Assessing the cloud-climate feedback: Systematic improvement of cloud processes in an Earth System Model exploiting observational data

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Summary

The central topic of the Junior research group is to study cloud-climate feedbacks at a large scale using as tools the Earth System Model with its atmospheric component ECHAM5, and observational data, particularly from satellites. We have developed methods allowing for a better comparison between model and data and thus model evaluation by implementing and developing satellite simulators, and by analysing and intercomparing different satellite datasets. Various aspects of cloud processes have been analysed, where a particular focus has been on aerosol-cloud interactions, which play an important role also for anthropogenic climate change forcing.

During the report period, the Junior research group has grown beyond the funding by DFG, with two scientists, six ongoing PhD projects, and three ongoing and three successfully completed diploma projects.

The research has until today lead to the publication or preparation of 20 peer-reviewed articles, and to more than 40 conference contributions. It has substantially promoted the scientific career of the young scientists involved, and contributed significantly to the model development and climate research within the Max Planck Institute for Meteorology, the University of Hamburg, and the broader national and international research community.

International model intercomparison and evaluation: Aerosol-cloud interactions

Aerosol indirect effects, the radiative forcing anthropogenic aerosols exert by serving as cloud condensation nuclei and altering cloud distributions and properties, constitute the main uncertainty among climate forcings (IPCC, 2007). This “uncertainty” is commonly estimated as the spread in forcings simulated by different general circulation models. Much of this variability is due to the different parameterizations in these models. We have developed methods to evaluate and constrain these parameterizations using observational data from satellites (Quaas et al., 2006; 2008). In a new initiative for an international model intercomparison project, this method has been applied to ten global aerosol-climate models, with contributions from almost all of the major modelling centres. We found that over oceans, the basic parameterizations of aerosol-cloud interactions (the aerosol activation scheme) works relatively well (within a factor of two compared to the observations), while models overestimate the strength of the aerosol indirect effect over land, compared to the satellite data. Second aerosol indirect effects, the impact on cloud liquid water path and cloud cover, are much less well simulated. We were able to trace this back to the parameterization of autoconversion in the models, which too strongly depends on cloud droplet number concentration. Finally, the satellite observations in combination with the newly developed metric to evaluate the aerosol-cloud interactions in the models have been used to compute a constrained estimate of the aerosol indirect radiative forcing at -0.7±0.5 Wm^{-2}, with a total radiative forcing by anthropogenic aerosols at -1.2±0.4 Wm^{-2} (Quaas et al., 2009a)

Assessment of satellite observations and satellite simulators

Liquid water path retrievals

Cloud liquid water is an important geophysical quantity forming a crucial link between the hydrological and radiative properties of the climate system. Shallow oceanic clouds, whose longwave and shortwave radiative fluxes are mostly determined by their liquid water content, play a particularly important role due to their ubiquitous nature. These boundary layer clouds, such as marine stratocumulus (Sc) and trade wind cumulus (Cu), represent the major source of uncertainty in simulated tropical cloud feedbacks because the interannual variability of their albedo is underestimated in current climate models. Consequently, future climate projections would significantly benefit from accurate observations of marine cloud liquid water content. Unfortunately, existing satellite observations show considerable discrepancies in the global distribution of this quantity. Our research aims at better constraining passive space-borne cloud liquid water estimates by systematically investigating inconsistencies between microwave and optical remote sensing methods with the ultimate goal of creating a consensus cloud liquid water climatology which would combine the strengths of the individual retrieval techniques.

We compared one year of AMSR-E and MODIS cloud liquid water path (LWP) estimates in warm marine clouds. In broken scenes AMSR-E increasingly overestimated LWP compared to MODIS, and retrievals became uncorrelated as cloud fraction decreased, while in overcast scenes the techniques showed generally better agreement but with a MODIS overestimation. We found microwave and optical retrievals being most consistent in extensive marine Sc clouds with correlations up to 0.95 and typical rms differences of 15 gm^{-2}. The overall MODIS high bias in overcast domains could be removed, in a global mean sense, by adiabatic correction; however large regional differences remained. Most notably, MODIS showed strong overestimations at high latitudes, which we traced to 3D effects in plane-parallel optical retrievals over heterogeneous clouds at low Sun. In the tropics/subtropics, microwave-optical differences also depended on cloud type, with MODIS overestimating in stratiform and underestimating in cumuliform clouds, resulting in large-scale coherent bias patterns where marine Sc transitioned into trade wind Cu. We noted similar geographic variations in AMSR-E cloud temperature errors and MODIS 1.6-3.7 μm droplet effective radius differences, suggesting that microwave retrieval errors due to cloud absorption uncertainties, and optical retrieval errors due to cloud vertical stratification might have contributed to the observed liquid water path bias patterns. Finally, cloud-rain partitioning was found to introduce a systematic low bias in AMSR-E retrievals above 180 gm^{-2} as the microwave algorithm erroneously assigned an increasing portion of the liquid water content of thicker non-precipitating clouds to rain (Seethala and Horváth, 2009).

ISCCP-Simulator

In order to assure comparability between model results and satellite observations, and to properly define cloud fraction and cloud properties, “satellite simulators”, or operators that generate cloud fields comparable to the satellite retrievals, are essential. The International Satellite Cloud Climatology Project (ISCCP) is now commonly used for climate model evaluation. It features two aspects, which are the sampling of a cloud field in the way the satellite 'sees' it (i.e., the shielding of low-level clouds from above and the use of the same assumptions as in the satellite retrieval e.g. sampling only sunlit scenes for the retrieval of cloud optical thickness), and the generation of subgrid-scale information in the model for comparability to the relatively high-resolved satellite data. The standard version of ISCCP simulator implementation uses the vertical cloud overlap assumption (maximum-random overlap) for the generation of subgrid-scale variability information. Sub-columns are generated in which each level is either entirely clear or entirely cloudy. In the atmospheric general circulation model ECHAM5 (Roeckner et al., 2003) including the horizontal PDF of total water content, a better estimate of the subgrid-scale variability is possible by stochastically “generating” sub-columns combining the horizontal variability with the vertical cloud overlap within the ISCCP simulator diagnostics. To account for the horizontal sub-grid variability, we have used the stochastic cloud generator based on (Räisänen et al., 2004). The generator is initialized with information from the GCM grid cell mean values (cloud fraction, liquid water and ice amount) and with the horizontal PDF of cloud water (Tompkins cloud scheme of beta distribution for current case) and vertical maximum-random overlap assumption (in a more generalized way, de-correlation lengths determining the degree of maximum vs. random overlap depending on wind shear may be applied). The generated sub-columns consist at each level of entirely clear sky or are entirely cloudy with a constant cloud condensate mixing ratio. The cloud condensate mixing ratio is chosen from the PDF stochastically by randomly selecting one sub-column from the generated sub-columns at each level. This approach leads to an unbiased estimation of sub-grid scale variability using the pdf of cloud water. The implementation of the cloud sub-grid variability information by the use of stochastic cloud sub-column generator is successfully done with ECHAM5. An analysis of global summer average maps was done to compare the model output with ISCCP satellite observations. The first comparisons with the initial control run (standard simulator) showed a decent agreement with the new version as no substantial modification of mean variables like the total cloud cover was seen. The new version also showed reasonable global distributions of the ISCCP cloud types as well as ISCCP histograms compared to ISCCP and MODIS satellite data (Gehlot and Quaas, 2009).

