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Problem: how to process 250 million bits of information for each Nimbus pass and then distribute data to weather centers within 105 min

Nimbus data in operational meteorology

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The use of satellite data in operational weather analysis and forecasting in the near future will be based primarily on current applications and the results of research now in progress, as discussed by Jones and Mace on page 32 and Fritz on page 70. The operational value of satellite observations will be enhanced substantially when data from the entire earth become available on a routine basis. The need for regular observational coverage at frequent intervals cannot be overemphasized.

Progress is being made in inferring positions of the jet stream, streamline patterns, convergence zones, and positions of storms and fronts from satellite cloud pictures. This information will have direct applicability to hemispheric analyses produced by the National Meteorological Center (NMC) of the Weather Bureau, particularly over the vast areas of the earth where few conventional observations are now available. Techniques are being investigated whereby satellite cloud and radiation observations can be incorporated into numerical analysis and prediction schemes. Less than 20% of the earth's atmosphere is adequately observed by conventional techniques. The satellite offers a means of filling these great data voids.

The ability of weather satellites to identify and track storms, including devastating hurricanes and typhoons, has been amply demonstrated by the Tiros series. As a result, Congress has appropriated funds to the Weather Bureau to establish and operate the National Operational Meteorological Satellite System (NOMSS) to provide worldwide observations on a regular basis. When this system becomes operational, storm detection and tracking can be performed on a regular basis for the entire globe to the benefit of all mankind. Detailed investigations of severe storms, moreover, can be performed by reconnaissance aircraft guided by these satellite observations.

Variations in the atmospheric heat budget as a function of space and time can be measured for the first time over the entire earth by satellite-borne radiometers. Preliminary research results indicate that these data are correlated with the large-scale, general circulation of the atmosphere and the important energy movements and transformations which govern our weather.[1] This work holds considerable promise of improving long-range forecasting. The determination of atmospheric heat sources and sinks, another important consideration in extended forecasting, will be aided by satellite measurements of surface characteristics, including ice- and snow-covered areas and surface temperatures on a global basis.

Many types of atmospheric phenomena, structure, and thermodynamics appear to be associated with specific cloud types and patterns as seen in satellite pictures. Based on the many research studies conducted during the past three years, work is now underway to catalog classes of satellite cloud images in terms of the atmospheric conditions in each class.

The uses of meteorological satellite data beyond the next few years will expand with available new types of measurements[2-7] and increased understanding of atmospheric processes.

The plan for a National Operational Meteorological Satellite System (NOMSS) is based on the use of the Nimbus satellite now under development by NASA Goddard Space Flight Center (GSFC) (see page 42). With one Nimbus satellite in operation, every point on the earth's surface will be observed twice a day, once in daylight and once at night. This will represent a significant advance over Tiros in observational coverage. The Tiros satellite can observe only about 18% of the earth on any one day, and the area viewed changes constantly from day to day. A fully operational system must provide global observations on a regular basis.

The development of NOMSS is guided by the requirements for meteorological data in satisfaction of the needs of civil and military organizations. The table on page 53 presents a summary of the current requirements. While the early version of NOMSS will not satisfy all these requirements, research and development now in progress and planned for the future will attempt to improve the system to fulfill as many of these requirements as possible. This may necessitate development of additional types of spacecraft (see page 57).

