Applications of SCIATRAN radiative transfer modelling in ocean-atmosphere systems including inelastic scattering processes

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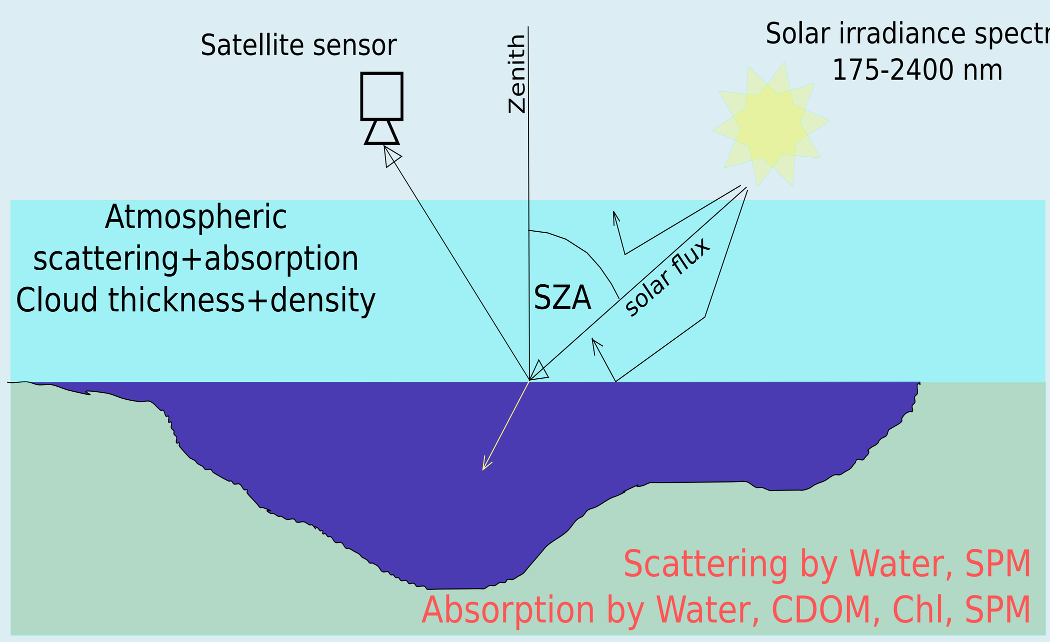
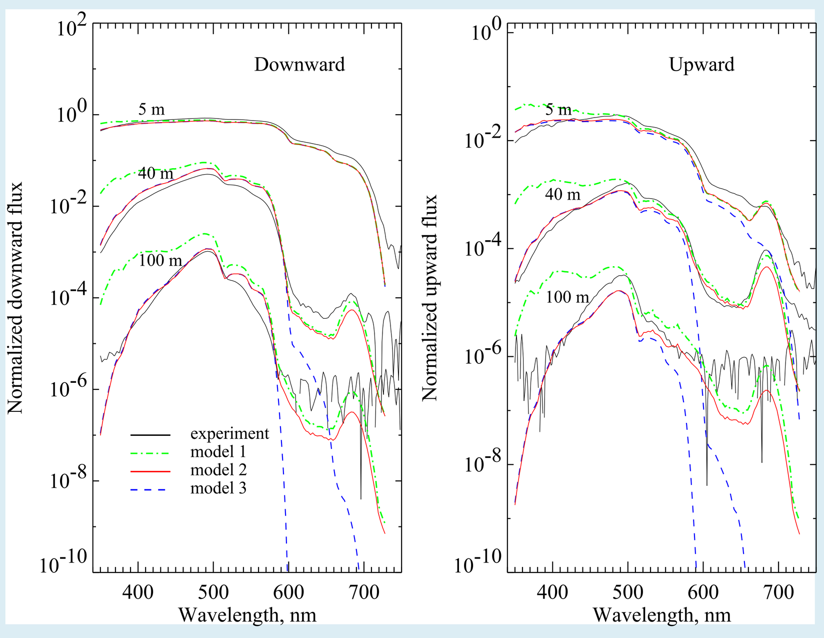
The radiative transfer model SCIATRAN

Radiative Transfer Model SCIATRAN:
The Radiative Transfer Model (RTM) SCIATRAN provides calculations of radiation between 175 to 2400 nm [Rozanov et al. 2002]. Recently the model is extended for a coupled atmosphere-ocean system to include calculations of the light field inside the ocean body with constituents [Rozanov et al. 2014]. All optical relevant parameters can be considered (absorption, elastic and inelastic scattering). Three different forms of inelastic scattering as transpectral processes of oceanic waters are included in the model: Vibrational-Raman-Scattering, fluorescence of chl-a and CDOM.
The SCIATRAN software package along with a detailed User's Guide is freely available for scientists affiliated at public scientific facilities and students via the webpage of the Institute of Environmental Physics (IUP), University of Bremen: http://www.iup.physik.uni-bremen.

