OBSERVATION OF SURFACE ALBEDO AND ITS VARIATION FOR CLIMATE MODELS*

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ABSTRACT

The present status of surface albedo parameterization in three dimensional climate models is reviewed and found to be inadequate. This is because present data sets do not sufficiently account for the highly variable nature of surface albedo. Ground truth observations are presented, exemplifying this variability in time and space. Case studies show the albedo of surfaces covered by fresh deep snow varied by 61% as a result of different vegetation densities. The range of spectral reflectivities in this case was 45% in the near infrared (NIR, 0.7-2.8μm) and 72% in the visible (VIS, 0.28-0.7μm). The albedo variation of these same surfaces was only 10% 18 days later when the ground was almost snow free. The range in reflectivities when the ground was snow free was greater in the NIR (18%) than in the VIS (8%). Examples also show the variability of surface albedo due to differences in the spectral distribution of incoming radiation and due to changes in surface moisture. Satellites offer the best potential to improve the albedo data sets. However, the task can not be successfully completed without an extensive well documented ground truth program

1. INTRODUCTION

Approximately one quarter of the incoming solar radiation is directly absorbed in the atmosphere. Twice as much energy reaches the earth's surface, which is the principal level at which the atmosphere is heated. Surface albedo measures the efficiency of this heating. It is only in recent decades that the importance of surface albedo in the climate system has become fully realized. Surface albedo is one of the critical variables in three dimensional climate models. Unfortunately, the data from which the climate modelers can draw the needed information is insufficient. Available references do not adequately account for the fact that the albedo of

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most natural surfaces is a sensitive time dependent parameter which varies not only with the developmental state of the vegetational cover, but also with surface moisture, angular and spectral distribution of incoming radiation, etc. Differences between albedo sets are largest over land in the middle and high latitudes where snow cover is a transitory feature.

In this paper, the present status of albedo parameterization in climate models is reviewed. Examples of the variable character of surface albedo over land follow, exemplifying the rudimentary nature of present parameterizations and suggesting the types of ground truth needed to improve surface albedo sets compiled from satellite data

2. MODEL PARAMETERIZATIONS

The method of albedo representation employed varies amongst climate models. In simple energy balance models, (see, for example, Budyko, 1969; Sellers, 1969; Cahalan and North, 1979; North et al., 1981), the system albedo is generally parameterized as a function of zonally averaged surface temperature. More complicated models handle surface atmospheric reflection separately. Table 1 reviews the land surface albedos used in a wide selection of general circulation models (GCMs). Carson (1981) grouped the treatment of snow free land albedos into three categories; 1) a single fixed value for bare land, 2) land albedo specified as a function of latitude only, 3) specified realistic geographic distribution of fixed albedos. The general trend in GCMs is towards the third category.

Carson (1981) and Henderson-Sellers and Wilson (1983) identify three types of snow covered and ice covered surfaces as recognized in GCMs; 1) surfaces with an instantaneously variable depth of snow either predicted or implied, 2) permanent or seasonally prescribed snow or ice covered land, 3) permanent or seasonally prescribed areas of sea ice. There are numerous parameterization schemes employed to model the albedo over snow and ice (Table 1).

3. GLOBAL SURFACE ALBEDO SETS

There are basically two ways of compiling global surface albedo for use in climate models, a) a satellite data composite and b) a geographic land type classification with albedo values assigned to each recognized surface type. Figure 1 illustrates three global albedo fields. Surface albedo in (1a) was derived by Preuss and Geleyn (1980) from Nimbus 3 satellite data analyzed by Raschke et al. (1973). Figure 1b is Posey and Clapp's (1964) reconstruction of surface albedo, based on a compilation of ground and aircraft measurements applied to classifications of vegetational cover. The map of Hummel and Reck (1979) (1c) is an update of the earlier works of Posey and Clapp (1964) and Schutz and Gates (1972), supplemented by the results of newly acquired ground observations.

Other efforts to generate global surface albedo sets using various land classifications (method b) include ones by Kung et al. (1964), Kukla and Robinson (1980), and Robock (1980). Recently, a new data set developed by the CLIMAP group (CLIMAP, 1981) parameterizes albedo in 2°x2° blocks separately for wet and dry snow free and snow covered conditions, using a combination of methods a and b.

