A proposal to the Deutsche Forschungsgemeinschaft entitled

Remote sensing of aerosols, clouds and trace gases using synergy of AATSR, MERIS, and SCIAMACHY onboard ENVISAT

(RESINC-2)

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1. General Information (Allgemeine Angaben)

Application for a research grant – continuation of DFG projects BU 688 and MA 2548.

1.1 Applicant(s) (Antragsteller)

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The DFG code number of the latest application or of any previous application(s) for project-funding by the DFG: BU 688/18-1

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1.2 Topic (Thema)

Remote sensing of aerosols, clouds and trace gases using synergy of AATSR, MERIS, and SCIAMACHY onboard ENVISAT.

Fernerkundung von Aerosol, Wolken und Spurengasen unter Nutzung der Synergie von AATSR, MERIS und SCIAMACHY auf ENVISAT.

1.3 Scientific discipline and field of work (Fachgebiet und Arbeitsrichtung)

Atmospheric physics and chemistry, cloud physics, radiative transfer, remote sensing, scattering and absorption of radiation

The **Institute of Environmental Physics and Remote Sensing (IUP/IFE)** at the University of Bremen performs research on atmospheric physics and chemistry with a special focus on remote sensing. The research activities of the IUP/IFE include:

- aerosol and cloud remote sensing;
- atmospheric correction;
- remote sensing of trace gases from space and ground;
- experimental and theoretical studies of atmospheric radiative transfer;
- laboratory studies of spectroscopy and kinetics of atmospheric free radicals and gases;
- development and application of atmospheric models to test our current understanding of the processes which determine the behaviour of the atmosphere and the predictive power of these processes;
- development of ground based and aircraft, balloon, and satellite atmospheric remote sensing instrumentation and techniques.

Of particular importance for this proposal is the satellite-based remote sensing of the Earth's atmosphere by passive remote sensing spectrometers. IUP/IFE has pioneered the development of the Global Ozone Measurements Experiment (GOME) and Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY (SCIAMACHY).

The **Institut für Physik der Atmosphäre (IPA)** at DLR (Oberpfaffenhofen) performs research on physics and chemistry of the atmosphere including both troposphere and stratosphere. In particular, investigations are done in the following areas:

- physics of the atmosphere and all aspects of air chemistry with respect to climate (water vapour, clouds, precipitation, trace gases, aerosols), ozone (stratosphere and troposphere) and mesoscale meteorology (e.g., for the Alpine and Bavarian regions);

- aeronautical research with respect to the interaction of air traffic with the atmosphere (the influence of emissions on climate and the impact of meteorology on traffic);
- applications of remote sensing from space and developments of methods for remote sensing with radar, lidar and passive remote sensing systems.

1.4 Scheduled duration in total (Voraussichtliche Gesamtdauer)

The project duration is planned to be 3 years.

1.5 Application period (Antragszeitraum)

Funding is requested for 36 months, December 1, 2008 – November 30, 2011

1.6. Summary (Zusammenfassung)

Accurate satellite retrieval algorithms are needed to study long–term trends in trace gas abundances related to climate change. The main aim of this project is to develop improved aerosol and cloud retrieval algorithms in order to get more accurate SCIAMACHY trace gas retrievals. The results will contribute to a better understanding of aerosol and cloud properties and their changes on a global scale. This will be achieved by utilising the synergetic data from the optical instruments onboard ENVIronmental SATellite (ENVISAT), launched by the European Space Agency (ESA) on March 1st, 2002. The data of Advanced Along-Track Scanning Radiometer (AATSR), Medium Resolution Imaging Spectrometer (MERIS), and SCIAMACHY, all of which measure the same ground scene, will be used. The three instruments continue to have excellent performance and have already generated more than five years of data. Compared to just one single instrument, combined data from these optical instruments having different spatial resolutions, observation modes, spectral resolutions and spectral bands characterize aerosol, cloud, and trace gas properties to a much better degree. In this project, a new validation and testing strategy based on extended realistic simulated satellite scenes will be followed.

Für die Quantifizierung von Trends in Spurengaskonzentrationen in einem sich wandelnden Klima sind genaue Satellitenbeobachtungen erforderlich. Ziel des Projektes ist die Entwicklung verbesserter Fernerkundungsverfahren für Wolken und Aerosol. Die Ergebnisse werden nicht nur zu einem verbesserten Verständnis von Aerosol- und Wolkeneigenschaften und ihrer Änderungen auf globaler Skala beitragen, sondern vor allem auch direkt Eingang in die Fernerkundung von Spurengasen mit SCIAMACHY finden. Zur Realisierung wird die Synergie verschiedener optischer Instrumente auf ENVISAT (ENVIronmetal SATellite), genutzt, der am 1. März 2002 von der ESA gestartet wurde. AATSR (Advanced Along-Track Scanning Radiometer), MERIS (Medium Resolution Imaging Spectrometer) und SCIAMACHY liefern kontinuierlich seit mehr als fünf Jahren wolken- und aerosolrelevante Beobachtungen mit weiterhin exzellenter Performance. Die Kombination der Daten dieser drei Instrumente mit

unterschiedlichen räumlichen Auflösungen, Beobachtungsgeometrien und Spektralkanälen wird eine deutlich bessere Charakterisierung von Aerosol, Wolken-, und Spurengasen ermöglichen. Im Rahmen des Projektes wird eine neuartige Validierungsstrategie verfolgt, basierend auf realistisch simulierten Satellitenbeobachtungen.

2. State of the art, preliminary work

2.1 State of the art

2.1.1 Introduction

Earth is now entrenched in an “anthropocene” epoch, where the activities of humans on a planetary scale are altering the processes that control the Earth’s system. The system comprises of a complex set of biological, physical and chemical processes taking place in and between the oceans, continents and the atmosphere. It is important to monitor possible changes in the system using space-borne sensors. This will make it possible to issue warnings in case/as soon as certain thresholds are reached. The aim of this project is to enhance atmospheric remote sensing techniques used for a number of instruments currently orbiting the planet. Therefore, this research contributes to several national and international programs, e.g., World Climate Research Programme, Global Aerosol Climatology Project, the Integrated Global Atmospheric Chemistry Observations Theme, and Forschungsstrategie zum Global Wandel.

SCIAMACHY onboard ENVISAT, which is a primary target of this project, was designed to measure trace gas concentrations and pollution from space (Bovensmann et al., 1999). For an accurate determination of trace gas columns, information on aerosols and clouds is needed. In particular, the calculation of correspondent air mass factors used in the trace gas retrieval procedures requires:

- aerosol optical thickness at the wavelengths where trace gas retrieval algorithms operate;
- cloud parameters (cloud fraction, cloud top height, cloud albedo);
- spectral albedo of underlying surfaces;
- vertical profiles of atmospheric constituents.

Correspondent aerosol, cloud, and surface parameters can be obtained either from SCIAMACHY itself or from other optical sensors on board ENVISAT, offering much better spatial resolutions (e.g., AATSR and MERIS, see Table 1). Errors and biases in atmospheric and surface parameters used in trace gas retrieval algorithms will necessarily bias vertical gaseous columns producing artefacts and possibly wrong trends and changes (e.g., due to the seasonal surface changes not accounted for in the algorithms).

The DFG project BU 688 (01.01.2004-31.12.2006) was aimed at the quantification of the influence of broken cloud characteristics common for the large SCIAMACHY science pixel size (typically, 1800 km^2) on the SCIAMACHY gas/aerosol/cloud retrieval procedures on the basis of the development of new parameterisations and their use in retrievals. The objectives were successfully achieved as summarized in our report to DFG (Kokhanovsky et al., 2006a). However, from this study it was verified that

a) clouds significantly disturb aerosol retrievals;
b) accurate cloud information is needed for trace gas retrievals, in particular for species with a large fraction of the total column in the troposphere;
c) correct cloud optical property retrievals can only be performed if the cloud fraction is known with a high accuracy.

From this we conclude that the following applications are required:

a) an improvement of the cloud fraction retrieval technique for large SCIAMACHY pixels;
b) an improvement of cloud screening;
c) an application of the new cloud fraction for the improvement of the aerosol and cloud retrievals needed for an accurate determination of trace gas vertical columns from space.

