Earth System Data Record/Climate Data Record Name (ESDR/CDR)
Global Land Surface Albedo and Anisotropy

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Science Requirements and Rationale
Surface albedo, or the ratio of the radiant flux reflected from the Earth's surface to the incident flux impinging that surface, is a key land physical parameter controlling the planetary radiative energy budget. Variations in snow cover, vegetation phenology, inundation, and agriculture are all accompanied by significant changes in land albedo. The recession of snow cover associated with warm periods in earth's history has led to more absorption of solar energy (and hence amplified warming). Aerosol radiative forcing, which may be the most uncertain anthropogenic forcing to global climate, depends strongly on the albedo of the underlying surface. Aerosols like dust and soot may also contaminate snow and reduce its albedo greatly. Therefore, regional surface albedo with an absolute accuracy of 0.02-0.05 for snow-free and snow-covered land is required by climate, biogeochemical, hydrological, and weather forecast models at a range of spatial (from a few hundred meters to 5-30km) and temporal (from daily to monthly) scales (Dickinson, 1983). To monitor anticipated changes in land albedo on the global mean radiation budget, decade-scale trends in continental-mean surface albedo should be measured to an accuracy of 0.01. The global forcing of changes in surface albedo would then be known as well as those of anthropogenic greenhouse gases.

As albedo depends on both the unique anisotropy of the surface (related to the intrinsic composition and structure of the land cover) and the atmospheric condition at any time, remote sensing offers the only viable method of measuring and monitoring the global heterogeneity of albedo. A number of satellite-based land surface albedo Earth System Data Records (ESDR) are now routinely retrieved and archived and these measurements play a role in each of the six NASA Earth Science Focus Areas (Climate Variability and Change, Carbon Cycle and Ecosystems, Earth Surface, Atmospheric Composition, Weather, and Water and Energy Cycle). The challenge for the remote sensing community is to provide consistent high-quality, high resolution, global land albedo data sets over a sufficient period of time to constitute stable Climate Data Records (CDRs) for the modeling and climate diagnostics communities.

Approaches to generating the measurements
All of the current operational remote sensing approaches to generating accurate measures of land surface albedo rely on an initial characterization of the underlying anisotropy. As the MODerate Resolution Imaging Spectroradiometer (MODIS) instrument is a single field of view scanning radiometer, the MODIS BRDF/Albedo algorithm (MCD43) utilizes all cloud-free, atmospherically-corrected directional surface reflectances sequentially observed over a

multi-date period and couples these with a linear, semi-empirical, kernel-driven, parametric model of bidirectional reflectance to characterize the land surface anisotropy (Schaaf et al., 2002). This characterization of the Bidirectional Reflectance Distribution Function (BRDF), couples data from the MODIS instruments on board both the Aqua and Terra platforms and occurs every 8 days (based on the last 16 days worth of data - a time frame selected as a trade-off between the potential availability of sufficient cloud-free surface reflectances sampling the viewing hemisphere and the stability of land covers over time). The product is provided at a nominal spatial resolution of 500m and linearly averaged to resolutions of 1km and 0.05degrees. The anisotropy model thus retrieved can then be used to correct directional observations to a common viewing geometry (the Nadir BRDF-Adjusted Reflectance (NBAR) is an additional standard product) or can be integrated to obtain the intrinsic surface quantities of directional hemispherical reflectance (DHR or black-sky albedo) at any solar illumination angle and bihemispherical reflectance (BHR under isotropic illumination or white-sky albedo). With knowledge of the atmospheric optical depth, these intrinsic albedos values can be coupled to provide actual albedos at any given point in time. The products are generated for each of the first 7 channels of MODIS (which cover the visible, near-infrared and shortwave-infrared) and, through the use of narrow to broadband conversion coefficients, for the three broadbands commonly used by modelers (0.3-0.7µm, 0.7-5.0 µm and 0.3-5.0µm) or collected by field instruments. For the ease of use by the atmospheric and land modeling communities, the MODIS BRDF/Albedo products have been also produced as global snow-free, gap-filled datasets (Moody et al., 2005).

The Multi-angle Imaging SpectroRadiometer (MISR) on the EOS Terra platform consists of nine pushbroom cameras, viewing symmetrically about nadir in forward to aftward directions along the spacecraft track in it four visible and near-infrared spectral bands. The unique capabilities of MISR's multiple cameras therefore allow for a simultaneous sampling of the surface anisotropy and provide the opportunity to couple angular information with spectral information. After these data are radiometrically calibrated, georectified, and averaged to a uniform resolution of 1.1 km, the land data are processed to provide a set of model variables and parameters describing the surface scattering properties, including the spectral hemispherical-directional reflectance factor (HDRF) at the nine MISR view angles and the associated bihemispherical reflectance (BHR). The HDRF is a measure of the directional reflectance of the surface under ambient atmospheric illumination (i.e., direct plus diffuse radiation). It is the ratio of the directionally reflected radiance from the surface to the reflected radiance from an ideal lambertian target under identical illumination conditions as the surface. The BHR is the HDRF integrated over all reflection angles in the upward hemisphere, i.e., it is the surface albedo under ambient atmospheric illumination. Related MISR surface parameters are the spectral bidirectional reflectance factor (BRF) at the nine MISR view angles and the directional-hemispherical reflectance (DHR). The BRF and the DHR characterize the surface in the same way as the HDRF and BHR, respectively, but are defined for the condition of direct (i.e., collimated beam) illumination only. Thus, the top-of-atmosphere (TOA) MISR radiances are first atmospherically corrected to produce the HDRF and the BHR, surface reflectance properties as would be measured at ground level but at the MISR spatial resolution. The HDRF and BHR then are further atmospherically corrected to remove all diffuse illumination effects, resulting in the BRF and DHR. In addition to these spectral surface reflectance products, the BHR and DHR, integrated over the wavelength region of photosynthetically active radiation are also computed (Martonchik et al., 1998) and the three parameters of the Modified RPV BRF model are determined by a linear least squares fit to the MISR BRF (Engelsen et al., 1996),.

