Comparison of Northern Hemisphere Snow Cover Data Sets

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ABSTRACT

Four Northern Hemisphere snow cover data sets are compared on a weekly basis for the 25-month period, July 1981 through July 1983. The data sets are the NOAA/NESDIS Weekly Snow and Ice Chart, the Composite Minimum Brightness (CMB) Chart, the U.S. Weekly Weather and Crop Bulletin (data only for North America), and Air Force data. The NOAA/NESDIS chart is produced through the use of photo-interpretation of visible satellite imagery and ground observations. The U.S. Crop Bulletin is also done manually, using only ground observations. The CMB chart and the Air Force data are both produced using automated processes, the first by way of visible satellite imagery and the second by way of ground observations, climatology, satellite observations and persistence. Since the NOAA/NESDIS chart is the only standard and complete data set dating back to the mid 1960s, it is used as the basis for the study. The main emphasis of this paper is a comparison of the CMB and the NOAA/NESDIS chart.

The CMB frequently overestimated snow cover, especially the southward extent of the main snow boundary and areas far from the snow boundary which were not present on the NOAA/NESDIS chart. On numerous occasions, the outline of mountain ranges was either distorted or totally missed by the CMB. The CMB also underestimated snow cover, especially in densely forested areas. Other regions of underestimation by the CMB can be attributed to the bias factor of the NOAA/NESDIS chart. (The NOAA/NESDIS chart uses the latest snow cover information while the CMB is composited over a week.) The U.S. Crop Bulletin agreed fairly well with the NOAA/NESDIS chart east of the Rockies, but often differed to the west. The Air Force data set, an undocumented operational product, differed quite a bit from the NOAA/NESDIS chart.

1. Introduction

It is becoming increasingly evident that snow cover is a very meaningful tool for detecting climatic changes and reflects, as well, the impulsive character of our climate. Much of the research has been directed at the interaction between the extent of the snow cover and synoptic-scale atmospheric conditions. Several observational studies have indicated the relationship of snow to both surface air temperature and monsoon rainfall over India.

Several studies have documented the effects of anomalous snow cover on surface air temperatures on both daily and monthly time scales. Dewey (1977), in a diagnosis of Model Output Statistics errors, found that large errors were produced by extensive snow cover. Wagner (1973) showed that monthly average snow cover and surface air temperature are highly correlated at individual stations. Foster et al. (1983) and Robock and Ahnert (1983) found relationships between observed monthly average snow cover and monthly average surface air temperature. Walsh et al. (1982, 1985) found that snow cover was an important influence on monthly average surface air temperature in the eastern two-thirds of the United States. Barnett (1985), in an observational study of sea level pressure variations, suggested that a feedback between snow cover and circulation was responsible for the variations he detected.

In a number of papers, Namias has used case studies to illustrate the effects of snow cover and temperature on each other. Namias (1960) related snowfall amounts in the northeastern United States to 700 mb height patterns and found an inverse relationship. Dickson and Namias (1976) performed a similar study, but used data from stations in the southeastern United States and found the same result. Namias (1962) showed the influence of snow on temperature and circulation through feedback mechanisms. Namias (1974, 1978) discussed snow as an integral part of an interactive feedback process that caused anomalies to persist for longer periods than they would have without the snow for specific cases.

Some studies have indicated significant correlation between Eurasian snow cover and amount of monsoon rainfall in India during the following summer. Hahn and Shukla (1976) studied an 8-yr period (1967–75) and found an inverse relationship between the two. Dickson (1984) updated this study by adding 5 yr to the existing 8-yr data set while also adjusting for known deficiencies in satellite snow observations. The resulting correlations still showed the inverse relationship; however, the magnitudes were not as large.

The studies just mentioned illustrate the significance of snow and climate, meaning that a comprehensive and repetitive survey of snow fields would be of great benefit. For many years, snow cover was monitored by human observers at ground stations located primarily in midlatitude populated areas. The evolution of polar-orbiting satellites provided a rapid and economical means of obtaining this information for research and operational purposes. Satellite monitoring of snow cover is very useful because it provides instantaneous observations over extensive areas and good temporal resolution. The NOAA/NESDIS Weekly Snow and Ice Chart was the first snow cover product derived exclusively from satellite data.

The purpose of this paper is to compare and contrast four different methods and their corresponding products for mapping snow cover. These products include the NOAA/NESDIS Weekly Snow and Ice Chart, the Composite Minimum Brightness Chart, the United States Weekly Weather and Crop Bulletin, and Air Force snow cover data. This study will cover a 25-month period from 1 July 1981 to 31 July 1983. The main goal in this project is to evaluate the efficiency of the automated CMB technique in mapping snow cover. We will use the CMB charts in an "automatic snow cover detection" sense and verify its snow cover with the more standard and complete NOAA/NESDIS data set. The ultimate goal in snow cover mapping would be to devise an automatic detection system, thereby eliminating satellite photo interpretation. We are only concerned here with snow cover overlying land areas and do not consider sea ice cover. In section 2, each data set will be described in detail along with an example of each. Then, six weekly comparison maps representing examples of the differences between the data sets will be discussed. Finally, conclusions about the utility of the different data sets will be presented.

2. Description of the data

a. NOAA/NESDIS

The Synoptic Analysis Branch (SAB) of NESDIS has prepared a weekly snow and ice chart for the Northern Hemisphere since November, 1966, based on satellite observations covering a period from Monday through Sunday (Matson and Wiesnet, 1981). This "Northern Hemisphere Weekly Snow and Ice Cover Chart" is based upon 6 to 7 days of visible satellite imagery supplemented by ground observations (Dewey and Heim, 1981). Each chart displays a polar-stereographic view of the areal extent of Northern Hemisphere snow cover. The brightness of the snow, in a three-category subjective classification, was also included in the past but in May 1982, was discontinued due to its limited usefulness. A digitized version of the weekly and monthly maps on the NMC grid was produced by Dewey and Heim (1981, 1982) and is continually updated and available from NESDIS. For the period of this study, the combination of visible imagery from the polar orbiting satellites NOAA 6 and 7, and the equatorial orbiting satellites (GOES series) were primarily used for analysis of the snow cover.

The procedure for producing the snow and ice charts was simplified recently in 1981. The old method (Matson and Wiesnet, 1981) required a satellite meteorologist to make a pencil trace of the previous week's chart onto a new snow and ice chart early in each week. Then, daily visible data were collected and compared to the previous week's chart and changes were made if necessary. The analyst also examined surface synoptic reports to confirm any drastic changes in snow cover due to new snowfall or rapid snowmelt. Therefore, each weekly chart included snow boundary changes observed during the week.

In the updated procedure, the satellite meteorologist begins to analyze visible images at 1200 Universal Coordinated Time (UTC) every Monday, and completes and finalizes the chart by Monday evening. The new procedure requires the analyst to collect all the previous week's visible data and arrange them chronologically with the most current data on top. Beginning with the most current imagery, a boundary is drawn around all snow and ice regions on the visible images themselves. If the latest satellite photograph of a region is cloud covered or not available, the preceeding picture of the same area is used. The analyst also compares satellite images with appropriate surface synoptic reports where necessary. After all regions of the Northern Hemisphere have been analyzed, the analysis is transferred from the visible imagery to a new snow and ice chart. In areas where the snow boundary cannot be determined or is cloud covered or data are not otherwise available, the previous week's analysis is used. The chart is reviewed to make sure a complete analysis has been done and then traced onto a new finalized chart. The final chart reveals the extent of the snow cover for the week and can be compared to previous years for climatic studies. These charts are based on interpretations by a variety of observers; thus operator bias is undoubtedly present.

In differentiating between snow cover and cloud cover, the analyst must be aware of the following: 1) texture—snow fields appear smoother than cloud fields; 2) cloud fields are more transient than snow fields; 3) clouds display a higher reflectance than snow cover; and 4) geographical features such as forests, rivers and lakes, if visible on the imagery, indicate a cloud-free look at the surface and, hence, the adjacent bright area is a snow field. Mountains are not always good indicators of the absence of clouds since some orographic-type clouds can stay over an area for days and give the appearance of snow on mountains. It must also be recognized that the earth's orbital orientation causes a portion of the polar latitudes to lie in total darkness or near darkness during the period between the autumnal and vernal equinoxes. The circle of nonillumination is illustrated on the weekly charts during this time period, and it indicates the region where the visible satellite sensors are unable to monitor the snow and ice cover. Therefore, all land areas within this nonilluminated zone were assumed to be snow covered and, likewise, the water areas were assumed to be ice covered.

This data set is not without problems. On occasion, persistent cloudiness and forests prevented detection of snow cover for several weeks in a row. A few times broken satellites created missing data over wide regions. In the early years, the Himalayan area was not adequately mapped (Ropelewski et al., 1984). Still it is the longest consistent hemispheric record of snow cover, and so we chose to regard it as the basis for comparison with the other data sets.