To meet the needs specified above, we propose to improve the SCIAMACHY aerosol, cloud, and trace gas retrieval techniques using the synergy of several optical instruments onboard ENVISAT. Neither cloud nor aerosol retrievals can be performed if the cloud fraction remains unknown. In our earlier work, cloud fraction was obtained using the SCIAMACHY Polarization Measurement Devices (PMDs) colour space algorithm (Loyola, 2004). However, the accuracy of this algorithm is low for scenes with neutral reflection in the visible (e.g., snow) and it is furthermore limited in terms of the spatial resolution (30 km*7.5 km). Therefore, we will use cloud fractions obtained from the analysis of MERIS data for SCIAMACHY retrievals. In particular, MERIS-derived Cloud Fraction (MCF) will be used for the SACURA cloud retrievals based on the independent pixel approximation (Kokhanovsky et al., 2006a). In addition to this, MCF will be applied to the selection of SCIAMACHY cloud free scenes. This enables an accurate determination of the spectral aerosol optical thickness in the UV and in the visible, where micro-windows of gaseous absorbers exist. The SCIAMACHY aerosol retrieval is required because the MERIS-derived aerosol optical thickness (at wavelengths $\lambda > 412nm$) cannot simply be extrapolated to the UV, while SCIAMACHY data are used to perform retrievals of ozone vertical columns. This is due to uncertainties related to the generally unknown spectral behaviour of the aerosol single scattering albedo in the UV. A preliminary pilot study has been undertaken for SCIAMACHY cloud retrievals (e.g., see http://www.iup.physik.uni-bremen.de/sacura) and some first results have been reported by Kokhanovsky et al. (2006b) demonstrating the feasibility and relevance of the approaches being applied.

Validation of satellite-derived properties is a complex task, in particular when clouds are involved. Clouds are extremely inhomogeneous on all spatial and temporal scales. A comparison with in-situ observations is, therefore, complicated as there is currently no independent observation which could provide cloud optical and microphysical properties at the scale of a satellite pixel, neither for the SCIAMACHY nor for the MERIS/AATSR-pixel size. On the other hand, knowledge about radiative transfer in the cloudy atmosphere and cloud physics is mature enough (Cahalan et al., 2005) to start a new attempt: a model-based validation of satellite-retrieved cloud-, aerosol-, and trace gas characteristics. Three-dimensional radiative transfer codes allow the simulation of satellite radiances with high precision. Using as-realistic-as-possible input fields for cloud, aerosol, and trace gas distributions, retrievals may be verified by applying them to the synthetic satellite observations. Comparison of the retrieval results to the model input will enable a quantitative assessment of the accuracy of the retrieval for cases very close to those occurring in reality. In the proposed project we will for the first time provide artificial satellite observations (SCIAMACHY, AATSR, and MERIS, see Table 1) including realistic cloud synoptic fields as model input. This will form a unique new approach to the validation of retrieval schemes. This new approach will complement the validation by comparison with independent observations and is particularly useful for components where a gap in scale between the observation (either at a point location or along an aircraft trajectory) and the satellite retrieval (SCIAMACHY, 30x60 km^2) prevents a valid comparison.

This work will enable the preparation of comprehensive data sets of aerosol and cloud properties (2002-2011 and, probably, beyond 2011, depending on the performance of SCIAMACHY and ENVISAT) and will allow to detect changes and trends in trace gases, aerosol and clouds on a global scale. Special attention will be paid to the analysis of monthly and yearly global and regional means. To achieve this, the retrieval technique must be improved further to solve the problems with cloud retrievals over ice/snow. Strict criteria with respect to the selection of pixels used in the averaging procedure must be applied. Measurements using MERIS and AATSR onboard ENVISAT will be used to enhance SCIAMACHY retrievals. At the same time, the SCIAMACHY spectral reflectance will be used to improve MERIS and AATSR cloud and aerosol retrievals (Holzer-Popp and Schroedter-Homscheidt, 2006; Kokhanovsky et al., 2006b).

An important fraction of aerosol that has only been recently considered in global model simulations is the secondary organic aerosol (Kanakidou et al., 2000; Tsigaridis et al., 2005). SCIAMACHY hyperspectral measurements in the UV and in the visible region of the electromagnetic spectrum enable better characterization of the secondary organic aerosol microphysical and absorptive properties (de Graaf et al., 2005a,b; 2006).

Table 1. Characteristics of AATSR, MERIS, and SCIAMACHY on ENVISAT

Instrument	Spectral bands	Spatial resolution	Observation mode
AATSR	0.55-12 μm, 7 channels	1 km^2	nadir, dual view
MERIS	0.4-1.0 μm, 15 channels	$(0.3\ km)^2$, $(1\ km)^2$	nadir, single view
SCIAMACHY	0.24-2.4 μm, hyperspectral	30x60 km^2	nadir, limb, occulatation

2.1.2 Retrieval of cloud characteristics

Current retrieval methods for the determination of cloud optical and microphysical properties are based on the look–up–table approaches (Nakajima et. al., 1991; King et al., 1992; Platnick et al., 2001). For thick clouds (optical thickness larger than 5-10), the asymptotic radiative transfer theory may be employed to replace the usual lookup-tables (Kokhanovsky et al., 2003). The optical thickness and the effective droplet radius can be retrieved using a bi-spectral algorithm, combining at least one band where liquid water does not absorb with one where it does (King et al., 1992). To avoid gaseous absorption, the bands around 412nm, 865nm, 1250nm, 1550nm, 1650nm, and 2100nm are often used, all of which (except the last one) are covered by the SCIAMACHY measurements. The cloud-top-height can either be retrieved using a thermal AATSR channel (e.g., at 12 μm) or by the oxygen A-band method (Yamamoto and Wark, 1961; Fischer and Grassl, 1991). The thermodynamic state of a cloud is obtained from measurements in a spectral range where the absorption coefficients of water and ice are considerably different, e.g., 1400-1600 nm (Knap et al., 2002; Kokhanovsky et al., 2006c). This enables the ice/water discrimination. The mixed cloud and supercooled water cases can be determined using a simultaneous analysis of near IR (SCIAMACHY) and thermal (ATTSR) measurements as demonstrated by Kokhanovsky et al. (2006c).

2.1.3. Retrieval of aerosol properties

Aerosol retrievals require thorough cloud screening algorithms. This is especially important for atmospheric chemistry instruments such as SCIAMACHY, GOME, GOME-2, and Ozone Monitoring Instrument (OMI). In the proposed project, cloud screening for the SCIAMACHY ground scenes will be performed using MERIS data. The retrieval of aerosol optical thickness will in turn enable more accurate retrievals of trace gas vertical columns (e.g., NO_2 (Richter et al., 2002, 2005; Petritoli et al., 2006)).

There are many different techniques to retrieve the aerosol optical thickness. Near-infrared (e.g., at 0.87 μm) reflectance of ocean surface is low. Therefore, near infrared channels are used in the retrieval procedures over ocean. Then the retrieved aerosol optical thickness (AOT) is extrapolated to the visible. However, these channels can not be used over land, where the reflectance in near IR is quite large. Special care must be taken over land with respect to the model of the ground reflectance. In particular, one can use algorithms which utilize the fact that the ground reflectance is low in the ultraviolet and blue regions of the spectrum (von Hoyningen–Huene et al., 2003; Hsu et al., 2004). Algorithms based on the correlation of surface reflectance in the near-infrared and the visible (Kaufman et al., 1997a,b) can also be used. The aerosol contribution to the top-of-atmosphere reflectance at some channels in the near-infrared is quite small (e.g., at 1.6 μm and 2.2 μm). This enables the determination of the surface albedo. The surface albedo determined in the near-infrared can be extrapolated to the visible as discussed by Kaufman et al. (1997a,b). The extrapolation procedures depend on the underlying surface type (Lee et al., 2006). In this work, the Bremen Aerosol Retrieval Algorithm (BAER) (von Hoyningen-Huene et al., 2003) will be used to retrieve the aerosol optical thickness in micro-windows of gaseous absorbers (e.g., 337 - 357 nm for BrO, 420 - 470 nm for NO_2, and 300-330nm for SO_2). Simultaneously, the atmospheric correction is performed and surface spectra are retrieved by BAER (von Hoyningen-Huene et al., 2006).

2.1.4. Retrieval of tropospheric NO_2

Tropospheric NO_2 columns are arguably the most mature tropospheric product from satellite measurements. As NO_2 is mainly produced from surface NO_x sources, its vertical profile has a large maximum close to the ground. Also, both in the case of anthropogenic and fire sources, NO_x emissions are often linked to aerosol production. As a result, quantitative retrievals of tropospheric NO_2 columns critically depend on proper correction of cloud and aerosol effects. It therefore can be considered to be an excellent test case for the application of improved cloud and aerosol products.

