REMOTELY SENSED CHARACTERISTICS OF SNOW COVERED LANDS

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ABSTRACT

Estimates were made of visible surface albedo over regions in North America with full or partial snow cover from satellite images. The distribution of gray scale levels as analyzed on an image processor and the resultant distribution statistics were used for making this assessment. The mean reflectivity of fully snow covered 3° x 3° blocks varied from 39-76% depending on the type and density of the vegetation. Differences in albedo up to 30% were found between old and fresh snow cover of equal depth within a given area. The results will help improve albedo parametrizations for use in climate models.

snow cover, albedo, climate, image processor

INTRODUCTION

Snow cover can be identified by its characteristic image brightness, surface patterns, and pattern stability (Barnes and Bowley, 1974). Image brightness has been correlated with depths of fresh and variably aged snow covers (McGinnis et al., 1975; Lillesand et al., 1982).

The direct measurement of surface albedo from satellites is difficult for a variety of reasons (Otterman and Fraser, 1976). One obstacle is that sensors have limited spectral ranges. Multispectral studies have shown planetary albedo to differ up to 8% between visible and near-infrared wavelengths over snow covered fields (Schneider et al., 1981). Variations of dust and moisture in the atmospheric column have an impact on the reflected radiation measured by satellites.

While satellite limitations are not negligible, they are minor when assessing the dramatic differences in surface brightness between regions with contrasting types and densities of vegetation and under varying snow conditions.

Snow cover is an important variable in the climate system (Namias, 1962; Dewey, 1977; Robinson, in press), particularly due to its high albedo. There are, however, only a few studies of albedo with snow cover present which are not site specific. Aerial measurements of surface albedo along flight paths over North America were made by Jackson (1961), Kung et al. (1964) and McFadden and Ragotzkie (1967) among others. Satellite measured planetary albedos on a single day along a few transects in the western and central U.S. were reported by Schneider et al. (1981). No studies treat albedo on a regional basis. Information is needed over larger areas to improve parameterizations of surface albedo in climate models, particularly in areas and at times when snow cover is an erratic and unstable feature.

Data:

Very High Resolution Radiometer (VHRR) and Advanced VHRR imagery from National Oceanic and Atmospheric Administration polar orbiting satellites was examined. Only images recorded from the .6 - .7 μm channel were used. Nadir resolution is approximately 1.0 km.

Proceedure:

The imagery was analysed on a processor system which treats the image as 307,000 discrete pixels, assigning each a gray scale value from black (0) to white (255). Image statistics computed included histograms of gray scale levels, standard deviation, skewness and kurtosis. Ground truth information on snow fall, and snow depth were obtained from Climatological Data (NOAA) and Canadian reports (Atmospheric Environment Service).

Correlation of brightness between images was achieved by setting large snow covered lakes and/or snow free land to correspond to a brightness level of 210 and 80 respectively, through aperture adjustments of the processor lens. This technique minimizes differences in bright-

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ness between images caused by atmospheric variability.

Adjusted brightness was converted to estimated visible surface albedo by linear interpolation between a bright snow covered lake with a parameterized visible albedo of 85% and snow free land, assigned a visible albedo of 13%.

Results:

Figure 1 shows locations of regions where the brightness of the surface with deep snow on the ground (> 25 cm) was measured. The results are shown in figure 2 and table 1. The following observations should be noted:

1) The range of reflectivity within individual regions is large. This is due to differences of surface types which influence albedo even when fully snow covered. For example, the dark pixels in G (fig. 2) are mainly dense coniferous forest where snow is masked beneath the canopy. The relatively bright pixels contain combinations of forests and bright snow covered lakes and fields. The non-forested bright snow covered areas are too small to be recorded individually as a full pixel due to the limited resolution of the imagery. Large lakes, such as Lake Winnipeg (cf. right side of A, fig. 2) are detectable in the histograms.

2. Estimated albedos of selected surface types within study blocks were found to agree with aerial measurements of similar surfaces elsewhere. For example, the dark forests in G with albedos as low as 15-20% and farmland in F with albedos up to 75% compare favorably with measurements of Kung et al. (1964) in Wisconsin.

3. The brightness range between regions is large, but does not approach the extremes of individual surface types. This is because none of the study areas was represented entirely by a single surface, particularly in forested blocks where bright lakes raise the mean reflectivity.

4. Region A (fig. 2) has the largest variety of surface types with different snow cover brightnesses and B, D, and F the fewest in the study areas. Standard deviation shows this well.

