Seasonal Albedo Variation of Black Spruce and Sphagnum-Sedge Bog Cover Types¹

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ABSTRACT

Albedo measurements were made over two northern Minnesota bog cover types. Two Kipp and Zonen pyranometers were cycled over black spruce [*Picea mariana* (Mill.) B.S.P.] and sphagnum-sedge bog canopies within a one year period.

During the snow-free seasonal periods black spruce had a 6–8% albedo and did not exhibit a response to new shoot growth and maturation. Albedo increased to 8.2% with an 80% bog surface snow cover in late November while a 100% bog surface snow cover increased the albedo to 10.5% in February–March.

The sphagnum-sedge bog exhibited an increase from 11.6% in April–May to 16.1% in June with a gradual decline to 13.5% in October–November. A 50–60% old snow cover increased the November–December albedo to 35.1% while the albedo of a fresh continuous snow cover in February–March was 81.7%.

The effect of cloud cover on the albedo was negligible.

1. Introduction

North central Minnesota has approximately 2.8 million hectares of bogs which constitute the headwaters of the Mississippi, Rainey, Red and St. Louis rivers. Due to increasing water demands, research efforts in bog management have been directed toward evaluating basic forest hydrology relationships and possible augmentation of low stream discharges and ground-water supplies.

Previous studies have centered around bog hydrology with evapotranspiration being a primary factor (Bay, 1967). Evapotranspiration, a phase change relationship, requires an energy input. The net radiant energy may be expressed by $R_n = R_L + S(1 - \alpha)$, where R_n is net radiation, R_L net longwave radiation, S global radiation, and α albedo, the ratio of radiation reflected from a surface to the total (global) radiation incident on the surface. The term $S(1 - \alpha)$ expresses the solar energy available for evapotranspiration, sensible heat, soil heat, vegetative storage and photosynthesis. Consequently, for a given solar energy input the magnitude of available solar energy is controlled by the albedo alone.

The albedo of monolayers has been found to greatly influence water evaporation (Beard and Gainer, 1970). In addition to evapotranspiration control by atmosphere conditions, Sturges (1968) found a bog surface to be a good solar energy sink and that more solar energy to a bog is available for evaporation than that available

to a water body. Furthermore, studies indicating bog evapotranspiration in excess of pan evaporation have been attributed to the virtually unlimited water supply to the immense surface area of the bog's micro-relief. It follows that an albedo analysis of bog vegetation may be interpreted as potential evapotranspiration differences.

Albedo differences may be due to specific surface features such as vegetative cover types and seasonal variation in vegetation maturation and to alterations of the incident radiation by cloud cover differences (Lykowsky, 1970).

2. Study area

Albedo measurements were conducted over black spruce and sphagnum-sedge bog cover types representative of northern Minnesota bogs. Both sites were located on the Marcell Experimental Forest, North Central Forest Experiment Station, U. S. Forest Service, at 93°28'W, 47°31'N. The elevation was 424 m MSL.

The black spruce bog supported a stand of 80–100 year old black spruce [*Picea mariana* (Mill.) B.S.P.] 11.9 m in height with a live crown length of 6.1 m. The basal area of 24.8 m² ha⁻¹ was comprised of 3869 stems ha⁻¹. The relative crown closure nine meters either side of the tramway was estimated to be 55% by utilizing a dot grid superimposed on a vertical periscope-type viewer. Principal black spruce ground cover species of Labrador tea (*Ledum groenlandicum* Oeder), leatherleaf

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[*Chamaedaphne calyculata* var. *angustifolia* (Ait.) Rehd.], and yellow clintonia [*Clintonia borealis* (Ait.) Raf.] grew on sphagnum moss (*Sphagnum* sp.) hummocks.

The sphagnum-sedge bog supported a 0.6 m vegetative cover on sphagnum moss hummocks. Principal species consisted of sedges (*Carex* sp.), leatherleaf, swamp laurel (*Kalmia polifolia* Wang), and cotton grass (*Eriophorum* sp.).