Different approaches have so far been used to account for aerosol effects in the retrieval. Richter et al. (2005) use a simple climatological approach based on the LOWTRAN aerosol model. Martin et al. (2004) use aerosol properties modelled by the GEOS-chem model on a daily basis. Boersma et al. (2004) do not explicitly account for aerosols in their retrieval but argue that their cloud correction scheme implicitly also corrects for aerosol effects. All of the current approaches used are based on strong simplifications and do not use measured aerosol properties. Given the spatial and temporal variability of aerosol distributions and their correlation to tropospheric NO_2 concentrations, use of aerosol properties measured simultaneously with the NO_2 have the potential to significantly reduce the resulting uncertainties.

Cloud correction schemes in current retrievals also vary. In the IUP Bremen retrieval, data are only screened for clouds and no additional correction is applied so far (Richter and Burrows, 2002, Richter et al., 2005). Velders et al. (2001) applied a simple global correction factor without detailed cloud treatment. Martin et al. (2004) and Boersma et al. (2004) use cloud fraction and cloud top height in combination with a model predicted NO_2 vertical profile to correct for cloud effects. These corrections are based on two different cloud retrieval algorithms which are both using the O_2-A absorption band. The main weakness of current cloud treatment is the large SCIAMACHY pixel size. In most cases, it leads to inhomogeneous cloud fields which can not be resolved by cloud retrievals based on SCIAMACHY data alone and the uncertainty on the vertical NO_2 profile. Using coincident high resolution cloud measurements (e.g., MERIS, AATSR) can reduce part of this uncertainty (Kokhanovsky et al., 2008a).

All current tropospheric NO_2 retrieval schemes use the GOME surface spectral reflectance climatology from Koelemeijer et al. (2003), in some cases in combination with TOMS data. The problem of this data base is that it is static and does not reflect changes in surface reflectance over time. It furthermore can not account for short-term variations, e.g., from snow fall, rain or vegetation changes and its spatial resolution is inappropriate for SCIAMACHY measurements. However, in particular for dark surfaces, even small changes in surface reflectance can have a significant effect on the NO_2 columns retrieved. Therefore, the application of surface reflectance values retrieved using the BAER algorithm at the time and spatial resolution of the NO_2 measurement have the potential to substantially reduce the uncertainties in the NO_2 retrieval.

2.1.5 Model-based validation of cloud properties

As outlined in the introduction, we propose a model-based validation of satellite-retrieved cloud-, aerosol-, and trace gas profiles, using three-dimensional radiative transfer simulations of SCIAMACHY, MERIS, and AATSR observations for realistic synoptic cloud conditions. Previous work has shown that cloud inhomogeneity and three-dimensional effects are highly relevant for radiance calculations, e.g., (Zinner and Mayer, 2006). Sub-pixel inhomogeneity is most relevant for large pixels (e.g., SCIAMACHY) and could possibly be considered with the independent-pixel approximation (Kokhanovsky et al., 2006a). Three-dimensional radiative transfer effects, on the other hand, are relevant for smaller pixel sizes (e.g. MERIS, AATSR) where the independent pixel approximation fails. For these reasons, three-dimensional radiative transfer is the natural solution to the problem. For this application, atmospheric data are required both for large spatial domains and with high spatial resolution. At DLR/IPA we will work on the generation of such cloud data sets in the framework of a Eumetsat Research Fellowship aimed at the validation of cloud property retrievals for Meteosat Second Generation (MSG). It is planned to use the output of a Numerical Weather Prediction (NWP) model, e.g., the Local Model (LM) of the German Weather Service, with spatial resolution enhanced by statistical downscaling, as input to our three-dimensional radiative transfer code MYSTIC (Monte Carlo code for the physically correct tracing of photons in cloudy atmospheres; Mayer 1999, 2000). We have shown in a feasibility study that this approach is computationally demanding but possible. In the present proposal we suggest to extend these studies, which have been focussed on cloud properties only, to the retrieval of trace gases and aerosols. This is an entirely different problem which we will approach in a PhD work. In particular, the issues to address are:

1. The suggested large-scale high-resolution calculations are only feasible with a backward Monte Carlo technique such as MYSTIC. The uncertainty of the Monte Carlo result decreases only with the square root of the number of photons and hence with the square root of the computational time. In a previous DFG-project we have shown that the 3D simulation of SCIAMACHY spectra suitable for ozone column retrieval is entirely possible while the simulation of spectra suitable for NO_2 retrievals is possible but extremely challenging. The latter is due to the high signal-to-noise ratio required. For this purpose we will develop a novel photon-pathlength-distribution method taking advantage of the slow spectral variation of Rayleigh, cloud, and aerosol scattering and extinction, where the trace gas (e.g., NO_2) absorption cross section varies rapidly (Kokhanovsky et al., 2006a). The algorithm will also enable the consideration of different trace gas profiles with a single Monte Carlo run. The use of the algorithm will be demonstrated for the case of NO_2 retrievals.
2. A carefully selected, spatially consistent set of input data (including water and ice clouds, aerosols, and trace gases) will be prepared as input to the simulation of the SCIAMACHY, MERIS, and AATSR radiance observations. These will allow us to test the hypotheses and retrievals developed in this project; in particular, the synergetic cloud screening and retrieval algorithms as well as the aerosol and trace gas retrievals. Satellite radiances will be simulated with MYSTIC, including those spectral ranges and channels required for the different retrieval techniques.
3. Finally, the new retrieval techniques will be tested with the artificial satellite observations; conclusions will be drawn on the accuracy of the products and recommendations for improvements will be given.

The model-based validation project is an interesting, self-contained three-year PhD topic.

2.2 Preliminary work, Progress report (Eigene Vorarbeiten, Arbeitsbericht)

Preliminary work on the subject includes the development of the radiative transfer model SCIATRAN (Rozanov et al., 2005, see http://www.iup.physik.uni-bremen.de/sciatran) and a number of retrieval algorithms to obtain microphysical and optical properties of clouds, trace gases, and aerosols (Rozanov et al., 1998; Bovensmann et al., 1999; Kokhanovsky et al., 2003; von Hoyningen-Huene et al., 2003; Richter et al., 2005). All of them were used for the retrieval of atmospheric parameters from a number of radiometers and spectrometers, e.g., GOME and SCIAMACHY. Both GOME and SCIAMACHY were developed with the participation of IUP/IFE. The cloud retrieval algorithm SACURA (see http://www.iup.physik.uni-bremen.de/sacura), which can be also applied to inhomogeneous cloud fields, has been developed in the framework of the DFG Proposal BU 688/8-1. This algorithm shall be modified and used in the framework of this project in synergy with AATSR and MERIS retrievals over cloudy fields. Such a synergy for the classification of cloud thermodynamic state (water, ice, mixed cloud, supercooled water) was used, e.g., by Kokhanovsky et al. (2006c) (based on the SCIAMACHY hyperspectral measurements in near IR and information coming from AATSR thermal channels for a given ground scene, see Fig.1).

In addition, if the cloud top height is known from thermal AATSR measurements, the cloud bottom height can be determined from oxygen A-band measurements of SCIAMACHY (Rozanov and Kokhanovsky, 2004). This technique was first introduced and applied to satellite data by Rozanov and Kokhanovsky (2006). It is planned to use the cloud bottom height determination technique for the retrievals in the framework of this project.

Satellite retrievals of tropospheric NO_2 are routinely performed at the University of Bremen using measurements from the GOME, SCIAMACHY, and GOME-2 instruments. The effect of clouds, aerosols and surface albedo have been studied with radiative transfer calculations (Nüß, 2005) and more recently in a comparison with predictions from WRF-chem model runs over the western part of the US (Heckel et al., paper in preparation). An example is shown in Fig. 2, where results from two retrieval runs using different assumptions on the aerosol loading are compared with each other.

