BIOGRAPHICAL SKETCH

DONALD R. BAKER: Water Resources Coordinator for Department of Commerce, Plans and Programs of the National Oceanic and Atmospheric Administration (NOAA). BS degree in Engineering Physics, University of Kansas (1948); MS degree in Hydrology, Stanford University (1968). Professional Member of Americal Meteorological Society and Member of American Geophysical Union. Weather Forecaster, U.S. Air Force (1943-46); Weather Forecaster, U.S. Weather Bureau (1949-52); Research Hydrologist, U.S. Weather Bureau (1952-55); Asst. Chief, Hydrologic Research Branch, U.S. Weather Bureau (1955-68); Liaison from Weather Bureau to Environmental Sciences Group (ESG) (1968-70); Water Resources Coordinator for Dept. of Commerce (1970-present). Mr. Baker, currently an administrator, was a part of a research team (ESG) which developed applications of environmental satellite data to hydrologic problems. He has published numerous papers in scientific journals and Government reports.

REMOTE SENSING OF SNOW FIELDS FROM EARTH SATELLITES

by Donald R. Baker
National Oceanic and Atmospheric Administration, U.S. Department of Commerce

1. Introduction

Large scale mapping of certain hydrologic parameters has economic and scientific importance to the social welfare of mankind. For example, a large proportion of the water necessary for man's water supply, power generation, and inland waterways for transportation comes from snow and ice fields. Comprehensive or repetitive survey of this and other hydrologic parameters over large areas and on a timely basis has been impractical and too expensive by conventional ground-based or airborne stations and vehicles. Given the appropriate sensors and data relay equipment, polar-orbiting and geosynchronous satellites can provide a practical means of securing and relaying such useful information to local users or to data processing and product distribution centers.

Before satellite information can be useful to hydrologists, techniques must be developed to put the data in a form suitable for hydrologic applications. Data used in developing these techniques are from NOAA's environmental satellites and National Aeronautics and Space Administration (NASA) technological satellites. In addition to the unmanned satellites' data, photographs from NASA's manned satellites, such as the Apollo 9 S-065 experiment, have been studied for familiarization with data comparable, in resolution and wavelength, to that expected from future Earth Resources Survey (ERS) satellites. The techniques discussed here are those for delineating snow fields. Essentially only two techniques will be described. First, one based on photographic interpretation; and second, an attempt to automate this delineation of snow fields by data digitization and computer processing and redisplay.

2. Satellites and Sensors

Orbits and altitudes are important characteristics of satellites, for it is these characteristics along with those of the sensors that largely determine the resolution and areal coverage of the data. For a single satellite, a polar orbit permits global coverage twice a day provided that the sensor's field of view allows overlap on adjacent orbits. With an Earth-synchronous orbit, a satellite can continuously monitor over one quarter of the Earth provided the sensor has both daytime and nighttime sensing capability. A brief resume of orbit characteristics of those satellites pertinent to this paper are listed in Table 1.

TABLE 1

Satellite	Orbit	Altitude
ESSA and ITOS	Near-Polar Sun-Synchronous	1,460 km
Nimbus	Near-Polar Sun-Synchronous	1,110 km
ATS	Equatorial Earth-Synchronous	35,800 km

ESSA - Environmental Survey Satellite
ITOS - Improved TIROS Operational Satellite
ATS - Applications Technology Satellite

Sensor's field of view or areal coverage, wavelength it senses, its resolution, and the method of readout are important characteristics in determining the type and amount of data that will be obtained for analysis. The first four sensors described in Table II are carried on the near-polar-orbiting satellites and the fifth sensor is a type used on geosynchronous satellites.

TABLE II

Sensor	Wavelength	Resolution (Nominal)	Areal Coverage	Remarks
AVCS	0.45-0.65 μm	3.7 km	3150 x 2410 km	Central readout, global coverage, daytime only, daily coverage.
APT	0.45-0.65 μm	3.7 km	3260 x 3260 km	Local readout, daytime only, daily coverage.
SR	0.52-0.73 μm 10.5-12.5 μm	3.7 km 7.4 km	Continuous strip about 3200 km wide	Central and local readout, global coverage, daytime and nighttime, daily coverage.
IDCS	0.45-0.65 μm	3.7 km	2600 x 2600 km	Local readout, daytime only, daily coverage.
SSCC	0.38-0.48 μm 0.48-0.58 μm 0.55-0.63 μm	3.7 km	13,000 km diameter	Central readout, daytime only.