Difficulties in compiling global data sets by method b include, 1) finding a classification system best related to surface albedo and 2) obtaining appropriate albedo observations for each category under a variety of surface and atmospheric conditions. Satellite composites have the advantage of monitoring conditions over wide spaces in daily and even shorter intervals. However, direct interpretation of satellite data in terms of surface albedo is impossible without adequate ground truth. Ground truth is needed to calibrate satellite image brightness under a variety of atmospheric conditions, correct for the spectral limitations of most satellite sensors, relate bidirectional satellite measured reflectances to hemispheric albedo and to take into account variations due to clouds and the diurnal cycle.

4. SURFACE ALBEDO OBSERVATIONS

The major limitation in the creation of any representative data set is the considerable spatial and temporal variability of surface albedo. Figure 2 illustrates this variability, showing the change of surface albedo of a snow covered region northwest of New York City. Data was gathered in a continuing program involving the collection of photographically documented albedos over typical middle latitude surfaces throughout the year. In this particular case, shortwave albedo (0.28µm-2.8µm) was measured using wingtip mounted Eppley pyranometers on a low-flying aircraft over a prescribed 100 km route. Six flights documented the decrease in surface albedo following the blizzard of February 11 and 12, 1983. The storm deposited approximately 45-65 cm of snow in the study area over a 10-15cm base. Daily high temperatures during the 2/14-3/3 period monitored ranged between 2°C and 14°C, averaging 9°C. No measurable snow fell during the 18 day period and no significant rain occurred until 3/2, when approximately 25 mm fell over the area. On 2/14 the snow surface albedo was only 1-2% lower than the fresh snow measured at the end of the snowfall. On 3/3 only scattered patches of snow remained, keeping regional albedos slightly higher than the annual minimum. Observations of particular interest include:

1) The 61% range in albedo over surfaces with different vegetational cover under full snow on 2/14. The range decreased to 10% on 3/3.

2) The 8% drop in albedo from 2/14-2/18 over surfaces with little exposed vegetation (A-C). An identical drop was measured on the ground over a fully snow covered test site near the flight path. This change is attributed predominantly to snow metamorphosis and partial snow contamination. Also, the snow pack was moister on 2/18.

3) A larger, 14%, decrease in albedo during the 2/14-2/18 interval over the area with shrubs, tall grass and herbs (D). Here, the proportion of exposed dark vegetation rapidly increased as the snow depth dropped.

4) The timing of the largest drop in albedo. This occurred during the first week in areas with tall vegetation but during the last week over the open fields.

5) The albedos of surfaces D-G were halfway between their maximum and minimum values by the 7th day, whereas areas A-C took between 10 and 12 days to reach this mark.

The relatively rapid decrease of surface albedo following a significant snowfall, such as illustrated in figure 2, does not occur when the daily high temperatures remain close to or below freezing over extended periods following an event. For instance, we have recorded an albedo drop of only 9% over a short grassy field, from an initial value of 84%, over a 14 day period when high temperatures ranged from -11°C to 4°C, averaging

-3°C. One rain and snow event (30mm water equivalent) occurred in the middle of this period which resulted in no change in snow depth or increase in albedo.

Surface moisture is a critical variable affecting the albedo of a snow free landscape. Values for light sandy as well as wet dark peaty soils in the test area show drops amounting to 50-60% of their dry state albedos.

Differences in surface albedo were also found to be due to the varying distribution of incoming radiation. This is weighted more heavily toward the visible (VIS, 0.28μm - 0.7μm) on cloudy days. As a result, the albedo of a snow free grassy field in the test region on a cloudy day in April was 11% while under clear skies it was 22%. Incoming radiation in the near infrared (NIR, 0.7μm-2.8μm) amounted to 32% of the total incoming shortwave radiation on the heavily overcast day (atmospheric transmissivity 7%) and to 50% on the clear day (transmissivity 70%).

The range in NIR reflectivity of the surfaces shown in figure 2 when fully snow covered on 2/14 was 45% (68%, area B to 23%, area G). The range in VIS reflectivity was considerably larger at 72% (88% (B)-16%(G)). On the contrary, when snow free on 3/24 the range in the NIR was larger than in the VIS. It was 18% (between 10% (B) and 28% (A)) in the NIR and 8% (between 4% (B) and 12% (A)) in the VIS. This is primarily due to the dramatically different spectral responses of snow and vegetation. Snow reflectivity is high in the VIS and low in the NIR. The reverse holds for vegetation.

