1991

Slope Effects on Shortwave Radiation Components and Net Radiation: Interim Report for Period April 1, 1991- December 31, 1991

E. A. Walter-Shea
University of Nebraska - Lincoln

B. L. Blad
University of Nebraska - Lincoln

C. J. Hays
University of Nebraska - Lincoln

M. A. Mesarch
University of Nebraska - Lincoln

Slope Effects on Shortwave Radiation Components and Net Radiation

Interim Report for Period
April 1, 1991 - December 31, 1991

NASA Grant NAG5-894

by

Elizabeth A. Walter-Shea, Blaine L. Blad, Cynthia J. Hays and Mark A. Mesarch

Department of Agricultural Meteorology
Institute of Agriculture and Natural resources
University of Nebraska-Lincoln
Lincoln, Nebraska 68583-0728

AgMet Progress Report 92-1
January 1992

INTRODUCTION

The main objective of the International Satellite Land Surface Climatology Project (ISLSCP) has been stated as "the development of techniques that may be applied to satellite observations of the radiation reflected and emitted from the Earth to yield quantitative information concerning land surface climatological conditions." The major field study, FIFE (the First ISLSCP Field Experiment), was conducted in 1987-89 to accomplish this objective. Four intensive field campaigns (IFCs) were carried out in 1987 and one in 1989. Factors contributing to observed reflected radiation from the FIFE site must be understood before the radiation observed by satellites can be used to quantify surface processes. Analysis since our last report (Walter-Shea et al., 1991) has focused on slope effects on incoming and outgoing shortwave radiation and net radiation from data collected in 1989.

MATERIALS AND METHODS

Instrumentation and Experimental Site

A Barnes Modular Multiband Radiometer (MMR) 12-1000, Radiation Energy Balance Systems (REBS) single dome net radiometers and Eppley Precision Spectral Pyranometers (PSPs) were used to collect incoming and reflected radiation over 15 prairie vegetative plots and one bare soil plot at FIFE experimental Site 966 (2437-BBS) in 1989. Plots were selected from hill tops (horizontal surfaces) and from slopes with aspects aligned in the four cardinal directions and in close proximity to each other.

The MMR collects spectral data in eight wavebands ranging from the visible to the thermal infrared. The MMR, set with 15° field of view, was mounted on a portable, inclinable mast three meters above the soil surface producing a target spot size of 0.8m at nadir. The MMR was calibrated in 1989 by Dr. Brian Markham at NASA/Goddard Space Flight Center in Greenbelt, Maryland according to the method of Markham et al. (1988). Bidirectional reflected radiation was measured at seven to eight view zenith angles in the plane parallel to the slope aspect at nadir, 20°, 35° and 50° on either side of nadir and normal to the plot (if it varied from the other viewing directions).

Nadir-viewed MMR data were collected over a horizontally-mounted, calibrated Labsphere halon reference panel (Labsphere Inc., P.O. Box 70, North Sutton, NH 03260) to estimate incident radiation in each MMR wave band. The panel was calibrated using the Department of Agricultural Meteorology's field-reference panel calibration goniometer (Walter-Shea et al., 1992) following the field calibration method of Jackson et al. (1987). This method corrects panel reflected radiation data for the panel's non-Lambertian properties. Incoming radiation values were estimated from the panel reflected radiation data using MMR calibration coefficients provided by B. Markham to yield units of spectral radiance (W m^{-2} sr^{-1} μm^{-1}).

A portable A-frame was mounted with: (1) one upright Eppley PSP to measure incoming shortwave radiation on a horizontal surface; (2) two inverted Eppley PSPs to measure reflected shortwave radiation component measurements (one horizontally-mounted, the other mounted parallel to the slope); and (3) two net radiometers to measure net radiation (one horizontally-mounted, the other mounted parallel to the slope). The inclined PSP and net radiometer were adjusted at each plot to the appropriate angle representing the plot slope aspect.

A limited number of MMR and A-frame measurements were made due to terrain roughness and equipment restrictions. Approximately two hours were required to complete an entire run (multidirectional measurements over all plots on all slopes) so that large changes in solar zenith angle resulted during a single run. Thus, discussion will be limited to comparisons of radiation measured from instruments horizontally-mounted (nadir) or mounted parallel (normal) to the sloped surface. Comparisons will be used to indicate errors (or lack of error) involved when the effective illumination is not taken into account.

