Accuracy of Snow and Ice Monitoring

George Kukla
D. Robinson
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York, U.S.A.

It is well known that snow and ice covers have a large influence on the global heat budget, mainly because of their high albedo (Hummel and Reck, 1978; Kung et al., 1964). Knowledge of the variation of these covers in time and space is essential in the attempt to reach an understanding of climate changes (Wiesnet and Matson, 1976). Today, several groups produce operational snow and ice cover charts. These maps, mostly done on a weekly basis, extend from regional to global scales. Production techniques and the charted characteristics (i.e., snow depth and relative composition; surface reflectivity, age of cover; concentration of ice) of the snow and ice cover differ (Dickinson et al, 1974; U.S. Naval Oceanographic Office, 1974; U.S. National Environmental Satellite Service, 1974-75).

Tables 1 and 2 list the charts used in our study. The week to week changes in the extent and reflectivity of the snow and ice covers in both hemispheres are measured, and the results expressed in the form of several snow and ice related climatic indices (Kukla and Gavin, in press).

Table 1. Current series of snow charts used in the study.

Chart Name	Produced By	Area	Projection and Approx. Scale	Interval	Content	
Northern Hemisphere Average Snow and Ice Boundaries	Analysis & Evaluation Branch of the National Environmental Satellite Service, NOAA	Continents of the Northern Hemisphere North of 25°-30° N. Latitude	Polar Stereographic 1:50,000,000	Weekly: 1967-Present	Boundaries of Snow and Ice-Covered Areas in 4 Classes: 1) Least Reflective 2) Moderately Reflective 3) Highly Reflective 4) Scattered Mountain Snow	*
Current Snow and Ice Depth	USAF, Air Force Global Weather Central	Northern Hemisphere 0-90° N.	Polar Stereographic 1:30,000,000	Weekly: 1976-Present	Depth of Snow and Ice for 6 Categories: 1) <2"; 2) ≥2"; 3) ≥4"; 4) ≥6"; 5) ≥8"; 6) ≥10"	*
Age of Surface Snow/Ice	USAF, Air Force Global Weather Central	Northern Hemisphere 0-90° N.	Polar Stereographic 1:30,000,000	Weekly: 1976-Present	Age of Snow and Ice in 7 Categories: 1) No Snow 2) Fresh ≤24 hrs. 3) New ≤48 hrs. 4) Aging at least 3 days old 5) Old at least 3 weeks 6) Very old at least 2 months 7) Permanent at least 6 months	S N O W
Weekly Weather and Crop Bulletin Snow Chart	U.S. Dept. of Commerce National Weather Serv., NOAA, U.S. Dept. of Agriculture & Statistical Reporting Service	Continental U.S.	Albers Equal Area 1:30,000,000	Weekly: 1934-Present	Depth of snow on ground at 7 a.m. E.S.T. for Monday, December - March only	*

*Quality Checked

Accuracy of snow and ice monitoring (with G. Kukla).
Glaciological Data Report GD-5, 91-97, 1979.

Table 2. Current series of pack-ice charts used in the study.

Southern Ice Limit	U.S. Naval Oceanographic Office, Fleet Weather Facility	Two Sections, Eastern and Western, North of 40° N: $\sim$120°W-90°E $\sim$90°E-120°W	Polar Stereographic $\sim$1:15,000,000	Weekly: 1972-Present (1971: Incomplete information on Charts)	Sea Ice Concentration in Oktas, open water polynyas. Also shown: Isoline of +2°C sea surface temperature, 0°C average air temperature	*
Ice at the End of the Month	Climatological Services Meteorological Office Bracknell, United Kingdom	Northern Hemisphere North of 40° in the North Atlantic, and North of 45°-60° in the North Pacific	Polar Stereographic $\sim$1:22,000,000	End of Month: 1960-Present 1960-61 (North Atlantic only)	Sea Ice Concentration in Tenths, open water polynyas. Also shown: isopleths of degree days, sea surface isotherms, 0°C air isotherm	ARCTIC ICE
Ice Summary and Analysis 1) Canadian Arctic 2) Hudson Bay and Approaches 3) Eastern Canadian Seaboard	Ice Forecasting Central, Environment Canada	Eastern Canadian Arctic, including Foxe Basin, Western Arctic including North Coast of Alaska and, Western Queen Elizabeth Is.	Polar Stereographic	Weekly: May-October 1964-73	Sea Ice Concentration (in Tenths) and by age including open water polynyas. Also included: mean temperature and wind flow chart +1200 GMT and Central Sea Level pressure of migratory lows	
Northern Ice Limit	U.S. Naval Oceanographic Office, Fleet Weather Facility	Antarctic South of 50°	Polar Stereographic $\sim$1:18,000,000 (1973-74 1:35,000,000	Weekly: 1973-Present	Sea Ice Concentration in Oktas, including open water polynyas. Also shown: isopleths of degree days, sea surface isotherms, 0°C surface air isotherm	ANTARCTIC ICE *