5. CONCLUSIONS

Present parameterizations of snow free and snow covered surfaces in climate models are inadequate. The variable nature of surface albedo in space and time requires a detailed data base. Satellites are the optimal source for obtaining this information. However, without extensive well documented ground truth the utility of satellite surveillance is restricted. Observations made as part of a recent survey in an area northwest of New York City exemplify the need for improvement of surface albedo parameterization schemes presently employed in climate models.

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Table 1. Surface albedoes used in atmospheric general circulation climate models

EXAMPLE CENTRE/REFERENCE	MODEL	SNOW- AND ICE-FREE SURFACES	SNOW- AND ICE-COVERED SURFACES
Atmospheric Environment Service (Canada) Boer and McFarlane (1979)	AES	No specific details but implied geographical distribution based on Posey and Clapp (1964)	Follows Holloway and Manabe (1971) - Equation (5) - see GFDL
Australian Numerical Meteorology Research Centre McAvaney et al. (1978)	ANMRC	Latitudinal variation based on Posey and Clapp (1964)	Snow albedo prescribed as latitudinal variation of α. α(sea-ice) = 0.07
Computing Centre, Siberian Academy of Sciences Marchuk et al. (1979)	CCSAS	$\alpha = \begin{cases} 0.2 & \text{bare ground} \\ 0.1 & \text{ocean} \end{cases}$	Snow: $\alpha = 0.2 + 0.4\, d_{sw}$ $\alpha \leqslant 0.6$ (Same as NCAR) Ice: $\alpha = 0.6$
Geophysical Fluid Dynamics Laboratory Holloway and Manabe (1971)	GFDL	Geographical distribution based on Posey and Clapp (1964)	Snow - Equation (5) $\alpha = \begin{cases} \alpha_l + (0.6 - \alpha_l) d_{sw}^{1/2} & d_{sw} < 1\text{cm} \\ 0.6 & d_{sw} \geqslant 1\text{cm} \end{cases}$ (5) Poleward of 75° lat., albedo for land and pack-ice 0.75.
Manabe and Stouffer (1980)	GFDL	Geographical distribution based on Posey and Clapp (1964)	Sea ice: 0.5 for lat. < 55° 0.7 for lat. > 66.5° 0.45 if top melting
Goddard Laboratory for Atmospheric Sciences Halem et al. (1979)	GLAS	Feb. Geographical distribution based on Posey and Clapp (1964) Aug. Charney et al. (1977) Vegetated land 0.14 Desert 0.35 Ocean 0.07	Snow/Ice 0.70 Holloway and Manabe (1971) Equation (5) - see GFDL
Goddard Institute for Space Studies Hansen et al (1983)	GISS	Land - 8 vegetation types have seasonally varying albedoes for < 0.7 µm and ≥ 0.7 µm.	Snow free ice: 0.45 ocean 0.5 land Snow albedo: $\alpha_s = 0.5 + e^{-age/5}$ Ground partly snow covered albedo: $\alpha_l + (\alpha_s - \alpha_l)(1-e^{-d_{sw}/d_{mask}})$ Two spectral regions
Meteorological Office, U.K. Corby et al. (1977)	UKMO	5-level model: Snow-free land values vary with latitude Range 0.150-0.223.	Snow: $\alpha = \alpha_l + 0.38\, d_{sw}^{1/2}$ $\alpha \leqslant 0.6$ Similar to Holloway and Manabe (1971), Equation (5) - GFDL. Sea-ice and permanent snow cover: $\alpha = \begin{cases} 0.8 & T_0 < 271.2\text{K} \\ 0.5 & T_0 \geqslant 271.2\text{K} \end{cases}$
Saker (1975)	UKMO	11-level model: Land 0.2 Sea (where effective) 0.06	Transient snow cover 0.5 Permanent snow cover, land- and sea-ice 0.8
National Center for Atmospheric Research Washington and Williamson (1977) Dickinson et al. (1981 unpub.)	NCAR	Originally: Geographical distribution based on Posey and Clapp (1964). Third-generation model: two spectral regions < 0.7 µm and > 0.7 µm. Dependence on vegetation type and extent.	Originally: Snow or ice: $\alpha = 0.2 + 0.4\, d_{sw}$, $\alpha < 0.6$ (6) Third-generation model: Snow albedo function of age and depth of snow - two spectral regions.
Oregon State University Schlesinger and Gates (1979)	OSU	Geographical distribution based on Posey and Clapp (1964) and models 9 surface types.	Fixed value.
Rand Corporation Gates and Schlesinger (1977)	RAND	Geographical distribution based on Posey and Clapp (1964)	
University of California at Los Angeles Arakawa (1972)	UCLA	Bare soil 0.14 Ocean 0.07	Snow covered 0.7 Ice-covered soil or sea water 0.4

where (i) d_{sw} is the water equivalent depth of snow (cm).
(ii) age is the snow age (days).
(iii) d_{mask} is the vegetation snow masking depth equivalent thickness of water (cm)
(iv) α_l is the snow-free land albedo.