3. Methods

Time-sequence sampling is necessary to estimate a specific parameter over a time period and, because of a forest canopy's spatial variation, both space and time averages are necessary (Reifsnnyder, 1962). Space-time averages for each cover type were obtained from a tramway system similar to Leonard and Eschner's (1968a) technique. The black spruce and sphagnum-sedge bog tramways were each supported by two galvanized steel towers triangular in cross section. Both of the black spruce bog's 15.2 m towers were anchored in mineral soil 1.2 m below the bog's surface which resulted in a cable height of 13.1 m above the bog surface. The towers were 39.2 m apart at an azimuth of

FIG. 1. The cart-mounted pyranometer triggering the tramway limit switch.

341°. A platform on the north tower 1.1 m above the bog surface supported the recording and cycling equipment while a platform at 11.3 m facilitated work with the pyranometers.

The sphagnum-sedge bog's towers were stabilized on 3.7 m pipes driven into the organic soil with the tramway cables 2.0 m above the bog surface. The towers consisted of one 3.0 m section each and were 33.5 m apart at an azimuth of 350°.

The Kipp and Zonen pyranometers were utilized to measure global and reflected radiation for selected periods from August 1968 through August 1969. Tests after the study revealed identical output and response time and less than 1% error upon inversion for both pyranometers. A similar test was not performed before the study was initiated.

Two channels of a 24-point, strip-chart recording potentiometer were used to record each pyranometer's millivolt output once per minute. A 2-sec instrumentation delay existed between the global and reflected radiation recordings.

The pre-leveled pyranometers traversed the tramway while mounted opposite each other on a 26.2×26.2×2.5 cm transparent plastic cart that was alternated between sites (Fig. 1). Two ball bearing sheave wheels on each side were centered 27.4 cm apart which was equivalent to the tramway width. The cart was automatically cycled along the tramway by a 0.02-hp shunt-wound, gear-reduced electric motor regulated by a variable speed and direction control. The motor reversed directions when the cart triggered a microswitch extending 1.1 m from either end of the tramway. The cart speed was maintained at 30 min per pass over the tramway. Total assembled cart weight was 9.3 kg.

The 53 partial and total days of record for each cover type were divided into periods of April–May, June, July, August–September, October–November, November–December, and February–March. The specific dates and times of the observations are recorded in Table 1. Each

TABLE 1. Observation dates and time intervals for the black spruce and sphagnum-sedge bog radiation measurements.

Black spruce bog		Sphagnum sedge bog	
Date	Time interval	Date	Time interval
(1968)		(1968)	
19 September	1200–1730	28 August	0730–1830
20	1000–1300	29	0630–1830
28	0700–1800	4 September	0800–1900
29	0630–1730	5	0830–1800
6 October	0900–1700	6	0700–1200
3 November	0830–1630	9	1100–1830
24	0900–1600	10	0730–1830
29	0900–1630	11	0700–1700
30	0830–1630	12	0630–1700
(1969)		5 October	0730–1630
23 February	0830–1700	12	1000–1700
9 March	0930–1700	26	0730–1630
10	0700–1800	2 November	0730–1630
29 April	0600–1900	23	0800–1700
2 May	0630–1900	1 December	0830–1230
7	0500–1930	(1969)	
8	0500–1800	22 February	1200–1730
19 June	0530–1700	30 April	0730–1800
24	0800–1900	6 May	0530–1900
25	0500–0800	20 June	0500–1500
26	1100–1830	27	0730–1630
17 July	0430–1830	1 July	0800–1100
18	0500–1300	15	1200–1800
24	0500–1830	16	0830–1800
25	0530–1330	22	0500–1930
		23	0730–1930
		29	0600–1900
		30	0500–1730
		(1970)	
		7 March	1100–1700
		8	0930–1530
Total: 24 days	211.5 hr	29 days	249.5 hr

TABLE 2. Black spruce bog linear regression results of reflected vs global radiation for each seasonal period within cloud classes I, II, III, IV, and I-IV.

