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ANTHROPOGENIC INCREASE OF WINTER SURFACE ALBEDO

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SUMMARY

The range of surface albedo in winter increased fourfold after densely forested swamps in Orange County, New York were turned into farmland, making the local microclimate considerably more sensitive to the presence and duration of snow cover. Today, the peaty onion fields when dry have an albedo of 0.08 when snowfree and 0.79 when covered with fresh snow. Before clearance in the late 18th century, the albedo of the swamps ranged from approximately 0.10 when snowfree to 0.28 when snow covered. Prior to the arrival of white settlers, the regional surface albedo, as modeled over a large portion of southeastern New York, ranged from 0.12 when snowfree to 0.31 when snow covered. It ranged from 0.15 (snowfree) to 0.59 (snow covered) when deforestation peaked in the late 19th century. Present values are 0.14 and 0.47, respectively. As a result of these changes in albedo, we estimate that approximately the same amount of solar radiation was absorbed in the naturally vegetated New York region in a snowy winter (with the ground snow covered 75% of the time) as in a snow-dry winter in the late 19th century (with a 10% duration of snow). Deforestation elsewhere in the middle latitudes has had qualitatively similar effects.

1. INTRODUCTION

Use of land for agriculture has resulted in extensive deforestation in the middle latitudes of the Northern Hemisphere (DARBY 1956, MATTHEWS 1983). Consequently, the seasonal and annual range of surface albedo has changed considerably (SAGAN et al. 1979, ROBINSON & KUKLA 1985). Because of winter snow cover, the land in the middle and high latitudes displays larger annual and interannual variations of surface albedo than elsewhere (KUNG et al. 1964, KUKLA & ROBINSON 1980, ROBOCK 1980). The albedo feedbacks in these seasonally snow covered regions play an important role in expected climatic impacts of the increasing CO_2 or of the "nuclear winter" (RAMANATHAN et al. 1979, ROBOCK 1984).

Considerable work has been done regarding the man induced increases in albedo resulting from overgrazing in semi-arid zones and tropical deforestation (SAGAN et al. 1979, OTTERMAN 1974, 1977, HENDERSON–SELLERS & GORNITZ 1984). These activities, as indicated by climate model studies, can affect atmospheric dynamics and hydrologic cycles (CHARNEY et al. 1977, WALKER & ROWNTREE 1977, POTTER et al. 1980, SUD & FENNESSY 1982, SUD & SMITH 1985). Relatively little attention, however, has been paid to the artificial alteration of albedo in the middle latitudes. Here, we report an extreme change of winter albedo in a mid-latitude region where man has had a major impact on the environment.

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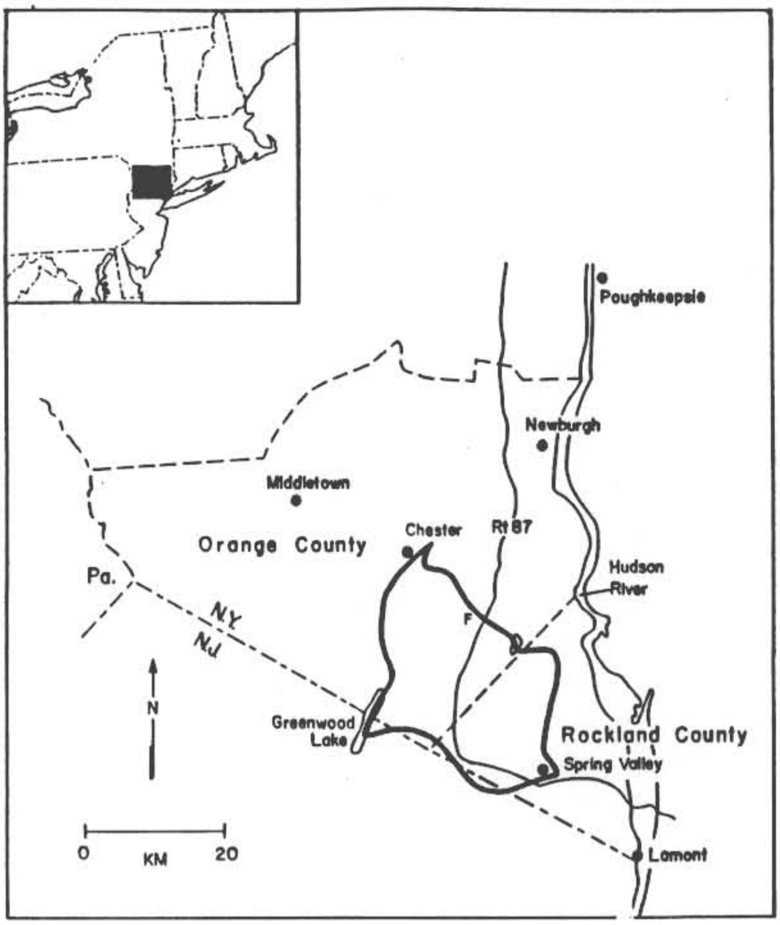