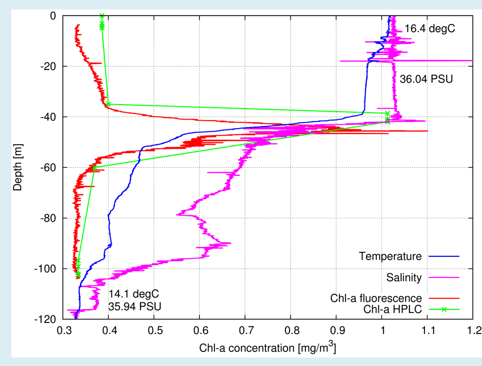


Modelling, comparisons and results

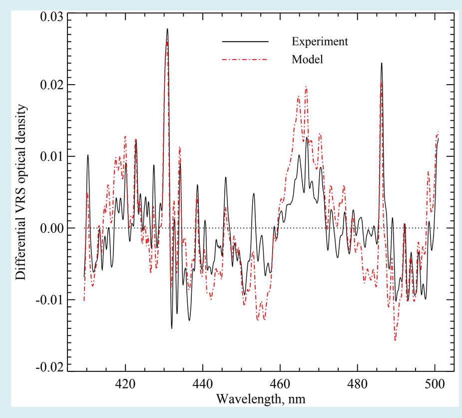
Comparison of SCIATRAN with in-situ radiation and VRS measurments



Comparison of measured and modeled spectral distribution of the down- and upwelling underwater normalized fluxes at three selected depths: "model 1" -simulations including VRS, CDOM and chl-a fluorescence. "model 2" - simulations as in "model 1" with two and a half times larger concentration of fulvic and humic acid; "model3" - simulations as in "model 2" but excluding all inelastic processes.

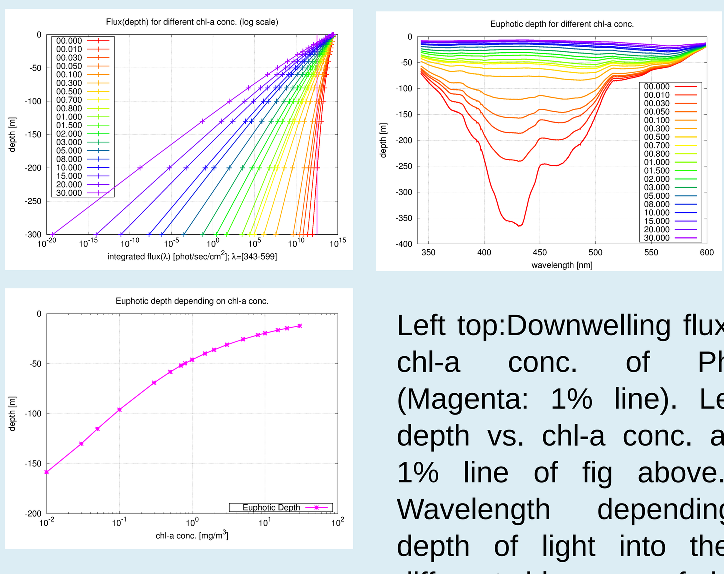


Settings: chl-a profile with maximum of 1.025 mg/m³ at 40m depth, measured on vessel campaign 15 May 2008 at 40.81N, 10.68W. Absorption is calculatet by CASE 1 water model [Morel&Maritorena, 2001]. SCIATRAN demonstrates the ability to reproduce realistic light field conditions in complex oceanic systems.



