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# Satellite-based Analysis of Clouds and Radiation Properties of Different Vegetation Types in the Brazilian Amazon Region

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**Abstract.** Land-use changes impact the energy balance of the Earth system, and feedbacks in the Earth system can dampen or amplify this perturbation. We analyze here from satellite data the response of clouds and subsequently radiation to a change of land use for the example of deforestation in the Amazon Basin. In this region, the characteristics of different cloud types over two vegetation types (forest and crop-/grasslands) were calculated for a time period of five years by using satellite data from the instruments MODIS and CERES. The cloud types are defined according to height, optical thickness, and fraction of cloud cover. For calculating the radiative forcing caused by deforestation, the dependency of spatial and temporal averages for the reflected shortwave and outgoing longwave radiation of the top of the atmosphere on vegetation types were determined as well. The results show distinct differences in cloud cover and radiative forcing over crop-/grasslands and forests for the two vegetation regimes, implying a potentially significant positive cloud feedback to deforestation.

**Keywords:** Land-use change, Deforestation, Cloud-climate feedbacks, Satellite observations.
**PACS:** 92.60.J-

## INTRODUCTION

Nowadays, global climate change is one of the most intense problems worldwide. Thus, a main scientific goal is to find out how and how strongly anthropogenic activities impact the energy balance of the Earth. Besides the emission of greenhouse gases, IPCC AR4 [1] also reports that other antropogenic activities may change the energy balance, e.g. the change of surface albedo, as a result of a change of land use as well as from deposition of black carbon on snow. Land use change due to deforestation of the Brazilian rain forests is especially substantial [2] and may impact the radiative energy budget and the hydrological cycle caused by different cloud distributions above forest and grassland.

In this study, the effect of a change in land use on clouds and radiation is investigated for a region in the Amazon Basin in Brazil. Statistics of satellite data over areas with crop- and grassland and areas with forest are analyzed for clouds in all layers. Finally, the effect on the energy cycle, namely the radiative forcing caused by deforestation, is calculated for the considered region in the Amazon Basin.

## DATA AND METHODOLOGY

The study is based on satellite data from the MODerate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra satellite [3], obtained from the Clouds and the Earth's Radiant Energy System (CERES; [4]) SSF Edition 2 data set. The equator crossing time of the Terra satellite is about 10:30 AM local time, and the data set covers the period January 2001 to December 2005. The spatial resolution is about 20 km x 20 km. The high-resolution surface data set of the project Global Land Cover 2000 (GLC 2000; [5]) was used for getting information on the vegetation type. The resolution was aligned to the combined cloud data of CERES/MODIS to 0.25° x 0.25°. The data in the original vegetation data product are given as percent of each vegetation type per grid cell. From this a mask is generated for both broad vegetation types considered in this study, forest and grass-/cropland, based on a

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threshold coverage of ≥ 60% of the respective vegetation type. Area-averages for the Amazon Basin in Brazil are computed for the domain 50°W-65°W and 5°S–10°S. Due to climate characteristics of the equatorial Tropics location there are only two seasons: dry and wet season. The definition of the periods for the mentioned region was adapted from [6] and [7], thus, they were set to June to October for the dry season and November to May for the wet season. The clouds are characterized by their fractional cover, top height and optical thickness. The cloud classifications used in this study are described in Tab. 1.

**TABLE (1).** Cloud Classification Scheme including thresholds.
CLF: Cloud Fraction, ECLP: effective cloud pressure, $\tau$: optical depth.

| cloud free | cloud cover CLF [%] | cloud height ECLP [hPa] | optical thickness $\tau$ |
|---|---|---|---|
| clear air (CA) | partly cloudy (pc) 0.1-40 | low clouds (LC) > 680 | thin clouds (tn) < 3.35 |
| | mostly cloudy ( mc) 40-99 | middle clouds (MC) 440-680 | moderate clouds (mo) 3.35-22.63 |
| | overcast (oc) 99-100 | high clouds (HC) < 440 | thick clouds (tc) > 22.63 |

To prepare the statistical analysis, the swath-based level 2 footprint data have been gridded to a resolution of 0.25° x 0.25°. In the next step, the data have been analyzed by calculating histograms and frequency distributions for the considered two surface types forest and crop-/grasslands. Afterwards, the reflected shortwave and outgoing longwave radiation at the top of the atmosphere have been analyzed by cloud type. Finally, the resulting radiative forcing due to the deforestation over the years 2000 – 2005 in the Amazon region has been calculated.