AVCS - Advanced Vidicon Camera System
APT - Automatic Picture Transmission
SR - Scanning Radiometer, 2 channel
IDCS - Image Dissector Camera System
SSCC - Spin Scan Cloud Camera

3. Data and Data Handling

The details of the digitizing and computer processing of NOAA's television data have been given elsewhere, so only a brief description is given here. A sensor's signal is converted from analog to digital form and then processed in a computer so that each frame is annotated for such things as time, location, satellite, and date. Frames of data are cropped and mosaiced within the computer with each datum point representing an area of approximately 5 km on a side. Each point within the digitized mosaic gives a measure of the brightness of the Earth's background, including clouds, on an integral scale of 0 to 14. The original brightness values are for variations in response of the camera system and inequalities in solar illumination. The mosaics are mapped onto polar-stereographic and Mercator map projections.

4. Snow Field Delineation

There are two approaches to snow field delineation used today in the United States. The first of these is the viewing of individual frames or a daily mosaic of digitized data. These data are displayed on a cathode ray tube device and then photographed to maintain the 15 brightness levels to which they are displayed. Reliable identification of snow cover can be made by use of photo-interpretation techniques that include the following: 1) reference to concurrent cloud observations; 2) recognition of terrestrial features; 3) pattern stability (from day to day); and 4) pattern appearance.

An example of this photo-interpretative technique can be given using figures 1 and 2 (ESSA-9 digitized mosaics of 8 and 10 March 1970). In order to demonstrate the method, nine areas will be referred to:

1. The ice lead in Hudson Bay.
2. White Sands area in New Mexico.
3. Dendritic pattern of the snow in the Canadian and United States Rocky Mountains.
4. White area located where the Sierra Nevada should be.
5. Dark area to the north of the Great Lakes and which extends to the northwest.
6. Ice and snow covered Lakes Winnepeg and Nipigon.
7. The snow line in Northcentral United States.
8. The Great Lakes.
9. Clouds over Southern United States.

Indication of little or no clouds interfering with the view can be gained from topographical or pattern recognition of such features as 1 through 8. In photo-interpretation, knowledge of an area is an important asset. For example, the dark appearing area to the north of the Great Lakes and extending to the northwest is not an area of less snow depth, but an area of relatively dense stands of coniferous trees, which results in the darker tone. In figure 2 some of the features listed above are partially or completely blocked from view by clouds. The ice lead in Hudson Bay is not as discernible as before. The streakiness over this area is quite typical of the appearance of clouds over snow fields. In this figure, White Sands, New Mexico, is not apparent because of clouds in the area. Also because of cloud cover the appearance of the snow fields in the Midwest has changed and the Sierra Nevada snow fields are not visible. After determining which areas are clear of clouds, the snow fields can be delineated by hand compositing the snow line from several of these daily photographs into a snow map.

A second approach to snow line delineation is a technique designed to automatically screen out most clouds. Since the satellite data can be presented digitally, the data can be manipulated within a computer. Knowing that the clouds are generally transitory relative to snow cover, it has been shown that a multi-day compositing of minimum brightness (CMB) from digitized ESSA satellite data has a fair-to-good success in filtering cloud or differentiating the snow cover from the more time-dependent cloud cover. These CMB charts are composited over a selected period of days by saving only the minimum brightness observed for a given array point during the compositing period. The resulting

CMB chart is displayed in 15 brightness levels on a cathode ray film device or in the form of a computer printout in rectified form. Latitude and longitude, as well as geographic and political boundaries, are added electronically during the processing (see figure 3).

Clouds, which are often comparable in brightness to snow and ice, are retained in the CMB chart only when they are present in a given area (i.e., over a particular array point) everyday of the compositing period.

The positioning of snow lines derived from CMB charts has been verified by comparing with snow lines derived from ground observations. The verification showed that this method is very effective for the Great Plains and relatively unforested areas in the Midwest, but rather less so in areas of heavy, coniferous forest.

