

McIDAS

An Interim Report on the Development of the
MAN-COMPUTER INTERACTIVE DATA ACCESS SYSTEM

By the

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McIDAS

(MAN-COMPUTER INTERACTIVE DATA ACCESS SYSTEM) *

FOREWORD

At the date of this report, Geostationary Satellite ATS-I has stopped operating just short of its sixth year in orbit, and ATS-III is approaching its fifth year of operation. With these satellites the weather moves—not the spacecraft.

These platforms provide the opportunity to view the weather in the time domain. Despite the opportunity over these years we have been unable to fully exploit this capability. It may come as a surprise that the difficulty is not too little data, but too much! Most of the data are organized in the x-y image plane—not the time dimension. The McIDAS system—which stands for Man-computer Interactive Data Access System—now fills our long-awaited need to be able to treat data in the time domain in a quantitative fashion. This report tells what McIDAS is, how it works and some of its results.

The McIDAS prototype is functioning daily and provides University of Wisconsin meteorologists with quick and easy access to ATS data. Plans for expansion now being implemented will enable the system to efficiently access and process multispectral image data in many different formats from other spacecraft such as SMS, Mariner, Nimbus, ERTS, ITOS and ESSA.

A few of the people involved in building McIDAS have authored portions of this report, but recognition should go to all who had a hand in the development of the successful McIDAS prototype:

Eric Smith and Dennis Phillips—conception and construction of the software which demonstrated the superiority of digital alignment and measuring techniques;
Terry Schwalenberg—design and management of TV storage and display system construction;
Stan Sitts—hardware assembly and testing;
Robert Krauss—management of software development and system integration and editing of this report;
John Benson—systems programming and computer/display interfacing;
J. T. Young—system integration and operation;
Debbie Czerwonka—typing of this manuscript and the many others from this project in the past 18 months;
Thomas Haig—for providing vision and guidance toward a successful project conclusion; and, lastly,
The authorities in NASA and NOAA for the trust and encouragement they have shown in sponsoring our efforts.

Verner E. Suomi
Principal Investigator

*A special joint project report.



1. INTRODUCTION*

A. Basic Principles of McIDAS

The Man-computer Interactive Data Access System (McIDAS) for measuring cloud motion vectors from Applications Technology Satellite spin-scan camera images is the result of a number of parallel efforts undertaken at the University of Wisconsin's Space Science and Engineering Center over the past two years. It was the culmination of over four years of intensive effort to achieve easy access to satellite data in the time domain, the dimension which opens up the earth's atmosphere to observation as a dynamic system rather than a qualitative still photograph. With the completion of a breadboard model of the McIDAS TV display hardware, there now exists a functioning prototype system with demonstrated capability to economically process ATS/SMS satellite image data to obtain cloud motion data in a real time research environment.

Significantly, the data storage, access and display techniques developed at SSEC have applications in many areas of data processing besides cloud motion data for meteorology. An existing problem in many fields is the lack of ability to gain efficient access to the vast quantities of data which have been generated by modern remote sensing instruments. Referencing small subsets of these data in a fast and economical way, with accompanying observation and guidance by a human operator in an interactive mode with the system, is of considerable value. Furthermore, these benefits are not necessarily limited to a small user group. The use of standard TV components within the system assures complete access to the whole spectrum of communications technology developed in the television industry. Thus, the development of McIDAS opens up the possibility of data not only being processed in real time, but disseminated in real time as well to both scientists and the public over already existing communications channels.

The spin-scan camera gave for the first time a view of the weather in motion over the earth's surface, in both the sense of a time lapse movie, and in a more quantitative sense of gaining a look at a global dynamic system. Much of this was accomplished with a small-scale, hand-constructed effort, perhaps best typified by the meticulous movie-making which Fujita developed to a high art. Extracting dynamical information from ATS images turned out to be exceedingly time consuming. Moreover, the development of ever more sophisticated models of atmospheric dynamics demanded accurate information in larger and larger quantities. At SSEC, photographic

* Prepared by Robert Krauss.

techniques were developed for display and measurement using precision photofax images and electronic enhancement procedures. At the National Environmental Satellite Service (NESS), Hubert carried this a step further by using a TV system to generate motion pictures electronically. At Stanford Research Institute sophisticated measuring techniques were developed using TV. However, the most reliable and accurate output in any great quantity still appeared to be based on measurements from movie loops, the technique used by NESS in its operational program.

It is hard to see at first glance why it should be so difficult to make sufficiently accurate measurements of cloud motion in the desired quantities. ATS in geosynchronous orbit is a massive fly-wheel spinning at 100 rpm on frictionless bearings, an observing platform with great inertial stability. The spin-scan cloud camera on ATS thus has the necessary resolution, precision geometry and stable scan rate built into the system. Yet, four years after launch an accuracy of about 3 meters per second was the best attainable in large quantity, with an operator making individual measurements from projected 16 mm motion pictures on a digitizing table. The measurement of winds to an accuracy of better than 1.5 meters per second is a major requirement of the Global Atmospheric Research Program (GARP) in order to provide atmospheric models with sufficiently accurate data for global forecasting and study of mesoscale phenomena. It was in the context of the gap between experimenter requirements and existing image processing outputs, and with knowledge that the impending launch of the second generation spin-scan camera on the Synchronous Meteorological Satellite (SMS) would compound the data reduction problem with a 20-fold increase in data quantity, that a group at SSEC began a reassessment of all the techniques used to obtain wind fields from cloud motion in ATS pictures. We found that in order to make a significant increase in our ability to use these data effectively, it was necessary to take account of six factors:

a) The precision geometry and resolution in the ATS images must be retained. The geometry must be exactly repeatable from picture to picture to ensure freedom from systematic error. Highest precision displacement measurements require full data resolution. Transferring data to photographs, 16 mm film, TV or any intermediate medium causes an irrecoverable loss in resolution and introduces in each image systematic errors of unknown magnitude. Hard copy processes limit accuracy which then cannot be improved by greater care and effort.

b) Precision navigation and alignment are necessities. No matter how well the geometry is preserved, a one-resolution element alignment error between two ATS data sets taken 20 minutes apart will introduce a 3 m/s systematic bias in the measured wind vectors. To achieve 1-2 m/s error implies picture alignment to a fraction of a line. This can be done reliably by computer using the navigation program developed at SSEC. It is impossible with any sort of manual alignment technique.

c) The smaller the cloud, the better the wind tracer. Small clouds grow and diminish, but their shape is relatively constant and their small size guarantees that no nearby cloud modifying processes are occurring. To find and measure such clouds requires high resolution and a short interval between pictures. Longer time intervals allow cloud evolutionary processes to degrade measurement accuracy.

d) We have too much data. The volume of image data from ATS is bad enough; one picture occupies a full digital tape. SMS promises to be much worse. Solving this problem by going to larger computers is not practical. The solution must be found by selecting data as early in the data stream as possible. To do this we need a TV display which is cheap and fast, but rather than measure with it we use it only to select data of interest. This cuts data volume down before it is expensively processed by the computer.

e) Machines can measure better than humans can. In contrast to manual systems, the SSEC approach does not require the operator to measure cloud motion or to align picture frames. The TV display gives the advantage of being able to show motion and allows the operator to select a cloud of interest. The computer then takes over to process only that digital data near the indicated cloud, and the computer performs the final measuring process not on the degraded operator-viewed image, but on the original digital data.

f) Machines cannot do everything. The complex interaction between the computer correlation techniques and the information and noise content of the images is in many cases not yet understood. As time goes on new techniques will be developed to filter the data before, during and after correlation to improve consistency and reject bad measurements. Multispectral data handling will add to system complexity but will improve discrimination of cloud forms and altitudes by automatic means. As the system tasks become better defined, decision-making may be transferred to the hardware, but at present an essential ingredient is human judgment and versatility, and it is doubtful that in a research-oriented system one would ever want to completely eliminate the guiding scientist.

The characteristics required for a system to process ATS pictures for quantitative cloud motion measurements are therefore:

1. Best possible navigation,
2. Preservation of inherent resolution and geometry,
3. Speed and precision of automated techniques,
4. Human interaction only for decision-making but not for data handling or measurement,
5. Combination of digital and analog hardware, and
6. Real or near real time processing.

The situation may be likened to the data matrix in Figure 1. Raw data from ATS enters at the upper left with high volume and low information density. The matrix operates with either digital or analog techniques as most appropriate at any given stage, but the net result is output at the lower right of low data volume and high information density. The reassessment of our position at SSEC in light of what we had learned from past experience helped to point out the best alternatives for passing through the matrix.

The best possible navigation requires measurement of landmark line-element positions in the ATS picture, since no other existing method of orbit or attitude measurement can match the precision inherent in the image geometry itself. Dennis Phillips developed a highly accurate least squares method of fitting satellite attitude analytically in such a way that random landmark measurement errors were distributed over a number of sequential images. Relative image alignment to better than one picture element is now possible. The computerized approach to navigation is consistent, fast and precise—an obviously preferred choice.

Analysis of the geometric and photometric inaccuracies inherent in both film and TV indicated that a good deal of the error in previous techniques was due to the medium in which the cloud displacement measurements were made. Getting as close as possible to the original ground station satellite data is highly desirable, meaning an essentially digital approach, even though the data access problem is compounded by the high volume and low information density of digital image data.

Any human or electromechanical measurement technique would be doomed to failure in maintaining the data rates essential for real time processing of future data. People also become tired and inaccurate. Two new and promising approaches were investigated—one an electronic cross-correlation machine guided by a human operator and working from hard copy, and the other a computerized correlation process using fast Fourier transforms developed by Phillips. The computer technique was by spring 1971 obviously further advanced and had the advantage of being more accurate in principle since it operated on original digital data. Eric Smith demonstrated that computer cross-correlation was also more accurate in fact and could be implemented with little risk of delay.

The next problem was one of finding a way of getting sufficient human interaction with the measuring process to admit the judgment required to guide the computer. The potential of TV as a substitute for the hard copy photographic process and 16 mm film was suggested by Thomas Haig. The advantage of a wide bandwidth display was primarily one of speed since the human could remain outside the processing matrix, yet still maintain guidance and control without becoming a bottleneck in processing. Another advantage was that besides helping in the data processing, use of standard TV components would also help in data dissemination. The final step was Terry Schwalenberg's discovery that it was possible in principle to lay down an analog signal of 4 MHz bandwidth on a videodisk and still retain enough counting accuracy to reference the exact line and picture element in the digital data from a TV screen.

DATA PROCESSING MATRIX

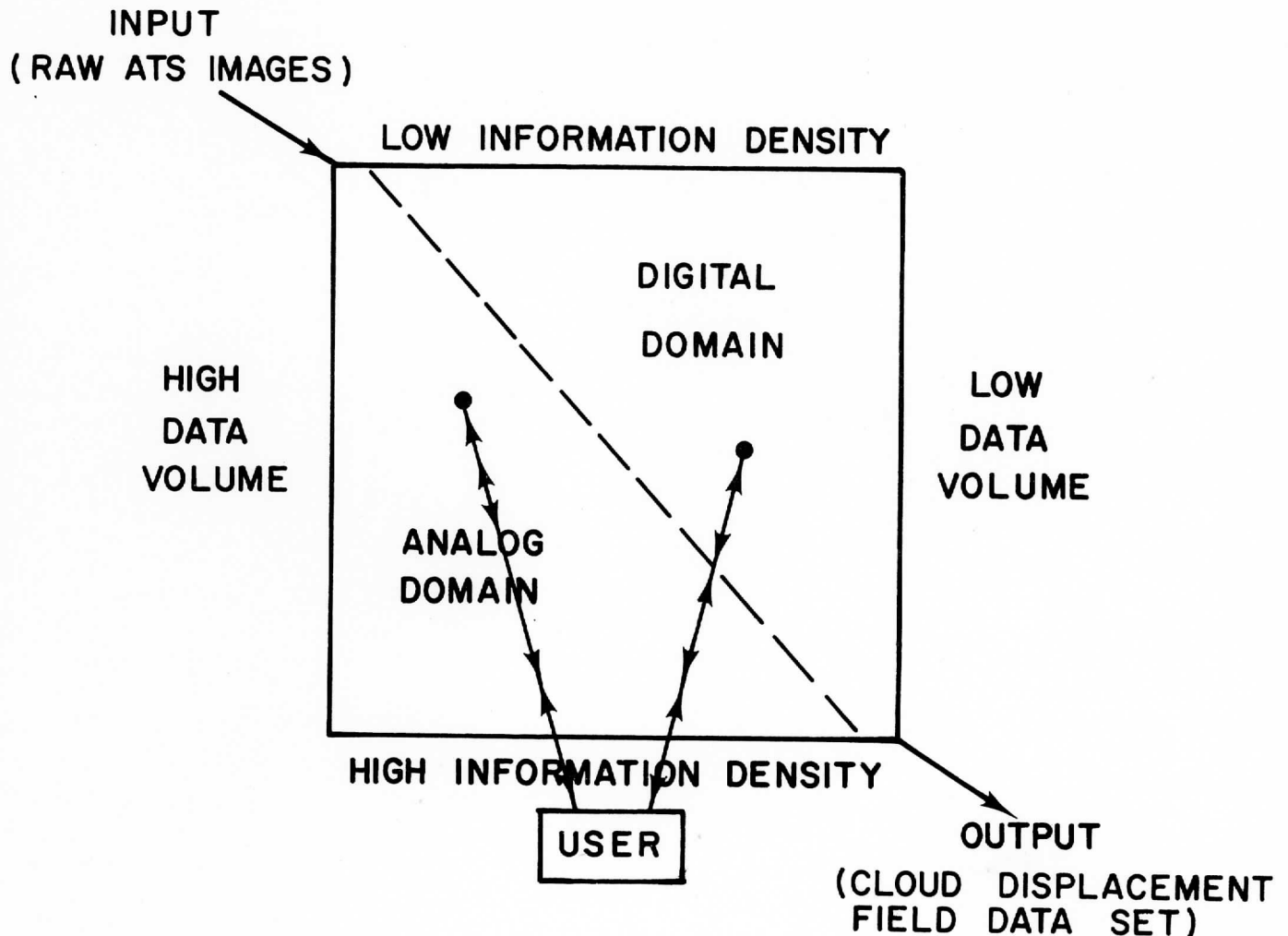


Figure 1. The most efficient path for extracting vector field data from cloud motion in ATS images may pass anywhere through the matrix, using any number of digital or analog processes. The uniqueness of McIDAS lies in the recognition that the best parts of both analog and digital techniques are required and that the human operator using the system must remain outside the matrix and communicate through the high information density channels, maintaining maximum control, but not becoming a data bottleneck.