Fig. 1: Study region in southeastern New York and northern New Jersey, showing the flight path (heavy line) and the boundaries of Orange and Rockland Counties.

2. STUDY REGION

The study region is located in southeastern New York and northern New Jersey (fig. 1). Much of it falls in two counties, Orange and Rockland, which cover approximately 3100 km^2 and today are composed of approximately 46% forests, 27% farmland and open meadow and 27% commercial and residential areas and overgrown farmland (table 1). Land-use was determined from county surveys, Landsat images and aerial and ground surveys conducted under this study.

In AD 1600, prior to the arrival of white settlers, vegetation was close to its natural state (table 1). Indians only cleared small fields for farming and some forest underbrush to aid hunting (TOMPKINS 1902, SALWEN 1976). The region remained almost completely forested through the early 18th century (HULL 1975). Regional deforestation peaked in the late 19th century, when farmland and open meadow covered 65% of the region and forest the remainder; as estimated from reported farm acreages, mining reports and several photographs (RUTTENBER & CLARK 1881, COLE 1884, RIES 1895, RANSOM 1966, HULL 1975). Agricultural and dairy farming was near its peak in the valleys, while reforestation of

Tab. 1: MODELED DISTRIBUTION OF MAJOR SURFACE COMPONENTS WITHIN ORANGE AND ROCKLAND COUNTIES, NY AT PRESENT AND IN THE PAST (COVERAGE). ALSO THEIR SURFACE ALBEDO IN WINTER UNDER DRY SNOWFREE CONDITIONS, UNDER DEEP (OVER 15 cm) FRESH DRY SNOW COVER (MAX) AND UNDER MEAN SNOW COVER (SEVERAL DAYS OLD, OVER 15 cm DEEP, WET). AVERAGE ALBEDO OF THE BI-COUNTY REGION AS A WHOLE IS ALSO SHOWN.

Surface component	Coverage (% area)			Albedo		
	AD 1600	AD 1900	Present	Snowfree	Snow covered MAX	Snow covered MEAN
Forest	95	35	46	0.12*	0.29	0.24
Farmland, open meadow	5	65	27	0.17**	0.75	0.67
Commercial, residential, overgrown farmland			27	0.14	0.50	0.40
Bi-county albedo		AD 1600		0.12	0.31	0.26
		AD 1900		0.15	0.59	0.52
		Present		0.14	0.47	0.40

* 90% deciduous, 10% coniferous
** 90% open field, 10% deciduous

surrounding hills was only beginning, following the decline of iron mining. Our data refer specifically to the bi-county region, but similar trends at different times are characteristic of the entire eastern United States (SICCAMA 1971) and to some degree of other previously forested mid-latitude regions (MATTHEWS 1983).

