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COMPUTER TRACKING OF TEMPERATURE-SELECTED CLOUD PATTERNS

Washington, D.C.
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NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
Richard A. Frank, Administrator

National Environmental
Satellite Service
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COMPUTER TRACKING OF TEMPERATURE-SELECTED CLOUD PATTERNS

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ABSTRACT. Cloud-tracking experiments were performed with Geostationary Operational Environmental Satellite infrared picture sequences after the images had been modified by deleting various threshold temperatures. The purpose was to assess the effectiveness of this type of image manipulation for segregating cloud layers for computer tracking. Such studies can contribute to design of an operational wind-derivation system based on the man-computer approach. The interactive system at Goddard Space Flight Center (GSFC) known as the Atmospheric and Oceanographic Interactive Processing System (AOIPS) was augmented to provide the capabilities needed for this co-operative work between GSFC and National Environmental Satellite Service.

The temperature-threshold technique was found to be effective in a restricted range of situations where a single temperature threshold could be applied to isolate either a high-level or a low-level cloud pattern. It was not successful in segregating middle clouds by applying both upper and a lower threshold. Analysis revealed that the radiating characteristics of clouds in the upper troposphere and, to a lesser degree the crude resolution of infrared imagery, created large temperature changes during picture sequences which limited the success of this thresholding technique. It must be carefully applied by an experienced operator working on man-computer interactive equipment. Earlier work had already shown that thresholding improved the percentage yield of acceptable low-cloud vectors. The present experiments showed this improvement to be the consequence of eliminating correlation arrays that are heavily influenced by upper clouds rather than any capability to measure low-cloud motions visible through holes in the upper layers.

These experiments showed that temperature thresholding is not applicable to routine use for all cloud layers. Rather it is an auxiliary tool more useful for diagnosis and development. An incidental result was the finding that all tracking algorithms appeared to underestimate speed of cloud patterns.

These experiments on AOIPS (a system designed for research use) suggested several capabilities that should be included in the design of an operational wind-derivation system. First, the need for an interactive system was reemphasized. Second, temperature and brightness thresholding should be available. It was found to enhance quality control in some situations. Third, design will benefit from the conclusion that in many cases interactive tracking techniques can yield accurate vectors with simple and fast-running algorithms, thereby eliminating the need for the slower-running temperature-thresholding algorithm. Finally, two AOIPS features should be included in order to enhance the quality of the operational product: (a) The capability to calculate vectors from a portion of displayed sequence, and (b) quality control procedures similar to those described for these experiments.

1. INTRODUCTION

Early in the era of geostationary satellites it became clear that one could distinguish between clouds in different layers by their contrasting motion. Lower clouds can be seen moving beneath broken or thin layers of upper clouds, thereby displaying two distinct fields of motion. Fixing attention on one flow field, an analyst could ignore conflicting motions and measure the displacement of selected clouds, despite their changing brightness, size, and shape--first in one layer and then in the other.

Automated pattern-matching algorithms for measuring cloud displacement soon appeared. While highly successful in computing displacement of cloud patterns which are confined to a single layer, these automated techniques are unable to cope with more than one field of motion within the same array. Vectors calculated under such circumstances represent the displacement of whichever layer produced the greatest pattern variance. If both layers contributed significantly to the variance, a mean displacement, of sorts, is calculated, representative of neither.

With the advent of infrared imagery (in the water vapor window), cloud layers were distinguishable by their apparent temperatures as well as by their contrasting motion. This suggested a way to handle multilevel situations. Clouds at different levels, it was suggested, might be segregated on basis of their temperature before the pattern-matching was performed. For example, in a region where three layers of clouds existed in scattered or broken layers, pixels (picture elements) with temperatures greater than 269°K (700 mb in the standard atmosphere) and temperatures less than 252°K (500 mb) might be deleted, leaving only the selected "slice" to be pattern-matched. The computer would then derive displacement of the cloud pattern which lay in the nominal 700-mb to 500-mb layer. If successful, this would eliminate the influence of clouds at other levels and provide a measurement of middle-cloud motions.

Several years ago we carried out some experiments with "sliced" arrays using the National Environmental Satellite Service (NESS) operational automated procedure (Bristor 1975). Results were mixed. Deletion of all lower temperatures (viz, those less than the 700-mb temperature analyzed by the National Meteorological Center) improved the percentage yield of acceptable low-level vectors, principally by eliminating vectors influenced by upper-level clouds. That is, arrays representing high clouds were discarded before they reached the editor. Deletion of vectors that would otherwise have to be edited manually improved efficiency and so was incorporated into the operational routine. But the results with middle and upper clouds were often puzzling and generally unsatisfactory.