COSP-Simulator

The active radar and lidar remote sensing instruments on-board the CLOUDSAT and CALIPSO satellites provide a three-dimensional view of cloud structures; as well as information regarding the formation, evolution and distribution of aerosols and clouds. To best utilise these two new satellite data sets in the evaluation of global circulation models (GCM) the Cloud Feedback Model Intercomparison Project's 'CloudSat and CALIPSO Simulator' (CFMIP Observational simulator package, COSP) was implemented within ECHAM5. The satellite simulators take into account effects such as instrument sensitivity, cloud overlap, spacial resolution and signal attenuation producing a product directly comparable to satellite data (Chepfer et al., 2008; Marchand et al., 2009).

Comparison of the output from the CALIPSO lidar simulator and satellite observations (Chepfer et al., JGR in press) reveals the global distribution of high clouds in ECHAM5 agrees well, despite an excess of tropical ice clouds. There is, however, a significant underestimation of mid and low clouds, in particular in the subtropical and tropical regions. Recently it has been shown that the clouds in ECHAM5 have both higher scattering ratios and a greater frequency of such an occurrence compared to satellite observations. Future experiments will look into the cause of such high scattering ratios and its effect on the attenuation of the lidar signal.

Initial evaluation of the output from the CLOUDSAT radar simulator shows the frequency of precipitation in ECHAM5 is generally too high for all cloud types when compared to observations (Marchand et al., 2009). The two most prominent features in the evaluation of ECHAM5 includes a lack of non-precipitating boundary layer clouds and an overestimation of the cloud ice fraction. The latter supports the results found by the CALIPSO simulator (Nam and Quaas, 2009).

Evaluation and improvement of cloud parameterizations using satellite data

Statistical cloud scheme

The subgrid-scale variability scheme for water vapor and cloude condensate (Tompkins, 2002) in the ECHAM5 climate model has been evaluated by means of the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instrument. The results show that the mean total water path (TWP) and the mean cloud cover are on average relatively well simulated. However, large deficiencies are revealed by the evaluation of both variance and skewness of the PDF. Systematically negative deviations of distribution width are found for almost all regions of the globe. Skewness of the TWP is strongly overestimated in the Tropics, and underestimated over extratropical oceans. Sensitivity tests were made to improve the parameterization of skewness and distribution width (variance). Improved results are achieved with distribution width increased by reducing the dissipation caused by horizontal and vertical eddies, or, alternatively, by switching off the vertical diffusion. In particular, the large positive bias in skewness in the Tropics could be reduced modifying the influence of deep convection on the PDF. Moreover, some model runs were carried out to allow negative skewness in the cloud cover scheme. Especially, the modeled skewness in the tropics could be improved through the combination of allowing negative skewness, reducing the dissipation of distribution width caused by vertical eddies, applying skewness only in deep convection and generally increasing skewness by 20% (Weber and Quaas, 2009).

Convection

In order to evaluate the convection parameterization in the ECHAM5 model, a study for analysing the diurnal cycle of convection was performed. Four tropical areas (comprising of land and sea areas) were chosen as study areas, where the diurnal cycle of convective clouds, and other ISCCP cloud types was analysed. The comparison with ISCCP and MODIS satellite data shows that the model has a fairly decent and robust diurnal cycle for land as well as sea regions. The total cloud cover is relatively well simulated in the model. However, the convective clouds are over-estimated and the low-clouds are under-estimated in the model when compared to satellite observations, which also suggests that perhaps the reasonably good simulation of total cloudiness is due to a cancellation of errors in estimation of high and low clouds in the model. A similar trend is seen when the ISSCP histograms for the test areas are compared with the satellite data (Gehlot and Quaas, 2009).

Boundary layer clouds

Boundary layer clouds have a significant impact on the Earth's radiation budget, and those in the tropics have been shown to cause the greatest spread in model uncertainty amongst 15 different GCMs (Bony and Dufresne, 2005). As a such, the lack of boundary layer clouds identified in the subtropics and tropics of ECHAM5 proves that an improved boundary layer scheme is vital to the development of ECHAM5. Steps are being made towards the evaluation of three different boundary-layer cloud schemes using by the CALIPSO and CLOUDSAT simulator. Besides two variants of the standard low-level cloud scheme in ECHAM5 (Roeckner et al., 2003), we implemented in collaboration with the Dutch weather service (KNMI) a novel parameterization for stratiform and cumuliform shallow clouds, the Eddy-diffusivity-dual-mass-flux scheme EDMF-2M (Neggers et al., 2009; Neggers, 2009). This study aims at a better representation of shallow clouds, which is of great importance for both, aerosol-cloud interactions and cloud-climate feedbacks.

Analysis of cloud processes in satellite data

Satellite-based estimate of aerosol indirect forcing

The radiative forcing by anthropogenic aerosols, mediated by their influence on clouds, has been identified as the main uncertainty among forcings of global climate change (IPCC, 2007). The range given in the IPCC assessment report for the first indirect effect (cloud albedo effect) stems from the difference in global climate model estimates, where some of the smaller forcings are derived from models constrained with satellite data (e.g., Quaas et al., 2006). We here used a statistical method to obtain an estimate from observational data alone. For this, data from two different instruments on board the same polar-orbiting satellite were combined, a spectroradiometer (MODIS) and an Earth radiation budget experiment (CERES). This estimate confirmed the findings of the climate models constrained by satellite data, yielding a relatively weak forcing estimate for the first aerosol indirect effect of -0.2±0.1 Wm^{-2}, with stronger values in the Northern compared to the Southern hemisphere, and particularly strong forcings over the low-level marine clouds downwind continental anthropogenic aerosol sources (Quaas et al., 2008).

