Fire-induced albedo change and its radiative forcing at the surface in northern Australia

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[1] This paper investigates the impact of fire on surface albedo and the associated radiative forcing over 56% of continental Australia encompassing the fire-prone northern tropical savanna. Fire-affected areas and albedos are derived for the 2003 fire season using daily Moderate Resolution Imaging Spectroradiometer (MODIS) surface reflectance data. Near-infrared and total shortwave albedos are observed to generally decrease after fire occurrence. Regionally, the total shortwave albedo drops by an average of 0.024, with increasing reductions as the dry season progresses and larger reductions in grasslands than woody savannas. These fire-induced albedo changes exert a positive forcing at the surface that increases from March to November. A mean "instantaneous" shortwave surface radiative forcing of 0.52 Wm^{-2} is estimated for the study region. **Citation:** Jin, Y., and D. P. Roy (2005), Fire-induced albedo change and its radiative forcing at the surface in northern Australia, *Geophys. Res. Lett.*, *32*, L13401, doi:10.1029/2005GL022822.

1. Introduction

[2] Surface albedo affects the Earth's radiative energy balance, by controlling how much incoming solar radiation is absorbed by the surface. It is well established that land use changes that affect physical surface properties including albedo impose a radiative forcing on the climate [*Intergovernmental Panel on Climate Change* (*IPCC*), 2001]. Confidence in albedo-related radiative forcing estimates remain low due to several factors, including the small number of investigations and uncertainties in the land cover change and the albedo data sets used to drive them [*IPCC*, 2001]. Most studies have concentrated on anthropogenic land use/cover changes which generally lead to increased albedo and negative radiative forcing [*Betts*, 2001; *Myhre and Myhre*, 2003]. Human-induced albedo changes are estimated to have caused a mean global radiative forcing of -0.2 Wm^{-2} since the pre-industrial period and may be comparable with forcings due to anthropogenic aerosols, solar variation, and greenhouse gases [*Hansen et al.*, 1998].

[3] Fire is a major cause of surface change and occurs in most vegetation zones across the world. Fire destroys vegetation and deposits charcoal and ash, which generally reduces reflectance, especially at infrared wavelengths [*Roy et al.*, 2005]. *Govaerts et al.* [2002] analyzed a Meteosat temporal surface albedo data set over Northern Hemisphere Africa and estimated that fires cause a relative albedo decrease of up to 25%. The effect of fire on albedo is complex and depends on the pre-fire vegetation structure and underlying soil reflectance; the combustion completeness of the fire; unburned leaf drop; and vegetation regrowth and recovery after the fire [*Roy and Landmann*, 2005]. Fire-induced albedo changes and their impact on the radiation balance have not been comprehensively investigated, especially at regional and continental scale, in contrast to numerous studies on the radiative impact of greenhouse gases and aerosols emitted from biomass burning [*IPCC*, 2001].

[4] This study aims to quantify the albedo change due to fire and the associated shortwave radiative forcing at the surface under typical incoming solar radiation. To decouple the forcings contributed by albedo and aerosol changes, we do not explicitly consider the impact of biomass burning aerosols on incoming radiation [*Christopher et al.*, 2000]. Rather than using imprecise inventory data, we derive fire-affected areas and pre- and post-fire albedos in a spatially and temporally explicit manner using satellite data. We restrict our study to the predominant 2003 fire season of Australia north of 26.5°S, an area equivalent to 56% of continental Australia, encompassing the tropical savanna. The monsoon-driven wet November–April summers and dry May–October winters produce moderate to severe fire weather and accumulated dry fuels which result in a high frequency of fires [*Bradstock et al.*, 2002]. Recent continental-scale mapping using NOAA-AVHRR satellite data for 1997 to 2001 has shown that the greatest extent of Australian fire occurs in the tropical savanna, where an average of 19% of the area burned annually (with annual means varying from 13% to 27%) [*Russell-Smith et al.*, 2003]. Global sensitivity analysis performed by increasing albedo by 0.01 indicates more significant forcing in this and other tropical regions than at mid- and high latitudes [*Myhre and Myhre*, 2003].

2. Data and Methods

[5] We map fire-affected areas and quantify surface albedo changes using time series of daily atmospherically corrected surface reflectance at 500 m resolution acquired from the MODIS instruments aboard the NASA Terra (morning overpass) and Aqua (afternoon overpass) polar orbiting satellites [*Vermote et al.*, 2002]. MODIS has seven reflective bands for land studies, from the visible to middle infrared wavelengths. We reject all observations with cloud, snow, bad quality, high solar or view zenith angle (>65°) [*Roy et al.*, 2005]. Recently processed (Collection 4) 2003 MODIS data are used.

[6] The location and approximate day of burning is mapped using a change detection approach applied to the MODIS near-infrared and shortwave infrared bands [*Roy et al.*, 2005]. The RossThick-LiSparse reciprocal (RTLSR) Bi-directional Reflectance Distribution Function (BRDF) model [*Schaaf et al.*, 2002] is inverted against 7 or more

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surface directional reflectances observed within 16 to 32 days. Model prediction at subsequent observation sun-view geometries provides an expectation and uncertainty of their reflectance. A statistical measure is used to determine if the difference between the predicted and observed reflectance is significant. Spectral constraints defined by the noise characteristics of the reflectance data and knowledge of the spectral behavior of burned vegetation are used to reject non-fire related changes. By moving through the time series, temporal constraints capitalizing on the spectral persistence of fire-affected areas are applied, and the day of burning derived. The fire-affected areas are generated here by combined use of the daily MODIS Aqua and Terra observations which provides improved detection over using one of these data streams alone.