*Quality Checked

As a part of the study, we tested the accuracy of the operational maps, placing emphasis on fall, winter, and spring when maximum changes occur in the observed variables. This was made possible by completing the charts with additional information, unavailable at the time when the operational charts were being produced. Both NOAA/NESS and NAVY-FLEWEAFAC interpreters cooperated in the work and provided the original satellite imagery actually used in generating the charts. Great attention at this stage was paid to the quality of the snow charts. This is because significant regional changes in the extent and character of snow and ice covers often occur during a single day.

The snow cover on land is frequently discontinuous. For example, south facing slopes may be exposed more rapidly than horizontal surfaces or north facing slopes. Drifting may also expose bare ground. More importantly, the presence, type, and density of vegetation affect local and regional albedos, even with an otherwise thick snow cover on the ground. A dense coniferous forest with over a foot of snow on the ground, but with a dark canopy or a steep rock cliff may approach summer albedo values. Conversely, grass-covered pastureland with even 5-10 cm of snow may reach extremely high albedos, comparable to those found over Antarctica and Greenland.

Each group producing these snow and ice charts uses different techniques. These are described in detail in other papers presented at this workshop. NESS uses satellite images and relies on skilled interpreters recognizing characteristic textured surface features of the snow-covered land. Images for each consecutive day of the particular week are used. The snow areas are placed in one of three relative reflectivity classes depending on the visible surface brightness.

The Air Force chart used in this study shows the extent and depth of snow on the ground, the data being generated by a sophisticated computer program. The depth of snow is determined by combining satellite brightness data, snow depth reports, precipitation and temperature data, etc. Blank spots are reconstructed from climatology.

The Weekly Weather and Crop Bulletin reports snow cover extent and depth from December through March in the continental United States at 7 a.m. EST on the chart date. The map is produced from telegraphic reports of selected stations across the country.

Ice cover is mapped weekly by the Navy and NOAA. NOAA reports the general extent and relative reflectivity of ice cover and assigns the cover to a reflectivity class, whereas the Navy reports the ice concentration in octas (eighths). Visible, infrared, and microwave imagery gathered during three consecutive days of each week are used to construct the charts. Data are supplemented by ship and coastal station reports.

Accuracy of Snow Charts

In order to examine the accuracy of the operational snow charts, we produced a new, independent, updated set of snow maps for three selected blocks in the United States (figure 1). The Western section, west of approximately 105°W longitude, includes the Range and Basin province. The Central section includes the flat north central Plains, principally represented by farmland, and the Eastern section represents a moderately hilly region with extensive forests. For technical reasons, the Central and Eastern sections overlap over Iowa.

Satellite information for each day was recharted and completed by incorporating reports from the ground stations shown in figure 1. The area covered by snow is measured and expressed as the percentage of the total area of the block. Selected results refer at this stage to snow area only and are shown in figure 2. Differences between the summaries found in the operational and the corresponding updated chart, in percent of the block area covered, are plotted in table 3. Day 7 is the last day of the analysed week. It is seen from the results, that:

1) the best fit is reached on the last, or the penultimate day of the week;

2) the departures tend to be smaller in the more recent charts;

3) the average differences are usually less than 10 percent of the area of the block;

4) largest differences are in the mountainous Western block.

Given the frequently irregular and sketchy character of the snow fields, difficulties in distinguishing snow in heavily forested areas, and the rapid changes of snow cover in the selected intervals, we consider the accuracy of the charts to be sufficiently high for climate-related studies on a continental or hemispheric scale.

Accuracy of the Ice Charts:

The Navy and NESS operational charts of sea ice covers were checked using a method similar to that used in the snow map analyses. Results will be reported in more detail elsewhere. In general, the quality of both sets was found to be sufficiently high for use in climate related studies. Navy charts very accurately show the proportion of open water (sometimes perhaps including a very thin ice cover) to the sea ice. They do not, however, indicate relative reflectivity.