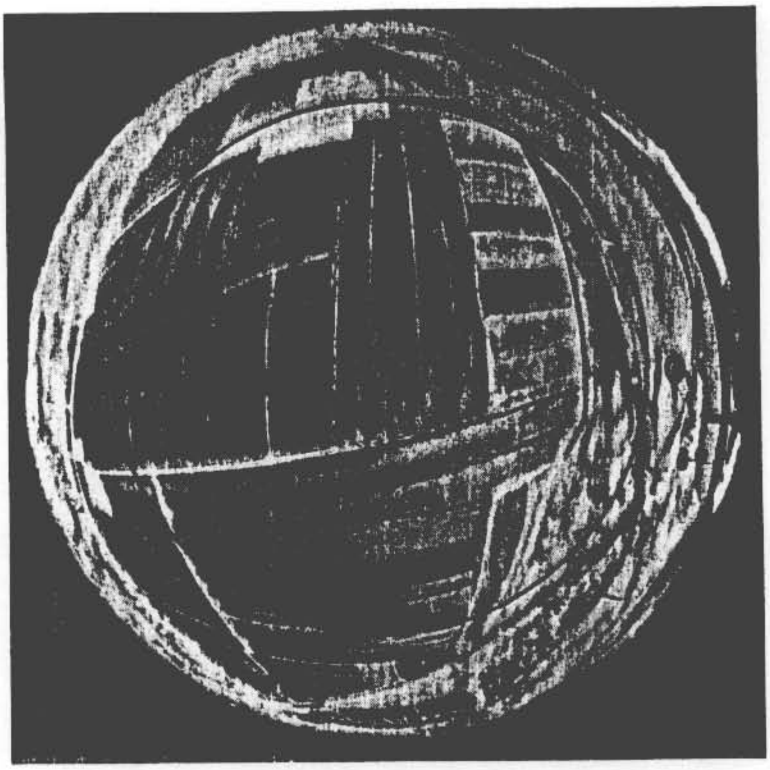
Of particular interest in the study zone is an area of Orange County, NY where black peaty soil filled the bottom of former Late Pleistocene glacial lakes. Presently, onions are the major crop grown on this drained fertile soil. The basins, locally called "mucklands" or "drowned lands", cover approximately 80 km^2. Until the arrival of settlers in the late 18th century, these lands were densely vegetated swamps (EAGER 1847, RUTTENBER & CLARK 1881, RIES 1895, HULL 1975). Clearance and drainage proceeded slowly until the 1880's when major cooperative projects began, which continued to approximately 1940 (EVERETT & EVERETT 1941, BOOTH 1975).

A representative portion of the mucklands near Chester, NY is shown in photo 1. This particular basin, which we will refer to as the Chester fields, is elliptical, covering an area of 1 × 3 km. Its flat surface of black soil (histosol) has a microrelief of 10-25 cm in winter. The Munsell value of the soil is 2.5YR 2.5/0 when dry and 2.5YR 5/1 when wet. In winter, only scattered patches of grass and weeds up to 1 m tall, in fallow plots or along drainage ditches, intersperse with the bare peaty soil.

3. MEASUREMENTS

Hemispheric shortwave albedo in the 280 to 2800 nm range was measured with Eppley pyranometers mounted on 1.5-2 m tall stands and on the wingtip of a Cessna 172 aircraft. The primary flight route is shown in figure 1. Instrumentation and methodology are described in detail by ROBINSON (1984). At the average flight altitude of 200 m, 90% of the reflected signal comes from an area of approximately 0.5 km^2. The low flight altitude makes any corrections for differences between the radiation income at the surface and at the aircraft