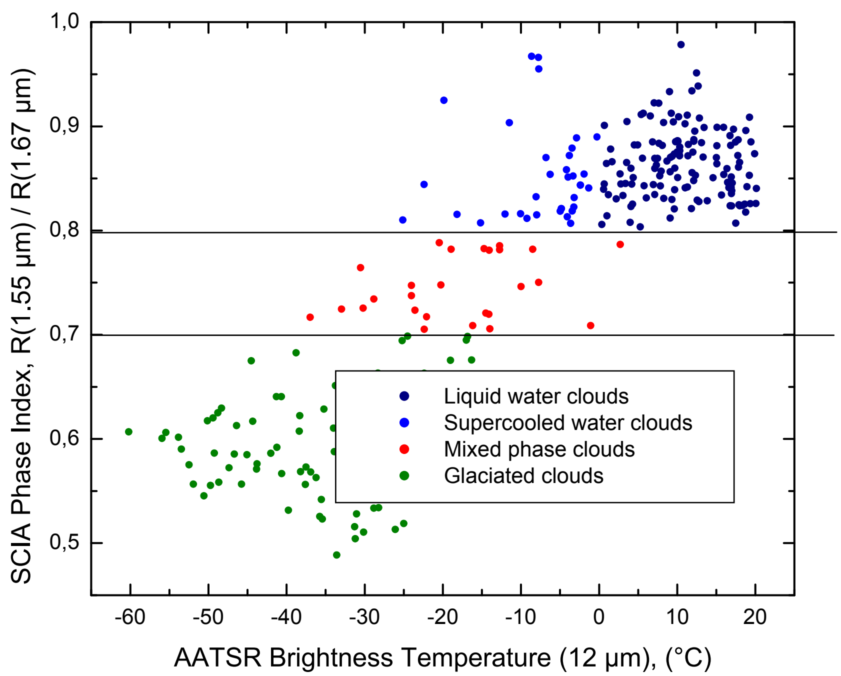

Figure 1: The cloud phase classification scheme (Kokhanovsky et al., 2006c).

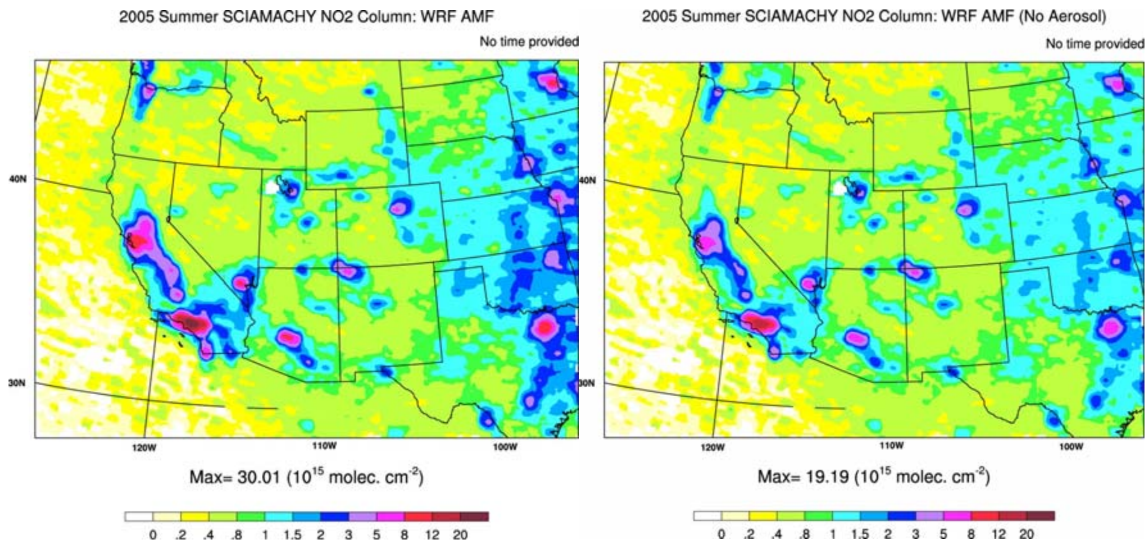

Figure 2: Comparison of SCIAMACHY NO_2 columns retrieved using two different aerosol scenarios. Left: IUP Bremen standard scenario, right: retrieval assuming Rayleigh only (no aerosols) atmosphere.

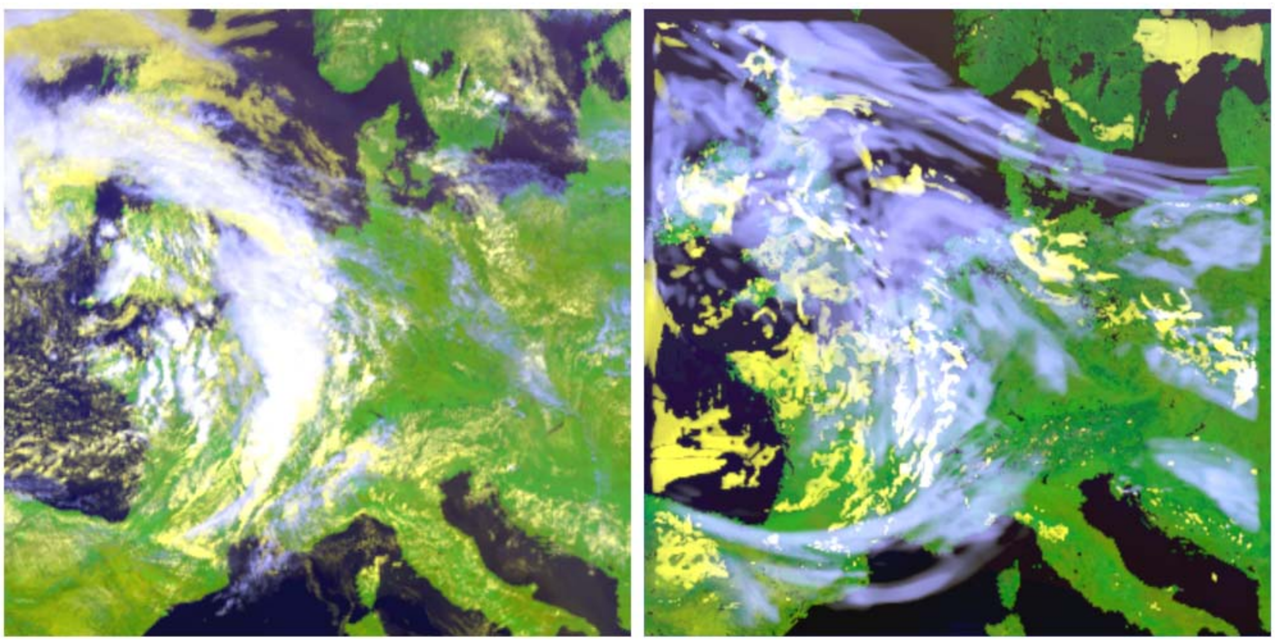

Figure 3: An example of a large scale artificially-generated Meteosat Second Generation (MSG) image. MSG false-colour composite for 12 August, 2005, 12:00 UTC is given on the left panel. The radiative transfer simulation of this image, based on a forecast of the German Weather Service (DWD) Local Model, is presented on the right panel.

Concerning the simulation of satellite observations we have built up considerable experience in our earlier studies on the remote sensing of inhomogeneous clouds (e.g., Zinner and Mayer, 2006), in particular with one- and three-dimensional radiative transfer (e.g., Mayer 1999, 2000; Mayer and Kylling, 2005) as well as with the generation of small-scale (e.g., Zinner et al., 2006) and large-scale cloud fields to be used as input to three-dimensional radiative transfer studies. An example is shown in Fig. 3. This figure clearly demonstrates the feasibility of the approach, although there is a considerable potential for improvements (e.g., the over-estimation of the cirrus clouds (shown in blue in Fig. 3) and the missing mid-level clouds in the LM). For the model-based validation approach, it has also to be kept in mind that we do not require the real and the artificial images to be identical, but only that the input to the radiative transfer simulations is realistic.

These issues will be addressed in the mentioned Eumetsat Research Fellowship. In our proposed project, we will concentrate on the aerosol and trace gas related problems. In a previous DFG-Project we have simulated SCIAMACHY spectra for the retrievals of cloud-top-height and ozone column using 3-D cloud models (Kokhanovsky et al., 2006a, 2007a,b). While these studies were limited to more or less academic cases (e.g., randomly distributed cubic clouds), we are confident that realistic large-scale synoptic situations (see Fig.3) can be modelled This provides a unique opportunity for the validation of all SACURA cloud products and also the IUP trace gas and aerosol retrievals based on comprehensive 3-D simulations.

3. Goals and work schedule (Ziele und Arbeitsprogramm)

3.1 Goals (Ziele)

The goal of the proposal is to develop an algorithm for the simultaneous retrieval of trace gas, aerosol, and cloud characteristics for a given satellite scene using synergy of several optical instruments (namely, AATSR, MERIS, and SCIAMACHY) on board ENVISAT. The general scheme of the planned algorithm is given in Fig. 4. The algorithm will not just be a mechanic mixture of already existing separate SCIAMACHY retrieval algorithms but a number of improvements will be performed in all algorithms. In particular,

- cloud screening will be improved considerably using the synergy of different sensors on ENVISAT;
- a snow-cloud discrimination algorithm will be developed;
- the current cloud retrieval algorithm SACURA used extensively at IUP, DLR, ESA, and also at University of Marburg will be improved;
- the NO_2 retrieval algorithm will take into account the retrieved aerosol and cloud parameters (currently, the pre-defined aerosol model is used in the retrievals of NO_2 vertical columns);
- a validation of all newly developed methods and products by comparison with independent satellite data and by the model-based approach will be performed;
- temporal trends in trace gas, aerosol, and cloud parameters at different locations worldwide (including the interaction between them) will be studied;

- radiative forcing by clouds and aerosols will be assessed for several locations.