Cloud class	Period	<i>n</i>	<i>r</i>	<i>m</i>	<i>b</i>	<i>G_r</i>	$\bar{G}$	$\bar{\alpha}$
I	April-May	40	0.994	0.085	-0.141	0.8-39.3	19.4	7.2
	June	11	0.973	0.080	-0.343	0.2-34.7	17.6	6.0
	July	41	0.991	0.081	-0.324	0.2-40.2	21.1	6.5
	September	17	0.976	0.086	-0.216	1.2-29.9	16.0	7.3
	October-November	13	0.985	0.077	-0.185	2.8-26.8	18.4	6.7
	Late November	8	0.992	0.077	0.034	0.4-17.7	7.9	8.1
	February-March	22	0.991	0.110	-0.194	1.1-32.2	20.1	10.0
II	April-May	16	0.996	0.073	-0.010	1.2-35.9	18.5	7.3
	June	15	0.992	0.086	-0.254	0.4-39.2	25.1	7.6
	July	15	0.990	0.087	-0.468	13.8-38.5	29.5	7.1
	September	8	0.995	0.070	0.098	0.4-28.3	17.8	7.6
	October-November	5	0.983	0.071	-0.106	11.1-24.7	17.3	6.5
	Late November	8	0.985	0.083	-0.152	1.7-18.3	12.5	7.1
	February-March							
III	April-May	14	0.974	0.073	-0.089	6.7-27.0	18.4	6.8
	June	14	0.990	0.088	-0.335	12.4-32.4	21.3	7.3
	July	7	0.979	0.072	-0.035	23.3-39.0	30.5	7.1
	September	16	0.961	0.079	-0.141	6.2-25.4	17.0	7.1
	October-November	4	0.936	0.086	-0.354	13.5-17.6	16.3	6.4
	Late November	6	0.959	0.121	-0.422	6.5-13.5	10.3	8.0
	February-March	5	0.997	0.126	-0.301	6.1-17.3	11.8	10.0
IV	April-May	21	0.990	0.070	0.010	4.6-22.0	12.4	7.0
	June	24	0.993	0.074	-0.089	0.0-23.4	10.0	6.5
	July	20	0.994	0.073	-0.105	0.0-28.9	15.2	6.6
	September	15	0.927	0.064	0.058	4.0-18.5	10.5	7.0
	October-November	8	0.991	0.065	0.036	0.9-13.1	5.7	7.1
	Late November	23	0.985	0.091	0.018	0.7- 9.3	4.0	9.5
	February-March	27	0.996	0.114	0.001	1.3-17.7	9.7	11.4
I-IV	April-May	91	0.992	0.077	-0.077	0.8-39.3	17.4	7.1
	June	64	0.986	0.083	-0.218	0.0-39.2	17.3	7.0
	July	83	0.991	0.079	-0.249	0.1-40.2	22.0	6.7
	September	56	0.972	0.079	-0.097	0.4-29.9	15.1	7.2
	October-November	30	0.987	0.069	-0.038	2.8-26.8	14.6	6.7
	Late November	45	0.974	0.074	0.054	0.4-18.3	7.0	8.2
	February-March	54	0.988	0.104	0.016	1.1-32.2	14.1	10.5

n number of half-hour observations.

r statistical correlation coefficient.

m linear regression slope; theoretical albedo.

b linear regression intercept with reflected radiation axis [*y* (30 min)⁻¹].

G_r range of global radiation of observations [*y* (30 min)⁻¹].

$\bar{G}$ mean global radiation [*y* (30 min)⁻¹].

$\bar{\alpha}$ mean albedo (percent).

seasonal period was subdivided into cloud classes according to both field and data observations. One-half hour intervals within the periods were assigned to arbitrary cloud classes of I, II, III, and IV, which corresponded to cloud cover percentages of <10, 10-50, 51-90, and >90.

4. Results and discussion

Basic data observations were made at half-hour intervals corresponding to one pass over the tramway. Each interval consisted of 30 individual values of reflected and global radiation. Data analyses utilized the total global and reflected radiation for each time interval. The albedo for any extended time period was computed as the ratio of the radiation fluxes instead of an average of individual albedo values. This technique was utilized so as to give more weight to the greater

radiation flux values and minimize instrumentation and chart reading errors on the lesser fluxes.

Graphical analyses of global (independent variable) and reflected radiation for each cloud class within each seasonal period revealed a linear relationship. By utilizing the linear model of $y = mx + b$, the *y*-intercept *b* should theoretically equal zero because reflected radiation would equal zero only when the global radiation (*x*) is zero. By dividing the linear model by *x*, the albedo yx^{-1} would equal the slope *m* because bx^{-1} would equal zero. However, all the analyses had non-zero intercepts due to instrumentation sensitivity, chart-reading errors, and statistical procedures.

a. Black spruce bogs

A summary of the linear regression analyses is presented in Table 2. The high correlation coefficients

FIG. 2. Seasonal albedo variation of black spruce for various cloud classes.

indicated that a high degree of linear association existed between reflected and global radiation. The non-zero intercept values were minimal, but when computing albedo values from each linear regression the reflected radiation component becomes unrealistic as global radiation approaches zero. Consequently, this phenomenon necessitated the use of mean reflected and global radiation measurements for determining the albedo of each seasonal period and cloud class and over all cloud classes together (Fig. 2).

