SATELLITE RECORD OF WINTER SNOW COVER IN NORTH AMERICA AND EURASIA 1966-1975

by

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ABSTRACT

In view of a much-discussed global cooling since about 1940, the late energy shortage in North America and Europe, and the recent poor winter wheat crops in the Soviet Union, a great deal of interest centers about the severity of continental winter weather. Snow cover is an important indicator of the severity of winter weather. Winter season snow and ice charts of the Northern Hemisphere based on NOAA satellite data from 1966 through 1975 were examined to determine the extent and area of snow cover in North America and Eurasia. Graphical analysis indicates no significant overall increase in North American winter snow cover for the nine-year period of data, whereas over the same period, a large fluctuation occurred in Eurasia. Regression analysis yielded several equations with correlation coefficients significant enough to indicate possible application for 30-, 60-, and 90-day forecasting of seasonal, continental, and hemispheric snow cover. The satellite record of the past nine years is the most complete record of hemispheric snow cover available. NOAA satellites provide a reliable and rapid method of monitoring worldwide snow cover, which has important effects on global temperature and albedo, with attendant impact on hydrology, energy use, agriculture, and weather forecasting.

INTRODUCTION

Since 1966 camera- and radiometer-equipped NOAA satellites have been providing images from which snow and ice cover are estimated on a weekly basis. The Weekly Snow and Ice Charts (Figure 1) developed from the imagery by the Analysis Branch of NOAA's National Environmental Satellite Service (NESS) form an almost unbroken set of winter snow and ice data for the last nine years. Two months of data--December 1967 and January 1968--have been lost. The weekly charts represent the most complete record of continental snow cover available.

The weekly snow and ice boundaries are drawn on a 1:50,000,000 polar stereographic projection of the Northern Hemisphere. The snow cover is divided into three degrees of reflectivity, in which scale 1 is lowest (see Figure 1). Areas of scattered mountain snow are so indicated but are considered to be of moderate reflectivity. Operationally, the analysis is prepared by one, or occasionally two, individuals over a period of a week. All snow and ice that is visible daily throughout the 6 or 7 days of satellite imagery is mapped. Areas of previous snow and ice cover that are cloud-covered during the week are included unless subsequent cloudfree imagery shows that the extent of snow in these areas has changed. Apparent

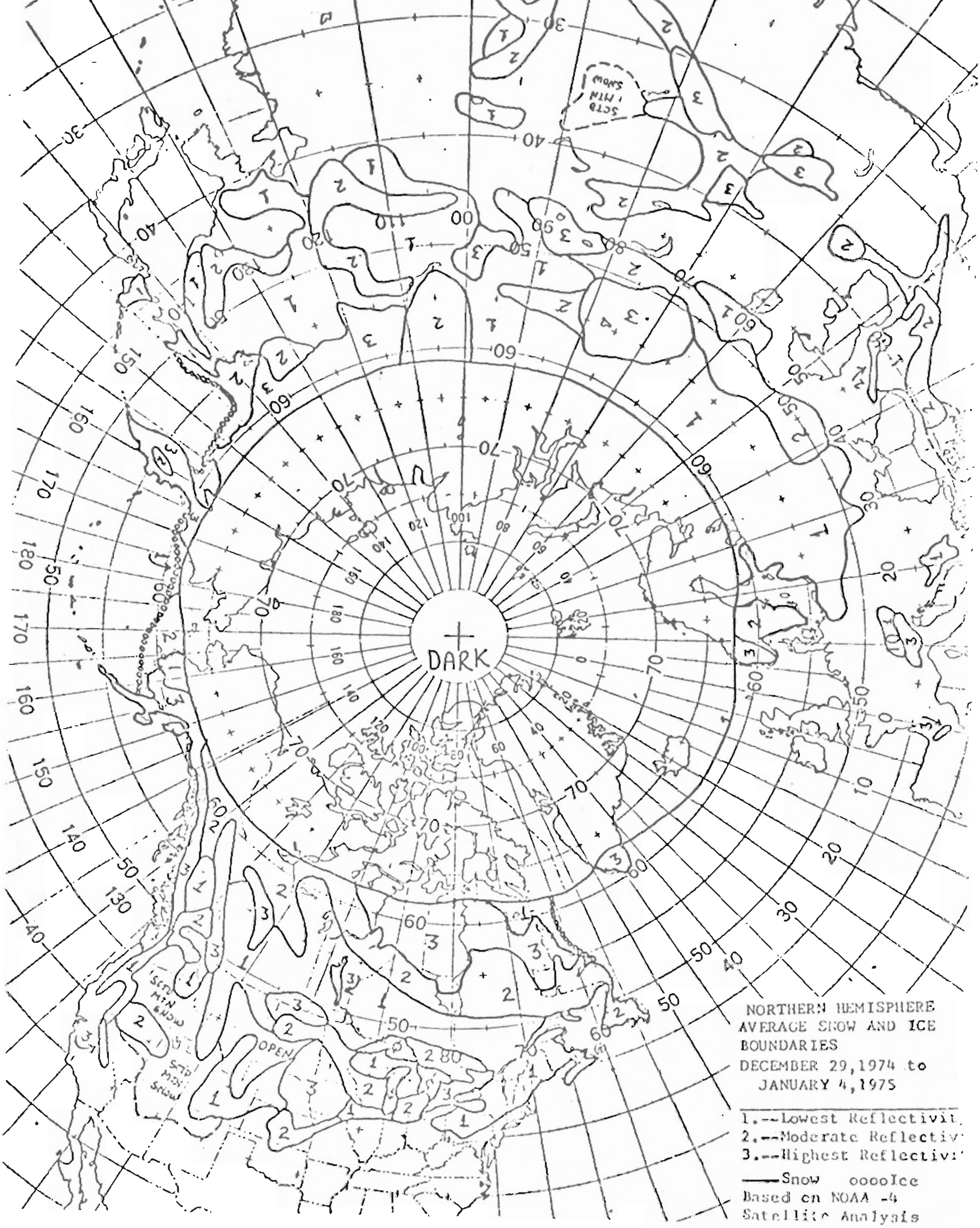


Fig. 1. Typical snow and ice chart of the Northern Hemisphere for the 7-day period 29 December 1974 through 4 January 1975 (scale: 1:50,000,000), prepared by Analysis Branch, NOAA/NESS. Note the various reflectivities and the areas of scattered mountain snow. Also note the "dark" area where visible data cannot be collected during the polar winter.

rapid changes in snow and ice cover are verified by checking meteorological and surface reports.