It is our firm belief that the skill of the interpreters in individual agencies is constantly increasing, and that further improvements in the charts' quality will soon follow.

We recommend at present that existing charts be subdivided into three sets:

1) Pre-satellite era...A good time series for parts of the Northern Hemisphere, but only some indices are useful. Generally good for depicting the ice boundary, but data on ice type and concentrations are not very reliable.

2) Satellite era, 1966-1973...Relatively good representation of the general boundaries of snow and ice cover but not too much detail. Sufficient for studies on a continental scale.

3) Satellite era, 1973 onward...Introduction of microwave and improvement of existing methods. With more detailed information available on a global scale, this period could be used as a "normal", as sets of high internal homogeneity can be generated.

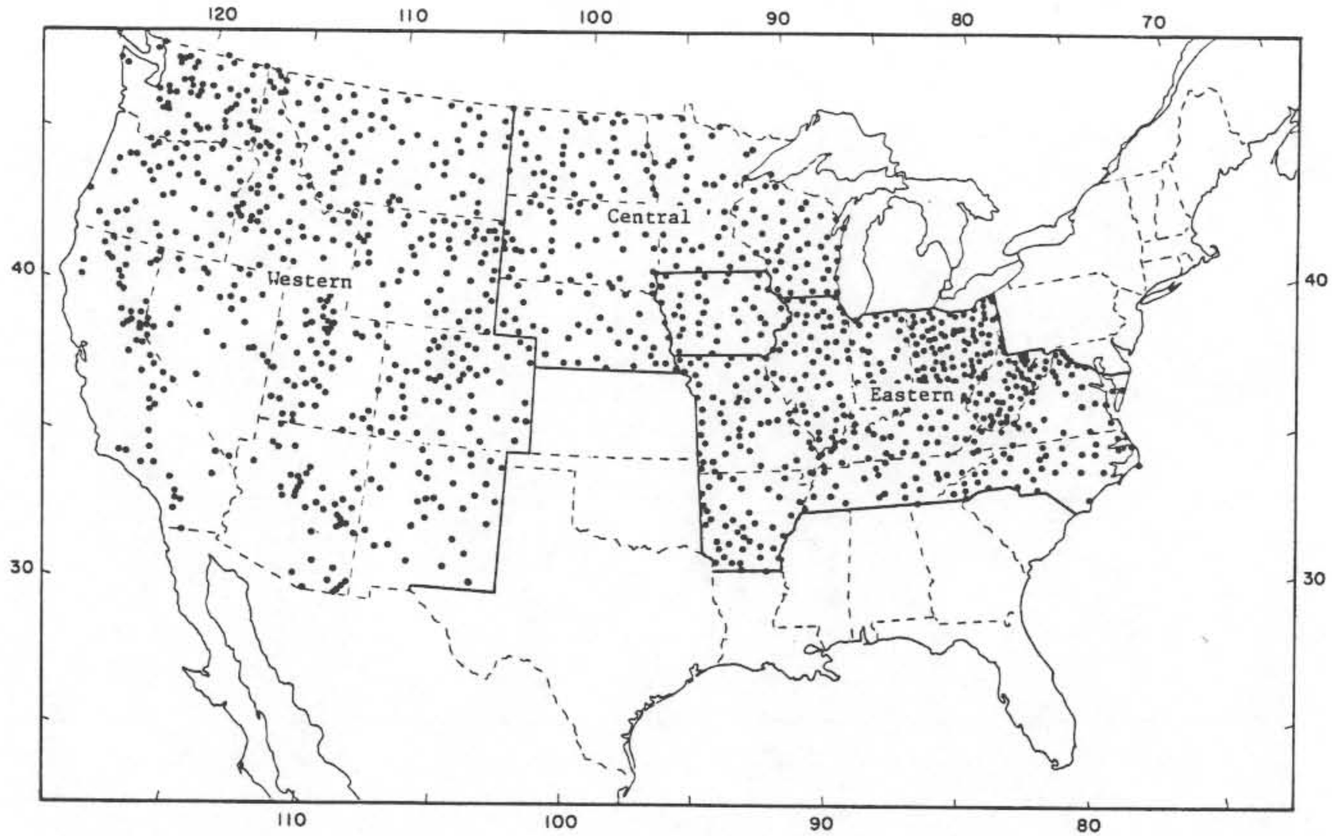

Figure 1. Location of the ground stations in the Western, Central and Eastern blocks. Iowa is included in both the Central and Eastern block. Snow reports are from monthly climatic data.