Aerosol absorption effect in the presence of clouds

In cloud free conditions, aerosols usually exert a negative radiative forcing (RF) at the top of the atmosphere (TOA) due to their scattering properties. When located above clouds, absorbing aerosols can reduce the shortwave local planetary albedo α, resulting in an often significant local positive direct radiative forcing (DRF; e.g. Keil and Haywood, 2003). A method for deriving the aerosol radiative effects of absorbing aerosols in cloudy situations from satellite retrievals has been developed. Data of 2005 and 2006 from various sensors aboard satellites of the ”A-Train” constellation, restricted to the tropical and subtropical Atlantic ocean, have been used. A multiple linear regression was performed to identify the dependence of α in cloudy scenes on cloud liquid water path (LWP) and aerosol optical depth (AOD), using the OMI UV Aerosolindex (UV-AI) as an indicator for absorbing aerosols. The results show an increase of α with increasing aerosol load, and a relative decrease of α with increasing amount of absorbing aerosols in cloudy scenes. This allows to derive the direct aerosol effect of absorbing aerosols above clouds, with the effect of aerosol absorption over clouds in the Atlantic contributing $+0.08 \pm 1.2\cdot10^{-3}$ Wm^{-2} to the global TOA RF (Peters et al., 2009).

Role of aerosols for cloud cover variability

Satellite data show a distinct positive relationship between cloud cover and aerosol optical depth. Some studies attributed this relationship to an aerosol cloud lifetime effect (e.g., Kaufman and Koren, 2006). If this was true, a very large radiative climate forcing by anthropogenic aerosols would be implied. However, this hypothesis is very debated in the literature, and other causes, such as co-incidence, or satellite retrieval errors, have been invoked as other possible reasons. We have used a global aerosol-climate model to investigate potential reasons for the positive relationship. We concluded that the main reason is that aerosols swell in the high relative humidity in the vicinity of clouds, but that to a minor extent also retrieval errors, and the cloud lifetime effect, play a role (Quaas et al., 2009b).

Analysis of weekly cycles

Weekly cycles have been identified for a variety of atmospheric and meteorological quantities. In particular, aerosol precursor gases and aerosols have been observed to show a weekly cycle over Europe with minima at weekends, and maxima during weekdays, attributable to lower emissions on weekends. We have exploited this cycle to analyse aerosol-cloud interactions. In two different general circulation models, we carried out a control simulation with weekly constant emissions, and an experimental simulation in which anthropogenic aerosol emissions were lowered during weekends. We were able to show that, compared to the observed weekly cycles, the models do well reproduce the cycles in aerosols and cloud droplet number concentration. We also concluded from the comparison of experimental and control simulation with the observed cycles, and from statistical significance tests, that there is no evidence yet which would allow to attribute weekly cycles in cloud liquid water content, top-of-the-atmosphere radiation, surface temperature, or precipitation, to aerosol indirect effects (Quaas et al., 2009c).

Dust-convection interactions

The Saharan Air Layer (SAL) is an intensely dry, warm, and mineral-dust-laden mass of desert air which often propagates westward, overlaying cooler, more humid air of the tropical Atlantic Ocean. The SAL has been shown to be detrimental to tropical cyclone formation and, as such, been cited among potential causes of the weaker-than-anticipated 2006 Atlantic hurricane season. We sought to better understand the evolution of Atlantic deep convection as influenced by the SAL during June-September 2006, as well as to create satellite diagnostics of absorbing aerosols and deep convection (DC) to evaluate ECHAM5. Specifically, we created a Lagrangian data base of convective systems by tracking cloud patterns in high temporal resolution, Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) observations using cross-correlations. These Lagrangian cloud trajectories were composited with aerosol data from the Ozone Monitoring Instrument (OMI) and MODIS, microwave sea surface temperatures from Remote Sensing Systems, and radiative flux measurements by the Geostationary Earth Radiation Budget (GERB) sensor.

We found that convective activity was suppressed during heavy aerosol loads compared to weak aerosol loads. However, while the number of convective targets sharply decreased, their maximum extent (strength) rapidly increased with aerosol index. This suggests that the dust- and/or smoke-laden air layer increased the energetic barrier to convection, which only stronger storms could overcome.

The direct instantaneous short-wave radiative effect of desert dust, 50-100 Wm^{-2}, was significantly larger than that of biomass smoke, 30-45 Wm^{-2}, with corresponding radiative efficiencies of ~45 Wm^{-2} AOD_{550}^{-1} and ~8 Wm^{-2} AOD_{550}^{-1}, respectively. Dust-smoke radiative differences were likely due to their different optical properties, such as enhanced absorption by smoke.

The NET deep convective cloud radiative effect has large diurnal variations driven by the SW component, whose prediction requires the accurate simulation of the convective diurnal cycle. Over ocean, ECHAM5's DC diurnal cycle was in fair agreement with observations; over land, however, it needs further improvement. In particular, the significant overestimation of morning convective activity needs to be remedied (Horváth and Soden, 2008).

Aerosol effects on the Indian summer monsoon

Water supply by the Indian summer monsoon precipitation is essential for agriculture in India and surrounding countries, assuring the nutrition of over 1 billion people. Research on the monsoon system is thus of large importance in atmospheric sciences. It has recently been postulated that the very large amounts of aerosols due to pollution and desert dust may influence monsoon precipitation distributions. In particular, it has been proposed that light absorption by aerosols above the bright snow-covered surfaces of the Tibetan Plateau might serve as an "elevated heat pump", leading to an intensified circulation with earlier onset and increased intensity of summer monsoon precipitation. The availability of the new spaceborne lidar data now allowed for a measurement-based assessment of this effect. Profiles of aerosol amount and optical properties for two entire pre-monsoon seasons (March-April-May) have been used in combination with a radiative transfer model. We concluded from this study, that aerosol amounts in the Tibetan Plateau region are far too scarce to allow for a substantial radiative effect, and that thus this "elevated heat pump" hypothesis should be seen as disproved (Kuhlmann and Quaas, 2009).