The quality of the weekly charts is affected by several factors:

(1) The weekly snow maps are based on subjective interpretation by a number of observers. Operator bias is undoubtedly present.

(2) The satellite images have come from a variety of satellites and sensors as evidenced by Table 1, all subject to instrumental variation, degradation, and drift.

(3) The skill of the meteorologists who prepare the weekly maps has presumably increased with time so that today's charts may be more detailed than those of the first few years.

When considering the above factors, the error in positioning the snowline on the weekly charts is estimated to be 5 to 7 percent from 1966-1970, 5 percent from 1970-1973, and 3 percent from 1974 to the present. This positioning error is randomly distributed.

DETERMINATION AND MEASUREMENT OF MONTHLY MEAN NORTHERN HEMISPHERE WINTER SNOW COVER

Monthly mean snow cover charts (Figure 2) for December, January, February, and March south of 52°N were constructed from the weekly charts by the Environmental Sciences Group of NESS (Wiesnet and Matson, 1975). The average monthly snow boundary was determimed by subjective analog averaging of the weekly snowline boundaries. The area measured within this boundary included all three classes of reflectivity and scattered mountain snow and is corrected for an equal area projection. The error in the value of areal snow cover owing to the analog averaging of weekly data to derive the monthly mean snowline is approximately 5 percent and is also randomly distributed. Planimetry and areal correction errors are believed to range from 1 to 2 percent.

The northern boundary of 52°N was chosen because of the lack of illumination from 60°N to 90°N during midwinter. Furthermore, the area covered by snow from 52°N to 60°N is nearly constant during the winter season when considered on a continental basis, and most of the population centers and agricultural areas of the Northern Hemisphere that are affected by snow cover lie south of 52°N.

All measurements used in this paper are for each <u>entire</u> continent (i.e., North America and Eurasia) and <u>not</u> just the area south of 52°N. This was accomplished by 1) measuring on an equal area map projection the land mass of each continent north of 52°N, 2) converting each land mass so measured into an equivalent constant snow cover area, and 3) adding this constant onto the corresponding continental winter snow cover south of 52°N.

Table 1.--Satellites and sensors used in mapping Northern Hemisphere snow and ice cover

Satellite	Sensor*	Spectral band (μm)	Subpoint resolution (km)	Period of operations
ESSA 3	AVCS	0.5-0.75	3.7	Oct. 2, 1966-Oct. 9, 1968
ESSA 4	APT	0.5-0.75	3.7	Jan. 26, 1967-Dec. 6, 1967
ESSA 7	AVCS	0.5-0.75	3.7	Aug. 16, 1968-July 19, 1969
ESSA 8	APT	0.5-0.75	3.7	Dec. 15, 1968-Mar. 12, 1976
ESSA 9	AVCS	0.5-0.75	3.7	Feb. 26, 1969-Dec. 15, 1973
ITOS 1	AVCS	0.5-0.75	3.7	Jan. 23, 1970-June 17, 1971
	APT	0.5-0.75	3.7	
	SR	0.52-0.73	3.7	
		10.5-12.5	7.4	
NOAA 2	VHRR	0.6-0.75	1-1.9	Oct. 15, 1972-Jan. 30, 1975
		10.5-12.5	1-1.9	
	SR**	0.52-0.73	3.7	
		10.5-12.5	7.4	
NOAA 3	VHRR	Same as NOAA 2		Oct. 6, 1973-present
	SR	Same as NOAA 2		
NOAA 4	VHRR	Same as NOAA 2		Nov. 15, 1974-present
	SR	Same as NOAA 2		
SMS-1 (GOES)	VISSR	0.55-0.70	1-7.4	May 17, 1974-present
		10.5-12.5	7.4-14.8	

*Cameras and sensors:
AVCS - Advanced Vidicon Camera System
APT - Automatic Picture Transmission
SR - Scanning Radiometer
VHRR - Very High Resolution Radiometer
VISSR - Visible and Infrared Spin Scan Radiometer