The snow-free seasonal albedo variations within and between cloud classes from April–May through October–November were not significant at the 5% level. The absence of marked albedo increases for each cloud class in June is surprising since in June black spruce buds burst and shoots begin to elongate. Baumgartner (1966) reported that seasonal changes in albedo depend upon the state of crop development, and Olson and Good (1962) and Reifsnnyder and Lull (1965) report new conifer needles to have a higher reflectance than older needles.

The greatest range in albedo between cloud classes for a given period was in June. For April–May, June, July, September, and October–November the ranges were 0.5, 1.6, 0.6, 0.6, and 0.7%, respectively. It is probable that the high albedo of new shoot growth in June was the prime factor in causing greater albedo variability.

Since the albedo values between cloud classes for a given seasonal period were not significantly different, the data for all cloud classes combined resulted in average albedo values of 7.1, 7.0, 6.7, 7.2, and 6.7% for April–May, June, July, September, and October–November, respectively. These values lie within the 5–15% albedo range of coniferous forests as stated by Sellers (1965). The lack of any distinct snow-free seasonal albedo variation suggested that other dominant factors were present.

Goodell (1966) stressed that in addition to the albedo of the foliage itself, the depth and spatial arrangement of the foliage are important. The canopy structure of conifers has been found to be more effective in trapping radiation than that of hardwoods because of the conifers' fine needle arrangements (Gay, 1966). Because this stand was only 67% stocked when compared to yield tables of Fox and Kruse (1939) and had an average crown density of 55%, sufficient openings were present to permit reflecting surface areas of tree boles, older needles, and lower vegetation to dominate over the new black spruce growth. Therefore, it may be hypothesized that the lack of distinct black spruce snow-free seasonal albedo variation, especially in June, was attributable to the heterogeneous black spruce stand structure.

Winter data were obtained under partial snow cover conditions in late November (80%) and uniform snow cover conditions in February–March (100%). No intercepted snow was evident on the black spruce crowns for either period. An open snow surface has an albedo of 69.5–81% (Ångström, 1925). Therefore, it would be expected that the black spruce bog albedo would increase above that of the snow-free season, but remain less than that of an open snow surface. The late November and February–March albedos (Fig. 2) appear to be low when compared to open snow surface albedos; however, Leonard and Eschner (1968b) found similar albedo magnitudes while studying intercepted snow on a dense red pine (*Pinus resinosa* Ait.) canopy. After the red pine intercepted snow had left the crowns, they found the albedo of a red pine stand with a snow-covered ground to remain constant at 15%. Perttu (1970) also found a snow-free coniferous forest with a snow-covered forest floor to have an albedo from 13–16% while utilizing an aircraft for measurements.

The mean albedos for late November and February–March were 8.2 and 10.5%, respectively, in comparison

TABLE 3. Sphagnum-sedge bog linear regression results of reflected vs global radiation for each seasonal period within classes I, II, III, IV, and I-IV. See Table 2 for definitions of symbols.