The major elements of NOMSS will

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REQUIREMENTS FOR METEOROLOGICAL OBSERVATIONS

(a) For broadscale (hemispheric) analysis

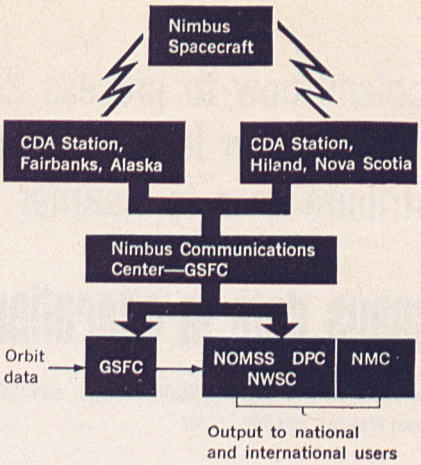
Observation[a]	Resolution: Horizontal D	Resolution: Horizontal A	Resolution: Vertical D	Resolution: Vertical A	Accuracy D	Accuracy A	Observation Frequency D	Observation Frequency A
Cloud cover	½ mi.	3 mi.	1000 ft	5000 ft	—	—	4/day	1/day
Surface temp.	4 mi.²	30 mi.²	—	—	<1 C	<3 C	4/day	1/day
Atmospheric temp.	4 mi.²	30 mi.²	<500 ft	<2500 ft	<1 C	<5 C	2/day	1/day
Atmospheric moisture	4 mi.²	30 mi.²	<500 ft	<2500 ft	<10%	<20%[b]	2/day	1/day
Density	4 mi.²	30 mi.²	<500 ft	<2500 ft	<1%	<1%	2/day	1/day
Atmospheric heat bal.	30 mi.²	30 mi.²	—	—	<5%	<20%	2/day	1/day
Precipitation	4 mi.²	30 mi.²	<1000 ft	<5000 ft	0.1 in./hr.	0.2 in./hr	—	—
Winds	100 mi.²	1000 mi.²	<2000 ft	<5000 ft	<5 kt	<15 kt	4/day	1/day
Surface pressure	30 mi.²	500 mi.²	—	—	<1 mb	<5 mb	2/day	1/day

(b) For mesoscale (regional) analysis

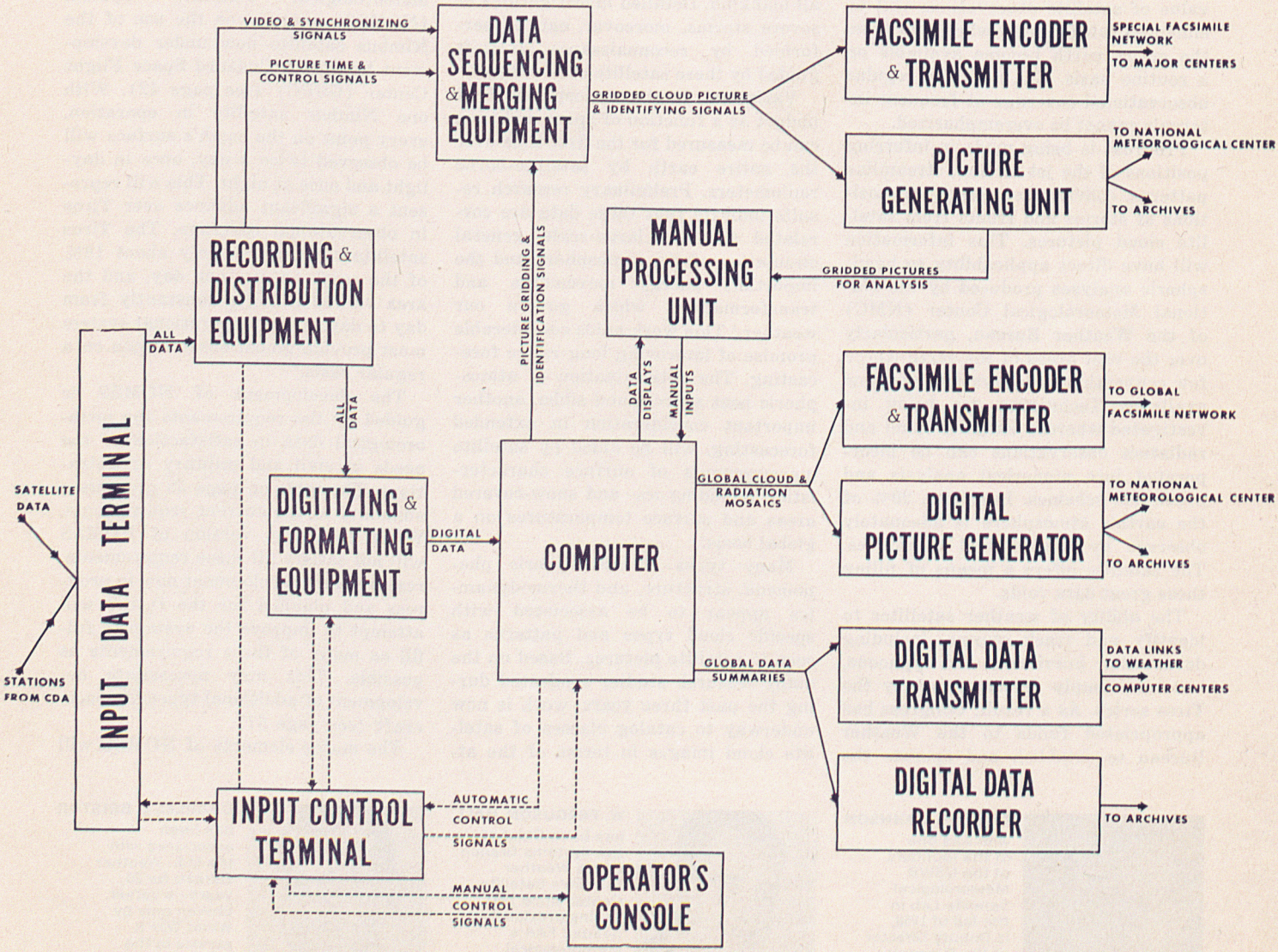
Observation	Horizontal D	Horizontal A	Vertical D	Vertical A	Accuracy D	Accuracy A	Observation Frequency D	Observation Frequency A
Cloud cover	0.1 mi.	0.5 mi	100 ft	1000 ft	—	—	1/hr	2/day
Surface temp.	1 mi.²	4 mi.²	—	—	<½ C	<1 C	1/hr	2/day
Atmospheric temp.	1 mi.²	4 mi.²	<200 ft	<500 ft	<½ C	<1 C	1/hr	2/day
Atmospheric moisture	1 mi.²	4 mi.²	<200 ft	<500 ft	5%	10%[b]	1/hr	2/day
Precipitation	1 mi.²	4 mi.²	<500 ft	<1000 ft	0.1 in./hr	0.1 in./hr	—	—
Surface pressure	4 mi.²	30 mi.²	—	—	<0.5 mb	<1 mb	1/hr	2/day

