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SPECTRAL BIDIRECTIONAL AND HEMISPHERICAL REFLECTANCE CHARACTERISTICS OF SELECTED SITES IN THE STRELETSKAYA STEPPE

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ABSTRACT

Measurements of plant canopy bidirectional reflectance made by the PARABOLA (Portable Apparatus for Rapid Acquisition of Bidirectional Observations of the Land and Atmosphere) instrument in three spectral bands (662, 826, 1658 nm) are analyzed for steppe grassland sites of differing productivity levels. The variation of spectral reflectance and the normalized difference vegetation index in the solar principal plane is presented. Comparisons are made with PARABOLA measurements from selected FIFE grassland sites in the Konza Prairie, Kansas. The Streletskaia Steppe sites showed no strong hot spot reflectance, while this effect was present in some FIFE sites but absent in others. The hot spot effect seems to be dependent on canopy geometry and background reflectance characteristics of these sites. Spectral hemispherical reflectance was computed from the angular integration of the directional measurements for the steppe sites. Total shortwave albedo was estimated from these hemispherical reflectance measurements and compared to albedo measured by pyranometers. The albedo estimates from PARABOLA were found to be from approximately 12-17% higher than the pyranometer measurements.

INTRODUCTION

As a part of the Soviet Kursk Experiment 1991 (KUREX-91), a team of US researchers participated in the July 1991 intensive field campaign on the Kursk Biospheric Reserve (51.6 N, 36.1 E). A component of the US team effort was ground based measurements of plant canopy spectral bidirectional reflectance which were made from July 7-25 on selected grassland sites of the Streletskaia Steppe portion of the Biospheric Reserve with the PARABOLA instrument. Measurements of the bidirectional reflectance of grasslands on selected FIFE sites have shown these surfaces to be highly anisotropic in nature with the anisotropy varying as a function of solar zenith angle (Deering and Middleton [1]). In order to more accurately interpret and thus utilize more fully the measurements made by off-nadir viewing satellite sensors, the dynamics of the bidirectional reflectance characteristics of various earth surface types need to be more fully understood. The principal objective of the field study reported here is to determine the dynamic characteristics of the bidirectional reflectance distribution for grassland sites of differing primary production levels on the reserve. Measurements focussed on the changes in bidirectional reflectance as a function of solar zenith angle and as a function of the changes in phenology of the vegetation at these sites. Another primary objective of this experiment is the establishment of relationships between field measured bidirectional reflectances and biophysical parameters, including an assessment of spectral vegetation index variability with solar and view angles.

In this paper we will present a comparison of spectral bidirectional reflectances of the KUREX-91 sites with those of selected FIFE sites. We also utilize these measurements to make preliminary estimates of the total albedo which we compare to pyranometer measurements of albedo.

EXPERIMENT SITES AND INSTRUMENTATION

Measurements were made with the PARABOLA instrument on three sites in the Streletskaia Steppe from the period July 7-25, 1991. One site was mowed (Site #13) just prior to the start of our experiment, while the second site (Site #14) is never mowed or grazed ("absolutely reserved"), and the third site (Site #12) is mowed 3 out of every 4 years

and was last mowed in 1989. The mowing and subsequent removal of hay affects the soil productivity at mowed sites. The dominant species of grasses at both KUREX sites 12 and 14 were calamagrostis, bromis, and stipa. The average leaf area index (LAI), measured by a LI-COR LAI-2000, in early July 1991 at site 12 was 3.59 and at site 14 was 4.06. Both sites 12 and 14 had significant amounts of dead grass litter on top of the soil from previous years growth. In this paper we present measurements for two sites, site 14 on July 8, 1991 with cloud cover of about 10 % cumulus and site 12 on July 14, 1991 with about 5% cumulus cloud cover. The percent diffuse irradiance was low on both days, 15% at 662 nm on July 8 and 8% at 662 nm on July 14. The bidirectional reflectance at these KUREX-91 sites were compared to three grassland sites measured by PARABOLA in FIFE 87. These sites were FIFE site 2 on June 6, 1987 with an average LAI of 1.39 and dominant species of smooth brome and prairie dropseed, FIFE site 6 on June 5, 1987 with LAI of 0.94 with big and little bluestem, and FIFE site 10 on August 16, 1987 with LAI of 1.91 and big bluestem and western ragweed. It is noted that at the FIFE 87 sites, LAI was measured with a LI-COR Leaf Area Meter which may yield significantly different values of LAI than values inferred from a LI-COR LAI-2000, as was used at the KUREX sites. However, it is reasonable to assume that the LAI at both KUREX sites is significantly higher than that of the FIFE sites selected here. FIFE sites 2 and 6 were unburned in 1987, thus leaving the dead grass litter of the previous season while site 10 was burned in the spring of the same year. Measurements were taken under sky conditions ranging from cloudless to 5% cloud cover for the 3 FIFE sites.