Experimental Procedures

MMR nadir-viewed measurements of the reference panel were taken at the beginning of the measurement run, followed by MMR multi-angle reflected radiation measurements over prairie vegetative and bare-soil plots. Repeated measurements from the A-frame were made in the same plots as the MMR, immediately following bidirectional reflected radiation measurements. Nadir-viewed reflected radiation from the reference panel were periodically measured during the run with a final nadir-viewed reflected reading completing the sequence of measurements.

Incoming radiation received on a horizontal surface was corrected to represent radiation received on an inclined surface. Correction requires the effective (or local) solar zenith angle. The effective solar zenith angle was calculated (from Iqbal, 1983) as:

$$\cos\theta_e = \cos\beta\cos\theta_s + \sin\beta\sin\theta_s\cos(\psi-\gamma) \qquad [1]$$

where:

β = slope of surface (measured from the horizontal)
γ = surface azimuth angle (ranging in value from 0 to ±180 with east = +90 and west = -90)
θ_e = effective solar zenith angle
ψ = solar azimuth
θ_s = solar zenith angle
$\arccos(\sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega)$
ω = hour angle
ϕ = geographic latitude
δ = declination angle

Incoming radiation values (from the upright PSP and MMR nadir-viewed reflected radiation from the field-reference panel) were cosine corrected to account for incident radiation received at the sloped surface (values multiplied by the ratio of the cosine of the effective solar zenith angle (θ_e) and the cosine of the solar zenith angle (θ_s), i.e., $\cos\theta_e/\cos\theta_s$). Nie and Kanemasu (1989) corrected the direct beam component. Total incoming radiation was cosine corrected in our study.

RESULTS AND DISCUSSION

Variation in actual and effective solar zenith angles. The effective solar zenith angles of four of the fifteen vegetative plots (one from each slope) at Site 966 observed during the measurement period are given in Table 1. Table 1 provides an example of the variation in effective solar zenith angles possible for sloped surfaces at the FIFE site. Inclination angles of these four plots ranged from 12 to 18° from the horizontal. For the relatively gentle slopes and limited times of measurement at site 966, the greatest difference observed between the actual solar zenith angle and the effective solar zenith angle was approximately ±18° (resulting in a correction of 1.3 and 0.62 times the measured value). Both situations (i.e., corrections which increase and decrease the horizontal surface irradiance value to simulate that irradiance received on an inclined surface) occurred on the east-facing slope.

Field-reference panel cosine correction test. A simple test was conducted to estimate the error involved in using the cosine correction method to estimate irradiance on a sloped surface. MMR reflected radiation data from a Labsphere Spectralon field-reference panel collected using the field-panel calibration goniometer (Walter-Shea et al., 1992) was used in the test. The goniometer permits the inclination of field-reference panels at 10° increments, to effectively illuminate panels at 15 to 75° illumination angles in a short period of time. The calibration requires panels be measured at various inclination as well as in a horizontal position. Thus, the horizontal measurement simulates the reference data measured at site 966 while the inclined panel values give an indication of values expected at all possible illumination angles on sloped surfaces. The data were collected under three different diffuse sky conditions. Nadir-viewed MMR data measured from a horizontally-mounted field-reference panel were cosine corrected to represent irradiance received on a sloped surface. These corrected values were compared to values from inclined panels effectively illuminated at various angles. The method was tested for all seven MMR optical wave bands (Table 2). The cosine corrected values on the average overestimated the actual inclined measured reflected values. However, the largest relative error of 0.5% was in the blue portion of the spectrum (wave band 1) with the lowest relative error of 0.03% in the mid-IR region (wave band 7).

Slope Effect on Bidirectional Spectral Radiance. Nadir-viewed reflected radiation values generally are used as an estimate of surface albedo. Generally, surfaces are assumed to be Lambertian so that a simple cosine correction is applied to simulate the radiation reflected in the direction normal to the sloped surface. Difference between nadir-viewed reflected radiation and that from a view direction normal to the surface were investigated. MMR reflected radiation collected at nadir was compared to MMR reflected radiation collected in a position normal to the inclined surface (Table 3). The largest difference between nadir-viewed radiances and that measured from a view direction normal to the surface occurred on the north-facing slopes for all seven wave bands with the reflected radiation measured for the surface normal 1-3 $W\ m^{-2}\ sr^{-1}\ \mu m^{-1}$ lower than the nadir-viewed values. Mean relative errors were approximately 4-10%.

Cosine-Correction Effect on Bidirectional Reflectance Factors. Comparisons for all seven MMR optical wave bands were made between reflectance factors calculated using nadir-viewed panel data and reflectance factors calculated using cosine corrected-nadir-viewed panel data (Table 4). Reflectance factors are for all view zenith angles. The greatest mean relative errors (approximately 9%) are for those values from the north and west-facing slopes. Although the mean bias error (MBE) and mean relative error (MRE) are low for the east facing slopes, the graphs (Fig. 1) and r^2 indicate that large differences between the two methods of calculating reflectance factors can result. Differences are attributed to the large difference in actual and effective solar zenith angles (Table 1).