**SR - SN #016, failed 3/3/74
Visible channel spectral band 0.5 - 0.94

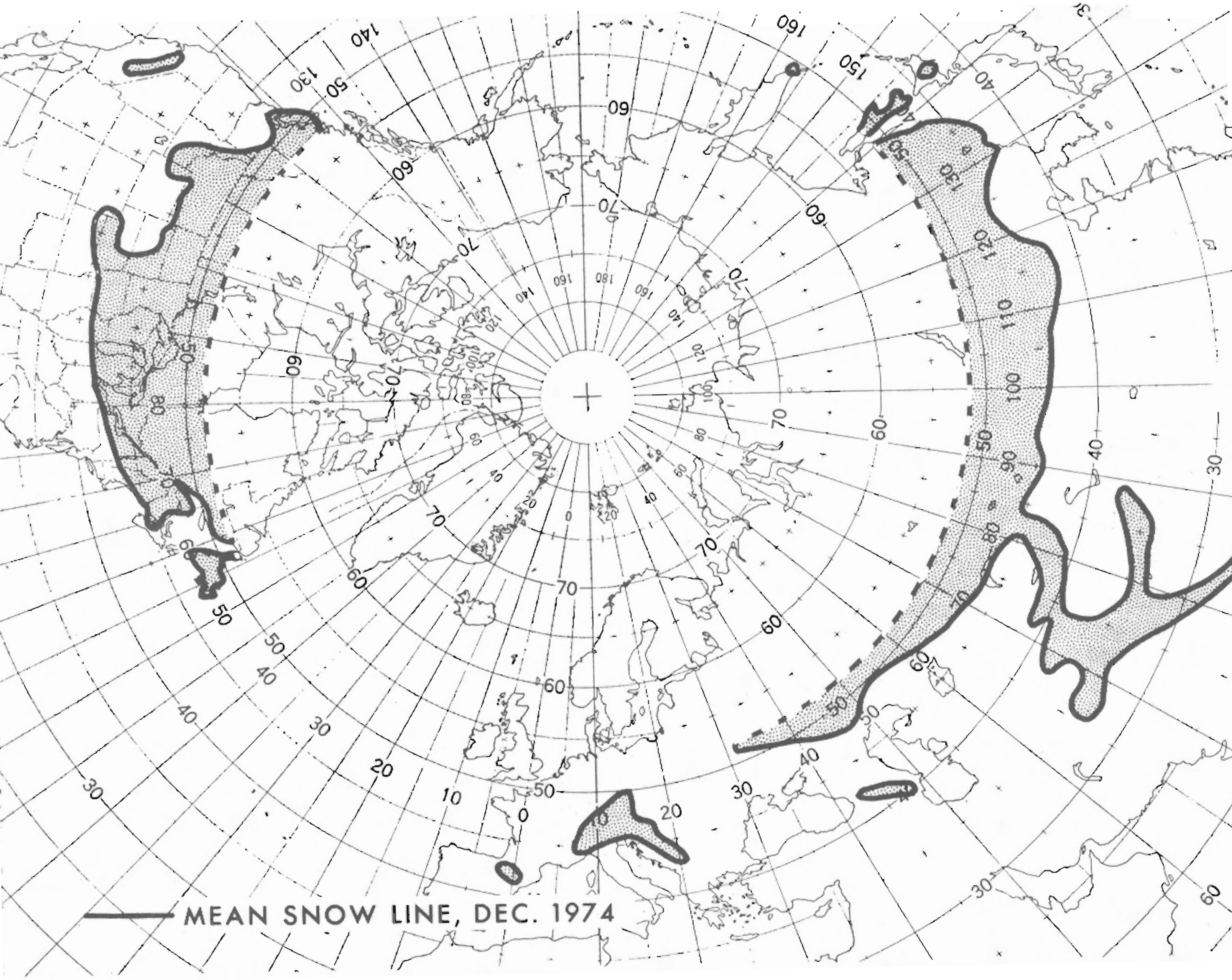


Fig. 2. Monthly mean snow-cover chart of the Northern Hemisphere for December 1974 on a stereopolar projection at a 1:50,000,000 scale. This chart was prepared from the weekly charts.

COMPARISON OF MONTHLY MEAN SNOW COVER

DECEMBER - MARCH

A complete chart showing graphs of winter snow cover for the entire 9-year period for the Northern Hemisphere is given in Figure 3. A graph of winter snow and ice cover over a 6-year period (1967-68 to 1972-73) by Kukla and Kukla (1974) is provided for comparison purposes. Note the similarity of the two data sets. The continental winter snow cover of North America and Eurasia are also compared (Figure 4). Whereas the North American data show considerable variation in snow cover from year to year, no well-defined trend is apparent.

A few unsurprising facts concerning the North American winter snow cover may be noted:

(1) January snow cover regularly exceeds that of December (except in 1972-73).

(2) February snow cover regularly exceeds that of March (except in 1974).

(3) December and March snow cover is highly variable.

A fact of considerable interest is that no significant overall increase in North American winter snow cover over the nine-year period is apparent. The greatest North America monthly snow cover of this period occurred in January 1970; 15.4×10^6 km^2. The least monthly snow cover was in March 1968 when only 11.4×10^6 km^2 of North America was covered.

The variation of monthly mean winter snow cover is clearly shown in Figures 5 through 8, which facilitate comparisom from year to year. The even-odd ten-year variation in February in North America (Figure 7) is striking as is the lack of variation in January (Figure 6). Also note the wide variation in March in North America (Figure 8).

The vast snow-covered areas of Eurasia statistically dominate the smaller areas of snow cover on the North American continent (Figure 5 to 8). The result is that trends in the Northern Hemisphere and Eurasian data are similar (See Figures 3 and 4).

Over the last three winter seasons (1972-73 through 1974-75), a steady decrease in Eurasian snow cover is apparent. However, over the preceding 3-year period (1968-69 through 1971-72), there is an annual increase in snow cover. Figure 3 serves to emphasize the inadequacy of using short-term data to forecast long-term trends.

REGRESSION ANALYSIS

From a preliminary examination of the data it was decided that a simple least squares regression analysis might yield some type of usable monthly forecasting relationship, and so possible antecedent relations of each month beginning with January were examined (Wiesnet and Matson, 1976). Widespread snow certainly raises the albedo of the land surface and increases