The PARABOLA instrument field radiometer (Deering and Leone [2]) was employed to measure the directional radiance in essentially the complete sky and ground hemispheres. The PARABOLA is a three channel (650-670, 810-840, 1620-1690 nm) radiometer with a scanning head that turns on two axes, which enables the acquisition of radiance data for almost the complete sky and ground looking hemispheres in 15 degree instantaneous field of view sectors in 11 s. The PARABOLA is mounted on a tripod and boom system which places the instrument head about 5 m above the ground level, and a downward viewing camera with wide angle lens is mounted adjacent to the PARABOLA.

Measurements of the grassland canopy albedo at the KUREX sites were made with upward and downward facing Eppley PSP pyranometers mounted on a boom extending about 2 m south of a tripod mount and about 1.5 m above ground level.

RESULTS AND DISCUSSION

The bidirectional reflectance in the solar principal plane for the three PARABOLA wavebands for KUREX site 12 on July 14, 1991 is shown in Fig. 1. In the red band, 662 nm, there is a strong increase in the backscatter reflectance from 45-75 degrees view angle as solar zenith angle increases from 33 to 48 degrees, while for other view angles the changes in reflectance are much smaller. It is noted that there is a lack of a strong hot spot effect at the anti-solar point, which for the range of data presented would occur at the 30 or 45 degree backscatter view direction observations. The large increase in red reflectance at 75 degree forward scatter view angle is due in part to viewing of senescent inflorescences which are brighter in the visible and taller than the green leaves of the canopy and therefore obscure the green leaves from view for far off-nadir view angles. In the near infrared band, 826 nm, the 75 degree forwardscatter reflectance does not increase very rapidly relative to the 60 degree forward scatter view angle since the inflorescences are not as highly reflective as green leaves in this wavelength region. The back scatter (60-75 degrees) near infrared reflectance increases as solar zenith angle increases, similar to the

visible band. The middle infrared, 1658 nm, also shows relatively large increases in backscatter reflectance as solar zenith angle increases.

The normalized difference vegetation index or NDVI ((NIR-Red)/(NIR+Red)) exhibits a strong view angle dependence and also a significant solar zenith angle dependence for near nadir views. From 30 degrees backscatter to 30 degrees forwardscatter there is a nearly linear increase in NDVI which is due to viewing an increasing percentage of