An example of a NOAA/NESDIS Weekly Snow and Ice Chart for 11 January through 17 January 1982 is shown in Fig. 1.

b. Composite minimum brightness

Satellite imagery also helped to yield another end product called the CMB Chart. The purpose of the CMB technique was to filter out temporary cloudiness so that the bright areas retained in the CMB Chart represented the relatively permanent snow cover. The visible satellite imagery was digitized, then rectified and composited over a time period for the Northern and Southern hemispheres on a polar stereographic projection. The first CMB charts, displayed in black and white mapped imagery using five grey tones, were produced in October of 1968 over a 5-day period. In 1974, the compositing period was increased from 5 to 10 days. Then in 1979, the polar sectors were replaced by hemispheric sectors which covered a much larger area. The compositing period was reduced to its present day interval of 7 days and was updated daily, i.e., each chart is an overlapping 7-day composite. Since the NOAA/NESDIS chart is our basis for comparison purposes and is produced from data for Monday through Sunday, we accessed a CMB chart for every Monday of the study period, i.e., CMB data encompassed Monday through Sunday. The polar orbiting satellites NOAA 6 and NOAA 7 provided the visible data for the creation of the CMB charts during our 2-yr study period. The CMB data that have been produced by NOAA from 1968 to the present are archived as images only; no digital analyses are saved.

McClain and Baker (1969) give the best description of the process by which the CMB chart is produced. The first step involves the digitization of the incoming video data so that they can be used for further computer processing. After digitization, all video data for a given day are resolved into a so-called "full-resolution" array, based on the Numerical Weather Prediction (NWP) grid system of the National Meteorological Center. There are 4096 NWP grid squares in each hemisphere, and a subarray of 64 × 64 satellite data points (4096 in all) is mapped into each grid square. Thus, a total hemispheric array of full-resolution satellite data comprises 4096 × 4096 data points. Each data point of the full-resolution array represents an area approximately 5 km on a side and gives a measure of the brightness of the earth's background, including clouds, on an integral scale (relative) ranging from 0 to 14.

A mesoscale data array is produced from the full-resolution array by reducing the data points by a factor of 8 in each dimension. (The mesoscale area is thus about 40 km on a side.) However, in 1973 the resolution became 55 km (McClain, 1973). In order to retain much of the original information content of the full-resolution data during this data compression step, the original relative brightness range of 0 to 14 is divided into five equal classes, and a frequency distribution of the full-resolution population of each mesoscale spot is stored on magnetic tape. The full-resolution brightness data for each mesoscale spot are then spatially averaged; this average is computed from the brightness histogram. These average brightnesses are then composited over a selected period of days by saving only the minimum value for a given mesoscale spot during the compositing period. The resulting CMB chart is displayed on a cathode ray film device in rectified form; latitude and longitude lines as well as geographic and political boundaries are added electronically.

McClain and Baker (1969) were the first to apply satellite data to snow cover for the purpose of mapping the major snow boundary across North America. They used the CMB technique applied to three 7-day periods in the winter of 1967. Seven-day composites were available for all three periods, while 3- and 5-day composites were derived for the first period. Comparisons of CMB Charts for the various compositing periods showed that those clouds retained in the 3-day composite were eliminated or suppressed in brightness in the 5-day composite. A lesser amount of additional cloud filtering occurred when the compositing period was lengthened to 7 days. In verifying the CMB Charts with ground observations, the 5-tone mesoscale CMB Chart generally was effective in delineating the main snow line in the Great Plains and in the relatively unforested areas of the Midwest. However, it was less effective or totally ineffective in heavily forested areas such as the upper Great Lakes Region, the southern portions of Ontario and Quebec, and much of the northeastern United States and Appalachian mountains. This last point agrees with Conover (1965) and Barnes and Bowley (1968) in that, generally, the denser and more extensive the stands of trees—particularly if the trees are predominantly coniferous—the darker the area will appear, even when snow of considerable depth is present. McClain and Baker (1969) also found that the snow-covered higher elevations (generally above the tree line) of the Canadian and American Rocky Mountains and of Canada's Coast Mountains appeared fairly bright in all CMB charts, but the snow present on the lower, more heavily forested slopes generally was not displayed in the five-tone mesoscale composites.

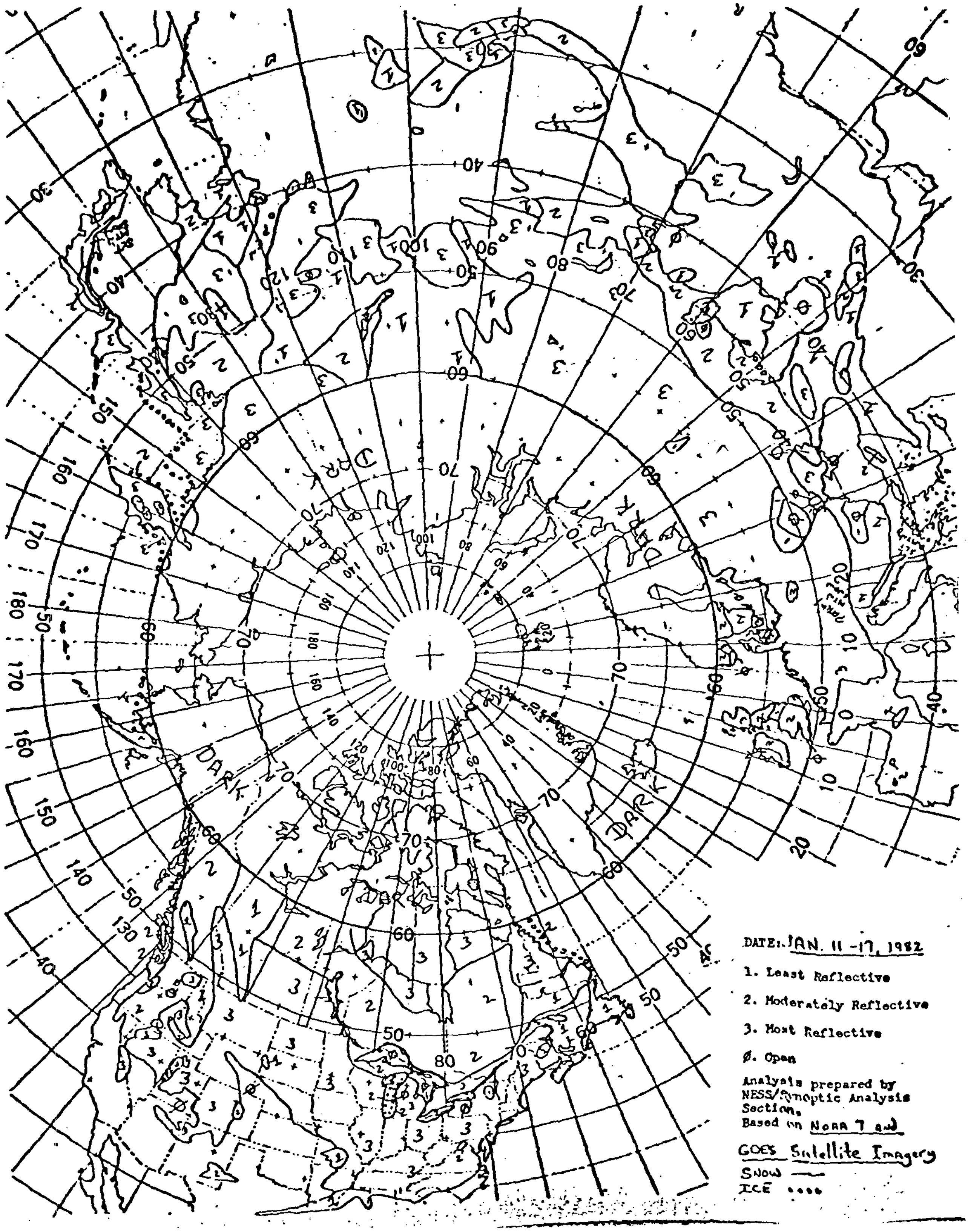

FIG. 1. NOAA/NESDIS Weekly Snow and Ice Chart for 11–17 January 1982.