A



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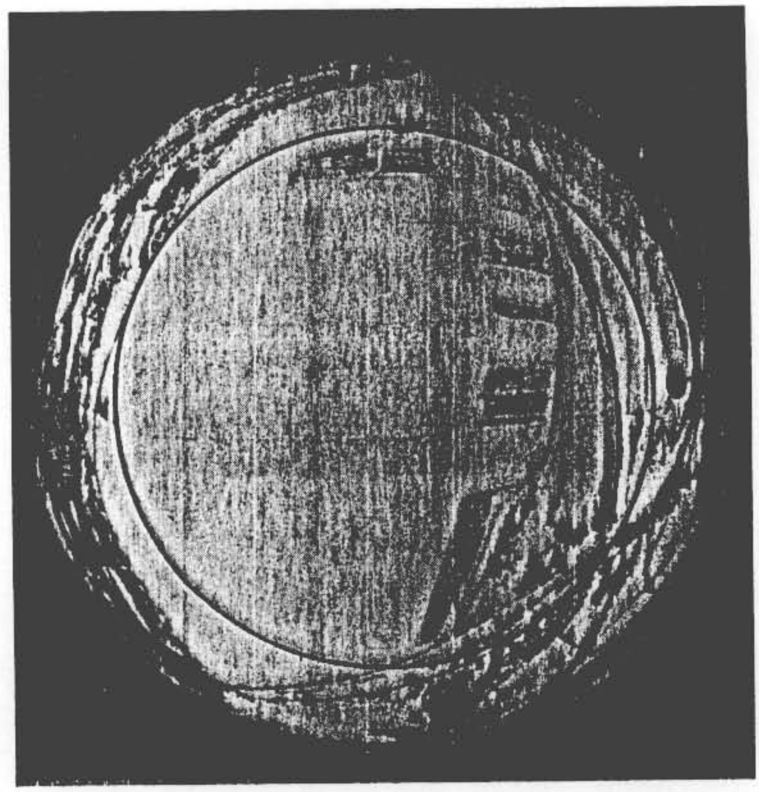

Photo 1: (a) Fisheye aerial photograph of the snowfree mucklands near Chester, NY on March 24, 1983. Taken from 200 m. The albedo of the scene is 0.06. Note the specular reflection off the partly flooded black soil fields. North is towards the top and 90% of the signal recorded by the pyranometer comes from within the encircled area.
(b) The same site under 30 to 60 cm deep fresh snow cover on February 14, 1983. Albedo is 0.79.

unnecessary (BAUER & DUTTON 1962, BARRY & CHAMBERS 1966). The confidence limit of albedos gathered is ±4% and was established by comparing data among multiple flights taken over key surfaces and by comparisons of aerial measurements with ground readings. Photographs taken with a fisheye (180°) lens documented the albedo measurements. Flight data were gathered when skies were clear or covered with a uniform altostratus cloud deck. Any effects of cloudiness on albedos are within the estimated confidence limit.

Tab. 2: PAST AND PRESENT DISTRIBUTION OF SURFACE ELEMENTS IN THE MUCKLANDS (COVERAGE). ALSO THEIR SURFACE ALBEDO IN WINTER UNDER DRY SNOW-FREE CONDITIONS AND MAXIMUM AND MEAN SNOW COVER (cf. table 1). ALBEDO OF THE MUCKLANDS AS A WHOLE IS ALSO SHOWN.

Surface component		Coverage (% area)	Albedo Snowfree	Snow covered MAX	Snow covered MEAN
PAST	coniferous forest	40	0.09	0.13	0.13
	deciduous forest	40	0.12	0.31	0.25
	swampy thicket	15	0.11	0.44	0.34
	ponds, streams	5	0.05	0.82	0.75
	Mucklands past average		0.10	0.28	0.24
PRESENT					
	black soil	87	0.05	0.83	0.77
	grass and weeds (snowfree)	20	0.20	0.50	0.45
	(snow covered)	13			
	Mucklands present average		0.08	0.79	0.73

Note: Past coverage from references, present measured from aerial photographs.

4. PRESENT ALBEDO OF THE CHESTER FIELDS

Without snow, the Chester fields have an aerial measured albedo of 0.06 when wet (photo 1a) and 0.08 when dry (table 2). The latter reading is about 0.03 higher than the value of dry bare soil measured at the ground. Measurements of aerial photographs show that the snow-free surface of the Chester fields during the winter of 1982-83 was composed of 80% bare soil and 20% grass and weed. It is assumed that the albedo of a scene is the area weighted arithmetic average of individual components. From ground measured albedos of 0.05 for the dry soil and 0.29 for dry grass and weed, the weighted albedo is 0.08, the same as that measured from the aircraft. Only a few published land albedos are as low as those found in the Chester fields (eg. BERGLUND & MACE 1972, KONDRATYEV et al. 1981).

