NOAA Technical Report EDS 21

GATE Convection Subprogram Data Center: Comparison of Ship-Surface, Rawinsonde, and Tethered Sonde Wind Measurements

Washington, D.C.
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U.S. DEPARTMENT OF COMMERCE
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GATE Convection Subprogram Data Center: Comparison of Ship-Surface, Rawinsonde, and Tethered Sonde Wind Measurements

Center for Experiment Design and Data Analysis

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April 1977

U.S. DEPARTMENT OF COMMERCE
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GATE CONVECTION SUBPROGRAM DATA CENTER: COMPARISON OF SHIP-SURFACE, RAWINSONDE, AND TETHERED SONDE WIND MEASUREMENTS

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Abstract. Comparisons are made of wind data obtained from instruments aboard U.S. ships, from rawinsondes, and from tethered sondes during the GARP Atlantic Tropical Experiment (GATE) in the summer of 1974. Results of comparison between winds derived from radar-tracking of rawinsondes on the *Vanguard* with those obtained from tethered sondes aboard the *Dallas* indicate the feasibility of using tethered sonde data to supplement rawinsonde measurements in the lowest kilometer. Vorticity and divergence computations based on ship-surface, rawinsonde, and tethered sonde data covering a triangle formed by the U.S. ships, *Oceanographer*, *Researcher*, and *Dallas*, are evaluated. Hourly values of vorticity and divergence are interpreted in the light of synoptic conditions for a 17-hr period on September 2, 1974.

1. INTRODUCTION

The multinational GARP[1] Atlantic Tropical Experiment (GATE) was conducted in the summer of 1974 in the eastern Atlantic. Field operations were divided into three major Observation Phases, with additional data obtained during three brief Intercomparison Periods.

Various instruments were used during GATE for wind measurements in the planetary boundary layer. On all five U.S. ships, winds were measured with instruments mounted on the masts and on booms extending from the ships' bows and with rawinsondes. On three of the ships, the *Researcher*, *Dallas*, and *Oceanographer*, wind data were also obtained with the Boundary Layer Instrument System (BLIS), a specially designed tethered-balloon system. The rawinsondes provided data from the surface to well above the tropopause, while the BLIS soundings reached from the surface to a height of slightly over one km. In this study, wind data from these two independent sets of instruments are compared to ascertain whether they are mutually consistent and also to deter-

[1]Global Atmospheric Research Program.

mine whether they are consistent with the boom and mast wind data. Three different comparisons are presented.

First, individual rawinsonde soundings from the U.S. ship Vanguard are compared with wind profiles obtained with the BLIS aboard the Dallas during Intercomparison 2, August 16-18. Second, based on BLIS and rawinsonde data, 12-hr average vorticity and divergence height profiles are calculated for the mesoscale triangle formed by the Researcher, Dallas, and Oceanographer within the B-scale array during Phase III, August 30-September 19 (fig. 1). Third, vorticity and divergence calculated from hourly averaged mast and BLIS wind data from the three ships are discussed.

A case study is also presented, in which the time series of vorticity and divergence are interpreted in light of prevailing synoptic conditions and percent radar echo area coverage for the Researcher-Dallas-Oceanographer triangle.

2. INSTRUMENTATION AND DATA USED

The boom and mast wind instruments on the Researcher, Dallas, and Oceanographer consisted of cup anemometers and wind vanes. The characteristics of these sensors and wind data derived from them have been discussed by Godshall et al. (1976). In this study, only 3-min and 1-hr average surface winds are used, the latter computed from the 3-min GATE data archived at World Data Center-A, National Climatic Center, Asheville, North Carolina.

The Omega windfinding system, which has been described in detail by Acheson (1974), was used during rawinsonde soundings from four of the five U.S. ships. The exception was the Vanguard, which relied on conventional radar tracking. Rawinsondes from the three ships forming the triangular array shown in figure 1 were generally launched every 3 hr. The wind data used in this analysis consist of 1- or 2-min consecutive values recorded during rawinsonde ascent, which corresponds to approximately 25-mb segments in the lowest kilometer of the atmosphere.

One of the components of the Boundary Layer Instrument System (BLIS) was a specially designed sonde attached to the tether line of a balloon. As many as five of these sondes, variously spaced, could be attached to the same line at one time. The balloon and winch were designed so that the instruments could reach a maximum height of 1,500 m, but during GATE they rarely attained heights greater than 1,200 m. Wind data from the BLIS were recorded at a rate of 0.5 samples per second (sps). Wind speed was measured with a three-cup anemometer, while the direction was obtained from the orientation of the sonde, which acted as a wind vane. The design of the instrument has been discussed in detail by Burns (1974), and the editing of the BLIS data for the GATE archive has been documented by Almazan (1977). An error analysis by Ropelewski (1976) of the wind direction and speed as measured by the BLIS, based on data from 12 flights, showed the rms error to be 3.8° in direction and 0.2 m s^{-1} in speed.