5. Kurtosis is a good indicator of the presence of abundant open or lightly vegetated lands in a region.

6. Large skewness occurs where a small proportion of pixels considerably darker (negative) or brighter (positive) than others in the block exist. For example, the large negative skewness over farmland (F) results from darker forests and towns widely scattered in this bright region.

The progressive melt of snow cover over forest and tundra areas of Alaska (fig. 1, I and J respectively) is monitored with histogram statistics in figure 3. Drops in albedo are accompanied by simultaneous but differing shifts in other statistics within and between regions. For instance, standard deviation decreases and kurtosis rises as snow disappears in the forests and fields of area I and brightnesses of the two surfaces become more alike. Skewness remains positive in forested regions with the commencement of melt, as dark pixels remain most abundant. In the tundra, skewness becomes negative once snow free areas begin to appear. It remains negative until dark snow free areas predominate and skewness shifts to positive values.

A variety of snow cover situations over portions of the central U.S. were examined. All areas are highly reflective when fully snow covered (eg. fig. 1-F). A dense network of stations reporting snow fall and depth is available for these regions and was utilized as ground truth information. Figure 4 shows the shift of both ends of bimodal histograms 1-4 toward darker values as melt progresses in one area (Fig. 1, K). Also, note the increase in the number of dark mostly snow free pixels and decrease of bright pixels.

The area was also analysed the day after a 2-15 cm snowfall over a portion of the previously snow free region (fig. 4 - histogram 5). A comparison of histogram and station data from this date with the February melt period (table 2) shows similarities between 3/16 and 2/7 histogram statistics and 3/16 and 2/10 depth and station coverage data. The depth-albedo relationship seen during the melt period obviously is not fixed for all snow cover situations.

Figure 5 incorporates data from table 2 and from 17 other central U.S. scenes on various dtes to illustrate the impact of snow depth, age, and distribution on image brightness. The latter two are found to be important in establishing relationships between reflectivity and depth. Fresh covers over this lightly vegetated region have albedos of 60% with snow depths of 2 cm. As depth increases to 10 cm any low vegetation becomes covered and albedo rises to its maximum albedo of approximately 70%. This relationship parallels one found over a fresh snow pack by McGinnis et al. (1975) but reaches its brightness peak at lower depths as their area was more heavily vegetated.

Lillesand et al. (1982) looked at depth-brightness relationships over a portion of our region using GOES data. They found lower correlation values than McGinnis et al. (1975) and ascribed the difference to possibly the larger variability in the age of the snow packs studied. Our findings strongly support this suggestion. The estimated albedo of deep, aging snow shown in figure 5 is 20% lower and thin covers 30% lower than fresh covers of comparable depths.

The scenes marked with circles on figure 5 represent situations where fresh snow covered only a portion of a previously snow free region. As the percentage of stations reporting snow fall increases from 50-68-84 percent albedo rises in close to a linear manner.

CONCLUSION

Surface reflectivity of regions under partial or total snow cover were studied with the use of an image processor. Image brightness was converted to estimated visible surface albedo by linear interpolation. Brightness histograms and their statistical characteristics exhibited marked differences which can be utilized to recognize and describe differences of surface type and varying snow conditions. We specifically found:

1) The regional albedo over areas of forest and frozen lakes was estimated to be 39% under fully snow covered conditions and as high as 76% over tundra.

2) The albedo of individual surface types under full snow cover compared favorably with aerial measurements, ranging from 15-20% over patches of dense coniferous forests to 75% over portions of farmland.

3) Histogram statistics differed considerbly within and between regions of tundra and forest in Alaska as snow melted. They are useful in monitoring this process.

4) Image brightness varies over a lightly vegetated portion of the central U.S. due to differences in the depth, age, and/or distribution of regional snow cover. Regional albedo differs by up to 30% between fresh and aging snow packs of equal depth.

These results will help improve albedo parameterizations in climate models. Additional work will continue to assess relationships of image brightness to surface type and under varying snow cover conditions over regions of the Northern Hemisphere

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TABLE 1

DATA PERTAINING TO FIGURE 2

Surface Type	Histogram	Mean Brightness	Estimated Visible Surface Albedo	Standard Deviation	Skewness	Kurtosis
Mixed forests*, lakes, fields	A	157	56	35	-.1	2
Tundra	B	193	76	11	-.1	30
Mixed forest, lakes	C	145	49	23	+.2	3
Shrubland, lakes	D	184	71	11	-1.2	18
Deciduous forest, urban, fields	E	130	41	19	+.1	3
Farmland, pasture	F	184	71	12	-1.7	22
Coniferous forest, lakes	G	127	39	31	+1.3	5
Shrubland, thin forest, lakes	H	156	55	17	-.2	4

*Listed in decreasing abundance.

