Reply

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21 December 1971

The discussion by Phillips *et al.* contend that the bias noted in our paper between the manual and computer results is directly attributable to the procedures used to compute the cross-correlation coefficients. These procedures were based on assumptions normally used in computing spectra, cross spectra, autocorrelation and cross-correlation coefficients. The specific assumption is that the maximum lag needed to match the displacement is small relative to the number of data points used. The maximum lag is usually taken to be one-third the number of data points. A discussion of this is given by Blackman and Tukey (1958) for applications to one-dimensional analysis, and by Leese and Epstein (1963) in the two-dimensional case. We agree with Phillips *et al.* that the application of the procedures we used without regard for the maximum lag can lead to biased results. However, the maximum speed observed in the case we used was 40 kt. This corresponds to a maximum lag of one-eighth the number of data points used in each dimension. This factor alone indicates that the deviations between the manual and computer results in our paper are not entirely due to the specific procedures used in computing the cross-correlation coefficients.

The cross-correlation method was used in an operational test during the GARP data collection month in June 1970. Cloud motion vectors were obtained with this method on 23 days during the month. These vectors were used to make a detailed evaluation between the manual and computer methods. The results showed that the vectors obtained from the computer method were, on the average, about 10 kt slower than vectors obtained from the manual method. A significant portion of this deviation was found to be due to a combination of the moving cloud patterns and the fixed boundaries used in the 64×64 array. Clouds moving in or out of the fixed grid during the time interval between two pictures affected the value of the correlation coefficient. The effect was particularly severe when the boundary between two different cloud patterns came inside the fixed boundary of the 64×64 grid. Indeed, the only cases in which the effect of moving cloud patterns was not significant were those having a uniform cloud pattern over an area larger than the 64×64 array.

The results from the GARP month of June 1970 showed the need for more of a Lagrangian coordinate system to compute the cloud displacements. Our procedures were modified to use a smaller array of cloud data at one time period and search for the best match in a larger array at the other time period. The center of each array is located at the same geographical location as a reference starting position for the search. An optimum size for each of the two arrays could be the subject of a detailed study depending upon factors such as the expected speed of the clouds and the eventual use of the resultant vectors. Our choice was based mainly on the expected speed of the clouds. A 32×32 array is used for the small area and a 64×64 array for the large area. These modifications necessitate a change in the procedure used to compute the cross-correlation coefficient

$$R(p,q)=\frac{\mathrm{Cov}(p,q)}{\sigma_{t_0}(P,q)\sigma_{t_1}},$$

where $R(p,q)$ is the cross-correlation coefficient, Cov (p,q) is the covariance, and $\sigma_{t_0}(p,q)$ is the rms variation in the input array at time t_0. Each of these parameters must be computed at lag values p and q. The rms variation σ_{t_1} in the smaller input array at time t_1 remains constant over all lags.

The vectors obtained using this procedure on the June 1970 data were, on the average, about 6 kt slower

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Fixed manually measured speed

Manually measured speed minus average computer measured speed	C	5	10	15	20	25	30
(a) Initial procedures	−2.5	−1.9	+4.0	+5.3	+6.3	+11.3	+13.6
(b) Modified procedures	−8.3	−8.6	−3.1	−1.1	+2.8	+3.7	+6.4
Difference	5.8	6.7	7.1	6.4	3.5	7.6	7.2

than vectors obtained from the manual method. The remaining difference can be due to any one or combination of the factors which are different between the manual and computer methods. The picture registration procedures are different, and the time interval is 24 min for the two pictures in the computer method and more than 2 hr for the loop movie used in the manual method. The approach used in the computer method is to determine the displacement of the cloud patterns over a relatively large area. The manual method makes use of a much smaller cloud tracer to measure the displacement.

The effect of the modified procedures on the results for November 7, 1969 are given in the above table.

Row (a) labeled "Initial procedures" refers to the results presented in Table 2, part *a* of our paper and is the same as Table 1 in the discussion by Phillips *et al.* Row (b) labeled "Modified procedures" summarizes the results obtained from the same data set using the two different size arrays in computing the cross-correlation coefficients. The difference between the two procedures is fairly uniform across the range of manually measured speeds. This indicates that a systematic bias toward slower speeds resulted from a combination of the particular cloud patterns, and the fixed boundaries in the procedures used.

These results confirm that the deviations between the manual and computer methods for the case of 7 November 1969 are due to more than just the method of computing the cross-correlation coefficients. We are continuing an evaluation of the vectors obtained from the two methods to isolate the types of cloud patterns for which the computer can make valid and reliable measurements of cloud displacements. This is in accordance with the conclusion given in the original paper that "the best operational solution at this time is a combined man-machine interface system in which the man has access to the time-lapse display of the gray-scale imagery and can control and override the cloud displacements computed by the automated technique."

REFERENCES

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