ARE MONTHLY AND SEASONAL SNOW COVER FORECASTS POSSIBLE?

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ABSTRACT

Continental snow cover, because of its slowly varying nature, is one feature of the climate system that may favor seasonal or monthly advance estimates. The NOAA/NESS satellites have recorded continental snow cover since 1966, thus providing some of the necessary observational data input for testing such advance estimates. This paper examines some satellite-based regression algorithms for continental snow cover estimates and the usefulness of the algorithms over a six-year period, 1976-81.

INTRODUCTION

The need for monthly and seasonal climatological estimates is growing simply because many economic, social, and political activities are affected by short-term climate fluctuations. Improved climate predictions are needed by Federal, State and local governments which must deal with climate-related problems in areas of energy, food, and water resources. Modest gains in the precision of monthly and seasonal climate predictions and the development of a capability to state them farther in advance would benefit planners facing climate-related problems. Recognizing this need, the National Climate Program (1980) has proposed the following goals in its first five-year plan:

1) Seasonal outlooks issued up to several months before the season begins, having skill similar to those now issued one day before the season begins.

2) Improvement of outlooks for forthcoming months and seasons through greater accuracy, variety of elements predicted, and better information content e.g., more specific statements of probability, greater spatial resolution, and specification of risks of extreme events.

3) Continuous monitoring of the current state of global and regional climate in terms of formats useful to those involved in gaging impacts.

The Global Atmospheric Research Program (GARP, 1975) has noted that there are some features of the climate system that may favor extended range predictivity by their slowly varying nature, such as sea-surface temperature, land and sea ice, and continental snow cover. The GARP report specifically states that "it seems to be only a question of time before models will be developed for predicting snow and ice cover." The NOAA/NESS satellites can and do record hemispheric and continental snow cover, thus providing some of the necessary observational data input required for developing and testing statistical and numerical climate prediction models, as well as monthly and seasonal forecasts of snow cover. This paper restricts itself to a discussion of these monthly and seasonal forecasts.

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THE FORECAST EQUATIONS

For the past six years, "advanced estimates" of monthly and seasonal snow cover of the Northern Hemisphere, Eurasia, and North America have been attempted by the authors using an experimental, empirical statistical technique developed and modified annually by the authors. (Wiesnet and Matson, 1976) The technique relates snow cover for a particular winter month or combination of months to subsequent snow cover using simple regression analysis. The particular regression equations and their coefficient of determination (r^2) are shown in Tables 1 through 3. Regression equations have been developed only for the Northern Hemisphere and Eurasia. North American winter snow cover showed no statistically valid relationships between various months. The number of data years jumps from 9 to 11 because of the availability of 1968 January and February monthly snow cover data which had previously been missing.

TABLE 1. Summary of regression equations used in making advance estimates of snow cover for January.

EURASIA

Number of Data Years	Period of Snowcover Forecast (Y)	Data Source (X)	Equation	r^2
8	January	December	Y = .92X + 4.80	.72
9	January	December	Y = .88X + 5.51	.71
11	January	December	Y = .91X + 5.26	.72
12	January	December	Y = .80X + 7.25	.70
13	January	December	Y = .82X + 7.42	.66
14	January	December	Y = .62X + 12.32	.58

NORTHERN HEMISPHERE

Number of Data Years	Period of Snowcover Forecast (Y)	Data Source (X)	Equation	r^2
8	January	December	Y = .55X + 19.39	.57
9	January	December	Y = .53X + 19.98	.57
11	January	December	Y = .63X + 18.72	.58
12	January	December	Y = .66X + 17.70	.63
13	January	December	Y = .69X + 16.35	.64
14	January	December	Y = .56X + 21.96	.60

TABLE 2. Summary of regression equations used in making advance estimates of snow cover for February.

EURASIA

Number of Data Years	Period of Snowcover Forecast (Y)	Data Source (X)	Equation	r^2
8	February	December	Y = .71X + 7.10	.81
9	February	December	Y = .70X - 6.68	.82
11	February	December	Y = .66X - 6.19	.76
12	February	December	Y = .62X - 4.02	.75
13	February	December	Y = .58X - 2.49	.70
14	February	December	Y = .46X + 3.83	.58

NORTHERN HEMISPHERE

Number of Data Years	Period of Snowcover Forecast (Y)	Data Source (X)	Equation	r^2
8	February	Dec. & Jan.	Y = .59X - 4.22	.78
9	February	Dec. & Jan.	Y = .57X - 3.08	.78
11	February	Dec. & Jan.	Y = .52X + .55	.70
12	February	Dec. & Jan.	Y = .53X - .23	.75
13	February	Dec. & Jan.	Y = .50X + 1.76	.73
14	February	Dec. & Jan.	Y = .38X + 11.98	.56

TABLE 3. Summary of regression equations used in making advance estimates of snow cover for the January through March period.