Slope Effect on Reflected and Incoming Shortwave Radiation, Albedo and Net Radiation. Reflected shortwave radiation measured with the two inverted Eppley PSPs over horizontal and inclined surfaces were compared (Table 5). Reflected radiance from the two PSPs over the horizontal surfaces varied, indicating a variation in target surface and instrument performance as well as experimental error. Variation between measured reflected radiation from the sloped plots as measured with the two PSPs (horizontal- and parallel-mounted) is lower than the variation between measured reflected radiation from the horizontal surfaces (hill tops) as measured with the two PSPs (both of which are horizontally-mounted). Therefore, we cannot say that there is a true difference in reflected radiation from inverted horizontally-mounted PSP and the PSP mounted parallel to the surface. Correlation coefficient values were high regardless of surface and instrument inclination. R^2 were similarly high for MMR directional radiances regardless of the surface inclination (Table 3).

Incoming shortwave radiation (measured on a horizontal surface) was cosine corrected to estimate the irradiance on inclined surfaces. Irradiance received on horizontal surfaces was compared to simulated irradiance received on sloped surfaces. Values differed the least for the south-facing slope (north, east and west facing slopes had high MBE and MRE and/or low R^2) (Table 6). As a result, albedo values calculated from reflected and incoming shortwave radiation from horizontally- and parallel-mounted PSPs differed considerably (Table 7 and Fig. 2). North-facing slope corrected values are consistently larger than uncorrected values since the effective solar zenith angle was always larger than the actual solar zenith angle during the measurement period (See Table 1). Only during large solar zenith angles would the effective angle be larger than the actual for the north-facing slope. East and west-facing slope data are "random" in nature since differences in effective and actual solar zenith angles varied during the measurement period.

Reflected radiation varied little with sensor orientation (nadir or horizontally oriented as compared to those mounted parallel to the sloped surfaces) (Tables 3 and 5). Irradiance on horizontal and inclined surfaces varied considerably (Table 6) so that calculated values of reflectance and albedo depended on instrument orientation (Tables 4 and 7). Likewise, net radiation differed according to instrument mounting as was reported by Nie and Kanemasu (1989) (Table 8).

Conclusion

Results indicate the need for careful consideration of instrument orientation in characterizing radiation balance components and net radiation of sloped terrain even on the gentle slopes (12 to 18° slopes) of our FIFE study site. Of particular concern is measurement of incident radiation. Albedo and net radiation values measured over vegetation on inclined surfaces varied considerably between values measured from instruments mounted parallel and those mounted in a horizontal position.

References

Iqbal, M. 1983. An Introduction to Solar Radiation. Academic Press, New York. pp. 390.

Jackson, R. D., M. S. Moran, P. N. Slater and S. F. Biggar. 1987. Field calibration of reference reflectance panel. Remote Sens. Environ. 22:145-158.

Markham, B.L., Wood, F.M. and Ahmad, S.P. 1988. Radiometric calibration fo the reflective bands of NS001 Thematic Mapper Simulator (TMS) and Modular Multispectral Radiometers (MMR). SPIE Recent Advances in Sensors, Radiometers and Data Processing for Remote Sensing 924:96-108.

Nie, D. and E. T. Kanemasu. 1989. A comparison of net radiation on slopes. In: Proceedings of the 19th Conf. on Agricultural and Forest Meteorology, Charleston, SC. American Meteorological Society, Boston, MA. pp. 142-143.

Walter-Shea, E. A., B. L. Blad, C. J. Hays and M. A. Mesarch. 1991. Remotely-sensed estimates of surface radiation balance components, APAR and spectral reflectance, AgMet Progress Report 91-3, Dept. of Agric. Meteorol., Univ. of Nebraska, Lincoln, NE.

Walter-Shea, E. A., C. J. Hays, M. A. Mesarch, and R. D. Jackson. 1992. An improved goniometer system for calibrating field reference-reflectance panels. (submitted to Remote Sens. Environ.)

Table 1. Solar zenith angle and effective solar zenith angle for four plots along north-, south-, east- and west-facing slopes at Site 966 during MMR and A-frame measurements.