Figure 3 is a five-day composite of minimum brightness. It includes the data that are presented in figures 1 and 2. Note the ice lead in Hudson Bay, the ice-covered lakes of Winnipeg and Nipigon, the appearance of White Sands, and the disappearance of the bright areas (clouds) in Florida (figure 1) and Texas (figure 2). These are all indications of the ability of the CMB technique to filter clouds from the scene. Further confirmation of cloud filtering is the appearance of the Sierra Nevada snow fields in the CMB. The bright areas in Canada and the United States are snow fields, and it is relatively simple to determine their areal coverage as part of the computer processing.

Preliminary studies leading to computer evaluation of the fraction of the basin covered by snow have been made in the Western Mountain States. To evaluate how well one might expect to do, a comparison was made between satellite photography and aerial survey data. The percentage of basin covered was evaluated by planimetering aerial values of snow cover. Also, percentages of snow cover were computed using maximum resolution of ESSA photographs. When the two percentages of basin covered were compared for several basins in the Southern Sierras, they differed by 5 percent or less. The mean difference in snow line elevation computed from the corresponding satellite and aerial survey for one specific (but typical) basin was about 150 meters. Where snow mapping by satellite is more difficult because of more forest area, narrower basins, and more cloud cover (for example in the Upper Columbia River Basin), the results were not as good. Nevertheless, for several test basins the mean difference in snow line evaluation from satellite data and that measured by aerial survey was less than 300 meters. The snow line was consistently estimated from satellite to be higher than aerial survey measurements, probably due to the effects of dense forests.

5. Future Satellite Data

Whereas the snow field evaluations discussed above were made using 3 to 5 km resolution data, there are future satellites (by 1972) that will have sensors capable of 1.5 km to 100 meter resolution. In anticipation of this type of data, photographs with comparable resolution and spectral bandwidths to that expected on future satellites were obtained from the S-065 experiment on Apollo 9. Figure 4 is such a photograph; it shows the snow cover on the Mogollon Rim north of Globe, Arizona. The wavelength interval is from 0.59 μm to 0.72 μm, and the ground resolution is approximately 100 meters. The picture presents an area of approximately 285 km on a side. A comparison of this photograph with others taken of the same area at the same time, but with different spectral intervals, indicates only a slight preference of one spectral bandwidth over another for snow line delineation.

From the detail of the snow line seen in figure 4, it is apparent that snow line mapping from ERS satellites will be more comparable to that now done from aerial observations. Furthermore, identification of small clouds over snow field may be done more readily by identifying shadow of clouds. See shadow of small clouds toward lower right corner of figure 4.

6. Concluding Remarks

Considerable effort has gone into snow line delineation using available satellite data. Furthermore, increasing emphasis is being put on automated extraction of such information and generation of a useable product for hydrologists. Although nothing has been said, the implications are clear that the impact from future satellite and sensor systems will create an increased demand for computer processing before the data can be used by the hydrologist. If the coarse-resolution, broad spectral band data available from current satellites already create a demand by hydrologists for computer processing of the data, it is obvious there will be an even greater demand for computer analysis and evaluation when the future ERS data represented by figure 4 become available.

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GLOSSARY

APT: Short name for Automatic Picture Transmission. Certain satellites of the TIROS and Nimbus series have had special camera and transmitter equipment such that television pictures and radiometer data taken while the satellite is within range of a station on Earth's surface can be received and displayed on relatively simple and inexpensive equipment.

Compositing: Here it refers to the use of data taken over the same region but at different times.

Digitization: The process whereby a continuous analog signal received from the satellite is converted to discrete numerical values.

Earth synchronous: An Earth satellite orbit in which the orbital plane is equatorial and the altitude (35,800 km) such that the velocity of the satellite just matches that of Earth's surface vertically below.

ESSA photograph: Television image from one of the Environmental Survey Satellites, an operational satellite of the TIROS series.

Geosynchronous: Same as Earth synchronous.

Mosaic: Rectified imagery covering a large area that is constructed from single frames taken at intervals throughout a 24-hour period.

NOAA: National Oceanic and Atmospheric Administration (formerly ESSA), an agency of the U.S. Department of Commerce, which operates the National Environmental Satellite Service.

Planimetering: A technique for determining the areal extent of a quantity or parameter whose distribution is in mapped form.

Rectified data: Satellite imagery or scanner measurements that have been mapped onto some standard map projection for Earth's surface, such as Mercator or polar stereographic.