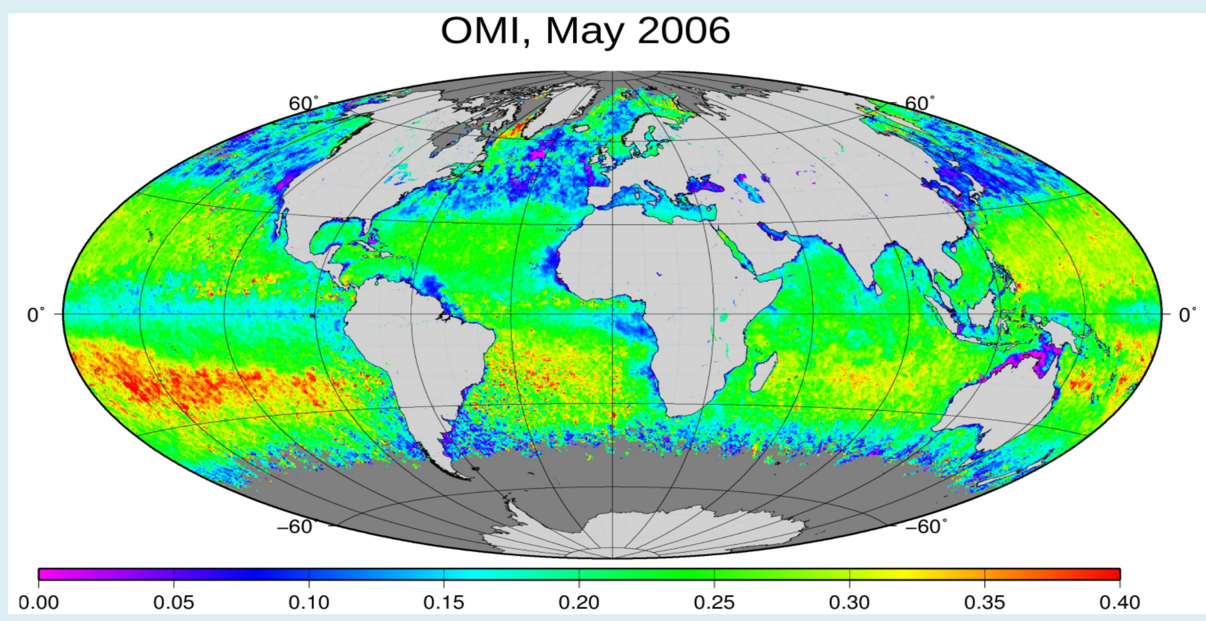
Experimental and modeled differential VRS spectra. Solid black line: Retrieved from MAX-DOAS measurements [51]. Dash-dotted red line: Calculated using SCIATRAN with the geometrical settings according to the ground-based measurements performed during the TransBrom campaign.

Investigations of underwater light fields with SCIATRAN in CASE I water