3. COMPARISON OF BLIS AND RAWINSONDE PROFILES

During GATE Intercomparison 2, August 16-18, the Vanguard and Dallas were stationed close to each other. As part of the intercomparison, several high-resolution rawinsonde wind profiles were taken aboard the Vanguard, while the Dallas was engaged in a program of comparing several different kinds of sondes attached to the same line as the BLIS. Data obtained from the latter flights are being analyzed at the GATE Boundary Layer Subprogram Data Center in Hamburg, Federal Republic of Germany, and are not pertinent to the study presented in this report. However, three of the flights were fortuitously made at the same time as rawinsonde soundings were taken aboard the Vanguard, making direct comparison between wind profiles as measured by the BLIS and by the rawinsondes possible.

The results of the comparison are presented in figure 2, which shows large differences in wind speed at the lowest levels, but decreasing with increasing height and becoming less than 1 m s^{-1} between 950 and 920 mb. The marked differences at the surface are most likely the result of erroneous rawinsonde measurements at that level, as has been noted in other tropical experiments. Analysis of data from the Barbados Oceanographic and Meteorological Experiment (BOMEX), for example, showed that the rawinsonde winds were not reliable below 300 m. Similarly, rawinsonde wind data collected during the Atlantic Tropical Experiment (ATEX) were found to be questionable below 500 m. Both BOMEX and ATEX investigators therefore had to interpolate wind values in the lowest layers for analytical purposes. No doubt interpolations schemes will be used also in analyzing GATE rawinsonde data, but, since the rawinsonde and BLIS data agree at upper levels, the latter may be useful in supplementing the rawinsonde observations in some analyses.

4. VORTICITY AND DIVERGENCE CALCULATIONS

Vector average winds were used to calculate vorticity and divergence for the triangular array formed by the Researcher, Dallas, and Oceanographer during Phase III of GATE, August 30-September 19. In order for the computations based on such an array to be interpreted in a meaningful way, the predominant scale of motion in the atmosphere should be at least as large as the separation of the ships. For example, interpretation is meaningless for the situation in which only one of the ships is under the influence of an intense, small-scale disturbance. The discussions that follow will demonstrate that the vorticity and divergence calculations presented here do lead to meaningful results at the spatial scale defined by the three ships.

4.1 Error Analysis

The errors in the calculated values of vorticity and divergence for relative errors in wind direction, to which such calculations are very sensitive, are shown in figure 3 as a function of wind speed. Since the absolute errors are a function of area size, this figure is applicable only to the triangular array discussed here. Errors in wind speed and ship position are assumed to be negligible.

Systematic errors in the wind direction data were removed before computations were made. Biases in wind direction as measured by the mast instruments on the three ships were eliminated by use of correction factors suggested by Godshall et al. (1976). During the field phase, the BLIS wind direction measurements were compared with those obtained from the mast instruments in a baseline check at the beginning of most soundings, and further adjustments were made during processing of the data at the Center for Experiment Design and Data Analysis, the U.S. National Processing Center for GATE. Baseline checks were not available for every sonde on every BLIS flight, however; the possibility of intersonde wind direction biases therefore exists. In a study of the quality of the BLIS data, Ropelewski (1976) showed that biases of 5° were typical, with biases of up to 10° occurring on some flights in the case of hourly averaged data. The error analysis illustrated in figure 3 indicates that relative wind direction errors of 5 to 10° can result in errors on the order of 10^{-5} s^{-1} in vorticity and divergence for typical observed wind speeds. These errors estimates are based on 1-hr winds averaged over the triangular array.

4.2 Vorticity and Divergence Profiles Based on Twelve-Hour Average Winds

Profiles of vorticity and divergence based on 12-hr average BLIS and rawinsonde wind values for two different cases are shown in figure 4. In the first case, the agreement between the two is quite good. In the second case, differences appear, most probably because of inconsistencies resulting from the averaging methods used. The BLIS averages were formed from the continuous time series of 0.5-sps data over the entire 12-hr period, while the rawinsonde values were obtained by averaging over the three or four soundings taken during the same period.