EURASIA

Number of Data Years	Period of Snowcover Forecast (Y)	Data Source (X)	Equation	r^2
8	January	December	$Y = 4.89X^{0.87}$	.79
9	January - March	December	Y = 2.85X + 9.56	.77
11	January - March	December	Y = 2.57X + 16.24	.74
12	January - March	December	Y = 2.32X + 21.88	.74
13	January - March	December	Y = 2.35X + 21.51	.73
14	January - March	December	Y = 1.57X + 41.01	.53

TABLE 3. Summary of regression equations used in making advance estimates of snow cover for the January through March period (CONTINUED).

NORTHERN HEMISPHERE

Number of Data Years	Period of Snowcover Forecast (Y)	Data Source (X)	Equation	r^2
8	January - March	December	$Y = 12.30X^{0.62}$	.82
9	January - March	December	$Y = 1.98X + 42.2$	.81
11	January - March	December	$Y = 1.96X + 47.98$	.80
12	January - March	December	$Y = 2.07X + 43.68$	.83
13	January - March	December	$Y = 2.12X + 42.04$	.83
14	January - March	December	$Y = 1.44X + 69.30$	.62

Tables 1 through 3 highlight an interesting aspect of the regressions, namely that the Eurasian r^2's have decreased over time. Thus less snow cover variance is being explained by the regressions as each new year of snow data has been added to the data set. The decrease became rather pronounced after the inclusion of the 1979-80 winter data (fourteenth data point). The same decrease also occurred in the Northern Hemisphere but is quite understandable since the Eurasian landmass dominates the Northern Hemisphere. The physical basis for such a decline is not known but the general decrease is to be expected as an initially short data set expands temporally and includes more extreme cases about the mean.

THE "ADVANCE ESTIMATE" RECORD

Tables 4 and 5 present our record of advance estimates for the 6-year period 1976-81 for the Northern Hemisphere and Eurasia, respectively. Our estimate is compared to the 10-year mean used as an estimate and the better of the two is indicated by a **. Table 4 shows that for the Northern Hemisphere 67% (16 of 24) of our estimates of Northern Hemisphere snow-covered area (SCA) were better than the 10-year means. Our estimates of total winter (January-March) SCA were more accurate than the 10-year means five out of six years. However, when compared to the 10-year mean estimates, our 1980 estimates were very poor.

For Eurasia alone, 12 of 24 of our estimates (50%) were superior to the 10-year means. Since January 1979 our estimates have only once been more accurate than the 10-year means. Estimates of total winter Eurasian SCA were better than the 10-year means from 1976-79, but were poorer in 1980 and 1981. In 1980 we were grossly in error (15.1% too high) while in 1981 our estimate was close, -2.6% versus a mean estimate that was off by -2.1%.

Figure 1 compares graphically the estimates and the actual total winter snowcover data for the Northern Hemisphere. Obviously, the 1980 decrease, which exceeded our prior lowest figure, was inadequately handled by the regression. However, in 1981, after the 1980 data were incorporated into the regression model, the advance estimate (made in the first week of January) proved to be much better.

TABLE 4. Comparison of advance estimates, 10-year mean, and measured snow cover for the Northern Hemisphere, 1976-1981.