There is a marked change in the appearance of the mucklands when they are covered by deep snow. Photo 1b was taken shortly after the blizzard of February 11-12, 1983, which left the fields covered with 30-60 cm of snow. On the 14th of February, the albedo of two day old dry snow was 0.83, measured on the ground with a clear sky. The aerial value over the Chester fields was 0.79. The difference was due to the presence of tall grass and weeds protruding through the snow in portions of the fallow plots. The 0.79 value is among the highest aerial values reported in the middle latitudes (eg. KUNG et al. 1964, GRIGGS 1968, O'NEILL &

GRAY 1973) and approaches the albedo of polar tundra or snow covered ice sheets (eg. MCFADDEN & RAGOTZKIE 1967, WELLER et al. 1972, DINGMAN et al. 1980, CARROLL & FITCH 1981).

5. RECONSTRUCTION OF PAST ALBEDO IN THE CHESTER FIELDS

Since none of the mucklands have been left with undisturbed natural vegetation, their past albedo had to be reconstructed. From qualitative descriptions and early photographs, it is estimated that the swamps were covered by approximately 40% deciduous woods, 40% conifers, 15% dense shruby thickets and 5% streams and ponds (EAGER 1847, RUTTENBER & CLARK 1881, RIES 1895, HULL 1975) (table 2). The closest present equivalents of each of these key components were located and their albedo measured from the aircraft. Past muckland albedo was then computed as an area weighted average of the measured values of the individual components. Only relatively level surfaces were measured, avoiding shading and enhanced reflection in hilly terrains.

The average snowfree mid-day albedo of leafless deciduous woods was 0.12 on 3 flights in November, January and March (unless otherwise stated, all subsequent snowfree flight albedos are averaged from these flights). An albedo of 0.31 was measured on February 14 with almost 50 cm of fresh snow on the ground. The deciduous forests are composed primarily of oak and maple and the forest floor is covered with leaves, occasional protruding rocks and bushy undergrowth. Canopy height is between 20 and 30 m.

No sufficiently extensive coniferous forest is located in the study region large enough to dominate the aerial albedo signal. Therefore, a mixed coniferous/deciduous stand was studied and the areal proportion of individual tree species determined in aerial photographs. Patches of deciduous trees with less than 5% conifers compose 40% of the measured stand. The remainder is 85% conifers interspersed with 15% deciduous trees. The canopy height is 20-30 m. Snowfree albedo of the stand was 0.10, as opposed to 0.12 over the deciduous woods. On February 14, with snow on the ground but with a snowfree canopy, the albedo of the mixed site was 0.20 and the surrounding deciduous forest 0.31. From these differences, the albedo of a fully coniferous stand was computed to be 0.09 when snowfree and 0.13 when snow covered. These values are considered representative of the past muckland coniferous stands.

Albedo of a swampy thicket, composed of dense deciduous bushes up to a few meters in height with scattered stands of deciduous trees, was also measured. In winter and early spring, when snowfree and unfrozen, standing water was seen from the air through the leafless vegetation and the thicket albedo was 0.11. On February 14, when frozen and snow covered, the albedo was 0.44.

The last component of the past mucklands is open water. Winter mid-day albedo over ice-free lakes in the region was 0.05. An albedo of 0.77 was measured on 14 February where a snow covered lake contributed 90% of the reflected signal, with the remainder coming from a deciduous forest with an albedo of approximately 0.30, meaning the snow covered lake had an albedo of 0.82.

Table 2 lists the winter albedos of each of the surface components composing the past and the present mucklands, as well as the computed albedo of the entire area. Values for snowfree and maximum snow covered surfaces are plotted in fig. 2. The snowfree/snow covered range is largest for the fields and the water.

