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Deriving Albedo from Coupled MERIS and MODIS Surface Products

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Abstract

MERIS Level 2 surface reflectance products are now available to the scientific community. This paper demonstrates the production of MERIS-derived surface albedo and Nadir Bidirectional Reflectance Distribution Function (BRDF) adjusted reflectances by coupling the MERIS data with MODIS BRDF products. Initial efforts rely on the specification of surface anisotropy as provided by the global MODIS BRDF product for a first guess of the shape of the BRDF and then make use all of the coincidently available, partially atmospherically corrected, cloud cleared, MERIS observations to generate MERIS-derived BRDF and surface albedo quantities for each location. Comparisons between MODIS (aerosol-corrected) and MERIS (not-yet aerosol-corrected) surface values from April and May 2003 are also presented for case studies in Spain and California as well as preliminary comparisons with field data from the Devil's Rock Surfrad/BSRN site.

1. Background

Land surface albedo is one of the key geophysical parameters for global climate models, surface energy balance models, weather forecast models and biogeochemical models. Thus global surface albedo is always among the desired products/data sets for recent moderate to coarse resolution satellite missions, such as MODIS (Schaaf et al., 2002), MISR (Dinner et al., 1998), POLDER (Leroy et al., 2000) and in the past AVHRR (Csiszar et al, 1999) etc.

The EnviSat/MERIS was launched on March 1, 2002. It is comprised of five pushbroom CCD arrays that cover a field of view of 68.5 degree with the swath of 1150 km (see Table 1). Compared to some instruments with large fields of view such as MODIS and POLDER, the MERIS instrument can only provide limited angular observations at large view zenith angle, which may cause some biases if BRDF is retrieved from MERIS observations alone. The MERIS global coverage is about 3 days and the repeat cycle for EnviSat/MERIS is 35 days. Therefore, MERIS obtains about 10 complete global coverages within a month period, which contain different viewing and illumination geometries. Therefore, monthly albedo production period is a good compromise for MERIS albedo products in terms of available observations and model requirements. However, cloud contamination further reduces valid bidirectional observations. Our previous studies have shown that a typical full inversion for a 3-parameters kernel-driven BRDF model would require at least 7 angular observations [Wolfgang et al., 2000; Schaaf et al., 2002]. Otherwise, the inversion will need ancillary information support. Due to the limited angular observations provided by MERIS instrument, the BRDF/Albedo retrieval from MERIS data will therefore require ancillary information supports for most cases.

The MODIS instruments aboard on the Terra and Aqua platforms were successfully launched on December 18, 1999 and May 4, 2002 respectively. The MODIS instrument provides similar spatial resolution products (see Table 1) to MERIS. They provide four similar spectral bands from blue to near infrared spectral wavelength as defined in Table 2. Two instruments (MERIS and Terra/MODIS) are just about 30 minutes apart on their equator crossing. The MODIS surface products provide cloud-cleared and atmospherically corrected surface reflectance as inputs for the MODIS BRDF/Albedo product [Schaaf et al., 2002]. The MERIS surface level 2 products provide the normalised reflectance (bulk corrected but with aerosol still present) and QA flags for cloud [ESA, 2002]. The aerosol effects will be removed in the MERIS level 3 product [Santer et al., 2000]. There is over a year overlapping period for MERIS and MODIS products. Therefore it is possible to cross validate MODIS and MERIS data and produce the coupled BRDF/albedo products.

Table 1. Technical Comparisons between MERIS and MODIS Instruments

	MERIS	**MODIS**
Spectral Bands (4 close bands)	15 (13 for level 2 products) 412.5 nm – 865.0 nm	36 (7 for land products) 495 nm- 2155 nm (for land)
Delivered Spatial Resolution at Nadir	300m (Full Resolution) 1200m (Reduced Resolution)	250m (2 bands) 500m (5 bands) 1km (29 bands)
Field of View (swath width)	68.5° (1150 km)	110° (2330 km)
Global Coverage	3 days	1-2 times / day (Terra & Aqua)
Repeat Cycle	35 days	16 days
Orbit Altitude	800 km	705 km
Equator Crossing	10:00 am descending	10:30 am descending (Terra) 1:30 pm ascending (Aqua)
Launch Date	March 1, 2002 (EnviSat)	Dec. 18, 1999 (Terra) May 4, 2002 (Auqa)

Considering the many similar features between MODIS and MERIS observations, the MODIS BRDF product is as an ideal a priori information source for MERIS BRDF/albedo retrieval. In this study, we first compare the daily reflectance from MODIS and MERIS products. The current operational MODIS BRDF/Albedo backup algorithm (magnitude inversion) was used to generate the MERIS BRDF/Albedo products. Two versions of the backup BRDF databases (a priori) for magnitude inversion were used. One is the current operational MODIS BRDF database that is based on the land cover types and MODIS BRDF shapes. The other is the coincident MODIS BRDF extracted from the same period MODIS BRDF/Albedo products.

Two test sites in California and Spain were selected for this study. Both MODIS and MERIS products were available for the California site during a clear period from April 6 to 24, 2003 and for the Spanish site during a more hazy period from May 2 to 21, 2003.