Thus by late summer 1971 the plan for McIDAS was laid out. The system would be a combination of both digital and analog elements as had been foreseen, but if development work proceeded as planned the result would be an interactive man-machine system for measuring winds from cloud motion which would be able to operate in real time at rates not only sufficient to support the research program at the University of Wisconsin, but to provide support for the GATE and FGGE experiments if necessary.

The full power and potential of the system in terms of general data access became apparent only after it was into development as a breadboard demonstration model, and ideas of other uses began to develop. These are described more fully in the last section of this report. For the time being, we will concentrate on McIDAS application to our initial goal—that of obtaining hemispheric fields of cloud motion measurements.

B. Functional Elements of McIDAS

Four distinct areas of operation are associated with McIDAS: two primarily in the digital domain utilizing the unmodified bit stream from the satellite, and two primarily in the analog domain providing the man-machine interface:

1. Data storage and access (digital)
2. Image alignment (analog)
3. Data selection (analog)
4. Measurement (digital)

These are illustrated in Figure 2. For the moment we shall ignore both data acquisition and system output, although for McIDAS to function effectively enough to provide experimental data in the real world, external interfaces to both the satellite and the meteorologist must be adequately defined. We are presently working in the area of SMS data acquisition and error analysis to make sure that all parts of the communications link from the satellite to SSEC will be satisfactory for McIDAS to meet GARP requirements. The connection with the meteorologist on the other hand exists at present only in the statements of GARP requirements. This will be changed in the future as research programs and students at the University of Wisconsin begin to use the McIDAS system and discover its potential for speed, accuracy, low cost and improved match between man and machine.

The system is not complete by any means. What exists now is a breadboard setup, which will require rebuilding in more permanent form for trouble-free operation. New power supplies and a TV monitor will be needed in the future since the existing ones must be returned to those from whom they were borrowed. The interface to the Raytheon 440 computer is slow and inefficient, utilizing a paper tape punch which necessitates several steps such as paper tape to

DIGITAL DOMAIN
(MAXIMUM PRECISION)

ANALOG DOMAIN
(MAXIMUM INFORMATION TRANSFER)

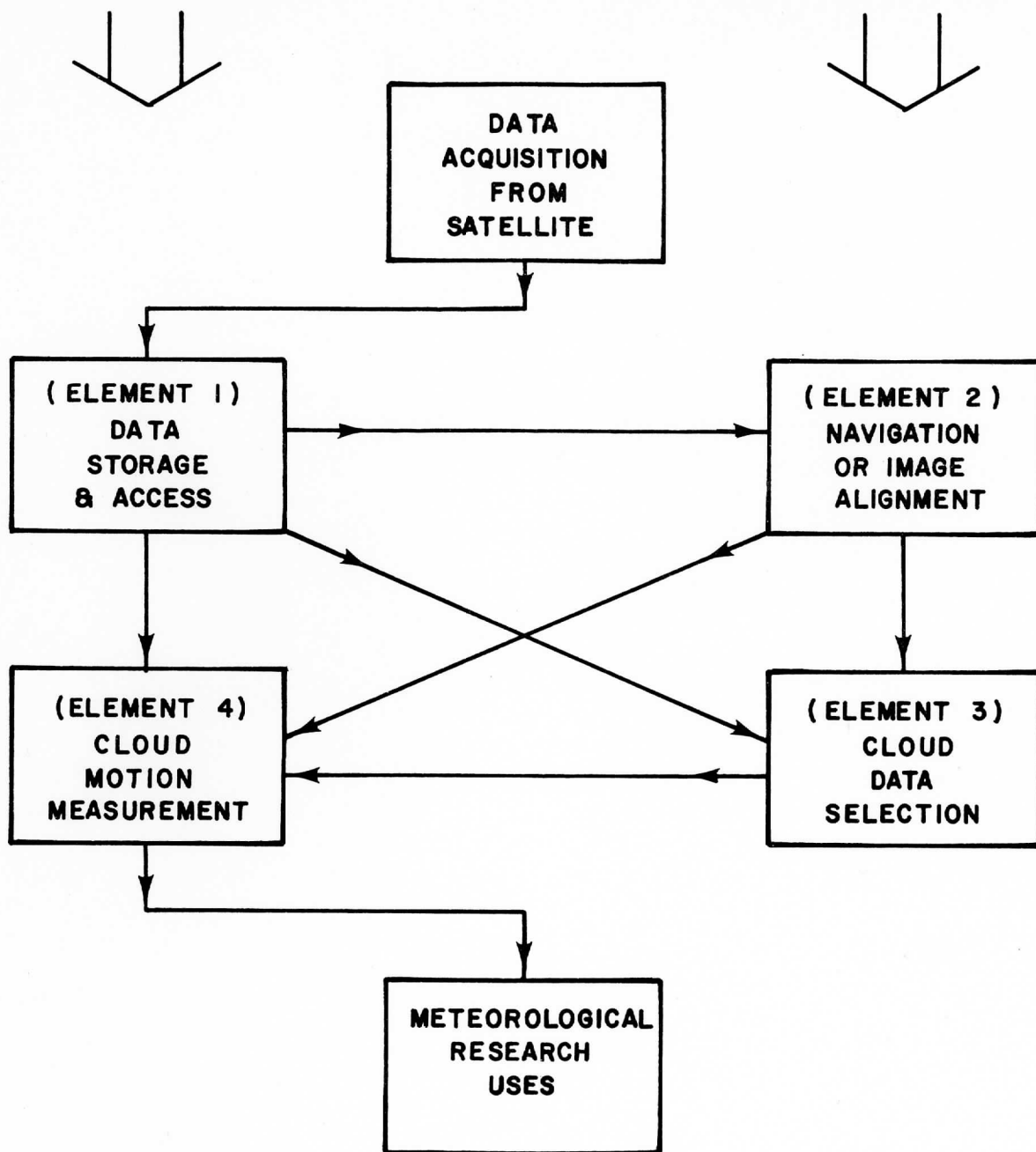


Figure 2. Four elements of McIDAS. McIDAS is the processing system between the satellite and the meteorologist. Note how each of the four elements impacts subsequent elements in the processing scheme. Poor performance in any area would seriously affect output. This is why the digital domain (elements 1 and 4) will require upgrading for use with SMS data. The prototype McIDAS hardware is capable of meeting anticipated real time data rates but the existing tape storage and time sharing computer system are not.

card conversion which would be unnecessary with direct hookup to a computer. A severe limitation on real time performance is the computer system we use. The Raytheon 440 in our building is too small for all the McIDAS cloud velocity measurement software, requiring use of the Univac 1108 across the street. The 1108 is a time-sharing machine. Running cloud displacement measurements in real time can yield widely varying waiting times for the results depending on system load. Data transfer is expensive, since I/O systems must be used which are not optimized to the processing scheme. Present methods of data access at SSEC are adequate to keep up with ATS data rates in referencing archived data, but the data increase expected when SMS becomes operational will severely overtax existing capacity. The greatest changes in the future must occur in the digital processing elements.

1. Data Storage and Access. The present technique of transferring images from digital computer tape through a small computer to analog video-disk is much too slow for use with SMS data. The measurement process in the large Univac 1108 computer is similarly I/O bounded. The present software makes full use of both tape and drum capability as well as squeezing the present billing system to get the most in both computing and turn-around time. About 65% of the present cost is not for cross-correlation, but merely a freight charge associated with getting the data into the right place at the right time. An order of magnitude more data will change this overhead ratio from 2:1 to 20:1. What is needed for the future is a lower volume, faster access storage medium with the type of efficient background data handling that comes from a thorough systems analysis and specific hardware design. We believe we have found an acceptable future storage medium in digital slant track videotape. The next task is to build a prototype recorder and analyze its function in a McIDAS system upgraded for use with SMS data.

2. Image Alignment. The spin axis of ATS is not exactly parallel to the earth's, so that due to ATS attitude drift relative to earth, the earth appears to drift in the image with a 24-hour period. In about three hours Cabo Barbas on the west coast of Africa moves over 20 lines in the image, introducing a 7 m/s systematic error in use of uncompensated imagery. Motion of clouds and weather patterns viewed on the TV screen would be at best misleading to the meteorologist, but actual measurements without correction for systematic error would introduce gross discontinuities into weather models. Thus, ATS navigation, as the image alignment process is called, remains absolutely essential even though it requires a small proportion of the total consumed processing time and a trivial amount of computer time.

The basis of the navigation procedure is the fact that the geometric integrity of the ATS spin-scan image is guaranteed by the laws of dynamics. The image is a better indicator of the satellite attitude than any other measure can be. Landmarks such as salt flats, lakes and coastlines are clearly identifiable in the pictures, although not as contrasty as cloud boundaries. Some brightness enhancement is usually required to bring out the landmarks clearly.

Accurate identification of a particular line and element in an ATS picture with a latitude and longitude on earth permits proper image alignment to make the landmarks stand still, view true cloud motion on the TV screen, select proper cloud tracers, and remove systematic error from the cloud displacement measurements.

Landmark selection is still done at SSEC by manual techniques because the computer cannot be depended upon to yield a good landmark correlation in the presence of low land-water contrast, low signal-to-noise, changing sun angles, and varying partial cloud cover. Since we are, after all, able to interpret landmarks by eye, it should be possible for a computer to give reliable automated measuring by application of proper noise removal, smoothing, filtering and enhancement. Then image alignment would be no more difficult than choosing a single cloud tracer. More accurate positioning would be possible, since the correlation process can measure to a fraction of a picture element using all the information in a 64-by-64 element matrix.

Another intriguing possibility is that the clouds themselves can be used as "landmarks," provided their exact location at the time of the picture is known. Clouds are much easier to correlate on. Martin and Suomi* have shown that it is possible to precisely correlate ATS cloud images with weather radar cloud images. When a number of stations in the national remote weather radar system or the RADEX network become operational, we will have at our disposal digitized radar images of a large portion of the country. This information will be available for the price of a three-minute long distance phone call to the station with the proper type of cloud cover. Thus, while the need for navigation will always exist, the possibilities for automating and speeding up the process look promising.

3. Data Selection. This process is at present very unsophisticated. This is not necessarily bad, for the speed with which clouds can be selected is tremendous, limited by the speed of our paper tape punch to one point a second. Since three points in three separate sequential images are needed to produce a trustworthy measurement, this amounts to a selection speed of 20 vectors per minute, quite ample for a system operating in real time. Section C discusses details of the selection process, so we needn't dwell on that here. The most intriguing part of the process is the realization that we have barely scratched the surface for effectively utilizing the man-machine interface. After only a week or two of operation with the system, new ideas are emerging daily. It should be possible to provide much more information on cloud type, motion and meteorological context to enable the computer to more accurately discriminate and correlate. Two motion fields in different directions can be more easily separated by a person watching a display of motion than by the computer, which can be confused by peaks in the correlation matrix generated by cloud patterns rather than motions. The computer could provide feedback to the human operator in difficult

* David W. Martin and V. E. Suomi, "A Satellite Study of Cloud Clusters Over the Tropical North Atlantic Ocean," Final Report on Tropical Cloud Organization Studies, Task Order Number 3 to STAG Contract E-127-69-(N), Space Science and Engineering Center, 13 August 1971.

cases, asking for aid in determining what algorithm to use. Electronic aids to the operator are possible, with TV techniques to do picture differencing, measuring, counting, edge enhancement, brightness enhancement, contouring, etc. All of the time-consuming techniques used in generating photographic hard copy can be simulated on the TV screen instantaneously.

4. Measurement. The measurement process is relatively straightforward, using the large memory and drum storage capacity of the Univac 1108 computer to simultaneously assemble as many as fifty 64×64 element grid areas intersecting a single line in the ATS image. After assembly of the areas, the cross-correlation program performs the lag or displacement computations using fast Fourier transform logic. The displacement analysis programs which use the navigation information to convert line-element displacements to distances on the earth's surface are the next step, and produce the cloud velocity printouts and vector field maps which constitute the final product of McIDAS. From this point, students can spend time profitably analyzing actual meteorological parameters instead of laboriously trying to access the image data and measure each cloud displacement.

The key to the power of McIDAS is that the operator of the system can see the data in a form suitable for easy interpretation. He can study patterns, motion, interactions of varying scale sizes, make his judgments, and then communicate exact coordinates and instructions for processing the digital data. In the future the computer will use the same display system to show results and ask for additional guidance; and always the system has the full precision digital data to work with, so maximum accuracy is possible in analysis.