Middle-cloud "slices" produced an erratic mix--sometimes neighboring measurements yielded vectors normal to each other with differences that exceeded 50 m sec^{-1}. Deletion of middle- and low-level temperatures to eliminate all but the coldest clouds, on the other hand, produced internally consistent vectors but, once nonrepresentative measurements were edited, the yield was very low. Most of the latter were those that (correctly) measured the sluggish motion of deep convective clusters rather than the motion of cirrus clouds which were being carried along by the upper-level flow.

These developments, together with theoretical arguments suggesting that results might be sensitive to the type of algorithm employed, indicated that this technique of temperature thresholding ("slicing") should be thoroughly investigated before NESS incorporated it into an operational system. Our previous experiments with the operational procedure on the central computer facility did not provide a means to study the effects of variables such as cloud conditions, so that work was terminated. More recently the Atmospheric and Oceanographic Interactive Processing System (AOIPS) at Goddard Space Flight Center, was augmented to provide the capabilities needed for this study. The following pages report the experiments carried out on AOIPS to investigate the characteristics of cloud tracking on arrays which were modified by temperature thresholding.

2. DESCRIPTION OF THE EXPERIMENTS

2.1 AOIPS Capabilities

Central to this study was the capability to monitor the behavior of "sliced" cloud patterns throughout a sequence of images to examine the effect of various temperature thresholds and to inspect the resulting calculation of motion, all in an efficient, interactive fashion. AOIPS programs (Billingsley 1976) were augmented so that thresholds could be controlled by joystick while the animated sequence displayed the consequences. Deleted pixels were rendered black.

As mentioned above, different correlation algorithms are expected to react differently to a given cloud condition. In order to study two commonly used algorithms, linear correlation computation was added to the algorithm already on AOIPS. The latter, called the Euclidean Norm, was developed at the Space Science and Engineering Center, University of Wisconsin (SSEC staff 1972). Both of these techniques were programmed to operate with either modified (sliced) or unmodified arrays. Different behavior was anticipated for the following reasons.

Design of the array-handling logic of AOIPS requires that correlations be calculated on arrays of some fixed size. That is, if the initial array were comprised of 15 by 15 elements, it must be matched with other 15 by 15 arrays. Therefore in the case of "slicing" all deleted elements must be replaced with some other number before correlating the patterns. Now the Euclidean Norm is essentially the sum of squared differences of corresponding elements. The best pattern match produces a minimum of that function. Where array elements are replaced with any arbitrary constant, sharp-edged "black holes" are produced. Large gradients thus created contribute strongly to the squared differences if they are mismatched. The Euclidean Norm is minimized when these gradients marking the "black holes" are matched, thereby tracking the very clouds which we sought to eliminate. This would be a serious deficiency when we sought to eliminate the effect of cold clouds in order to track warmer targets.

Similar argument militates against linear correlation obtained by means of the Fast Fourier Transform (FFT), an efficient procedure frequently used in array-handling systems. Because the FFT translates the spatial pattern into the wave domain, the "black holes" show up as significant waves and thereby exert a strong influence on the resulting correlation coefficient (Arking et al. 1978). The straightforward linear correlation computation, on the other hand, involves summed products of the paired temperatures minus the product of the means of those temperatures. Because of this subtractive term, it can be shown that if the deleted values are replaced with the mean of the paired temperatures, the "black holes" will have a minimum effect on the result. On basis of this argument, it appears that the linear correlation should be used for matching "sliced" patterns and that the deleted elements should be replaced with the mean of the nondeleted elements rather than an arbitrary constant. Linear correlation, with replacement of deleted pixels by the mean, was implemented in the AOIPS software. Further, in order to examine the validity of the argument for "replacement by the mean," an alternate command was provided to replace the deleted elements with zeroes. These options were programmed for the Euclidean Norm as well. Zero replacement gave the most stable results, however, and was the only mode used for the Euclidean Norm in these experiments.