Resolution: This term usually means "spatial resolution" or "ground resolution." It refers in simplest terms to the smallest detail detectible in satellite imagery of clouds or Earth's surface when there is reasonably good contrast between the target(s) and its background.

Spectral interval (or bandwidth): The width, generally expressed in micrometers (10^{-4} cm), of a particular portion of the electromagnetic spectrum a given sensor (e.g. radiometer detector or camera film) is designed to measure or be sensitive to energy received at the satellite from that part of the spectrum.

Sun synchronous: An Earth satellite orbit in which the orbital plane is near polar and the altitude such that the satellite passes over all places on Earth having the same latitude twice daily at the same sun time.

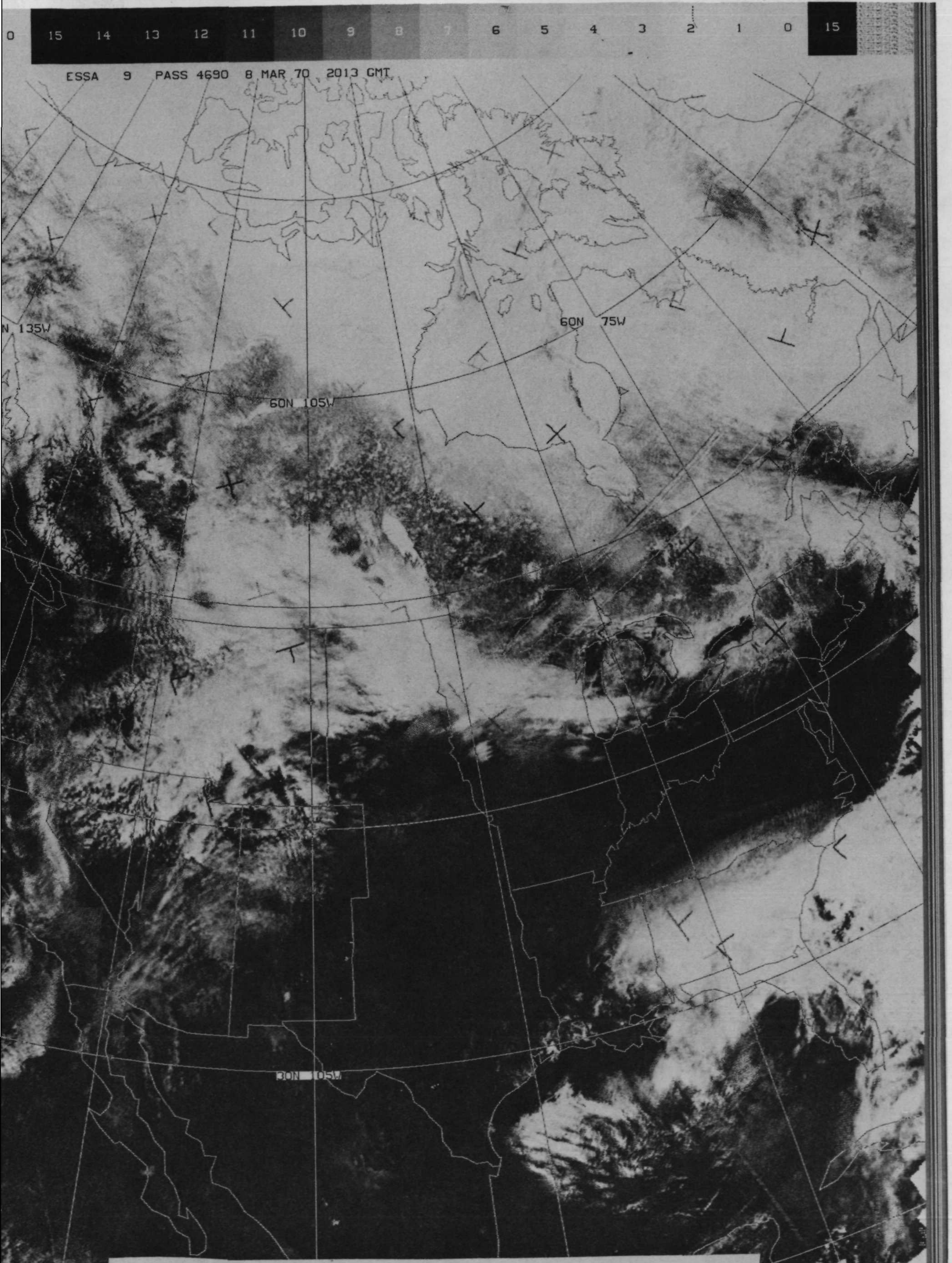

Figure 1.--ESSA-9, Digitized Mosaic for 8 March 1970.