C. Use of the McIDAS Display System for Cloud Motion Field Data

The selection and measurement of cloud tracers using the prototype McIDAS system is quite simple in concept. There are really only two major processes: navigation or image alignment and data point selection. Everything else that happens merely helps implement those two processes.

When the display is turned on, the test pattern shown in Figure 3 can be loaded and displayed. The vertical bars in groups of three show system resolution. They are, respectively, 7, 6, 5, 4, 3, 2 and 1 picture element or pixel wide. The top row is at maximum brightness, the second row at half brightness. The 2 pixel bars are just barely distinguishable; the 1 pixel bars are barely visible but not separable. Thus the display system has resolution between 1 and 2 pixels.

The gray scale shows 32 levels of gray, of which 22 are distinguishable by eye in a darkened room. The checkerboard pattern tests line-to-line coherence, as do the vertical white lines. If the oscillator were not laying each pixel down on the disk in exactly the right spot, the vertical lines would be jagged. Comparison with

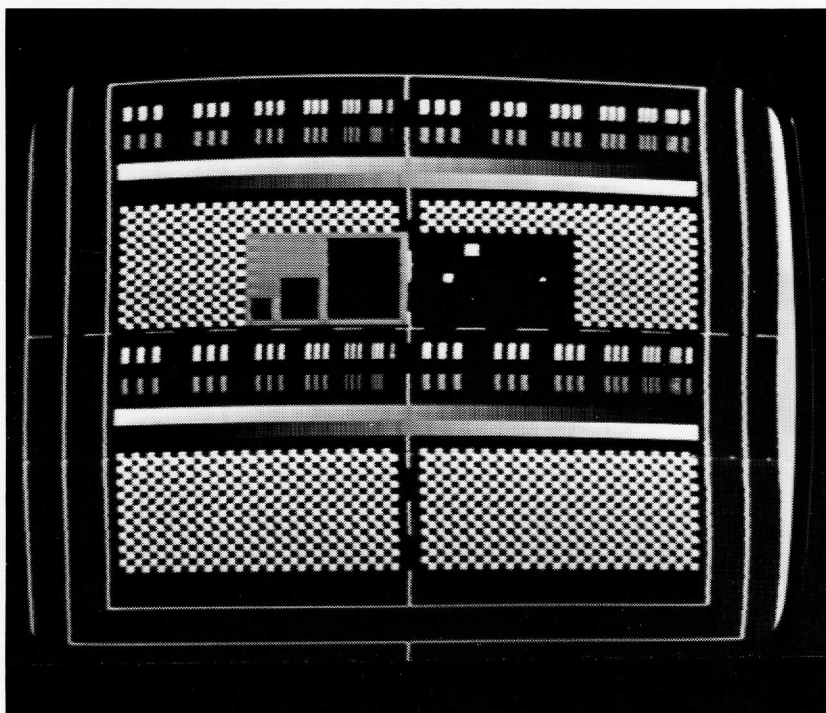


Figure 3. McIDAS test pattern display is used to demonstrate system resolution and stability and for calibration of cursor coordinate designator.

the resolution bars shows that horizontal position is held to better than 1 pixel from line to line.

Cursor size is set by using the squares in the center of the frame, corresponding to 8×8 , 16×16 , 32×32 , and 64×64 element grids. The slightly irregular appearance of the squares is due to an incompatibility in aspect ratio between ATS and a standard TV image. This distortion in the display, as well as the slight waviness of the vertical lines, is of little concern because the line and element count are accurately preserved relative to the picture sync signals. Since the TV screen is only used for display and not measurement, these nonlinearities have no effect on measurement accuracy of the McIDAS system.

Once the system is warmed up and operating, the navigation process begins. In real time operation, only the last ATS frame in a time lapse sequence would ever have to be aligned. The earlier images would already be aligned. Indeed, the attitude prediction ability of the navigation program is so good that one could even omit the alignment procedure for several hours without great risk. Prediction of satellite attitude within $\pm 1/2$ line width has been done for as far as 24 hours in one case. If, however, there has been an orbit or attitude adjustment, or if the McIDAS system is being started up cold, all the images must be properly aligned. In that case, if one displayed a small section cropped from each ATS picture, one would observe a sequence like that in Figure 4.

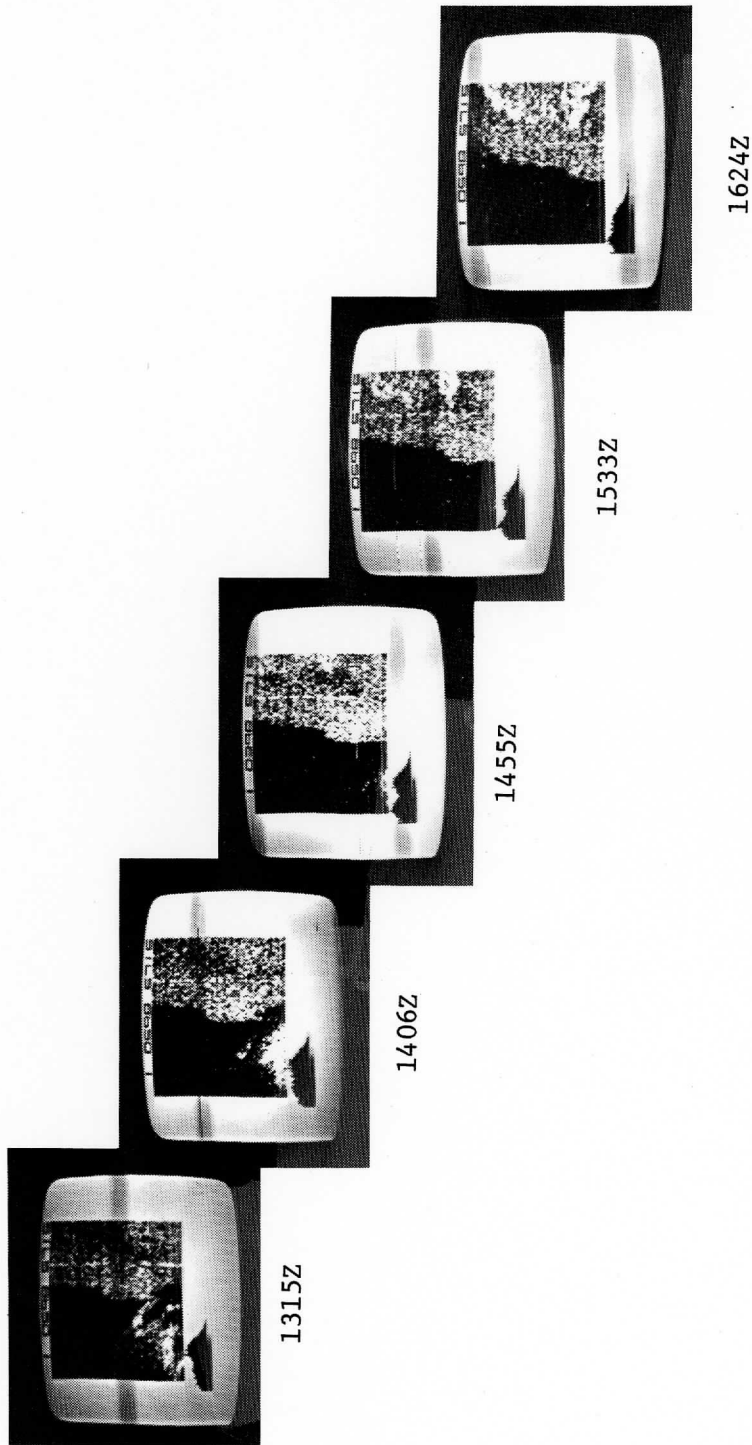


Figure 4. ATS navigation or image alignment is needed to keep the earth from shifting in the TV display, and is required to reduce cloud motion measurement error to acceptable levels. Motion of Cabo Barbas on the coast of Africa can be seen in this time lapse display of small segments with identical line-element coordinates in each of five ATS images. The apparent downward shift of the coastline is due to satellite attitude drift relative to earth. The ATS spin axis is not parallel to the earth's, so it drifts in the earth-centered inertial system. If this motion is not removed from the images, it is imparted to the cloud motion measurements as a systematic error. Note that the relative amount of cloud cover in each image remains approximately the same even though clouds are moving through the field of view from NE to SW. Thus, the brightness distribution at the bottom of each picture can be expected to show the effect of sun angle on the albedo of the underlying land surface.

The TV screen shows a greatly enlarged view of Cabo Barbas on the west coast of Africa. Each picture element is separately visible and the image has been enhanced by the computer to optimize the land/water boundary. The vertical motion of the coastline from one frame to another is easily distinguishable. Were this motion to persist in the measurement process, it would generate a large systematic error in measured cloud motion. A transparent map template overlay of the correct scale, made from USCGS navigational charts is aligned by eye to each TV frame, the McIDAS cursor aligned with a given point on the template, and the coordinate information punched on paper tape to be fed back to the computer. In this way, a single geographic point on the earth is defined as having a certain set of line-element coordinates in each ATS picture. The paper tape is converted to punched cards, which are input to the navigation program in the Univac 1108 computer. A least squares program determines a satellite orbit and attitude which best fits the series of measured landmarks.

When the navigation program is run, it outputs a line-element offset for the center of each TV frame to be displayed. As a result, when the cloud images are loaded and appear on the screen, the earth beneath is almost completely stationary. A small residual alignment error remains in the TV display since, besides x and y displacement, a rotation is needed to achieve perfect alignment. As in previous cases mentioned, this error does not carry over into the measurement process, since the analytic transform which produces the wind vectors in the earth coordinate system does take account of rotation.

Following navigation, the ATS image segments are loaded. The program loads an area of a fixed size—525 lines \times 2100 elements—and can start loading from any point in the picture. Every ATS line is written as one TV line and every third ATS element is displayed as a TV pixel. The same area from each ATS picture in a series is loaded in consecutive disk tracks so the TV frames can be viewed in a loop. Generally, small clouds are used as tracers and any information which might confuse the correlation algorithms is avoided. A cloud is selected in the first frame of the loop and the cursor located over it in such a way as to prevent other cloud types or cloud motion fields from falling within the cursor area. The cursor position need only be accurate enough to ensure that the cloud will be within the 32×32 data matrix. The operator can therefore work very rapidly.

The operator works as shown in Figure 6 with the right hand on the joystick cursor control and the left hand over four buttons. One button punches coordinates on paper tape, the second advances the loop one frame, the third both punches and advances one frame, and the fourth loops through the sequence of frames. During normal operation only the third and fourth buttons are used. The operator goes through the loop several times with button four picking cloud areas of interest and then advances through the loop a frame at a time punching coordinates with button three. A light on the con-

trol panel flashes at the beginning of each loop pass, signalling the operator to move the cursor to another cloud. With practice, a rate of 1 point per second is achievable, limited by the cycle time of the paper tape punch. A better computer interface will improve this, but even so, this corresponds to over 3000 points per hour or 1000 quality controlled vectors per hour. This rate matches the speed with which the Univac 1108 can cross-correlate provided we used 100% of its computing capacity.

After cloud selection is completed, the paper tape with TV line-element coordinates is read on the Raytheon 440 and converted to ATS line element coordinates. This is an inverse of the image alignment process. The final step is to output the ATS coordinates

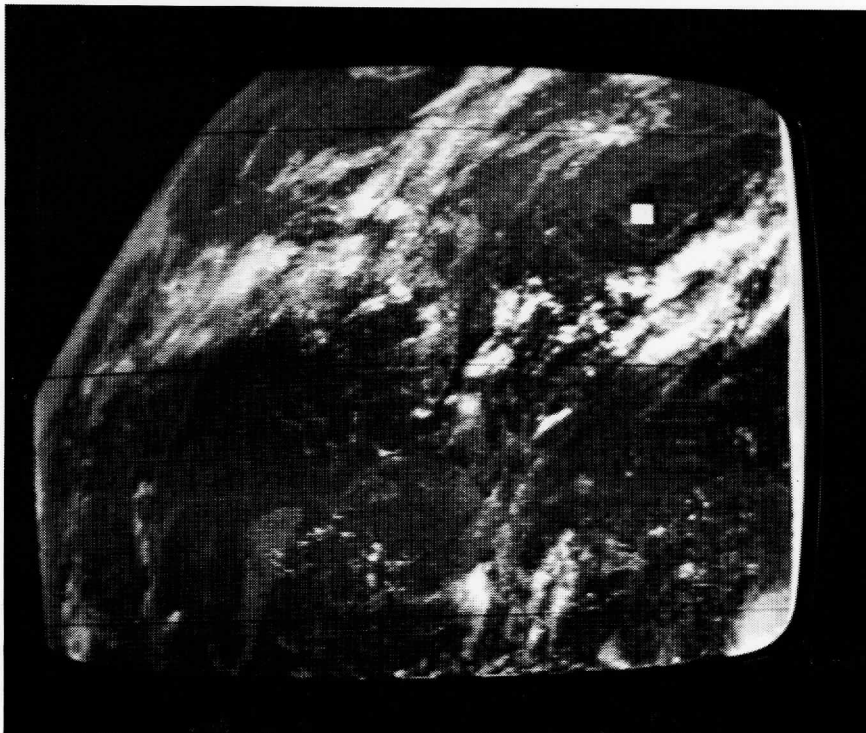


Figure 5. With the navigated ATS images loaded into the TV system, one can observe a time lapse display of the motion of the weather over a solidly fixed earth. The square cursor shown at the upper right is used to designate areas in which cloud measurements will be made.