## RESULTS AND DISCUSSION

### Cloud Occurrence in the Amazon Basin

Fig.1 shows the analyzed region (a) and the relative frequency of occurrence of cloud events sorted by cloud type above both surfaces (b). Fractional cloudiness is about 5% larger above forest compared to crop/grasslands pixels. There are more often overcast events above forest. Compared to forests, clouds above crop-/grasslands occur slightly more often in the middle atmosphere and slightly less often in the upper or lower atmosphere. Their optical depth is usually thin or moderate above both vegetation types. The results of the seasonal case study [8] show a 30% larger cloud occurrence for the wet season. The clouds are characteristically distributed in all cloud layers and occur with a moderate optical depth. 35 % of cloud events in the wet season are overcast situations. In the dry season, the clouds occur as well on all layers; preferentially it is partly cloudy with a small optical depth.

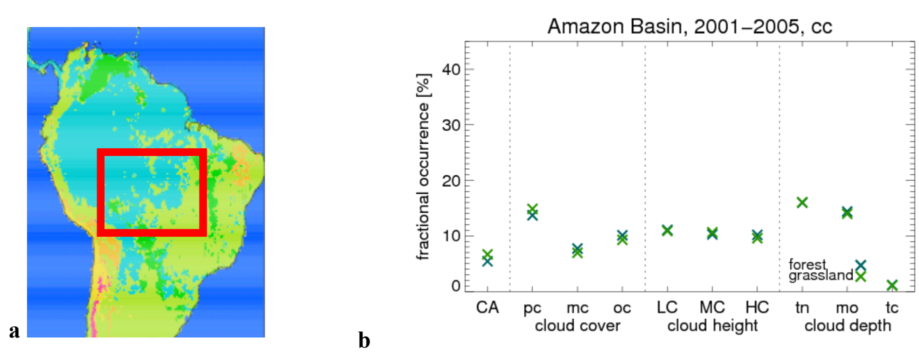


**FIGURE 1.** The Amazon Basin marked on the map by a red frame, where dark green pixels show forest and light green crop-/grassland pixels (a). Frequency of occurrence of cloud events sorted by cloud type (b).

## Reflected Shortwave (SW) and Outgoing Longwave (LW) Radiation at the Top of the Atmosphere

In absolute values, the amount of reflected shortwave radiation (SW) at the top of the atmosphere in the Amazon Basin is between 150 W/m² and 730 W/m² for all vegetation regimes (Fig. 2a). The outgoing SW correlates with the cloud cover, top height and optical depth: the higher the mentioned parameters, the higher is the reflected SW. The absolute outgoing longwave radiation (LW) at the top of the atmosphere ranges from 175 W/m² to 300 W/m². LW negatively correlates with cloud amount, top height, and optical thickness, as expected due to the cloud greenhouse effect. The difference of the mean absolute values for SW and LW between both vegetation types are displayed in Fig. 3a and b for the time period from 2001 to 2005. The values for crop-/grasslands are subtracted from the values for forest pixels, and show small numbers in absolute values, but may lead to a strong climate feedback: a negative difference implies a cooling- and a positive a warming feedback to a land-use change from forests to crop-/grasslands.