Figure 2 displays an example of a CMB Chart for 11 January 1982 to 18 January 1982. This finalized CMB chart shows the persistent bright areas representing snow or clouds. One striking feature that can be seen immediately is the very low surface brightness associated with the forested regions of southeastern

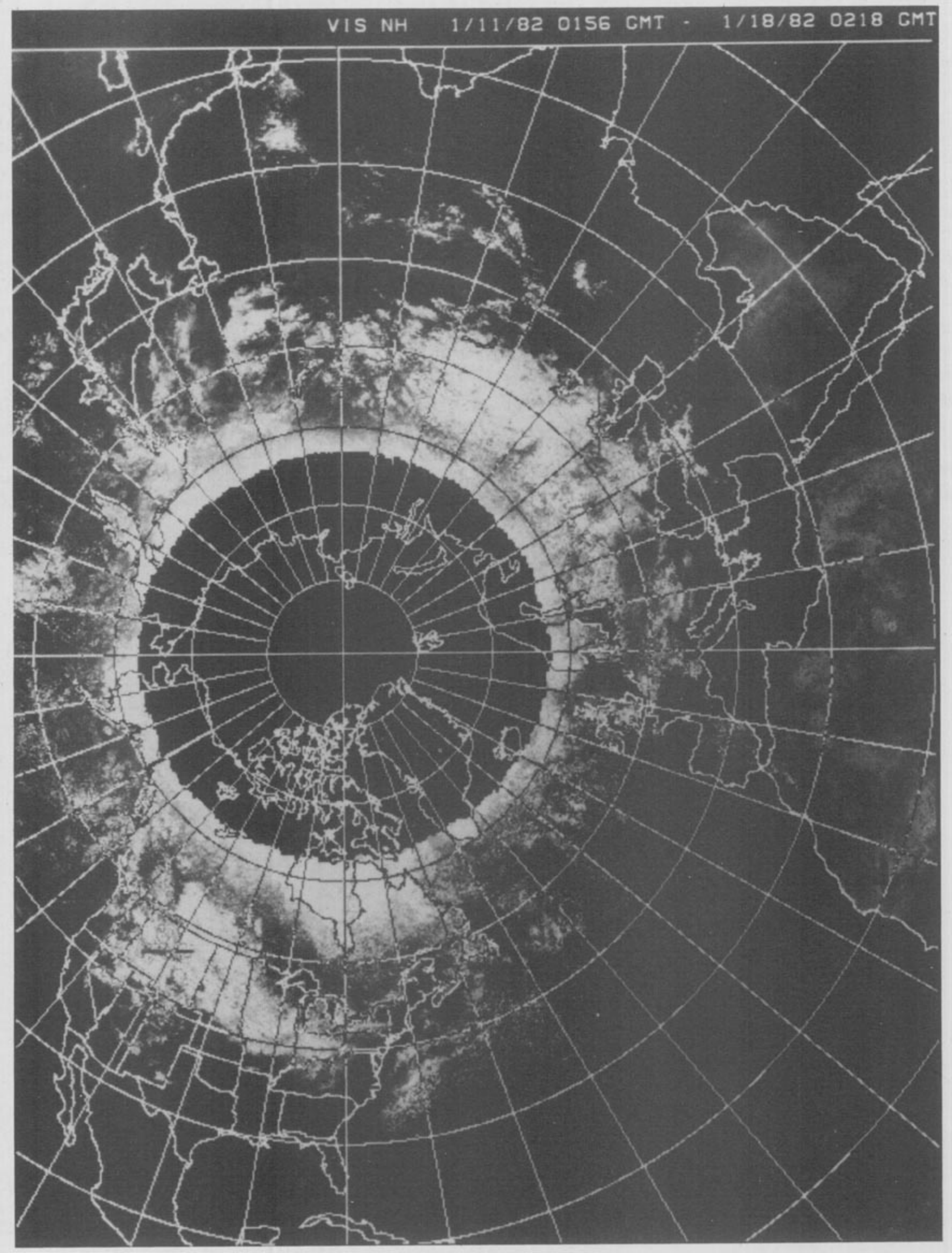

FIG. 2. Composite Minimum Brightness Chart for 11–18 January 1982.

Canada and northeastern Asia, even though these landscapes are snow covered. The bright areas appearing in the oceans are considered to be persistent cloudiness.

c. United States Weekly Weather and Crop Bulletin

The U.S. Weekly Weather and Crop Bulletin is published weekly and jointly by the U.S. Department of Commerce and the U.S. Department of Agriculture. This publication, originally called the "Weekly Chronicle", was first published in 1872. It yields a variety of information including a day-by-day summary of national weather events, data for selected cities, national precipitation and snowfall (December through March), and agriculture reports, as well as an international weather and crop summary. Snow cover maps within the bulletin date back to the early 1920s. National Weather Service stations along with selected cooperative stations throughout the United States and Canada measure the snow depth in inches at 1200 UTC every Monday from early December through late March. Through December 1983, the snow cover map exhibited values of snow depth along with a 1-in. (2.54 cm) snow depth contour line. Afterwards, only the snow depth values were shown.

Figure 3 shows a United States Weekly Weather and Crop Bulletin snow cover map for 18 January 1982. This map only covers the United States and southern Canada while showing the snow depth as well as extent of the snow cover.

d. Air Force

The U.S. Air Force Global Weather Central (AFGWC), located at Offutt Air Force Base in Omaha, Nebraska, prepares an automated, operational Northern and Southern hemispheric snow cover analysis daily, dating back to 1975 (Woronicz, 1981). Snow cover analyses are retained indefinitely at the National Climatic Center in Asheville, North Carolina, and are available on request. Their snow cover analysis model "SNODEP" is run once daily at AFGWC to produce a gridded analysis of snow depth and age. Data sources include the Defense Meteorological Satellite Program (DMSP) satellite imagery in the 0.4–1.2 μm band. A global data base of ground observations consisting of 5500 stations in the Northern Hemisphere and 2200 stations in the Southern Hemisphere is primarily used in the model. Additional sea ice data are obtained from the Navy/NOAA Joint Ice Center in Suitland, Maryland. The exact process by which "SNODEP" produces

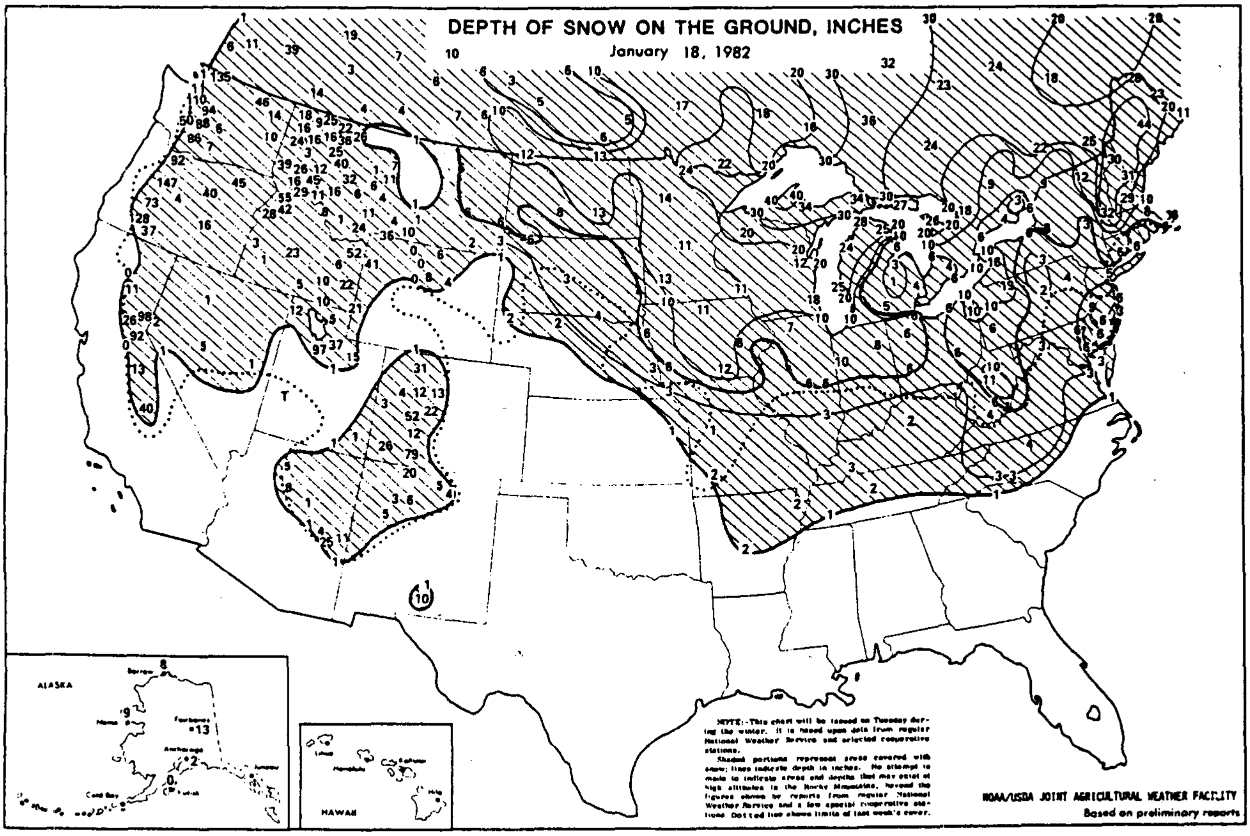

FIG. 3. United States Weekly Weather and Crop Bulletin Snow Cover Map for 18 January 1982. (1 in. = 2.54 cm)

a finalized chart is complex and not well documented; however, the preferential order of data used is surface observations, climatology, persistence and satellite observations.