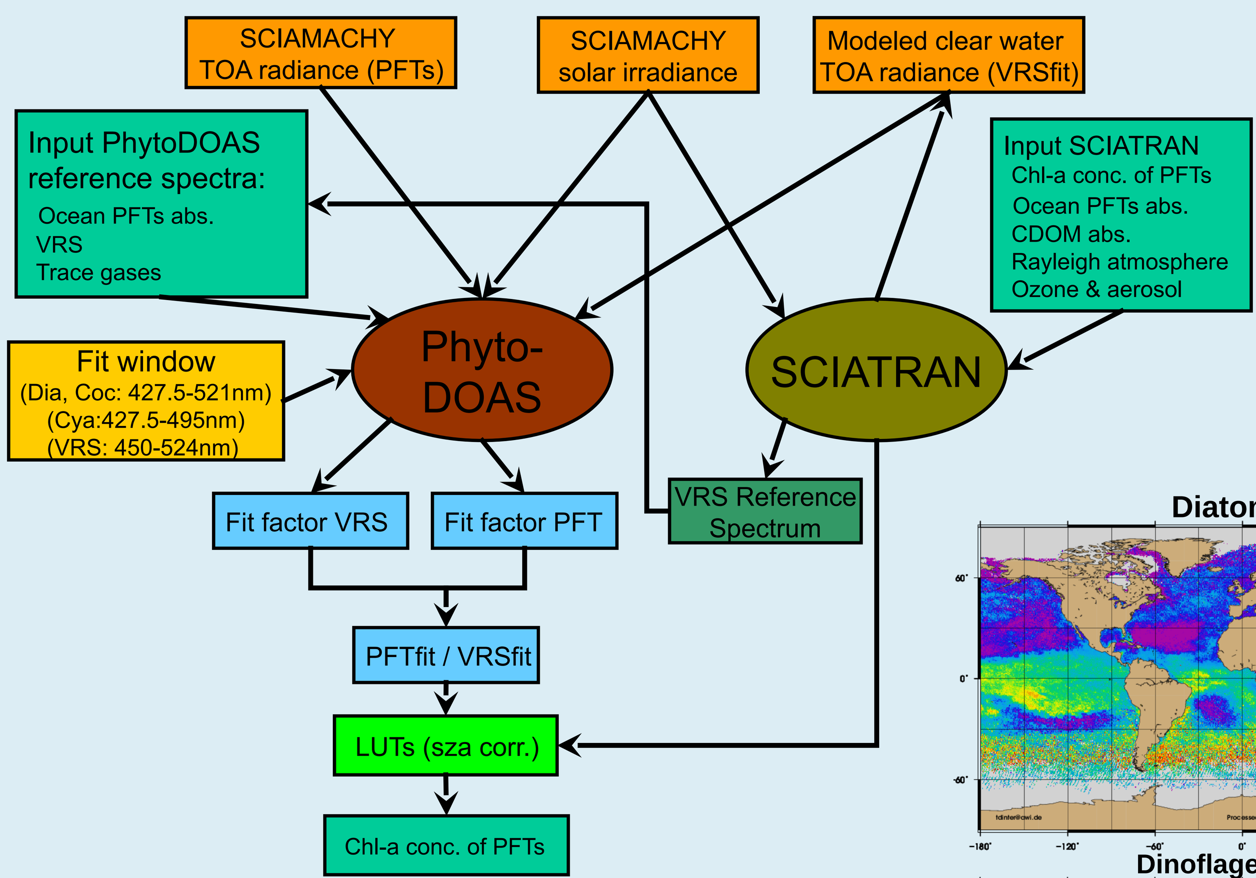
Left top:Downwelling flux for different chl-a conc. of Phytoplankton. (Magenta: 1% line). Left: Euphotic depth vs. chl-a conc. adapted from 1% line of fig above. Right top: Wavelength depending euphotic depth of light into the ocean for different chl-a conc. of phytoplankton.