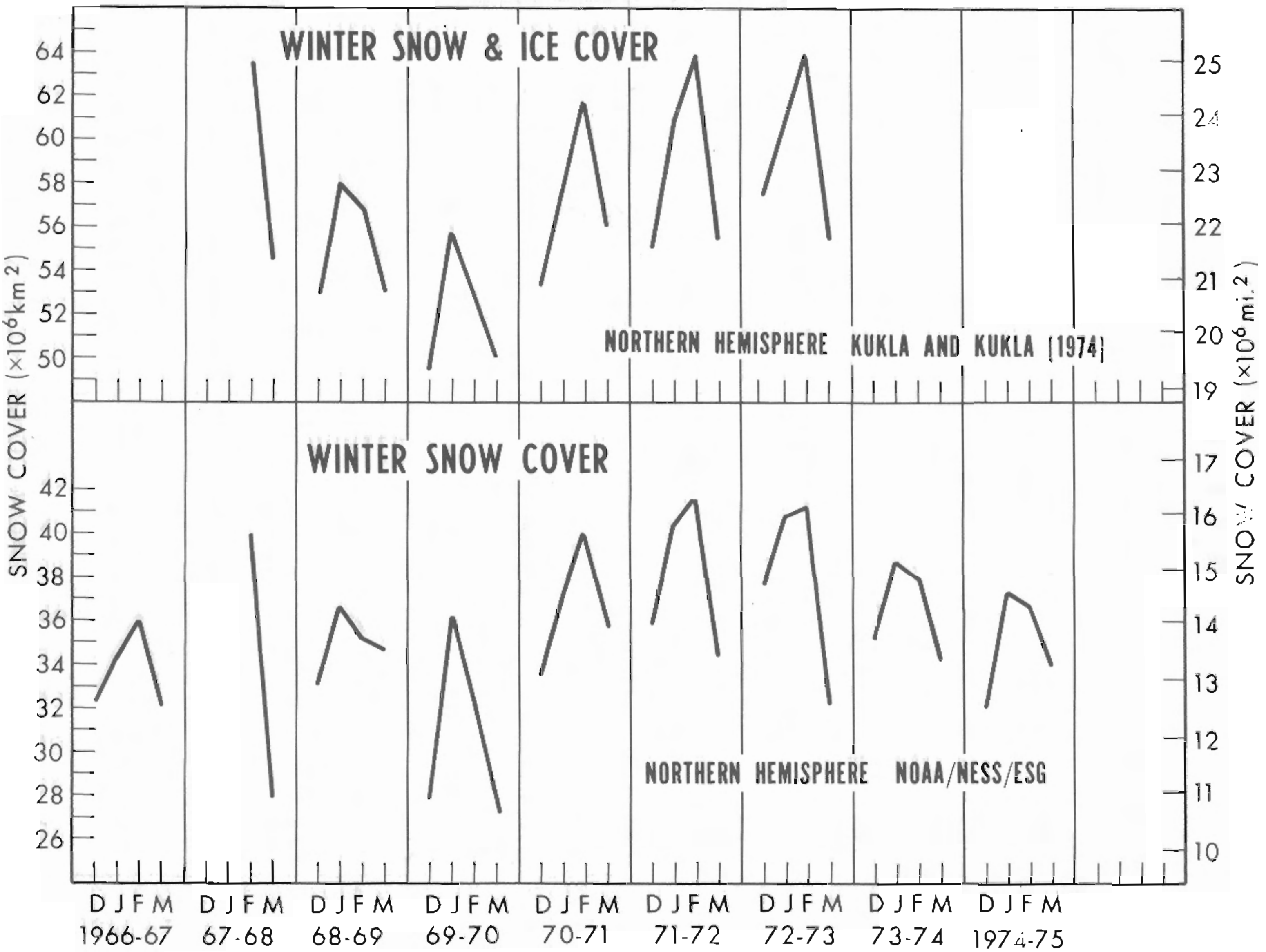


Fig. 3. Graph of total winter snow cover (North America plus Eurasia) for the Northern Hemisphere compared with total winter snow and ice cover derived from Kukla and Kukla (1974). Note the similarity of trends.

