SAND DUNE RIDGE ALIGNMENT EFFECTS ON SURFACE BRF OVER LIBYA-4 CALIBRATION SITE

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ABSTRACT

The Libya-4 desert area, located in the Great Sand Sea, is one of the most important bright desert CEOS pseudo-invariant calibration sites by its size and radiometric stability. This site is intensively used for radiometer drift monitoring, sensor intercalibration and as an absolute calibration reference based on simulated radiances traceable to the SI standard. The Libya-4 morphology is composed of oriented sand dunes shaped by dominant winds. The effects of sand dune spatial organization on the surface bidirectional reflectance factor is analyzed in this paper using Raytran, a 3D radiative transfer model. The topography is characterized with the 30 m resolution ASTER digital elevation model. Four different regions-of-interest sizes, ranging from 10 km up to 100 km, are analyzed. Results show that sand dunes generate more backscattering than forward scattering at the surface. The mean surface reflectance averaged over different viewing and illumination angles is pretty much independent of the size of the selected area, though the standard deviation differs. Sun azimuth position has an effect on the surface reflectance field, which is more pronounced for high Sun zenith angles. Such 3D azimuthal effects should be taken into account to decrease the simulated radiance uncertainty over Libya-4 below 3% for wavelengths larger than 600 nm..

1. INTRODUCTION

The Libya-4 desert area is one of the most important bright desert CEOS pseudo-invariant calibration sites by its size and radiometric stability. This site is intensively used for radiometer drift monitoring, sensor intercalibration and as an absolute calibration reference based on simulated radiances traceable to the SI standard. The Libya-4 morphology is composed of oriented sand dunes shaped by dominant winds. The effects of sand dune spatial organization on the surface bidirectional reflectance factor has been analyzed using a 3D radiative transfer model (RTM).

2. THE LIBYA-4 CEOS CALIBRATION SITE

The Libya-4 CEOS calibration site, centered at 28.55◦ N and 23.39◦ E in the Great Sand Sea, is composed of spatially-organized sand dunes. Monthly mean precipitation is about 1 mm over that area, with very low cloud cover. The global digital elevation model (DEM) derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) observations has been used for our sensitivity analysis. This DEM, based on stereo correlation, has a spatial resolution of 1s or about 30 m at the Equator. The corresponding estimated accuracy, *i.e.*, vertical root-mean-squared-error, ranges between 10 m and 25 m. The northeast part of the area has the lowest altitude, populated with the crescent sand dune (barchan) type.

Figure 1 shows a 20 km-long longitudinal elevation profile centered at 28.55◦ N and 23.39◦ E. Sand dunes are typically 60 m high with an inter-dune distance ranging from 1000 m to 2000 m.

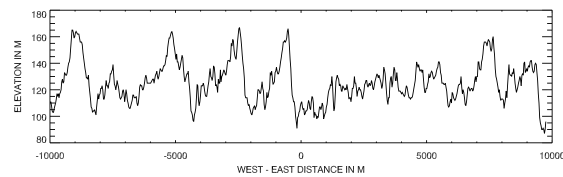

Figure 1: Twenty kilometer-long west-east longitudinal elevation profile over Libya-4 passing through the site center. Distances are given in meters.

The slope distribution has been analyzed based on the ATSER DEM. Results are shown in Figure 2. All ROIs exhibit a maximum slope frequency of around 6◦–7◦. The 20 km × 20 km and 50 km × 50 km ROIs have slightly less slopes with angles higher than 15◦ compared to the 10 km × 10 km and 100 ×100 km ones. Note that, whatever the ROI size, the maximum sand dune slope or repose angle does not exceed 35◦, a number in agreement with expected values for dry sand.

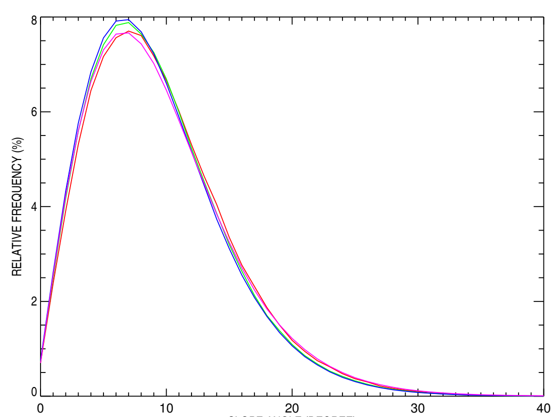

Figure 2: Slope angle relative frequency distribution over the four ROIs: 10 km × 10 km (red line), 20 km

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× 20 km (green line), 50 km × 50 km (blue line) and 100 km × 100 km (magenta line). Horizontal surfaces have a 0° normal direction.