after Henderson-Sellers and Wilson, 1983

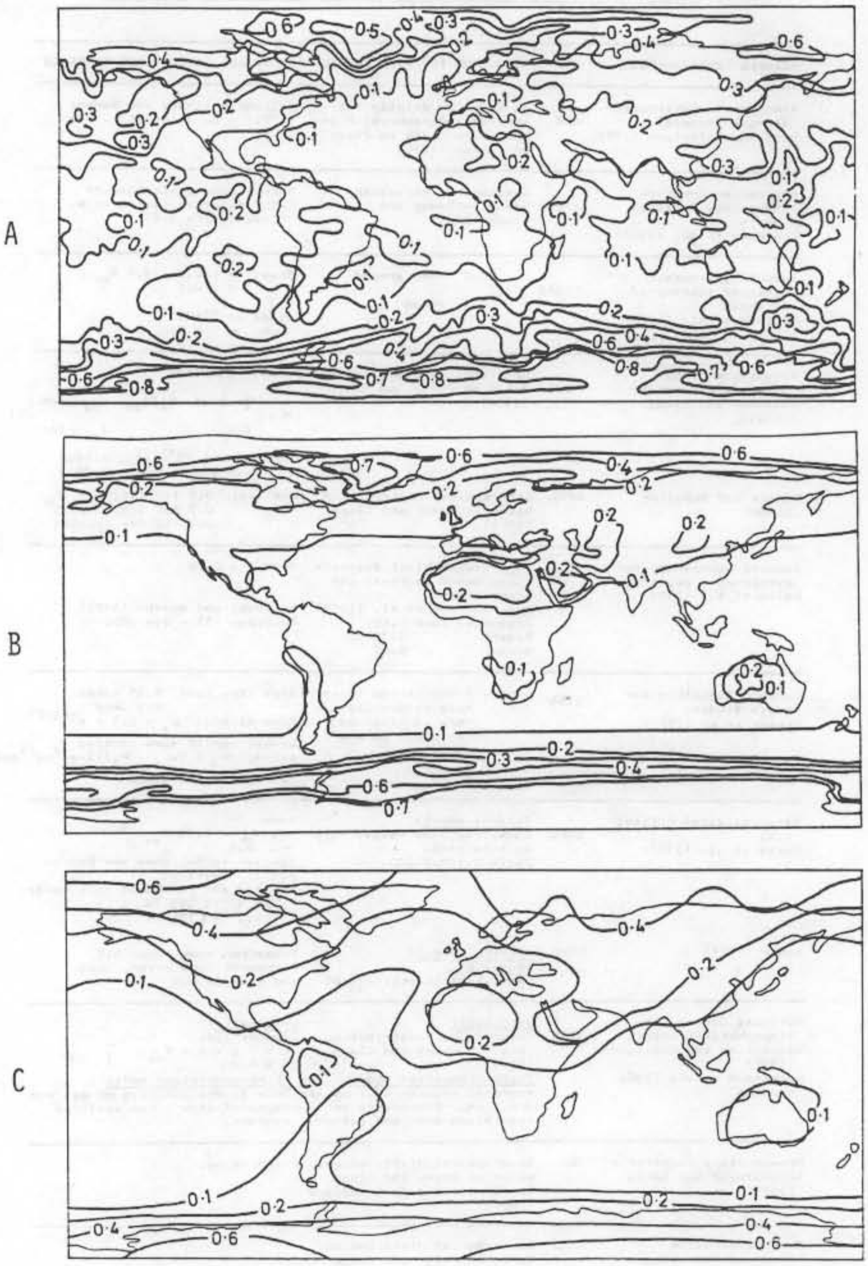

Figure 1. (a) surface albedos derived from satellite derived minimum albedos (after Preuss and Geleyn, 1980); (b) Geophysical Fluid Dynamics Laboratory surface albedos (redrawn from Preuss and Geleyn, 1980); (c) surface albedo map drawn from annual average surface albedo values of Hummel and Reck (1979). (from Henderson-Sellers and Hughes, 1982)