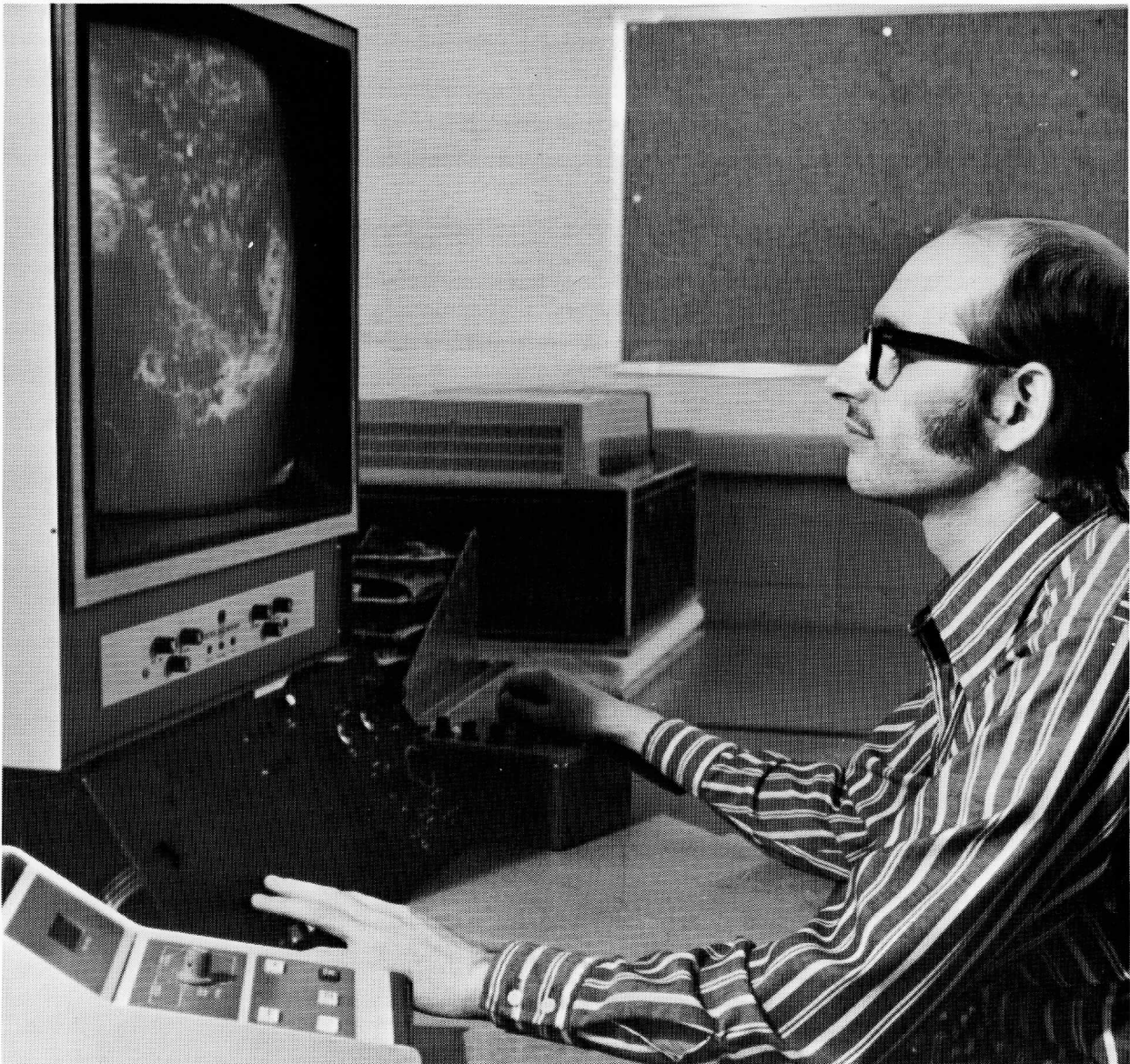


Figure 6. The operation of McIDAS is geared to provide speed and operator comfort. Since a large matrix is used in the measuring process, coordinate designation need only be approximate to $\pm 5-10$ pixels. The main task of the operator is to choose regions which do not contain multiple cloud layers or image data which would tend to confuse the computer algorithms. He moves the cursor to the desired region of the screen using a joystick, and then presses a button with the other hand to record the coordinate designation. The computer will then select the proper data from digital tape for the actual measurement process.

on punched cards for input to the 1108 correlation program. The program does the cross-correlation, generates a vector pair for each set of 3 data points for a given cloud, transforms the vectors to earth coordinates and makes sure the two velocities measured for each cloud over time intervals $T_2 - T_1$ and $T_3 - T_2$ agree within certain set limits. The result is one quality controlled displacement vector for every set of 3 data points.

D. Application of McIDAS to Other Data Handling Areas

McIDAS was originally developed to permit easy access to ATS image data for measuring cloud motions. Most of this report deals with that application, but we are now finding that other science programs at SSEC and the general public will also be able to benefit from use of the system. In the past, progress was often hampered by lack of easy, cheap access to imaging data. With that constraint now removed, new techniques of interactive data reduction and dissemination will be developed in many areas.

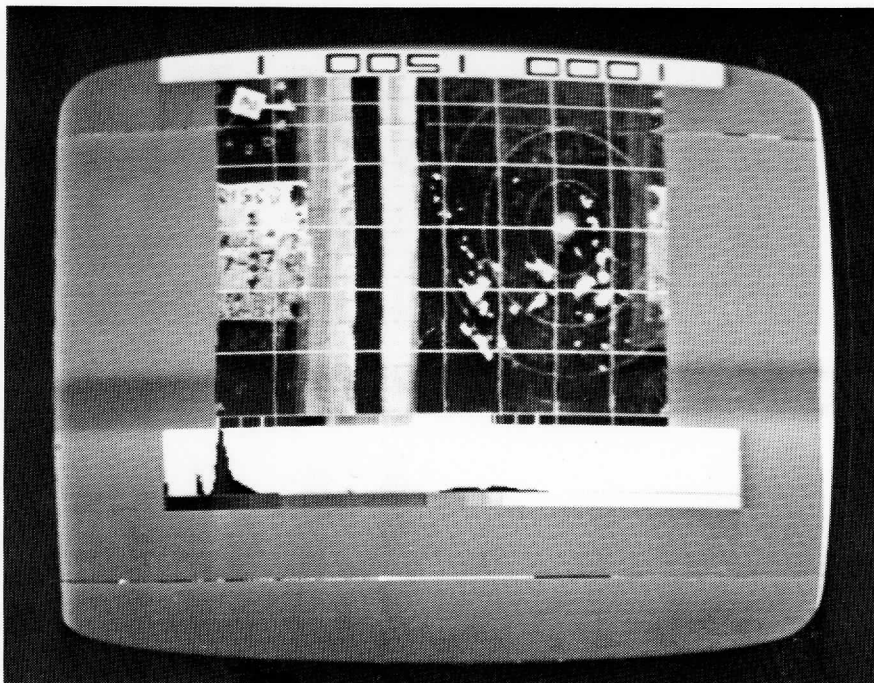


Figure 7. Use of radar images of clouds will permit McIDAS to align images absolutely as well as relatively. In addition to making all measuring processes fully automatic, this will allow one to designate a geographic point on earth and find the exact pixel corresponding to it in any of a series of satellite images.

1. Radar Navigation. The development of the RADEX network and remote weather radar systems linked by telephone lines will soon permit radar images to be transmitted for the price of a three-minute long distance phone call. Since the radar stations have precisely known locations, and the McIDAS software can correlate very well on clouds, it should soon be possible to locate geographic points precisely in satellite line-element coordinates, using cloud positions at a given time as a "landmark." This will eliminate the last remaining human measurement process in the system, and make absolute rather than relative image alignment a reality. Coupling this with the new SMS trilateration position measurement should generate satellite attitude and orbit determinations superbly suited to the increased resolution of SMS. McIDAS will be capable of interfacing to telephone lines to both receive and send analog and digital image data.

2. Earth Resources. The launch of the first Earth Resources Technology Satellite, ERTS-A, opens up a new era of geological and agricultural exploration. A group at the University of Wisconsin is actively participating in determining ways of registering land use by using ERTS multispectral imagery. McIDAS will be capable of accepting ERTS images as either digital tape or color prints, aligning, displaying in color, and performing designated recognition or measuring processes. The ability to display frames alternately or in rapid succession as a time sequence with various forms of enhancement will provide a powerful tool for analysis, limited only by the ingenuity of the experimenters.

3. Atmospheric Sounding. Work recently done at SSEC under contract to NASA* demonstrates the feasibility of adding a capability to SMS-B to do vertical temperature and moisture sounding of the earth's atmosphere from geosynchronous altitude. It will have 24-hour capability to provide hemisphere-wide, three-dimensional temperature profiles and high resolution soundings near fast developing mesoscale systems. This is highly desirable for the forthcoming GARP experiments and storm tracking programs. Only minor alterations in spacecraft telemetry formats are required, but ground data processing will now have a dozen channels to correlate in time sequence instead of merely two, as on SMS-A. McIDAS will have built-in provision to handle a large number of data channels simultaneously.

4. Space Meteorology. The forthcoming Mariner flyby flights to Venus and Mercury in 1973 and Jupiter and Saturn in 1977 provide a rare opportunity to study planetary atmospheres other than Earth's. Using these planetary laboratories in the sky permits comparative meteorological study of atmospheric processes which are similar to those on Earth, but occur under different conditions. Such experimental observations can help us understand more about how our own atmosphere works and will aid in producing more accurate weather forecasts. SSEC is represented on the 1973 imaging

* V. E. Suomi, L. A. Sromovsky, R. J. Krauss, and A. J. Stamm: "SMS Sounder Specification," SSEC Final Report under extended NASA Contract NAS5-21607, (April, 1972).

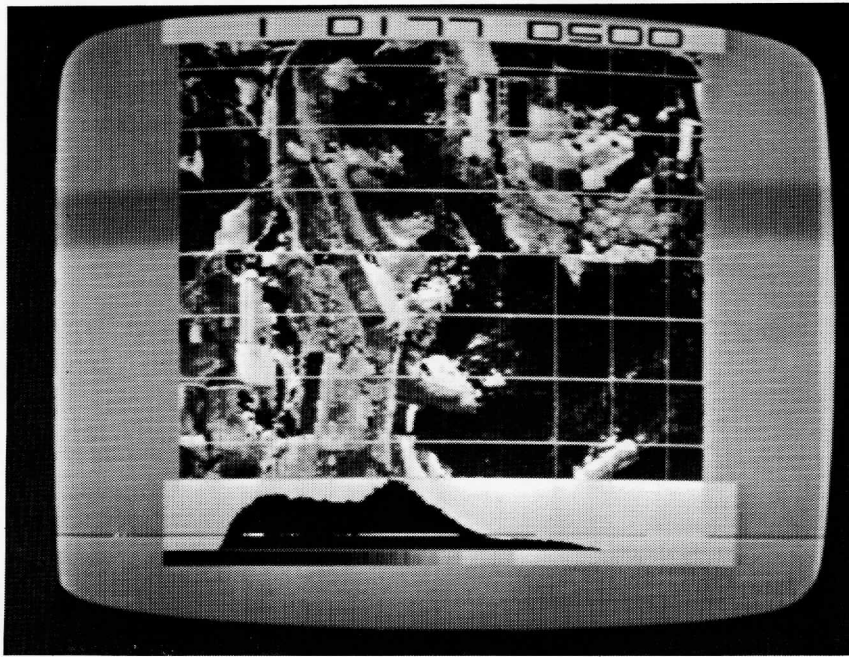


Figure 8. Processing earth resources data may be considerably speeded up using the image comparison and measurement capabilities of McIDAS.

mission and will be studying the Venus clouds and measuring their motion using McIDAS.

5. Sunlint Studies. Recent studies by Levanon and Kornfield* at SSEC have shown that wind speed and direction can be determined from study of the pattern and brightness of the sun's reflection off the ocean. The method has been proven for the geostationary ATS satellites in the subtropics and an experiment is being studied for inclusion on lower orbiting sun synchronous spacecraft such as Nimbus and ITOS in order to see the sunlint over other portions of the earth. The technique requires looking at the same spot on the earth at several different illumination or observation angles. Use of McIDAS will permit isolating the necessary data very quickly, and the algorithms to obtain the wind velocities can be part of the system.

6. Air Pollution Studies. Recent work at SSEC has been concerned with monitoring air pollution from satellites. McLellan**

* N. Levanon, "Determination of the Sea Surface Slopes Distribution and Wind Velocity Using Sun Glitter Viewed from a Synchronous Satellite," SSEC Final Report on NASA Contract NASw-65 (1968). Also see J. Kornfield, Ph.D. Thesis, University of Wisconsin (1972).

** Alden McLellan IV, "Atmospheric Pollution Detection by Satellite Remote Sensing," Proceedings of the Seventh International Symposium on Remote Sensing of Environment, 17-21 May 1971, University of Michigan Willow Run Laboratories.