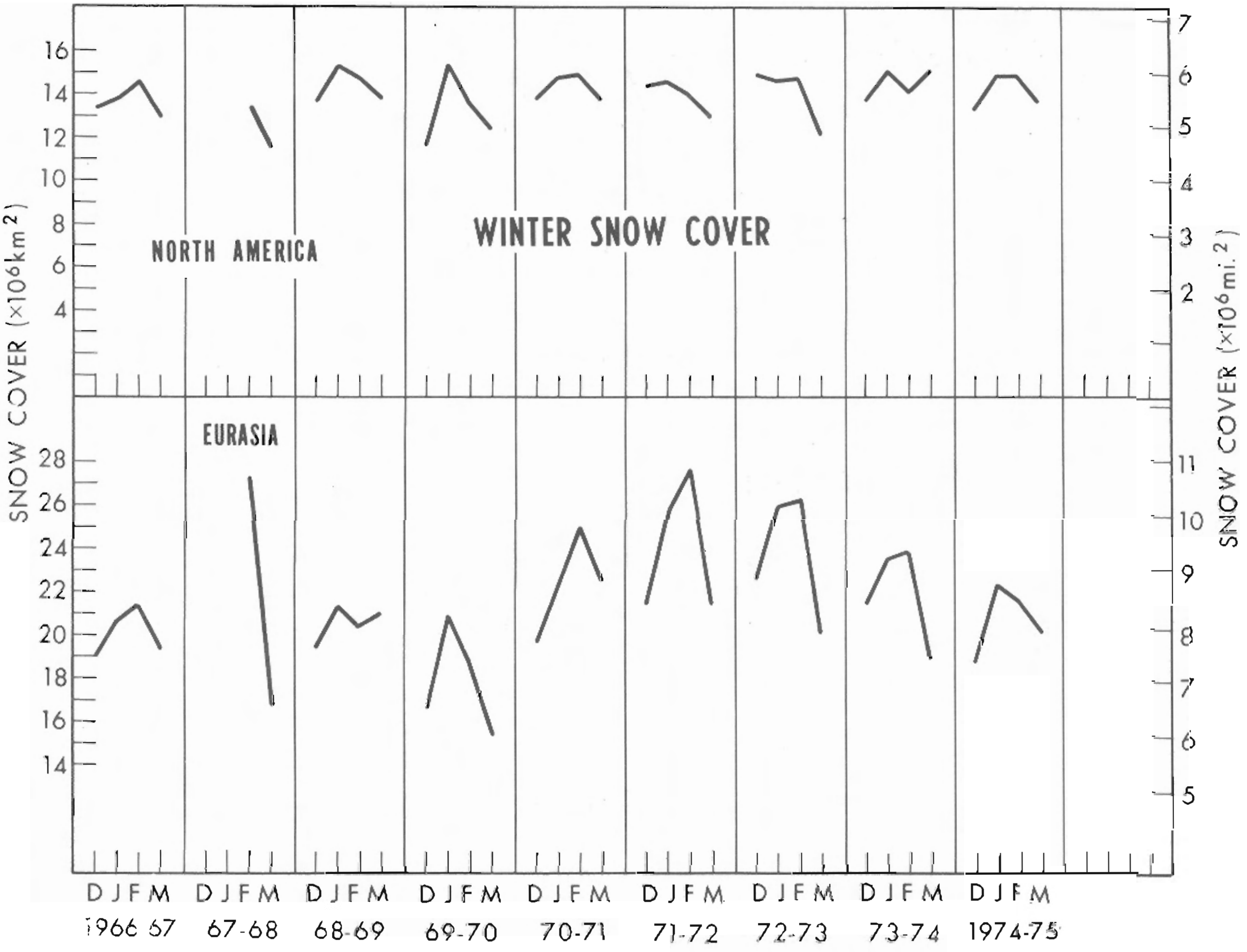


Fig. 4. Graph of winter season snow cover for North America and Eurasia from 1966-1975.

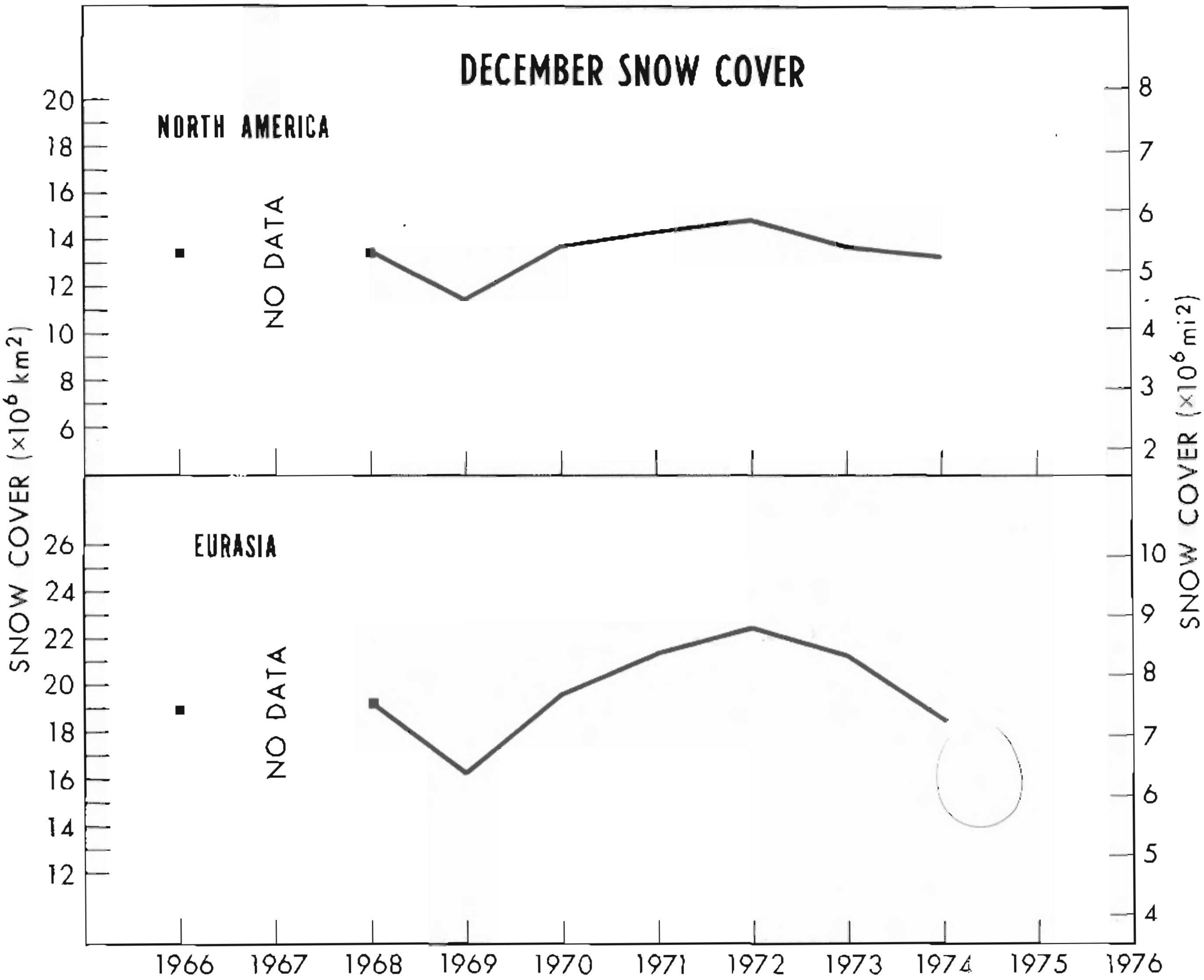


Fig. 5. Graph of December snow cover for both North America and Eurasia from 1966-1974.