Two estimates of the daily average surface vorticity for the entire Phase III of GATE are plotted in figure 5. The circles represent the vorticity values derived from the ship boom winds, with the daily average being the mean of twenty-four 3-min averages centered on the hour. Thus these individual 3-min values are typical of the values to be expected from each rawinsonde flight. The dots represent the vorticity derived from the ship mast winds, the daily average being the mean of 1-min wind averages. Note that the differences can be quite large and typically amount to between 2 x 10^{-5} s^{-1} and 3 x 10^{-5} s^{-1}.

Since different methods were used in averaging the BLIS and rawinsonde data, we should not expect the vorticity values to agree any closer than the values just quoted for the boom and mast winds. Differences in divergence values would be of the same order.

4.3 Vorticity and Divergence Profiles Based on One-Hour Average Winds

Hourly averages were formed from the basic 0.5-sps BLIS data, and data obtained at the same height from each of the three ships in the triangular array were used in computing the vorticity and divergence profiles. To establish this height, sondes were taken to be at the same level when their pressure readings agreed within 10 mb. Assuming that the BLIS pressure sensors were accurate, this means that sondes flying at the "same level" had a vertical separation of no more than 100 to 200 m. Sonde heights were also checked against the BLIS Event Log, a manual record kept aboard each ship (Almazan, 1977).

An example of vorticity and divergence profiles for a 5-hr period, 1300 to 1700 GMT, September 2, is given in figure 6, based on data from three different sondes. As seen in this figure, there is a high degree of consistency in both types of values in the vertical, which could not be expected if the noise in the BLIS data were large. The fact that the values computed from the three ships' mast winds, also shown in the figure, are consistent with the BLIS profiles lends further credibility to the latter. The temporal changes are large from hour to hour, which might lead one to suspect that the data are contaminated by noise despite the vertical consistency. However, the temporal changes are also reflected in the ship-surface values, which again lend credibility to the computations.

4.4 Time Series of Vorticity and Divergence

Hourly values of vorticity and divergence for the 17-hr period from 1300 GMT, September 2, to 0600 GMT, September 3, were calculated from the ships' mast data and from BLIS data at three pressure levels corresponding to nominal height of 100, 500, and 900 m. The time series of vorticity are presented in figure 7, where the surface values are plotted on the same axis as the BLIS 100-m values. The similarity of the temporal behavior of the vorticity at all four levels is evident in this figure, which also shows that the vorticity changes rapidly with time.

The standard deviations of the time series of vorticity and divergence at the surface and at 100 m, and the standard deviation of differences between these two levels, are presented in Table 1.

Table 1.--Mean and standard deviation of vorticity and divergence (units of 10^{-5} s^{-1})

	Ship surface			BLIS 100 m			Differences (surface-100 m)	
	Mean	Stand. dev.	No. of obs.	Mean	Stand. dev.	No. of obs.	Mean	Stand. dev.
Vorticity	0.8	2.3	18	0.9	2.5	14	-0.5	1.1
Divergence	-1.3	3.8	18	-0.1	3.7	14	-0.8	0.8

Note that the standard deviation in the vorticity time series at both levels is more than twice the standard deviation of differences between the two levels. In the case of the divergence, the contrast is even greater, again indicating a high degree of consistency in the independent ship-surface and BLIS measurements. A close examination of the time series of vorticity at the surface and at 100 m, figure 7, shows that the differences between the two levels are indeed small, with the exception of the values at 2200 GMT, which one might be tempted to discount although both appear reasonable (figure 8). The time series of the divergence for all four levels, plotted in figure 9, also show a high degree of consistency in the vertical.

In summary, the time series of vorticity and divergence at four levels show variations that are consistent in the vertical and in time. Also, there is agreement between the ships' mast and the BLIS values. Finally, the surface wind pattern, plotted in figure 10, shows that the scale of the disturbance is comparable to the spatial scale defined by the three ships and thus that the hourly values of vorticity and divergence are meaningful.

5. A CASE STUDY

The rapid changes in the computed time series of vorticity and divergence discussed in the preceding section will now be examined in light of the prevailing synoptic pattern to ascertain their validity. Since it has been demonstrated that vorticity and divergence behaved similarly at the four levels of observation on September 2, the discussion will be limited to the surface values.

5.1 The Synoptic Pattern

"Quick-look" surface streamline charts were prepared in Dakar, Senegal, during the GATE field operations. Four of these charts for the period 0600 GMT, September 2, to 0000 GMT, September 3, with the Researcher-Dallas-Oceanographer triangular array indicated on each, are shown in figure 11. Figure 11a, for 0600 GMT, indicates weak anticyclonic flow in the ship array and cyclonic flow to the northeast just off the African coast. The flow over the array becomes cyclonic at 1200 GMT (fig. 11b) as the disturbance off the coast moves closer to the array. By 1800 GMT (fig. 11c) the streamline analysis shows the original cyclonic center to the northeast and another center that has formed over the ship array. At 0000 GMT (fig. 11d) the flow over the array becomes weak as the cyclonic center moves off to the west.