VRS fit of OMI (Ozone Monitoring Instrument) data

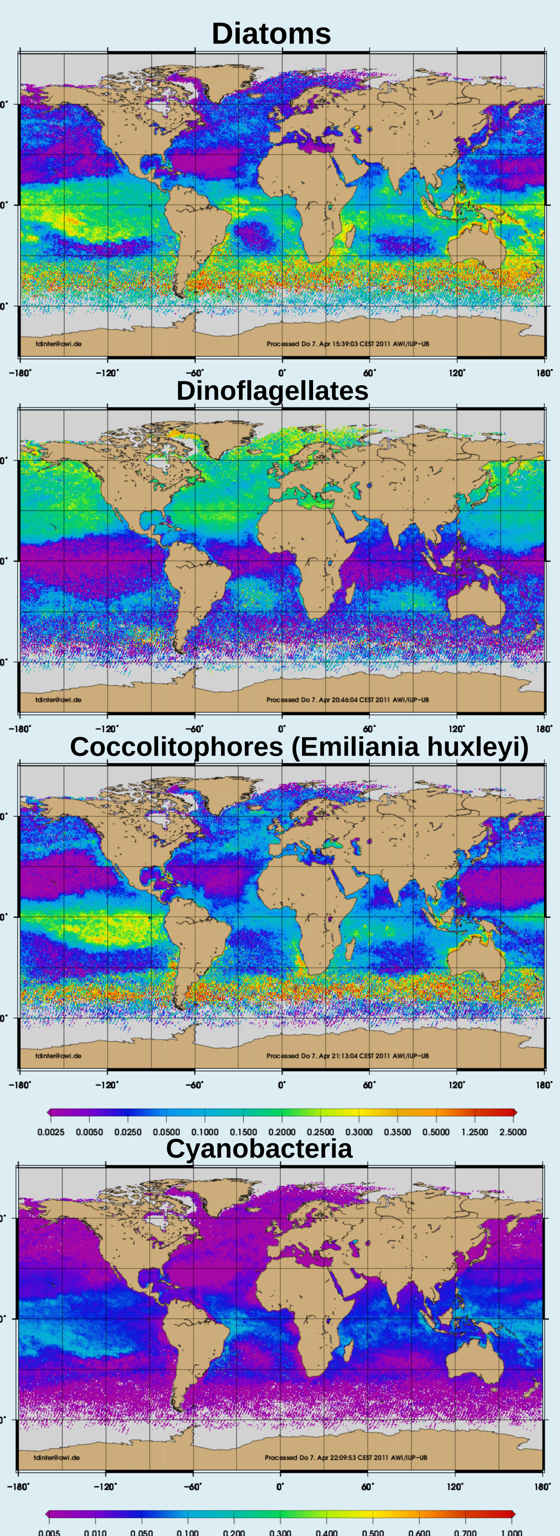


Monthly mean of a VRS pseudo-absorption reference spectrum which is calculated by SCIATRAN and fitted in a wavelength window of 446-497nm. Considered in the fit are also absorption of atmospheric trace gases, atmospheric Ring effect and a weighting-function for other oceanic parameters

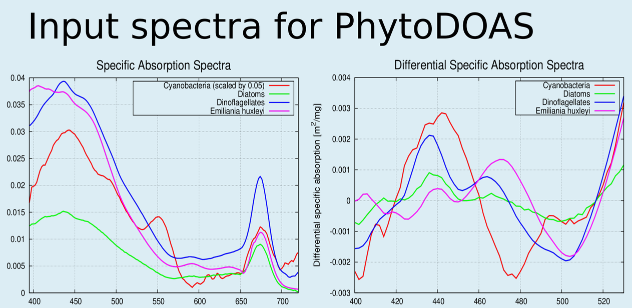
Applications I: PhytoDOAS



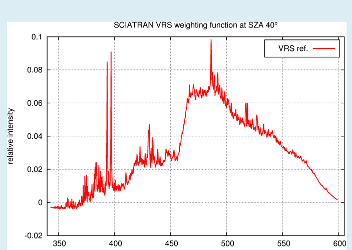
This Scheme shows the framework of the combined PhytoDOAS-SCIATRAN retrieval application. The satellite input data are the Top Of Atmosphere (TOA) radiance and solar irradiance. Further water absorption and specific absorption spectra from in-situ or laboratory PFT measurements. As first a Look-Up Table (LUT) is build up from modeled TOA radiance spectra leading to an definite relation of fitfactors and chl-a concentrations. This LUT is used afterwards to determine the real chl-a concentrations of the different PFTs from the simultinous fits of PFTs and the reference spectra of the Vibrational-Raman-Effect (VRS) which is used as a proxy of the euphotic depth.



Input spectra for PhytoDOAS



Left: Specific absorption spectra for four different PFTs from in-situ measurements. Right: Differential absorption spectra for four different PFTs.

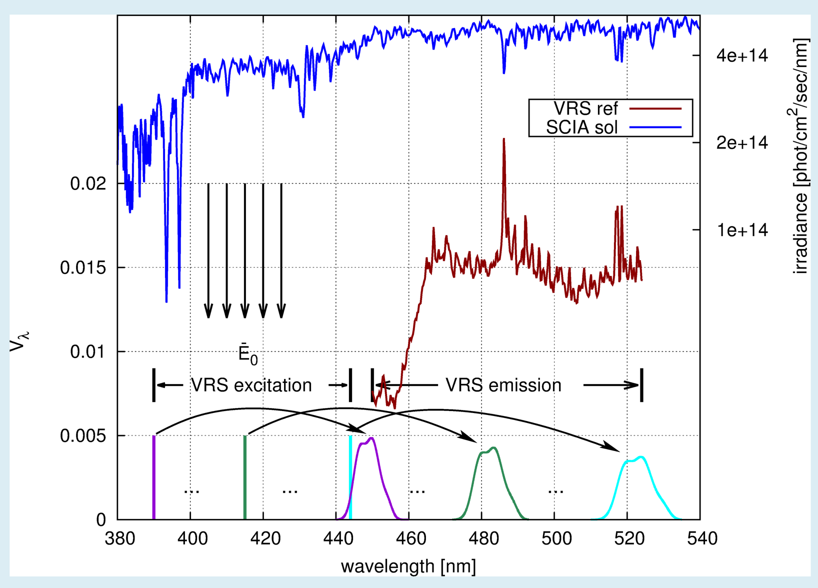


VRS weighting function as reference spectrum calculated with the formular above at 40° sza and a chl-a difference from 0.1 to 0.11mg/m^3 for a SCIAMACHY solar irradiance spectrum

