Radiative effect of surface albedo change from biomass burning

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Received 6 March 2005; revised 10 June 2005; accepted 13 September 2005; published 26 October 2005.

[1] The radiative impact of burn scars from biomass is investigated. Changes in surface albedo derived from satellite observations over the African continent are used as a first order indication of this impact. Because the direct radiative effect of aerosols from biomass burning is dependent on the underlying surface albedo, we investigate the interaction of the direct radiative effect due to biomass burning aerosols with the change in surface reflection due to the burn scars. The radiative effect of reduced surface albedo from burn scars is estimated to be close to 0.1 Wm⁻² over a region covering the African continent. Citation: Myhre, G., Y. Govaerts, J. M. Haywood, T. K. Berntsen, and A. Lattanzio (2005), Radiative effect of surface albedo change from biomass burning, Geophys. Res. Lett., 32, L20812, doi:10.1029/2005GL022897.

1. Introduction

[2] Anthropogenic activity has caused a variety of radiative forcing mechanisms [Intergovernmental Panel on Climate Change (IPCC), 2001] and over the last years further mechanisms have been proposed [Forster and Shine, 1999; Ackerman et al., 2000; Koren et al., 2004; Hansen and Nazarenko, 2004; Boucher et al., 2004; Myhre et al., 2004]. For example, Hansen and Nazarenko [2004] suggest that black carbon (BC) aerosols emitted by fossil fuel and biomass burning activities impact snow and ice albedo and give a significant positive radiative forcing. Hansen et al. [1998], Betts [2001], and Myhre and Myhre [2003] show that surface albedo changes resulting from anthropogenic land cover changes have significantly impacted the radiative balance. It has been known for some time that the gases and aerosols emitted by the process of biomass burning exert significant local, regional and global radiative forcing [Penner et al., 1992; Hobbs et al., 1997]. Biomass burning occurs particularly over the African continent with smaller contributions from South America and the southern part of Asia; all of these regions display a distinct seasonal cycle in emissions with significant interannual variations.

[3] Here we investigate the radiative forcing mechanism from biomass burning from alteration of surface albedo caused by burn-scars. This radiative forcing mechanism with direct impact on the surface albedo is quite different from the mechanism proposed by Hansen and Nazarenko [2004] of transported aerosols that influence surface albedo of snow and sea-ice. The surface albedo effect and the effect of changes in the atmospheric burden of aerosols from biomass burning both lead to changes in the short wave radiation budget over Africa. Since the radiative effect of aerosols is dependent on the surface albedo, we investigate the albedo effect alone and in combination with the direct aerosol effect over the African continent.

2. Method

2.1. Surface Albedo Decrease

[4] The seasonal analysis of surface albedo derived from observations acquired by the Meteosat Visible and InfraRed Imager (MVIRI) instrument onboard the European geostationary Meteorological Satellite (Meteosat) over Africa using the method proposed by Pinty et al. [2000] revealed the high sensitivity of albedo to biomass burning. This is assessed by looking at the perturbation of surface albedo variations during the dry season, i.e., reduction to abnormally low values, rather than the expected increase [Govaerts et al., 2001]. The comparison between pixels affected and non-affected by this process shows that the relative reduction in surface albedo in fire prone areas in the 5°–10°N region over the African continent typically ranges between 5 to 8%. Albedo decrease due to fires over the African continent south of equator is less important and does not exceed a few percent on the average. Despite the fact that surface reflectance may locally be reduced very significantly over a burn scar (e.g., by a factor of approximately 2), relatively small changes in the surface reflectance are observed at a coarse spatial resolution, in particular when annual averaging is performed.