SLOPE	DATE	PLOT	ASPECT	AZIMUTH	SOLAR ZENITH θ_s	EFFECTIVE SOLAR ZENITH θ_e	DIFFERENCE $\theta_s - \theta_e$	$\frac{\cos\theta_e}{\cos\theta_s}$
15°	166	2	NORTH	87.1	54.6	55.2	- 0.60	0.985
	166	2	NORTH	199.6	16.5	31.0	- 14.50	0.894
	166	2	NORTH	257.0	37.2	42.8	- 5.60	0.921
	195	2	NORTH	91.4	52.5	54.3	- 1.80	0.959
	195	2	NORTH	113.9	31.9	40.1	- 8.20	0.901
	221	2	NORTH	122.4	35.7	45.3	- 9.60	0.866
	221	2	NORTH	152.9	25.6	39.5	- 13.90	0.856
17°	166	7	SOUTH	91.2	49.6	51.4	- 1.80	0.963
	166	7	SOUTH	226.9	21.2	15.5	5.70	1.034
	166	7	SOUTH	262.6	42.6	43.2	- 0.60	0.990
	195	7	SOUTH	93.7	49.7	50.7	- 1.00	0.979
	221	7	SOUTH	117.5	38.6	33.7	4.90	1.065
	221	7	SOUTH	163.9	24.2	9.1	15.10	1.083
18°	166	10	EAST	97.7	42.3	24.6	17.70	1.229
	166	10	EAST	266.3	46.6	64.6	- 18.00	0.624
	195	10	EAST	95.0	48.2	30.3	17.90	1.295
	221	10	EAST	114.6	40.5	25.1	15.40	1.191
	221	10	EAST	169.1	23.8	26.7	- 2.90	0.976
12°	166	14	WEST	102.9	37.3	49.1	- 11.80	0.823
	166	14	WEST	268.0	48.6	36.6	12.00	1.214
	195	14	WEST	97.3	45.7	57.6	- 11.90	0.767
	221	14	WEST	112.0	42.5	53.8	- 11.30	0.801
	221	14	WEST	180.5	23.5	26.1	- 2.60	0.979

Table 2. **Mean relative error associated with estimating irradiance on a inclined surface using irradiance received on the horizontal cosine corrected. Inclined surface irradiance on a field-reference panel was measured with a MMR using the field-panel calibration goniometer.**

MMR Wave Band	Mean Relative Error (%)
1	0.55
2	0.29
3	0.15
4	0.25
5	0.17
6	0.08
7	0.03

Table 3. Comparison of nadir-viewed canopy radiance to radiance measured in the direction normal to the surface for all seven optical MMR wave bands at site 966. (2437-BBS)

BAND	ASPECT	MBE W/m²/sr/μm	MRE %	RMSE W/m²/sr/μm	Radiance				R	R^2	N
					NADIR W/m²/sr/μm		NORMAL W/m²/sr/μm				
					MEAN	SD	MEAN	SD			
1	NORTH	-1.667	-9.745	2.064	15.503	4.102	13.837	3.192	0.974	0.949	63
	SOUTH	0.862	3.744	2.034	17.629	5.153	18.491	6.299	0.967	0.935	54
	EAST	0.741	3.910	2.293	17.770	5.661	18.511	5.749	0.926	0.858	45
	WEST	-0.154	-2.227	1.929	17.627	5.181	17.473	6.571	0.973	0.946	45
2	NORTH	-2.290	-8.521	2.812	24.928	6.234	22.639	5.171	0.975	0.952	63
	SOUTH	1.129	3.440	2.624	25.926	6.370	27.055	7.877	0.966	0.932	54
	EAST	1.116	3.661	2.996	27.948	7.920	29.064	8.243	0.940	0.884	45
	WEST	- 0.263	-2.023	2.450	26.195	7.095	25.932	8.739	0.973	0.946	45
3	NORTH	-1.893	-9.659	2.307	17.519	4.855	15.626	3.772	0.984	0.968	63
	SOUTH	0.881	2.904	2.268	21.922	7.422	22.803	8.656	0.977	0.955	54
	EAST	0.745	3.119	2.501	21.533	7.391	22.278	7.457	0.947	0.897	45
	WEST	- 0.156	-2.050	2.125	21.658	6.566	21.502	8.146	0.980	0.961	45
4	NORTH	-3.039	-3.903	4.250	74.587	17.739	71.548	16.708	0.987	0.974	63
	SOUTH	1.897	2.639	3.816	66.504	12.102	68.401	13.552	0.972	0.945	54
	EAST	1.933	2.618	3.962	72.238	14.388	74.171	14.973	0.972	0.946	45
	WEST	-0.614	-1.528	3.210	62.846	12.161	62.232	14.308	0.984	0.968	45

Table 3 (continued)