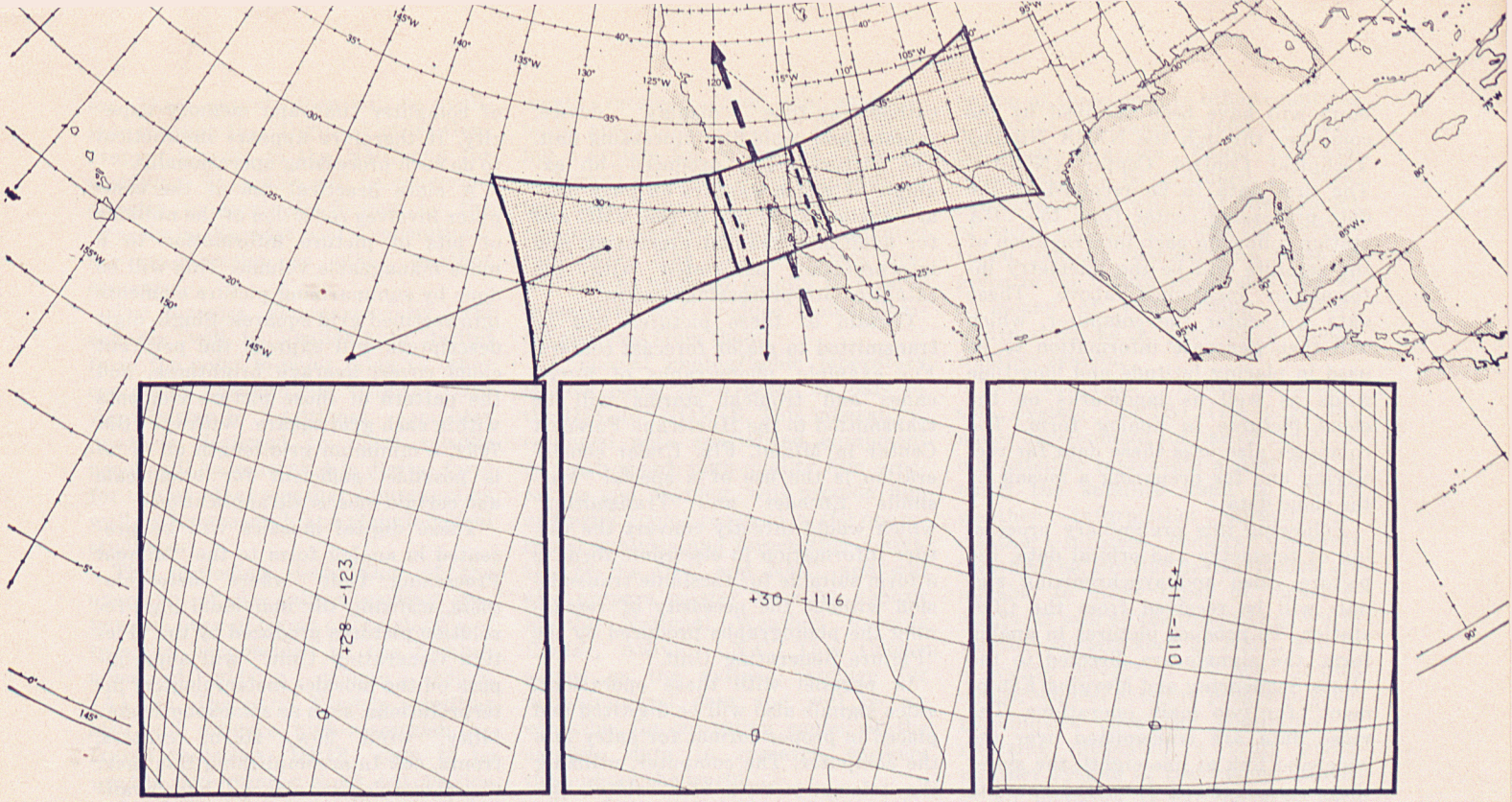
[a] D=desirable; A=acceptable.
[b] Relative humidity.