The streamline analysis charts were available at 6-hr intervals only, and some other estimate of the strength and movement of the disturbance with greater temporal resolution was needed since the largest changes in vorticity and divergence occurred within a 6- to 9-hr interval. This information was available in the form of 3-hourly composite radar photographs that have been prepared for publication in the GATE International Meteorological Radar Atlas (Arkell and Hudlow, 1977). Composites for the period of interest here include images from the radars aboard the Researcher and Oceanographer, and are shown in figure 12. The bright areas in the photographs correspond to areas of precipitation and were taken to reflect the movement of the disturbance identified on the streamline charts. As seen in figure 12a, there is no activity over the ship array at 0600 GMT on September 2. The radar echo increases at 0900 GMT (fig. 12b) and 1200 GMT (fig. 12c) as a band of precipitation begins to form. This band enlarges and moves through the ship array during the next two observation periods, 1500 and 1800 GMT (figs. 12d and e). By 2100 GMT (fig. 12f) the band of precipitation had moved out of the array.

Since the vorticity and divergence values used in this study were plotted for every hour, still finer time resolution was desired than that provided by the radar photographs. Data for 1-hr intervals were made available by F. Marks of the Center for Experiment Design and Data Analysis, who calculated the percent of the Researcher-Dallas-Oceanographer triangular area covered by the most active cumuli. Radar echoes were counted if they had an intensity corresponding to rainfall rates greater than 1 mm/hr. The results of the calculations are plotted in figure 13, which shows that the precipitation over the array increased rapidly from 1100 to 1700 GMT on September 2. The peak activity at 1700 GMT was followed by a rapid decrease to virtually no activity at 0000 GMT on September 3. This agrees well with the synoptic analysis and the radar composite photographs. The film loops from the Synchronous Meteorological Satellite-1 (SMS-1) for September 1974 also show a disturbance that formed in the ship array and moved to the northwest.

5.2 Relationship Between Surface Vorticity and Divergence and Precipitation

The hourly surface values of vorticity and divergence computed from the ships' mast winds are plotted in figure 14. When compared with the 1-hr values of the percentage of the array area covered by radar echoes, two points are evident. First, the maximum positive vorticity occurs at 1700 GMT on September 2. The corresponds to the time of maximum area coverage of active cumuli. Second, the divergence goes from strongly negative at 1400 GMT to positive at 1800 GMT on the same day. The transition from convergence to divergence occurs very rapidly, and the time of this transition also coincides with the time of maximum echo coverage. Previous studies by Fernandez-Partagas (1973) and Zipser (1969) suggest one possible sequence of events to explain this behavior of the vorticity and divergence. Strong convergence induces cyclonic flow and an increase in precipitation until 1700 GMT. The precipitation-induced downdrafts counteract the initially convergent flow, forcing it to become divergent. The vorticity then becomes less cyclonic and the area of precipitation decreases. One would not expect the same sequence of events to be reflected with the passage of every system in the array. In this particular case study the synoptic charts and radar data indicate that a disturbance formed, or grew, in the array, reached its peak activity, and then started to dissipate as it moved out. For systems moving through the array at different stages of their development, the time series of the vorticity and divergence as well as the time series of precipitation might be entirely different. The value in presenting this case study is that it demonstrates that hourly average vorticity and divergence are meaningful on the spatial scale defined by the triangular ship array.

6. SUMMARY AND CONCLUSIONS

Rawinsonde and BLIS wind data attained during GATE have been shown to be generally compatible in the lowest 1,000 m. Near the surface, however, the differences are large and are attributed to the difficulty in balloon-tracking immediately after launch. In two other tropical experiments, BOMEX and ATEX, investigators were forced either to ignore the wind data collected in the lowest 300 to 500 m or to interpolate between the surface and these heights. It is suggested that the BLIS wind profiles be used to supplement the rawinsonde data, provided that intership and intersonde wind direction biases are removed.

Comparison of 12-hr averaged vorticity and divergence values derived from rawinsonde and BLIS winds show agreement in one case but differences from $2 \times 10^{-5}\ s^{-1}$ to $3 \times 10^{-5}\ s^{-1}$ in the other, the latter the result of differences in averaging methods.