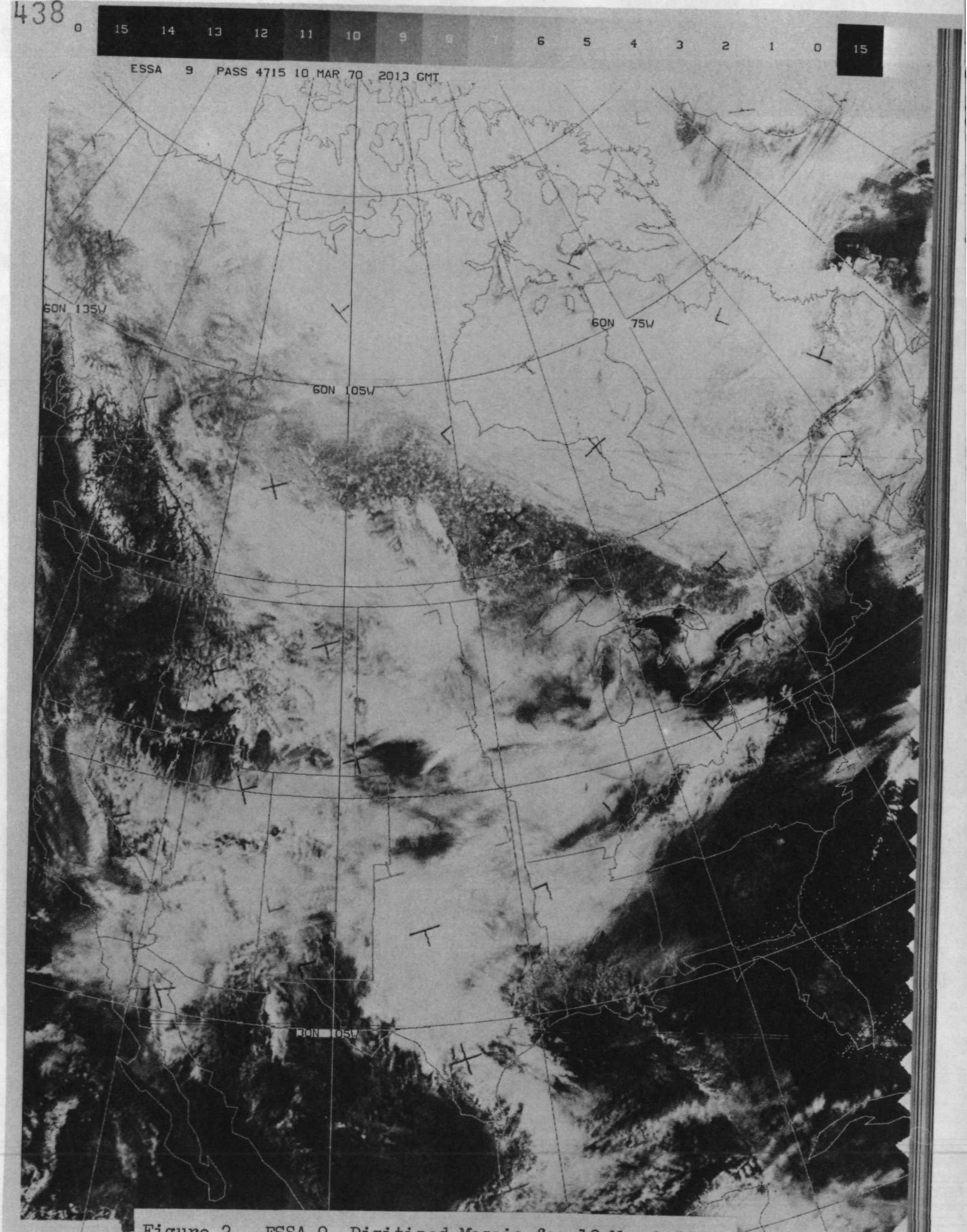

Figure 2.--ESSA-9, Digitized Mosaic for 10 March 1970.