5	NORTH	-1.344	-4.339	1.719	29.643	6.596	28.299	6.144	0.988	0.976	63
	SOUTH	0.672	1.990	1.604	29.937	5.896	30.609	6.558	0.978	0.956	54
	EAST	0.761	2.316	1.615	30.771	6.433	31.532	6.745	0.977	0.955	45
	WEST	-0.402	-1.971	1.590	28.681	6.054	28.279	7.034	0.983	0.966	45
6	NORTH	-0.693	-6.152	0.851	10.333	2.546	9.641	2.201	0.988	0.977	63
	SOUTH	0.258	1.664	0.766	12.031	3.135	12.289	3.491	0.982	0.964	54
	EAST	0.348	2.656	0.824	11.680	3.007	12.027	3.146	0.971	0.943	45
	WEST	-0.165	-2.161	0.776	11.730	2.916	11.565	3.408	0.983	0.966	45
7	NORTH	-0.160	-7.258	0.202	1.934	0.637	1.774	0.532	0.993	0.987	63
	SOUTH	0.051	1.328	0.200	2.590	0.920	2.642	0.998	0.983	0.965	54
	EAST	0.076	3.030	0.214	2.295	0.723	2.371	0.742	0.962	0.926	45
	WEST	-0.043	-2.826	0.213	2.499	0.718	2.456	0.855	0.979	0.959	45

MBE = $N^{-1}\Sigma$NORMAL-NADIR

MRE = $N^{-1}\Sigma${(NORMAL-NADIR)/NADIR}*100

RMSE = {$N^{-1}\Sigma$NORMAL-NADIR)**2}**0.5

Table 4. Comparison of canopy reflectance factors calculated using nadir-viewed panel reflected measurements as estimates of incoming radiation to canopy reflectance factors calculated using cosine corrected nadir-viewed panel reflected measurements as estimates of incoming radiaiton for all seven MMR optical wave bands at all view zenith angles at Site 966.

BAND	ASPECT	MBE %	MRE %	RMSE %	RF (%)		Cosine corrected RF (%)		R	R^2	N
					MEAN	SD	MEAN	SD			
1	NORTH	0.358	9.323	0.415	3.842	0.811	4.200	0.919	0.978	0.956	504
	SOUTH	-0.092	-1.968	0.179	4.222	0.739	4.130	0.669	0.981	0.963	438
	EAST	-0.191	-0.862	1.069	4.700	1.319	4.509	1.324	0.682	0.466	360
	WEST	0.403	9.059	0.788	4.468	1.071	4.871	1.349	0.868	0.753	363
2	NORTH	0.639	9.322	0.738	6.965	1.574	7.603	1.727	0.979	0.958	504
	SOUTH	-0.149	-1.968	0.289	7.023	0.924	6.874	0.839	0.965	0.931	438
	EAST	-0.332	-0.863	1.904	8.405	2.053	8.072	2.085	0.589	0.347	360
	WEST	0.676	9.059	1.319	7.455	1.612	8.132	2.121	0.850	0.722	363
3	NORTH	0.505	9.322	0.599	5.241	1.217	5.746	1.443	0.985	0.970	504
	SOUTH	-0.141	-1.968	0.277	6.333	1.492	6.192	1.383	0.989	0.978	438
	EAST	-0.334	-0.863	1.492	6.888	2.039	6.554	1.745	0.714	0.510	360
	WEST	0.527	9.058	1.161	6.649	1.565	7.247	1.959	0.863	0.745	363
4	NORTH	3.134	9.322	3.532	35.403	8.052	38.536	8.142	0.980	0.960	504
	SOUTH	-0.633	-1.968	1.239	32.053	4.971	31.420	4.996	0.977	0.955	438
	EAST	-1.215	-0.863	7.981	36.735	7.476	35.520	8.027	0.483	0.233	360
	WEST	2.675	9.059	5.278	30.575	5.353	33.250	7.190	0.774	0.599	363

Table 4 (continued)