An Air Force snow cover map for 17 Jan. 1982 can be viewed in Fig. 4.

3. Results

Three steps were taken in order to accurately compare and contrast the four snow cover data sets. The first step consisted of finding a universal time period which would satisfy all four data sets. Since the NOAA

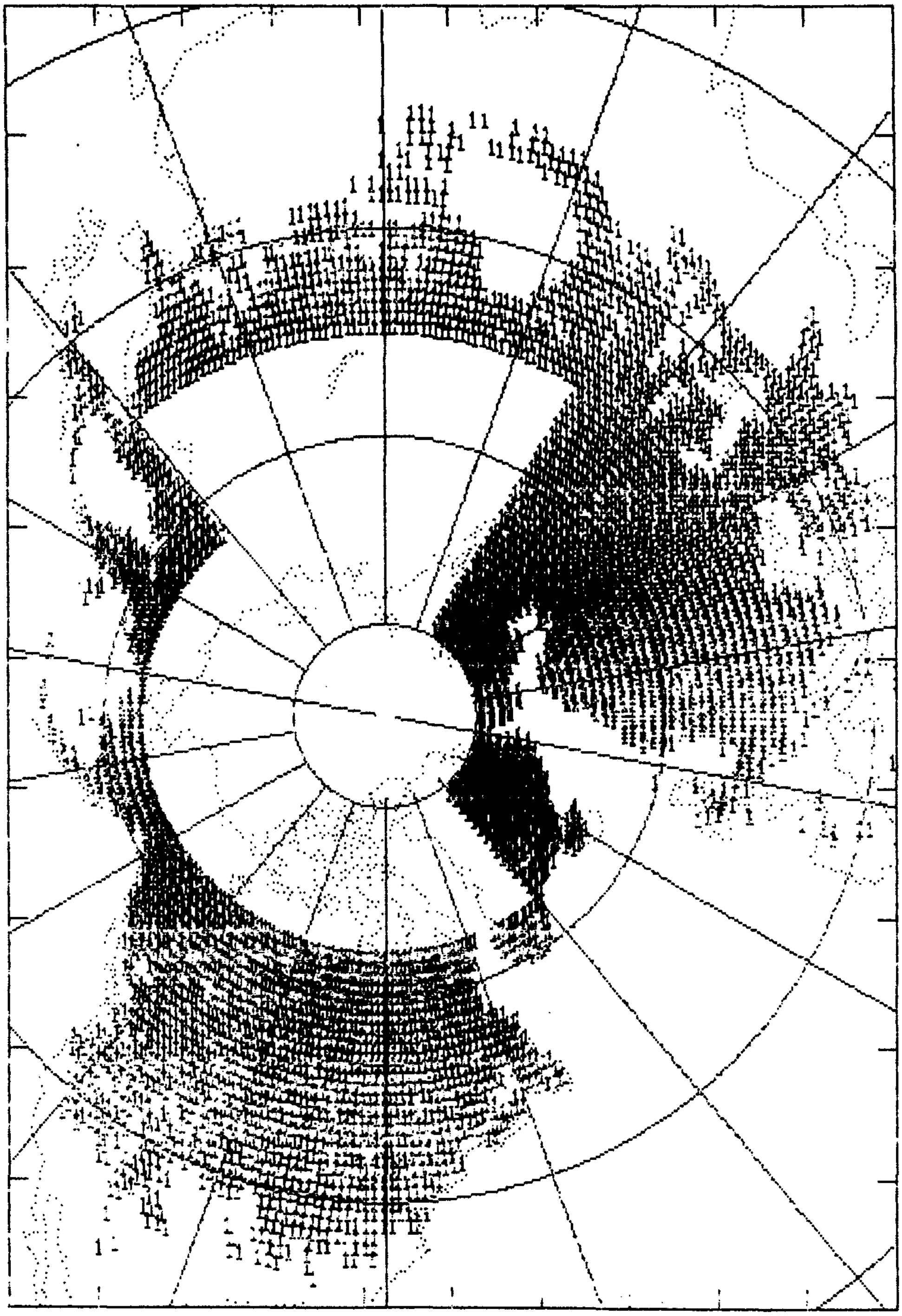

FIG. 4. Air Force Snow Cover Chart for 17 January 1982. Each snow-covered grid point is represented by the digit "1"; the blank area near the pole contained snow but was not plotted to save computer time.

data set was chosen as the standard, its period, Monday through Sunday, was used as basis for the comparisons. Since the CMB product is a 7-day 0000 to 0000 UTC composite produced daily, Monday through Monday was used; for our purposes this is within our time frame. The Air Force snow cover final analysis is produced once daily, and since NOAA is biased toward the end of the week, we used Sunday's data, representing the last day of the comparison period. The U.S. Crop Bulletin utilizes ground observations taken at 1200 UTC Monday, the morning following the end of the time period. The next step was to decide what base map should be used as a basis for all data comparisons. Since the NOAA data set is the most widely used Northern Hemispheric snow cover map, it was used as the base map. The final step to be taken was to transfer all four data sets to the polar stereographic base map by simply tracing the outline of the snow cover.

The U.S. Crop Bulletin yields snow cover maps only for the United States from December through March, so they will be referred to on occasion in the discussion. The Air Force snow cover is based on surface observations, satellite observations, persistence and climatology, but this is a complex process whose detailed procedure is not well documented. For this reason, it was decided to trace Air Force data onto selected base maps. Approximately once a month seemed appropriate. Snow cover appearing on every negative image of the CMB as well as on each Air Force and United States Crop map had to be hand traced, which is subject to some subjective judgment and error.

McClain and Baker (1969) identified a definite problem with mapping snow cover in forested landscapes using the CMB technique for a few selected cases. Because of the angle at which satellites view dense forests, these areas appear dark regardless of the snow depth. A good portion of Canada and Asia are covered by woodlands so this problem should be visible in the upcoming comparisons. When snow was obviously present south of the forested area, the entire forest was assumed to be snow covered. This was also evident in the American and Canadian Rockies where snow existing on the lower, more heavily forested slopes was not well detected.

Since we are using the CMB technique as an automatic snow cover detection system, all bright areas over land are assumed to be snow covered. However, it is probable that some areas represent cloudiness that persisted throughout the 7-day composite period. This can happen in one of two ways; the first, in which a bright area appears far from the major snow boundary so that we must consider the latitude and geography of the area to determine snow or clouds; and the second situation, where the bright area extends farther south than the actual main snow boundary; this obstructs the main snow line.

Over the 2-yr study period, 108 weekly maps were produced to compare the four data sets. In this report, six comparison maps (Figs. 5–10) are shown as examples of the differences between the data sets. The data sets will be abbreviated in the comparisons as follows: NOAA/NESDIS as NOAA, Composite Minimum Brightness as CMB, United States Weekly Weather and Crop Bulletin as CROP, and Air Force as AF.

Five problems became apparent when the CMB snow cover was compared to the NOAA snow cover:

1) *The CMB extended the main snow boundary farther south than the NOAA snow line.* This condition appeared in all of the figures in the North Atlantic and Pacific oceans as well as in the Arctic, Asia and Europe.

2) *Persistent bright areas occurred far from the main snow boundary.* This was particularly frequent in Southeast and West Asia, as seen in Figs. 8, 9 and 10. The bright areas associated with these first two problems are interpreted to be persistent cloudiness. The dominant storm track apparently coincided with the snow boundary. This may have been due to a feedback, where the snow/no snow boundary induced storm formation or tracks and the storms produced the snow, but this cannot be determined here. Persistent cloudiness also existed frequently in both oceans.

3) *The CMB also had trouble with most major mountain regions.* This was especially true for the Himalayas in central Asia. In each figure, either the southern part was missed, the whole range was shifted to the east, or persistent white areas covered the entire outline. The Rockies of North America posed problems for the CMB in each figure while the Pyrenees of Spain went undetected constantly. The CMB handled the Caucasus and Elburz mountains of West Asia fairly well while the Alps were picked up repeatedly. This problem can be attributed to positioning errors. Each day, the polar orbiting satellites cover different strips of the earth's surface and the location that they cover must be calculated from imperfect knowledge of the orbits. Furthermore, grid points have a finite size and do not cover exactly the same location on each day, shifting about as orbits vary. The result is that a grid point which includes a mountain and is bright on one day, may be slightly to the side of the mountain on the following day and appear dark. If this only happens on one day during the compositing period, the minimum brightness will be low and the snow will not appear on the chart. Except for the Himalayas, the other mountain ranges mentioned have locally dense forests below their crests which decrease the surface brightness when snow covered. Also, circulation surrounding the mountainous area may be oriented in such a way to produce orographic cloudiness for an extended period of time, and this was quite evident in the Himalayas.

