Comments on "An Automated Technique for Obtaining Cloud Motion From Geosynchronous Satellite Data Using Cross Correlation"

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In their paper Leese, Novak and Clark (1971) present an automated procedure for measuring cloud displacements from ATS Mercator-mapped digital data. An investigation of their results has revealed a significant bias in the resulting cloud speeds. After inspecting their computational model, we determined that their method of computing the cross-correlation coefficients, used in the detection of cloud displacements, contained a serious error. This error spuriously reduces the size of cloud displacement measurements as their magnitudes increase. Leese *et al.* note this bias but guessed that it may be due to mis-alignment of picture pairs. The dependency of the bias on the size of the cloud displacements demonstrates that picture alignment cannot be the sole source of error. Because cloud displacement can form a basis for obtaining highly useful global winds, it is important to correct their error.

If the misalignment of pictures is the main source of the discrepancy between the manually measured cloud displacements and the computer-measured cloud displacements, then the deviation of the average computer-measured cloud speeds from the manually measured cloud speeds, for fixed manually measured cloud speeds, should remain relatively constant. As shown in Table 1 this is not the case. The deviation of the average computer-measured cloud speeds from the manually measured cloud speeds steadily increases as the fixed manually measured cloud speeds increase. Furthermore, the percentage error that this deviation constitutes is greatest (45%) at the 25 and 30 kt cloud speeds where

TABLE 1. Manually measured cloud speeds minus average computer-measured cloud speeds as a function of manually measured cloud speeds. Values, in knots, computed from Leese *et al.* (1971, Table 2, part a).

Fixed manually measured speed	C	5	10	15	20	25	30
Manually measured speed minus average computer-measured speed	−2.5	−1.9	+4.0	+5.3	+6.3	+11.3	+13.6

the percentage error would be least. One must conclude that their automated procedure systematically measures cloud speeds smaller than they actually are and that this systematic error increases with increasing cloud speed. Their data are summarized in Table 1.

An explicit description of the method that Leese *et al.* used in computing a cross-correlation matrix is essential to the interpretation of their results. They kindly provided us with the following descriptions. Let A be a square data array from an ATS Mercator-mapped grid at time T_1 with elements $a_{i,j}$ for $i=1,\ldots,64$ and $j=1,\ldots,64$. Let B be a square data array taken from the same area of a similar grid at time T_2. Likewise, B has elements $b_{i,j}$ for $i=1,\ldots,64$ and $j=1,\ldots,64$. Let B′ be a new square array defined from B in the following manner: B′ has elements $b_{i,j}'$ for $i=-63,\ldots,128$ and $j=-63,\ldots,128$. Let $b_{i,j}'=b_{i,j}$ for $i=1,\ldots,64$ and $j=1,\ldots,64$. Let $b_{i+64,j}'=b_{i,j}'$ and $b_{i,j+64}'=b_{i,j}'$. B′ is shown in Fig. 1. Let $\bar{a},\bar{b}$ and σ_a,σ_b be the means and standard deviations of arrays A and B, respectively. The formula for a cross-correlation coefficient $c_{p,q}$ is

$$c_{p,q}=\frac{1}{\sigma_a\sigma_b}\sum_{i=1}^{64}\sum_{j=1}^{64}(a_{i,j}-\bar{a})(b_{i+p-1,j+q-1}'-\bar{b}),$$

where p and q are the row and column lags from the zero lag position.

To view the computation of the cross-correlation coefficients let data array A be placed over the created array B′ with the respective rows and columns parallel. The array A can now assume various positions with respect to B′. When A completely overlaps the center B data array of B′, this is designated the zero row lag and zero column lap position. When A is shifted to the right and/or down, the column lag and/or row lag are positive. However, when both the column lag and row lag are non-zero, as in Fig. 2, the correspondence between A and B array points are composed of four different lag positions. The contribution to the correlation coefficient from part A1 of A is for a q row lag and p column lag; part A2 of A is for a q row lag and a p minus 64 column lag; part A3 of A is for a q minus 64 row lag and a p column lag; part A4 of A is for a q minus 64 row lag and a p minus 64 column lag.

We believe that if the cross-correlation coefficient computed at the p column lag and the q row lag position is considered a measure of how well the cloud fields match at that position, then parts A2, A3 and A4 of A must be considered mismatched data. Therefore, the contribution to the cross-correlation coefficient from parts A2, A3 and A4 of A will have tendency to diminish any positive contribution from part A1 of A. As p and q increase, parts A2, A3 and A4 increase. Positive cross-correlation coefficients at larger lags are expected to be smaller and hence the probability of the maximum cross correlation coefficient occurring at large lags is reduced. Unfortunately, this method of computing cross-correlation matrices is systematically biased toward cloud displacement measurements smaller than they are. Thus, the automated procedure that Leese *et al.* present for measuring cloud displacement is invalidated by their accompanying results. The bias generated by their method of computing cross-correlation coefficients causes these errors.

With a cross-correlation technique and a solution to the navigation problem that we have developed at the Space Science and Engineering Center over the past eight months, we are obtaining good wind measurements (Smith and Phillips, 1971). We use two sets of criteria for judging the quality of the wind measure-

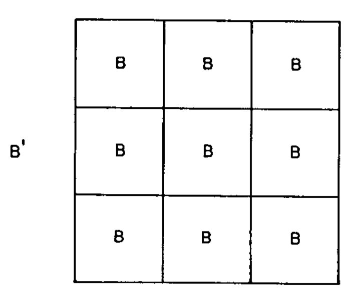

FIG. 1. Array B′ consisting of nine data blocks of B configured to form a square.

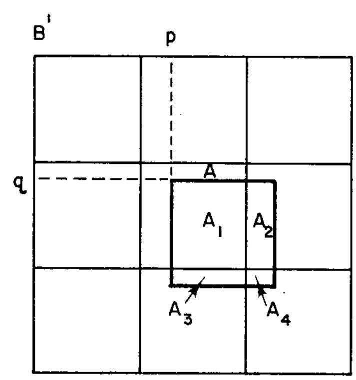

FIG. 2. Data block A overlapped on block B′ at column lap p and row lag q.

ments: the repeatability of the wind vectors measured over different time intervals within a 2-hr time span and the comparison of computer-measured wind vectors with manually measured wind vectors. We have completed a three day wind study during the Bomex time period 26–28 July 1969. On these days both our north/south and east/west wind component measurements were repeatable within 2 kt. An overlay of the computer-measured wind field on a manually measured wind field shows a generally good match in direction and speed. We will have this study completed shortly and at that time will describe our results in detail.

REFERENCES

Leese, J. A., C. S. Novak and B. B. Clark, 1971: An automated technique for obtaining cloud motion from geosynchronous satellite data using cross correlation. *J. Appl. Meteor.*, **19**, 118–132.

Smith, E. A., and D. R. Phillips, 1971: Automated cloud tracking using precisely aligned digital ATS pictures. *Proc. Two-Dimensional Digital Signal Processing Conf.*, Columbia, Mo., 1–26 February 1972.