Figure 9. A picture taken from Mariner 9 on 2 March 1972 in the region of Mare Acidalium. Regions on Mars above 45° north latitude have been blanketed by clouds, probably of carbon dioxide. The only surface detail to be seen here is a frost-rimmed crater with wave clouds propagating from it due to the diverted air flow. Measurements of cloud motion relative to landmarks, as well as the wavelength and shape of the clouds, will provide information about atmospheric flow patterns. Future Mariner missions will be sent to Venus in 1973 and Jupiter and Saturn in 1977, with the possibility of orbiter satellites with spin-scan cameras to follow. Increasing our knowledge by comparatively studying other planets' atmospheres under other physical conditions is an opportunity equivalent to performing laboratory experiments on a planet-wide scale. We thereby can improve our ability to understand and forecast what goes on here on earth.

at SSEC has studied hourly growth of aerosol content in the Los Angeles basin and followed its movement and dissipation. The ability to detect and track pollution depends greatly upon knowledge of the optical properties of the always present underlying surface. McIDAS now makes it practical to generate a library of the reflectance and absorption characteristics of regions of the earth's surface from ATS, SMS, Nimbus and ERTS data and subtract it out, leaving only the atmosphere and the optical effects of its particulate content visible. McIDAS will then track the dispersion and transport of pollution in the various sensing bands. It will be possible to track the wind-swept sands off Africa and pollution from slash-and-burn agriculture in Central America with such accuracy in space, time and concentration that their sources and dispersal patterns can be well defined for computer models. Future satellite sensors will be sensitive to individual gases such as carbon monoxide and sulfur dioxide. McIDAS will be able to correlate all these channels and aid in determining short-range pollution forecasts as well as studying long-range effects as these pollutants slowly dissipate into the general atmosphere.

7. Classroom Aids. One well received feature of the satellite program at SSEC is the production of daily photographs of the weather from ATS or the polar orbiting Nimbus or ESSA satellites. The students enjoy operating the equipment and making comparisons between the satellite photos and weather maps and forecasts. As classroom aids, the immediacy of pictures of today's weather helps maintain interest and provides real life examples of topics under discussion. McIDAS will add the time dimension here so that the weather patterns will move and evolve on the TV screen. Production costs will be much less per picture.

8. Rainfall Measurement. Precipitation plays a significant role in storm energetics through interaction with the air flow, yet often goes unmeasured because of the sparse network of rain gauge stations throughout the world. The use of satellites in determining rainfall on a large scale has obvious advantages over discrete earth-based measurements. Sikdar at SSEC has demonstrated excellent correlation of rainfall with variation of both the cirrus shield size and brightness anomalies associated with storm complexes and frontal zones.* Excellent correlation is also obtained between rainfall and the rate of change of radar echoes in the cloud complex. McIDAS, with ability to access radar data, to measure areas, and to provide various display enhancements, will be able to monitor rainfall on a global basis similar to its wind measurement capability. Recent results of work with the Temperature Humidity Infrared Radiometer (THIR) experiment on Nimbus-IV also point to much extended use of water monitoring in the atmosphere to aid in following energy transport and improving predictive capability.

*D. N. Sikdar, "ATS-III Observed Cloud Brightness Field Related to Mesoscale to Subsynchronous-Scale Rainfall Pattern," SSEC Annual Report on Contract NAS5-11542, 1970-1971 (February 1972).

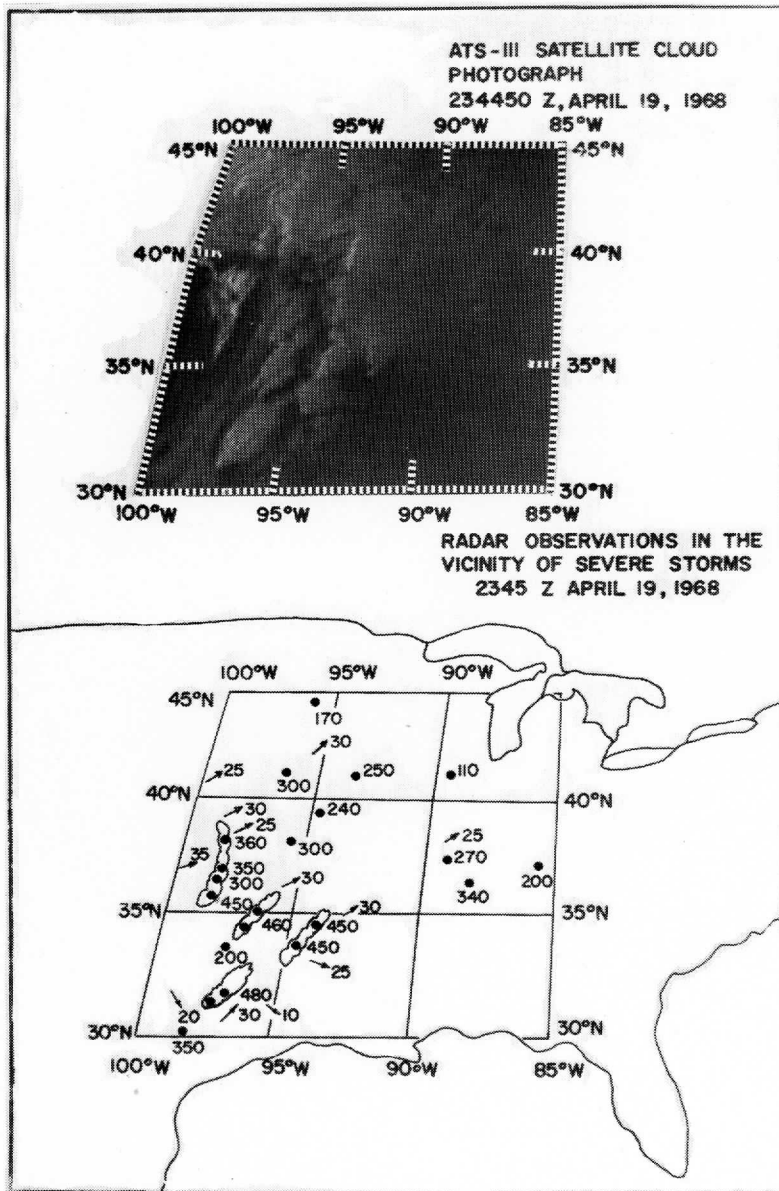


Figure 10. Recent studies have shown a correlation of both cloud growth and radar echoes with rainfall measurements. Monitoring rainfall on a global basis using McIDAS would be of great use to atmospheric modelers and dynamicists studying heat transport.

9. Atmospheric Dynamics. Much work at SSEC in the next year will place emphasis on detailed quantitative study of dynamical weather systems and their interactions on various scales. These studies will range in scale all the way from a statistical examination of cloud activity and development in the evolution of small storms to the measurement of planetary flow patterns, and in time from energy injection at localized subtropical storm centers to eventual dissipation of synoptic flow in mesoscale and subsynoptic phenomena. Most of this research will initially be used to develop techniques of data access and useful descriptors of dynamical quantities with the end of predicting the rearrangement of momentum, heat, moisture and mass distribution in time, i.e., generating an accurate long-range weather forecast.

All these plans are now emerging after only a short operating period for the McIDAS prototype. As we become more knowledgeable in its use, other ideas for the future will emerge. What is very clear now is that we have achieved at SSEC a breakthrough of major proportions, in that the right combination of analog and digital techniques is leading to an unexpected and immensely exciting frontier of new possibilities.

2. RECENT SOFTWARE INVESTIGATIONS FOR McIDAS CLOUD DISPLACEMENT MEASUREMENTS*

In the search for faster and more effective methods of generating cloud displacement measurements, two different methods were tested for replacement of cross-correlation. The first was a simple binary matching process. Brightness values from image grid pairs are mapped into a [0,1] range. A "1" value represents a brightness interval; a "0" represents values outside the interval. The appropriate brightness intervals can be determined by analyzing frequency distributions of ATS picture brightness values. The matching coefficient at each lag position is the sum of the number of 0 matches and 1 matches. This sum is a measure of matching cloud edges in the brightness interval. The basic advantage of this technique is that the computational requirements are minimized. By the use of masking operators, arithmetic operations can be removed from the computation. The disadvantage of binary matching is that, when an image is reduced to cloud edge/no cloud edge, cloud texture information is lost.

An analysis of the test results has shown that in certain cases, the binary matching technique can resolve cloud motion. Unfortunately, it fails too often. Figure 11 illustrates a comparison between cross-correlation (b) and binary matching (c). The surfaces of six cross-correlation matrices were plotted along with corresponding surfaces of binary matched lag arrays. The matching technique

* Paper prepared by Eric Smith and Dennis Phillips.

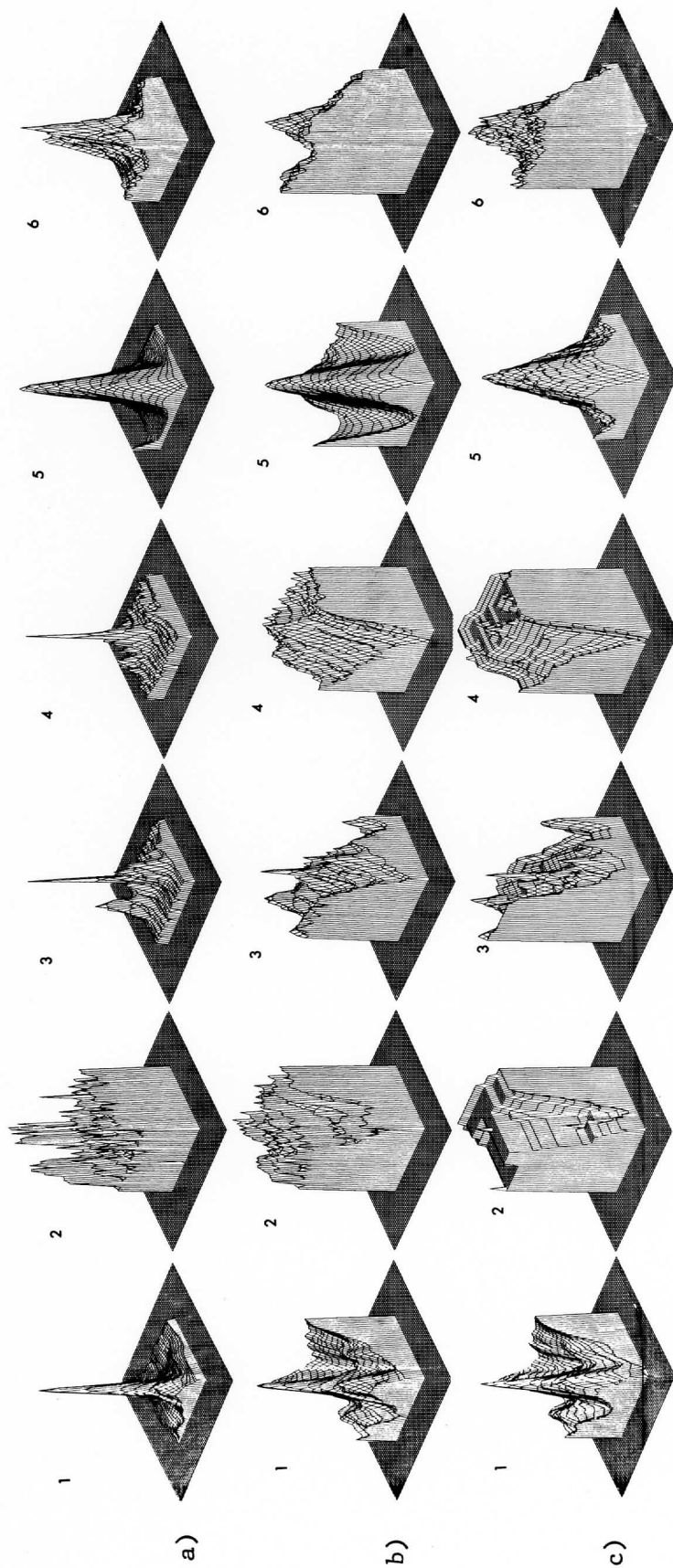


Figure 11. Comparison of lag matrices in six test cases for each of the three measuring techniques: (a) Euclidean norm; (b) cross-correlation; (c) binary matching.

appears to succeed in cases 1, 5 and 6. However, only in case 1 do the actual lag shift coordinates agree. In cases 2 and 4, binary matching yields no apparent displacement information, and in case 3 the true displacement peak is dominated by two other spurious peaks. In general the tests suggest that binary matching is inappropriate for the smaller cloud-tracers (4-10 n.m. diameter).

A second method has shown more promise as an alternative to cross-correlation. Instead of computing normalized sums of products to derive displacement information, sums of differences squared are used (Euclidean norm). Since we are working in a 1024 dimension Euclidean space, the Euclidean metric induced by the topology of the space is a natural measure of similarity between "surface" vectors. Cross-correlation techniques only measure angles between vectors in a Euclidean space. Conceivably, the use of a Euclidean distance technique could improve cloud displacement measurements.

Preliminary tests of the Euclidean norm techniques have indicated that it is no worse than the cross-correlation technique. Figure 11(a) contains six surface plots of lag matrices generated by the Euclidean norm method and corresponding to the six cases seen in Figure 11(b). In each of these cases the displacement measures did not deviate significantly from the displacement measures using cross-correlation. It is not readily apparent which method is superior. However, if the Euclidean norm lag matrices are scaled by taking the square root of the terms (thereby generating the Euclidean metric), Euclidean norm surfaces appear somewhat smoother than cross-correlation surfaces. The smoother surfaces enable better interpolation of the surface maximum. Unless further evidence indicates that the Euclidean norm technique is inappropriate for cloud displacement measures, it will be incorporated into the McIDAS system.

Applying a one-dimensional or two-dimensional Hanning filter to the raw data (Figure 12(b)) smooths out the cross-correlation surfaces at the expense of sometimes increasing the size of spurious peaks. The effects of techniques that amplify high frequencies such as the gradient or Laplacian transforms are seen in Figure 12(c) and (d). The gradient tends to amplify cloud edge information, and in many cases yields satisfactory results; however, it often strengthens spurious peaks. The Laplacian yields virtually no cloud displacement information since it seems to remove cloud signal information while retaining the signal noise. Figure 13 shows that displacement information decreases as the wave number of the passed frequencies increases. However, chopping mid-range frequencies that have any substantial power has the undesirable effect of destroying the cloud edges.