[7] Surface albedos and their uncertainties are derived independently before and after the date of burning using a modified MODIS albedo product approach [*Schaaf et al.*, 2002]. The RTLSR BRDF model is inverted against 7 or more directional surface reflectance observations sensed within a temporal window of 16 days. The temporal window is expanded as necessary until there are 7 observations, up to a maximum window duration of 32 days. The white-sky albedo (diffuse illumination) is then derived for each of the seven spectral bands by integrating the retrieved BRDF over the illuminating and reflecting hemispheres [*Wang et al.*, 2004]. The spectral albedos are converted to broadband albedos in the visible (0.3–0.7 μm), near-infrared (0.7–5.0 μm) and total shortwave (0.3–5.0 μm). The albedo uncertainty is quantified as the product of the noise magnification factor and the root mean square error of the BRDF inversion [*Lucht and Lewis*, 2000]. Both the daily MODIS Terra and Aqua observations are used for more reliable albedo estimates [*Lucht and Lewis*, 2000].

[8] For each fire-affected 500 m pixel, the shortwave radiative forcing at the surface ($\Delta F_{surface}$) contributed by fire-induced albedo change only is estimated as:

$$\Delta F_{surface} = -I^{\downarrow}_{surface} \cdot (\alpha_2 - \alpha_1) \qquad 1)$$

where $I^{\downarrow}_{surface}$ is the surface incoming solar radiation [Wm^{-2}] and ($\alpha_2 - \alpha_1$) is the "instantaneous" surface albedo change computed by subtracting the pre-fire albedo (α_1) from the post-fire albedo (α_2). The European Centre for Medium-Range Weather Forecasts 40-year Reanalysis (ERA40) provides monthly mean surface incoming solar radiation at 2.5° by 2.5° grid cells from September 1957 to August 2002 [*Allan et al.*, 2004]. To derive climatology of incoming solar radiation $I^{\downarrow}_{surface}$, we calculate ERA40 multi-year monthly means from January 1979 onward. The MODIS 1 km land cover product [*Friedl et al.*, 2002] is also used to examine differences among IGBP land cover types.

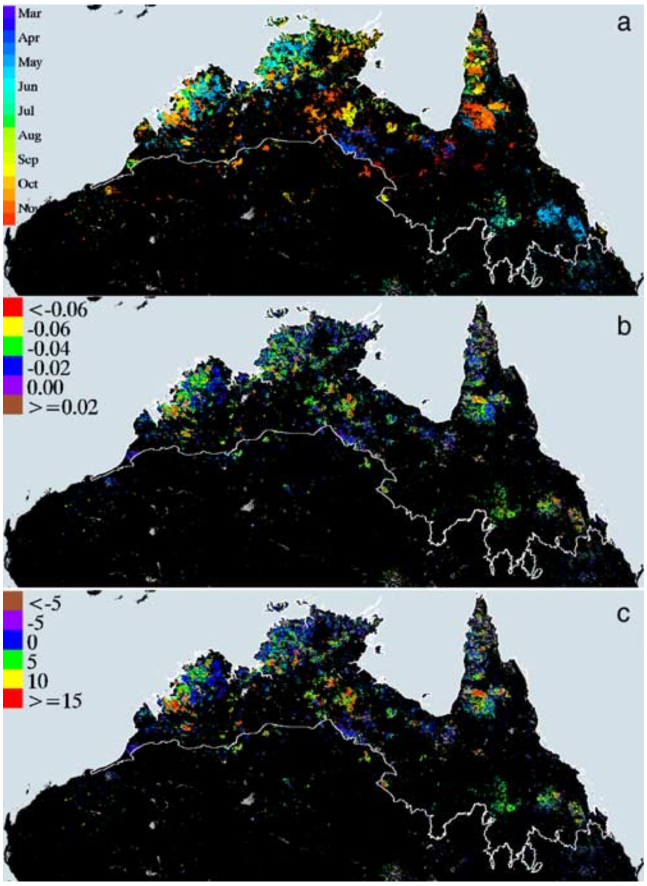

Figure 1. Spatial distribution of (a) fire affected areas and approximate day of burning (colors) in 2003; (b) "instantaneous" albedo change; (c) surface radiative forcing [Wm^{-2}] in the total shortwave, for Australia north of 26.5°S (in Lambert Azimuthal projection). Light grey indicates locations with insufficient data to produce results. The white vector illustrates the extent of the Australian Tropical Savanna.

4. Summary and Discussions

[15] Regional forcing studies have been recommended for a better understanding of climate response to land use/cover changes [*National Research Council*, 2005]. This regional study quantifies the "instantaneous" albedo change within 16 to 32 days after fire and the associated shortwave surface radiative forcing for Australia north of 26.5°S. In 2003 the total shortwave albedo decreased by an average of 0.024 over a burned area of 422,640 km^2. The albedo decreased by a greater amount in grasslands than woody savannas and as the dry season progressed. These fire-induced albedo changes resulted in a positive surface shortwave radiative forcing, estimated as 6.23 Wm^{-2} on average over the burned areas and as 0.52 Wm^{-2} over the study region. Our analysis reveals an increasing trend of forcing from March to November, indicating that the overall forcing will be reduced if more burning occurs in the early dry season for the same annual area burned.

[16] Long-term studies of the temporal evolution of fire-induced albedo change are needed to derive annual mean regional forcing estimates. These studies should consider forcing over several years to capture interannual variability in the seasonality of burning and the annual area burned. Our analysis did not explicitly consider the impact of biomass burning aerosols on incoming solar radiation, although aerosol climatology was used in the ERA40 reanalysis [*Allan et al.*, 2004]. The aerosols from biomass burning often cause a negative forcing [*Christopher et al.*, 2000], which may counteract the positive forcing due to albedo decreases. For a complete account of forcing from fire, further research is needed to consider both albedo and aerosol effects.