This work will lead to the creation of an improved simultaneous trace gas-aerosol-cloud satellite retrieval algorithm at IUP. 3-D Monte-Carlo calculations with high spectral and spatial resolutions and ground-based measurements will be used to asses the accuracy of the algorithm.

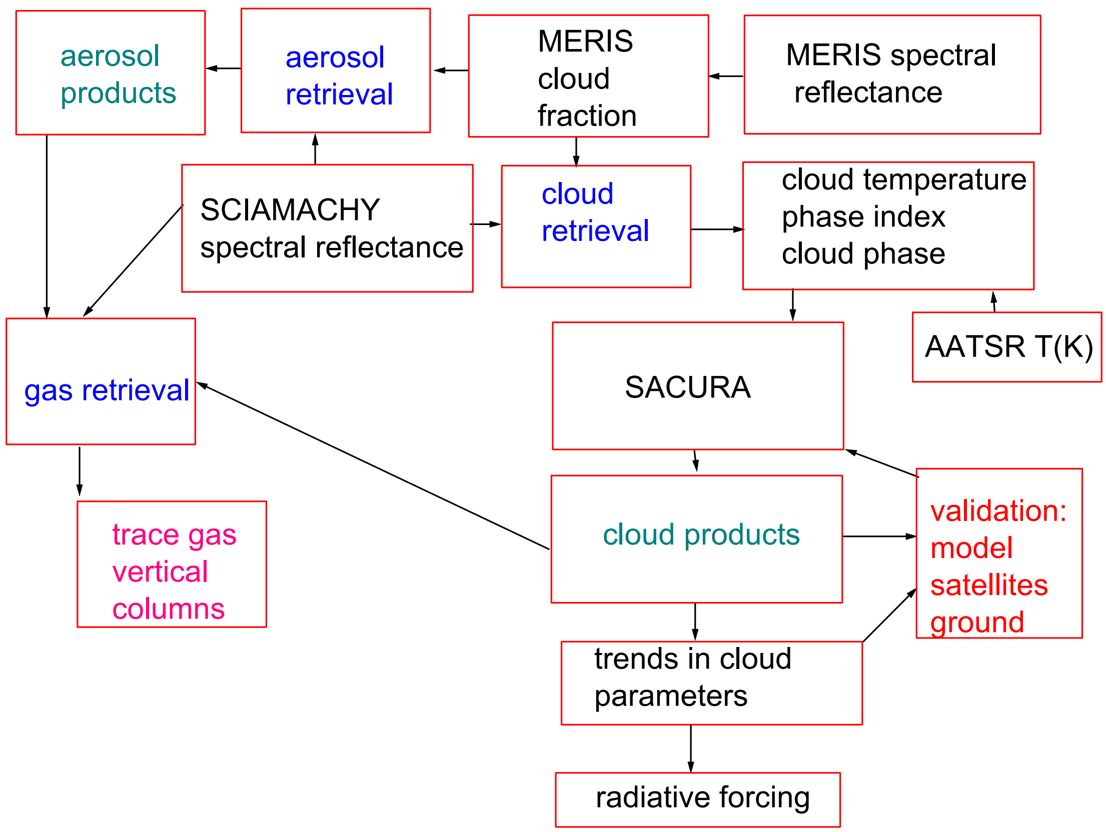

Figure 4: The general scheme of the improved retrieval algorithm.

3.2 Work schedule (Arbeitsprogramm)

Overview

The project is split into the following work packages:
WP1. Development of a synergetic cloud screening algorithm
WP2. Development of a synergetic cloud - snow discrimination algorithm
WP3. Development of improved cloud and aerosol retrieval algorithms
WP4. Validation of the cloud and aerosol retrieval algorithms by comparison with independent satellite products

WP5. Improvement of NO_2 retrievals using aerosol and cloud information from previous work packages as input
WP6. Model-based validation of the cloud, aerosol, and trace-gas retrievals
WP7. Study of trends in aerosol, trace gas (NO_2) and cloud parameters (and also trace gas – aerosol – cloud interactions) at selected locations; estimation of radiative forcing by clouds and aerosols.
WP8. Publications and reports

The work packages of IUP and DLR/IPA are closely related. IUP needs the simulations from DLR/IPA as input for several work packages in order to develop and test the new retrieval methods. DLR/IPA, on the other hand requires the expertise of IUP to apply the trace gas retrievals. In the previous project (Kokhanovsky et al., 2006a, 2007a, b), the close collaboration between both institutes has proven to be very fruitful.

The following milestones are introduced to monitor the progress in the work schedule:
M1. The cloud screening algorithm is developed and validated
M2. The cloud – snow discrimination algorithm is developed and validated
M3. The modified versions of SACURA and BAER are developed
M4. The modified versions of SACURA and BAER are validated
M5. The improved NO_2 retrieval using aerosol and cloud information is developed
M6. The tests of operational run of SACURA using combined SCIAMACHY, MERIS and AATSR data are performed
M7. The fast Monte-Carlo model for NO_2 retrieval simulations is developed
M8. The first combined SCIAMACHY/MERIS/AATSR observation is simulated
M9. Model-based validation of cloud, aerosol, and trace gas retrievals is finished
M10. Studies of changes in cloud and aerosols properties at several locations are accomplished
M11. Radiative forcing by clouds and aerosols is studied using the retrieval data
M12. Final report and publications

The schedule of the work is as follows:

- IUP: Milestones M1, M2 will be reached after 8 months. The same period of time is needed to reach milestones M3, M4. 8 months is needed to reach milestones M5, M6 and one year is requested to reach milestones M10, M11, M12.
- IPA: Milestones M7, M8, M9 are part of a PhD student work at DLR/IPA and will be accomplished within three years.

Detailed work schedule

The unified aerosol-cloud-trace gas retrieval algorithm is to be developed in WP 1-5. WP6 is aimed at the validation of the algorithm. WP7 is aimed at the operational application of the algorithms and studies of long-term trends of aerosol, trace gas, and cloud properties at selected locations.

WP1, Cloud screening

The cloud screening algorithm must be capable to distinguish satellite pixels into several classes such as "clear", "cloudy", and "partly cloudy with the derivation of the cloud fraction". This will be done using threshold techniques for ultraviolet and visible reflectances, reflectance in the oxygen A-band absorption band, SCIAMACHY PMD measurements, spectral reflectances measured by MERIS, and AATSR thermal measurements. In particular, the following thresholds for MERIS reflectances R will be used to identify clear pixels (Kokhanovsky et al., 2008a):

- $R(412nm)/R\left(443nm\right)\geq\alpha$, where $\alpha=1.2$ over ocean and $\alpha=1.1$ over land
- $\dfrac{3R\left(754nm\right)}{R(412nm)+R(560nm)+R(754nm)}\geq 1.15$,
- $R(412nm)<0.2$.

The difference between the reflectances at 412 and 443 nm is mostly due to Rayleigh scattering. This difference is large for a clear sky. The differences are less pronounced for a cloudy sky. The second and third criteria reflect the well known fact that clouds are highly reflective white objects. The validation of cloud screening procedures will be performed by the comparison of the retrieved cloud fraction in the SCIMACHY scene with correspondent MERIS browse images and spatial distributions of reflectivity. The inter-comparison of the results with those obtained by optical instruments onboard other satellites such as Aqua, Terra, Meteosat, and CloudSat will be carried out as well. Obviously, this will be not always possible due to cloud movements. However, such comparisons can be used to identify false cloud retrievals for clear sky cases and also false clear sky retrievals for overact situations. An independent validation will be provided by the model-based approach, WP6.

WP2, Snow-cloud discrimination algorithm

The visible reflectance of snow is close to that of thick clouds. Therefore, if snow areas are not screened properly, wrong results for cloud retrievals will be obtained. One needs to distinguish snow and cloud fields for an accurate trace gas retrieval. Several thresholds to identify snow will be incorporated in the retrieval algorithm. They will include:

- thresholds based on the ratio of reflectances inside and just outside of the oxygen A-band (for clouds shallow absorption A-band spectra are observed in reflected light; this is not a case for a clear sky over snow);
- near IR reflectance, which is considerably lower for snow as compared to cloud (Kokhanovsky and Schreier, 2008);

- thermal channels thresholds (e.g., 3.7 μm , see Fig.5);
- SCIAMACHY polarization measurement devices analysis (ratio of signals in near IR and the visible);
- spatial homogeneity tests (spatial distribution of reflectivity is different for snow and clouds).