4) *Forested areas appeared very dark when snow covered, resulting in underestimation of the snow fields by the CMB.* This can be seen, for example, in North America (Figs. 5, 7, 8, 9), Asia (Figs. 6, 7, 9, 10) and

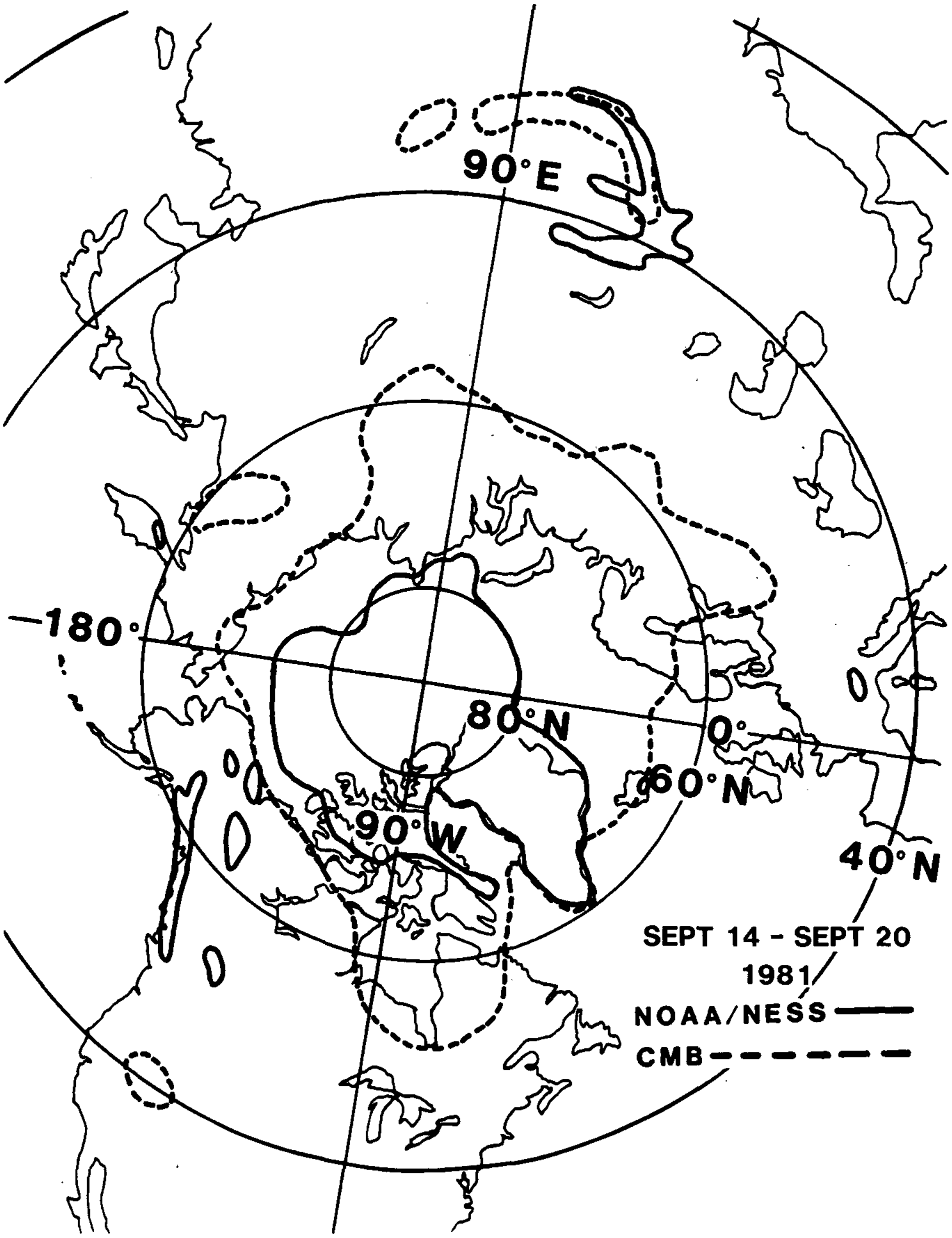

FIG. 5. Weekly Comparison Map for 14–20 September 1981.

Japan (Figs. 6, 7). This was a particular problem when the main snow boundary was located in the forested region. McClain and Baker (1969) found very low surface brightness associated with snow-covered forested regions of North America. Robock and Kaiser (1985) found that planetary albedos of forested areas were significantly lower than farming and grazing lands when snow covered. Kukla and Brown (1982) found similar results observing surface brightness of various surface types. Robinson and Kukla (1985) computed zonal averages of surface albedo of Northern Hemisphere lands under maximum snow cover and found low values in Eurasia and North America between 45° and 65°N.

5) *In some areas which were not forested, the CMB still underestimated snow cover with respect to NOAA, due to the fact that the CMB shows the minimum for the week while NOAA uses the most recent data with a bias toward the end of the week* (Figs. 6, 7, 9, 10). The NOAA/NESDIS Weekly Snow and Ice Chart is compounded over a week's period from Monday through Sunday; however, it incorporates only the most up-to-date information in its final outline, i.e., only data from the end of the week are used. In the CMB

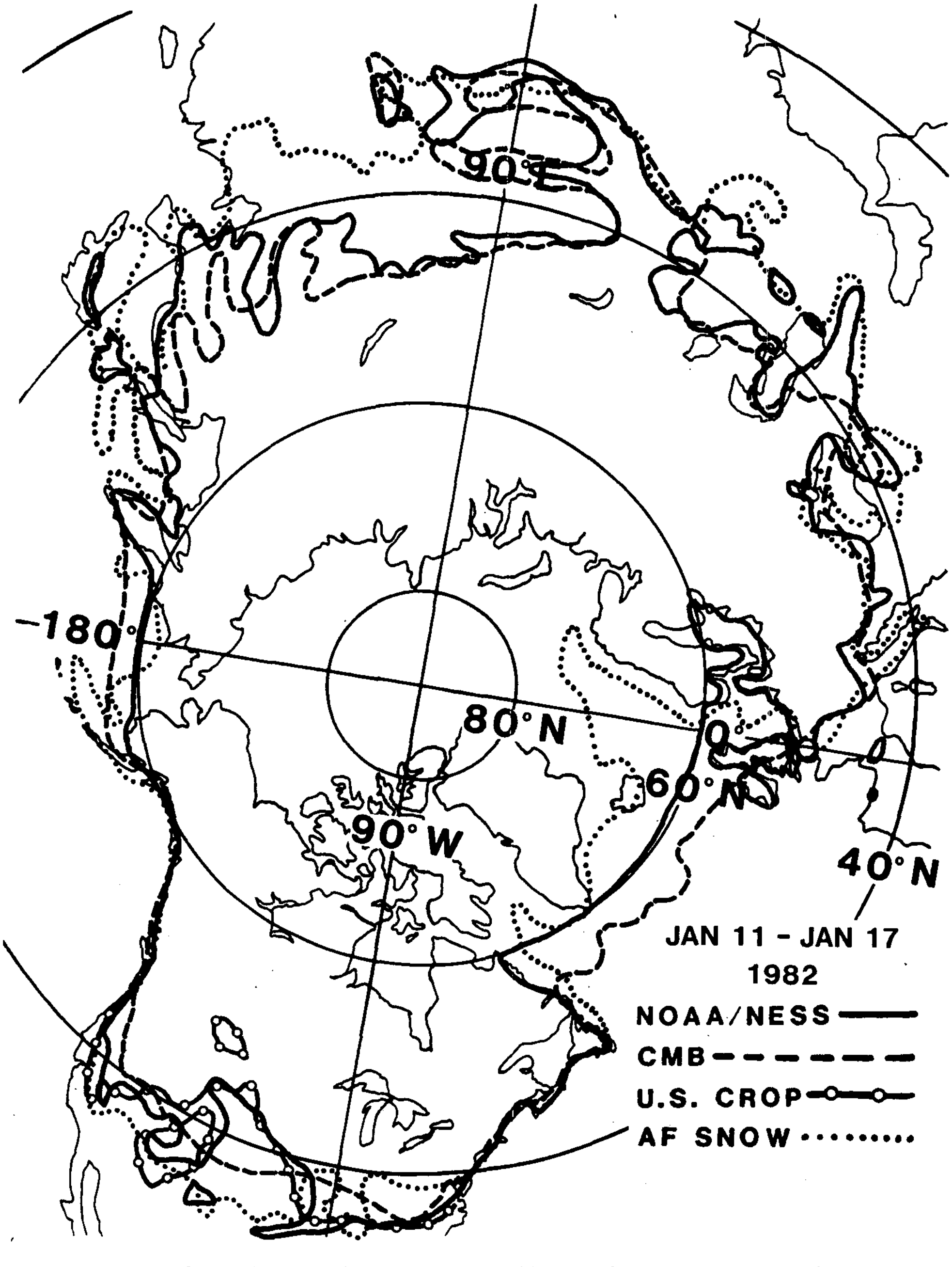

FIG. 6. Weekly Comparison Map for 11-17 January 1982 (contains the data shown in Figs. 1-4).

technique, only minimum values of surface brightness are retained. Essentially, each technique serves a different purpose. The CMB technique displays the minimum amount of snow cover while NOAA reveals more than the minimum, especially if snow is increasing toward the end of the week.