NORTHERN HEMISPHERE

	Advance Estimate ($km^2 \times 10^6$)	Measured ($km^2 \times 10^6$)	Difference	10-Yr. Mean ($km^2 \times 10^6$)	Difference from 10-Yrs. Mean
1976					
J	44.2	43.6	+1.4%**	42.9	-1.6%
F	44.8	43.8	+2.3%	43.1	-1.6%
M	38.9	40.3	-3.5%**	37.9	-6.0%
	128.4	127.7	+0.6%**	121.8	-4.6%
1977					
J	44.6	47.3	-5.7%**	42.9	-9.3%
F	46.8	45.0	+4.0%**	43.1	-4.2%
M	35.7	37.1	-3.8%	37.9	+2.2%**
	129.8	129.4	+0.3%**	121.8	-5.9%
1978					
J	45.8	46.4	-1.3%**	42.9	-7.5%
F	47.0	47.3	-0.6%**	43.1	-8.9%
M	39.3	40.7	-3.4%**	37.9	-6.9%
	132.1	134.8	-2.0%**	121.8	-9.6%
1979					
J	45.0	46.7	-3.6%**	42.9	-8.1%
F	46.4	44.8	+3.6%**	43.1	-3.8%
M	36.1	40.1	-10.0%	37.9	-5.6%**
	37 7	40.1	-6.0%		
	129.2	131.6	0.7%**	121.8	-7.4%
1980					
J	38.4	41.3	-6.2%	42.9	+3.9%**
F	38.4	43.5	-11.4%	43.1	-0.9%**
M	24.9	38.4	-33.7%	37.9	-1.3%**
	109.7	123.2	-11.0%	121.8	-1.2%**
1981					
J	41.3	38.8	+6.1%**	42.9	-10.0%
F	39.8	40.6	-1.8%**	43.1	-5.8%
M	37.9	38.0	-0.1%	37.9	+0.0%**
	119.0	117.4	+1.3%**	121.8	-3.6%

TABLE 5. Comparison of advance estimates, 10-year mean, and measured snow cover for Eurasia, 1976-1981.

EURASIA

	Advance Estimate ($km^2 \times 10^6$)	Measured ($km^2 \times 10^6$)	Difference	10-Yr. Mean ($km^2 \times 10^6$)	Difference from 10-Yr. Mean
1976					
J	28.3	27.5	+2.9%	26.8	-2.6%
F	28.7	28.0	+2.5%	27.4	-2.1%
M	24.6	25.8	-3.1%**	23.5	-8.9%
	81.7	81.3	+0.5%**	77.7	-4.4%
1977					
J	28.8	30.2	-4.6%**	26.8	-11.3%
F	31.2	29.3	+6.5%**	27.4	-6.5%**
M	22.9	23.0	-0.4%**	23.5	+2.1%
	84.3	82.5	+2.2%**	77.7	-5.8%
1978					
J	30.6	28.9	+5.9%**	26.8	-7.3%
F	31.2	29.7	+5.0%**	27.4	-7.7%
M	25.9	25.5	+1.6%**	23.5	-8.5%
	87.7	84.1	+4.2%**	77.7	-7.6%
1979					
J	27.7	29.7	-6.7%**	26.8	-9.8%
F	29.8	27.4	+8.8%	27.4	0%**
M	20.2	25.0	-19.2%	23.5	-6.0%**
	(22.6)	(25.0)	(-9.6%)		
	79.7	82.1	-2.9%**	77.7	-4.1%**
1980					
J	22.7	25.6	-11.3%	26.8	+4.7%**
F	23.2	27.2	-14.7%	27.4	+0.7%
M	12.4	24.1	-48.6%	23.5	-2.5%**
	65.2	76.9	-15.1%	77.7	+1.0%**
1981					
J	25.4	24.7	+11.5%	26.8	-7.8%**
F	24.9	26.4	+4.3%	27.4	-3.6%**
M	23.8	25.0	+8.5%	23.5	+6.4%**
	74.1	76.1	-2.6%	77.7	-2.1%**