Pixels identified as snow will be used to derive the snow albedo (Kokhanovsky and Zege, 2004; Kokhanovsky and Schreier, 2008) needed for trace gas retrievals.

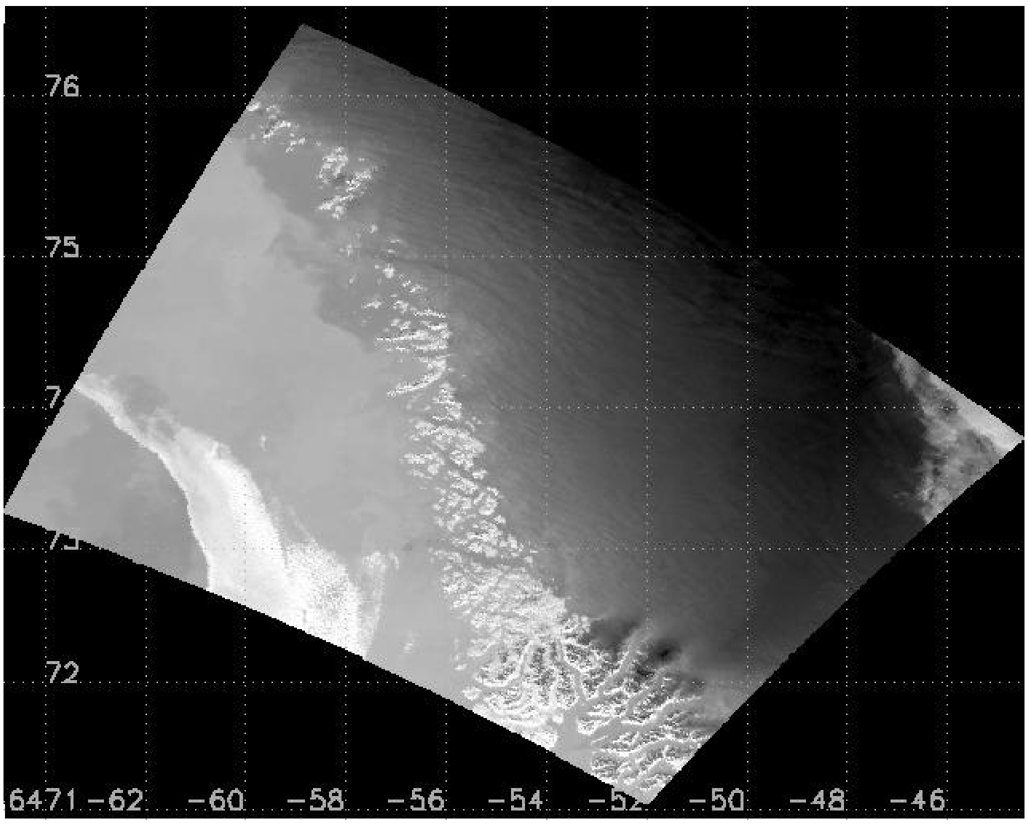

Figure 5: The spatial distribution of 3.7 μm AATSR reflectance over the western coast of Greenland. The cloud over snow in the right corner of the picture is clearly seen. The same cloud is not observed in the corresponding visible imagery (Kokhanovsky and Schreier, 2008).

The validation of snow screening procedures will be performed using comparisons with other instruments (e.g., Meteosat, CALIPSO on CloudSat) combined with measurements in some test areas where permanent snow exists (e.g., Greenland). Due to movements of clouds, CALIPSO can be used only for the case of a clear sky or for a completely overcast sky. This will enable us to derive the probability of false alarm (the detection of a cloud – although there was no cloud at the moment of the measurements).

WP3, The development of the improved cloud retrieval algorithm SACURA and BAER

SACURA retrieves cloud optical thickness, cloud top altitude, and water droplet or ice particle sizes for overcast cloud systems using visible and near IR measurements. During this work it is intended to extend SACURA for the case of optically thin clouds using a look-up-table approach. In addition, SACURA will be improved to account for arbitrary absorption of radiation by atmospheric air with inclusions of various absorbing particles (e.g., soot and large snow crystals) following results described by Kokhanovsky and Nauss (2006). At present, SACURA is only valid for the case of small absorption with probabilities of light absorption by an elementary cloud volume no larger than 2%.

Retrievals using combined AATSR, MERIS, and SCIAMACHY data (Kokhanovsky et al., 2008a, b) will be performed at European Space Agency (ESA) facilities in Frascati (Italy) (at the place where all data are stored), installing SACURA on the ESA server. By these means, the transfer of huge satellite databases to our computers at IUP becomes unnecessary. Only results of retrievals will be taken by us from ESA computing facilities. This will be one of the first employment of a new computing option proposed to users by ESA. ESA has already selected our proposal for the determination of MERIS cloud fraction in SCIMACHY pixels and corresponding work has been commenced (see http://eogrid.esrin.esa.int/index.asp). ESA did not provide any funds to us to carry out the work. It is planned that the funds will be available from other international or national sources.

BAER will be improved to process the information contained in the SCIAMACHY top-of-atmosphere reflectance in the O_2 A-band. Furthermore, the absorption band of O_2 - O_2 (Pfeilsticker et al., 1997; Acarreta et al., 2004) as seen in the SCIAMACHY reflectance spectra will be investigated. This will enable retrievals of the aerosol height and aerosol vertical structure (Timofeyev et al., 1995; Rozanov and Kokhanovsky, 2004; Corradini and Cervino, 2006; Kokhanovsky and Rozanov, 2008). To achieve this, BAER look-up-tables will be improved and extended.

WP4, The validation of SACURA and BAER products

The modified SACURA retrieval products will include:

- cloud fraction;
- cloud optical thickness;
- cloud albedo;
- cloud thermodynamic state;
- effective size of water droplets or ice particles;
- cloud top height;
- cloud bottom height;
- snow fraction and grain size.

The validation of retrievals is planned with the use of data from ENVISAT validation campaigns and also by analysing data from other orbiting instruments (e.g., MODIS, CALIPSO). We also plan to use a number of ground based stations such as the facilities at ARM SGP (USA) site (36.6N-97.5W) and the radar at Chilbolton (UK) (51.15N-1.43W). In addition, model-based validation of SACURA products will be performed as explained in WP6. BAER aerosol retrieval products will be evaluated using ground-based AERONET measurements and with the help of the model-based validation described in WP6.

WP5, The improvement of satellite retrievals of nitrogen dioxide vertical columns

Derived aerosol and cloud properties will be used for test cases to improve the retrieval of tropospheric NO_2 from measurements of the SCIAMACHY instrument. Three different scenarios will be studied: an urban situation, a biomass-burning situation and a background aerosol situation. The focus will be on quantifying the impact of aerosols and clouds on the retrieval and on studying the potential improvement by using the retrieved aerosol properties in the trace gas retrieval.

For the urban aerosol tests, the NO_2 time series above China will be investigated as over this area. Significant changes in aerosol loading and aerosol type are expected over the ENVISAT measurement period. It therefore is an excellent test case for the investigation of the impact of improved aerosol correction schemes, e.g., on trend assessments as presented in Richter et al. (2005). For the biomass burning test case, data over Africa will be selected, where NO_2 signals from soil emissions, lightning, and biomass burning can be observed depending on season and region. If possible, at least part of the data will be selected to be coincident with in-situ measurements performed during the AMMA campaigns (see, e.g., https://www.amma-eu.org/). This could provide some validation for both NO_2 and aerosol properties.

Validation of tropospheric NO_2 retrievals is still difficult due to the lack of appropriate reference data sets. However, in the current European project GEOMON (http://geomon.ipsl.jussieu.fr/), data sets of tropospheric NO_2 columns will be created both at permanent stations and on campaign basis. It is planned to use these data for a first validation of the improved NO_2 satellite products. In addition, the model–based validation approach as described in WP6 will used.