In Figs. 6, 9 and 10, CROP agreed fairly well with NOAA east of the eastern edge of the Rockies but often disagreed to the west. This may have been due to the sparse network of ground observation stations, or to errors in the NOAA data which is also subject to the cloud and mountain problems previously discussed. This is understandable due to the location of the point stations, especially in the western United States. We must also consider the possibility of poor precision in reporting the actual snow depths.

The AF data showed large differences in location of major snow cover boundaries when compared to NOAA in North America, Asia and Europe in Figs. 6,

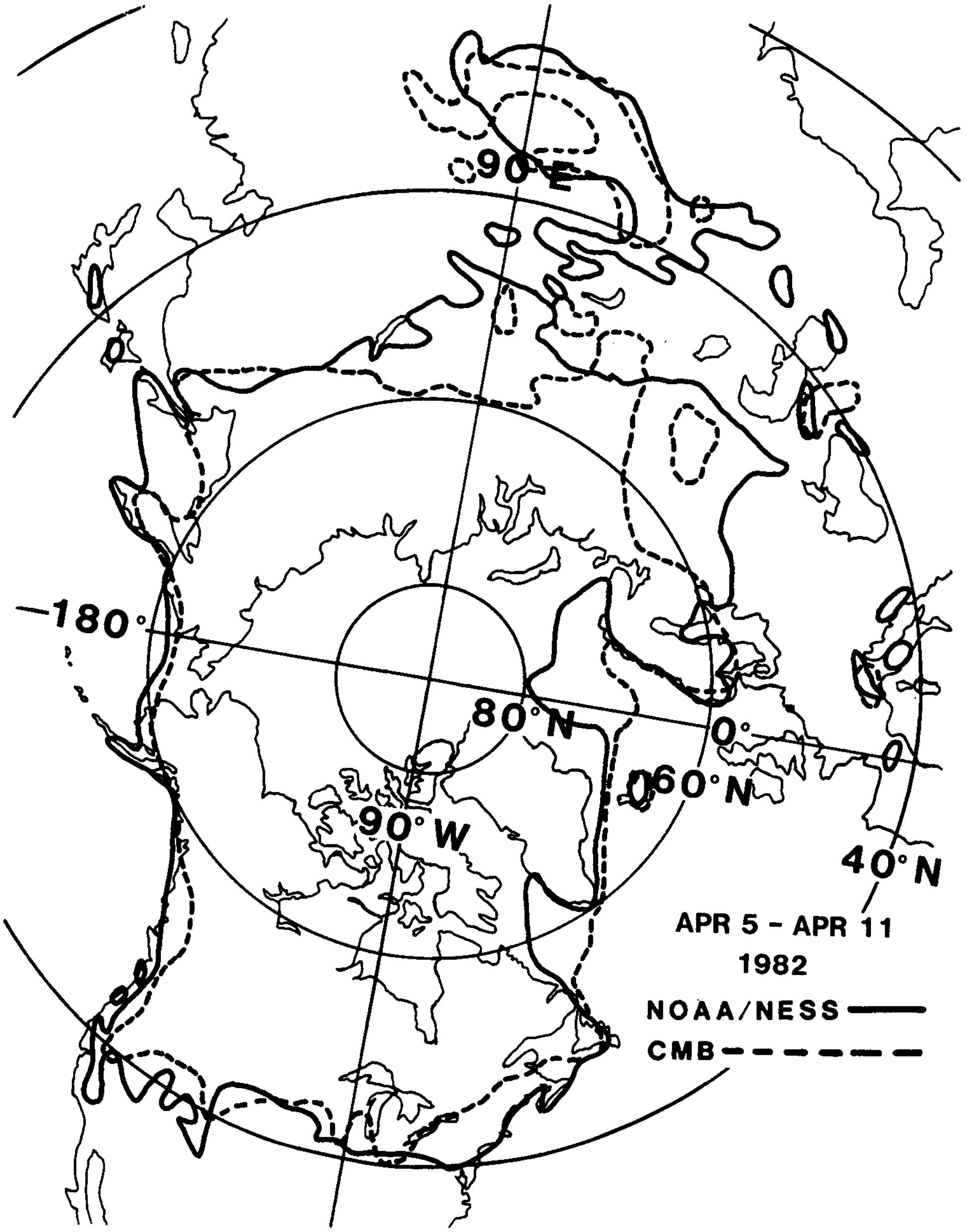

FIG. 7. Weekly Comparison Map for 5–11 April 1982.

8 and 10; however, AF revealed the probable sea ice/open water delineation in the Arctic during the winter months (Figs. 6 and 10). This is made possible through the use of the Navy/NOAA ice charts. It has been stated that the primary source of data used in producing an Air Force snow cover chart is ground reports, although the exact procedure is not well defined. When observed data are missing, persistence and climatology are used, sometimes supplemented with satellite data. Glancing at Figs. 6, 8 and 10, our tentative conclusions suggest poor precision in reporting snow depths as well as the spreading of depth values over great distances. The lack of documentation of the data source for each grid point for each day for this operational product hinders the usage of these charts by the research community.

Table 1 displays a quantitative comparison between NOAA and the other data sets as a function of area difference. Each category represents a problem that was found on the weekly comparison maps and is rated separately on a linear scale of 0 (no difference) to 5

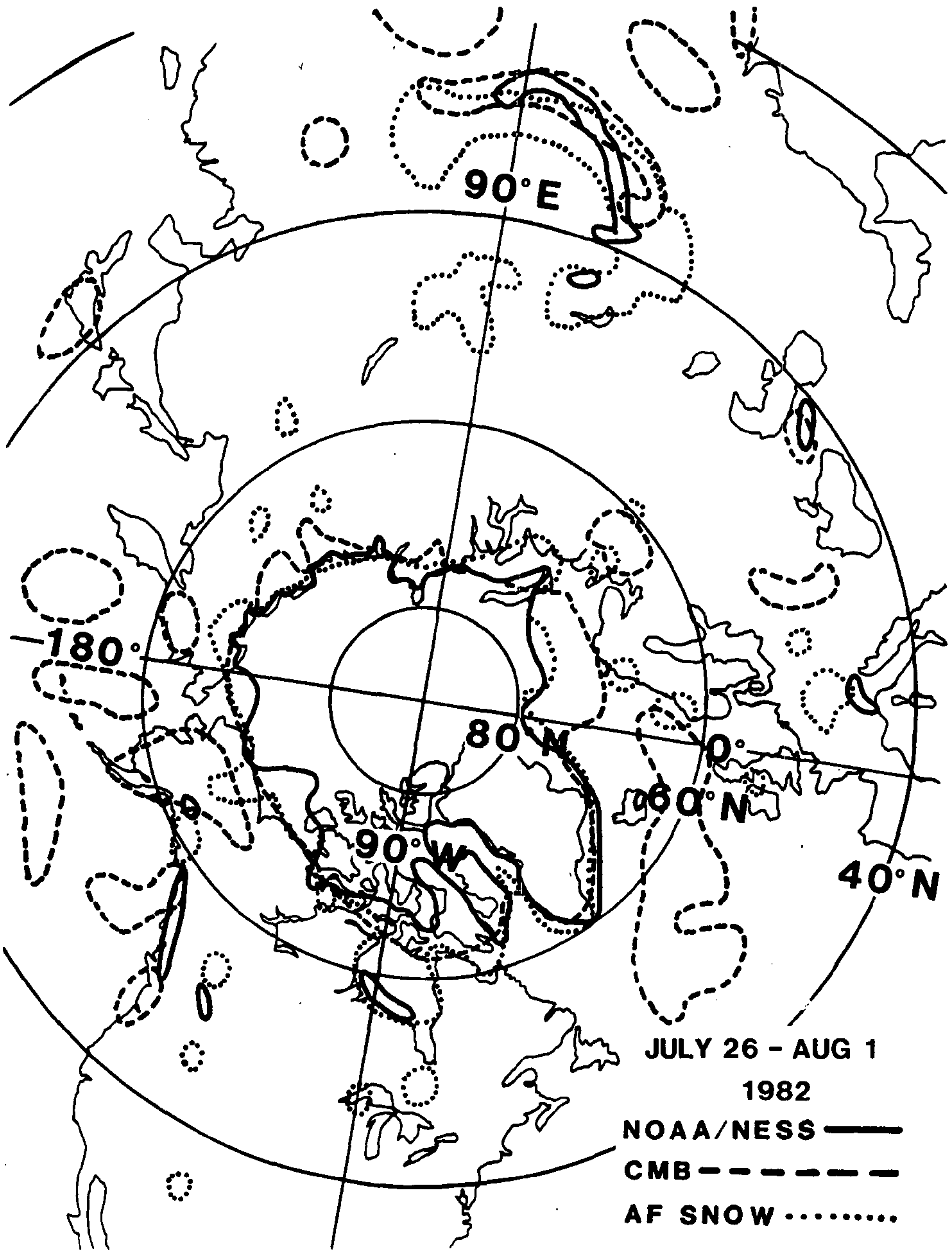

FIG. 8. Weekly Comparison Map for 26 July–1 Aug. 1982.