Vegetation-cloud-radiation interactions

One of the important drivers of global climate change are modifications in land-use patterns. Particularly in the Tropics, large areas have been deforested and converted into grass- and cropland. So far, studies have only quantified the radiative forcing by the surface albedo change due to land use change (IPCC, 2007). However, when vegetation is altered, so are surface fluxes of latent and sensible heat, and of radiation. It seems likely that cloud distributions and properties react to these modifications, introducing a feedback that enhances or reduces the top-of-the-atmosphere radiative forcing. We used satellite data for cloud properties and TOA radiation, and compared them statistically for underlying forest and grasslands in the Amazon region. It has been found that indeed cloud fields are significantly different over the two vegetation regimes, and that this difference affects TOA cloud radiative effects. With this method, we were able to estimate the radiative forcing due to deforestation in the Amazon region in the time period 2000 – 2005 as a positive +0.16 Wm^{-2} (Schneider et al., 2009).

Radiative forcings and feedbacks

Assessment of methods to estimate forcings and feedbacks

The sensitivity of earth climate to a given forcing depends highly on the acting of feedback mechanisms, which can dampen or amplify the climate response. The forcing and feedback strength depend to some degree on the chosen analysing method (Klocke et al., 2009). Those methods differ mainly on how accurately different feedback parameters get separated from each other and on the time scale on which feedbacks are separated from the forcing. Cloud feedbacks contribute most to the inter model spread of climate sensitivity (IPCC, 2007). The cloud response is most sensitive to the chosen method as clouds respond on relatively short time scales to a forcing. This time scale is not necessarily the time scale of the change in surface temperature, as clouds are mainly dynamical driven. This effect is analysed with the Gregory method (Gregory and Webb, 2008), where top of the atmosphere (TOA) radiative fluxes are regressed against the change in surface temperature. This method does not separate different feedbacks accurately. In the clear sky component of the radiative fluxes feedbacks are not separable which is also valid for the traditionally used cloud radiative effect (CRE) leading to too small estimates of the cloud feedback. To separate feedbacks more accurately, the partial radiative perturbation (PRP) method is commonly used. Under the assumption of linearity and separability partial derivatives of TOA radiative fluxes are calculated with respect to different model variables. Analysing several years in a single climate model, the inter annual variability in cloud feedback strength is contributing most to the variability in the total feedback parameter (Klocke et al., 2009), mostly caused by variability of the short wave component in the cloud feedback. Also geographical patterns stay robust, the (yearly globally averaged) cloud feedback parameter can vary substantially and change singe between years. In an unperturbed climate the CRE can vary between years up to the order of the cloud feedback.

There has been some debate on how radiative forcings by aerosol indirect effects can be included in forcing estimates (e.g., Quaas et al., 2009d). When aerosol processes are simulated interactively in climate models, and more so, when cloud microphysics are parameterised explicitly, then the traditional forcing concept is useless, since the unperturbed background conditions cannot be defined adequately. In a model intercomparison, we were able to show, however, that for a variety of radiative forcings, the alternative definition of a “radiative flux perturbation” yields quantitatively similar results to the traditional forcing definition. The “radiative flux perturbation” is obtained as the difference in two simulation with and without the perturbation, and with sea surface temperatures held fixed. Conceptually, all “fast” feedbacks are convolved in the forcing, and only “slow” feedbacks reacting to surface temperature change are left over for the feedback term in the climate sensitivity equation (Lohmann et al., 2009).

Influence of ship emissions on clouds and climate

The effect of ship emissions on clouds is investigated by means of satellite and model data. Sea-going ships are the least regulated sources of anthropogenic emissions, burning low-quality residual fuels containing high amounts of sulfur or even heavy metals. Combustion of such fuels produces, aside from gaseous species, large amounts of particulate matter (PM) consisting of elemental (black) and organic carbon, sulfate, ash and particles forming from sulfuric acid. Marine boundary layer (MBL) mixing and diffusion of the ships plume distribute the respective emissions, eventually reaching the top of the MBL. If conditions for erosol-cloud-interactions at the top of the MBL are fulfilled, a certain number of emitted particles serve as cloud condensation nuclei (CCN) leading to aerosol indirect effects. The resulting phenomenon is referred to as a ”ship track” which can often be depicted in satellite images. A number of experimental and observational studies have attempted quantifying this process; modelling studies have been performed to assess the radiative forcing of the former on a global scale with values ranging from -0.11 Wm^{-2} to -0.6 Wm^{-2} .

In this study, a first step towards quantifying ship emission influence on clouds is performed using ATSR-2 satellite imagery to investigate low cloud variability over European coastal waters following the methods described in Devasthale et al. (2006). Additionally, using a newly compiled emission inventory from the EU-integrated project QUANTIFY (Quantifying the Climate Impact of Global and European Transport Systems), simulations with ECHAM5-HAM are used to assess the impact of ship emissions (black and organic carbon, sulfur) on clouds. First results indicate the effect not being as spatially confined and consistent as expected. Future work will focus on studying the representation of specific aerosol species in HAM, concentrating on modelling of black carbon, including its radiative effects, being a major constituent of ship emissions.

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Appendix

Publications

Peer-revied journal publications

in preparation

Devasthale, A., K.-G. Karlsson, **J. Quaas**, and H. Grassl, Correction of the orbital drift signal in time series of AVHRR convective cloud fraction using rotated empirical orthogonal functions.

Horváth, Á., and **C. Seethala,** Heterogeneity effects in optical cloud liquid water path retrievals.

Kuhlmann, J., and **J. Quaas**, Assessment of aerosol impacts on the Asian Summer Monsoon using lidar satellite data and radiative transfer modelling.

Lonitz, K., and **Á. Horváth**, Evaluation of MISR cloud-motion winds using Meteosat-9 data.

submitted / in press

Egri, Á., Gy. Kriska, **Á. Horváth**, and G. Horváth, Sunlit water drops on leaves do not cause sunburn: Refutation of a widespread myth, *New Phytologist*, under revision.

Lohmann, U., L. Rotstayn, T. Storelvmo, A. Jones, S. Menon, Y. Ming, **J. Quaas**, A. Ekman, L. Donner, D. Koch, and R. Ruedy, Total aerosol effect: forcing or radiative flux perturbation, Atmos. Chem. Phys. Discuss., submitted.