Table 2. Corresponding Spectral Bands Among MERIS, MISR and MODIS (in nm)

MERIS	MISR	MODIS
490 (10)	425-467	459-479
560 (10)	543-572	545-565
665 (10)	661-683	620-670
865 (20)	847-886	841-876
		1230-1250
		1628-1652
		2105-2155

2. Approach

2.1 Data Preparation

The level 2 MERIS products are available at two spatial resolutions. The full resolution (FR) has a resolution of 300 meters. The FR scenes contain 36 * 36 tie points for a 575 km * 575 km image. Each tie point controls a 64 * 64 window. The reduced resolution (RR) has a resolution of 1200 meter. The RR scenes contain 71 * 71 tie points for an 1150 km * 1150 km image. Each tie point controls a 16 * 16 window. Since the map projection, data format and organization in MERIS are different from MODIS products, extensive pre-processings are required to combine two data sources.

The MODIS land products are gridded in the fixed tiles in a sinusoidal projection. Each tile has a fixed image size and location. The MERIS level 2 products are saved in swath data format with associated tie points for each image. These tie points and viewing and solar geometries are included in the MERIS level 2 annotation data sets (ADS). Reprojection from the MERIS scene to the MODIS sinusoidal tile involved several steps. First, the ADS auxiliary data sets were interpolated to the same resolution as the reflectance data sets (1200 m). Then a location look-up table between the MODIS sinusoidal tile and the MERIS tie points image was established. Based on this look-up table, all reflectance and viewing and solar angles were reprojected into the given MODIS tile. The most compute-consuming step of the above processes was in building the location look-up table. To reduce the location search-time, we reserved the previous matching results for the next search and thus reduced the searching window while building a relational map between the MODIS tile and the MERIS scene. This improvement reduces the computing time dramatically.

The MERIS level 2 products include cloud, land and water flags in measurement data sets (MDS) flags. They were translated into the MODIS 1-km aggregated reflectance quality control (QC) bits according to conversion values listed in Table 3. The Band QC and aggregate QC were defined according to the QC bits defined in the MODIS aggregation reflectance file specifications (see ftp://modular.gsfc.nasa.gov/pub/LatestFilespecs/MODAGAGG.fs). The MODIS BRDF/Albedo algorithm only uses the clear observations from all inputs and will only process land and shallow water pixels (Schaaf et al., 2002).

Table 3. Conversion of Quality Control from MERIS to MODIS

	Band_QC	Agg_QC
Clear Land	192	4
Clear Water	192	12
Cloud	254	777

Data preparation also includes some metadata adjustments, such as scale factor and data range adjustment. For example, the scale factor for MERIS level 2 normalised reflectance is $1.5259255*10^{-5}$, but is $1.0*10^{-4}$ for MODIS 1-km aggregated reflectance. The range of azimuth angle for MERIS data is 0 to 360 degrees, while MODIS used –180 to 180 degrees.

Two research sites were selected for this study. The California site includes MERIS data from April 6 to 24, 2003. Four clear days (April 6, 8, 9 and 24) were selected for this study. The MODIS BRDF/Albedo products for the tile h08v05 during the period of April 7 to 22, 2003 were used to compare the MERIS derived albedo. The major land surface types of the California site are shrublands, barren or sparely vegetated, grassland and evergreen needleleaf forest. The Spanish site includes MERIS data from May 2 to 21, 2003. Four days (May 2, 14, 20 and 21) were used. The MODIS BRDF/Albedo products for tile h17v04 during the period of May 9-24, 2003 were used in this study. The major land surface types at the Spanish site include croplands, shrublands, savannas, evergreen broadleaf forest.

2.2 BRDF/Albedo Retrieval

2.2.1 MODIS BRDF/Albedo Operational Algorithm (Approach A)

The MODIS BRDF/Albedo algorithm uses a semi-empirical kernel-driven BRDF model (

RossThick-LiSparse-Reciprocal) to retrieve surface BRDF and albedo. The operational code requires at least 7 clear observations for a full BRDF retrieval. Due to the limited angular observations over two test sites, all MERIS pixels in this study used the MODIS backup algorithm (or magnitude inversion).

The MODIS backup algorithm determines BRDF shapes from a predetermined BRDF database. Suppose we know the underlying BRDF can be represented as f, where f is the function of three BRDF parameters (isotropic, volumetric and geometric) and viewing and illumination geometries. The new BRDF adjusted by the actual observations (here MERIS) can be expressed as

$$f' = s * f$$

where "s" is a scale factor in the magnitude inversion. The scale factor "s" can be calculated with a least-square fitting method.

The current MODIS BRDF database was originally derived from the Olsen land cover map and MODIS derived BRDF shapes. The 94 Olsen land cover types have been converted into 24 BRDF appropriate land cover types [Strugnell et al., 2001]. Each BRDF land cover type shares a common BRDF shape that is produced from the MODIS angular observations or ground measurements. There are three layers in the current BRDF database. The active season layer represents green vegetation covers. The inactive season layer represents scenecent seasons. The snow-covered layer represents the cases covered by snow. We will denote the land cover type based BRDF database as approach A in the next.

The land cover based BRDF database is easy to implement and maintain. However, since database is based on the land cover types, it can't describe the heterogeneity within a class and can't describe BRDF phenology changes and may therefore introduce errors in the BRDF retrieval.