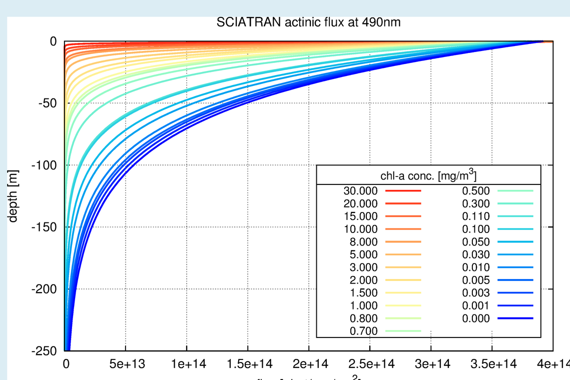
The figures show 3-month, seasonal global averages (April-June 2009) of four different PFTs (Phytoplankton Functional Types) diatoms, dinoflagellates, coccolithophores, and cyanobacteria biomass distribution in mg chl-a/m^3 determined with SCIAMACHY data processed with PhytoDOAS; 3-months, seasonal global averages April-June 2009 (which is shown as an example here). The grey color depicts areas, where no cloud-free SCIAMACHY data were available for further ocean colour evaluation or where the PhytoDOAS analysis of cloud-free SCIAMACHY data did not receive information on the distinct groups because they were not present in the surface waters. In the subtropical gyres hardly any diatoms and dinoflagellates are present. In the tropics diatom biomass shows large seasonal variation with higher values in Apr-Jun 2009. Cyanobacteria show at most places low concentrations, but contribute significantly to the biomass in the tropics and subtropics, especially in areas were the total chl-a is low. High concentrations of cyanobacteria are found in the open ocean Pacific areas around the equator.

Applications II: Vibrational Raman Scattering and light availability

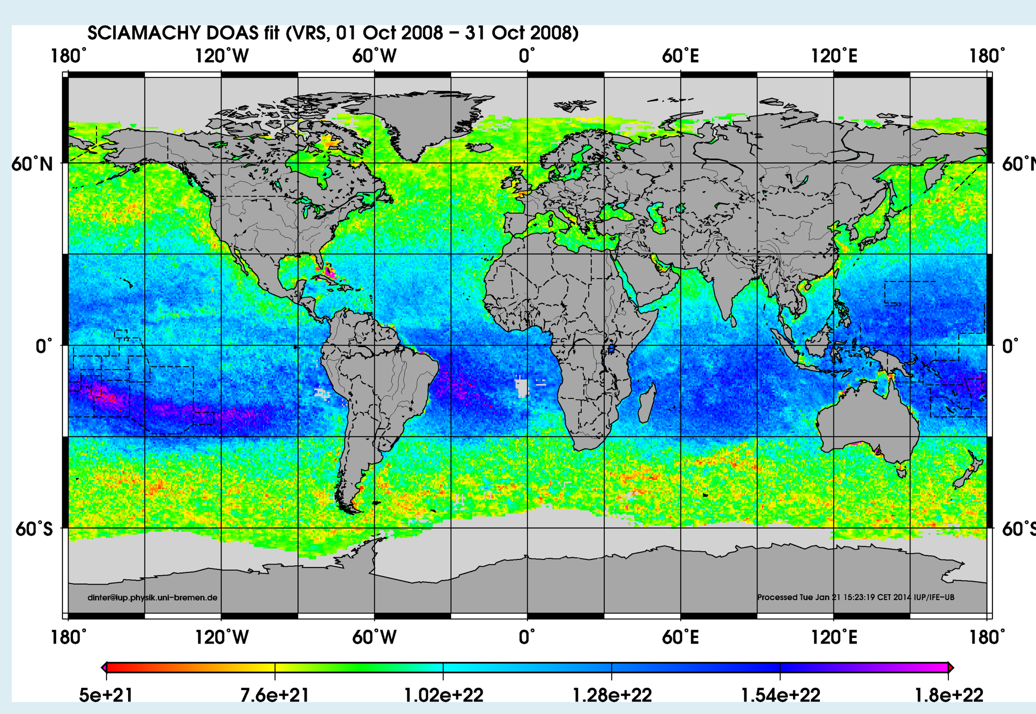
Blue: Extraterrestrial solar spectrum as measured by the satellite sensor SCIAMACHY.
Brown: Incoming radiation in the VRS excitation wavelength region (390-444.5nm) leads to a filling-in at the VRS emission region (450-524nm) calculated with the RTM SCIATRAN.
Magenta, green, cyan: Redistribution in the emission range for three specific excitation wavelengths.