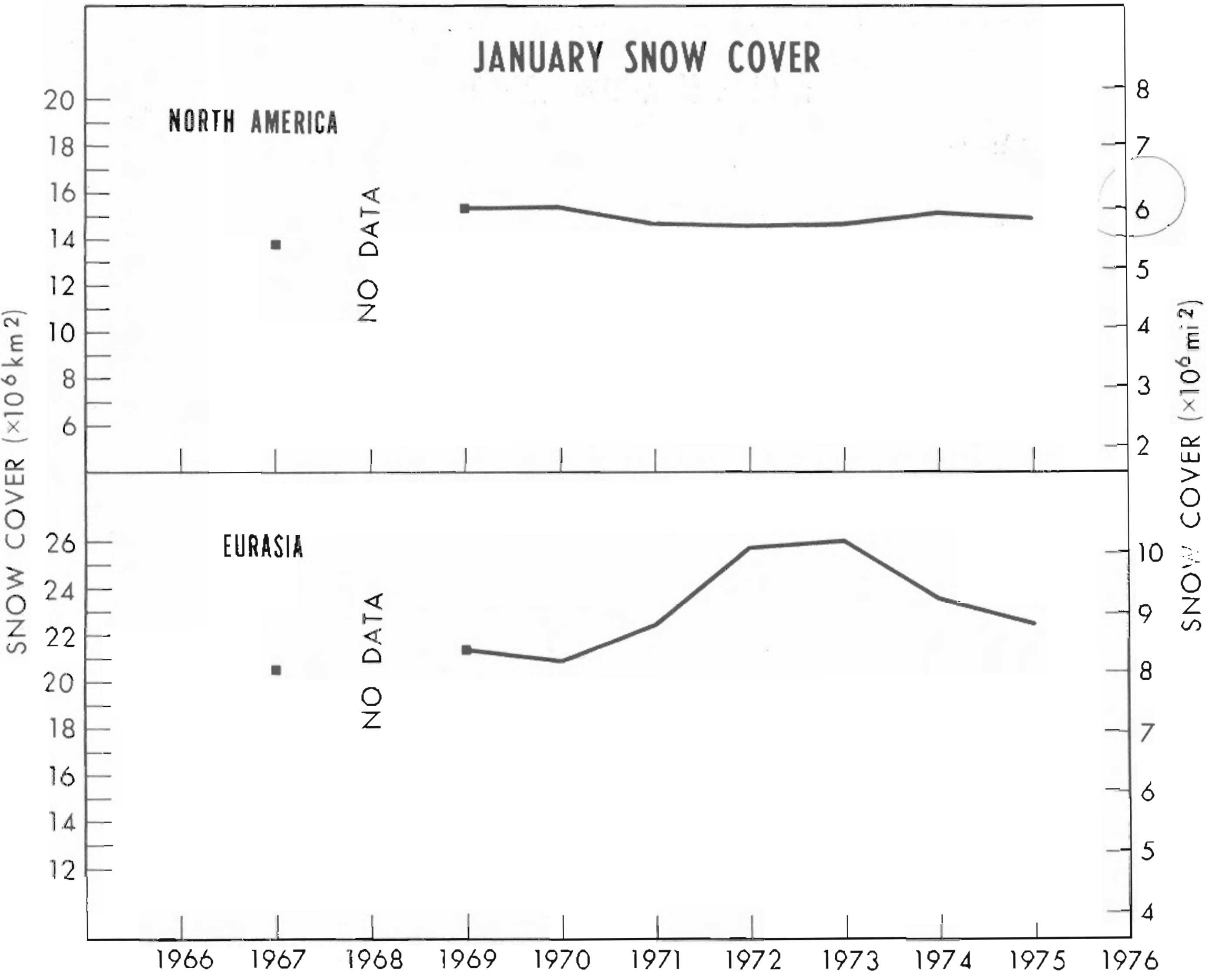


Fig. 6. Graph of January snow cover for both North America and Eurasia from 1967-1975.