In the past, the difference between the modeled albedo of snowfree (0.10) and snow

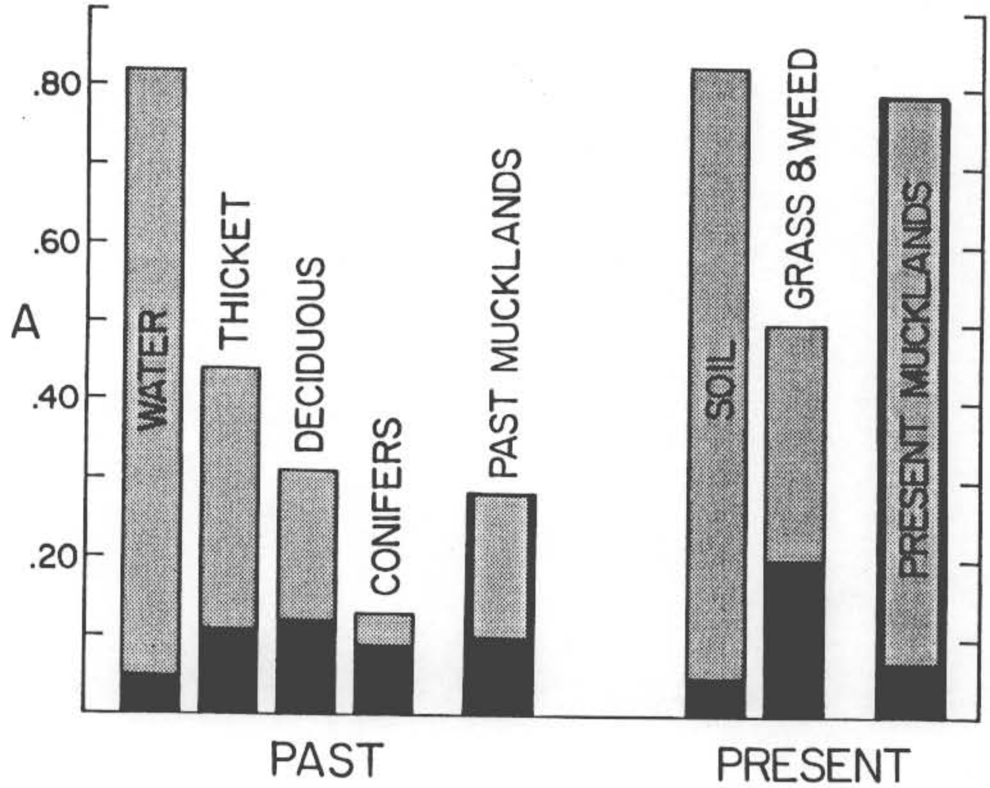

Fig. 2: Winter surface albedo of mucklands when snowfree and covered by deep (over 15 cm) fresh dry snow, as measured at present and reconstructed for the past. Also for individual surface components. The range between the snowfree and snow covered values is shown with light stippling.

covered (0.28) mucklands was 0.18, approximately one fourth of the present range of 0.71. The past range was low because tall vegetation masked the underlying snow covered surface. Today's range is the largest yet reported over a land surface anywhere.

6. BI–COUNTY ALBEDO RECONSTRUCTION

Next, we expand our study to the Orange and Rockland bi-county area. Albedo of each major surface type covered by deep fresh snow is derived from the data collected in the February 14 flight (table 1). Data are grouped based on similarities of albedo with and without snow. Snow covered forests, which are 90% deciduous and 10% coniferous, have an albedo of 0.29. Farmland and open meadow, which contain approximately 10% deciduous tree stands, have an albedo of 0.75 and commercial and residential areas and overgrown farmland have a 0.50 albedo. Snowfree winter values range from 0.12 for forests to 0.17 for farmland. Regional values are computed by area weighting of individual components. Our model shows that deforestation between AD 1600 and AD 1900 raised the winter albedo under deep snow cover by 0.28 (from 0.31 to 0.59) (table 1). The present value is 0.47. Snow-free values changed by only 0.03.

