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THE WINDCO SYSTEM

The Space Science and Engineering Center

The University of Wisconsin

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The measurement of winds to an accuracy of three knots (± 1 meter per second) over large regions presently lacking ground or rawinsonde observations is a major requirement of the Global Atmospheric Research Program. An interactive man-computer system called WINDCO is being developed at the Space Science and Engineering Center to measure cloud motion from ATS pictures from which wind field data can be derived. This system is capable of providing individual real-time cloud motion measurements to an accuracy better than 1.5 m/sec. The required GARP wind measurement accuracy can be achieved by averaging several cloud displacement measurements obtained within a GARP grid area. The accuracy may be improved by as much as a factor of 4 when high-resolution visible Synchronous Meteorological Satellite (SMS) data become available.

The photographic coverage of the earth's atmosphere provided by ATS-I and ATS-III satellites has been a valuable data source for studies of atmospheric phenomena. ATS pictures have enabled us to view weather in motion and the geometrical precision inherent in the ATS spin-scan camera data provides a basis for measurement of cloud motion.

Tracking cloud tracers between two digitized ATS images is the function of the WINDCO system. The system requires a human operator to select individual small clouds or distinctive features of larger cloud masses to serve as cloud tracers. Rough locations of tracer clouds are then input to a computer which references the original ATS data from which cloud motion vectors are computed. In this way, any errors introduced in data selection are ignored by the computer in the final measuring process. The displacement measurement is accomplished by the application of two-dimensional cross-correlation analalysis for each individual cloud element.

The ATS satellite is a massive flywheel spinning about 100 revolutions per minute. The large inertial stability of this viewing platform provides a very precise earth scanning motion for the imaging system. Scan lines are so straight and scan rates are so constant that short-term errors are not detectable. It is this precision derived from the large body spinning in space that makes it possible to determine cloud motions accurately. Development of sufficiently precise techniques for aligning two of the earth images has been the major problem in making accurate cloud motion measurements. Any misalignment of the earth images causes systematic errors in cloud displacement measurements. The spin axis of the ATS satellite is not precisely parallel to the earth's spin axis and because of oscillating satellite orbit motion, earth images appear to move slightly within the picture frame. This apparent earth motion must be removed or compensated in determining the cloud motion vectors. In the WINDCO system, this apparent motion is removed by applying several correction factors to the function which transforms the data from satellite coordinates to earth coordinates. This process is called "ATS Navigation."