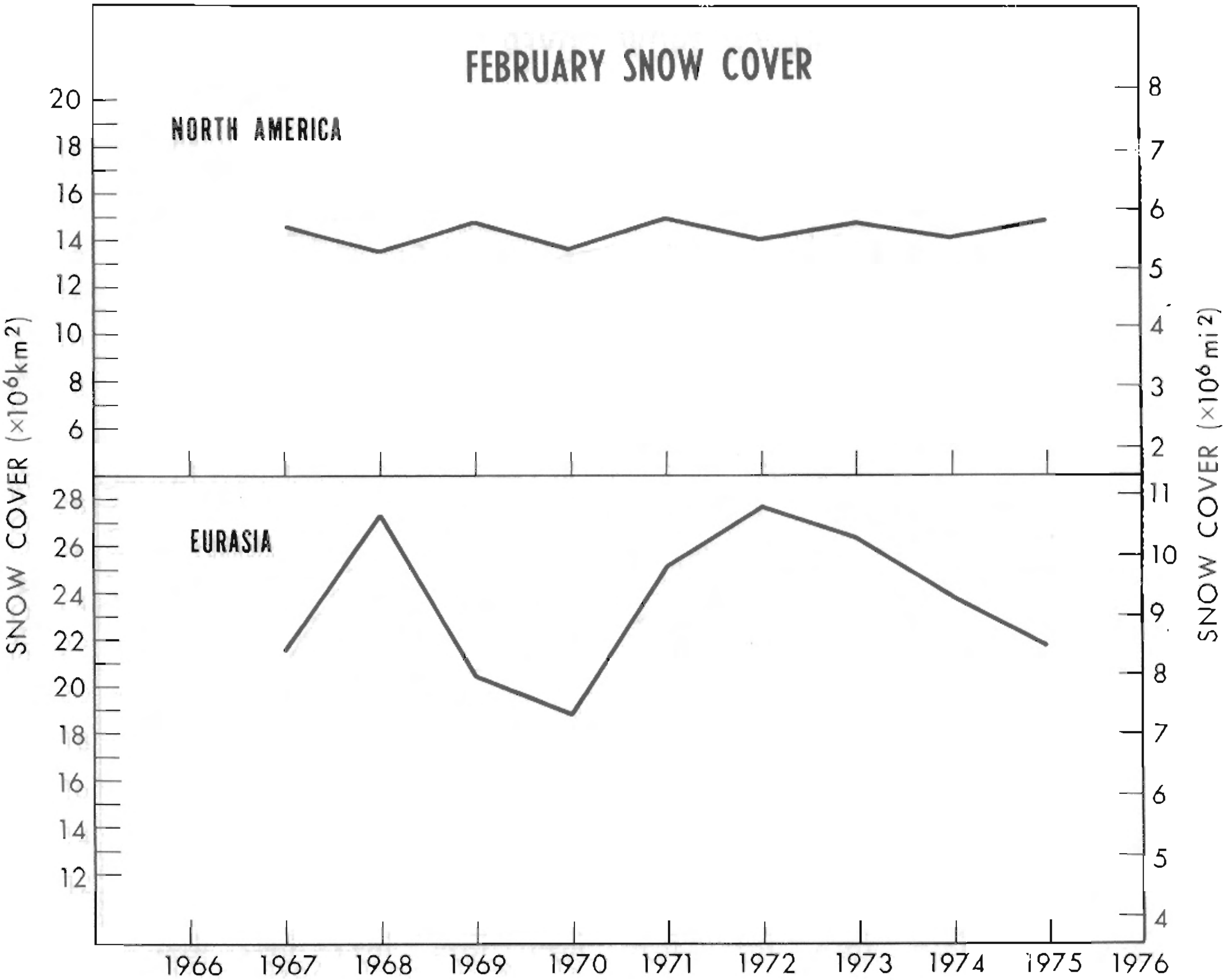
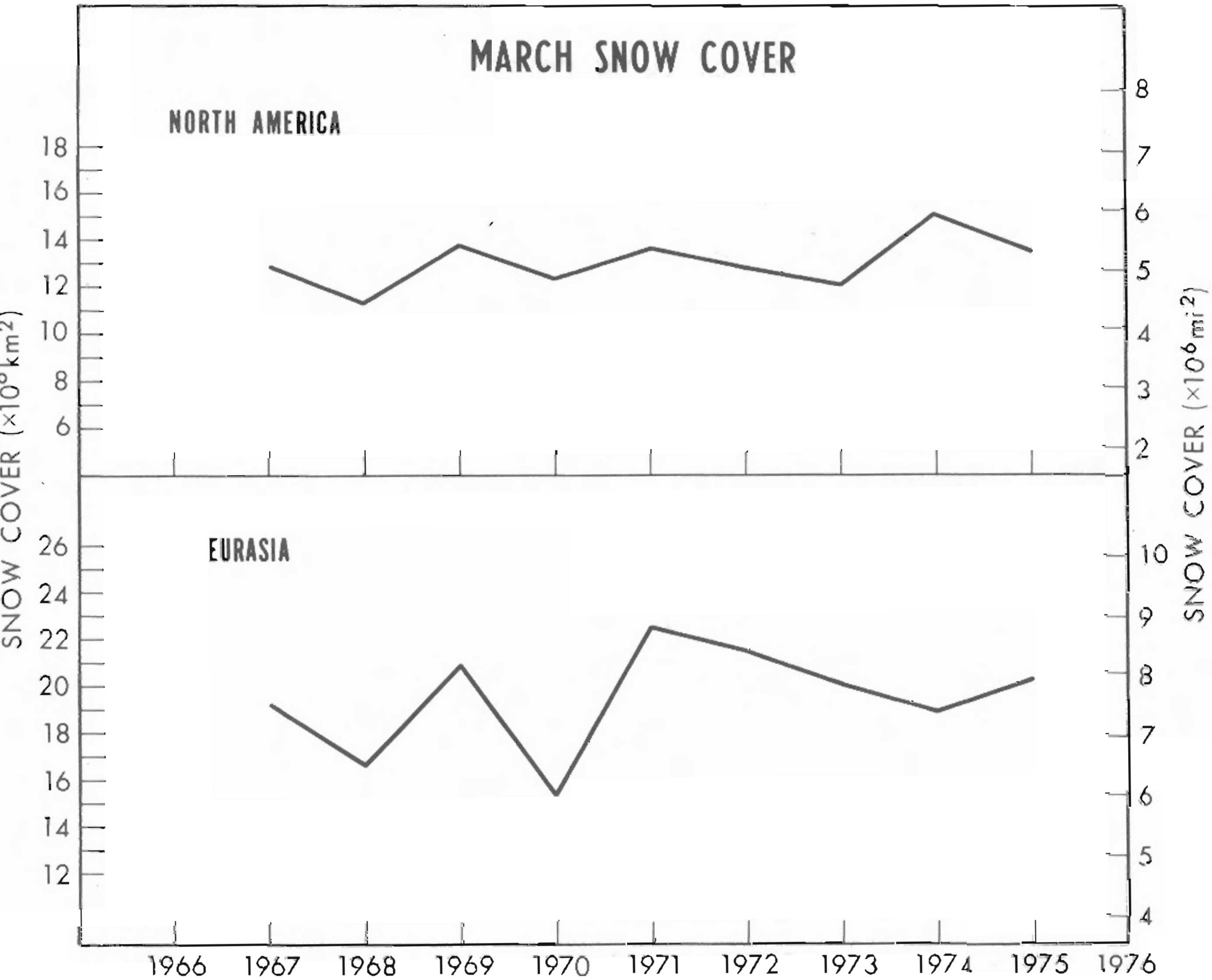


Fig. 7. Graph of February snow cover for both North America and Eurasia from 1967-1975.



ig. 6. Graph of March snow cover for both North America and Eurasia from 1967-1975.

the net longware heat lost to space by radiation. Further, the cooling effect of the snow cover may induce snow rather than rain from storms in adjacent snow-free regions. The results of the regression analysis are shown in Table 2. It should be remembered, however, that the correlations in themselves have, of course, no connotation of causality.

The data sample size used in the regressions (Table 2) is obviously small, but equally obvious is the impracticability of collecting several hundred samples at a rate of one per year. An analysis of the significance of the sample correlation coefficient, r, demonstrates the potential usefulness of the empirical formulas. For eight data points and two variables, r is significant at the 95% level when it exceeds 0.71. All correlation coefficients of Table 2 are 0.75 or greater, thus indicating that the relationships derived have a high degree of credence. At the 99% level of significance r is significant when it exceeds 0.83. All but two of the correlation coefficients in Table 2 are greater than 0.83. It should be remembered, however, that high correlation coefficients are not infrequently encountered in small samples drawn from a noncorrelated population. On a more positive note, the data set does include a wide range of snow cover conditions.