TABLE 2

DATA PERTAINING TO FIGURE 4. DEPTH MEASURED ON FLAT OPEN FIELDS WITH > 50% SNOW COVER. AGE IS THE NUMBER OF DAYS SINCE AN AVERAGE STATION IN THE AREA RECORDED A SNOW FALL > 2.5 CM. APPROXIMATELY 90 STATIONS REPORTING

Histogram	Date	Average Depth (cm)	Stations with Snow Cover (%)	Age (days)	Estimated visible albedo	Standard deviation	Skewness	Kurtosis
1	2/1/77	8.9	81	7	41	27	-.5	2
2	2/7/77	5.8	68	11	30	27	-.1	2
3	2/9/77	4.1	65	13	28	31	0	2
4	2/10/77	2.3	50	14	18	23	+2.0	12
5	3/16/76	2.5	50	1*	30	30	+.3	2

*refers only to the stations with snow cover.

Figure 1. Locations of study areas A-K.

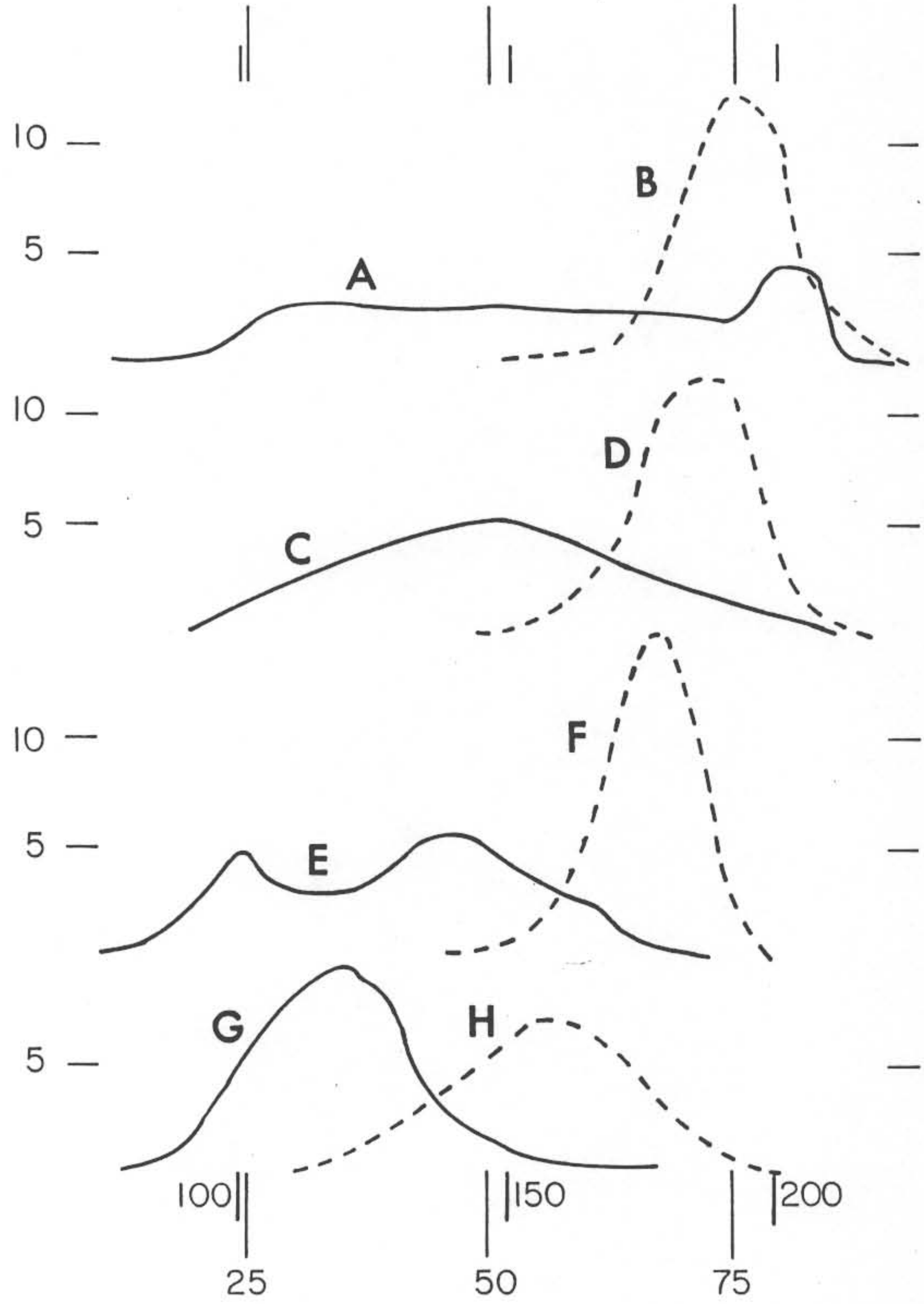

Figure 2. Brightness histograms of fully snow covered regions. See Fig. 1 for locations and table 1 for surface description. Vertical axis shows the number of processor pixel (x 10^3) with a particular brightness or estimated visible albedo (horizontal axis, top and bottom respectively).

