Some Statistical Characteristics of Cloud Motion Winds Measured over the Indian Ocean during the Summer Monsoon

DONALD P. WYLIE AND BARRY B. HINTON

Space Science and Engineering Center, University of Wisconsin-Madison, Madison 53706

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ABSTRACT

Cloud motions over the Indian Ocean for May-July 1979 were used to obtain spatial autocorrelations of the deviations of the wind components from local means. Best correlations were associated with u', low altitude clouds and alongwind displacements. Worst correlations arose from v', high clouds and crosswind displacements. The crosswind anisotropy was ~15%. All correlations were 0.49 or greater at 5° separation or less.

1. Introduction

We have examined the spatial correlations of the cloud motion observations made at the University of Wisconsin for the FGGE data set.[1] Our purpose was to determine what scales of atmospheric motion the cloud motions represented and the noise level in these data. Our results provide information useful for developing objective interpolation schemes that will treat these data properly.

The shape of the weighting function is important in the design of an interpolation scheme. Exponential functions, or functions that are close approximations over short distances, are usually used. Endlich and Mancuso (1968) provided for anisotropy by using weighting functions that were elongated in the direction of the wind. But it has been convenient to assume that wind fields are isotropic (Ogura, 1958). A recent study of cloud motions in a limited region by Maddox and Vonder Haar (1979) indicated that they were not. Therefore, we decided to calculate the spatial correlations for a part of the FGGE data set and to test for isotropy.

2. Data used

Cloud motions were measured over the Indian Ocean for the FGGE year at the University of Wisconsin using images from the geostationary satellite positioned near 58°E longitude. The Man Computer Interactive Data Analysis System (McIDAS) was used for tracking the cloud features on the images (Smith, 1975). The technique used at Wisconsin involved a manual selection of the cloud features by an operator viewing the picture who also provided a first guess of the feature's motion. Then the McIDAS software defined the motions more precisely using a cross-correlation algorithm applied to the digital satellite images (Smith and Phillips, 1972). Infrared (IR) geostationary satellite images were used to derive the altitudes of the cloud features. Because of an equipment failure there were periods when the geostationary IR images were not available and the IR sensors on the TIROS-N satellite were used. Other details on the data processing procedures used during FGGE are given by Mosher (1979).

The cloud motions were divided into two groups: low-level clouds with tops below 700 mb altitude (mostly shallow cumuli), and high-level clouds with heights measured from 300 to 100 mb (cirrus or cirrus anvils emanating from cumulonimbi). All cloud features tracked at levels between these two groups were ignored in this study.

Special attention was given to the summer monsoon period from 1 May to 31 July 1979. During this time the wind-tracking effort was doubled to increase the density of observations made over the Indian Ocean. From 600 to 2000 observations were made each day by two groups, one at the Madison campus of the University of Wisconsin and the second at the Milwaukee campus.

We chose to restrict our analyses to the images taken during the daylight hours. A second analysis was made after dark, 12 h later, using only IR images. However, the IR sensor malfunctioned during the summer of 1979 causing a loss of about 60% of the geostationary IR images.

The daytime analysis, in effect, contained cloud motions that were tracked on both visible and IR images, when the IR images were available. The low clouds were best defined on the visible images while high cirrus clouds often appeared to be very dim in the visible images. Where the cirrus clouds existed

[1] FGGE is an acronym for the First GARP Global Experiment where GARP represents the Global Atmospheric Research Program. FGGE is sometimes referred to as the Global Weather Experiment.

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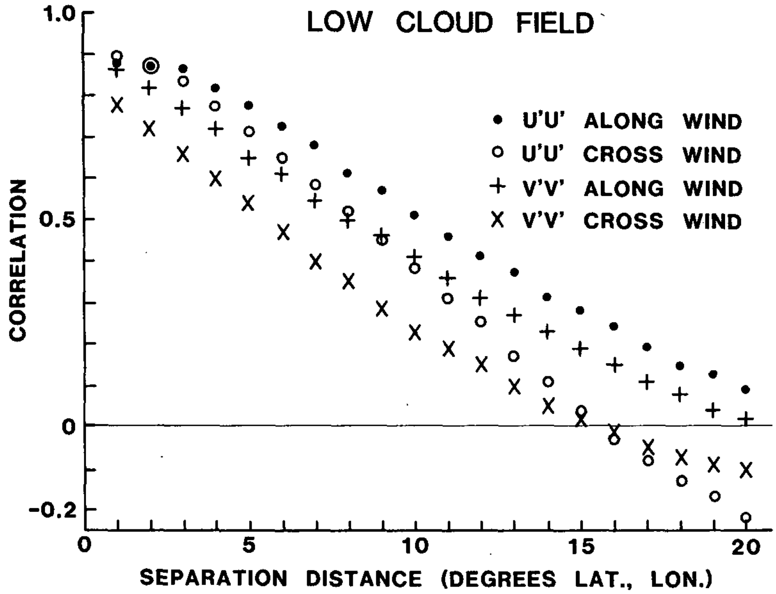

FIG. 1. The correlation of low-cloud motions (below 700 mb) measured over the Indian Ocean during the summer monsoon, 1 May–31 July 1979.

the operators had the option of tracking them on the IR images if they could be more clearly identified. Thus to make the cloud motion analyses the operators switched to the image type that best defined each cloud tracer.