WP6, Model-based validation of the cloud, aerosol, and trace-gas retrievals

The MYSTIC Monte Carlo code will be improved to make extended simulations of SCIAMACHY, MERIS, and AATSR observations feasible. For this purpose, a new path length probability distribution technique will be developed taking advantage of the slow spectral variation of Rayleigh, cloud, and aerosol scattering and extinction, where the NO_2 absorption cross section varies rapidly. The algorithm will be able to account for different NO_2 profiles with one-and-the-same Monte Carlo run. In combination with the backward photon tracing technique, nearly arbitrarily large input data sets can be used in the simulation. A carefully selected, spatially consistent set of input data sets (including water and ice clouds, aerosols, and trace gases) will be prepared to test the hypotheses and retrievals developed in this project, in particular the synergetic cloud screening and retrieval algorithms as well as the aerosol and trace gas retrievals. Satellite radiances will be simulated with MYSTIC, including those spectral ranges and channels of SCIAMACHY, MERIS, and AATSR (see table 1) required for the different retrieval techniques. Finally, the new retrieval techniques will be tested with the artificial satellite observations; conclusions will be drawn on the accuracy of the products and recommendations for improvements will be given. WP6 will provide a unique new source of data for the development and testing of trace gas retrieval algorithms (WP7).

WP7, Application of the improved algorithm operationally

BAER and SACURA will be applied operationally for AATSR, MERIS, and SCIAMACHY data at ESA facilities (Frascati, Italy) and also at IUP and at Marburg University. Retrieved data will be analysed using statistical methods with respect to understanding the global aerosol/cloud distributions and aerosol-cloud interactions. In particular, average values of aerosol and cloud products on monthly and yearly basis for all available data will be derived. Furthermore, correspondent standard deviations and other statistical characteristics will be studied. Radiative forcing due to aerosols and clouds for selected regions will be investigated using radiative transfer calculations. The work in this field has already been started (Schreier et al., 2006, 2007). The areas of particular interest for this project are those with high anthropogenic pollution loads. This includes the densely populated areas of China, India, Mexico, and Europe (e.g., London, Moscow, Munich), where both aerosol and trace gas concentrations are well above background values.

WP8, Publications and reports

The results of the project will be summarized in a final report and will be published in peer-reviewed scientific journals and presented at international conferences. Also three intermediate reports will be prepared during the first two years of the project (see the time schedule of the project given in Table 2).

Table 2. Time schedule of the project.

Months	1-8	9-16	17-24	25-36	Comments
WP1	x				cloud screening (IUP)
WP2	x				snow - cloud discrimination (IUP)
WP3		x			SACURA/BAER improvements (IUP)
WP4		x			validation (IUP)
WP5			x		NO_2 retrieval (IUP)
WP6	x	x	x	x	model-based validation (IPA)
WP7				x	retrievals and analysis (IUP)
WP8	x	x	x	x	reports (IUP/IPA)

3.3 Experiments with humans (Untersuchungen am Menschen)

None.

3.4 Experiments with animals (Tierversuche)

None.

3.5 Experiments with recombinant DNA (Gentechnologische Experimente)

None.

4. Funds requested (Beantragte Mittel)

The collaboration between IUP and IPA has proven to be extremely fruitful in a previous project funded by DFG (BU 688 and MA2548), as documented in a variety of publications (see, e.g., Kokhanovsky et al., 2007a,b) and also in the report to DFG (Kokhanovsky et al., 2006a). Contributions from both institutes are required to make the project successful: IPA has the expertise in the area of radiative transfer in inhomogeneous clouds and cloud physics while IUP has the expertise on cloud, aerosol, and trace gas remote sensing with SCIAMACHY, GOME, AATSR, MERIS and MODIS.

4.1 Staff (Personalbedarf)

1 Postdoc position for 3 years (Bat 1a) at IUP

The Postdoc will work within WP1-5 and 7,8. It is planned that Dr. M. Schreier will take this position.

1 Postdoc für 3 Jahre (Bat 1a) bei IUP

Der Postdoc ist verantwortlich für die Arbeitspakete WP 1-5 und 7, 8. Es ist geplant, dass Dr. Mathias Schreier diese Position einnimmt.

1PhD student position for 3 years (1/2 Bat 2a) at DLR/IPA

The topic of the PhD thesis will be the model-based validation of cloud, aerosol, and trace gas retrievals with SCIAMACHY, AATSR, and MERIS, as described in WP6. The proposed work, in particular the generation of extended cloud scenes is a demanding task, which will certainly require much more resources than requested from DFG. The DLR/IPA request to DFG is kept as small as possible, in the realistic knowledge that a larger request would be cut anyway by the reviewers. Should the DLR/IPA contribution be reduced further, a participation of DLR/IPA in the proposed project is neither meaningful nor possible.

1 Doktorand für 3 Jahre (1/2 Bat 2a) bei DLR/IPA

Ziel der Doktorarbeit ist die Modell-basierte Validierung der neuen Wolken-, Aerosol-, und Spurengasretrievalverfahren aus SCIAMACHY, AATSR und MERIS, wie in Arbeitspaket WP6 beschrieben. Die Verwirklichung dieses Arbeitspaketes ist sehr aufwendig und nur mit beträchtlicher personeller und instrumenteller Eigenleistung von DLR/IPA möglich. Der Antrag von DLR/IPA wurde auf ein absolutes Minimum von einer Doktorandenstelle begrenzt, in dem

Wissen, dass höhere Forderungen sowieso gekürzt würden. Bei einer weiteren Kürzung wäre die Teilnahme von DLR/IPA weder möglich noch sinnvoll.

4.2 Scientific equipment (Wissenschaftliche Geräte)

None.

4.3 Consumables (Verbrauchsmaterial)

IUP: Media for data storage	*100.- €*
IUP: Poster printouts	*100.- €*
IUP: Publication charges	*1800.- €*
IUP: Special literature	*1000.- €*
IUP: Presentation software	*1000.- €*
total 4.3	*4000.- €*

4.4 Travel expenses (Reisen)

IUP: International conferences	*5000.- €*
IUP: National conferences	*3000. - €*
DLR/IPA: Conferences and project meetings	*4500.- €*
total 4.4	*12500.- €*

1 national conference, 1 international conference per year.

4.5 Other costs (Sonstige Kosten)

None.

5. Preconditions for carrying out the project (Voraussetzungen für die Durchführung des Vorhabens)

5.1 Your team (Zusammensetzung der Arbeitsgruppe)

The following people will contribute to the project without being paid for by the DFG:

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Prof. J. P. Burrows will be the overall manager of the Project.

5.2 Co-operation with other scientists (Zusammenarbeit mit anderen Wissenschaftlern)

Close cooperation with colleagues from other groups involved in radiative transfer modelling, retrieval development, cloud physics and other topics will contribute significantly to the success of the proposed project. In particular, we will cooperate with the Department of Geography of Marburg University (Dr. T. Nauss) for the development of an operational cloud retrieval algorithm.

5.3 Foreign contacts and co-operations (Arbeiten im Ausland und Kooperation mit ausländischen Partnern)

IUP and DLR/IPA are in close collaboration with scientists from many foreign countries. Of particular concern for the proposed project is the collaboration with the NASA MODIS team. Recently two IPA scientists (Dr. Tobias Zinner, funded by a DFG Research Fellowship; Dr. Luca Bugliaro, funded by DLR) were visiting NASA Goddard Space Flight Center for one year and three months, respectively, to improve this collaboration. Also the cooperation with the Institute of Physics of National Academy of Sciences of Belarus (Dr. E. P. Zege) is planned with respect to the development of the snow screening and snow retrieval algorithm. We will also collaborate with Dr. O. Colin (ESA, Frascati, Italy) with respect to the synergetic MERIS-SCIAMACHY cloud screening algorithm development and operational processing (in the framework of currently running G-POD IUP-ESA Project (http://gpod.eo.esa.int/)).

5.4 Scientific equipment available (Apparative Ausstattung)

The cloud retrievals are computationally very expensive. They will be performed using available hardware at IUP and DLR, paid for by IUP/Bremen University and DLR basic funding and using correspondent computing facilities at ESA (Frascati, Italy) where all data are located. The correspondent proposal has been approved by ESA. ESA has selected 10 pilot satellite remote sensing projects in total, provided that these projects are funded using independent resources (see, e.g., http://eopi.esa.int/G-POD). The funding from DFG is crucial for the possibility to carry out our initiative with respect to the synergetic use of 10 years of MERIS-ATTSR-SCIAMACHY data. One- and three-dimensional radiative transfer calculations will be done on a 32-processor Linux cluster available at DLR/IPA.

5.5 Your institution's general contribution (Laufende Mittel für Sachausgaben)

The computing costs will be covered by IUP basic funding. Simulations for the model-based validation will be covered by DLR basic funding and in addition in the framework of a special project at ECMWF “Remote Sensing of Water and Ice Clouds with Meteosat Second Generation”.

