Commentary
On the importance of considering land surface reflectance in earth system studies

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If we consider the disciplinary divisions which make up earth science: ocean-atmosphere, land-atmosphere, hydrosphere, cryosphere, and stratosphere-troposphere, we can see the acknowledgement of the importance of the surface of the earth in understanding the stocks and fluxes of energy, water and matter. Yet understanding the features of the land surface lag behind our understanding of atmospheric chemistry and the health impacts of air pollution. This raises a philosophical question: 'if we are unable to understand the land surface accurately over a range of temporal and spatial scales, how confident can we be in our understanding of the earth system?'.

Response variables which measure structural conditions, as such the normalised difference vegetation index (NDVI, which measures greenness) and the fraction of absorbed photosynthetic active radiation (FAPAR), have been critical in allowing us to begin to assess the human impact on the earth system, and gain some insight into the magnitude and patterns of the risks to social-ecological systems. But we need be more creative. To this end, I suggest albedo as a key variable to consider using from the suite of routinely measured variables. Albedo measures the reflectivity of a surface to solar radiation, a ratio of the amount reflected to the amount of downwelling radiation, and has many attributes which make it suitable for answering questions which are systemic in nature: in particular, it can be measured at a range of scales, and technological advances mean that hand held instruments and satellite-based products cover opposite ends of these scales, making the measure accessible from local to global levels. At regional to global scales, satellite observations provide long time series for objective analysis of the human impact. Linking local to broader scale measures allows us to study how albedo impacts propagate across scales (Scholes 2015).

Surface albedo is a joint property of the sun, atmosphere and the earth's surface because it is determined by both the incoming and reflected radiation fluxes. It is a responsive indicator of land-atmosphere process interactions, but the interpretation depends on the spatial and temporal resolution of the dataset as well as the attributes of the environment in question. For instance, between seasons and years it can be used as a proxy for leaf emergence, as in the case study of the use of cover crops in Europe (Carrer et al. 2018). Over decades it could be used to assess species composition and structural/functional changes due to land use change, disturbance such as fire and wood harvesting, ecological succession or ecosystem rehabilitation (Halim et al. 2019).

The resolution of the measurement and the extent of the heterogeneity of the system being studied - for example in topography, vegetation structure and species composition – will determine what is being integrated. Measurements with a hand-held instrument with a small field of view might measure the albedo of a single leaf, while a more remote instrument will measure the albedo of the canopies of multiple plants species and soils with varying moisture levels. In moving from the leaf level to the community level and higher, we are able to assess different ecosystem characteristics and processes.

Understanding the patterns and trends of land degradation and desertification remains a key challenge facing scientists today. In the 1970's Joseph Otterman, Jule Charney and colleagues looked at changes in albedo to build a hypothesis about the desertification in the Sahel region. What was observed is typical in semi-arid and arid areas: vegetation loss results in an increased albedo and less energy is absorbed at the earth's surface. This means that relatively less energy then returns to the atmosphere as sensible and latent heat, which promotes the subsidence of air aloft and which may in turn reduce precipitation. The role and impact of land cover changes on albedo and the persistence of drought has remained controversial largely because of the influence of the climate belt/latitude where the changes occur, the role of water balance and different scale perspectives have not been reconciled.

To compare land-atmosphere interactions the Intergovernmental Panel on Climate Change popularised the use of the radiative forcing (RF) metric. This influenced later work with albedo which focused on comparing biophysical processes with biogeochemical processes. These trade-off assessments were highlighted by Richard Betts in 2000, who showed that negative forcing (or cooling) due to the carbon gains from forestation may be outweighed by the positive forcing (or warming) due to the lowering of albedo in boreal forest systems.

Since then the focus on mid-to-high latitude forest systems has continued, and the topic of albedo has largely been neglected for arid and semi-arid systems. The observation of greening in the Southern hemisphere due to La Niña in 2011 then highlighted the dominate role of these regions in the global carbon sink and its interannual variability (Poulter et al. 2014). Modellers have since agreed that regional characteristics, land cover changes and related feedbacks processes in current climate models have been neglected, and a closer look at the Coupled Model Intercomparison Project Phase 6 (CIMP6) ensemble run further underscores the importance of understanding the albedo in semi-arid systems (Jain et al. 2020).

Now international agreements and partnerships which seek to manage climate through the drawn down of atmospheric CO_2 through tree planting in grassy or savanna ecosystems, such as the Bonn Challenge and the AFR100 off-shoot, demand that we return our focus to Africa. We cannot accept a one-size-fits-all approach. The biophysical nature of our systems must be understood in all their variability so that we can maintain and conserve them. This biophysical conservation means that the benefits and drawbacks of any intervention need to be assessed at both a local and global level. The utility of albedo and surface energy budgets need to be communicated effectively across disciplines for a holistic assessment of net benefits to be achieved.

Efforts are being made to expand biodiversity stewardship agreements and extend the areas under formal conservation, while at the same time food demands increase and mining, urbanization and agricultural practices require more space. Albedo can be included as an informative variable in typical conservation concerns including the effects of habitat fragmentation, patch effects and species change and loss. It can be used to assess the impact of slimes dams of the radiative energy budget and potentially on rainfall. From these data we can contribute to better informed ecosystem management and restoration agendas.

The intentional manipulation of albedo, so-called "albedo enhancement", falls within the geoengineering climate mitigation strategies, and include approaches such as seeding clouds to reduce incoming solar radiation, or increasing the areal cover of pale surface to reduce the heat island effect in urban environments. Albedo manipulation has clearly captured the interest of purveyors of high tech solutions, while at the same time making up a fsundamental part of many climate change narratives, including sea ice melting (the well-known ice-albedo feedback at high latitudes), and thus should be included more explicitly in biology, chemistry, physics, meteorology, hydrology and ecology related fields.

A wealth of land surface data has already been collected and can be accessed through a number of channels. To access data that have already been collected, there are multiple satellite missions with otherwise well used products which offer albedo, such as NASA's MODerate-resolution Imaging Spectroradiometer (MODIS). Online interfaces such as APPEARS (portals) and Google Earth Engine (GEE, coding interface) are diversifying the access to the datasets and removing the limitations of data handling and storage. In South Africa, high resolution surface products from Multi-angle Imaging SpectroRadiometer (MISR) are processed at the Global Change Institute at Wits University (Verstraete et al. 2012). The multi-angular distribution from the instrument makes for a better constrained and therefore more accurate albedo at our disposal.

Despite the concept of albedo being relatively intuitively understood, its use in research is surprisingly sparse, and it is currently used within only a few specific disciplines. Land surface albedo should be key variable measured and used during future field campaigns, synthesis studies, databases, and modelling. The challenges facing us now and in the future are complex, and require trans- and inter- disciplinary work. The breadth of use of albedo can play an important part in the growth of an integrated earth system science and the shift to a holistic land management paradigm.

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