We next evaluate the azimuthal distribution of the slopes having a repose angles affecting surface BRF, *i.e.*, lying between 15° and 35°; Figure 2. For all ROIs, steep slopes are predominantly pointing toward the east direction, *i.e.*, downwind. The 100 km × 100 km ROI has the most regular slope azimuthal distribution and the smallest one, *i.e.*, 10 km × 10 km, the most irregular one. These steep slopes, observed facing away from the wind direction, cast more shadow than those on the opposite side, resulting in different reflectance magnitude as a function of the illumination azimuth direction. It is therefore expected that this uneven slope azimuth distribution is responsible for BRF effects, depending on the azimuth illumination angle

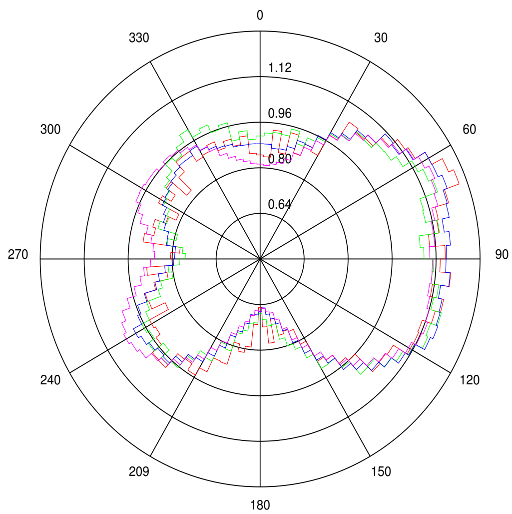

Figure 3: Steep slope, *i.e.*, with a repose angle ranging between 15° and 35°, azimuth direction relative frequency distribution over the four ROIs: 10 km × 10 km (red line), 20 km × 20 km (green line), 50 km × 50 km (blue line) and 100 km × 100 km (magenta line). Circles represent the relative frequency (%) of slope azimuth angles, and polar angles represent the azimuth with zero value pointing to the north.

3. BRF SIMULATIONS

Raytran, a 3D RTM, has been used to analyze the effects of sand dune spatial organization on surface Bidirectional Reflectance Factor (BRF) (Govaerts and Verstraete, 1998). This model has been extensively evaluated and has proven to be one of the most accurate surface RTMs (Widlowski et al, 2013).

Unfortunately, no Libya-4 *in situ* sand BRF property measurements are available. More generally, only very limited sand BRF datasets have been acquired. As the primary objective of this paper is to quantify the effects of sand dune spatial organization on surface BRF, we therefore assume a Lambertian sand reflectance. In other words, each triangle representing the sand dune topography within Raytran is assumed to be a Lambertian surface. Consequently, reflectance anisotropy over Libya-4 is only due to topography effects, *i.e.*, sand dune shadows in these Raytran simulations. Secondly, we assume that the sand reflectance properties at a given wavelength are the same over the entire ROI, *i.e.*, all triangles are assigned the same reflectance magnitude, i.e., 0.3.

4. RESULTS

Sand dune ridge alignment effects on surface BRF as a function of the Sun Azimuth Angle (SAA) are analyzed.

Figure 4 shows surface BRF polar plots over the 20 km side region-of-interest for five different SAA values, *i.e.*, 90°, 135°, 180°, 225° and 270°. Sun Zenith Angle (SZA) is set to 50° in this experiment. A visual inspection of these polar plots reveals the overall reflectance increase in the backscattering signature resulting from sand dune topography whatever the SAA value (Govaerts, 2015). This simulation has been performed for a sand reflectance equal to 0.3. The effects of sand dune ridge alignment on surface BRF are particularly visible when Sun Azimuth Angle (SAA) is equal to 180°. In the case of simulations performed with RTM that are only dependent on the actual relative azimuth angle between the Sun and viewing directions, as is the case with the 1D model, the BRF values of the left and right side part of the hemisphere with respect to the principal plane are symmetrical. Such symmetry is clearly not observed in the present case. Additionally, a visual comparison between SAA equal to 135° and 225° plots shows distinct differences between the two illumination conditions. These two SAA configurations correspond to typical mid-morning and mid-afternoon illumination geometry for Sun synchronous polar orbiting radiometers.

