MAXIMUM ESTIMATED SURFACE ALBEDO OF SNOW COVERED NORTHERN HEMISPHERE LANDS

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Abstract: Maximum estimated surface albedos for potentially snow covered Northern Hemisphere lands were derived in 1°x1° segments from Defense Meteorological Satellite Program image brightness. Average estimated albedo in qualified portions of Eurasia and North America was found to be 59.9% and 55.9% respectively. These areas comprise 84% of the land north of 25°N. Average 5° zonal albedos ranged from 43% to 77% and individual 1°x1° segments from 21% to 80%, primarily due to distribution, density, and height of vegetation. Image brightness was measured on an image processor and converted to estimated surface albedo by linear interpolation between a brightest snow covered surface assigned a parameterized albedo of 80% and a darkest snow covered surface given an albedo of 18%. Albedo was inferred where imagery meeting maximum brightness criteria was lacking. Results are the most detailed to date, providing improved information for operational charting of snow and cloud covers, long range weather forecasting, and climate modeling efforts.

1. INTRODUCTION

Maximum estimated surface albedos of potentially snow covered Northern Hemisphere lands were derived in 1°x1° segments from image processor analyses of Defense Meteorological Satellite Program (DMSP) image brightness. Results improve an earlier qualitative satellite brightness assessment (Kukla and Robinson, 1981).

Observational studies and climate models show snow cover to be an important variable in the climate system, particularly due to its high albedo (Namias, 1962; Dewey; 1977, Manabe and Wetherald, 1980). The impact of snow cover on continental surface albedo varies significantly, however, depending primarily on the type and density of vegetation and the snow condition (Robinson and Kukla, 1982). Numerous studies have observed large albedo varitions of snow covered lands on local and region levels (eg. Lillesand et al., 1982; Kung et al., 1964). These results have been incorporated with vegetation and snow distribution data to obtain global surface albedo estimates or to derive albedos in climate models (eg. Posey and Clapp, 1964; Hummel and Reck, 1979; Kukla and Robinson, 1980; Hansen et al., in press). Such an approach does not satisfactorily account for the highly variable distribution and density of vegetation in the middle and high latitudes of the Northern Hemisphere.

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Direct measurement of surface albedo from satellites is not possible, primarily due to sensor spectral limitations and atmospheric attenuation of short wave radiation (Otterman and Fraser, 1976). Various atmospheric models and ground truth standards have been employed in attempts to limit these factors (Preuss and Geleyn, 1980; Rockwood and Cox, 1978). While satellite limitations are not negligible, they are minor when assessing the dramatic differences in surface brightness between snow covered regions with contrasting types and densities of vegetation.

2. DATA

DMSP imagery is from the noon equatorial crossing polar orbiting F1 satellite with the series 5D sensor. Nadir resolution is 2.8 km, sensor spectral range is .4μm to 1.1μm, satellite altitude and cross tract width are approximately 930 km and 3000 km respectively (Fett et al., 1977). Signals are normalized for solar illumination and saturation is not a problem over snow covered regions (Bunting and d'Entremont, 1982). Daily imagery was available on ungrided positive film transparencies scaled at $1:15x10^6$.

3. PROCEDURE

Imaged scenes were measured on an image processor when the following specifications were met:

1) Clear skies. Distinguished by observing the "sharpness" of surface features, cloud patterns, and by comparison with surrounding days. The sensor spectral range is optimal for detecting haze and cirrus (Fett et al., 1977).

2) Solar zenith angle between 60° and 70°. To equalize specular and shading effects at different latitudes.

3) Scenes fell within the middle half of the image. To minimize scan angle and differences in solar angle and maximize resolution.

4) Good transparency quality. Images with washed out or exaggerated contrast or with pronounced vertical banding were eliminated.

5) The scene exhibited maximum surface brightness within the previously specified limits. Brightness is a function of snow depth and age (Lillesand et al., 1982; McGinnis et al., 1975). Maximum brightness was confirmed through comparisons of multiple images and with the assistance of publications reporting snow depths and/or ages on or close to the image date (Woronicz, 1982; Climate Perspectives, 1979- ; Weekly Weather and Crop Bulletin, 1914-; Clim.D). Average depth data was also examined (Kopanev, 1978). In most scenes snow was over 20 cm deep and a few days old.

Imagery was analyzed on a processor system which treats a projected image as 307,000 discrete pixels, assigning each a gray scale value from black (0) to white (255).

Correlation of brightness between images was achieved through aperture adjustments of the processor lens. This involved equalizing the brightness of identical 1°x1° segments and certain reference surface types found on most images. Adjusted images were input to the processor memory then measured in 1°x1° segments by projecting a carefully alligned grid onto the processor screen.