2.2.2 MODIS BRDF/Albedo Algorithm with Concurrent MODIS BRDF Database (Approach B)

This approach uses the same algorithm as in approach A except it uses the coincident MODIS BRDF product as BRDF shape database for the MERIS albedo retrieval. The MODIS BRDF/Albedo products are produced every 16 days. For the monthly MERIS BRDF retrieval, we can pick up the best quality value from two 16-day products as the monthly BRDF database. In this approach, each pixel has a different BRDF shape from the coincident MODIS BRDF/Albedo product if such value exists. However, we need to point out that only those pixels with full inversion from MODIS BRDF/Albedo products can effect the MERIS BRDF retrieval. The magnitude inversion of MODIS BRDF/Albedo algorithm won't be able to bring any new information about BRDF shape. It will use land cover based BRDF database as approach A.

2.2.3 Atmospherically Resistant BRDF Retrieval

Another method that could be implemented would be an atmospherically resistant BRDF retrieval. The atmospherically resistant BRDF inversion for vegetation canopy weights satellite observation according to its NDVI value. The weights of the observations are dynamically adjusted according to the latest inversion results until the point where two successive inversion results converge [Gao et al., 2002]. This M-estimator inversion approach allows us to decrease the impact of cloud contamination in the observations by lowering their contribution in the inversion. This approach would be appropriate for BRDF retrieval directly from combined MERIS and MODIS observations.

For a monthly albedo product, MODIS obtains much more observations than MERIS. Since the MERIS level 2 products haven't had the aerosol effects removed, they would be expected to have lower weights. Thus, the contributions from MERIS level 2 observations would be expected to be very low in a combined BRDF/Albedo retrieval at this time.

From an operational point of view, such a combined MODIS/MERIS product would also be a challenge for both data storage and computing. It would require the storage of daily MODIS reflectance and MERIS level 2 products for an entire month period. Therefore, this synergistic approach was not implemented in this study.

2.2.4 Spectral-to-Broadband Albedo Conversion

The spectral to broadband albedo conversion used in this study is based on the coefficients built for the MISR instrument by Liang et al. [1999] (see table 4). A specific narrow band to broad band conversion would be required for MERIS bandwidth especially for the near infrared band. The NIR broadband albedo could only be derived from the single spectral MERIS NIR band and therefore would need extensive validation for different land cover types.

Table 4. Spectral-to-Broadband Conversion Coefficients

	VIS-BB	NIR-BB	SW-BB
Blue	0.3511	0.0000	0.1587
Green	0.3923	0.0000	-0.2463
Red	0.2603	0.0000	0.5442
NIR	0.0000	0.6088	0.3748
Intercept	-0.0030	0.1442	0.0149

3. Results

The two BRDF/Albedo retrieval strategies discussed above (Approach A and B) were used to compute coupled MODIS and MERIS BRDF/albedos. For this study, the first strategy (A) is based on the current MODIS operational BRDF/Albedo backup algorithm with a land cover based BRDF database. In the second strategy (B), the coincident MODIS BRDF product is used as backup BRDF database.

Since EnviSat/MERIS and Terra/MODIS platforms are about 30 minutes apart from an equator crossing, the viewing and illumination geometries from two instruments are very close for overpasses on the same day. Figure 1 illustrates the MODIS and MERIS reflectance products on April 24, 2003 over the California tile (tile h08v05). Figure 1 (a1) and (b1) are the view zenith angles for MERIS and MODIS respectively. The MODIS nadir view is located in the north of the MERIS image. Figure 1 (a2) and (b2) are the solar zenith angles for MERIS and MODIS respectively. MERIS has larger solar zenith angles due to the earlier passing time. Figure 1 (a3) and (b3) show the false color composite maps for MERIS and MODIS reflectance respectively. General agreements between MERIS level 2 normalised reflectance and MODIS level 3 aggregated surface reflectance can be found from scattering plot (c1) (for red band) and (c2) (for NIR band), despite the fact that MERIS normalised reflectances still contain aerosol effects while MODIS surface reflectances have had the aerosol contributions removed from measurements. Note that the MERIS reduced resolution products have a resolution of 1200 meters while the aggregated MODIS surface reflectance has a resolution of about 927 meters. The widely spread blue dots in scatter plots may be partially caused by the resampling processes for the different resolution images. However, major trends in the scatter plots reveal the two data sources are very consistent for clear observations.

Figure 2 shows the broadband white-sky albedo derived from MERIS and MODIS products. The MODIS BRDF/Albedo products are the standard MODIS land product available from the USGS EDC gateway. The MERIS albedo was derived from the MODIS BRDF/Albedo backup algorithm and coupling MERIS observations with both the static BRDF database (approach A) and coincident MODIS BRDF (approach B). Figure 2 (a1), (a2) and (a3) are the MODIS white-sky albedos for visible, near-infrared and shortwave broadbands respectively. Figure 2 (b1), (b2) and (b3) are the MERIS white-sky albedos for the visible, near-infrared and shortwave broadbands derived from approach A. Figure 2 (c1), (c2) and (c3) are the MERIS white-sky albedo for visible, near-infrared and shortwave broadband derived from approach B. No major difference in results was found between approach A and B for this site. Figure 2 (d1), (d2) and (d3) show the scatter plots between MODIS and MERIS (approach B) albedos for three broadbands. The visible and shortwave broadband white-sky albedos are very consistent as shown in scatter plots d1 and d3. The MODIS NIR broadband white-sky albedos (a2) are higher than MERIS (b2 and c2). However, the linear relationship between MODIS and MERIS white-sky albedo for NIR broadband is obvious in Figure 2(d2).