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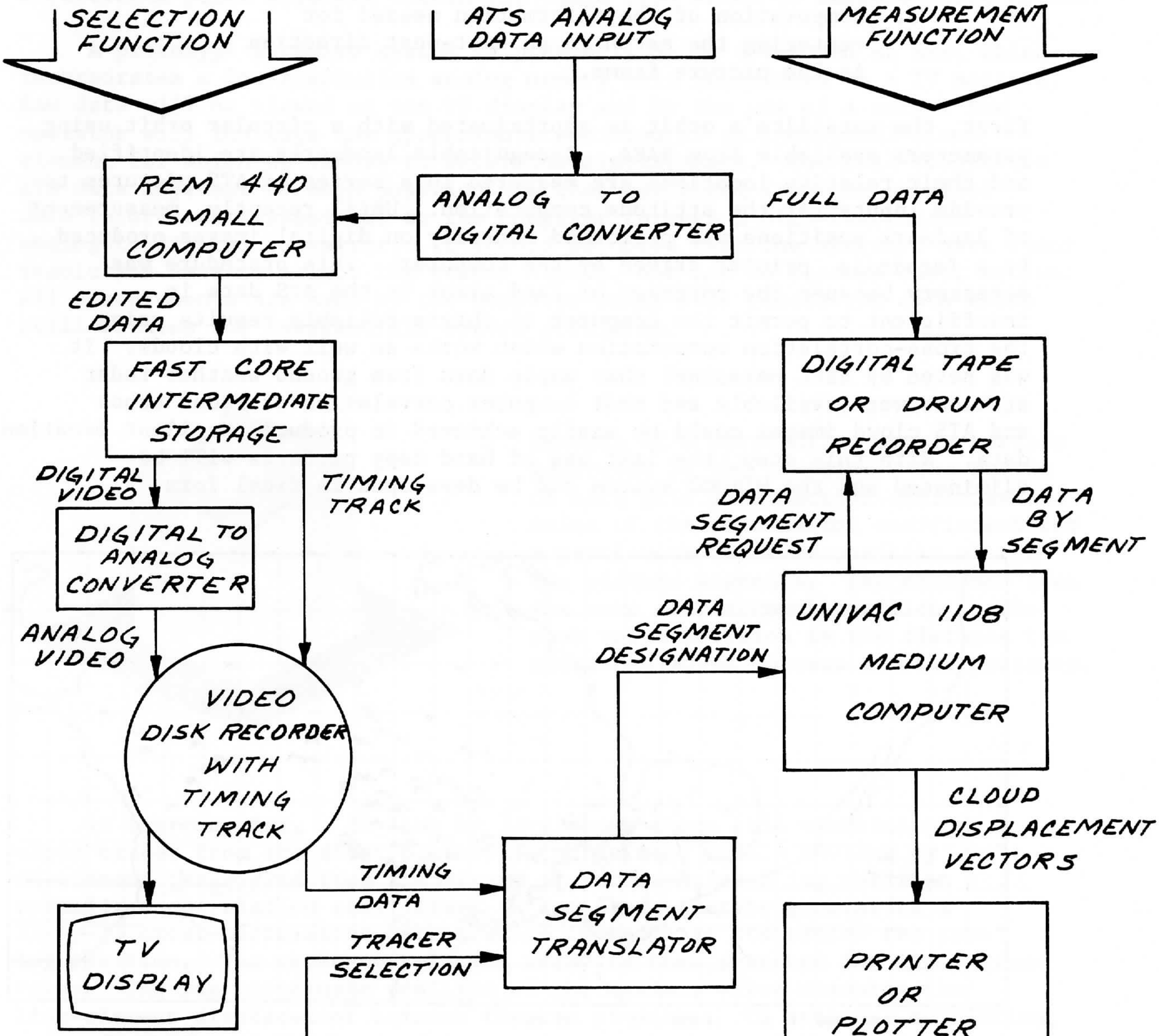
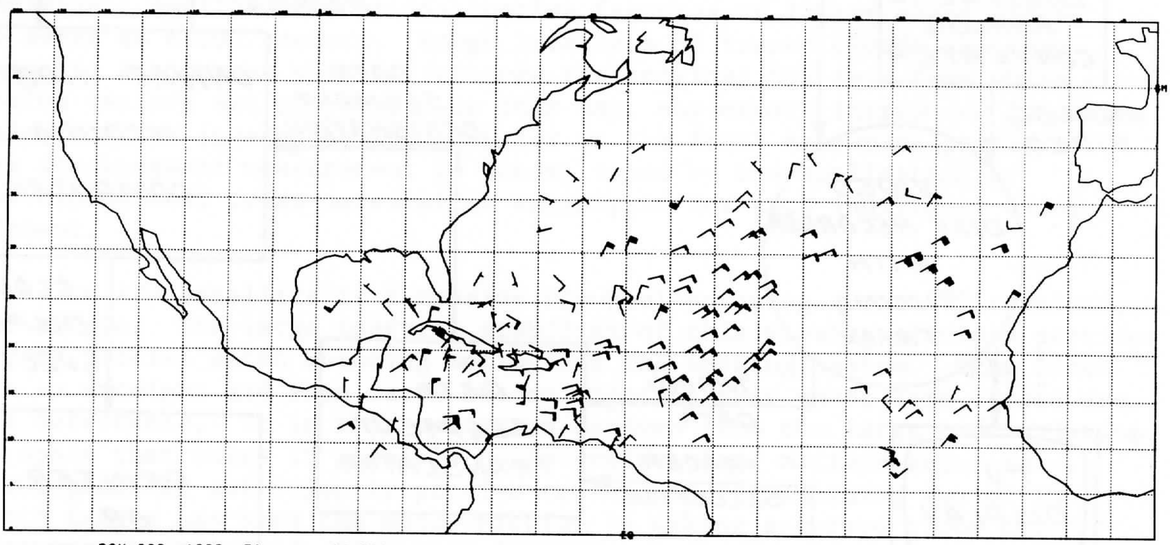


The prototype WINDCO system being developed by SSEC uses an operator to select individual tracer clouds from a TV picture and a computer to perform precision cloud displacement measurements. All video equipment is assembled from standard commercial TV components. The system is designed to produce 20 highly accurate cloud displacement vectors per minute at a cost of about 10 cents per wind.

The ATS navigation model is a three-step procedure:

1. Approximation of the satellite's orbit.
2. Derivation of the satellite's attitude.
3. Computation of the information needed for centering the earth in an east-west direction in the picture frame.

First, the satellite's orbit is approximated with a circular orbit using parameters available from NASA. Recognizable landmarks are identified and their relative locations are measured in a series of ATS pictures to provide inputs for the attitude computation. Until recently, measurement of landmark positions was performed manually on digital images produced by a facsimile printer driven by the computer. This procedure was necessary because the contrast of land areas in the ATS data is insufficient to permit the computer to obtain reliable results using the cross-correlation computation which works so well with clouds. It was noted by SSEC personnel that ample data from ground weather radar stations were available and that computer correlation of radar echos and ATS cloud images could be easily achieved to produce excellent location data. With this step, the last use of hard copy pictures will be eliminated and the WINDCO system can be developed in final form.