(maximum difference). A rating of 5 means that, for this week, the difference caused by the problem in this category was equal in area to the largest difference observed (for this category) for the entire data set. Occasionally, CMB data were not available during the 2-yr period so that the corresponding week was labeled as "MISSING".

After each weekly map from July 1981 to July 1983 was rated, several quantities were calculated. We first computed the average difference for each category, then we converted the average difference to percent values by dividing by 5. The Air Force data showed the largest average difference, 80% of the maximum difference, while CROP in the west was next highest at 62%. The CMB problems of clouds and mountains ranged from 56 to 58%. We then calculated the area of the average difference by multiplying the average percent by the area of the maximum difference, which is also shown in the table. After computing the average area difference for each category, the Air Force displayed the highest

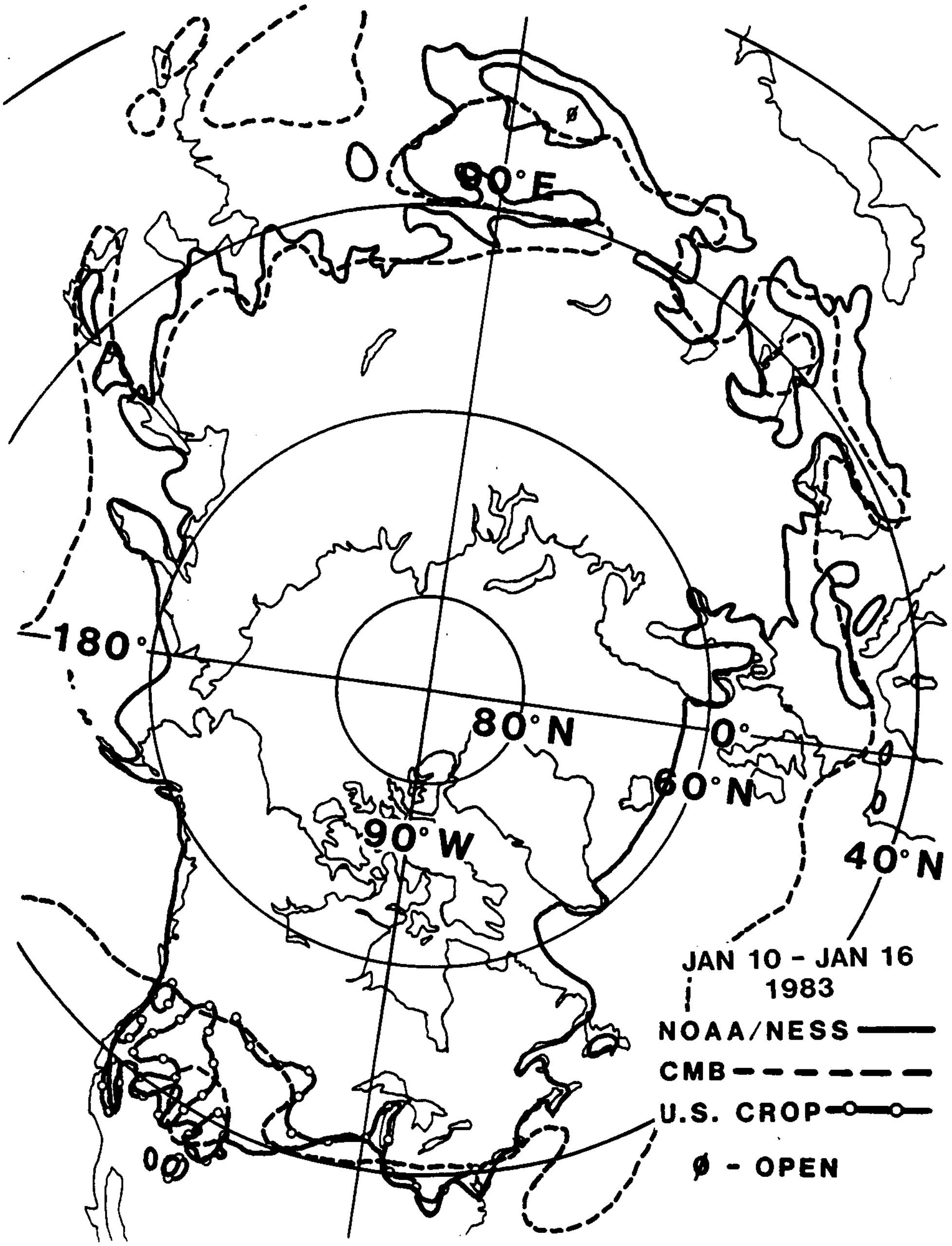

FIG. 9. Weekly Comparison Map for 10–16 January 1983.

value at 8.8 × 10^6 km^2 while cloud problems 1 and 2 followed at 5.1 and 2.5 × 10^6 km^2, respectively. If we add up the CMB average area differences (categories 1–5), the CMB area is larger than the Air Force area (10 and 8.8 million km^2, respectively.)

4. Conclusions

Up until the 1960s, the only source of snow cover data was obtained through point observations located primarily in the midlatitudes. With the development of satellite-derived snow cover data, instantaneous observation over extensive areas provides coverage for remote areas where no ground observations are present. Two satellite products, the NOAA and CMB charts, formulate the main course of study in this project.

Several differences arose between CMB and NOAA in analyzing two consecutive years of data. On many occasions, the CMB snow boundary stretched farther

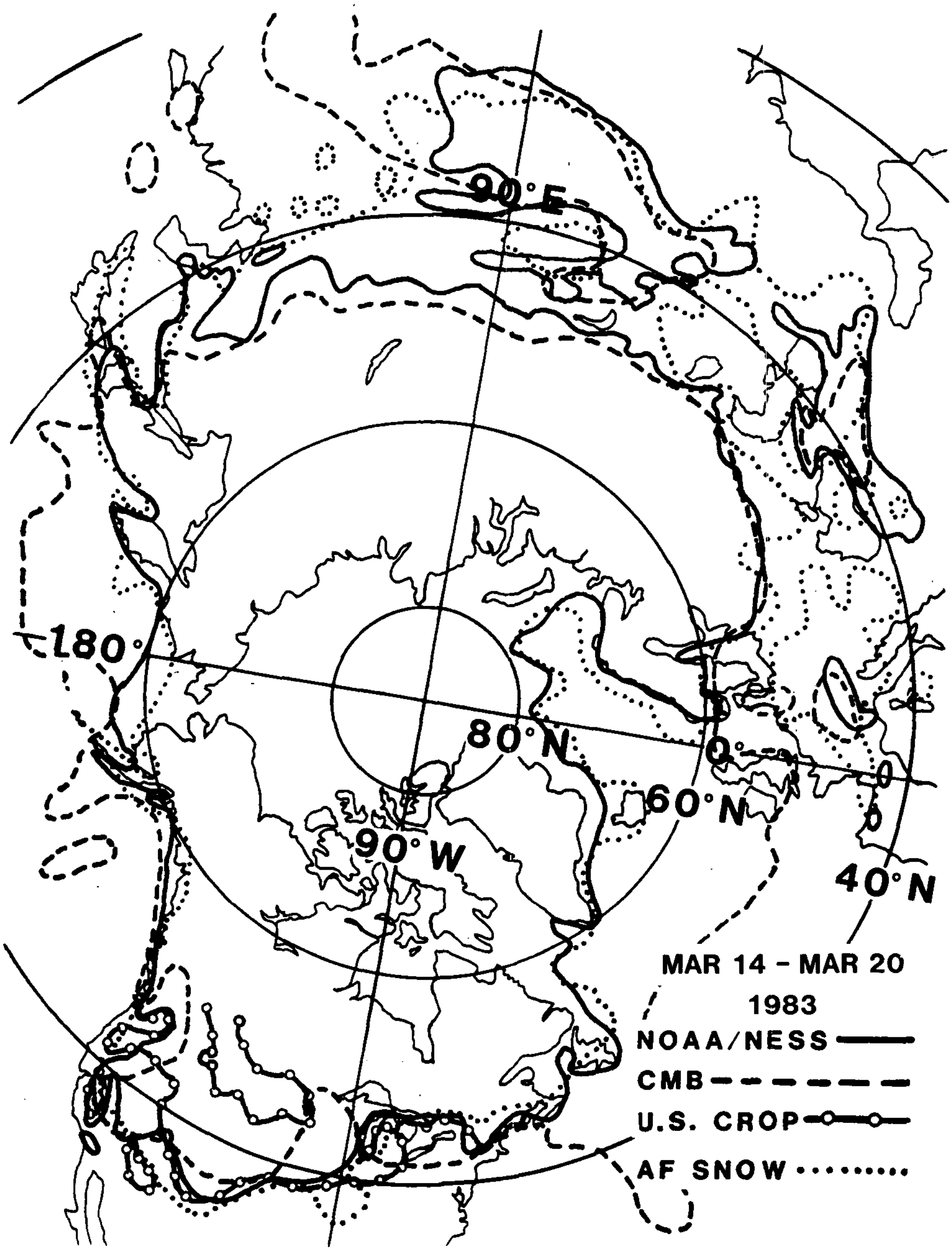

FIG. 10. Weekly Comparison Map for 14–20 March 1983.