Peters, K., J. Quaas, and N. Bellouin, Effects of absorbing aerosols in cloudy skies: A satellite study over the Atlantic Ocean, Atmos. Chem. Phys. Discuss., 9, 20853-20880, 2009.

Quaas, J., B. Stevens, U. Lohmann, and P. Stier, Interpreting the cloud cover - aerosol opticaldepth relationship found in satellite data using a general circulation model, Atmos. Chem. Phys. Discuss., submitted.

Quaas, J., Y. Ming, S. Menon, T. Takemura, M. Wang, J. Penner, A. Gettelman, U. Lohmann, N. Bellouin, O. Boucher, A. M. Sayer, G. E. Thomas, A. McComiskey, G. Feingold, C. Hoose, J. E. Kristjánsson, X. Liu, Y. Balkanski, L. J. Donner, P. A. Ginoux, P. Stier, J. Feichter, I. Sednev, S. E. Bauer, D. Koch, R. G. Grainger, A. Kirkevåg, T. Iversen, Ø. Seland, R. Easter, S. J. Ghan, P. J. Rasch, H. Morrison, J.-F. Lamarque, M. J. Iacono, S. Kinne, and M. Schulz, Aerosol indirect effects - general circulation model intercomparison and evaluation with satellite data, Atmos. Chem. Phys. Discuss., 9, 12731–12779, 2009.

Quaas, J., O. Boucher, A. Jones, G. P. Weedon, J. Kieser, and H. Joos, Exploiting the weekly cycle as observed over Europe to analyse aerosol indirect effects in two climate models, Atmos. Chem. Phys. Discuss., 9, 11269–11285, 2009.

Seethala, C., and **Á. Horváth**, Global assessment of AMSR-E and MODIS cloud liquid water path retrievals in warm oceanic clouds, *Journal of Geophysical Research*, under revision.

2009

Jones, T., S. Christopher, and **J. Quaas**, A six year satellite-based assessment of the regional variations in aerosol indirect effects, Atmos. Chem. Phys., 9, 4091–4114, 2009.

2008

Horváth, Á., and B. Soden, Lagrangian diagnostics of tropical deep convection and its effect upon upper tropospheric humidity, *Journal of Climate*, doi: 10.1175/2007JCLI1786.1, 2008.

Quaas, J., O. Boucher, N. Bellouin, and S. Kinne, Satellite-based estimate of the direct and indirect aerosol climate forcing, J. Geophys. Res., 113(D05204), doi 10.1029/2007JD008962, 2008.

2007

Horváth, Á., and C. Gentemann, Cloud-fraction-dependent bias in satellite liquid water path retrievals of shallow, non-precipitating marine clouds, *Geophysical Research Letters*, *34*, L22806, doi:10.1029/2007GL030625, 2007.

Lohmann, U., **J. Quaas**, S. Kinne, and J. Feichter, Different approaches for constraining global climate models of the anthropogenic indirect aerosol effect, Bull. Am. Meteorol. Soc., 88, 243–249, 2007.

Other peer-reviewed publications

2009

Quaas, J., Aerosol direct and indirect climate forcings – Clues from satellite data and global modeling, T. Nakajima and M. A. Yamasoe (eds.), Current problems in atmospheric radiation (IRS 2008): Proceedings of the International Radiation Symposium (IRC/IAMAS), vol. 1100, pp. 573–576, AIP Conf. Proc., doi 10.1063/1.3117050, 2009.

Quaas, J., S. Bony, W. D. Collins, L. Donner, A. J. Illingworth, A. Jones, U. Lohmann, M. Satoh, S. E. Schwartz, W.-K. Tao, and R. Wood, Current understanding and quantification of clouds in the changing climate system and strategies for reducing critical uncertainties, J. Heintzenberg and R. J. Charlson (eds.), Perturbed Clouds in the Climate System. Proceedings Ernst Strüngmann Forum, p. 576, MIT press, Cambridge, ISBN 978-0-262-01287-4, 2009.

Quaas, J., O. Boucher, and U. Lohmann, Aerosol-cloud-climate interactions: Climate modelling and satellite observations, S. Fuzzi and M. Maione (eds.), Atmospheric Composition Change Causes and Consequences - Local to Global. Proceedings of the Second ACCENT symposium, p. 196, Aracne, ISBN 978-8-854-82268-9, 2009.

2007

Denman, K. L., G. Brasseur, A. Chidthaisong, P. Ciais, P. Cox, R. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S. Ramachandran, P. da Silva Dias, S. Wofsy, and X. Zhang, Couplings Between Changes in the Climate System and Biogeochemistry, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. Averyt, M.Tignor, and H. Miller (eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 499–587, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, (contributing author), 2007.

Other publications

2009

Horváth, Á., *The Amount of Liquid Water in Global Clouds: Differences Between Satellite Measurements and Estimates From Combined Surface–In Situ Observations*, Saarbrücken: VDM Publishing House, ISBN 978-3-639-17135-8, p.122, 2009.

Quaas, J., Smoke and climate change, Science, 325(5937), 153–154, doi 10.1126/science.1176991, 2009.

2008

Yano, J.-I., **J. Quaas**, T. M. Wagner, and R. S. Plant, Toward statistical descriptions of convective cloud dynamics, EOS, 88, 23, 2008.

Conference contributions

2009

Horváth, Á., and **C. Seethala**, *Heterogeneity effects in optical cloud liquid water path retrievals*, American Geophysical Union Fall Meeting, 14-18 December 2009, San Francisco, California.

Lonitz, K., and **Á. Horváth**, *Comparison of MISR and Meteosat-9 cloud motion winds*, American Geophysical Union Fall Meeting, 14-18 December 2009, San Francisco, California.

Lonitz, K., and **Á. Horváth**, *Comparison of MISR and Meteosat-9 cloud motion winds*, MISR Data Users Science Symposium, 10-11 December 2009, Pasadena, California.

Horváth, Á., and **C. Seethala,** *Global assessment of AMSR-E and MODIS cloud liquid water path retrievals in warm oceanic clouds*, Earth Observation and Water Cycle Science Conference, 18-20 November 2009, ESA ESRIN, Frascati, Italy.

Schneider, N., **J. Quaas**, M. Claussen, and C. Reick, Analyse von Wolken- und Strahlungseigenschaften für verschiedene Vegetationen im brasilianischen Amazonasbecken, 8. Deutsche Klimatagung, Bonn, 5. - 8. Oktober 2009.

