Photoacclimation of phytoplankton in different biogeochemical provinces of the Southern Ocean and its significance for estimating primary production

Die Photoakklimatisierung von Phytoplankton in verschiedenen biogeochemischen Provinzen des Antarktischen Ozeans und ihre Bedeutung für die Abschätzung der Primärproduktion

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SUMMARY

The present thesis summarises the results from a series of publications where the production process of phytoplankton was studied in the Southern Ocean in order to assess its regional variability as defined by provinces and to provide basic data which can be used as bases for the estimation of productivity in the Southern Ocean. In Decembre to January 1995-96 during the German JGOFS cruise ANTXIII/2 various bioptical measurements, including the spectral composition of the underwater light field and phytoplankton absorption characteristics, and experiments on the relationship between photosynthesis and irradiance (P versus E curves) in the PAR and UV range were performed in the Atlantic sector of the Southern Ocean. These data were used to calculate primary production rates integrated over the water column for various stations; in addition, a diagnostic model was established to estimate synoptically the mesoscale distribution of primary production at the ambient region of the Antarctic Polar Front by using in addition to the P versus E relationships and absorbance characteristics obtained at certain points (stations) within the survey area, on-line chl *a* and underwater light data measured by sensors contained in a towed undulating vehicle. The composition of the phytoplankton communities was derived from HPLC data on pigment composition and from the distribution of the various size fractions on total chl *a*.

Phytoplankton composition and primary productivity in the study showed a regional distribution which was reflected in different biogeochemical provinces of the Southern Ocean: the Antarctic Polar Front (APF) with a diatom bloom and very high productivity (>1000 mg C m^{-2} d^{-1}), the interfrontal area between the APF and the marginal ice zone (MIZ) of the Antarctic Circumpolar Current (ACC) with scarce phytoplankton biomass, low primary productivity (<300 mg C m^{-2} d^{-1}), and the MIZ with a *Phaeocystis* bloom of large colonies and productivity values of 560 mg C m^{-2} d^{-1}. The observed phytoplankton blooms occured at sites of shallow upper mixed layers (UML; at least <50 m) and stratified water columns creating a light climate giving enough potential to result in high production and growth rates. Grazing by small-size-class zooplankton probably influenced size-fractionated distribution and species composition of phytoplankton within the two bloom sites. Only at the northern boundary of the APF silicate concentrations were nearly depleted and this fact probably limited phytoplankton (mainly diatom) growth. Low temperature and low iron availability might have

restricted growth of phytoplankton in the whole area, because the maximum biomass did not reach 2.5 mg chl *a* m^{-3}.

In addition, the thesis provides evidence that differences in biooptical characteristics coincide with the different biogeochemical provinces of the Southern Ocean, where the study was performed:

- Enhanced levels of UVR caused by stratospheric ozone depletion impaired primary production in the Southern Ocean more strongly outside of phytoplankton blooms than within. Within the phytoplankton blooms at the APF and the MIZ, dynamic photoinhibition as an photoprotective mechanism was governing the effect of UVR. Outside of the bloom, primary production decreased significantly and phytoplankton photosynthesis exhibited photodamage. Only inside both blooms shallow upper mixed layers (UMLs) caused an underwater light field, which induced MAA synthesis and repair mechanisms of PSII at a turnover rate sufficient to compensate negative effects of UVR. Although in all samples a significant amount of MAAs had been measured, outside the blooms efficient protection by MAAs would have been only achieved with an investment > 10% of the dry biomass due to the small size of the cells (diameter <20μm) which as a response to a single ecological factor this is regarded as waste of energy for the algal cell.
- Compared with other oceanic regions attenuation of light by non-algal material was low since in the Southern Ocean riverine input of terrestrially derived humic and dissolved material is very low. At a large scale the diffuse attenuation coefficient of underwater light, $k_d[\lambda]$, was correlated with changes of chl *a*. However, measurements of the spectral absorption by phytoplankton showed more subtle variations in the optical properties that are related to the phytoplankton population structure, which were missing in the bulk analyses to which the diffuse attenuation coefficient is subjected. Absorption by phytoplankton normalised to chl *a*, $a_\phi^*[\lambda]$, within the blooms was far lower than outside of the blooms, and decreased significantly below the upper mixed layer. The regional differences in absorption characteristics are due to differences in pigment composition and the package effect, which depends on phytoplankton cell size and photoacclimation in accordance to the UML.
- The comparison of *in situ* chl *a* to reflectance data of our survey, obtained from upwelling data measured *in situ*, showed that due to the low concentration of non algal material the global-processing-algorithm developed by Gordon et al. (1983) fails for

deriving chl *a* from remote sensing reflectance data in the Southern Ocean (mean difference 150% ± 84%); furthermore, the Southern-Ocean-algorithm developed by Mitchell and Holm-Hansen (1991a) fails too in calculating reasonable values of chl *a* (mean difference to *in situ* data 250% ± 150%) because the observed regional differences in $a_\phi^*[\lambda]$ result in different relationships between chl *a* and reflectance. In future, algorithms for deriving pigment concentrations from remote sensing reflectance data, should be even specific for the various biogeochemical provinces. Using different algorithms for the different provinces improved estimates by 50%.

This study showed that averaging chlorophyll and light attenuation values over depth, irradiance over the day and not spectrally weighting α, the slope of the P versus E curve, introduces severe errors in the calculation of primary production rates (mean difference 30-50% ± 10-40%). Hence, the spatial discontinuity in biooptical characteristics, recognised for conversion of reflectance data into chl *a*, has also to be considered when extrapolating *in situ* observations relevant for the estimation of primary production in space and time, to match satellite data.