Cloud class	Period	<i>n</i>	<i>r</i>	<i>m</i>	<i>b</i>	<i>G_r</i>	$\bar{G}$	$\bar{\alpha}$
I	April-May	10	0.997	0.121	-0.121	19.1-39.5	32.0	11.5
	June	9	0.998	0.160	0.014	1.9-38.7	23.4	16.0
	July	40	0.996	0.162	-0.221	0.2-39.5	22.9	15.2
	August-September	86	0.982	0.156	-0.132	0.1-34.7	19.9	15.0
	October-November	10	0.995	0.152	-0.248	9.3-26.0	2.16	14.1
	November-December							
II	February-March	12	0.999	0.822	-0.172	18.1-29.6	24.8	81.5
	April-May	12	0.999	0.115	-0.049	1.1-37.1	20.1	11.3
	June	8	0.996	0.150	0.407	12.1-44.7	24.2	16.6
	July	32	0.990	0.166	-0.159	0.2-39.5	25.7	15.9
	August-September	17	0.989	0.156	-0.223	2.1-36.1	19.7	14.5
	October-November	8	0.996	0.153	-0.161	0.2-22.8	8.6	13.4
III	November-December							
	February-March	6	0.999	0.835	-0.485	16.8-32.2	25.2	81.5
	April-May	10	0.998	0.123	-0.032	6.1-39.2	22.4	12.2
	June	9	0.994	0.152	0.135	14.8-31.8	25.4	15.7
	July	18	0.984	0.201	-1.005	10.7-35.0	22.1	15.5
	August-September	44	0.924	0.155	-0.049	0.1-30.7	20.3	15.2
IV	October-November	4	0.999	0.139	-0.091	0.5-21.4	14.4	13.3
	November-December							
	February-March	11	0.999	0.806	0.172	4.5-23.9	14.2	81.8
	April-May	10	0.998	0.111	0.095	6.8-29.6	18.6	11.6
	June	14	0.999	0.162	-0.016	3.3-26.4	15.1	16.1
	July	24	0.991	0.161	-0.123	0.3-23.6	8.3	14.6
I-IV	August-September	22	0.988	0.139	-0.022	0.6-21.1	7.8	13.6
	October-November	49	0.983	0.134	-0.018	0.1-15.7	6.3	13.1
	November-December	26	0.987	0.310	0.106	0.1- 6.0	2.5	35.1
	February-March	7	0.999	0.818	0.063	0.2-11.6	5.2	83.0
	April-May	43	0.996	0.117	-0.019	1.1-39.5	23.0	11.6
	June	40	0.997	0.158	0.067	1.9-44.7	21.1	16.1
I-IV	July	114	0.992	0.165	-0.206	0.2-39.5	20.5	15.5
	August-September	169	0.977	0.156	-0.126	0.1-36.1	18.4	14.9
	October-November	71	0.994	0.143	-0.074	0.1-26.0	9.1	13.5
	November-December	26	0.987	0.309	-0.106	0.1- 6.0	2.5	35.1
	February-March	36	0.999	0.812	0.074	0.2-32.2	17.8	81.7

to the snow-free October-November albedo of 6.7%. This reconfirms Leonard and Eschner's results that a snow pack below the forest canopy has only a small influence on the forested area's albedo with the canopy still being the dominant influence.

The cloud class IV albedo was highest for both the 80 and 100% snow cover on the black spruce bog's surface (Fig. 2). In late November the cloud class IV albedo

was 1.4-2.4% greater than the cloud classes I, II, and III albedos and in February-March it was 1.4% greater than the cloud classes I and III albedos. Although cloud cover did not influence the snow-free albedo, the albedo of the snow-covered bog increased under cloud class IV because of the uniform irradiation of the crown and snow surfaces by mainly diffuse global radiation. Without the cloud cover, the black spruce crowns intercept and reflect the majority of the direct solar radiation and the snow surface would then receive primarily diffuse and crown reflected radiation.

b. Sphagnum-sedge bog

The results of the linear regression analyses of global vs reflected radiation are summarized in Table 3. As with the black spruce bog analyses, the regression coefficients were high and the intercept values were minimal—but not equal to zero. Consequently, the mean global and reflected radiation fluxes determined the albedo per cloud class and per seasonal period (Fig. 3).

Cloud cover was found to have no significant influence on the sphagnum-sedge bog's albedo throughout the

FIG. 3. Snow-free seasonal albedo variation of the sphagnum-sedge bog for various cloud classes.

snow-free season. Therefore, the amount of diffuse radiation did not influence the reflected radiation relative to the global radiation.

The albedo values were minimal in the spring (April–May), rose rapidly in early summer (June), and steadily declined with the maturation of vegetation. The specific albedo values were 11.6, 16.1, 15.1, 14.9, and 13.5% for April–May, June, July, August–September, and October–November, respectively. In October–November, the vegetation was dead or dormant.

Two factors probably contributed to the low April–May albedo of 11.6%. First, the dead grass and sedges from the previous season had darkened and compacted from the moisture and snow cover. Second, a free-water surface interlaced the sphagnum moss hummocks. The low albedo of 3–10% for open water would tend to reduce the overall albedo despite the small surface area represented (Geiger, 1966).