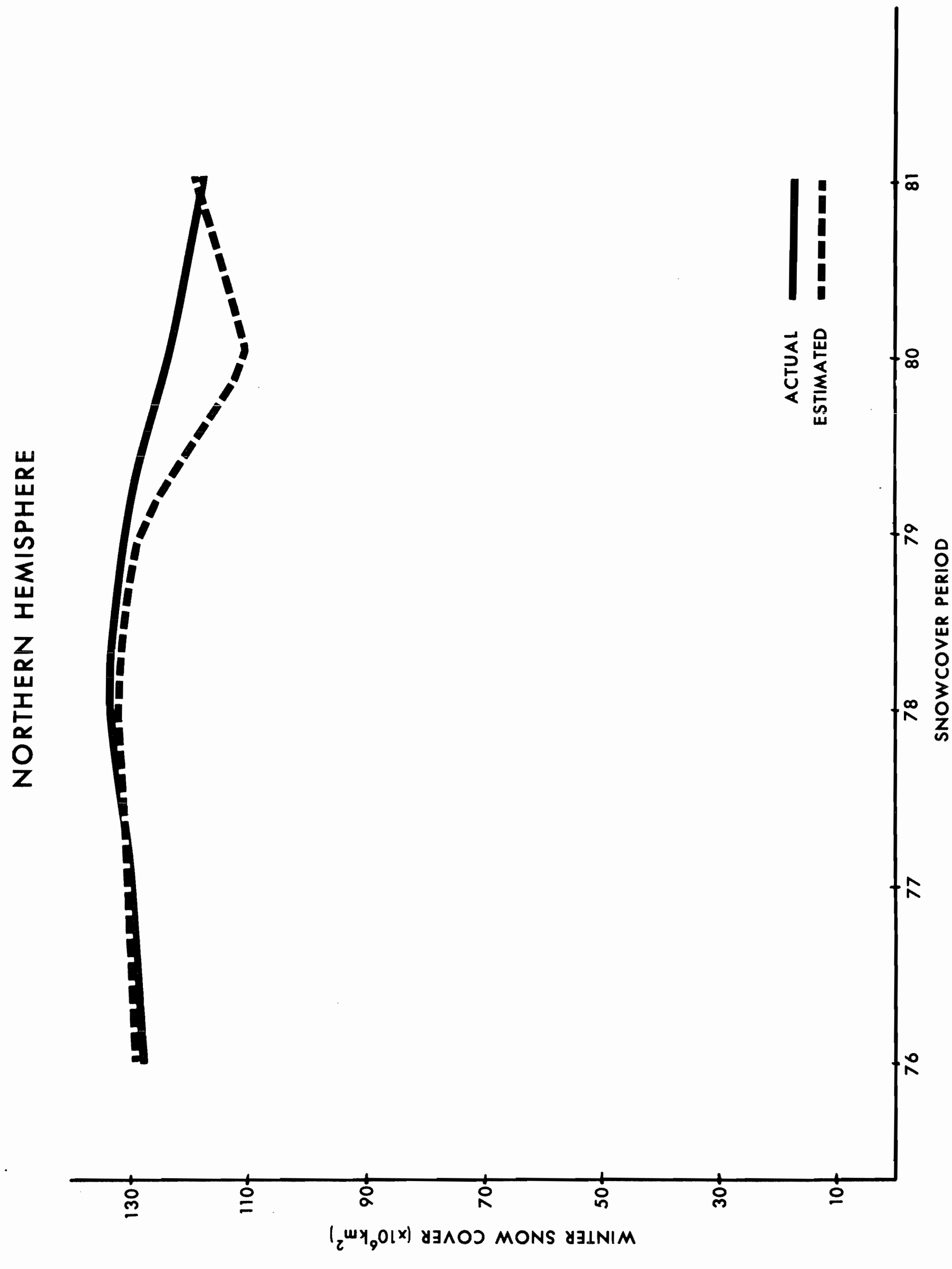

FIGURE 1. Comparison of actual and estimated total winter snow cover (January-March) for the Northern Hemisphere.