2.2 Data and Description of the Experiments

The experiments consisted of applying these various tracking calculations to identical cloud patterns in order to compare their behavior under various cloud conditions. Because of the time and effort needed to prepare AOIPS-compatible tapes, this investigation was confined to sequences that were already in the AOIPS tape library. Nevertheless, the following list shows that a variety of situations were represented. The following four-image sequences were used:

Tropical convection Atlantic	Centered about	1200 GMT	11 Sept. 1974
" "	" "	" "	15 Sept. 1974
Periphery of hurricane Gulf of Mexico	" "	2000 GMT	22 Sept. 1975
Cold front and Cyclone Atlantic	" "	2200 GMT	2 Feb. 1976
Jet stream cirrus Caribbean and W. Atlantic	" "	1300 GMT	5 Feb. 1977

Initially sought were situations where three different layers of clouds might be separated by temperature thresholds. No such cases could be found so this study treats only two-layer cases in which "sliced" upper level clouds and lower level clouds were tracked by each of five methods:

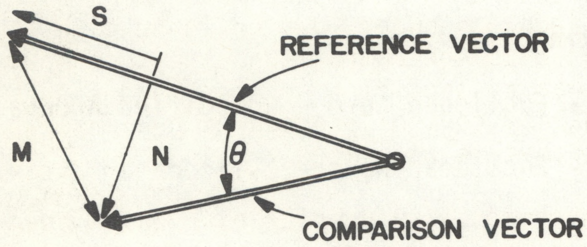
1. Manual cloud tracking
2. Computer tracking - Euclidean Norm - unmodified arrays.
3. Computer tracking - Euclidean Norm - "sliced" arrays - zero replacement.
4. Computer tracking - Cross Correlation - unmodified arrays.
5. Computer tracking - Cross Correlation - "sliced" arrays - mean replacement.

Method 1 was considered to be the "ground truth" for this experiment because of the demonstrated ability of experienced analysts to measure cloud motions under difficult conditions. Vector-by-vector differences from each of the computer measurements of high clouds are summarized in table 1. When our quality control procedure showed a vector to be questionable, it was discarded. This did not bias the comparisons in favor of any one algorithm, because no one of them was responsible for more than its fair share of failures. Stringent quality control procedures are available on AOIPS. The following diagnostic parameters were used.

1. Motions of a given cloud on successive pairs of images are displayed together with their standard deviation. In a 4-image sequence, for example, vectors are computed and displayed digitally from image 1 to image 2, from 2 to 3, and from 3 to 4. Large dispersion marks questionable measurements.

2. Where tracking is performed by correlation, the sharpness of the correlation peak is displayed, and
3. A warning appears if the correlation peak lies on the boundary of the search area.
4. After the above items appear, a cursor on the animated display is also animated and it flies along with the velocity just computed. It is easy for the operator to see if the calculated displacement is indeed the motion he attempted to measure.
5. The operator must accept or reject each vector. This ensures that a quality judgment is made on each measurement at the time the above-listed parameters are displayed.

Individual vectors calculated by each of the four computer methods were subtracted from the corresponding manual vector in a right-hand coordinate system oriented along the manual (ground truth) vector. This corresponds to the "reference vector" of figure 1.



θ = Directional difference (DIR DIFF)
S = Difference along streamline (STRM DIFF)
N = Difference normal to streamline (NML DIFF)
M = Magnitude of vector difference (VCTR MAGN DIFF)

Figure 1. Natural coordinate system and definition of differences between vectors.

2.3 Results

As these experiments progressed, it became evident that the crude (8-km) resolution of the infrared images compromised the physical model which is implied by this approach, namely, that within a given array a significant number of (the same) lower clouds could be clearly distinguished through the holes in upper clouds throughout a given sequence. This model turned out to represent a rare condition. The typical scale and nature of the cloud fields and their radiating characteristics eliminated all three-layer situations and a large fraction of two-layer cases.

Frequently the holes and clear spaces were sufficiently small to be smeared over by 8-km resolution. Further blurring was caused by the radiating characteristics of upper clouds. Edges of cloud patches tend to be more transmissive than their centers so that the apparent temperatures do not change abruptly at cloud edge. Hence, holes already blurred by crude resolution are further smoothed--an effect which reduces the temperature contrast between high and low clouds and makes it difficult to set a threshold which separates them. The difficulties caused by these characteristics vary with type of cloud condition and it could be evaluated only by inspecting their effect on the animated display.