FORECASTING SEASONAL SNOW COVER

During the winter season of 1975-76 the regression equations listed in Table 2 were used on an experimental basis to test their potential application in 30-, 60-, and 90-day forecasting of continental and hemispheric snow cover. The results are summarized in Table 3. It should be noted that the North America forecasts are derived by simple subtraction of the Eurasian forecast of the month desired from the corresponding Northern Hemisphere forecast. All Eurasian and Northern Hemisphere March forecasts are derived by subtracting the January plus February forecasts from the January through March forecasts.

The results of this forecast are encouraging. For the running total January - March, the error was 1% for the hemisphere and Eurasia, and less than 1% for North America. The worst forecasts were for March in Eurasia which were 5% off. The results of all forecasts are given in Table 3.

We are encouraged by these preliminary results, but stress that additional data are highly desirable. We plan to continue to test the models for several winters.

As demonstrated by the results listed in Table 3, it seems to be possible to forecast continental and global snow cover 30-, 60-, and 90-days in advance of actual snow cover with some accuracy. It is interesting to observe that January through March snow cover can be forecast solely from the December snow cover. Certainly, other satellite-derived and ground-based data can and should be applied in various long-range forecasting models to determine whether snow cover can be forecast more accurately on a weekly or biweekly basis.

The authors believe that these equations and graphs represent a reasonable phenomenological approach to seasonal, hemispheric, and continental snow cover forecasting. Further, the authors encourage additional workers to utilize the available satellite data in hemispheric

Table 2.--Summary of regression analyses for winter snow cover in the Northern Hemisphere and Eurasia

Period of Snowcover Forecast (y)	Forecast Area	Source Data (x)	Equation	Correlation Coefficients (r)	(r^2)
January	Eurasia	December snowcover	$y = 0.92x+4.80$	0.85	0.72
January	Northern Hemisphere	December snowcover	$y = 0.55x+19.39$	0.75	0.57
February	Eurasia	January snowcover	$y = 1.28x-6.29$	0.89	0.79
February	Northern Hemisphere	January snowcover	$y = 1.11x-4.29$	0.75	0.56
February	Eurasia	December plus January snowcover	$y = 0.71x-7.10$	0.91	0.81
February	Northern Hemisphere	December plus January snowcover	$y = 0.59x-4.22$	0.88	0.78
January thru March	Eurasia	December snowcover	$y = 4.89x^{0.87}$	0.89	0.79
January thru	Northern Hemisphere	December snowcover	$y = 12.30x^{0.62}$	0.91	0.82

TABLE 3

Summary of Forecasts of Winter Snow Cover in the Northern Hemisphere, Eurasia, and North America 1975-1976

NORTHERN HEMISPHERE

Period of Snow Cover	Forecast ($x 10^6 km^2$)	Measured ($x 10^6 km^2$)	Difference/ Forecast and Measurement	Difference/ Forecast and 9-Year Extreme
December 1975	----	36.0	----	----
January 1976	39.2*	38.6	+2%	+15%
February 1976	39.8*	38.8	+3%	+24%
March 1976	33.9	35.3	-4%	+22%
Jan -March 1976 (Running Total)	113.4*	112.7	+1%	+18%

EURASIA

Period of Snow Cover	Forecast ($x 10^6 km^2$)	Measured ($x 10^6 km^2$)	Difference/ Forecast and Measurement	Difference/ Forecast and 9-Year Extreme
December 1975	----	21.5	----	----
January 1976	24.6*	23.7	+4%	+19%
February 1976	25.0*	24.3	+3%	+33%
March 1976	20.9	22.1	-5%	+36%
Jan-March 1976 (Running Total)	70.5*	70.1	+1%	+28%

NORTH AMERICA

Period of Snow Cover	Forecast ($x 10^6 km^2$)	Measured ($x 10^6 km^2$)	Difference/ Forecast and Measurement	Difference/ Forecast and 9-Year Extreme
December 1975	----	14.5	----	----
January 1976	14.6	14.9	-2%	- 5%
February 1976	14.8	14.5	+2%	+ 9%
March 1976	13.0	13.4	-3%	-14%
Jan-March 1976 (Running Total)	42.9	42.8	0%	+ 3%

*Indicates forecast is based on a regression equation listed in Table 2.

and global modeling and heat budget studies. Other potential applications include estimation of winter wheat crop yield, which requires knowledge of snow cover conditions.

CONCLUDING REMARKS

Examination of the data leads us to conclude that in general, it is not possible to relate total continental winter snow patterns in North America to those of Eurasia. Over the period of record, the great variability of Eurasian snow cover contrasts with the comparatively stable North American snow cover. As the data set indicates, no significant change in North American snow cover occurs over the 9-year period of record. Because snow cover is an important, sensitive variable influencing climate, the lack of systematic increase in the Northern Hemisphere snow cover tends to contradict the evidence presented by proponents of climatic change, i.e., that the current trend in hemispheric climate is toward cooler temperatures.

The Antecedent Snow Cover Technique of forecasting snow cover 30-, 60-, and 90-days ahead offers a reasonable but not yet thoroughly tested method for forecasting continental and hemispheric winter snow cover. If the technique stands up under scrutiny, it affords an opportunity for climatologists to use the snow-cover parameter in global or hemispheric models (such as the model described by Manabe and Holloway, 1975), hopefully to refine these models for better seasonal weather forecasting.

The use of satellite data for certain aspects of climatic monitoring especially in the polar regions, is not merely a potential application of a new technology; it is the application of an established observation system that has been operational for many years. As the satellite sensors improve and become more varied, workers in the field of climatic monitoring and climatic change will become increasingly dependent upon this reliable and relatively unbiased source of data. The authors are confident that when a climatic change of significance occurs, the environmental satellites will document that fact convincingly.

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