south than the NOAA snow boundary, leading us to interpret this as persistent cloudiness. This condition had also occurred quite often far from the snow boundary. Snow cover in mountainous regions throughout the Northern Hemisphere went undetected or partially detected many times, while forested regions caused underestimation by the CMB. Due to the nature of their techniques, the CMB occasionally showed less snow cover than NOAA. The CROP and NOAA data sets showed significant differences which should be expected since CROP does not use satellite imagery. The AF overestimated snow cover like the CMB, but did, however, reveal the probable sea ice/open water delineation in the Arctic during the winter months, due to the inclusion of supplementary data.

For research purposes, we can recommend only the weekly NOAA data set for a consistent indication of snow cover on a hemispheric scale. Although this data set also has its problems, including effects of persistent cloudiness, forests and broken satellites (and hence

TABLE 1. Area difference for NOAA vs other data sets. values: 0—No difference, 5—Maximum difference (each category is rated separately); CMB(1): persistent clouds obstructing the main snow boundary; CMB(2): persistent clouds far from the main snow boundary; CMB(3): inconsistent detection in mountain regions; CMB(4): underestimation in forested landscapes; CMB(5): underestimation due to NOAA's end of the week bias; CROP(East): NOAA vs CROP agreement east of the Rockies; CROP(West): NOAA vs CROP agreement in the west; AF: Overestimation of AF vs NOAA.

	CMB					CROP		
Date	1	2	3	4	5	East	West	AF
			1981					
6–12 July	3	2	3	3	2			4
13–19 July	3	0	2	3	2			
20–26 July	1	2	4	3	1			
27 July–2 Aug	2	2	4	3	2			
3–9 Aug			Missing					
10–16 Aug	2	2	4	3	2			
17–23 Aug	3	3	4	3	1			4
24–30 Aug	4	2	3	2	1			
31 Aug–6 Sept	4	3	2	2	0			
7–13 Sept	4	3	2	5	1			4
14–20 Sept	5	3	2	1	1			
21–27 Sept	5	4	3	1	0			
28 Sept–4 Oct	5	4	3	1	1			
5–11 Oct	4	3	2	1	0			5
12–18 Oct	4	3	3	2	0			
19–25 Oct	3	3	3	3	2			
26 Oct–1 Nov	4	2	4	2	2			
2–8 Nov	4	1	5	2	2			5
9–15 Nov	3	1	3	2	2			
16–22 Nov	3	1	2	3	2			
23–29 Nov	4	2	3	3	3			
30 Nov–6 Dec	3	2	3	2	2	2	3	
7–13 Dec	2	1	4	3	3	1	3	3
14–20 Dec	3	2	2	2	2	1	3	
21–27 Dec	2	1	2	2	3	2	2	
			1982					
28 Dec–3 Jan			Missing			3	2	
4–10 Jan	2	1	2	1	3	2	2	
11–17 Jan	2	0	2	2	2	2	3	3
18–24 Jan	2	1	2	2	4	1	4	
25–31 Jan	2	1	3	2	2	2	3	
1–7 Feb	2	1	2	3	2	2	2	
8–14 Feb	2	2	2	2	2	5	4	3
15–21 Feb	3	1	2	2	3	3	3	
22–28 Feb	2	1	2	2	3	2	4	
1–7 Mar	2	1	2	2	3	4	3	
8–14 Mar	2	1	3	2	2	3	5	4
15–21 Mar	2	1	3	2	3	3	4	
22–28 Mar	2	0	2	2	2	2	3	
29 Mar–4 Apr	2	1	3	2	2			
5–11 Apr	2	1	3	4	3			
12–18 Apr	2	2	3	3	3			
19–25 Apr	2	2	3	3	4			5
26 Apr–2 May	1	0	3	3	2			
3–9 May	1	0	3	2	1			
10–16 May	1	3	3	2	2			4
17–23 May	1	4	3	2	1			4
24–30 May	1	2	2	3	0			
31 May–6 Jun	2	2	3	3	2			
7–13 Jun	1	3	2	2	4			
14–20 Jun	1	4	3	2	2			5
21–27 Jun			Missing					
28 Jun–4 July	1	5	4	1	1			
5–11 July	2	4	2	1	2			
12–18 July	2	5	3	1	2			
19–25 July			Missing					
26 July–1 Aug	2	1	2	2	1			4
2–8 Aug	2	5	3	1	2			
9–15 Aug	2	5	3	1	2			
16–22 Aug	4	5	3	1	1			
23–29 Aug	3	5	2	1	3			
30 Aug–5 Sept			Missing					
6–12 Sept	4	5	2	2	1			
13–19 Sept	3	4	4	2	3			
20–26 Sept			Missing					
27 Sept–3 Oct	4	4	3	3	2			
4–10 Oct	4	5	4	3	1			
11–17 Oct	3	5	4	2	2			
18–24 Oct	5	5	4	2	3			
25–31 Oct	3	5	3	2	3			
1–7 Nov	4	5	4	2	3			
8–14 Nov	3	5	2	2	2			
15–21 Nov	4	4	5	3	3			5
22–28 Nov	4	2	3	1	2			
28 Nov–5 Dec	3	3	3	1	2			3
6–12 Dec	5	3	3	2	3	5	3	
13–19 Dec	5	3	3	2	2	3	4	4
20–26 Dec	4	0	2	1	3	2	1	
			1983					
27 Dec–2 Jan	4	2	2	1	1	2	2	
3–9 Jan	4	3	2	1	1	2	3	4
10–16 Jan	5	4	3	1	3	5	3	
17–23 Jan	3	0	2	1	2	2	2	
24–30 Jan	5	1	3	2	2	3	3	3
31 Jan–6 Feb	4	0	3	1	2	3	4	
7–13 Feb	4	2	4	2	3	1	3	
14–20 Feb	3	1	2	1	3	1	3	
21–27 Feb	5	1	4	2	3	3	3	3
28 Feb–6 Mar	3	2	3	1	2	2	3	
7–13 Mar	3	3	4	3	2	3	4	
14–20 Mar	4	3	3	2	2	2	4	3
21–27 Mar	4	2	2	2	3	3	3	
28 Mar–3 Apr	3	2	3	1	2			
4–10 Apr	5	3	3	2	2			4
11–17 Apr	2	5	3	2	1			
18–24 Apr	3	5	4	4	2			
25 Apr–1 May	2	5	4	3	1			
2–8 May	2	4	3	3	3			
9–15 May	5	4	4	4	2			5
16–22 May	4	4	3	4	2			
23–29 May	2	5	4	4	2			
30 May–5 Jun	3	4	3	2	2			
6–12 Jun	2	5	3	2	3			
13–19 Jun	2	5	4	4	3			5
20–26 Jun	2	5	3	4	4			
27 Jun–3 July	2	5	3	3	2			
4–10 July	2	4	3	3	2			5
11–17 July	1	5	3	3	2			
18–24 July	2	5	2	3	2			
25–31 July	2	5	3	3	2			
Avg diff	2.9	2.8	2.9	2.2	2.1	2.5	3.1	4.0
Avg diff (%)[†]	58	56	58	44	42	50	62	80
Area of level 5 diff ($\times 10^6$ km^2)	8.8	4.4	1.1	3.3	0.55	1.1*	0.55*	11
Avg diff ($\times 10^6$ km^2)	5.1	2.5	0.64	1.5	0.23	0.55	0.34	8.8

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* Differences are zero in Eurasia because data set only covers North America.

[†] Maximum observed difference.

missing data), it is still—by far—the best source. The CMB process introduces too many errors to be used without additional information from surface observations or human interpretation of individual high-resolution imagery. The CROP data set does provide accurate coverage in regions with a dense surface observing network and without mountains. The AF data set, although daily incorporating large amounts of surface data, is an undocumented operational product. It contains large errors and is unsuitable for research purposes.

The ideal snow cover data set of the future will include the best aspects of each of the current data sets. Surface observations will supplement satellite images with the CMB technique perhaps helping to remove clouds. New technologies, including near-infrared snow detection channels on future DMSP and NOAA satellites and microwave techniques (Robinson et al., 1984), also show promise in producing better snow cover data sets.

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