Particularly damaging are the radiating characteristics which produce picture-to-picture changes of apparent temperatures. Infrared temperature of a cloud depends, among other things, upon its transmissivity and its background. For example, the apparent temperature of a cirrus patch with a transmissivity of 0.2 which is lying above a dense 400-mb cloud could increase by 16°K if the middle cloud moved away. Thinner cirrus with 0.5 transmissivity would show a 32°K increase under similar conditions. Hence, upper-cloud temperatures fluctuate over a wide range, depending on the chance superposition of clouds at different levels. A threshold value that excluded cirrus at one time might include a significant amount of cirrus half an hour later, and vice versa. Moreover, AOIPS displays revealed that a large proportion of apparent cloud temperatures corresponding to those of the middle troposphere were actually produced by cirrus. This fact, together with the pervasive problem of temperature change, was evidently responsible for our erratic results in the earlier attempts to track middle clouds. In brief, these experiments showed thresholding to be of limited utility for tracking multilayer clouds by computer but was useful for diagnosing complex situations and could be used to sort out layer interactions and aid the analyst in manual tracking complex cloud patterns. While it would be little used in routine derivation of cloud drift winds, it is a valuable capability to provide in an operational system.

2.3.1 Middle Clouds

Temperature changes produced by the interaction of middle and upper clouds preclude "slicing" and tracking middle clouds in situations where both an upper and a lower threshold must be applied to segregate an intermediate layer. AOIPS animation of those situations made it clear why no suitable three-layer situations could be found for the present work.

Temperature changes can produce enormous pattern changes from one "sliced" image to the next so the best pattern match yields erratic and erroneous vectors. Typically the computation showed the influence of cirrus clouds, either by means of their motion or through their effect on pattern changes. In either case, correspondence with motion at middle levels was only coincidental.

Our search for suitable three-layer cases in the present study failed, not only because situations where all layers can be seen are relatively rare, but because cirrus clouds cannot be excluded throughout a sequence by excluding low-temperature pixels. If properly used, imposing a single threshold to isolate either low or high clouds was somewhat more successful.

2.3.2 High Clouds

Consider the task of segregating upper clouds by deleting warmer temperatures. The effect of picture-to-picture temperature changes can be countered by setting the threshold sufficiently low to exclude the range of temperatures in which the greatest change occurs. Providing a low threshold can be found which also retains a substantial number of pixels for correlation, the results are almost always satisfactory.* Satisfactory vectors notwithstanding, the advantage of slicing is not great. Frequently cold cirrus dominate the pattern; consequently sliced and unmodified arrays yield about the same result. This is illustrated by the small difference between the first and third columns of table 1.

Column 3 indicates that the best automated vectors were obtained by tracking "sliced" patterns with the Euclidean Norm--a result that might seem to be incompatible with the earlier discussion of errors caused by tracking "black holes." No conflicts exist in the case of upper clouds. Where all higher temperatures are deleted, the only remaining pattern is that of the cold clouds which appear against a uniform (black) background. Therefore, no spurious "black holes" are created and only valid targets remain to be tracked. The slight advantage exhibited by the Euclidean Norm apparently arises from its sensitivity to the sharp gradients that exist at the boundaries of all cold clouds after slicing.

Application of a temperature threshold to the animated sequence appears to enhance one aspect of quality control. Upper cloud targets are isolated from the confusing image of low clouds or terrain so it is easy for the operator to verify that the computed motions shown by the flying cursor correspond to those of the cold targets.

Table 1 shows that most of the differences from manual measurements are due to speed rather than direction deviations. Normal differences are small and unbiased. The positive sign of all "STRM DIFF" on the other hand suggest bias. The computer vectors tend to underestimate cloud speed.

Table 1 suggests the following conclusions:

a) Vectors computed by the Euclidean Norm algorithm on cold targets, isolated by eliminating all but the lower temperatures, yield the best results. The worst results were obtained by calculating vectors on the same data by cross correlation.

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*This condition cannot always be satisfield. Where thin cirrus exists above lower clouds, setting a threshold sufficiently low frequently eliminates so many elements from the array that no valid correlation can be calculated.