The MODIS BRDF/Albedo products include BRDF parameters, albedo and nadir BRDF-adjusted reflectance (NBAR). The MODIS NBAR is the nadir viewing reflectance of the mean solar zenith angle over 16-day period derived from BRDF parameters. NBAR products eliminate the viewing angular effects and thus shows better temporal and spatial patterns. NBAR has been used in deriving MODIS global land cover map (Friedl et al., 2002). Therefore, using the same BRDF/Albedo algorithm, it is possible to produce MERIS NBAR products. Figure 3(a) shows a stitched MERIS surface reflectance map using the four different day's observations. An obvious stitch edge from northeast to southwest can be seen. It was caused typical BRDF effects -- a weaker forward scattering from the swath in the upper left side and a stronger backward scattering from another swath in the lower right side. The NBAR picture (Fig. 3b) from MERIS observations smoothed the edge effects. However, due to the very limited directional observations (only 1-3 cloud-free observations) from MERIS instrument, the stitch edge effect was not totally removed in MERIS NBAR comparing to the MODIS NBAR (Fig. 3c).

Figure 4 illustrates broadband white-sky albedo of MODIS and MERIS (approach A and B) over Spanish site. Similar to Figure 2, (a1), (a2) and (a3) in Figure 4 are the three broadband albedos from the MODIS BRDF/Albedo products. Figure 4 (b1), (b2) and (b3) are the three broadband albedos for MERIS derived from approach A and (c1), (c2) and (c3) are the three broadband albedos for MERIS derived from approach B. As we have learnt from California site, the MODIS NIR broadband albedo (a2) for Spanish site is also higher than MERIS albedo (b2 and c2) due to spectral band to broad band conversion. The higher spectral reflectance in the red spectral band (b1 and c1) and the lower reflectance in the spectral NIR band (b2 and c2) reveal the strong aerosol effects at the Spanish site during this period. The positive compensation in visible band (b1 and c1) and the negative compensation in NIR band (b2 and c2) however make the total shortwave broadband albedo (b3 and c3) still in fairly good agreement with the MODIS surface albedo (a3).

The MERIS approach B shows better agreement with the MODIS albedo in shortwave broadband in Figure 4. Figure 4(c3) reveals consistent spatial pattern to Figure 4(a3). The reason could be the Spanish site is more sensitive to the seasonal changes in May and the coincident MODIS BRDF captures BRDF seasonal changes better, while the California site is mainly consisted of shrubs and is less sensitive to the seasonal changes in April and thus there is no major difference between two approaches. However, due to the aerosol contamination in the MERIS level 2 product, quantitative analysis of how BRDF database effects the BRDF/Albedo retrieval is not possible at this point.

A field site of the BSRN/SURFRAD network, Desert Rock, Nevada, is within our California test site and has been used for field validation. The Desert Rock SURFRAD station measures downwelling (direct and diffuse) and upwelling solar radiance every 3 minutes (http://www.srrb.noaa.gov/surfrad). From the Desert Rock data, we can generate actual surface albedo at local solar noon and then compare it with the MODIS and MERIS derived albedo. Figure 5 shows MERIS and MODIS albedo at the Desert Rock during April 4 to 24, 2003. The MODIS actual albedo were calculated based on the daily measured downwelling diffuse/direct solar radiance and 16-day period MODIS BRDF. The field measurements show good agreement with satellite derived albedos except for day 105 (April 15, 2003) and around the cloudy day 112 (April 22, 2003).

4. Discussion and Conclusions

The BRDF/Albedo retrievals from MERIS observations require ancillary data support due to the very limited angular sampling capability from MERIS. The MODIS instruments have many similar features to MERIS in terms of orbit, band widths and spatial resolution and therefore the MODIS BRDF/Albedo products can provide ancillary data to MERIS BRDF retrieval. This study implemented two strategies in retrieving MERIS BRDF/Albedo by coupling MERIS and MODIS surface products. Approach A uses BRDF shape based on static land cover types as a priori knowledge. Approach B uses the coincident MODIS BRDF product as a priori knowledge.

Comparison between the MERIS level 2 normalised spectral reflectance and the MODIS level 3 aggregated surface spectra reflectance shows general good agreements over California site. Since MERIS level 2 reflectance didn't implement an aerosol correction, the agreement between MODIS level 3 surface reflectance and MERIS level 2 reflectance will largely depend on the clearness of observations. The scatter plots in Figure 6 show a better agreement of reflectance in the California site over the Spanish site. This may due to the fact that the California site in April is more clear (fewer aerosol effects) than the Spanish site.

For pixels with higher aerosol contamination, the visible broadband albedos are typically higher than MODIS and the NIR broadband albedo are lower than MODIS. This reflects typical aerosol effects on the satellite measurements over vegetated area. The total shortwave broadband albedo, due to the opposite compensation from visible and NIR bands, shows a better agreement between MERIS and MODIS.

For surface BRDF/Albedo products, it is very important to produce surface albedo based on the aerosol corrected surface reflectance, thus users can generate actual albedo based on white-sky and black-sky albedo with a simple linear equation according to the actual aerosol condition. The MERIS level 3 aerosol corrected surface reflectance are therefore expected to give much better agreements than shown here especially over hazy areas and provides better results.