NIMBUS DATA FLOW



NOMSS DATA PROCESSING SYSTEM





Nimbus AVCS (Three Camera) Coverage, showing typical mapping of one picture set and, in bottom boxes, corresponding computer-generated latitude and longitude grids. These grids will be merged with the cloud pictures automatically in the NOMSS Data Processing Center.

be the spacecraft (and launch vehicles), data acquisition, engineering monitoring and control, meteorological data processing, and data dissemination, the latter described by the flow chart on page 53. What follows concerns NOMSS data processing and data dissemination.

Two principal command and data acquisition (CDA) stations, located at Fairbanks, Alaska, and Hiland, Nova Scotia, will be used to acquire data from the Nimbus satellite. When Nimbus is launched in a 750-n.mi. orbit, as ultimately planned, these two stations will acquire data from all orbits. Communication channels with bandwidths of 96 kc/s will be used to transmit the data to Washington, D.C., for further processing for meteorological purposes at the National Weather Satellite Center (NWSC) as well as for engineering evaluation and monitoring at GSFC.

Approximately one-quarter billion bits of meteorological data will be obtained from each orbit of the early Nimbus satellite. Received at one of the two CDA stations, from a given orbit, these data must be transmitted to Washington, processed, and then disseminated to forecast centers within one orbital period (approximately 105 min) in order for the system to be ready to receive the data from the next orbit. This schedule also is compatible with the needs of meteorology; for operational purposes, the value of weather data rapidly diminishes with time after the observation has been made. The goal in the early phases of NOMSS is to make the processed satellite observations available to the user within 3 hr after the observations have been made. System design is predicated on these requirements.

The NOMSS Data Processing Center (DPC) is being established at NWSC, Suitland, Md. The selection of this site was based on several factors. DPC is being designed to handle data acquired at both CDA stations, so precluding the need for redundant installations at each station; and it is located adjacent to the NMC, where conventional weather observations from all over the world are collected and hemispheric analyses and forecasts are prepared. Both satellite and conventional meteorological observations will thus be available for interpretation and analysis by the two centers on an integrated basis.

DPC design has been based on the use of high-speed computers to obtain maximum flexibility.[8,9] In this manner, just as with the modular design of the Nimbus spacecraft, new types of observational data and new output products can be accommodated with a minimum change in the equipment required for processing. Also, data can be provided in digital form, suitable for use by other weather computers involved in numerical weather analysis and prediction. The basic computer to be used in DPC is an IBM 7094. Smaller computers are used for certain specialized tasks in the system.