The albedo maximum in June of 16.1% was related to new vegetative growth. These results were similar to the June albedos of 17.0 and 13.5% for heather and grass as found by Barry and Chambers (1966). Another study similarly reported higher albedos for luxuriant new growth in June followed by an albedo decline in July and September (Kung *et al.*, 1964). The albedo subsequently decreased steadily from July through October–November.

Snow had a significant effect on the albedo of the sphagnum-sedge bog. The mean albedo increased from 13.5% in October–November (snow-free) to 35.1% for an aged 50–60% snow cover in November–December and to 81.7% for a fresh continuous snow cover in February–March. These data agree favorably with other results. Sellers (1965) has reported the albedo of one-week-old snow to range from 40–70%; consequently, if the surface albedo is a more direct function of the snow coverage than the coverage of the sphagnum-sedge bog's associated species, a direct proportion from 55 to 100% snow cover would yield an albedo of 64% for the aged snow. Sellers also reported a fresh snow surface albedo to range from 75–95% while Ångström (1925) reported a 69–81% range.

Cloud class comparisons during snow conditions were not made because November–December data were recorded only during overcast sky conditions. The albedo for November–December cloud class IV was 35.1% while for February–March cloud classes of I, II, III and IV the albedos were 81.5, 81.5, 81.8 and 83.0%, respectively. As with the snow-free conditions, cloud cover did not have a significant influence on the albedo.

5. Conclusions

The available solar energy to black spruce was found to be independent of seasonal changes within the snow-free season. The albedo remained between 6 and 8% from April through November. The albedo analysis for

the sphagnum-sedge bog and numerous studies by other investigators have revealed a marked albedo increase with the initiation of bud growth and shoot development in the spring, but black spruce did not exhibit this phenomenon.

The presence of the black spruce stresses the importance of the stand not as a simple reflecting surface but as a complex three-dimensional array. Consequently, the lack of any albedo response to new black spruce bud growth may be due to the intricate canopy when, in fact, the new shoots may and probably do have albedos significantly higher than 6–8%. Further study of the black spruce albedo in winter found the albedo to increase to 8.2 and 10.5% with 80 and 100% snow cover on the bog surface, respectively, but with no snow intercepted on the crowns. The albedo increase is negligible when compared to the sphagnum-sedge bog's fresh snow surface albedo of 81.7% emphasizing again the dominance of the canopy structure.

Results indicated that the black spruce albedo was not influenced by the direct and diffuse solar radiation components during the snow-free season. Under clear sky conditions global radiation is approximately 70–80% direct (Reifsnyder and Lull, 1965). As cloud cover increases diffuse radiation increases until global radiation received is diffuse under complete overcast conditions. There were no significant albedo differences when direct, direct and diffuse, and diffuse radiation conditions were compared.

When snow was present on the black spruce bog's surface, the albedo was greater for the overcast cloud class IV conditions. This could be attributed to the receipt by the canopy surfaces of uniform diffuse radiation from the cloud cover; whereas, when direct solar radiation was present, the black spruce crowns intercepted the intense direct radiation while the snow-covered bog surface received only diffuse radiation.

The sphagnum-sedge bog did reveal the expected albedo increase in June which was attributed to new vegetative growth. The maximum albedo in June of 16.1% gradually decreased to 13.5% in October–November as the vegetation matured. Dead and dormant vegetation was darkened from moisture and compacted from snow accumulation during the winter and spring and yielded the minimum albedo of 11.6% in April–May.

Snow produced a significant albedo increase for the sphagnum-sedge bog. With a 50–60% snow cover, the albedo increased from 13.5 to 35.1%. Later, in February–March, a fresh continuous snow cover produced an albedo of 81.7% which agreed with other reports.

As with the black spruce bog, cloud cover was not found to influence the albedo of the sphagnum-sedge bog.

For a given solar energy input, absorbed energy is 5–10% greater in black spruce bogs than in sphagnum-

sedge bogs. As indicated by Beard and Gainer (1970), this added energy would conceivably result in greater evapotranspiration losses from black spruce than from the sphagnum-sedge bogs. However, actual evapotranspiration is ultimately controlled by physiological responses to abiotic stresses. An evaluation of the stress/response interactions on evapotranspiration is an area of needed research. A grasp of available energy for these processes is one step toward an eventual quantitative understanding of evapotranspiration.

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