The visible and total shortwave broadband albedo comparisons between MERIS and MODIS are very consistent for clear pixels. Some biases were found in NIR broadband for both the California site and the Spanish site. However, good agreements in NIR spectral band can be seen from figure 6b and 6d. Considering the MERIS NIR broadband albedos were converted from a single spectral NIR band (847-886 nm) while MODIS NIR broadband albedos were converted from 4 spectral NIR bands with wavelength spanning from 841 nm to 2155 nm, it is not surprising to see their inconsistency. New narrow-to-broad band conversion coefficients are required for MERIS NIR spectral band.

The nadir BRDF-adjusted reflectance can remove some BRDF effects from MERIS angular observations. However, due to the very limited observations from MERIS, the NBAR results were found not as good as MODIS in two test sites.

The BRDF/Albedo retrieval with the coincident MODIS BRDF database provides a better description of seasonal BRDF changes and thus is more appropriate for the MERIS BRDF/Albedo retrieval. Direct combination of MODIS and MERIS reflectance products is not feasible for several reasons at this time. First, the MERIS level 2 reflectance has not been aerosol corrected. Even though MERIS level 3 will provide aerosol corrected reflectance, differences in atmospheric correction and in bandwidth may still prevent the direct combination. Second, such combination processing is also a challenge from the operational point of view in terms of data structure, file transfer, data storage and operation environments. Therefore, the use of BRDF shape from MODIS products is a feasible scheme at the present stage.

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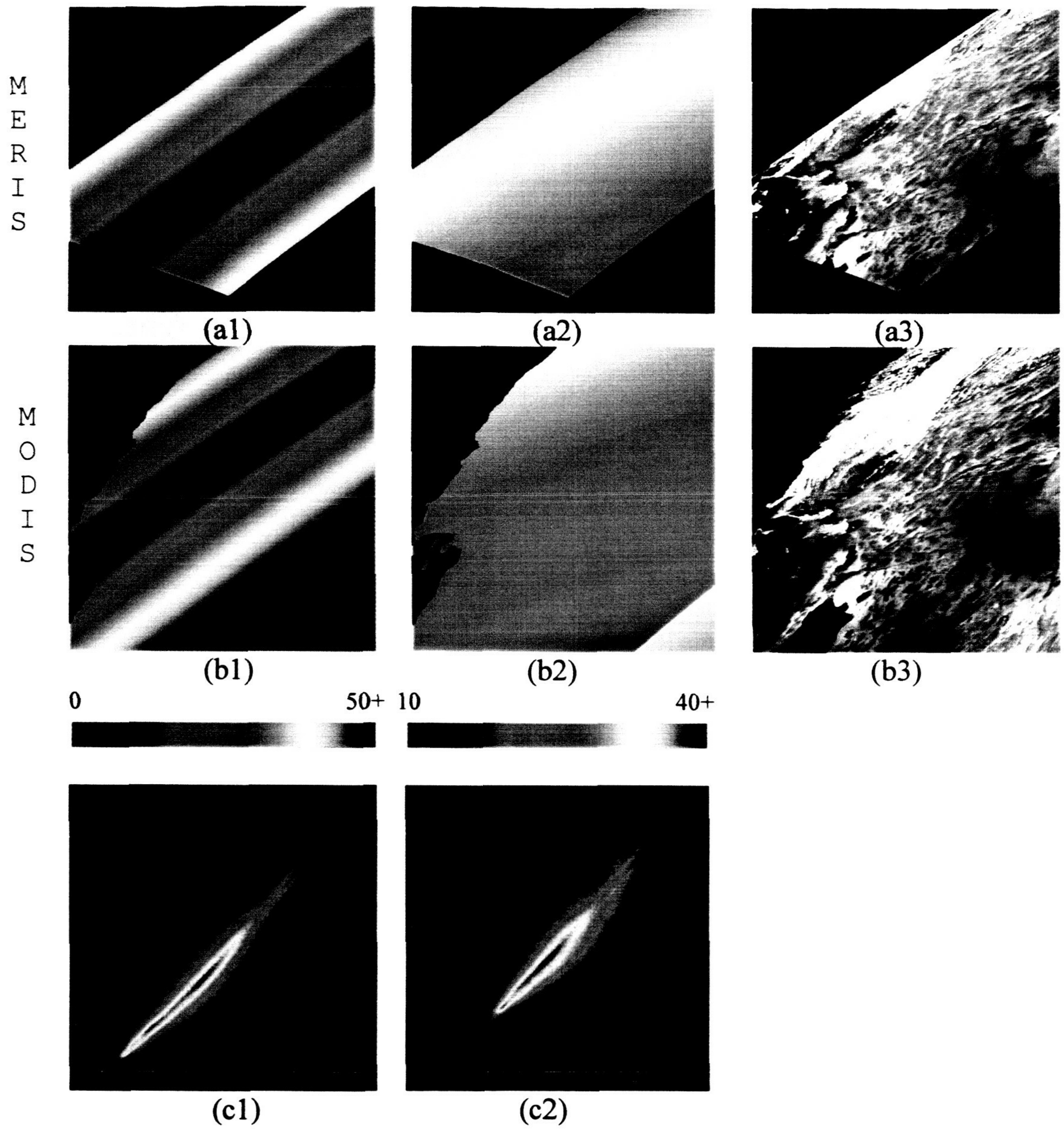