Weber, T. and **J. Quaas**, Evaluation of a statistical subgrid-scale variability scheme for water vapor and cloud condensate in a GCM using observational data, Erich Roeckner Symposium, Hamburg, 25. September 2009.

Stier, P., R. West, J. H. Seinfeld, U. Lohmann, and **J. Quaas**, Quantification of uncertainties associated with indirect aerosol effect parameterizations of various complexities, IAMAS-IAPSO-IACS Joint Assembly, Montreal, 19 - 29 July 2009.

Quaas, J., U. Lohmann, and P. Stier, Interpreting statistical relationships between cloud and aerosol quantities from satellite data using sensitivity studies with a general circulation model, IAMAS-IAPSO-IACS Joint Assembly, Montreal, 19 - 29 July 2009.

Horváth, Á, and **C. Seethala**, *Heterogeneity Effects in Optical Cloud Liquid Water Path Retrievals*, MOCA-09 IAMAS-IAPSO-IACS Joint Assembly, 19-29 July 2009, Montréal, Canada.

Horváth, Á, and **C. Seethala**, *Evaluation of Passive Satellite Remote Sensing of Cloud Liquid Water*, IEEE International Geoscience and Remote Sensing Symposium, 12-17 July 2009, Cape Town, South Africa.

Klocke, D, **J. Quaas,** and M. Giorgetta, Evaluating feedback factors in a GCM: focus on clouds, Gordon Research Conference on Radiaton & Climate, New London, 05 -10 July 2009.

Nam, C. and **J. Quaas,** Implementation of the CALIPSO and CloudSat Satellite Simulator within the ECHAM5 GCM, EGU General Assembly, Vienna, 19 - 24 April 2009.

Gehlot, S. and **J. Quaas**, ECHAM5 sensitivity runs for analysis of deep convective clouds using ISCCP simulator, EGU General Assembly, Vienna, 19 - 24 April 2009.

Peters, K. and **J. Quaas**, Absorbing aerosols above clouds: Getting hold of the direct aerosol effect, EGU General Assembly, Vienna, 19 - 24 April 2009.

Quaas, J., U. Lohmann, and P. Stier, Interpreting statistical relationships between cloud and aerosol quantities from satellite data using sensitivity studies with a general circulation model, EGU General Assembly, Vienna, 19 - 24 April 2009.

Seethala, C., and **Á. Horváth**, *Global Comparison of Microwave and Optical Cloud Liquid Water Path Retrievals in Warm Clouds*, European Geophysical Union General Assembly, 20-24 April 2009, Vienna, Austria.

Stier, P., R. West, J. H. Seinfeld, U. Lohmann, and **J. Quaas**, Assessment of aerosol -cloud-precipitation interactions employing parameterizations of various complexities, EGU General Assembly,Vienna, 19 - 24 April 2009.

Weber, T. and **J. Quaas**, Evaluation of a statistical subgrid-scale variability scheme for water vapor and cloud condensate in a GCM using observational data, EGU General Assembly, Vienna, 19 - 24 April 2009.

Klocke, D., **J. Quaas**, and M. Giorgetta, Evaluating feedback factors in a GCM: focus on clouds, EGU General Assembly, Vienna, 19 - 24 April 2009.

Kuhlmann, J., **J. Quaas**, and A. Devasthale, Aerosol impact on the Asian Summer Monsoon oberved by CALIPSO, EGU General Assembly, Vienna, 19 - 24 April 2009.

Devasthale, A., K.-G. Karlsson, **J. Quaas**, and H. Grassl, The rotated EOF analysis of convective cloud fraction over the Indian monsoon region, EGU General Assembly, Vienna, 19 - 24 April 2009.

Stevens, B., and **Á. Horváth**, *MPI-M and GlobCloud,* Workshop on European Contributions to Ensuring Long-Term Provision of Essential Climate Variables, 30-31 March 2009, Joint Research Center, Ispra, Italy.

2008

Kazil, J., **J. Quaas**, S. Kinne, S. Rast, P. Stier, and J. Feichter, Sulfate aerosol nucleation, primary emissions, and cloud radiative forcing in the aerosol-climate model ECHAM5-HAM, AGU Fall Meeting, San Francisco, 15 - 19 December 2008.

Klocke, D., **J. Quaas**, and M. Giorgetta, Climate sensitivity related to cloud processes in the general circulation model ECHAM5, AGU Fall Meeting, San Francisco, 15 - 19 December 2008.

Seethala, C., and **Á. Horváth**, *Evaluation of AMSR-E and MODIS Liquid Water Path Retrievals in Warm Clouds*, American Geophysical Union Fall Meeting, 15-19 December 2008, San Francisco, California.

Weber, T. and **J. Quaas**, Evaluation of the subgrid-scale variability scheme for water vapor and cloud condensate in the ECHAM5 climate model using satellite data, NCCR Climate Summer School 2008, "Key Challenge in Climate Variability and Change", Monte Verità, Switzerland, 31 August - 5 September 2008.

Horváth, Á., and B. J. Soden, *Influence of Saharan Air Layer on Convective Development: The Lagrangian Approach*, International Radiation Symposium 2008, 3-8 August 2008, Foz do Iguaçu, Brazil.

Horváth, Á., and B. J. Soden, *Lagrangian Diagnostics of Tropical Deep Convection and its Effect Upon Upper-Tropospheric Humidity*, International Radiation Symposium 2008, 3-8 August 2008, Foz do Iguaçu, Brazil.

Quaas, J., Aerosol direct and indirect climate forcings: Clues from satellite data and global modeling, International Radiation Symposium, Foz do Iguaçu, 3 - 8 August 2008.

Quaas, J., Evaluation of cloud microphysics in a general circulation model using satellite data, 7th WMO Cloud Modeling Workshop, Cozumel, 14 - 17 July 2008.

Quaas, J., Clouds in the ECHAM5 GCM, 15th International Conference on Clouds and Precipitation, Cancun, 7 - 11 July 2008.

Quaas, J., Planetary albedo as a function of cloud and aerosol properties: Statistical analysis from satellite data, Pan-GCSS meeting, 2 - 6 June 2008, Toulouse.