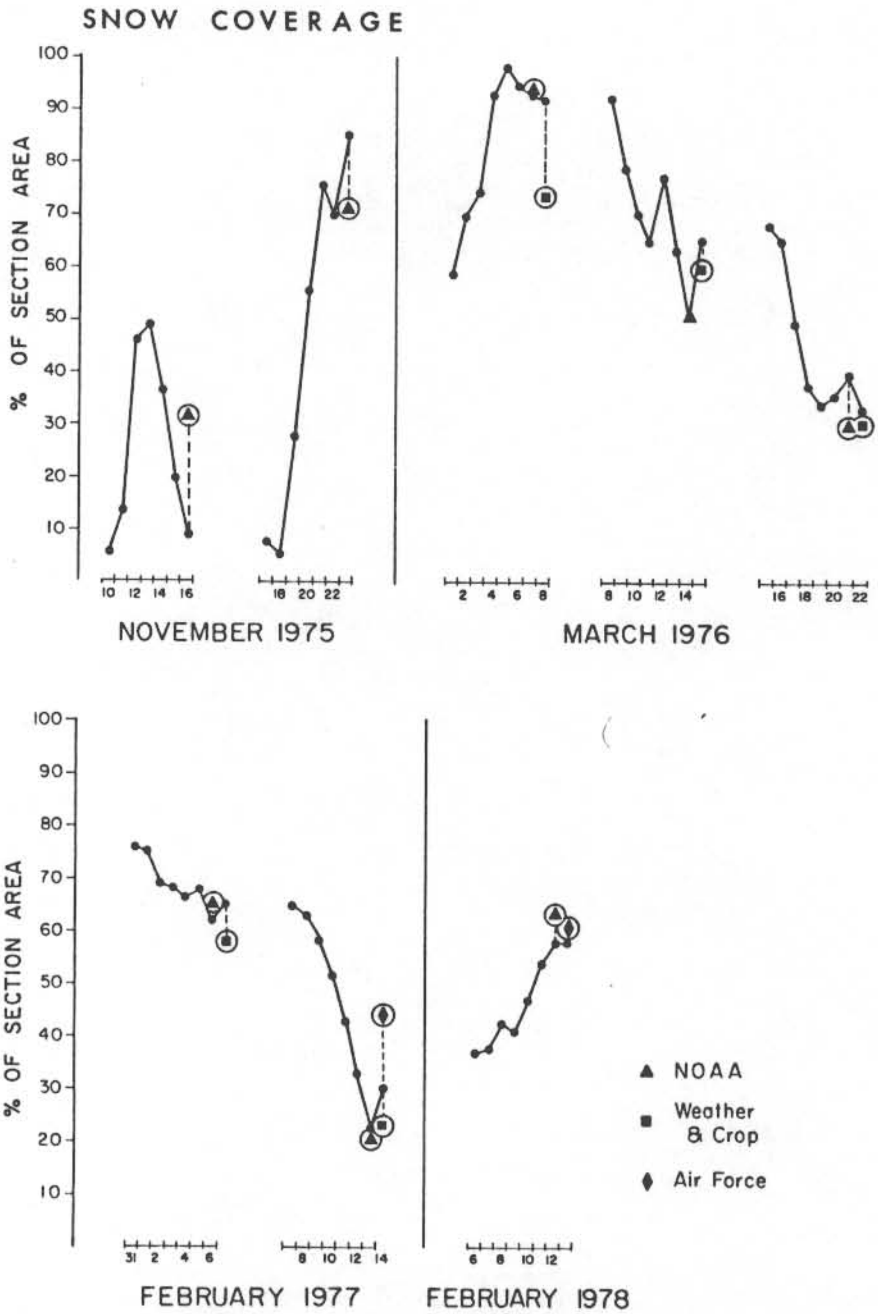

Figure 2. Percent of snow covered area on individual days at selected intervals in 1975-1978. November 1975 and March 1976 data are for the Central block (Iowa, Minnesota, Nebraska and Dakotas). February 1977 data are for the Eastern block, February 1978 data for the Western block. Circled triangles, squares and diamonds show the area shown in the corresponding operational charts.

Table 3. Snow area shown on the operational chart compared to the snow area on our updated map. Difference in the area of the block covered on each day (in percent). Negative sign shows our result to be smaller.