2.2. Model Simulations of Aerosols From Biomass Burning

[5] The distributions of aerosols from biomass burning are simulated with a global atmospheric chemistry transport model, the Oslo CTM2 [Berntsen et al., 2005; Myhre et al., 2003]. The simulations are performed with meteorological data from ECMWF for year 2000, with a spatial resolution of T42 (around 2.8 × 2.8 degrees) and 40 vertical layers. The biomass burning aerosols are included as hydrophobic and hydrophilic organic carbon (OC) and BC with a conversion rate from the hydrophobic to the hydrophilic fractions from Cooke et al. [1999]. The emissions from biomass burning are taken from Cooke and Wilson [1996] and Liouss et al. [1996], respectively for BC and OC. Optical properties are modelled based on aircraft measurements during SAFARI-2000 [Haywood et al., 2003]. The Oslo CTM2 has previously been used to model the aerosol distribution and radiative effect of biomass burning aerosols.
during SAFARI-2000 and the results from this model compared favourably with AERONET data, MODIS aerosol satellite retrievals, and aircraft data [Myhre et al., 2003].

Haywood et al. [2003] and Abel et al. [2003] showed that the single scattering albedo of fresh biomass burning aerosol is significantly lower than that of aged biomass burning aerosol due to condensation of scattering material and the formation of secondary organic aerosol particles. We have thus modified the single scattering albedo over land by reducing the value by 0.05 to 0.85 compared to 0.90 at 550 nm by Myhre et al. [2003].

2.3. Radiative Transfer Calculations

A multi-stream radiative transfer code using the discrete ordinate method [Stamnes et al., 1988] is adopted in this study. Rayleigh scattering, gaseous absorption, scattering by clouds, and scattering and absorption by aerosols are included [Myhre et al., 2003]. Meteorological data (including clouds) for the year 2000 from ECMWF are used in the model calculations which are therefore consistent with the data for surface albedo changes. A temporal resolution of 3 hours for the meteorological data is used in the radiative transfer calculations. Because we are unable to precisely quantify the fraction of anthropogenic and natural emissions, we use the term radiative effect, which include both anthropogenic and natural biomass burning activities [e.g., IPCC, 2001]. Monthly mean decreases in surface albedo as estimated from the satellite observations are used as input to the radiative transfer calculations.

3. Results

Radiative effects are first presented for the separate components of changes in surface albedo and in biomass burning aerosols and, thereafter as a combination of changes in both mechanisms.

3.1. Radiative Effect of the Surface Albedo Changes

Maps of monthly and annual mean surface albedo decrease due to fire estimated with the method proposed by Govaerts et al. [2002] for year 2000 is shown in Figure 1a. Surface albedo change data are expressed in percent (0–100%). A decrease in the surface albedo leads to more absorbed solar radiation at the surface and thus a positive radiative effect. The pattern of the radiative effect shown in Figure 2a is very similar to the pattern of surface albedo change given in Figure 1a. Myhre and Myhre [2003] showed in an experiment with a constant albedo change over all land areas that the radiative effect is very sensitive to surface albedo changes over Africa. For clear sky, this sensitivity is approximately constant over the whole of Africa, whereas it is reduced somewhat in the intertropical convergence zone by the presence of clouds. Table 1 shows the annual mean radiative effect both for the regional area shown in Figure 2 and the corresponding global mean. The global mean radiative effect of albedo change from biomass burning in Africa is 0.015 Wm$^{-2}\cdot$C$^{-1}$. The local maximum radiative effect is close to 2 Wm$^{-2}\cdot$C$^{-1}$ in the annual mean (see Figure 2a) and the local maximum in the current horizontal resolution is nearly 8 Wm$^{-2}\cdot$C$^{-1}$ in January.

3.2. Radiative Effect of the Biomass Burning Aerosols

Figure 1b shows the modelled annual mean aerosol optical thickness (AOT) at 0.55 μm due to biomass burning aerosols. The pattern and magnitude in the AOT is in
reasonable agreement with satellite data and ground based sunphotometers (AERONET) although a detailed comparison is complicated as several other aerosol components such as mineral dust exist over the African continent. The global and annual mean model estimate of the radiative effect of aerosols from African biomass burning is $-0.13 \text{ Wm}^{-2}$, with peak values stronger than $-20 \text{ Wm}^{-2}$ during the sub-Saharan burning period and stronger than $-10 \text{ Wm}^{-2}$ in the southern African burning period. Figure 2b shows the annual mean geographical distribution of the radiative effect. The positive radiative effect of the aerosols in certain regions is associated with reflective surfaces underlying the aerosol layer, either desert areas or clouds as also found during SAFARI-2000 [Myhre et al., 2003; Keil and Haywood, 2003].