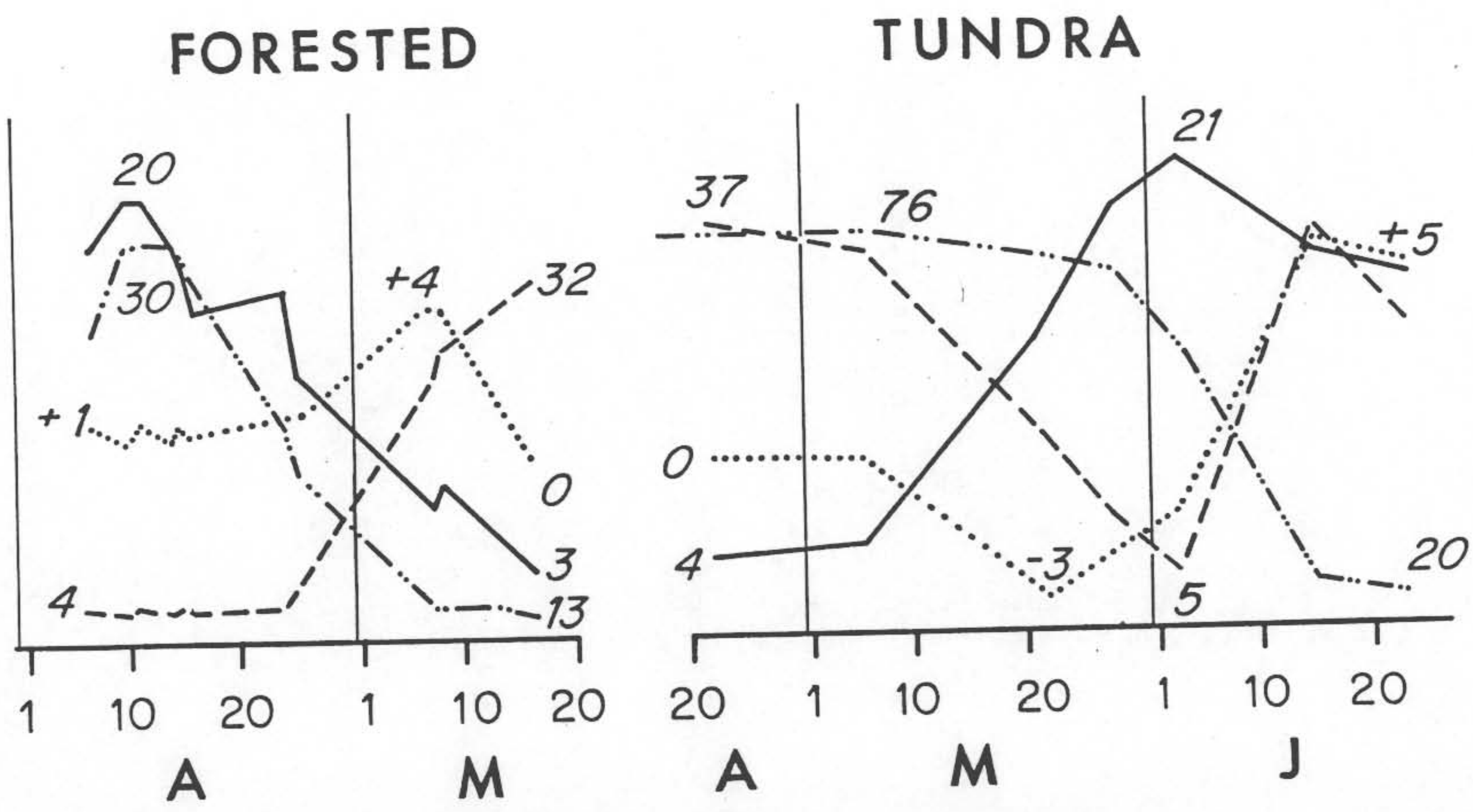

Figure 3. Response of brightness histogram standard deviation (———), skewness (....), kurtosis (----), and estimated visible surface albedo (-··-) to snow melt in forest and tundra areas of Alaska in the springs of 1981 