We feel that frequency filtering attempts have singularly failed to improve cloud displacement measurements. Furthermore, because of edge propagation problems (ringing), any filtering, except at high frequencies, is inappropriate. Any high frequency filtering should be done only to eliminate frequency fixed noise. The occurrence of such noise has not yet been substantiated in ATS data. However, due to the constant absence of substantial power in the

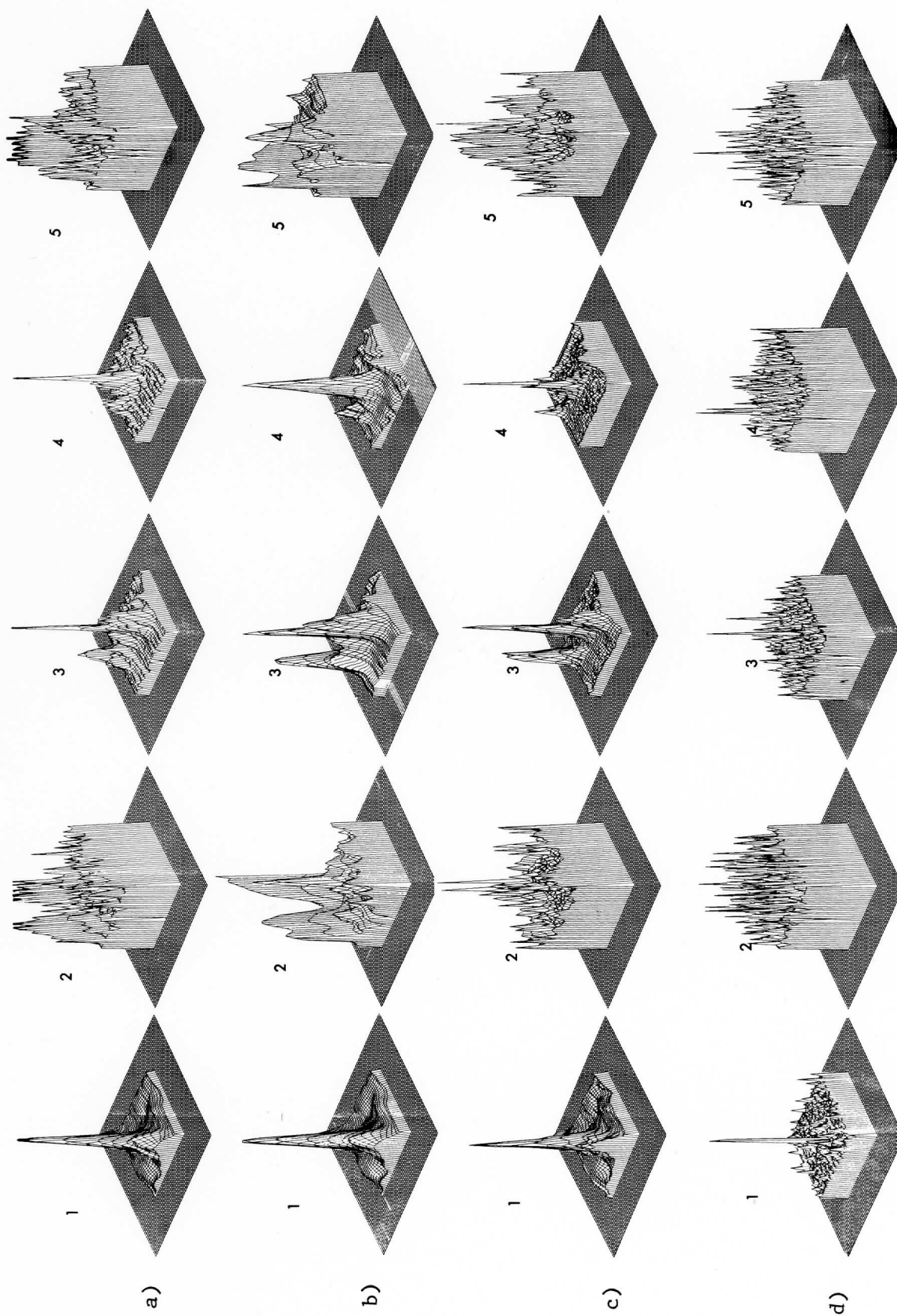


Figure 12. Normal cross-correlation surfaces for five test cases (a) are compared with application of (b) Hanning filter; (c) gradient transform; (d) Laplacian transform.

wave number = 1

5

9

15

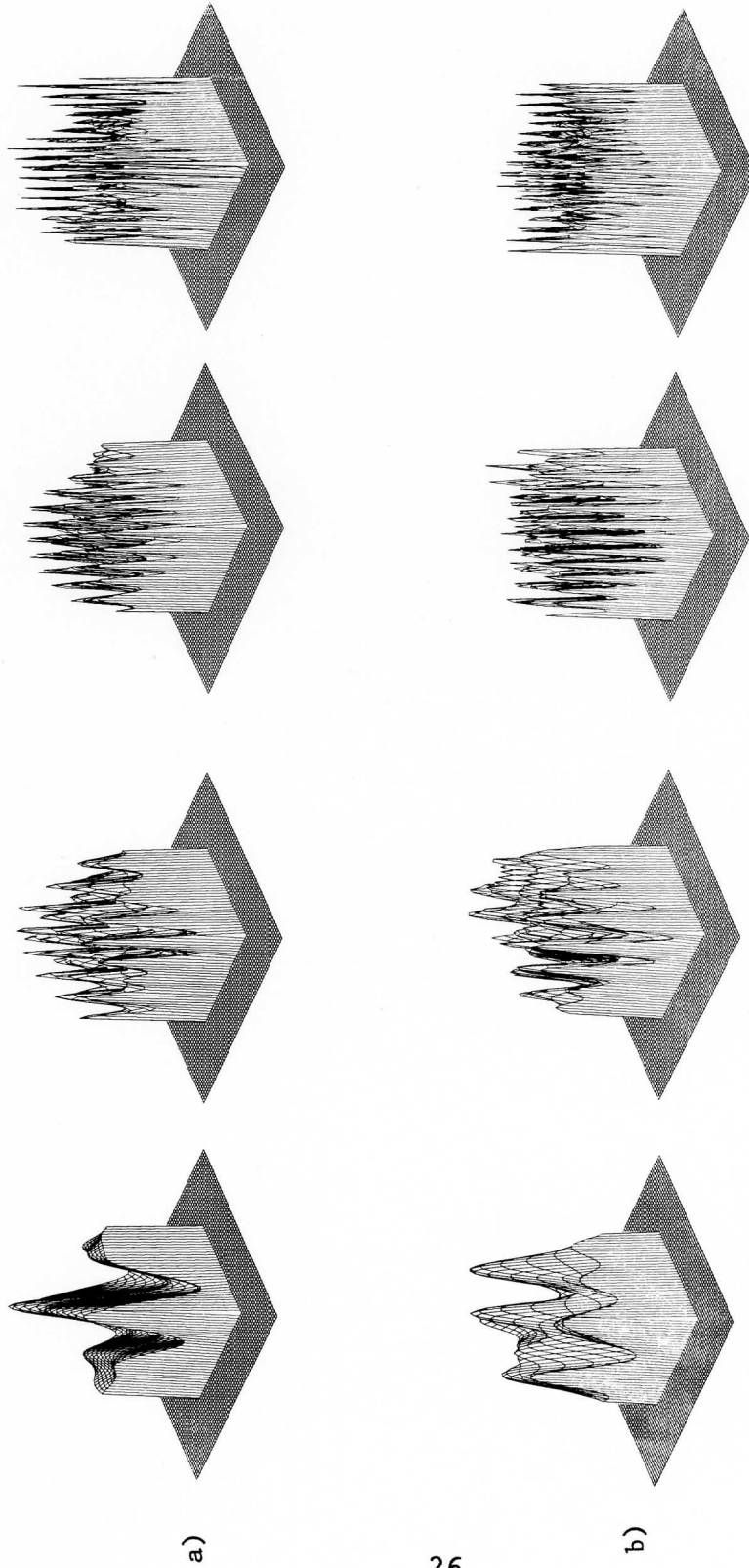


Figure 13. Two test cases (a) and (b) showing cross-correlation matrix for wave numbers 1, 5, 9 and 15. High spatial frequencies contain little, if any, displacement information.

higher frequencies of the cross-correlation matrix, high frequency cut-off filters could be used to improve computation time with very little degradation of the cross-correlation coefficients. Hence, the only apparent advantage in filtering at present is a reduction of computational time.

The method we have used to obtain cloud motion, i.e., cross-correlation using relatively large geographical areas, uses only a small portion of the information available in the ATS pictures. We investigated the extent to which spatial and brightness resolutions could be reduced before applying cross-correlation without significantly degrading the cloud displacement measurements. Our results which are based on a small data sample suggest that reducing spatial resolution by a factor of four by averaging, and decreasing the radiance scale resolution from an 8 bit word to 5 or even 4 bits produces acceptable results when dealing with relatively large-scale clouds or persistent small clouds.

Figure 14 illustrates the correlation surfaces of three cases where the spatial resolution is decreased by consecutive factors of N^2 where $N = 2, 8$. It is noted that basic surface structure is preserved in case 1 which represents a large cloud tracer. Averaging did not destroy the intrinsic features of the surface, which our correlation method is able to appreciate. In case 2 where a small cloud tracer was used, basic structure is retained until a resolution factor of $1/9$ is reached. At this resolution the original sharp intense peak is smoothed over allowing spurious peaks to dominate. In case 3, a small cloud was again selected; however, the dominant peak was not lost due to the absence of spurious peaks in the cross-correlation matrix.

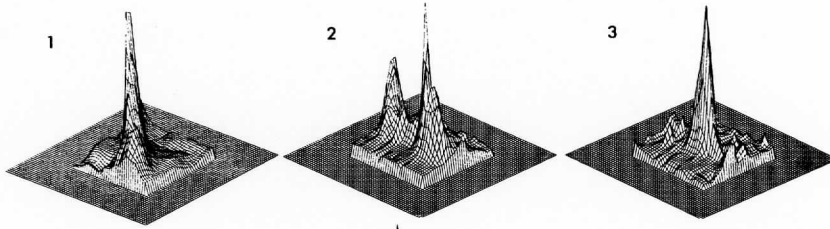
Figure 15 illustrates the same three cases as seen in Figure 14 but this time the gray scale resolution is decreased consecutively from 7 bits to 1 bit. In all three cases, surface information is nearly completely preserved until a 4 bit gray scale is reached. The dominant peak in case 1 is preserved even at a 1 bit gray scale level.

The conclusion to be drawn from this limited set of resolution tests is that full resolution data may not always be necessary for large-scale cloud displacement measurement over 20-60 minute intervals, and there may well be further room for improvement of the precision of existing measuring techniques. These tests also substantiate that the lower frequencies carry most of the displacement information for large-scale cloud motions. For mesoscale observation with SMS where time intervals will be 5-10 minutes, higher resolution will be essential to detect evolution of storms. Thus, processing techniques in McIDAS will be highly dependent on the data patterns and scale sizes of the phenomena to be studied.

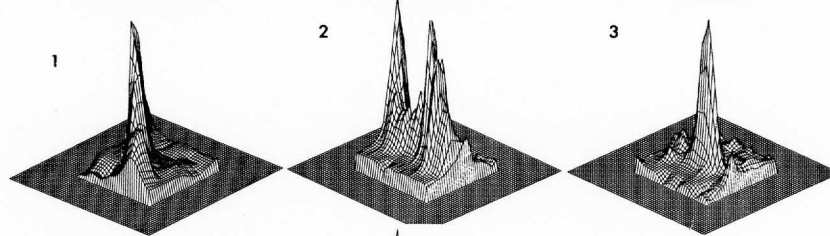
The design of the McIDAS software has been partially dictated by the billing structure maintained by the University of Wisconsin computing facility. We are linked on a remote basis to a Univac 1108 in a time-sharing environment. Wherever possible, advantage has been taken of the cost structure of the 1108 system. This has necessitated the division of the software into three parts:

Resolution
Factor

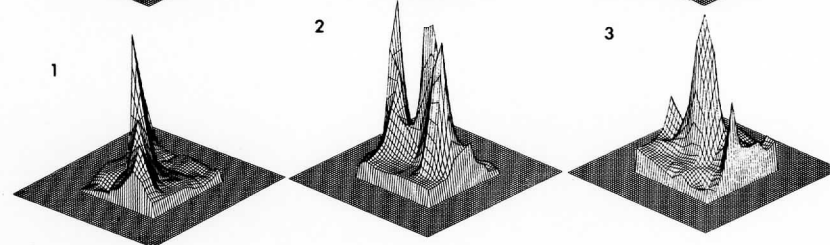
1/4



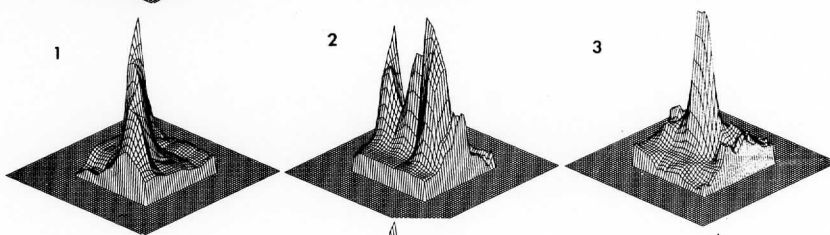
1/9



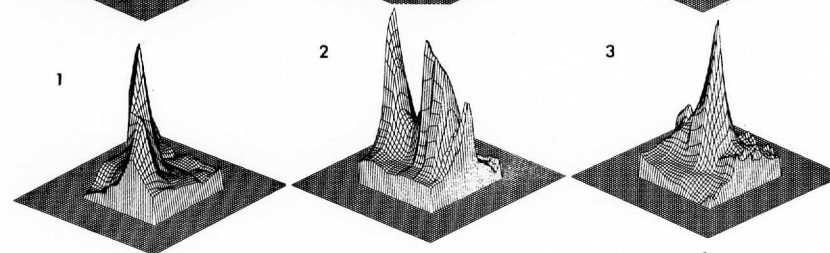
1/16



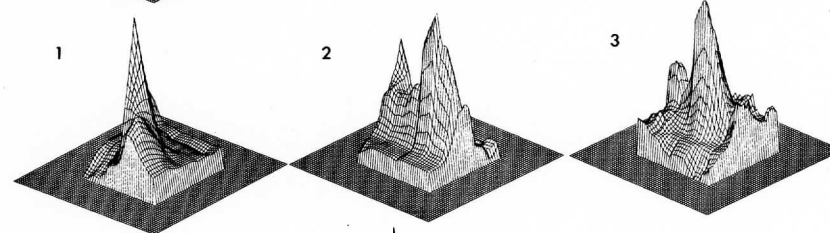
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1/36