Figure 1. Spectral reflectance from MODIS and MERIS products on April 24, 2003 over California site. In figure, (a1) and (b1) are the view zenith angles for MERIS and MODIS respectively; (a2) and (b2) show the solar zenith angles for MERIS and MODIS respectively; (a3) and (b3) show color composite map from MERIS and MODIS reflectance respectively with NIR band as red (range: 0-0.4), red band as green (range: 0-0.3) and green band as blue (range: 0-0.3); (c1) and (c2) are the scatter plots of red and NIR spectral band between MERIS and MODIS surface reflectance respectively. The surface reflectance derived from MERIS and MODIS are very consistent for clear pixels despite the fact that MERIS reflectance still contains aerosol effects while MODIS surface reflectance has removed aerosol contamination.

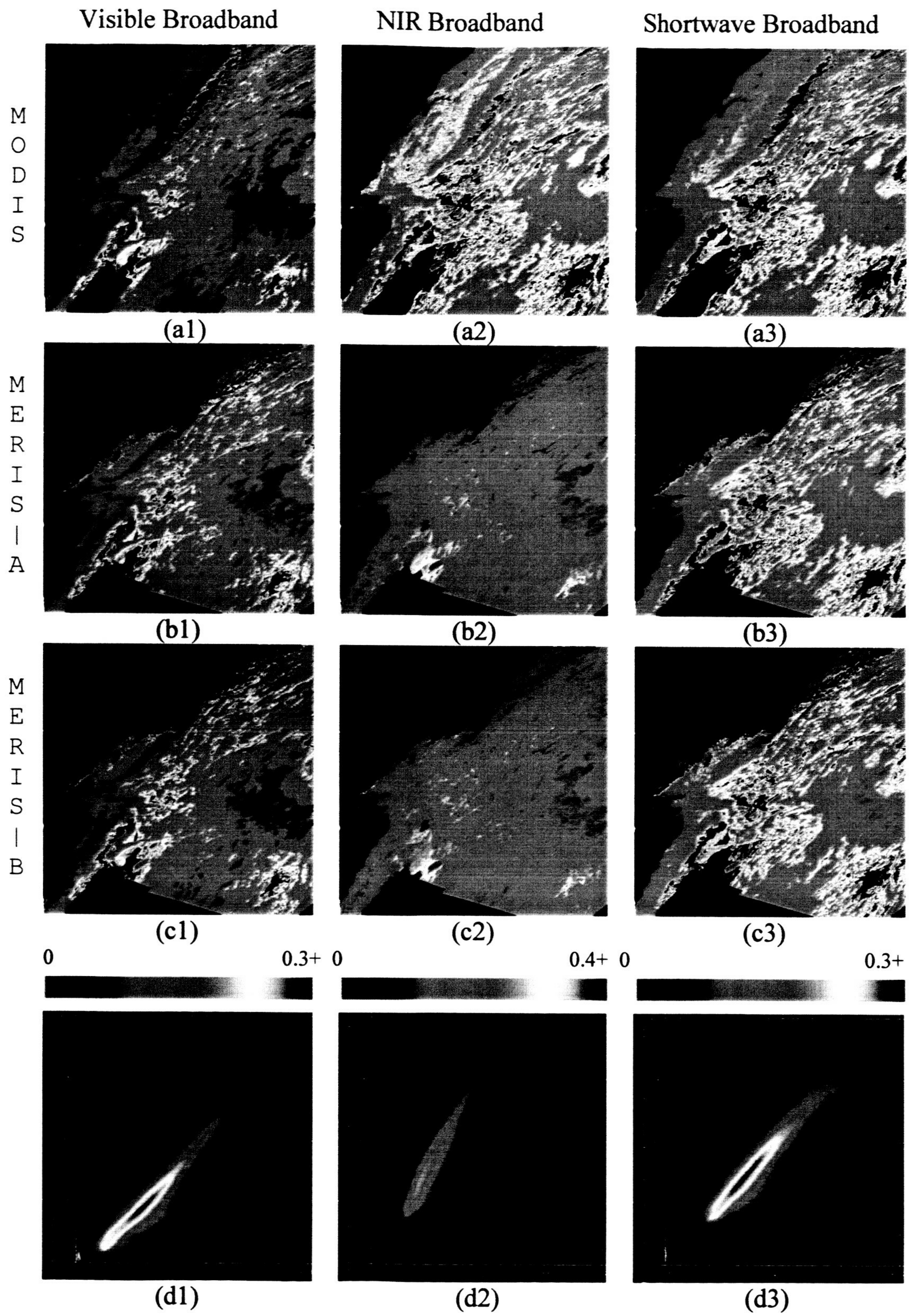
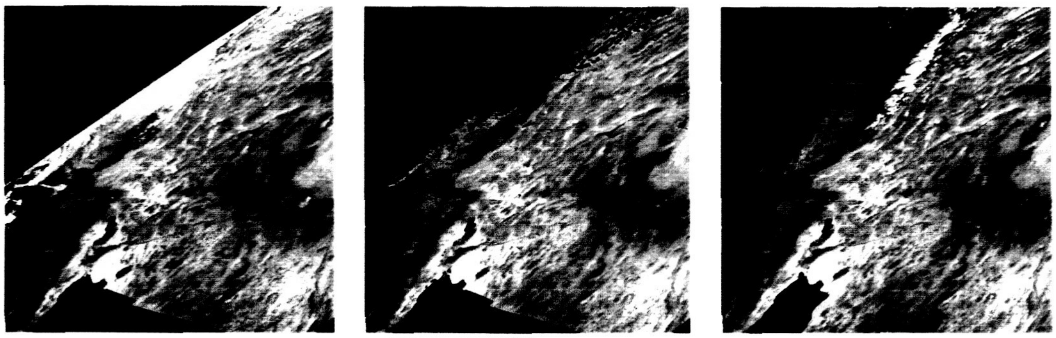