5. CONCLUSIONS

Results show that sand dunes generate more backscattering than forward scattering at the surface. Sun azimuth position has an effect on the surface reflectance field, which is more pronounced for high Sun zenith angles. Such 3D azimuthal effects should be taken into account to decrease the simulated radiance uncertainty over Libya-4 below 3% for wavelengths larger than 600 nm.

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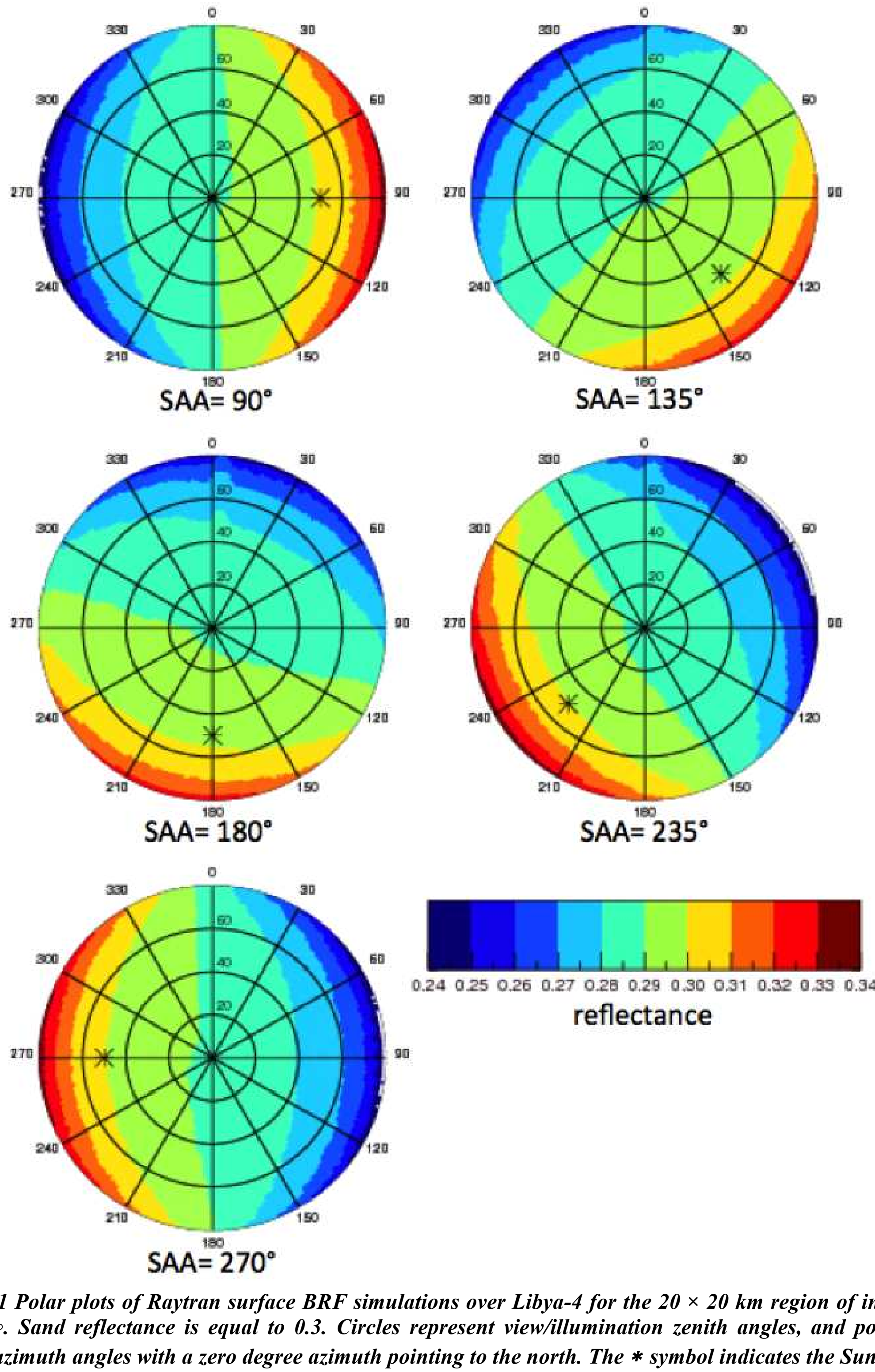

Figure 4: ***1 Polar plots of Raytran surface BRF simulations over Libya-4 for the 20 × 20 km region of interest and SZA = 50◦. Sand reflectance is equal to 0.3. Circles represent view/illumination zenith angles, and polar angles represent azimuth angles with a zero degree azimuth pointing to the north. The ∗ symbol indicates the Sun position.***