The chart on page 53 shows the major elements of the data-processing system. The over-all automatic operation of the center is controlled by the computer through the "Input Control Terminal." Manual over-ride can be initiated from the "Operator's Console." All of the data from the CDA stations required for data processing for meteorological purposes is received through the "Input Data Terminal" via wideband communication links. In addition, satellite ephemeris data will be received from GSFC.

Three general classes of data will be received in the Center from the first Nimbus satellites: (1) Video signals from the advanced vidicon camera system, (2) signals from the high-resolution infrared radiometer (HRIR, a mechanical scanning radiometer operating in a water-vapor "window" to provide night-time cloud-cover information and surface temperatures), and (3) telemetry data required to process and use the meteorological data, such as picture-taking times, attitude error signals, and voltages and temperatures which affect camera and radiometer calibrations. All these data move from the data terminal to the "Recording and Distribution Equipment." The data are also recorded should reruns be necessary.

Cloud-picture information will be processed in both analog and digital form. Before receiving data from a given orbit, the basic orbital param-

eters will have been received by the computer through the NASA Nimbus Technical Control Center (NTCC). The first data to be received at the data-processing center from the CDA station following each interrogation of the satellite will be the telemetry information mentioned above. These data will enter the computer, which will then generate information to be used in placing latitude and longitude grids as well as landmarks on the cloud pictures in analog form. The computer also uses these data for rectifying and for preparing a mosaic of the cloud data.

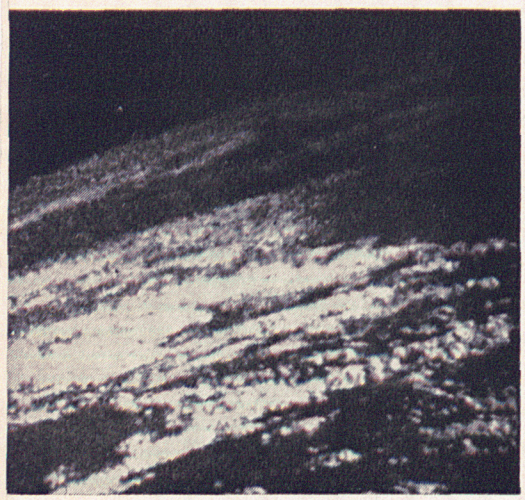
Following this preliminary processing of telemetry and orbital data, the picture video and synchronizing signals will be received from the CDA station. To produce pictures in analog form, the signals are directed to the "Data Sequencing and Merging Equipment" for two main operations. The video data are transmitted over the wideband link at one-eighth the speed they were received from the satellite at the CDA station. In the data-sequencing process, the data rate is returned to normal speed and placed in proper order for display. Secondly, the picture gridding and identification information generated by the computer is merged with the video signals. This combined output is fed to the "Picture Generating Unit," composed of a cathode-ray-tube display device, camera, and rapid film-processing unit. The pictures thus produced—an example of which appears on page 54—are available for use in the NMC and for additional manual processing and interpretation associated with the satellite data-processing system.

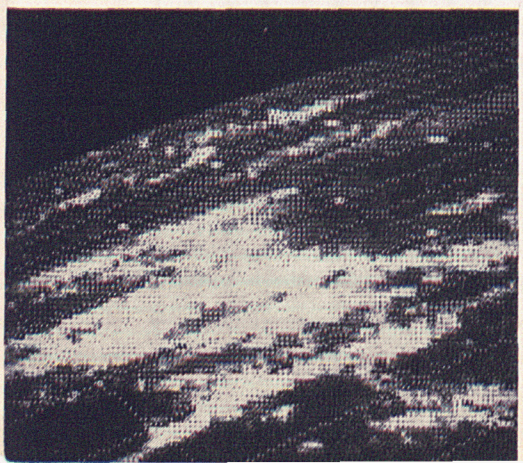
Certain of these pictures will be transmitted to major forecast centers. For example, photographs of hurricanes and tropical storms will be transmitted to the Hurricane Forecast Center in Miami, Fla. Under consideration is the use of a special "Facsimile Encoder and Transmitter" which would directly convert the picture information in electronic form to a form suitable for facsimile transmission without the necessity of rescanning the photographs produced by the "Picture Generating Unit."