From these cloud motion observations we calculated the spatial autocorrelations for each day available from

$$C = \frac{\Sigma U'U'(d)}{\Sigma U'^2} . \quad (1)$$

The correlations (C) were calculated for both the zonal (U) and meridional (V) components of the wind after removing the means of the data for each day, i.e., $U' = U - \bar{U}$. The zonal and meridional means ($\bar{U}$ and $\bar{V}$) were derived separately for each day's wind analysis. The correlations were calculated as functions of the distance (d) between observations. Each correlation was normalized by the total variance of the variable ($\Sigma U'^2$ or $\Sigma V'^2$) on a daily basis.

To determine the degree of anisotropy displayed by these data we divided the correlations [$\Sigma U'U'(d)$ or $\Sigma V'V'(d)$] into two groups: those displacements (d) aligned within ±20° of the mean wind direction, and those aligned within ±20° normal to the wind. The direction was defined for each $U'U'$ or $V'V'$ pair using the gridded value presented in the atlas of Young *et al.* (1980), at a location half-way between the two observations. The gridded values were derived from 2–10 winds within 6° radius of each grid point using the method of Endlich and Mancuso (1968). Grids were calculated at 2° latitude and longitude spacing.

3. Discussion

The spatial correlations for each of the 91 days examined were averaged to form the mean correlations for the 3-month period (Figs. 1 and 2).

It is apparent from the figures that the cloud motion data contain a high degree of horizontal consistency. The spatial correlations decreased slowly with distance between observations. This factor is partially the result of the method of analysis used at Wisconsin. The analysts who manually selected cloud tracers and edited the motion calculations tended to emphasize the large-scale characteristics of the wind fields. They were inclined to select only clouds that conformed to their view of the large-scale pattern.

The correlations show that the data are slightly anisotropic. The cross-wind correlations were 10–15% less (in variance) than the along-wind correlations. This difference was most notable at separation distances > 4°. The high-level winds exhibited slightly less difference between the along-wind and cross-wind directions.

The high-cloud fields had lower correlations than the low-cloud fields, in general. This result may have been an effect of the type of clouds tracked at each level. Low-cloud fields consisted primarily of trade wind cumulus or similar small cumulus clouds which were abundant over large areas and moved with uniform characteristics. The high-cloud tracers, on the other hand, were mainly cirrus fragments moving away from cumulonimbi cells or detached cirrus patches. Their organization was different than the low clouds because of the divergence caused by expanding anvils in large-cloud systems. It is sus-

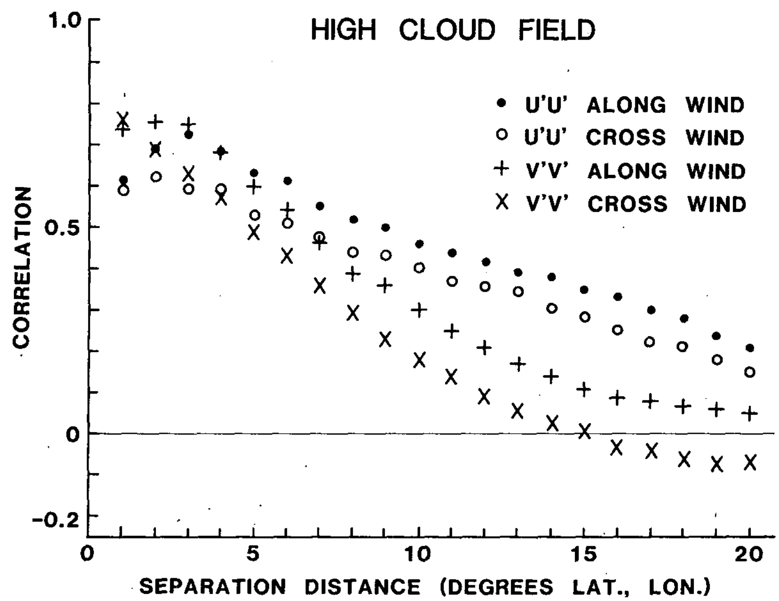

FIG. 2. The correlation of high-cloud motions (300–100 mb) measured over the Indian Ocean 1 May–31 July 1979.

pected that the true level of the winds that each high-cloud tracer represented also varied over the high-cloud field. This would have decreased the correlation because our definition of the high clouds included a deep layer, 300–100 mb.

The overall variances in the wind components at $<1°$ separation distance were considerably larger for the high clouds than the low clouds. These were 164 $m^2\ s^{-2}$ for U and 58 $m^2\ s^{-2}$ for V in the high clouds and 61 $m^2\ s^{-2}$ for U and 21 $m^2\ s^{-2}$ for V in the low clouds. Thus the high-cloud data contained more variable structure or noise than the low-cloud data.

4. Conclusions

From these statistics we conclude that the degree of anisotropic behavior of the cloud data was small. Anisotropic weighting functions are not necessary for these data if synoptic-scale flows only are considered. The cloud motions in general displayed a high degree of consistency between observations within 5° of latitude or longitude as evident from the shape of the correlations. Thus for defining the synoptic-scale wind fields the cloud motion observations can be directly used without extensive smoothing or editing procedures.

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