Figure 2. Broadband white-sky albedo for MERIS and MODIS over California site. In figure, (a) shows MODIS albedo for three broadbands; (b) shows MERIS albedo for three broadbands derived from approach A; (c) shows MERIS albedo for three broadbands

derived from approach B; (d) shows the scatter plots between MODIS (y-axis) and MERIS (x-axis) for three broadbands; (1) represents visible broadband; (2) represents NIR broadband; (3) represents shortwave broadband. The scatter plots of visible (d1) and shortwave (d3) broadband albedos show good agreements between two products. The scatter plot of NIR (d2) broadband reveals show biases between MERIS and MODIS albedo.



(a) (b) (c)

Figure 3. The MERIS daily reflectance mosaic picture (a) shows a strong stitch edge, while the MERIS nadir BRDF-adjusted reflectance (NBAR) (b) has smoothed the edge and shows a general consistency to the MODIS NBAR (c) data.

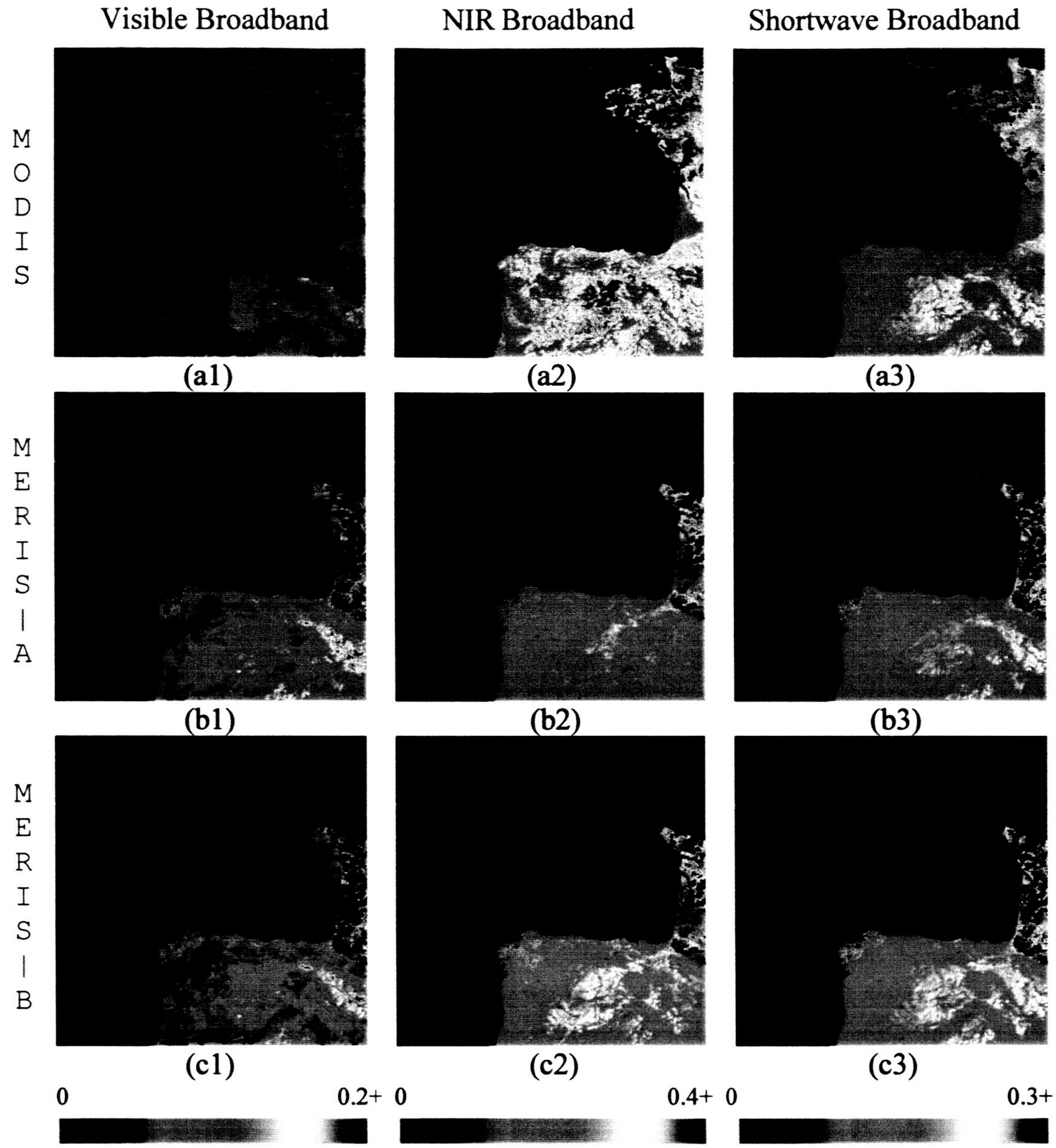


Figure 4. Broadband white-sky albedo of MERIS and MODIS over the Spanish site. Figure (a) shows MODIS albedo; (b) shows MERIS albedo derived from approach A; (c) shows MERIS albedo derived from approach B; (1) represents visible broadband; (2) represents near-Infrared broadband; and (3) represents shortwave broadband. Shortwave broadband albedo from approach B (c3) displays consistent spatial pattern comparing to (c1), which reveals the better description of BRDF shape from coincident MODIS BRDF product.