7. REGIONAL ALBEDO UNDER MEAN SNOW COVER

Up to now, we were concerned with extreme scenarios, with the ground snowfree or covered by deep fresh snow. However, in the middle latitudes albedo varies significantly throughout the winter season, depending on the age of the snow and the percentage of exposed bare ground (ROBINSON & KUKLA 1982). Following a snowfall, there is a period of time in the study region, ranging from a day to several weeks, depending on the initial snow depth and subsequent weather conditions, when the ground remains virtually entirely snow covered. Decreases in regional albedo are slow and are primarily a function of changes in the granulation, wetness and purity of the snow pack, as long as the snow depths are about 15 cm or more (KUNG et al. 1964, MCGINNIS et al. 1975, LILLESAND et al. 1982). When snow depth is below 15 cm and bare ground becomes exposed, snow melt increases and albedo decreases rapidly (ROBINSON & KUKLA 1984). Snow melt begins on south facing slopes (in the Northern Hemisphere), then proceeds to level fields, then level forest floors and finally to shaded north facing slopes.

Mean albedos over principal regional surfaces when the ground is fully snow covered are determined from a series of aerial measurements made following the February 1983 blizzard. The average albedos of fully covered regional surfaces are close to values measured on February 18, when the snow was wet, 6 days old and 20-30 cm deep over level open fields and 25-45 cm deep over level forests. Values ranged from 0.13 over conifers to 0.75 over snow covered lakes (table 2). The Chester fields had an albedo of 0.73. The corresponding value computed for the past snow covered mucklands is 0.24.

Albedos of the three major bi-county surface components under mean snow cover conditions range from 0.24 for forests to 0.67 for fields (table 1). This results in model bi-county albedos of 0.26 in AD 1600, 0.52 in AD 1900 and 0.40 today.

8. IMPACT ON SURFACE HEATING

The anthropogenic change of surface albedo had a major impact on the shortwave energy balance of the region. In the past with fresh deep snow present, the mucklands absorbed almost three and one half times more radiation than today. The bi-county block absorbed approximately 1.7 times more radiation in AD 1600 than in AD 1900. Without snow, the present mucklands and the bi-county region in 1900 absorb(ed) about 3% more radiation than when naturally vegetated. The estimates of absorbed radiation are derived from equation (1):

$$Q = (1 - \alpha)\, I \cdot K \tag{1}$$

where:
Q = absorbed solar radiation at the surface
α = surface albedo
I = solar radiation at the top of the atmosphere
K = atmospheric screening factor

Radiation outside the atmosphere (I) can be considered constant and cloudiness and atmospheric turbidity influencing K are assumed constant during the analysed time intervals, therefore $I \cdot K$ in the model is constant.

Full snow cover may be present in the study region for 10% to 75% of the winter season

(December through March). The variable duration of snow cover results in large interannual fluctuations of surface albedo and surface heating in winter. These fluctuations have increased as a result of man's impact on the surface. Using equation 1 and albedos for mean snow cover conditions, approximately 50% more shortwave radiation is today absorbed in the mucklands in a winter with a 10% duration than in a winter with a 75% duration of snow, assuming a random distribution of snow cover episodes. With undisturbed natural vegetation, the range is only 10%.

The same exercise for the entire bi-county region found the range of approximately 30% in AD 1900, 10% in AD 1600 and 20% today. The bi-county region absorbed approximately the same amount of solar radiation with a 75% snow cover duration in 1600 than with a 10% duration in 1900.

9. CONCLUSIONS

The mucklands are an extreme example of man induced changes of surface albedo in winter. Albedo with deep fresh snow cover increased from approximately 0.28 to 0.79 when the area was deforested and drained. Overall, the deforestation of Orange and Rockland Counties in New York had a qualitatively similar though quantitatively less extreme impact. At the time of peak deforestation in the late 18th century, surface albedo with fresh snow cover was approximately twice as high as that of the former naturally vegetated landscape. Man's use of the land has resulted in the shortwave energy balance of the region being considerably more sensitive to the duration of snow cover than when naturally vegetated.

It would be interesting to determine whether the conversion of eastern U.S., European and east Asian forests to farmland or midwestern U.S. woodlands and prairies to farmland resulted in a measurable change of winter severity. Since adequate observational records are not available, modeling efforts will be needed to examine this question and assess what climatic impact future deforestation in the higher latitudes might bring.

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