### 3.3. Radiative Effect of the Combined Surface Albedo Changes and Aerosols From Biomass Burning

[11] The two previous subsections have considered surface albedo changes and biomass burning aerosols separately. However, both processes are radiatively coupled as a decrease in surface albedo increases the efficiency of reflective aerosols. Furthermore, if aerosols reflect or absorb solar radiation this will lead to a smaller impact on the surface albedo changes because less solar radiation will reach the surface. Figure 2c shows the annual mean distribution of the radiative effect of the combined changes in surface albedo and biomass burning aerosols, which to a large extent resemble Figure 2b.

[12] The net result of the coupled radiative effect is $-0.76 \text{ Wm}^{-2}$ over the studied area around Africa (area shown in Figures 1 and 2) corresponding to a global mean forcing of $-0.12 \text{ Wm}^{-2}$. To investigate the impact of surface albedo change on the radiative effect of aerosols we have performed further calculations. Darkening of the surface by burnt scars enhances the radiative effect of the biomass burning aerosols by 2% (see Table 1). On the other hand including biomass burning aerosols reduces the radiative effect of surface albedo change by 14% from 0.095 Wm$^{-2}$ to 0.081 Wm$^{-2}$.

[13] Biomass burning over the African continent has a distinct seasonal variation with the sub-Saharan region (Region R1) most influenced by burning in the December, January, and February period and the southern part region (Region R2) most influenced in from May to September. Figure 3 shows the seasonal variation in surface albedo [Govaerts et al., 2002] and the modeled AOT from biomass burning (Oslo CTM2) and the associated radiative effect for the sub-Saharan and the southern part regions. The seasonal variation is evident with change in surface albedo and biomass burning aerosols having a corresponding radiative effect. The figure also reveals a clear seasonal distinction between the biomass burning in the two African regions. The small difference in the time evolution of the AOT and the surface albedo change in the southern hemisphere is likely that burnt areas are generally smaller in size and more scattered than in the North hemisphere, affecting also preferably understorey instead of the top of the canopy. Consequently, the effect on surface albedo is not necessarily linearly coupled with the fire intensity and the amount of corresponding released aerosols.

### 4. Summary and Conclusions

[14] Biomass burning influences climate and its radiative budget in many ways. The radiative effect of biomass due to albedo changes caused by burn scars has been investigated. Because the radiative effect from biomass burning aerosols is a function of the surface albedo and because the radiative effect due to surface albedo changes is a function of the surface insolation and hence on the aerosol optical depth, we have also investigated the radiative effect as a combination of the two radiative forcing mechanisms. The direct effect of biomass burning aerosols dominates over the effect of change in surface albedo from burn scars. A calculation of the combined radiative effects enhances the net radiative effect by just 2% compared to simply adding the results from separate calculations. These results suggest that the

### Table 1. Annual Mean Radiative Effect (Wm$^{-2}$) Due to Biomass Burning for the Region Shown in Figures 1 and 2 and the Global Mean*

<table>
<thead>
<tr>
<th>Regional Area</th>
<th>Annual Mean Radiative Effect, Wm$^{-2}$</th>
<th>Percentage Difference, %</th>
<th>Global Mean</th>
<th>Annual Mean Radiative Effect, Wm$^{-2}$</th>
<th>Percentage Difference, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface albedo change</td>
<td>0.095</td>
<td>-14</td>
<td>0.015</td>
<td>-14</td>
<td></td>
</tr>
<tr>
<td>Biomass burning aerosols</td>
<td>-0.84</td>
<td>-2</td>
<td>-0.13</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td>Combined effect</td>
<td>-0.76</td>
<td></td>
<td>-0.12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The percentage difference shown for surface albedo changes is when aerosols are taken into account, and for aerosols when reduced surface albedo are taken into account.
interaction of the two mechanisms is relatively weak on a global basis and simple addition of the radiative forcing from the two mechanisms is a reasonable approximation. The African biomass burning leads to annual mean radiative effect of surface albedo change from burnt scars around 0.1 Wm\(^{-2}\) for the African continent, despite monthly local maxima which can be as large as 8 Wm\(^{-2}\).

References