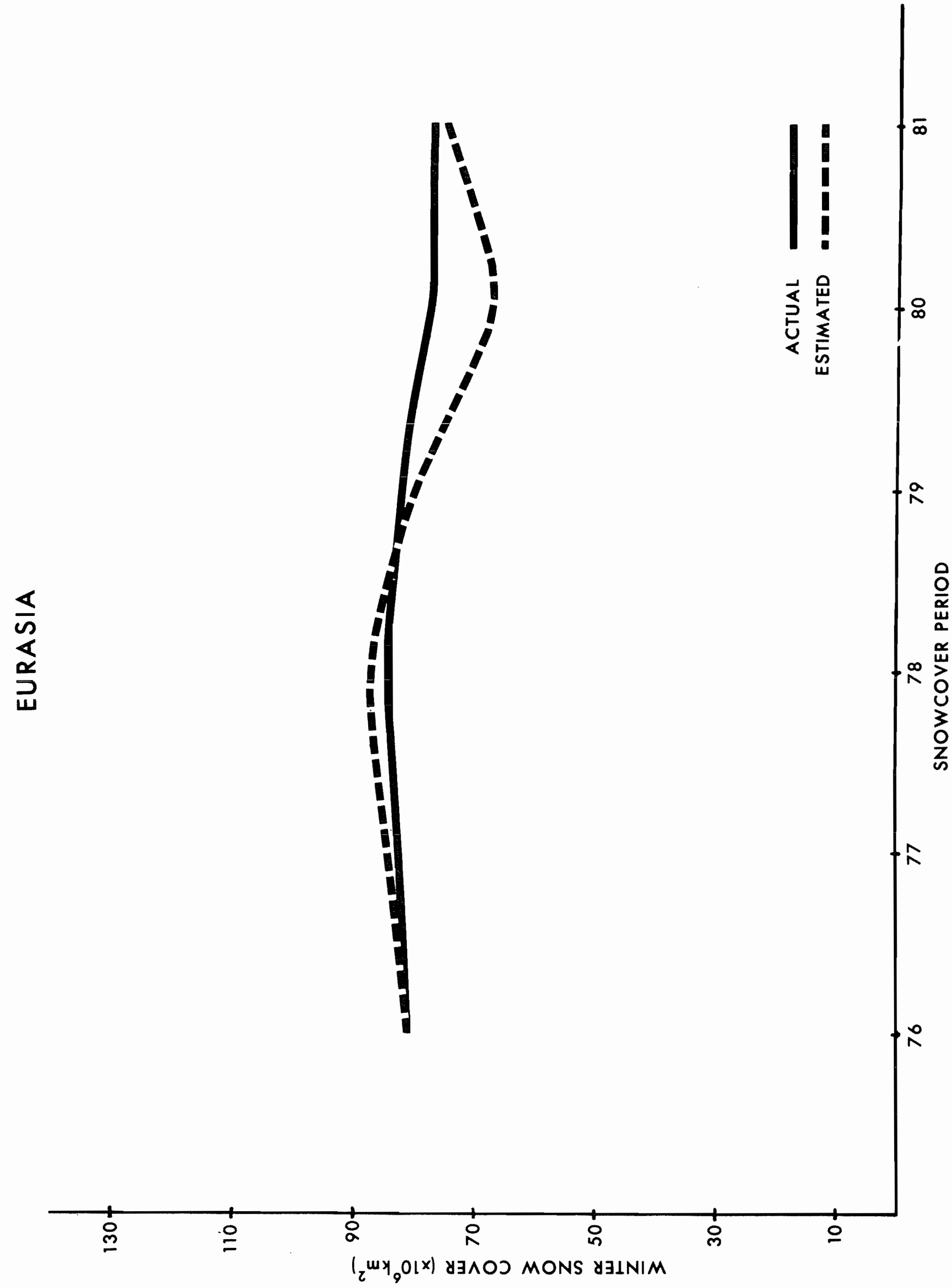

FIGURE 2. Comparison of actual and estimated total winter snow cover (Janaury-March) for Eurasia.

Figure 2 shows graphically how the total winter snowcover estimates varied over the six-year period for Eurasia. Although the absolute error was greatest in 1980, we are heartened that the trends of both the observed and estimated snow cover are similar. The ability to forecast trends is a valuable asset. It is hoped that the additional data gathered in the highly abnormal and extreme winters of 1978 and 1981 will ultimately improve the regression.

CONCLUDING REMARKS

It is apparent to us at this point that our statistical regression analysis technique remains interesting but inconclusive after six years of estimating and verifying. We are encouraged by our skill rates in estimating total hemispheric winter snow cover (January-March) from December snow cover data. Certainly forecasting winter snow cover for the Northern Hemisphere in early January has been done within ± 2.0% for five of the past six winters, as shown by Table 4 and Figure 1. This works out to an 83% skill rate on a seasonal estimate made three months before the end of the season.

Nevertheless estimate results for Eurasia are somewhat puzzling. In 1979 the estimates began to deviate farther and farther from the measured values (Table 5 and Figure 2). The 10-year means suddenly provided a more accurate technique for estimating SCA in 1979, 1980, and 1981. The sudden switch is disturbing, but may be a statistical quirk. Our skill rate has dropped to a paltry 43% for estimating Eurasian winter snow cover.

Testing and verifying the advance estimate technique for SCA will continue because of the need for seasonal winter forecasts and the potential of this statistical model or other more complex models for becoming NESS operational products.

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