NESS	1	2	3	4	5	6	7
11/10-16/75	26.5	18.1	-14.6	-17.3	- 4.8	11.8	22.7
11/17-23/75	63.5	65.8	43.3	15.6	- 4.5	1.2	-13.9
3/ 1- 7/76	34.6	23.8	19.2	.6	- 4.7	- 1.2	.6
3/ 8-14/76	-41.7	-28.5	-19.6	-14.0	-26.8	-12.8	- .3
3/15-21/76	-38.5	-35.4	-19.9	- 8.0	- 4.2	- 6.2	-10.2
1/31-2/6/77	-10.7	- 9.9	- 3.6	- 3.0	- 1.2	- 2.7	3.0
2/ 7-13/77	-45.1	-43.0	-38.5	-31.2	-20.6	-12.4	- 2.6
2/ 6-12/78	26.7	26.0	21.1	22.8	16.5	9.3	5.5
AIR FORCE	**1**	**2**	**3**	**4**	**5**	**6**	**7**
2/ 1- 7/77	1.3	7.6	8.2	10.0	8.5	14.0	11.5
2/ 8-14/77	-18.8	-14.3	- 7.0	3.6	11.8	21.6	14.0
2/ 7-13/78	23.4	18.5	20.2	13.9	6.7	2.9	2.9
WEATHER AND CROP BULLETIN	**1**	**2**	**3**	**4**	**5**	**6**	**7**
3/ 2- 8/76	3.6	- 1.0	-19.6	-24.9	-21.4	-19.6	-18.7
3/ 9-15/76	-18.7	- 9.8	- 4.2	-17.0	- 3.0	9.5	- 8.1
3/16-22/76	-34.8	-19.3	- 7.4	- 3.6	- 5.6	- 9.6	- 2.8
2/ 1- 7/77	-17.1	-10.8	-10.2	- 8.4	- 9.9	- 4.2	- 6.9
2/ 8-14/77	-40.0	-35.5	-28.2	-17.6	- 9.4	.4	- 7.2

Suggestions for future snow and ice map products:

1) A minimum scale of 1:30,000 is needed.

2) Reflectivity classes should be more detailed, at least six classes. (Brightness data are preferable to snow depth for the purposes of climate dynamic studies.)

3) Charts should distinguish between data recorded on the day that the chart is dated, and data collected on previous days.

4) The proportion of snow to bare ground should be given where possible.

5) Where possible, areas of melting snow cover on the pack ice should be indicated.

6) Where possible, relative reflectivity of sea ice should be indicated in Navy charts.

Acknowledgements:

We are grateful to the personnel of NESS/NOAA, Navy and Air Force for supplying us with needed charts and images, and for many helpful comments and advice. We especially thank Frank Smigielski, Mike Matson, Don Wiesnet and Paul McClain. We are indebted to B. Dehn and N. Untersteiner for help, to Robert Crane for careful editing, to G. Manzanares for miraculous typing, to A. Gordon and K. Hunking for reading.

The research was supported by National Science Foundation grant ATM77-28522. It is a Lamont contribution no. 2815.

References

Dickinson, L.G.; Boselly, S.E.; Burgmann, W.S. (1974) Defense Meteorological Satellite Program (DMSP) User's Guide, Air Weather Service, U.S. Air Force. 110 pp.

Hummel, J.R.; Reck, R.A. (1978) A global surface albedo model, General Motors Research Laboratories. Research Publication No. GMR-2607 (revised), p. 57.

Kukla, G.; Gavin, J. (In press) Recent secular variations of snow and sea ice covers. (Presented at the World Glacier Inventory Workshop, Riederalp, Switzerland, September 1978).

Kung, E.C.; Bryson, R.A.; Lenschow, D.H. (1964) Study of a continental surface albedo on the basis of flight measurements and structure of the earth's surface cover over North America, Monthly Weather Review, v. 92, pp. 543-563.

U.S. Department of Commerce. Environmental and Data Information Service. Weekly Weather and Crop Bulletin, 1914-.

U.S. National Environmental Satellite Service. Analysis and Evaluation Branch. Northern Hemisphere Average Snow and Ice Boundaries, U.S. Dept. of Commerce, April 1974-March 1975.

U.S. Naval Oceanographic Office. (1974) Report of the Arctic Ice Observing and Forecasting Program - 1971. Naval Oceanographic Office. Special Publication No. 70. 216 pp.

Wiesnet, D.R.; Matson, M. (1976) A possible forecasting technique for winter snow cover in the Northern Hemisphere and Eurasia. Monthly Weather Review, v. 104, pp. 828-835.