Lohmann, U. and **J. Quaas**, Overview and future perspective of aerosol-cloud-precipitation interactions from global climate model simulations, AGU Spring meeting, Fort Lauderdale, 27 - 30 May 2008.

Gehlot, S. and **J. Quaas**, Evaluation of diurnal cycle of convection in ECHAM5 general circulation model with satellite data, EGU General Assembly, Vienna, 13 - 18 April 2008.

Horváth, Á., and B. J. Soden, *Influence of Saharan Air Layer on Convective Development*, European Geophysical Union General Assembly, 13-18 April 2008, Vienna.

Peters, K. and **J. Quaas**, Satellite derived direct aerosol effect of aerosols above clouds, EGU General Assembly, Vienna, 13 - 18 April 2008.

Quaas, J. and Feichter, Climate change mitigation by seeding marine boundary-layer clouds?, EGU General Assembly, Vienna, 13 - 18 April 2008.

Quaas, J. and B. Stevens, Analysis of the relationship between cloud cover and aerosol concentration from MODIS satellite data and ERA-40 re-analyses, EGU General Assembly, Vienna, 13 - 18 April 2008.

Stier, P., J. H. Seinfeld, U. Lohmann, and **J. Quaas**, Quantification of uncertainties associated with indirect aerosol effect parameterizations of various complexities, EGU General Assembly, Vienna, 13 - 18 April 2008.

Weber, T. and **J. Quaas**, Evaluation of the subgrid-scale variability scheme for water vapor and cloud condensate in ECHAM5 using satellite data, EGU General Assembly, Vienna, 13 - 18 April 2008.

2007

Gehlot, S., **J. Quaas**, and A. Devasthale, Evaluation of diurnal cycle of convection in a GCM with satellite data, AGU fall meeting, San Francisco, 10 - 14 December 2007.

Stier, P., J. Seinfeld, U. Lohmann, and **J. Quaas**, Efficiency of primary and secondary aerosols in indirect aerosol effects, AGU fall meeting, San Francisco, 10 - 14 December 2007.

Quaas, J., Analysis of aerosol indirect effects with A-Train data and global climate models, A-Train Symposium, Lille, 22 - 25 October 2007.

Quaas, J., Analyse indirekter Aerosol-Effekte mit Satellitendaten und globalen Klimamodelle, Meteorologentagung DACH, Hamburg, 10 - 14 September 2007.

Quaas, J., Aerosol indirect effects: Modelling contraints inferred from satellite data, Second International Conference on Earth System Modelling, Hamburg, 27 - 31 August 2007.

Quaas, J. and S. Kinne, Constraints on GCM parameterizations of the aerosol indirect effect from multiple-instrument satellite data, EarthCare workshop, Noordwijk, 7 - 9 May 2007.

Invited presentations

2009

AEROCOM workshop, Princeton, USA

Geophysical Fluid Dynamics Laboratory (GFDL/NOAA), Princeton, USA

EarthCARE Joint Algorithm Development Endeavour, ESA-ESTEC, Noordwijk, The Netherlands

Atmospheric, Oceanic, and Planetary Physics, University of Oxford, UK

Deutsche Meteorologische Gesellschaft, Hamburg, Germany

Institute for Meteorology, Freie Universität Berlin, Germany

2008

AEROCOM workshop, Reykjavik, Iceland

International Radiation Symposium, Foz do Iguaçu, Brazil

Centre for Atmospheric and Oceanic Sciences, Indian Institute of Science, Bangalore, India

Indian Institute for Tropical Meteorology, Pune, India

Centre for Environmental Science and Engineering, Indian Institute of Technology Bombay, Mumbai, India

Gemeinsames Meteorologisches Kolloquium, Institut für Physik der Atmosphäre, Universität Mainz / Institut für Atmosphäre und Umwelt, Universität Frankfurt / Max-Planck-Institut für Chemie, Mainz, Germany

2007

Physikalisches Kolloquium, Fakultät für Naturwissenschaften, Otto-von-Guericke- Universität Magdeburg, Germany

Colloquium, Max-Planck-Institut für Physik, Munich, Germany

Meteorologisches Kolloquium, Meteorologisches Institut, Freie Universität Berlin, Germany

Kolloquium Atmosphäre und Klima, Institute for Atmospheric and Climate Science, Swiss Federal Institute of Technology Zurich (ETH), Switzerland

2nd ACCENT symposium, Urbino, Italy

Leibnitz-Institut für Meereswissenschaften an der Universität Kiel, Ifm-Geomar, Germany

Institut für Physik der Atmosphäre, Deutsches Zentrum für Luft- und Raumfahrt, Oberpfaffenhofen, Germany

Geophysikalisch-Meteorologisches Kolloquium, Meteorologisches Institut, Universität Bonn, Germany

Theses

PhD students

Karsten Peters, IMPRS/University of Hamburg, since December 2008
Topic: Analysis aerosol-cloud interactions in ship tracks from satellite data and atmospheric modelling

Daniel Klocke, IMPRS/University of Hamburg, since May 2008
Topic: Assessing the uncertainty in climate sensitivity related to cloud processes with observational data

C. Seethala, IMPRS/University of Hamburg, since May 2008
Topic: Investigating the sub-grid-scale variability of cloud liquid water path from satellites and cloud models

Christine Nam, IMPRS/University of Hamburg, since March 2008
Topic: Influence of cloud variability on aerosol indirect effects

Torsten Weber, IMPRS/University of Hamburg, since March 2007
Topic: Impact of inhomogeneities on non-linear cloud processes

Swati Gehlot, IMPRS/University of Hamburg, since January 2007
Topic: Feedbacks between convection and climate: Analysis with global modeling and satellite observations

PhD panel member

Mikhail Itkin, SICSS/University of Hamburg, since June 2009 (J. Quaas)
Topic: Precipitation retrieval over land using multi-sensor satellite records

PhD thesis rapporteur

Céline Déandreis, Université Pierre et Marie Curie (Paris VI), 2008 (J. Quaas)
Topic: Impact des aérosols anthropiques sur le climat présent et futur

Diploma Students

Elke Ludewig, University of Hamburg, since November 2009
Topic: Anthropogene Ursachen für den globalen Anstieg der Wolkenobergrenze?