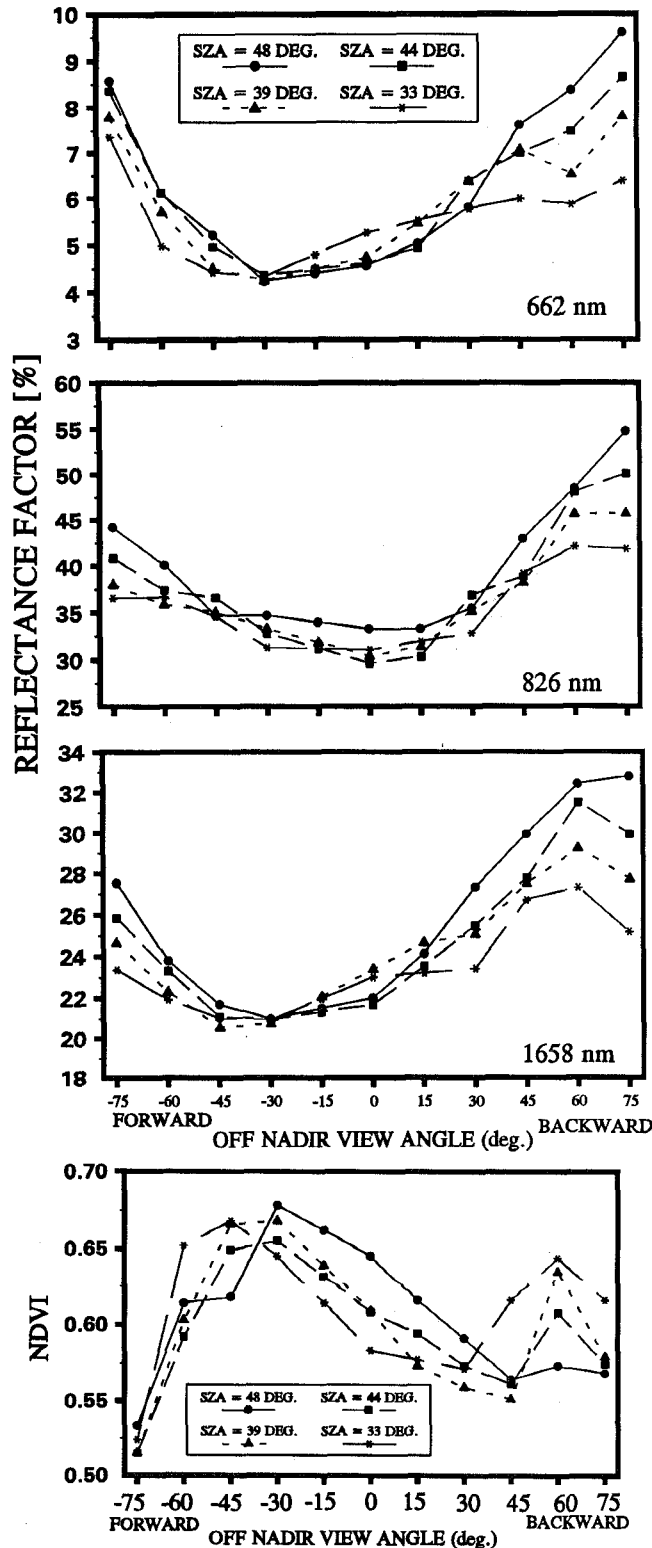


Figure 1. Bidirectional reflectance factors in three spectral bands and the NDVI, in the solar principal plane, for KUREX steppe site 12 on July 14, 1991.

shadowed area within the canopy, with the shadowing being stronger in the visible than the near infrared due to multiple scattering in the near infrared. From 30 to 75 degrees forwardscatter view direction the NDVI decreases rapidly due to the effects of the inflorescences previously described.

A comparison of principal plane bidirectional reflectance for KUREX-91 steppe sites with selected FIFE 87 grassland sites for 40 degrees solar zenith angle is shown in Fig. 2. In the red waveband, 662 nm, the only site which showed a strong hot spot is FIFE site 2 while the two KUREX sites and the other two FIFE sites show little or no local maxima at this view angle. Failure to detect the hot spot in some of these sites may be due to the relatively large field of view of the PARABOLA, 15 degrees, in relation to the width of the hot spot and due to the instrument shadow falling in the center of the hot spot. Jupp and Strahler [3] have shown through simulations that the width of the hot spot is dependent on the ratio of leaf diameter to canopy depth, with a broadening of the hot spot as leaf diameter increases relative to canopy depth. Therefore the narrow leaves of the grass in relation to the canopy depth may result in a hot spot width which is too narrow to detect with a 15 degree field of view. Inspection of downward viewing wide angle photographs of these sites shows that FIFE site 2 has a bright background in the visible relative to the green leaves and that the grass growth is in clumps thus exposing patches of bright leaf litter. Kimes et al [4] have shown from simulations of tree canopies that reflectance at the hot spot angle is the highest for canopies which are incomplete with vertical clumped vegetation and a bright background surface. The vertical photographs of the two KUREX sites show very little bright background component since these sites have relatively high LAI and more complete canopy coverage, and the other two FIFE sites also have little bright background visible due to less clumping of the grasses and a greater departure of leaf angle from the vertical.

KUREX site 14 has the lowest visible reflectance and highest near infrared reflectance at most view angles of all 5 sites, due largely to this site having the highest LAI. KUREX site 12 has a lower near infrared reflectance at most view angles than the other sites, which is due in part to the mix of senescent leaves and inflorescences with green leaves at this site. In the middle infrared waveband, 1658 nm, both KUREX sites have lower reflectances than the FIFE sites at most view angles as a result of higher LAI and possibly higher leaf water content than the FIFE sites.

Spectral hemispheric reflectances for the three PARABOLA wavebands for selected KUREX sites and solar zenith angles are shown in Table 1. These values were computed from the angular integration of the bidirectional reflectance measurements over the complete downward viewing hemisphere. Both sites show a decrease in hemispheric reflectance as solar zenith angle decreases for all three spectral bands. For KUREX site 12 there was a significant structural change in the canopy between July 14 and July 25 due to heavy winds and rain resulting in a laying down and compaction of the grasses. The difference in hemispheric reflectance between these two days at similar solar zenith angles is very small for the visible and middle infrared bands, but much larger for the near infrared band. Thus the differences in pyranometer measured total albedo (Table 1) between these two dates is most likely due to reflectance changes in the near infrared portion of the spectrum.