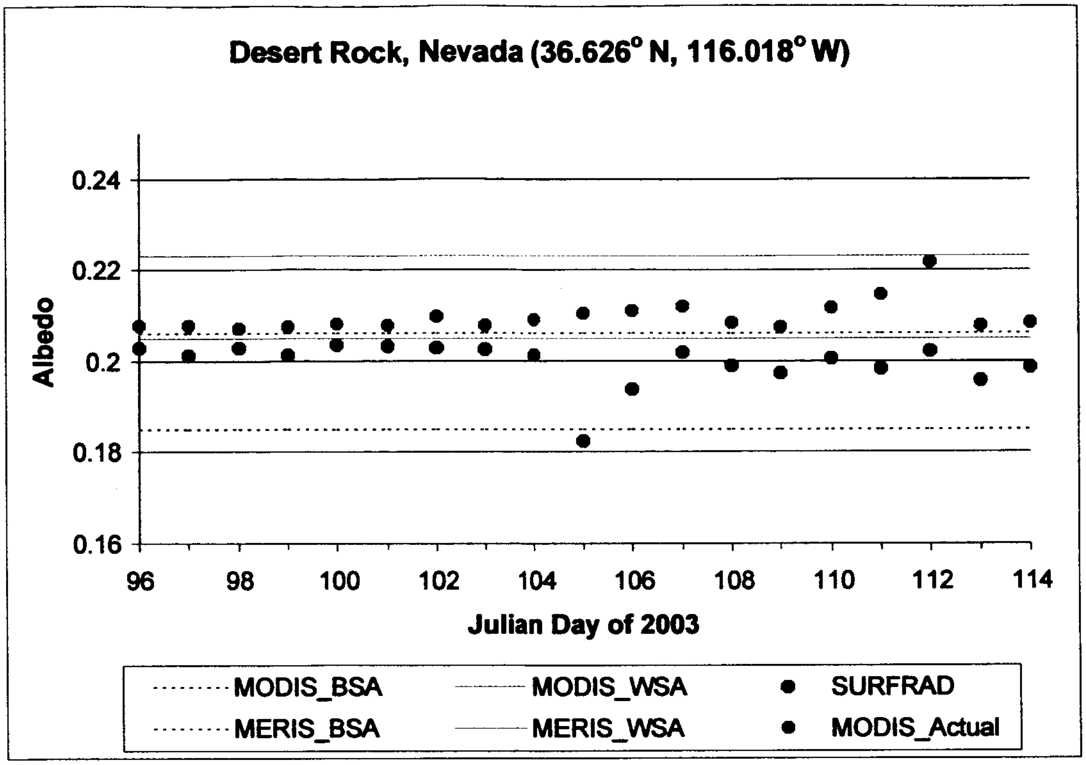
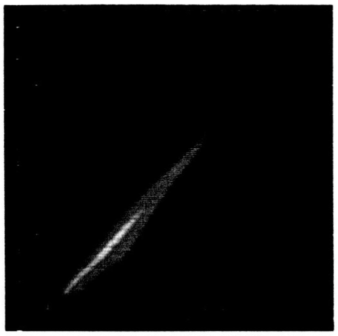


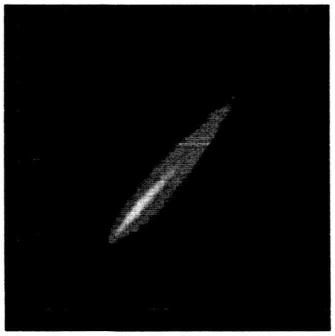
Figure 5. MERIS and MODIS albedo at Desert Rock, Nevada during April 4 to 24, 2003 (BRSN/Surfrad site). Red dots are the actual MODIS albedo calculated from the daily measured downwelling diffuse/direct radiance and 16-day period MODIS BRDF. Blue dots are the field measured albedos at local solar noon time. Figure shows general good agreement between field and satellite derived albedos except for day 105 (April 15, 2003) and some days around cloudy day 112 (April 22, 2003).

(a) Spain, red

(b) Spain, NIR



(c) California, red



(d) California, NIR

Figure 6. Scatter plots of MODIS vs. MERIS white-sky albedo for two spectral bands over California and the Spanish sites. Plots show general agreement between MODIS and MERIS albedo for spectral bands, which implies the biases in NIR broadband are due to the narrow band to broadband conversion. Also note that the clear site (California) shows better agreement of spectral albedo than the hazy site (Spain).