivities to model parameters with kappa values
- Development of combining approaches on convective cloud scheme

References

1) EMAC model
: Roeckner et al., 2006; Jöckel et al., 2005, 2006; http://www.messy-interface.org.
2) ARG scheme
: Abdul-Razzak et al.(1998), A parameterization of aerosol activation, 1. Single aerosol type, JGR
: Abdul- Razzak and Ghan(2000), A parameterization of aerosol activation, 2. Multiple aerosol type, JGR
3) To implement the ARG scheme in EMAC, we have made some modification with empirical fit to observations of reference (Pruppacher & Klett, 2000, Fountoukis & Nenes , 2005)
4) The effective hygroscopicity parameter k describes the chemical composition on the CCN activity of aerosol particles (Petters and Kreidenweis, 2007).
5) To calculate the kappa value in a prognostic aerosol model (GMXe, ISORROPIA): The global distribution of the effective aerosol hygroscopicity parameter for CCN activation (K. J. Pringle et al., 2010)

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