Table 1.--Differences between upper cloud vectors derived by various methods with 90-minute sequences of infrared pictures

		UNSLICED ARRAYS		SLICED ARRAYS	
		(G-H)	(G-I)	(G-J)	(G-K)*
DIR DIFF	Alg. Mean	-2°	-1°	-3°	-3°
	Abs. Mean	7	7	7	8
	RMS	10	9	9	11
STRM DIFF	Alg. Mean	1.1 m sec^{-1}	.59 m sec^{-1}	.71 m sec^{-1}	1.40 m sec^{-1}
	Abs. Mean	2.03	2.08	1.90	2.35
	RMS	2.43	2.59	2.32	3.01
NML DIFF	Alg. Mean	-.04	-.03	-.06	-.05
	Abs. Mean	.13	.12	.12	.14
	RMS	.17	.16	.16	.19
VCTR MAGN DIFF	Mean	2.05	2.08	1.92	2.36
	RMS	2.44	2.59	2.33	3.02
Number (N)		24	24	24	23

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* G= Manual tracking — 8-km IR images

H= Euclidean Norm Algorithm — 8-km unsliced data

I= Cross Correlation Algorithm — 8-km unsliced data

J= Euclidean Norm Algorithm — 8-km sliced data

K= Cross Correlation Algorithm — 8-km sliced data

b) The advantage purchased at the expense of time and effort needed to select and apply a threshold is minimal--the gain in accuracy shown in table 1 is not statistically significant.

c) All computer vectors tend to underestimate cloud speed, and the greatest bias is suffered by the cross correlation method applied to sliced imagery.

2.3.3 Low Clouds

Tracking low clouds with sliced arrays is subject to the problem caused by blurring of small holes in the overlying cloud layer. It turned out that our quality control procedure eliminated so many of the attempted measurements in two-layer situations that summary and analysis similar to that for high clouds could not be made. A great many low-level clouds were tracked with sliced arrays, but examination of the animation showed that most of them did not represent the situation we sought to study, viz, tracking low clouds which are visible through breaks in an overlying layer. When that type of two-layer condition was found, many measurements were so clearly in error they had to be discarded under the *a priori* quality control rules.

Careful inspection of animated sequences of successful versus unsuccessful low-cloud measurements led to the following conclusions which, unfortunately, cannot be documented by tables and figures.

- Satisfactory low-cloud vectors are derived with sliced arrays only if a large proportion of the elements represent a *contiguous area* of low clouds. That is, successful computations owe their success not to "seeing" low clouds through holes, but measuring the motion in a connected area that has clouds at a single level. This suggests that such arrays might be easily recognized automatically and that only more complex situations need be analyzed by the interactive procedures.

- Almost always, when the above condition is met, it is just as easy (with an interactive system) to adjust location of the initial and search arrays to avoid the pixels affected by clouds at two levels, thereby eliminating need for slicing.

- Once the array is dominated by clouds at a single level, the choice of algorithm is not critical.

- Some two-level situations cannot be handled by relocating the correlation arrays. Notable among these are the conditions near disturbances. In such cases only manual tracking succeeds.

2.4 Auxiliary Results

2.4.1 Differences between earlier and present study

The low yield of upper-cloud vectors from our earlier study and the high yield from this experiment deserve comment. The difference is that AOIPS provides interaction with the imagery while the NESS picture-pair procedure does not. The latter calculates vectors at preselected locations while AOIPS requires the operator to position the array outline on each successive image. Consequently, unsuitable cold patterns were frequently tracked by the picture-pair system while such arrays were avoided as a matter of course with the interactive system. In many cases only a minor relocation of the search array yielded measurements that would have been lost to the picture-pair computation.

The earlier unsatisfactory results stemmed from the inability to select target patterns on basis of their displayed behavior.

2.4.2 Low-cloud vectors in complex situations

In the periphery of disturbances where middle- and upper-level clouds become thin or broken, low clouds provide attractive targets because they trace flow in these regions of rich meteorological information. Only some of these low clouds can be computer-tracked. Success depends upon the existence of patterns that, throughout the sequence, are predominantly slowly changing, single level (low) clouds unobscured by upper clouds. Where those conditions cannot be met, manual tracking is the only recourse. A four-image sequence is superior to a shorter sequence of pictures for wind-derivation because the operator can select more suitable target clouds. However, tracers that behave well on two or three images may change on the others. For example, an upper cloud may move into an array on the last image. Therefore an accurate vector might be obtained from a portion of the displayed sequence, but not from the entire period. A wind-derivation system should provide a means to compute vectors for any portion of a displayed sequence.

These results are important to the design of an operational wind-derivation system. Our experiments have shown that computer tracking is accurate and efficient for many cloud conditions, if it is carefully operator-controlled. They have shown the futility of deriving an adequate coverage of winds near disturbances by computer techniques. An efficient means of manual tracking is critically important.