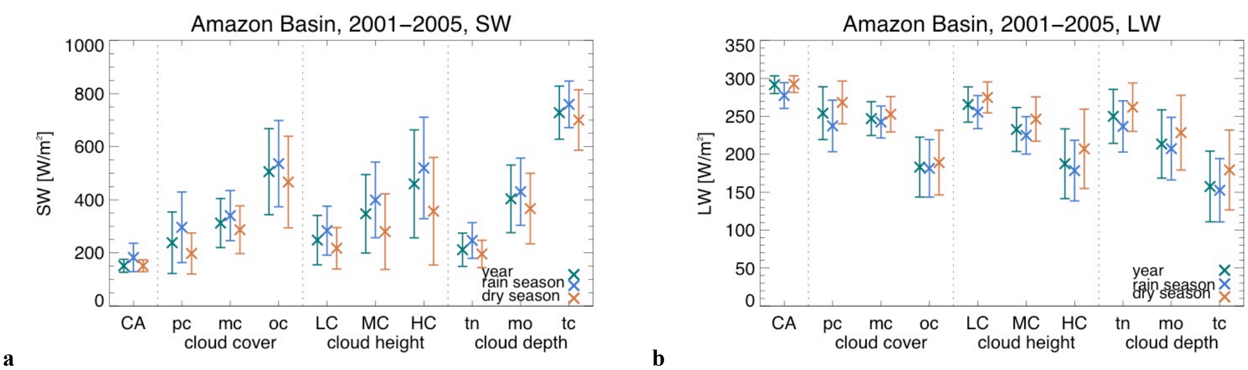


**FIGURE 2.** Mean outgoing shortwave (a) and longwave (b) radiation TOA above forest regimes in the Amazon Basin.

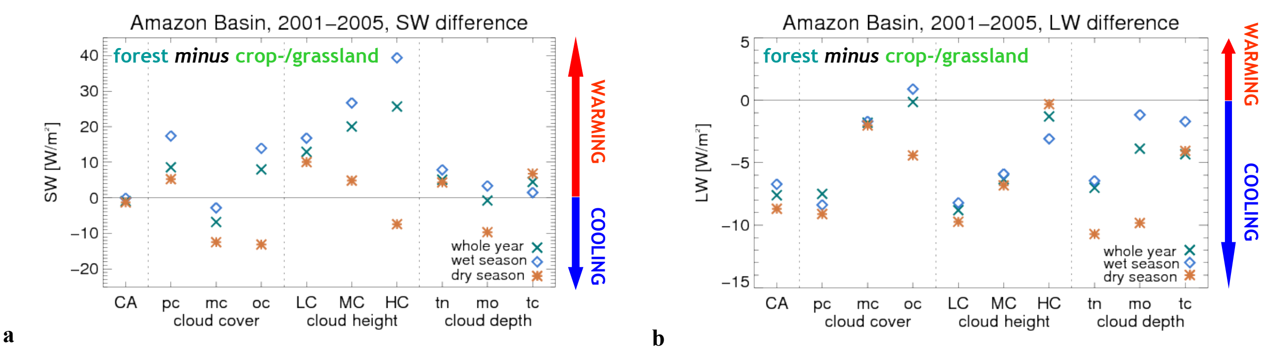


**FIGURE 3.** Difference of mean outgoing shortwave (a) and longwave (b) radiation TOA between the two vegetation regimes (forest minus crop-/grassland) in the Amazon Basin. Positive values indicate a warming effect due to cloud changes following deforestation, negative values a cooling feedback.

## Anthropogenic Trend

The results in Tab. 2 show the radiative forcing due to deforestation of 31,000 km², or 0.65% of the area, over the 2000 – 2005 period [9] for the Amazon Basin during the whole year, wet and dry season. Apparently, the radiative forcing for clear air (CA) events differs a lot from the radiative forcing for cloudy sky. A positive cloud feedback to deforestation in the SW spectrum is found, especially in the wet season. The results for LW in cloudy situations are similar to CA events, with a cooling effect in both cases. For the net radiative effect, the cooling in clear-sky situations is counteracted by a warming cloud feedback effect in the wet season. In the annual average, the cloud feedback still offsets 42% of the cooling in clear sky despite a slightly negative net cloud feedback in the dry season.

**TABLE (2).** Radiative forcing due to land-use change in the Amazon Basin (W/m²) for a deforestation of 0.65% of the area over a six-year period).

| **2001-2005** | **SW** | | **LW** | | **SW+LW** | |
|---|---|---|---|---|---|---|
| | **clear** | **cloudy** | **clear** | **cloudy** | **clear** | **Cloudy** |
| whole year | -0,058 | +0,130 | -0,103 | -0,063 | -0,161 | +0,067 |
| wet season | -0,044 | +0,188 | -0,084 | -0,057 | -0,128 | +0,131 |
| dry season | -0,077 | +0,047 | -0,130 | -0,072 | -0,207 | -0,025 |

## CONCLUSIONS

A statistical analysis of cloud distribution above the two vegetation regimes forest and crop-/grassland in the Amazon Basin based on satellite data has been presented. A substantially decreased cloud albedo over crop-/grasslands compared to forests is found for clouds in all layers, but particularly for clouds with high cloud tops in the rainy season. From this statistical analysis, we find for the reduction in forest area by 0.65 % over the Amazon region observed over the 2000 to 2006 period a radiative cooling effect of -0.161 W/m² for clear skies. A warming cloud feedback is found due to the reduction in cloud albedo mainly in the rainy season, of +0.067 W/m² in the annual mean, offsetting 42% of the negative forcing due to the surface albedo increase.

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