5	NORTH	3.185	9.322	3.611	34.975	6.067	38.160	6.392	0.964	0.929	504
	SOUTH	-0.727	-1.968	1.412	35.418	3.748	34.690	3.594	0.946	0.896	438
	EAST	-1.574	-0.863	8.213	39.146	7.279	37.573	6.215	0.292	0.085	360
	WEST	3.019	9.059	5.864	34.495	4.888	37.513	7.003	0.695	0.483	363
6	NORTH	1.933	9.322	2.210	20.610	2.942	22.542	3.456	0.956	0.915	504
	SOUTH	-0.523	-1.968	1.006	23.971	3.088	23.448	2.675	0.966	0.932	438
	EAST	-1.206	-0.863	5.343	25.684	5.451	24.478	3.908	0.418	0.175	360
	WEST	2.030	9.059	4.041	24.176	3.841	26.206	4.794	0.692	0.479	363
7	NORTH	0.992	9.322	1.140	10.475	1.659	11.467	1.992	0.969	0.939	504
	SOUTH	-0.301	-1.968	0.589	13.877	2.984	13.576	2.780	0.987	0.974	438
	EAST	-0.733	-0.863	2.958	13.947	3.801	13.214	2.624	0.656	0.431	360
	WEST	1.152	9.059	2.384	14.202	2.714	15.354	3.045	0.742	0.551	363

MBE = $N^{-1}\Sigma RFcc - RF$

MRE = $N^{-1}\Sigma\{(RFcc - RF)/RF\}*100$

RMSE = $\{N^{-1}\Sigma RFcc - RF)**2\}**0.5$

Table 5. Comparison of reflected shortwave radiation measured with an inverted Eppley PSP horizontally-mounted to reflected shortwave radiation measured with an inverted Eppley PSP mounted parallel to the surface at Site 966. (2437-BBS)

ASPECT	MBE w/m^2	MRE %	RMSE w/m^2	Reflected Shortwave				R	R^2	N
				Horizontal Mount w/m^2		Parallel Mount w/m^2				
				MEAN	SD	MEAN	SD			
LEVEL	-3.160	-2.209	8.714	128.908	19.294	125.749	18.484	0.905	0.819	30
NORTH	-1.740	-1.226	4.068	130.262	19.418	128.522	18.675	0.981	0.963	31
SOUTH	0.456	0.235	4.441	129.913	17.494	130.369	19.014	0.973	0.947	32
EAST	0.091	0.053	1.835	140.186	16.381	140.277	16.637	0.994	0.987	25
WEST	-2.985	-2.520	6.350	131.148	14.204	128.163	17.304	0.953	0.908	26

MBE = $N^{-1}\Sigma$(parallel-horizontal)

MRE = $N^{-1}\Sigma$((parallel-horizontal)/horizontal)*100.0

RMSE = {$N^{-1}\Sigma$[(parallel-horizontal)**2]}**0.5

Table 6. Comparison of incoming shortwave radiation as measured with an upright, horizontally-mounted Eppley PSP with estimated incident shortwave radiation received on an inclined surface. Estimated values calculated by multiplying total incoming shortwave radiation received on the horizontal with the ratio $\cos\theta_e/\cos\theta_s$.

ASPECT	MBE w/m²	MRE %	RMSE w/m²	Incoming Shortwave				R	R^2	N
				Horizontal Mount w/m²		Parallel Mount w/m²				
				MEAN	SD	MEAN	SD			
LEVEL	0.000	0.000	0.000	788.996	158.128	788.996	158.128	1.000	1.000	30
NORTH	-68.095	-7.942	79.189	793.416	159.983	725.321	125.304	0.988	0.976	31
SOUTH	17.438	1.681	32.250	810.116	154.567	827.553	177.730	0.996	0.992	32
EAST	33.010	4.073	118.465	823.416	145.541	856.426	182.845	0.773	0.597	25
WEST	-65.996	-7.735	100.127	826.961	158.359	760.965	167.732	0.891	0.793	26

Table 7. Comparison of hemispherical shortwave albedo from horizontally-mounted PSP and that measured from a PSP mounted parallel to the surface.

ASPECT	MBE	MRE %	RMSE	Albedo				R	R^2	N
				Horizontal Mount		Parallel Mount				
				MEAN	SD	MEAN	SD			
LEVEL	-0.004	-2.124	0.014	0.166	0.017	0.162	0.019	0.717	0.514	30
NORTH	0.012	7.404	0.014	0.167	0.021	0.179	0.020	0.945	0.893	31
SOUTH	-0.002	-1.353	0.008	0.162	0.011	0.160	0.014	0.858	0.736	32
EAST	-0.004	-0.825	0.033	0.173	0.026	0.169	0.028	0.248	0.061	25
WEST	0.009	6.783	0.022	0.162	0.023	0.172	0.018	0.547	0.299	26

Table 8. Comparison of net radiation values as measured with a REBS single dome net radiometer mounted horizontally and a REBS single dome net radiometer mounted parallel to the slope.