In parallel with these operations, video signals also will be digitized and placed in proper format for entry into the computer. The computer, utilizing the telemetry data and orbital elements previously received, will rectify the video data from an entire orbit and produce a mosaic in map form. Experimental results of digitizing and mapping cloud pictures are shown at bottom. Several formats for this type of output are under consideration. Production of full-resolution, rectified photo mosaics is very costly in terms of computer time and memory capacity. It therefore appears impractical to do such processing operationally.

A more practical use of the computer involves reduction of the millions of bits of picture information to a more manageable volume. This will be done by summarizing picture elements into rectified grid squares. Single digit descriptors will express the per cent cloud cover, average brightness, and the pattern of those picture elements within each grid square. With the IBM 7094, a minimum grid length of 15 mi is possible—sufficient for broadscale and certain mesoscale applications.

These digital mosaics will be presented in analog form to the "Manual Processing Unit" where meteorologists, utilizing the individual high-resolution pictures produced by the "Picture Generating Unit," will superimpose on the mosaics meteorological interpretations, such as atmospheric stability, wind flow, storm centers, fronts, etc. In accomplishing this task, the meteorologists also will have available the analyses of conventional meteorological data produced by the NMC. The analyst will utilize projected images with the interpretative information being automatically fed back to the computer during the analysis phase. Thus the final computer output will represent an automatic merging of the computer and manual analy-





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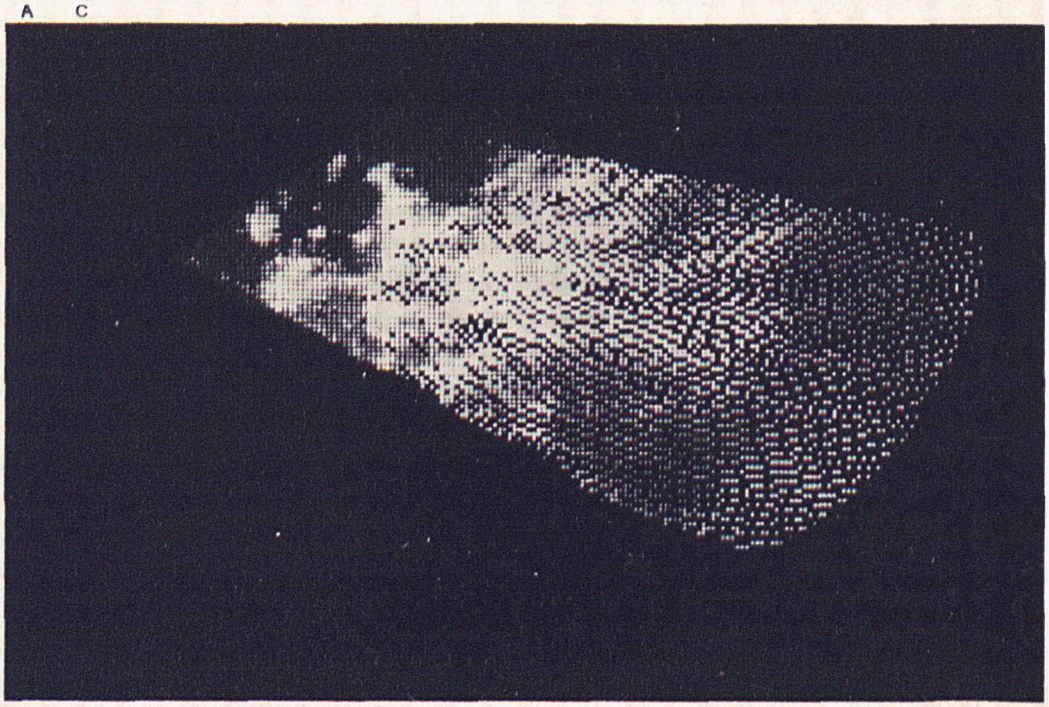

Experimental Digitizing and Mapping of Cloud Pictures.
(A) Copy of original photo taken by a rocket-borne 17-mm camera at an altitude of 85 mi.
(B) 100-scan-line digitization of original picture with superimposed latitude and longitude lines. (C) Same digital information computer rectified to a Mercator map projection. Foreshortening toward the horizon in the original picture results in larger spacing of scan spots in the right-hand portion of picture. To present a more pleasing picture to the eye, filler spots can be added by computer.

ses. These outputs then will be available through the "Digital Picture Generator" for use in the NMC and for archiving. They also will be converted directly to facsimile format by the "Facsimile Encoder and Transmitter" for transmission to other weather centrals.