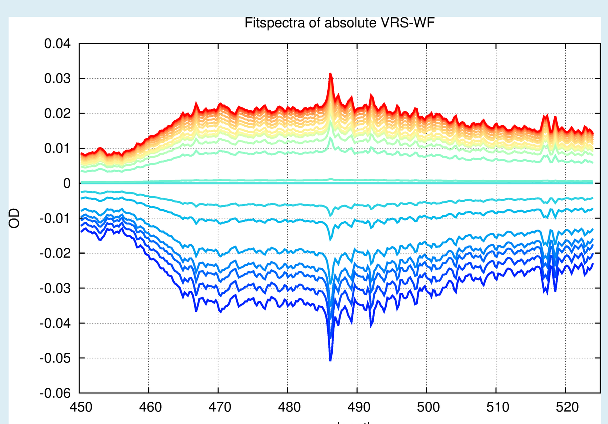
CASE I Water



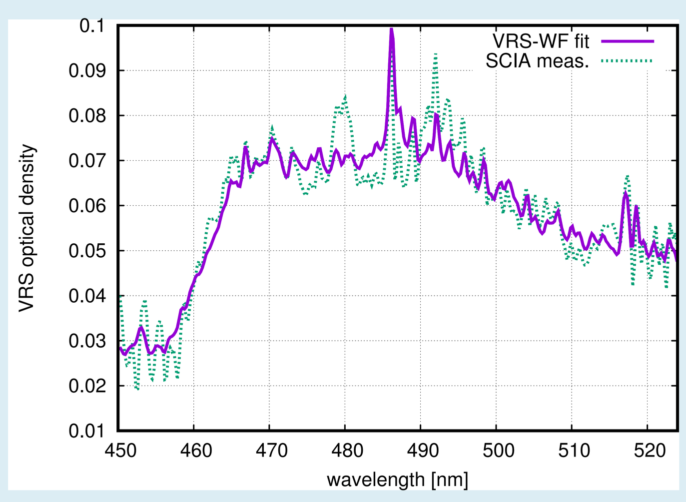
Modelled subsurface scalar irradiance depending on depth for different chl-a conc. at the wavelength of 490nm and a solar zenith angle of 40°.



Global map of the columnar scalar irradiance from DOAS VRS weighting function fits for the wavelength region of 390-444.5nm in units of [photons/sec/m] applying the LUT with including the solar zenith angle correction (see box below). Regions with high values coloured in blue/violet, correspond to well known large areas of oligotrophic waters.



Absolute spectral fit results (spectral optical density) of the VRS weighting function in the wavelength region of 450-523nm for 23 different chl-a concentrations.



Example of a VRS weighting function fit at a oligotrophic site over the South Pacific on the 23 October 2008. The solid line is the scaled VRS reference spectrum and the dashed line is the measuremend subtracted all considered parameters except VRS

References:
Bracher, A., Vountas, M., Dinter, T., Burrows, J.P., Röttgers, R., Peeken, I. (2009); "Quantitative observation of cyanobacteria and diatoms from space using PhytoDOAS on SCIAMACHY data" Biogeosc., Vol.6, pp.751-764
Vountas, M., Dinter, T., Bracher, A., Burrows, J.P., Sierk, B. (2007): "Spectral Studies of Ocean Water with Space-borne Sensor SCIAMACHY using DOAS ...", Ocean Sci., Vol.3, pp.429-440
V. Rozanov, M. Buchwitz, K.-U. Eichmann, R. de Beek, and J.P. Burrows (2002): "SCIATRAN - a new radiative transfer model for geophysical applications in the 240-2400nm ..." Adv. in Space Res., Vol 29, pp. 1831-1835
V.V. Rozanov, A.V. Rozanov, A.A. Kokhanovsky and J.P. Burrows (2014):"Radiative transfer through terrestial atmosphere and ocean: software package SCIATRAN", JQSRT, Vol 133, pp. 13-71
T. Dinter, V.V. Rozanov, J.P. Burrows, and A.Bracher (2013): "Retrieving the availability of light in the ocean utilising spectral sigatures of Vibrational Raman Scattering in hyper-spectral satellite measurements". OS, submitted

Acknowledgments:
We thank DLR and ESA for SCIAMACHY level-1 data. Funding has been supplied by the EU (project FRAM) and the Helmholtz Initiating and Networking Fund (Young Investigator Group Phytooptics), and the Alfred-Wegener-Institute.

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