ASPECT	MBE w/m^2	MRE %	RMSE w/m^2	Net radiation				R	R^2	N
				Horizontal Mount w/m^2		Parallel Mount w/m^2				
				MEAN	SD	MEAN	SD			
LEVEL	8.091	1.687	20.165	505.167	130.724	513.258	134.087	0.990	0.981	30
NORTH	-56.508	-10.275	67.141	522.429	139.830	465.922	119.480	0.972	0.944	31
SOUTH	17.521	2.899	36.921	511.671	123.177	529.192	142.787	0.980	0.960	32
EAST	17.600	3.964	97.558	533.166	122.421	550.766	142.305	0.736	0.542	25
WEST	-13.719	-0.877	65.667	537.261	126.045	523.542	120.299	0.860	0.739	26

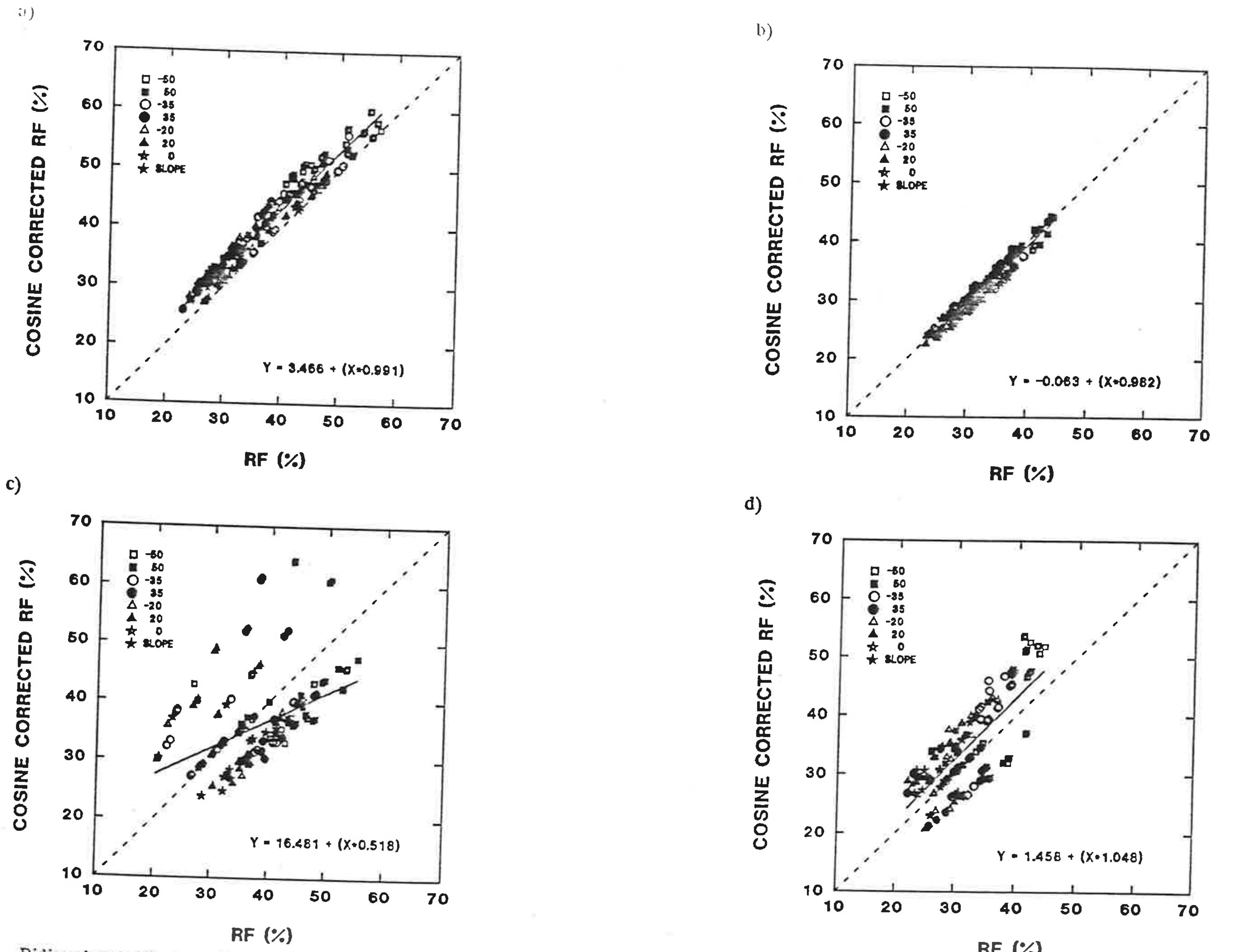

Fig. 1 Bidirectional reflectance factors for view zenith angles of nadir, 20, 35 and 50° either side of nadir and normal to the inclined surface for NIR radiation (MMR waveband 4) at site 966 on four sloped vegetated surfaces. Reflectance factors were calculated using nadir-viewed horizontally mounted Spectralon field reference panel data. Nadir-viewed data estimated incident radiation received on the horizontal while cosine corrected nadir-viewed data estimated incident radiation received on the sloped surface. (a) North-facing slope (b) South-facing slope (c) East-facing slope (d) West-facing slope.