The Clouds and the Earth's Radiant Energy System (CERES) products include both solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface (Wielicki et al., 1998). As such, the albedo products encompass both land and ocean with a particular emphasis on clouds (recognizing that the largest uncertainty in climate prediction models is how to determine the radiative and physical properties of clouds). The combination of CERES top-of-atmosphere radiation data with surface radiation measurements allows unprecedented studies of the absorption of solar radiation within the atmosphere and continues the long term record available from the Earth Radiation Budget Experiment (ERBE). Two pairs of identical instruments fly onboard the Aqua and Terra spacecrafts: one operates in a cross-track scan mode and the other in a biaxial scan mode. The cross-track scan measures radiative fluxes at the top of the atmosphere (TOA), while the biaxial scan mode provides directional information that improves the accuracy of angular models (Loeb et al., 2003) used to characterize the surface anisotropy of the combined surface and atmosphere system and derive the Earth's radiation balance. Each CERES instrument has three channels with a nadir resolution of 20km -- a shortwave channel to measure reflected sunlight, a longwave channel to measure Earth-emitted thermal radiation in the 8-12 µm "window" region, and a total channel to measure all wavelengths of radiation. The surface albedo is produced by a two stream calculation (fusing inputs from various sensors such as clouds from MODIS, aerosols based on MODIS and the MATCH assimilation, ozone from SBUV, and humidity fieldd from GEOS-4), that matches the broadband CERES top-of-atmosphere observation and yields a consistent Surface and Atmosphere Radiation Budget (SARB, Rutan et al., 2006). Gridded CERES surface albedos (comparable to the calculations currently used in climate and general ciculation models) are provided as monthly mean clear-sky and cloudy-sky products.

Thus, the sensor-specific anisotropy and albedo products each contribute unique observations of the Earth's radiative character. MODIS and CERES both sense wide swaths of the global land surface from both Terra and Aqua and their respective surface albedo products provide the greatest temporal and spatial extent. The multi-channel MODIS anisotropy and albedo products, (with their higher spatial resolution) compliment the broadband spectral coverage of CERES to capture all wavelength variations, while MISR (with its simultaneous multi-angle viewing capability) captures accurate instantaneous images of the variability of the inherent anisotropy of the surface.

Intended sources for the measurements

Sensor-specific anisotropy and albedo products, such as described above, will continue to be necessary to respond to specific and rigorous spectral, spatial, and/or temporal requirements. Clear-sky (i.e. cloud-free), gap-filled, snow-free (as well as snow-covered) versions of these albedo and anisotropy data archives are also needed as surface boundary conditions for many modeling and atmospheric parameter retrieval efforts. In order to provide consistent global products for climate studies, researchers will increasingly rely on data fusion efforts that combine directional observations from multiple concurrent satellite observations. Such fusion (e.g. the CERES product) however requires detailed attention to sensor band characteristics, calibration, and geolocation and thus is usually limited to the computation of broadband albedo measures at medium spatial resolutions. Similar issues plague attempts to fuse temporally successive data archives although several active research efforts are focused on coupling modern sensor data with data from historical satellites (e.g. AVHRR, ERBE, and geostationary platforms). Plans to incorporate future satellites systems (e.g. NPP/NPOESS) are also underway.

Necessary supporting activities

In addition to algorithm refinements, a concurrent program of validation and monitoring is crucial to the long term consistent retrieval of any biophysical parameter. The albedo field measurements obtained by the Baseline Surface Radiation Network (BSRN), the Surface Radiation Budget Network (SURFRAD) and the Atmospheric Radiation Measurement (ARM) facilities are particularly important due to their long-term record and a rigorous regime of instrument calibration and maintenance. These station data (in additional to vital atmospheric state measurements such as collected at most of these sites by AERONET - AErosol RObotic NETwork) are available from the various individual network archives or in a consistent format from the CERES ARM Validation Experiment (CAVE – Rutan et al., 2001). CAVE also provides corresponding subsets of CERES products, as well as the capability to run the source radiative tranfer codes on line. The AERONET-based Surface Reflectance Validation Network (ASRVN) is an operational system that receives subsets of MODIS, MISR, etc. measurements for more than 160 AERONET sites globally, and uses AERONET aerosol and water vapor data to perform accurate atmospheric correction and provide spectral BRF, albedo and incident radiative flux. The periodic reprocessing of all of the satellite data archives based on improved understanding or modeling of the radiation regime is another necessary requirement for all long term consistent data sets.

International collaborations

European sensors such as POLDER (Polarization and Directionality of the Earth's Reflectances) on board PARASOL (Polarization & Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar) innovatively captures simultaneous multiangular information of the global land surface at a medium resolution while MERIS (Medium Resolution Imaging Spectrometer) on board the Envisat platform provides additional sequential observations of the Earth. In addition, the many acquisitions possible under varying daily illumination geometries have been successfully utilized to obtain surface anisotropy and albedo information over Africa and Europe from the geostationary Meteosat and Meteosat Second Generation (MSG) satellites. European efforts to provide fused products from multiple sensor data streams are under development in projects such as CYCLOPES (Carbon cYcle and Change in Land Observational Products from an Ensemble of Satellites).

Key Citations

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