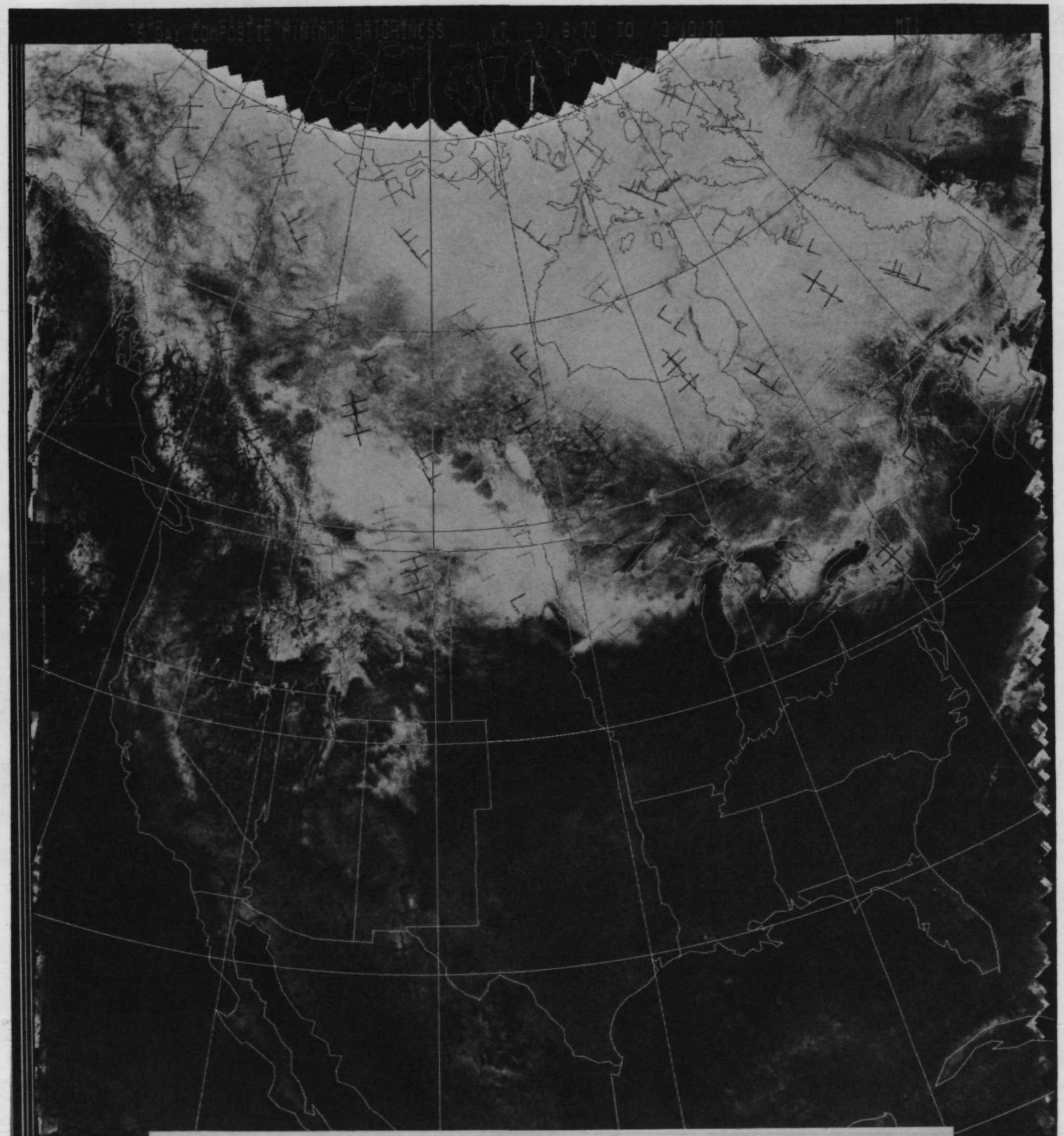

Figure 3.--5-day Composite Minimum Brightness (CMB) Chart for 6 March to 10 March 1970.

Figure 4.--Apollo 9, S-065 Photograph--12 March 1969.