Brightness was converted to estimated surface albedo by linear interpolation between bright tundra and dark dense coniferous forests assigned snow covered albedos of 80% and 18% respectively. These values were parameterized from numerous ground truth studies (eg. Kung et al., 1964; McFadden and Ragotzkie, 1967; Kondratyev et al., 1981).

Error estimates of measured brightnesses gave confidence limits of ± 2.5% to estimated albedos. This assumes parameterized albedos are representative of natural conditions and DMSP brightness is proportional to full spectral albedo. The latter seems reasonable as the broad spectral range of the sensor peaks close to the midpoint of incoming clear sky solar radiation.

Measurements were made on 75 images from 1979 and 5 from 1978, covering most of the potentially snow covered tundra, forests, and farmland of the Northern Hemisphere. Potentially covered land is defined as being within Dickson and Posey's (1967) 0% probability line of 1 inch or more snow cover at the end of January and/or December. This includes 87% of the land north of 25°N and 60% of all Northern Hemisphere lands.

Water bodies having at least one land free 1°x1° segment were not measured. Smaller bodies were frozen north of 40° and open to the south. Brightnesses exceeding the specified tundra were found only on high mountain tops and were adjusted to the lower elevation maximum. This amounted to no more than a few percent decrease in albedo in less than 5% of the segments.

Albedo was inferred where imagery meeting maximum brightness criteria was lacking with the aid of:

1) partially snow covered images of the area,
2) comparisons with analogous snow covered surface types and terrains,
3) vegetation charts and atlases (Olson and Watts, 1982; Wiebecke, 1971).
4) Landsat mosaics (Ni et al., 1975; National Geographic Society, 1976; USDA, 1974),
5) NOAA Very High Resolution Radiometer (VHRR), Advanced VHRR and GOES imagery.

Inferred regions were mainly in the arid and semi-arid areas of southern Asia where albedo estimation was simplified by the general absence of vegetation.

4. RESULTS

Average 5° zonal estimated albedos are reported in Table 1. Average albedos for Eurasia and North America differ by only 4% and are roughly three times their snow free value. The addition of Greenland raises the hemisphere average 0.7%. Zonal forest distribution is evident on both land masses, particularly in the 25% albedo change centered at 65°N in Eurasia.

Figure 1 presents results from 20° meridional bands in eastern Asia and central North America. The latter strip runs southward from the homogeneously bright tundra of the Canadian archipelago and Keewatin district through the lake dotted boreal forest to the plains and farmland of Canada and the U.S. The Asian band contains a wide forest zone, cut by the brighter Yablonovyy and Stanovoy ranges between 54° and 59°N. A snow covered mosaic of a portion of this segment is shown and discussed further in Kukla and Brown (1982). Ranges are high immediately south of the fully forested regions in both segments where forested areas gradually diminish.

Estimated albedos of individul 1°x1° segments ranged from 80% over tundra to 21% in dense coniferous forests. Most 1°x1° forested zones are not as dark for one or a combination of the following reasons:

1) They contain scattered fields and water bodies.
2) Forests are mixed or deciduous.
3) Forests may not be mature due to man's forestry activities in the past few centuries.

Steepe and open farmland albedos were generally 5% to 10% lower than tundra as were those of unforested mountains. The latter is most likely the result of exposed rock on steep slopes and shadowing.

5. CONCLUSION

Estimated maximum surface albedo over potentially snow covered Northern Hemisphere lands was found to be 58.7%. Albedo varied by up to 59% between individual 1°x1° segments. Data was gathered primarily from image processor analyses of satellite image brightness. Brightness was converted to estimated surface albedo using parameterized ground truth data. Results using this method in partially snow covered regions are found in Robinson and Kukla (1982). Present results are the most detailed to date, providing improved information for operational mapping of snow and cloud covers, long range weather forecasting and climate modeling efforts and may be of use to those assessing continental biomass.

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TABLE I

ESTIMATED SURFACE ALBEDO OF POTENTIALLY SNOW COVERED NORTHERN HEMISPHERE LANDS

Albedo (%)

Latitude	Eurasia	North America	Northern Hemisphere*
85-80	80.0	74.3	75.2
80-75	80.0	77.4	74.6
75-70	75.7	79.3	76.8
70-65	60.7	66.6	62.7
65-60	35.5	57.6	42.9
60-55	42.7	49.3	44.7
55-50	55.5	46.5	52.6
50-45	66.7	48.7	61.3
45-40	66.9	58.8	64.4
40-35	69.9	57.1	65.9
35-30	72.0	55.8	68.8
30-25	68.3	____	68.3
85-25	59.9	55.9	58.7

*excluding Greenland

FIGURE I

Estimated maximum surface albedo of potentially snow covered lands in 1^0 latitudinal steps averaged across two 20^0 Northern Hemisphere swaths (heavy lines). Albedo range of $1^0 x 1^0$ segments shown with thin lines.