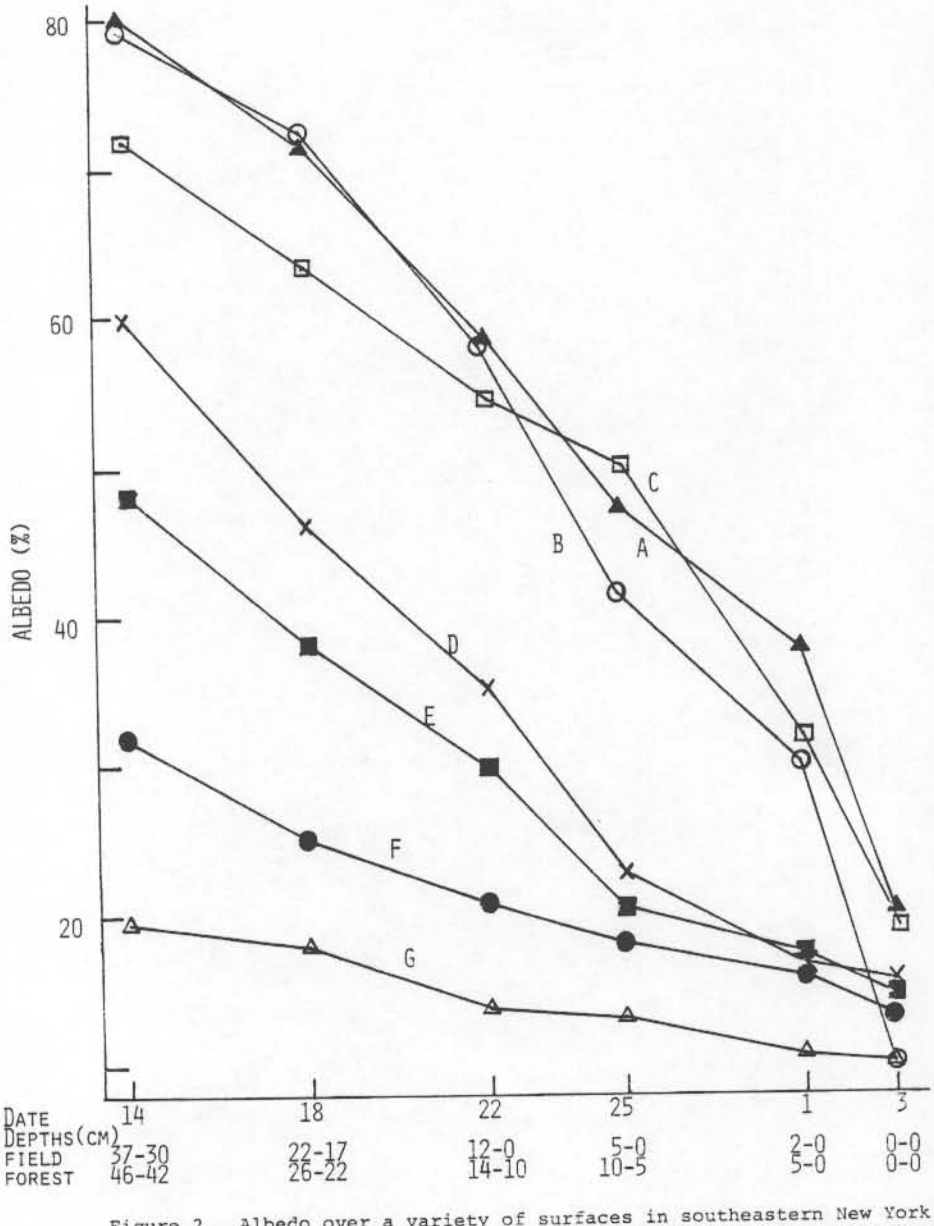

Figure 2. Albedo over a variety of surfaces in southeastern New York and northern New Jersey from February 14-March 3, 1983. Data are from 6 photo-documented flights. Snow depths are the average and minimum measured in a vegetation free dark soiled onion field (B) and a level deciduous forest (F). Other surfaces include: (A) corn field with exposed light sandy soil and corn stalks, (C) short grass meadow with widely scattered trees, (D) tall grassland with shrubs and herbs, (E) lightly wooded residential development and (G) mixed coniferous and deciduous forest (approximately 50% conifer-hemlock).