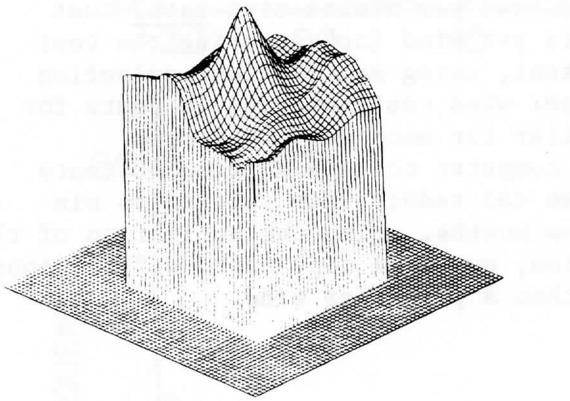


An example of cloud displacement vectors produced by WINDCO from ATS data for July 28, 1969. Cloud tracers were selected to test the WINDCO system and no effort was made to distribute vectors uniformly, nor were bad data points eliminated.

The information for centering the earth in each frame is derived from the satellite's orbit and attitude, and landmark measurements from that particular frame. Landmark location data from several frames are smoothed in accordance with functions which capitalize on the periodicity and great short-term stability of the ATS satellite attitude and orbit.

This smoothing provides relative image alignment with errors amounting to a very small part of a picture element. The final result of this procedure is the ability to transform ATS picture coordinates to earth coordinates and vice versa with great accuracy. Hence, the computer can establish a reference point anywhere within the image from which to measure cloud motion.

A prototype hardware system is presently being developed at SSEC which incorporates a low-resolution analog memory unit interfaced to a TV monitor. Raw data will be viewed on the TV display and by the use of a cursor the operator will indicate the approximate position of an individual cloud element for which he wishes to determine displacement. The full resolution ATS data adjacent to each position are then extracted from the original data record and transmitted to the computer through a high-resolution analog-to-digital converter. It should be noted that the operator uses lower resolution data to select the tracer clouds, but not to measure their motion. All measurements are made by the computer using full resolution data which still retains the inherent ATS system precision.



Example of a correlation matrix surface generated by the computer. The height of each grid intersection indicates the value of the correlation coefficient for a particular relative position of the two picture segments. The distance from the zero displacement position to the peak value position is the distance the cloud has moved between the two pictures.

In the computer, a 32-line by 32-element image grid containing a cloud tracer from the first picture is correlated with a 64-line by 64-element image grid from the second picture. At each lag position a normalized correlation coefficient is computed, thereby generating a 33-by-33 cross-correlation matrix which includes as its center the zero lag position. The cross-correlation array is then searched for its maximum value. The lag coordinate position of the maximum value measures the line-element displacement between the two pictures. To increase resolution, a two-direction quadratic is fitted to a neighborhood of the maximum coefficient. This interpolated lag coordinate allows measurements of displacement at non-integral positions. This shift information is transformed to latitude-longitude coordinate end points by using ATS navigation parameters and these are the cloud displacement vectors. Since the computer operates only on a small selected data subset and the navigation parameters are used to map only measured displacements rather than the entire original image, digital data handling costs are reduced to a minimum.

To be sure that only accurate cloud displacement vectors are finally printed out, a simple but very effective quality control system is used. Instead of using data from only two ATS images, three consecutive images are used, and vectors for the same cloud tracers are computed from image pairs 1-2, 2-3, and 1-3. These vector sets are subtracted and the distribution of the residuals examined. Differences larger than 1.5 m/sec indicate bad data, and those vectors (about 5 to 8 percent of the total) are rejected. This bad data is mainly due to cloud evolution over the 20-40-minute interval. As the time interval between pictures increases, cloud tracers have more time to grow, evolve, and disappear. If the mean of the differences is not zero, the cause is probably a residual navigation or line count error in one of the images and it can be identified and corrected by using all three difference sets. Of course, this quality control scheme is based on the assumption that the wind field over a large area will not exhibit a mean acceleration greater than 1.5 m/sec over a 20-minute period, but that seems to be a safe assumption.

The prototype system being assembled by SSEC is designed to produce approximately 20 cloud displacement vectors per minute at a total cost which we believe will be about 10 cents per wind (not counting the cost of the satellite, of course). At present, using manual cloud selection and manual landmark measurement, our per wind costs average 18 cents for computer processing plus about one dollar for manpower, hard copy production, etc. We have brought the computer costs down from 80 cents in five months, and we are confident we can reduce them further to six or seven cents per wind in the next few months. With the activation of the video console for cloud tracer selection, our hard copy costs will disappear and manpower costs will drop to less than a penny per wind.

To maintain quality of data SSEC obtains three cloud displacement fields from three consecutive ATS images in which the same tracer clouds are used. The curves in the following diagram show the distribution of the N-S component of the remainder after the displacement vector fields are subtracted one from another. Note the small and easily recognizable number of "bad data" cases which fall outside the acceptable three knot limit. The slight offset of the curves from zero mean indicates a small residual navigation error in two of the vector fields. This error can be removed by correcting vector values with a reiterated navigation output.

V-COMPONENT COMPARISONS FOR 28 JULY 1969 (DAY 209)

T_1=1432 Z, T_2=1458 Z, T_3=1524 Z