and 1980 respectively. Horizontal scale shows dates between April 1 and June 23.

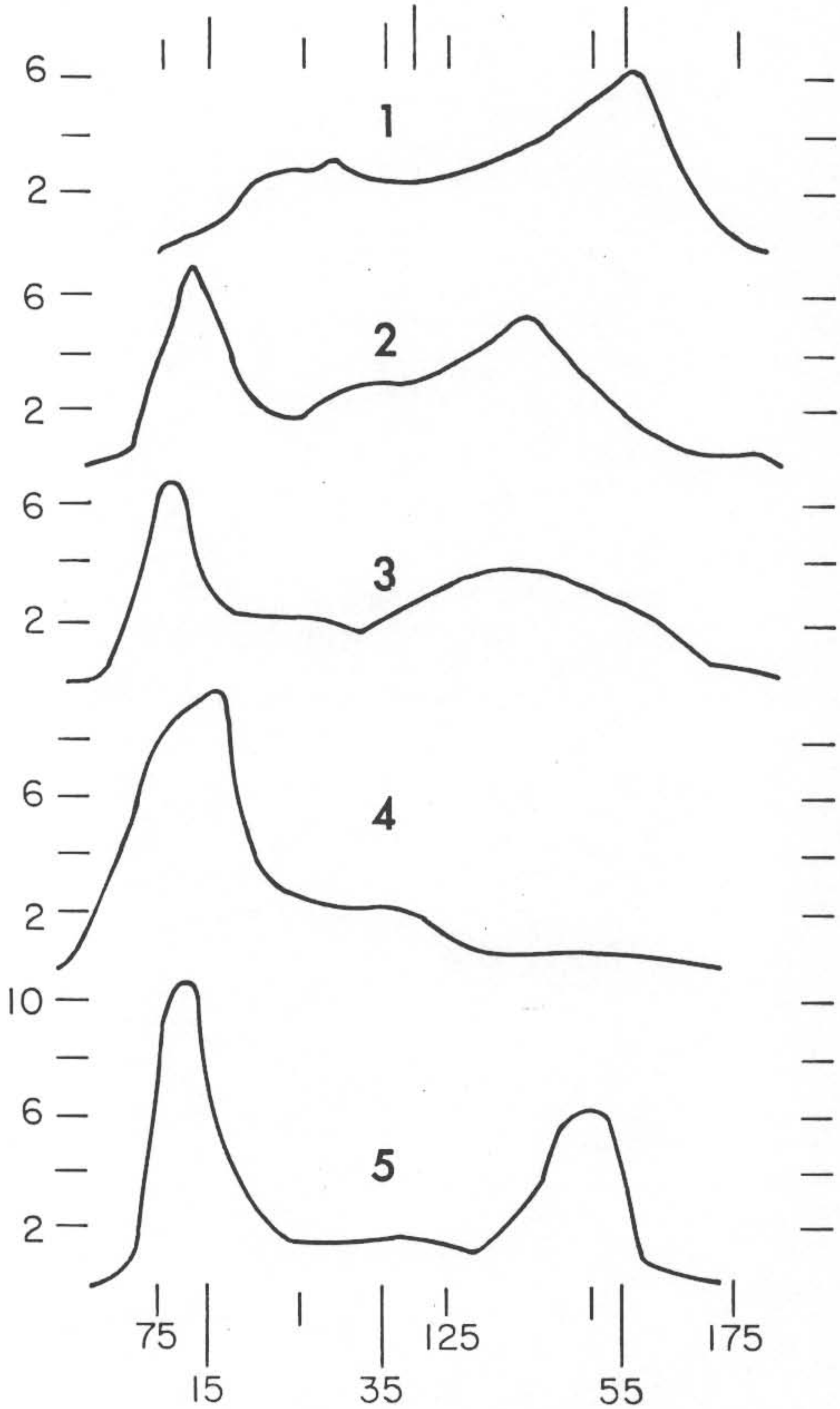

Figure 4. Brightness histograms with different snow cover situations over part of the midwest U.S. (fig. 1-K). Axes same as in fig. 2.