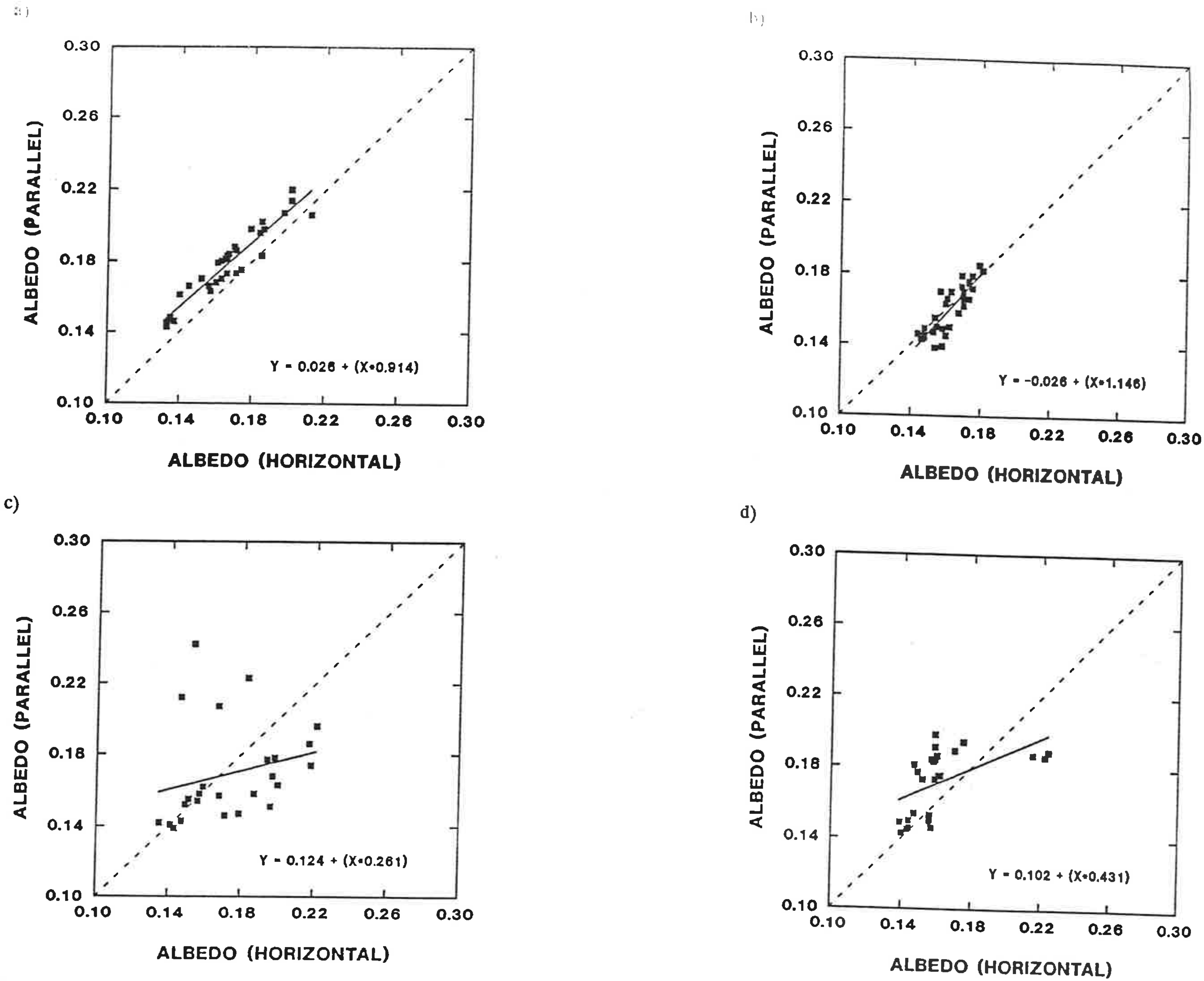

Fig. 2 Albedo calculated using reflected shortwave radiation from PSPs mounted horizontally and parallel to the slope. Incoming radiation was estimated from upright horizontally-mounted PSP and cosine-corrected. (a) North-facing slope (b) South-facing slope (c) East-facing slope (d) West-facing slope.