1/49



1/64

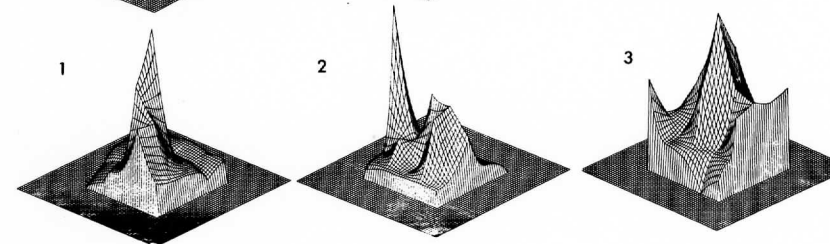


Figure 14. Effect of decreasing spatial resolution on cross-correlation matrix obtained by averaging neighboring resolution elements.

Resolution
(bits/pixel)

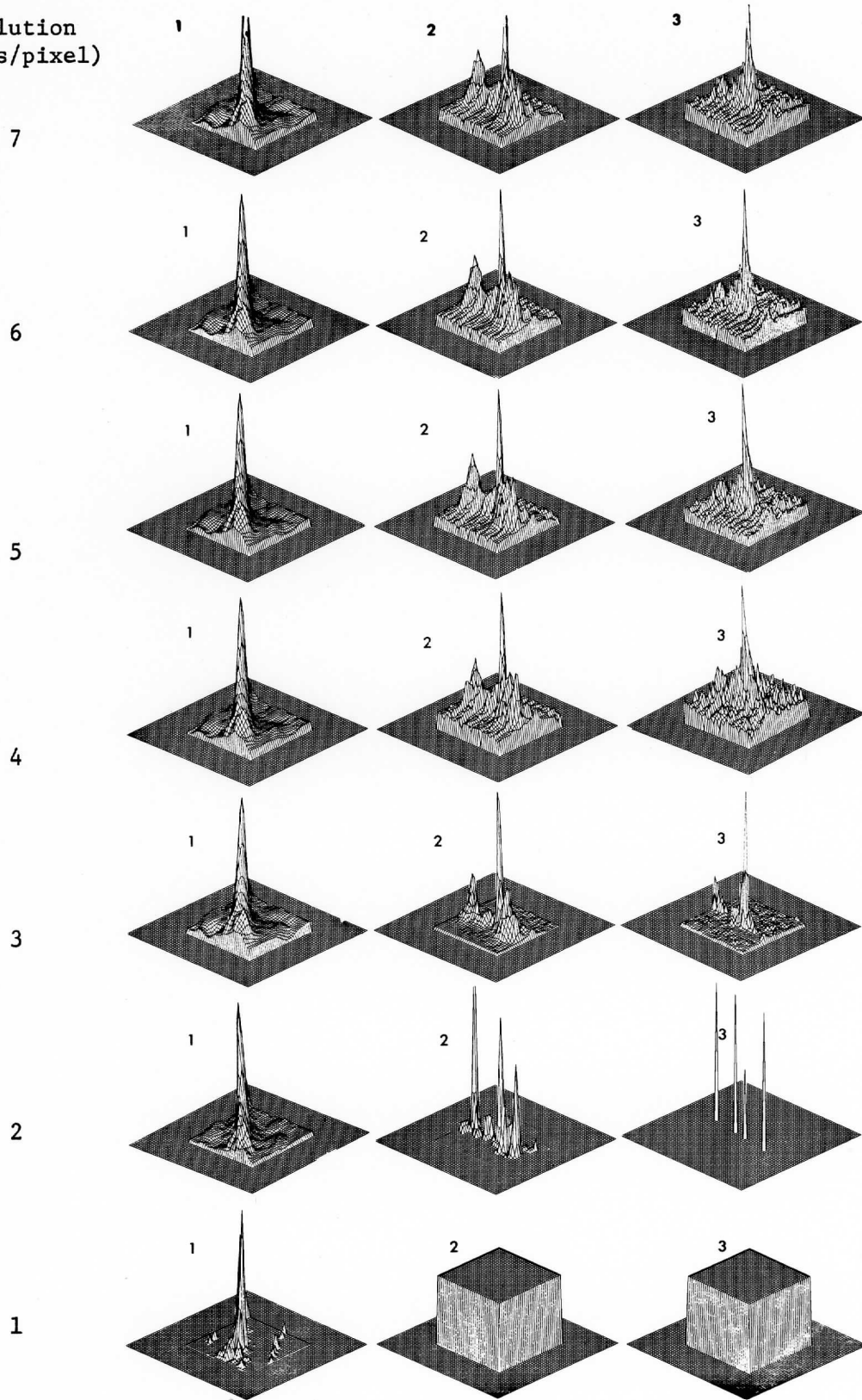


Figure 15. Effect of decreasing brightness resolution on cross-correlation matrix by successive elimination of least significant bit in each resolution element.

1. The ATS Navigation system (program NAVIGATE)
2. The cross-correlation system (program WINDCO)
3. The cloud displacement vector computation system (program WINDANALYSIS).

The function of program NAVIGATE is to compute the navigation parameters for a day of pictures. The inputs to this program are a landmark coordinate and an orbit position for each of a series of pictures. Program NAVIGATE does not have to access any data tape. The output is a set of punched cards containing the transformation parameters for each picture. Landmark coordinates are acquired by displaying landmark segment blowups on the TV monitor. When a feature of the landmark is selected, the cursor is positioned over the feature and a raw line-element coordinate of the feature is relayed to the NAVIGATE program. The accuracy of the cursor selection hardware is adequate for this task. No hard copy material is required.

The landmark coordinates are used to compute the satellite attitude and earth-centering information. The navigation program also prints out line-element coordinates of given latitude-longitude positions. These positions represent the centers of picture segments which will be displayed on the TV monitor for cloud tracer selection. This allows the operator to view a picture sequence with most earth motion removed. The rotation effect of a non-nominal attitude is not corrected on the TV display.

After the operator selects a set of cloud tracers, their coordinate positions are input to program WINDCO. WINDCO's function is restricted to inputting the small image grids and computing the cross-correlation coefficients. The program outputs the index coordinates of the coefficient maximums. These coordinates represent the raw displacement vectors. They are not yet translated into an Earth frame of reference.

Program WINDCO handles a large volume of data. Data segments from two ATS digital pictures must be available in a random access mode to the cross-correlation routines. An ATS picture is composed of 2400 line scans, each of which is sampled 8192 times. The radiance resolution of an ATS picture is 8 bits. Thus one ATS digital picture is composed of 19,660,800 pixels or 157,286,400 bits. This is obviously more data than can fit into even a large computer memory; hence peripheral storage devices are required. The WINDCO software was developed on a UNIVAC-1108 computer which is quite adequate for large volume data handling. By using an asynchronous I/O activity, picture segments are transferred to FASTRAND drum from digital tape, independent of the main program activity.

The digital tape that is accessed by both the TV display system and by the McIDAS software is a raw ATS digital photograph. The data are not remapped to correct for attitude and orbit perturbations. The navigation parameters are used only to remove apparent earth motion from the cloud displacement vectors themselves. The elimination of mapping represents a savings of approximately \$150 per picture.

Program WINDANALYSIS inputs the raw displacement vectors, the navigation parameters, and the missing record information to produce u and v components of cloud displacements. This program includes an optional set of subroutines which map and analyze the cloud displacement vectors. Any quality control technique applied to the vectors is incorporated in program WINDANALYSIS. By decoupling WINDCO and WINDANALYSIS, changes in the navigation parameters or changes in the analysis approach do not require recomputation of the cross-correlation matrices. Furthermore, WINDANALYSIS does not have to access any of the digital tapes.

Before the McIDAS software can be stabilized, there are some problems that have to be considered. The need for a more appropriate quality control scheme has been mentioned. One approach is designing an algorithm which analyzes a single cross-correlation surface and assigns a reliability coefficient to the surface peaks. This algorithm would have to consider a number of variables (slope, intensity, distance) and we do not have a data base large enough to develop a set of rules. Cloud heights are also needed, requiring the software to be able to ingest other types of data.

Presently cloud tracer criteria are needed. This has implications in the handling of multilayer cloud information. The enhancement of low contrast cloud or the amplification of the texture of cirrus cloud may be necessary before these types of clouds can be used. Certainly a good hard look at the tracking performance with cirrus clouds is essential if upper level cloud displacements are to be supplied. The search for an optimum time interval and an optimum grid size design is also a possibility.

McIDAS is now operating. Use of the system in creating a larger data base for further studies will enable many of these questions to be answered.

3. McIDAS TV DISPLAY*

A. Introduction

The McIDAS prototype display** has the capability of converting digital data into standard TV images, storing up to 600 of these images, displaying them in sequence and indicating the exact coordinates of any data point in terms of the original digital data.

* Paper prepared by Terry Schwalenberg.

** This equipment has also been called the "WINDCO System" after the short name of the auto-correlation computer program. It is more accurate to call it the "McIDAS prototype display."

The system utilizes a small computer for data formatting and some control, an Ampex DR-10 Analog Disk recorder for TV frame storage and monitor refresh, a standard TV monitor for viewing, a standard Electronic TV pointer for flagging data, and a specially designed fast storage unit for doing the necessary time base translation.

The system has two modes of operation. In the load mode, the system under complete control of the computer transfers data from the computer to the analog disk and converts it from digital data to standard 525 line TV frames. In the playback mode, the TV frames are presented to the monitor one at a time, or in sequence at variable rates, under the control of the operator. In this mode the computer is not used.

In addition, the system timing is such that the location of each of the $525 \times 768 = 400,000$ pixels of each TV frame is known at all times, with respect to the original digital data loaded from the computer.

It should be emphasized that the McIDAS Display generates standard 525 line TV video frames which are stored on the Ampex DR-10 analog disk. These signals are compatible with the TV industry and can be put on the air through any TV station. Some hardware would be necessary to make the actual patch to a TV station, but it is possible.

The TV compatibility also allows for the use of the standard line of video instrumentation hardware which exists. This line includes video analyzers, video plotters, video processors (enhancers), video quantizers, etc. This instrumentation is available without need for development and is reasonably priced. Also, it can be used at the display system itself, or it can be used after a distribution has been accomplished. In short, using standard TV format allows the operator to draw upon an existing industry of hardware and expertise in order to maximize his interaction with the data.

B. Load Mode

In the load mode, operation is controlled by the computer via a one-way 16-bit digital interface. Eight bits are used for data transfer and eight bits for control.

In actual operation the computer sends 768 eight-bit words to the fast storage unit. This data is sequentially stored according to a digital clock sent with the data. By having the computer provide the load clock, the display and the computer timing do not have to be phased, and they operate asynchronously. When all the data are transferred, the address of the TV line these data are to comprise is sent. This address is from 000 to 524. When the address is received, the system goes to internal timing and unloads the data from the fast storage unit at a high rate, converts it to an analog video signal, and records it on the appropriate section of the Ampex DR-10 disk. When this line is loaded, the computer sends the next line with a new address. In this manner, the entire TV frame is built up line by line.



Figure 16. McIDAS TV Display Hardware. The prototype McIDAS display includes a standard TV monitor mounted above a central control panel. Image data passes from the Raytheon 440 computer in another room to the fast storage module of the breadboard electronics package at the right. Fast storage readout is converted line by line to an analog signal which is recorded on the Ampex DR-10 video disk (not shown). The disk head position is controlled manually during loading by the control box between the telephone and the control panel. During playback, head position is automatically determined from the control panel which governs the number of displayed TV frames and the time interval between them in each time lapse cloud motion sequence. The joystick at the right of the control panel moves a rectangular cursor across the TV screen. Pushing a button will make a paper tape punch under the table record the cursor line-element position.

Proper interlace for TV is achieved in the computer by proper addressing. As the ATS lines are loaded in sequence, the first line is loaded in the first field and the next in the second field, etc.

To understand exactly how this loading is accomplished, one has to understand how video data are stored on an analog disk. The Ampex DR-10 disk consists of one 10-inch disk with two recording surfaces. The disk rotates at 1800 rpm or 30 revolutions per second. Each head then accesses a circular path or track on the recording surface. The heads, one on each surface, can be stepped in increments along the radius of the disk with each position accessing a different track. In this manner, over 600 tracks are available on the disk. At the 30 revolutions per second rate, the head-to-magnetic surface speed is sufficient to allow an FM signal with 4.2 MHz bandwidth to be recorded. This means that one entire TV frame can be recorded on each of the over 600 tracks and played back fast enough (30 frames per second) to be compatible with standard TV.