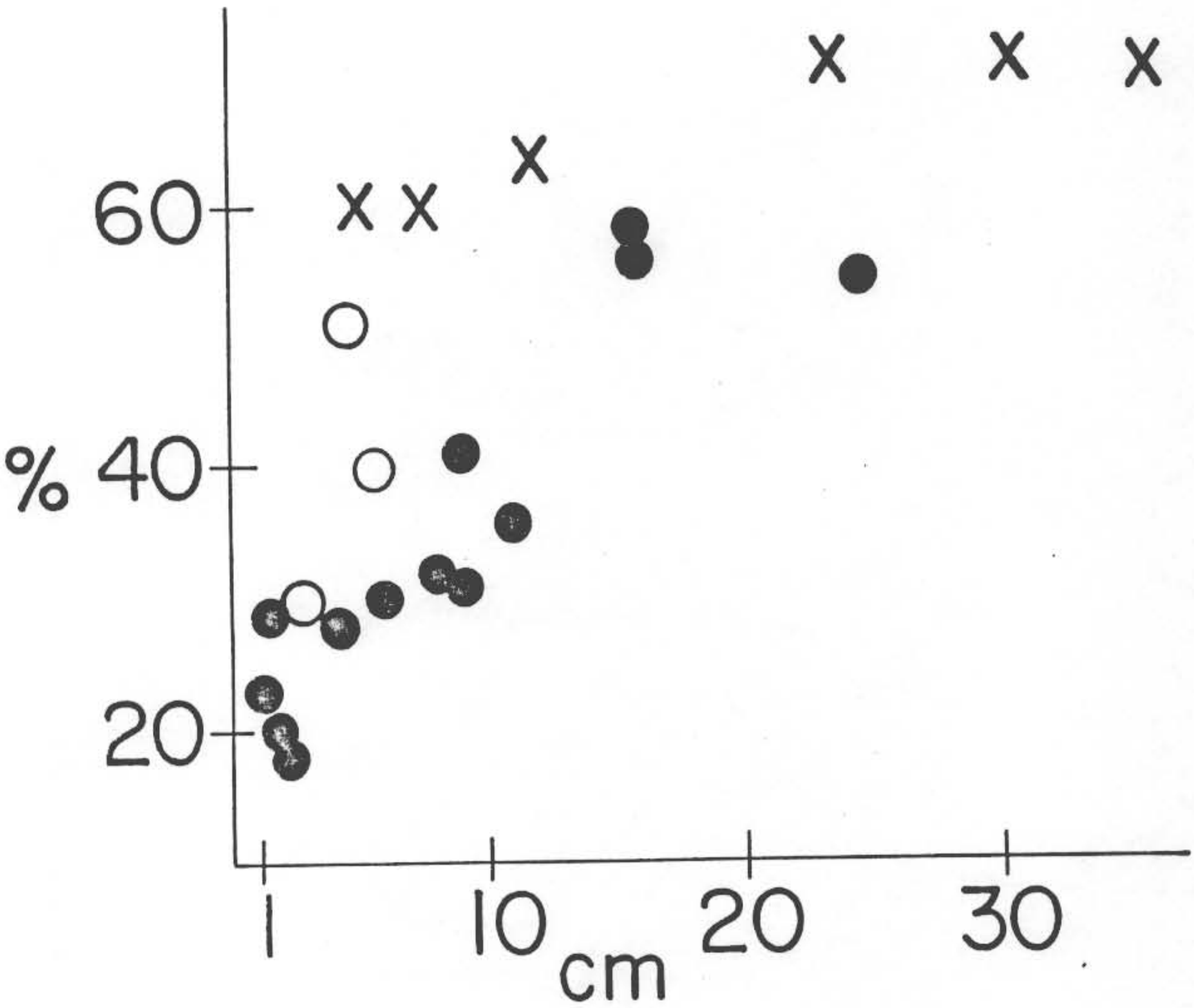

Figure 5. Estimated visible surface albedo (vertical axis) versus mean zonal snow depth over portions of the central U.S. Station density - 1 per 3500 km^2. Areas where 100% of stations had > 2.5 cm snowfall within 2 days prior to measurement (X), <50% with new fall (O), and previously snow free zones with 50% to 84% new fall (●).