5.6 Other requirements (Sonstige Voraussetzungen)

None.

6. Exploitation of research findings (Wirtschaftliche Verwertung)

The results of this project are purely scientific. A commercial exploitation is therefore not to be expected.

7. Declarations (Erklärungen)

A request for funding this project has not been submitted to any other addressee. In case we submit such a request we will inform the Deutsche Forschungsgemeinschaft immediately.

7.2 If you belong to a university who is member of the DFG you should inform the Vertrauens-dozent of your university about this application and mention this here.

8. Signature(s) (Unterschrift(en))

Prof. Dr. J. P. Burrows

Dr. B. Mayer

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10. List of appendages (Verzeichnis der Anlagen)

- **Appendix 1. Abbreviations (Abkürzungen)**
- **Appendix 2. Curriculum vitae of applicants (Lebensläufe der Antragsteller)**

Appendix 1. Abbreviations and Definitions (Erklärungen und Abkürzungen)

AATSR	Advanced Along Track Scanning Radiometer
BAER	Bremen AErosol Retrieval
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DWD	Deutscher Wetterdienst (German Weather Service)
ECMWF	European Center for Medium range Weather Forecasting
ENVISAT	ENVIronmental SATellite of the European Space Agency
ESA	European Space Agency
GOME	Global Ozone Monitoring Experiment
IFE	Institut für Fernerkundung
IPA	Institut für Physik der Atmosphäre, DLR (Institute of Atmospheric Physics)
IUP	Institut für Umweltphysik
LM	Lokalmodell des DWD (Local Model)
MERIS	MEdium Resolution Imaging Spectrometer
MODIS	MODerate resolution Imaging Spectroradiometer
MSG	METEOSAT Second Generation
MYSTIC	3D Monte Carlo code for the phYSically correct Tracing of photons In Cloudy atmospheres
NASA	NAtional Space Administration
NWP	Numerical Weather Prediction
OMI	Ozone Monitoring Instrument
PMD	Polarization Measurement Device
SCIAMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CHartograpHY
SCIATRAN	SCIAmachy radiative TRANsfer simulator
SACURA	Semi-Analytical CloUd Retrieval Algorithm

Appendix 2. Curriculum vitae of applicants (Lebensläufe der Antragsteller)

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Relevant experience/expertise:

Professor John Burrows has been active in research since 1975. His area of special expertise is the study of atmospheric physical and chemical processes using laboratory, in situ and remote sensing measurements. Professor Burrows has published approximately 250 scientific papers on these subjects. He is founder and Principle Investigator/Lead scientist of the Global Ozone Monitoring Experiment (GOME) and SCanning Imaging Absorption spectroMeter for Atmospheric ChartograpHY (SCIAMACHY). GOME has been successfully making measurements since its launch in April 1995 on the ESA ERS-2. SCIAMACHY has begun its mission in spring 2002 as part of the ESA ENVISAT payload.

Relevant publications:

Burrows, J. P., M. Weber, M. Buchwitz, V. V. Rozanov, A. Ladstätter, Weißenmayer, A. Richter, R. DeBeek, R. Hoogen, K. Bramstedt, K.U. Eichmann, 1999: The Global Ozone Monitoring Experiment (GOME): mission concept and first scientific results, *J. Atmos. Sci.,* 56, 151-175.

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Richter, A., J. P. Burrows, H. Nüss, C. Granier, U. Niemeier, 2005: Increase in tropospheric nitrogen dioxide over China observed from space, *Nature*, 437, 129-132.

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Relevant experience/expertise:

Dr. Bernhard Mayer has been active in radiative transfer and remote sensing since 1993. He got his PhD in 1996 on "Measurement and Modeling of Ultraviolet Radiation in Garmisch-Partenkirchen" at the Fraunhofer-Institute of Atmospheric Environmental Research (IFU) and the Technical University of Ilmenau, Germany. After a two-years Postdoc at NCAR, Boulder, Colorado, he joined the Institute of Atmospheric Physics (IPA) of DLR Oberpfaffenhofen where he heads the department for Atmospheric Remote Sensing since 2003. Dr. Mayer developed the freely available libRadtran radiative transfer package together with Arve Kylling, Norway. His main research interests include three-dimensional radiative transfer in the cloudy atmosphere and remote sensing of water and ice clouds. Dr. Mayer is a member of the International Radiation Commission (IRC).

Relevant publications:

Mayer, B. I3RC phase 1/2 results from the MYSTIC Monte Carlo model, 2000: In *Intercomparison of three-dimensional radiation codes: Abstracts of the first and second international workshops*. University of Arizona Press, ISBN 0-9709609-0-5.

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Zinner, T. and B. Mayer, 2006: Remote sensing of stratocumulus clouds: Uncertainty and biases due to inhomogeneity. *J. Geophys. Res.*, 111, doi:10.1029/2005JD006955.

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Relevant experience/expertise:

Dr. Andreas Richter has graduated in physics at the Ludwig Maximilians Universität in Munich in 1991. He received his PhD in 1997 at the University of Bremen where he has been working as a research scientist ever since. His research interest is the remote sensing of trace gas concentrations in the UV/visible spectral range using ground-based, air-borne and satellite platforms. He is strongly involved in the calibration, validation and retrieval algorithm development for the satellite instruments GOME and SCIAMACHY, and currently leading the DOAS group at the Institute of Environmental Physics, University of Bremen. Dr. Richter has published more than 60 papers in peer-reviewed journals and participated in 8 EU and 1 ESA projects over the last 5 years.

Relevant Publications:

Richter, A., F. Wittrock, M. Weber, S. Beirle, S. Kühl, U. Platt, T. Wagner, W. Wilms-Grabe, and J. P. Burrows, 2005: GOME observations of stratospheric trace gas distributions during the splitting vortex event in the Antarctic winter 2002 Part I: Measurements, *J. Atmos. Sci.*, 62 , 778-785.

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Relevant experience/expertise:
From 1973 till 1991 Dr. Rozanov has been working as a research scientist at the Department of Atmospheric Physics at the St. Petersburg University (St. Petersburg, Russia). Dr. Rozanov held a position as research scientist at Max-Planck Institute of Chemistry (Mainz, Germany) in 1990-1991. He has been holding a senior research scientist position at the University of Bremen since 1992. Main areas of interest include gas/aerosol/cloud remote sensing from orbiting optical instruments, radiative transfer, and light scattering. In cooperation with the SCIAMACHY algorithm development team, he has developed the semi-analytical cloud retrieval algorithm SACURA.

Relevant publications:
Rozanov, V.V., D. Diebel, R.J.D. Spurr, J.P. Burrows, 1997: GOMETRAN: A radiative transfer model for the satellite project GOME - the plane-parallel version, *J. Geophys. Res*., 102 (D14), 16683-16695.
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Dr. von Hoyningen-Huene has been working as a research scientist at the Institute of Meteorology (Leipzig University) from 1971 till 1997. He has been holding a senior research scientist position at University of Bremen since 1998. Main areas of interest include aerosol/cloud remote sensing from orbiting optical instruments, radiative transfer, light scattering and experimental ground-based atmospheric optical measurements. He has developed the aerosol retrieval algorithm BAER for multispectral nadir scanning instruments (e.g., MERIS, MODIS, SCIAMACHY). BAER has been implemented by ESA for atmospheric correction of land surface spectra measured by MERIS.

Relevant Publications:

von Hoyningen-Huene, W., P. Posse, 1997: Nonsphericity of aerosol particles and their contribution to radiative forcing **,** *J. of Quant. Spectr. and Rad. Transfer,* 57, 651-668.

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Mathias Schreier graduated in meteorology at the Ludwig Maximilians Universität in Munich in 2003, where he was working as student assistant and research scientist in the topic of measurement of aerosol and UV-radiation. He finished his PhD in November 2007 at the University of Bremen, where he is working as a research scientist at the moment. His research interest is remote sensing of clouds and the anthropogenic influence on clouds, known as indirect aerosol-effect, especially in the field of ship emissions. He is involved in the Project SeaKLIM, a cooperation of the Institute of Environmental Physics, University of Bremen, and the Institute of Atmospheric Physics (IPA) of DLR Oberpfaffenhofen.

Relevant Publications:

Schreier, M. A. A. Kokhanovsky, V. Eyring, L. Bugiaro, H. Mannstein, B. Mayer, H. Bovensmann, and J. P. Burrows, 2006: Impact of Ship Emissions on Microphysical, Optical and Radiative Properties of Marine Stratus: A Case Study, *Atmos. Chem.and Phys.,* 6, 4925-4942.

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