Marta Zygmuntowska, University of Hamburg, since October 2009
Topic: Einfluss von Wolken-Klima-Feedbacks auf den Klimawandel in der Arktis

Katrin Lonitz, University of Leipzig, since January 2009
Topic: Comparison of MISR and MSG cloud motion winds

Julian Kuhlmann, University of Dortmund, August 2008 – September 2009
Topic: Influence of aerosol on the Asian summer monsoon: Analysis of dust events using satellite observations

Nadine Schneider, University of Hamburg, July 2008-September 2009
Topic: Cloud-vegetation-radiation interactions: Analysis of the climate effect of land use changes using satellite data

Karsten Peters, University of Hamburg, October 2007 - September 2008
Topic: Radiative forcing of absorbing aerosols above clouds

Supervision of undergraduate students

Christine Nam, International Space University, Strasbourg, France (August 2007)
Topic: Representation of cloud overlap in a climate model: Evaluation with satellite data

Katrin Lonitz, University of Leipzig (March 2008)
Topic: Comparison of MISR and MSG cloud motion winds

Dwaipayan Chakraborty, Indian Institute of Technology Kharagpur (May – July 2008)
Topic: Application of Neural Network Techniques to Assess Cloud-Aerosol Interactions

Marta Zygmuntowska, University of Hamburg (November 2008)
Topic: Cloud seeding to balance global warming

Sebastian Schirber, University of Hamburg (April 2009)
Topic: Bewertung des Strahlungsantriebs und der Klimasensitivität in idealisierten Sensitivitätsexperimenten mit der Methode nach Gregory

Ann Kristin Naumann, University of Hamburg (June/July 2009)
Topic: Analyse von maritimen Grenzschichtwolken in Satellitendaten mit Hilfe von Trajektorienanalysen

Larisa Seregin, University of Cologne (August 2009)
Topic: Evaluation of different cloud regimes in ECHAM using the COSP simulator

Ribu Cherian, Indian Institute of Technology Bombay, Mumbai (August – October 2009)
Topic: Simulation and analysis of seasonal variability in aerosol-climate interactions over India using ECHAM model

Benjamin Grandey, University of Oxford, United Kingdom (October – December 2009)
Topic: Study of cloud-aerosol sensitivities using satellite data

Teaching

Aerosol- and cloud physics, University of Hamburg.
Lectures and exercises; 2 + 2 h/week
Winter term 2009/2010; Winter term 2008/09; Summer term 2008; Winter term 2007/08
(J. Quaas)

International Max Planck Research School of Earth System Modelling (IMPRS), University of Hamburg
Convener of PhD seminar,.2 h/week
every semester since Summer term 2007 (J. Quaas).

Cloud physics, University of Hamburg.
Lectures and Exercises; 2 + 1 h/week
Summer term 2007 (J. Quaas)

Academic responsibilities

Conference organisation

Session “Clouds, aerosol, and radiation”, EGU General Assembly. Vienna, Austria (2 - 7 May 2010; J. Quaas Convener)

Workshop on concepts for convection parametrisations in large-scale models. Warsaw, Poland (17 - 19 March 2010; J. Quaas Co-convener)

Session “Dynamical Implications of Aerosol-Cloud-Climate Interactions”, IAMAS/IAPSO/IACS Joint Assembly. Montreal, Canada (19 - 29 July 2009; J. Quaas Co-convener)

Session “Clouds, aerosol, and radiation”, EGU General Assembly. Vienna, Austria (19 - 24 April 2009; J. Quaas Co-convener)

Workshop on concepts for convection parametrisations in large-scale models. Prague, Czech Republic (25 - 27 March 2009; J. Quaas Co-convener)

Session “Clouds, aerosol, and radiation”, EGU General Assembly, Vienna, Austria (13 - 18 April

2008; J. Quaas Convener)

Workshop on concepts for convection parametrisations in large-scale models, Hamburg, Germany (12 - 14 February 2008 indirect; J. Quaas Local convener)

Session “Wolken, Aerosol, Strahlung”, DACH Meteorologentagung, Hamburg, Germany (10 – 14 September 2007; J. Quaas Co-convener)

Membership

International Commission on Clouds and Precipitation (IAMAS-ICCP)
since 2008 (J. Quaas)

Editing

Atmospheric Chemistry and Physics
Member of the Editorial board since 2007 (J. Quaas)

Atmospheric Research
Associate Editor since 2008 (J. Quaas)

Journal reviews

Quaas, J.: for Annales Geophysicae (1); Arabian Journal of Science and Engineering (1); Atmospheric Chemistry and Physics (2); Atmospheric Environment (1); Atmospheric Measurement Techniques (1); Atmospheric Research (2); Environmental Research Letters (1); Geophysical Research Letters (3); IEEE Journal of Selected Topics in Earth Observations and Remote Sensing (1); Journal of Atmospheric Sciences (1); Journal of Climate (1); Journal of Geophysical Research (9); Journal of Theoretical and Applied Climatology (3); Nature Geoscience (1); Science (2); Tellus (2)

Project reviews

Quaas, J.: for Dutch Research Council (2008); Höchstleistungsrechner in Bayern (HLRB, 2008; 2009); Research Council of Norway (2007); France’s National Research Agency (2007); Atmospheric Radiation Measurement Program, Department of Energy, USA (2007)

Third-party funding

amounts available to the Junior Research Group indicated

Extramural research project, German Weather Service (DWD).
2009 - 2012; 97 k€ (coordinator)

CliSAP Integrated Activity, University of Hamburg.
2009 – 2011; 130 k€, together with Felix Ament, University of Hamburg (coordinator)

Comprehensive Modelling of the Earth system for better climate prediction and projection, COMBINE, European Commission.
2009 – 2013; 132 k€ (sub-project coordinator)

Monitoring Atmospheric Composition and Climate, MACC, European Commission.
2009 – 2011; 108 k€ (contributing partner)

Max Planck - India Fellowship, Max Planck Society and Indian Department of Science and Technology.
2008 – 2011; 24 k€; together with Suresh Varghese, IIT Bombay, India (host partner)

Travel grant, German Research Foundation (DFG).
February 2008; 3 k€; visit to India (J. Quaas, awardee)

European International Re-integration Grant (IRG), European Comission.
2007 – 2011; 100 k€ (Á. Horváth awardee)

Aerosol indirect effects: A multi-satellite study in combination with global climate modelling, Max Planck Society.
2006 – 2007; 140 k€; together with Stefan Kinne, Max Planck Institute for Meteorology (coordinator)