The mosaics, summarized by grid squares, will be available in digital form for point-to-point relay to other computers through the "Digital Data Transmitter." Additional computer products designed to meet specific needs will be generated in digital form for use by other weather computers as well as for research and climatological studies.

The preceding description of the operation of the data-processing system has been in terms of the cloud pictures to be obtained by the Nimbus advanced vidicon camera system (AVCS). The early Nimbus satellites also will produce high-resolution infrared radiation (HRIR) data to be used in determining cloud distribution and surface temperatures at night. These data will be processed in a manner quite similar to that used for the AVCS data, except for a change in the synchronizing signals and in the amount and type of telemetry data required for location and rectification of the radiometer scans, and in determining the equivalent black-body radiation temperature of the earth's surface in clear areas or of cloud tops in cloudy areas.

The temperature information will be utilized in estimating cloud-top heights and producing surface-temperature maps. The temperature analysis will be performed by the computer utilizing climatological temperature data and current radiosonde observations, and will produce output maps of these parameters as well as superimposing estimated cloud top height information on the cloud mosaics.

The flexibility of the data-processing system provides for the processing of a wide variety of signal formats, both analog and digital. Changes can be accomplished in most cases by altering computer programs and changing settings on the associated auxiliary equipment. For example, the NWSC Meteorological Satellite Laboratory is developing an infrared spectrometer for use on future weather satellites which will produce a series of radiation measurements in the 15-micron carbon dioxide band.[1,10,11] Computer programs have been developed which can be used to determine the vertical profile of temperature beneath the satellite and above about 20,000 ft in the atmosphere from the measurements received from the satellite-borne spectrometer. GSFC is developing a system for future use on meteorological satellites which will digitize the data measured by their multichannel, medium-resolution infrared radiometer. The data-processing system can be adapted readily to receive these data and produce meteorological analyses from them.

A special photographic laboratory is now being constructed as part of the DPC for NOMSS. This laboratory, equipped with specialized equipment for high-speed, high-quality film processing and copying, will provide film and print copies required in the operational analysis and forecasting activities of the DPC and NMC, and will also prepare master films for deposit in the National Weather Records Center, Ashville, N.C. This Center serves as the national archive for meteorological data and will be responsible for providing copies of the satellite data to research workers throughout the world.

Two formats are planned for archival storage of pictures from the Nimbus AVCS. In the microfilm system, all sets of pictures, with superimposed latitude and longitude grids, from one orbit will be contained on a single film sheet. Approximately 10 days of pictures will be stored on each reel of Nimbus archival roll film. In addition to a legible legend for each picture, a machine-readable code block will be included to permit automatic search and retrieval of selected pictures.

Frequent mention has been made of the NMC where hemispheric and North American analyses and prognoses are prepared using both conventional observations and satellite data. These analyses and prognoses are used by military and civil weather centers scattered throughout the hemisphere in producing forecasts for specific applications and areas. With the additional data to be available from NOMSS, serious problems will exist in transmitting rapidly the products from NMC and NWSC to the major forecast centers. Therefore, a systems study is now in progress to develop the design of an optimum communications system whereby this information can be transmitted expeditiously to the forecast centers. Preliminary indications are that 14-kc/s channels will be used between Suitland and the major forecast centers in North America. Narrower bandwidth feeder circuits probably will be used between major forecast centers and local weather stations.

Limitations in conventional communications overseas present a serious obstacle to providing adequate dissemination of these data to other countries as well as U.S. bases beyond the limits of North America. Radio facsimile broadcasts will be continued, but present bandwidths will limit the amount of useful information that can be conveyed. Serious consideration must be given to the future use of satellites as a means of transmitting weather information as a part of a global weather system.

The Automatic Picture Transmission System (APTS) (see page 48) under development for use on the Nimbus satellite represents a first step in using the satellite itself to convey weather information directly to weather forecast centers wherever they may be. Similar developments, applicable to other types of measurements, as well as the products of world weather centers such as NMC, will be a logical extension of the current meteorological satellite program. Such possibilities offer the possibility of realizing ultimately a truly global weather system of tremendous benefit to all mankind. It can be said with certainty that today's evaluation of the future importance of satellites in meteorology will turn out to be vastly underestimated.

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