Standard TV format consists of two fields for each frame with line sequence interlacing. This means that two fields, each containing every other TV line, must be sent to the monitor 30 times per second. This also means that half of the circumference of each track contains one field and the other half contains the other field. In addition, because each TV field is made up of 262 TV lines sent serially, each half of the circumference of the disk is made up of 262 sections. Each of these sections contains 768 TV pixels (for full resolution studio quality TV), and each pixel represents one eight-bit word in the fast storage unit.

In order to load properly, timing is needed to define the track number, field number, TV line number, and TV pixel number. The DR-10 provides most of the timing by means of an optical tachometer mechanically coupled to the disk. Electronics in the DR-10 use the tachometer signals to generate standard TV sync. Vertical sync indicates each TV field, and horizontal sync indicates each TV line. In addition, the tachometer provides a frame start signal to differentiate between fields. To provide for the TV pixel timing, we added a gated oscillator locked to the horizontal sync and free running at approximately 768 times the frequency. The oscillator is released at the beginning of each TV line. The frame start, vertical sync and horizontal sync are tied directly to the surface of the disk. The TV pixel clock is gated for proper phasing, but is free running for each line. However, this is acceptable because the disk is driven with a synchronous motor tied to the 60 Hz line and the long-term and short-term stability of the disk is specified and measured to be about $\pm 1/4$ TV pixel. If necessary, this could be improved by adding another fixed head and using it to record a timing track.

In order to load the disk, the 768 digital words must be converted to an analog video signal at a rate of over 12 million words per second. The computer cannot supply words at this rate, and a unique aspect of the McIDAS display is a piece of hardware called the fast storage unit. The fast storage unit is a short term, sequential access, high speed digital memory implemented with MOS



Figure 17. Breadboard Electronics. The heart of the McIDAS display system is the fast core, a set of parallel shift registers which store digital image data line by line as it comes from the computer and, when the videodisk has rotated to the proper position, spits the line out at a 12 MHz word rate through a D/A converter to be written on the disk. Timing is preserved to better than 1/4 pixel through use of an optical tachometer, and gated oscillator, so that every pixel on every line of the TV image has a fixed angular position on the disk. A cursor is displayed on the TV screen to reference the exact line and element number of any point in the image.

integrated circuit dynamic shift registers. Each chip can store 256 four-bit words and read them out at over 15 million words per second. With just six of these chips and appropriate digital control and clock drivers, the fast storage unit achieves the time base translation necessary to allow a computer to generate a TV frame.

The digital-to-analog converter (DAC) is a standard item and has a 50 nsec settling time. Also, although most of the control is provided by the computer in the load mode, some hardware is still needed.

C. Playback Mode

Once the system has been loaded with TV frames, the frames can be played back from the disk to a standard TV monitor. Exactly what is recorded on each frame is not important to the operation of the system, but for our purposes we load portions of ATS pictures. The amount of data contained in a single ATS picture exceeds the capability of a single TV frame. However, a single ATS picture can be divided into 16 areas and each area loaded into a TV frame to give an ATS picture to near full resolution. Or, an entire ATS picture can be loaded into one TV frame at reduced resolution. This manipulation of the data is done in the computer during the load phase and allows great flexibility.

If the same area of a number of successive ATS pictures is loaded on adjacent tracks on the disk, these areas can be displayed in sequence by simply advancing the heads. The playback control provides the operator with the ability to set up a "loop" of up to 16 TV frames. The system will then automatically display the pictures in sequence, retrace back to the beginning and repeat. The rate at which the loop is advanced is controlled by the operator from about 10 new frames per second to about one new frame in two seconds. A manual loop advance option is also available. The important thing is that the operator can set the playback rate fast enough to give the "movie" effect and can therefore see weather in motion. Essentially, then, the McIDAS display allows the operator to go from raw digital data to a dynamic display without the time delay and registration problems inherent in hard copy and film loop methods.

Another very important aspect of the playback system is the coordinate unit. This subsystem allows the operator to flag any data point of interest in any TV frame and know the exact coordinates of that point in terms of the original digital data loaded by the computer. This capability is achieved by continuously keeping track of the line and TV pixel number coordinates of the TV spot as it traverses the raster which paints the TV picture. Actually the coordinates used are those of the head on the disk, but the head and the TV spot are always looking at the same data. These coordinates are known very accurately because of the vertical sync, horizontal sync and TV pixel element timing signals which are tied to the disk and which were used to load the data on the disk. A cursor is superimposed on the video. The location of the cursor is controlled by a joystick which allows the operator to position the

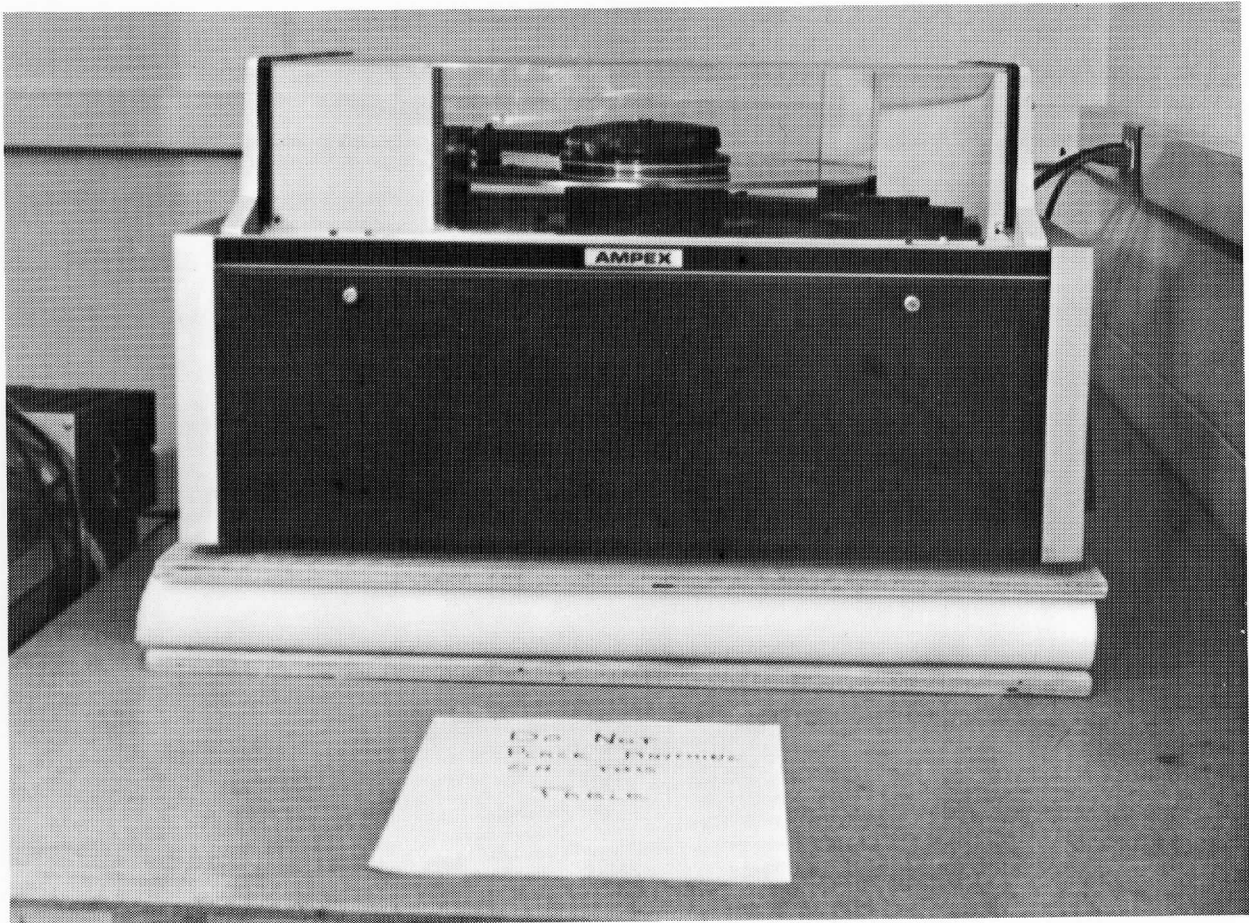


Figure 18. Ampex DR-10 Videodisk. The videodisk provides storage for over 600 separate TV frames. Video sync is governed by an optical tachometer mechanically coupled to the disk. During loading, a gated oscillator is locked to the horizontal sync pulses and determines the rate and starting time for emptying the fast core registers onto the disk. Playback for display is completely compatible with standard TV, permitting use of the entire range of industry technology available as off-the-shelf hardware. Interfacing to a TV station is also possible for transmission of the satellite images and other interpretive material to the general public.

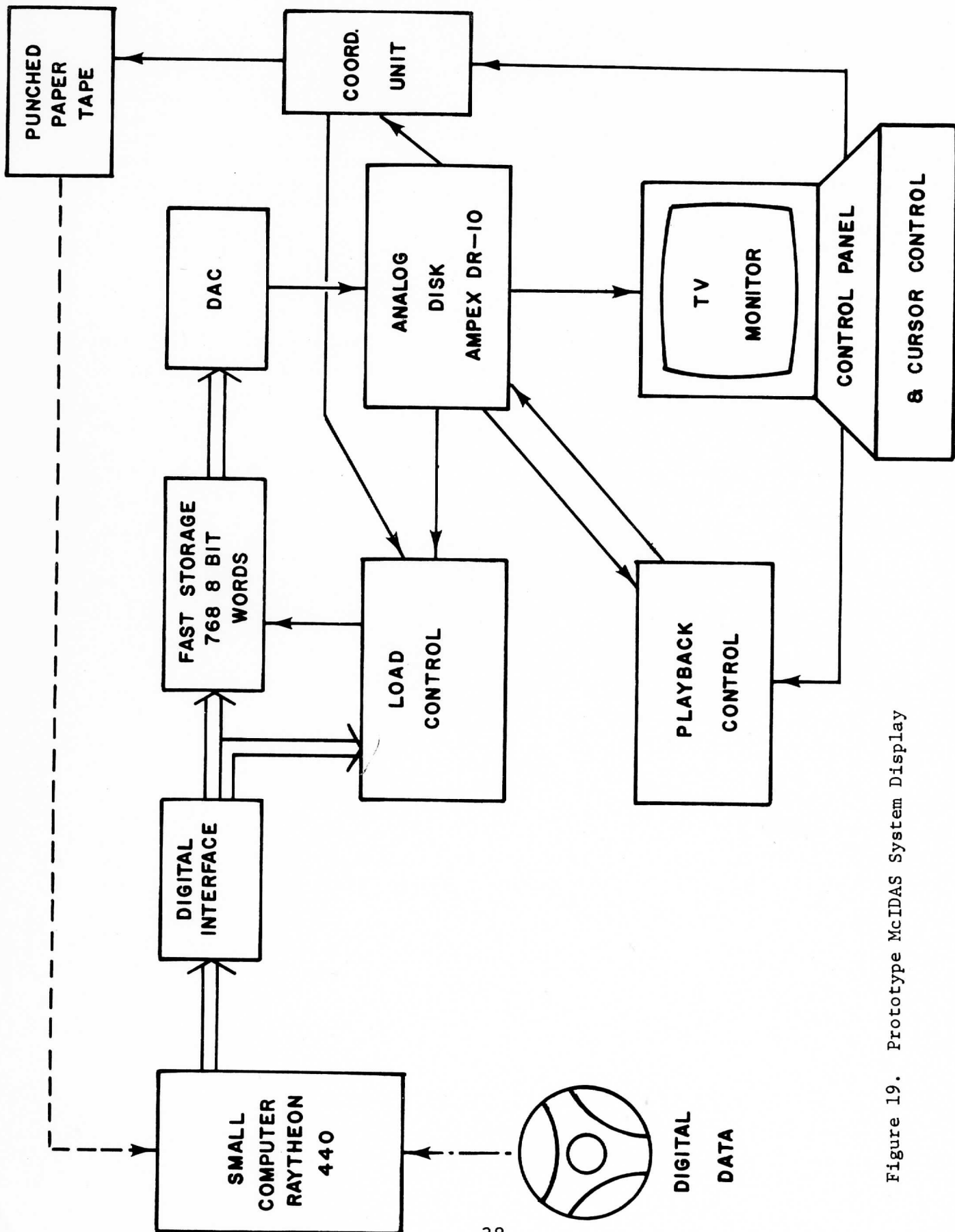


Figure 19. Prototype McIDAS System Display

cursor quickly and accurately anywhere on the display. The cursor is rectangular with the operator having control over its height, width and brightness. This cursor is generated with a standard electronic TV pointer. Such devices are available with other types of cursors in addition to the rectangle. The cursor is not generated using the timing signals, but because it is superimposed on the data, when it appears it must be at the location of the TV spot and therefore the disk head. The pulse which generates the cursor is also used to transfer the TV line number and pixel number of the head at that instant into holding registers. These coordinates are displayed to the operator and also stored on punched paper tape by means of an interface to a perforator. These coordinates can then be loaded back into the computer.

The operator can use this coordinate unit to flag clouds within the pictures that are to be processed for displacement vectors. These coordinates are then used by the computer to go to the original digital data and extract a small area which includes the cloud, for its correlation process. Thus, although the McIDAS System Display does degrade the video in both gray scale and resolution, it does retain the timing so that the actual data analysis can be performed on the original uncompromised data. The purpose of the Display System is to allow the operator to interact with the data easily and quickly in order to select areas of interest.