2.4.3 Algorithm running time and array size

Running times of the four algorithms used in these experiments are quite different. While slow computation was unimportant to this experiment, it would harm an operational system where speed is essential. Most complex and slowest is the program for cross correlation with "sliced" arrays, because a new mean value must be calculated at each different lag position. Hence this algorithm should not be used routinely.

Running time is also a function of the array size. Routinely AOIPS uses 15 x 15 initial arrays and 20 x 20 search arrays. Fast-moving patterns are accommodated within this ± 5 element displacement limit by relocating the search array on succeeding images so that the selected targets remain within the 20 x 20 region.

A few experiments were performed with 20 x 20 arrays searching within 25 x 25 for both sliced and unsliced patterns. The purpose was to see if the demands on the operator would be reduced sufficiently to justify the slower computations incurred by the larger arrays. Larger arrays turned out to be undesirable on two counts. First, the time was increased but no appreciable operator effort was saved--it is really quite easy to relocate a smaller search area if necessary. More important was the decrease of accuracy, particularly with sliced data. For some cirrus patterns, the deleterious effect of time changes increased with the increasing size of the area.

The conclusion from those tests, although subjective, was that upper-level clouds are most efficiently tracked by using the fastest possible algorithm on small arrays. It appears that initial arrays of 15 x 15 elements, where the infrared resolution is 8 km per element, is quite satisfactory. Nevertheless, some cloud patterns are better handled with different sized, non-square arrays. These experiments suggested it is desirable to provide for a capability, for slicing and for varying size of the initial array, for occasional use.

2.4.4 Effect of Resolution

It was mentioned earlier that the limited advantage of slicing was partly due to the crude (8-km) resolution of infrared imagery. This was suggested by examining the animation of "sliced" high-resolution, visible sequences. Some cirrus patterns exhibit different levels of brightness than their background clouds so that they can be made to contrast more sharply by application of a brightness threshold. Clearly defined holes and sharp edges can be seen on such high-resolution sequences. While this suggests that high-resolution infrared might yield more useable "sliced" images for computer tracking, it is not conclusive because brightness and radiance variations of clouds can be quite different.

The conclusion suggested by inspecting brightness-sliced high-resolution sequences is that the limited advantage of "temperature slicing" found by the present work may be due to the crude (8-km) resolution. Therefore, the limited success of "slicing" found here should not be extrapolated to other sensors with different resolution and spectral sensitivity.

3.0 SUMMARY AND CONCLUSIONS

"Temperature slicing" of infrared imagery was studied to determine if clouds at different elevations could be segregated and tracked by computer methods. Earlier work of this genre suggested that some cloud types might be amenable to this approach while others were not. The goal, with the hope of contributing toward design of an operational wind-derivation system, was to find the cloud characteristics that lent themselves to this procedure and to study the behavior of different tracking algorithms. Theoretical arguments suggested the specially designed linear correlation program would be superior. This did not prove to be true, probably because of complication caused by complex cloud fields.

The concept of computer-tracking temperature-thresholded cloud patterns rests on a rather simple model of cloud radiating characteristics and on theoretical behavior of correlation algorithms operating on these manipulated arrays. Real cloud fields confounded both ideas. That is, infrared images of real clouds do not fit the implicit model of stable radiance fields moving at their respective elevations with little inter-layer effect. At least with 8-km-resolution data, interaction is severe. Patterns change tremendously with time from this interaction, obscuring difference of various algorithms. As a consequence, it appears the choice between algorithms should be made on basis of speed and efficiency rather than the theoretical argument that favored linear correlation.

The principal result was that temperature thresholding for the purpose of segregating cloud layers for computer tracking is useful in only a limited range of cloud conditions. Such situations can be easily recognized on animated picture sequences. Equally important, nonapplicable situations can also be recognized on animated sequence. Manual tracking is successful in many such cases. An interactive wind derivation system is essential, for only by that means can these various tracking algorithms and efficient manual tracking be made available for rapid and cost-effective data reduction. These experiments suggest several capabilities needed in an operational interactive wind-derivation system, such as:

- Quality control procedures similar to AOIPS.
- Ability to invoke computer-tracking on operator-selected cloud patterns.
- "Temperature slicing" for occasional use, but not automatically implemented for each measurement.
- Ability to compute cloud displacement on any portion of the displayed sequence.
- Ability to vary size and shape of the correlation array.
- A means for automatic recognition of single-level low clouds and subsequent automatic tracking.

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