Estimates of total albedo were made with the hemispheric reflectances computed from the three narrow band PARABOLA channels. These bands were assumed to represent three broadband spectral regions: 300-700 nm, 700-1300 nm, 1300-4000 nm. The hemispheric reflectances were weighted by the percentage of total insolation in these spectral regions and the sum of the products of these weighting factors and the corresponding hemispheric reflectances yield an estimate of total albedo. The percentage of total insolation in the 300-700 nm band was assumed to be 47% based on the measurements of Weiss and Norman [5], who showed that PAR fraction (400-700 nm) was nearly constant at 46% over a wide range of solar zenith angles. The percentage of total insolation in the 1300-4000 nm range was assumed to be 15% based on simulations of Thekaekara [6], and the percentage of near infrared assumed to be 38%, the residual fraction. Estimates of total albedo based on the spectral hemispheric reflectances show relative percentage differences of 12.1 to 16.8% (overestimates) compared to pyranometer measured albedo. Starks et al. [7] calculated albedo from bidirectional reflectances over the FIFE sites and found mean relative errors of about 22 to 28%, also overestimates. Failure to account for the weighting of the narrow band reflectances to the vegetation reflectance spectra across the broadband spectral regions may have contributed to the errors in the estimates of albedo.

DATE	SITE	SZA	HEMISPHERIC REFL. [%]			TOTAL ALBEDO [%]		
			662 NM	826 NM	1658 NM	EST.	MEAS.	(E-M) / M
7/14	12	49.3	6.5	39.8	25.9	22.1	19.3	14.5
7/14	12	44.4	6.3	38.8	25.5	21.5	18.4	16.8
7/14	12	32.5	5.5	35.1	23.7	19.5	17.2	13.4
7/21	14	69.1	5.7	51.9	30.0	26.9	24.0	12.1
7/21	14	58.5	5.0	47.7	27.0	24.5	21.1	16.1
7/25	12	51.5	6.6	34.2	25.0	19.8	17.4	13.8
7/25	12	45.7	6.5	33.6	24.8	19.5	17.1	14.0

Table 1. Hemispheric spectral reflectances measured by the PARABOLA and total albedo measured by pyranometer and estimated from hemispheric reflectances, for KUREX steppe sites as a function of solar zenith angle (SZA).

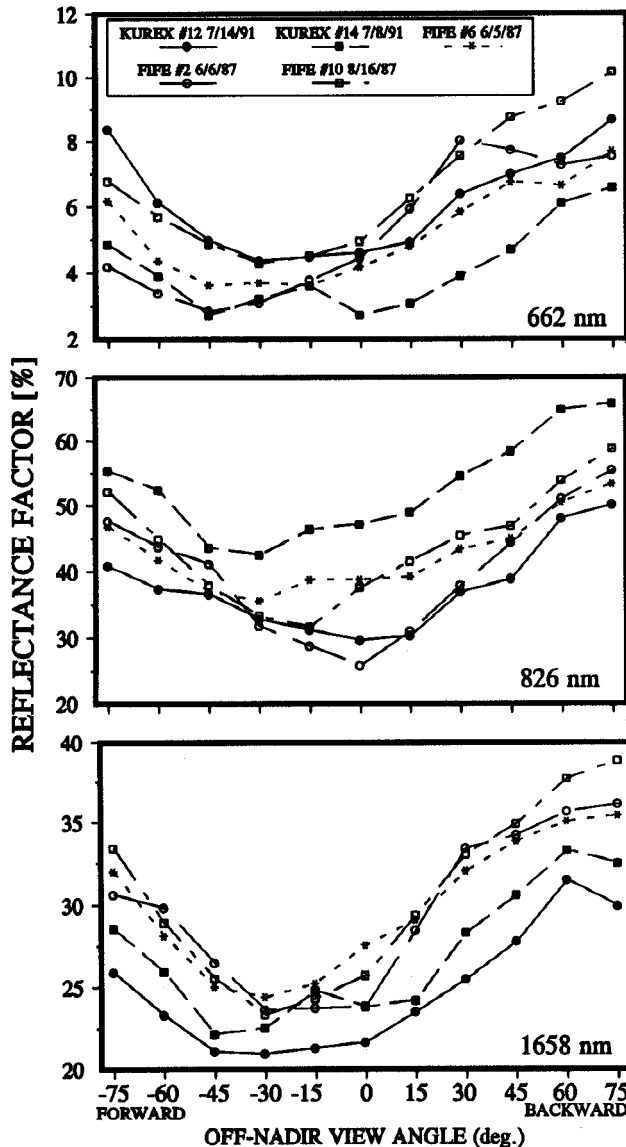


Figure 2. Spectral bidirectional reflectance factors in the solar principal plane for selected KUREX steppe sites and FIFE 87 grassland sites at a solar zenith angle of 40 degrees.

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