The agreement between vorticity and divergence values derived from the ship-surface and BLIS data demonstrates that these data can give meaningful values of hourly vorticity and divergence on the spatial scale defined by the Researcher-Dallas-Oceanographer triangular array, i.e., a spatial scale of 100 to 200 km. Large temporal changes observed at all BLIS flight levels and at the surface are shown to agree qualitatively with the changes in the synoptic pattern and with changes in the amount of convective activity as measured by the shipboard radars. This points out the usefulness of the hourly ship-surface and BLIS data as analytical tools in the study of short-lived mesoscale phenomena in the GATE array.

ACKNOWLEDGMENTS

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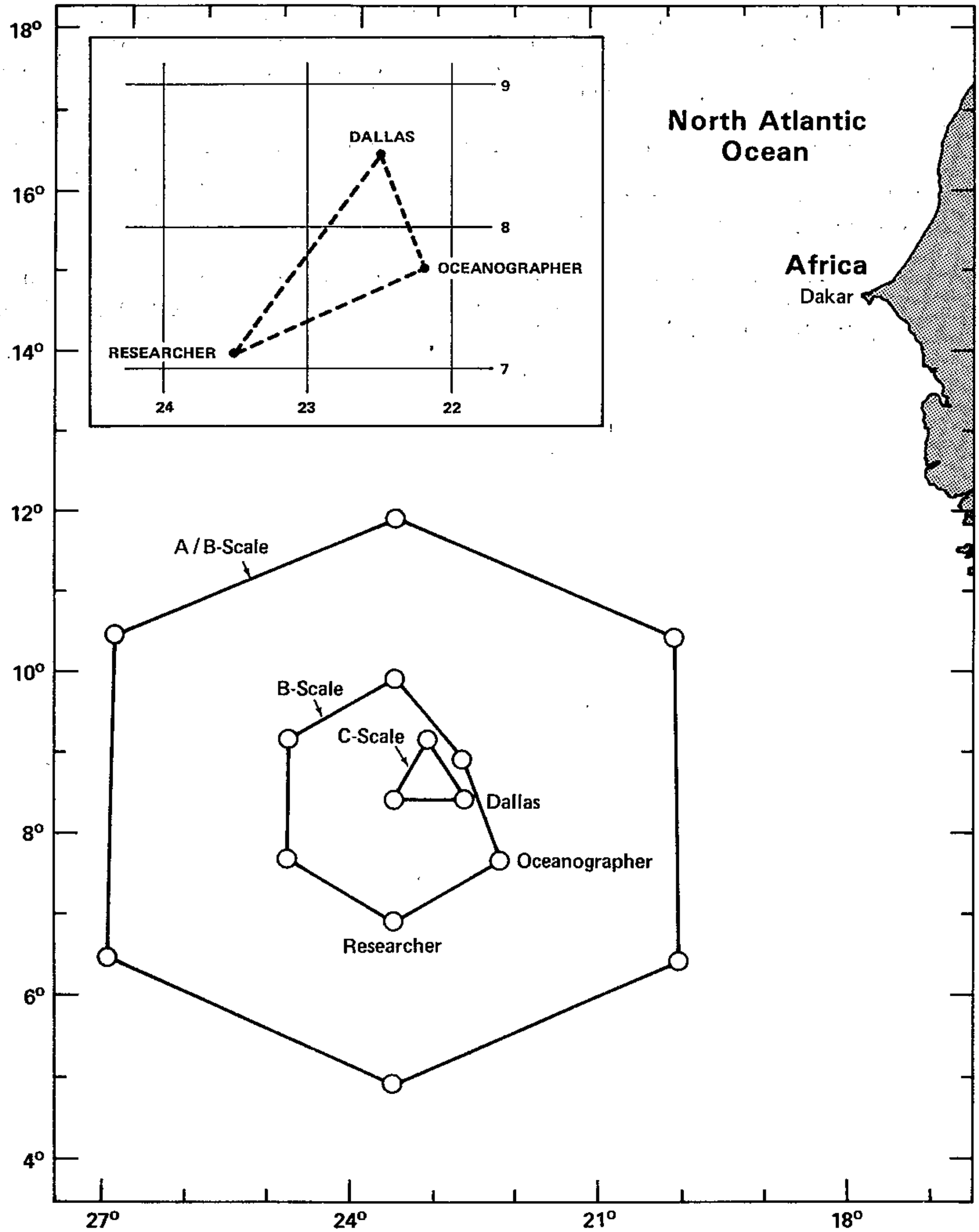


Figure 1.--Triangle of the U.S. ships Researcher, Dallas, and Oceanographer.

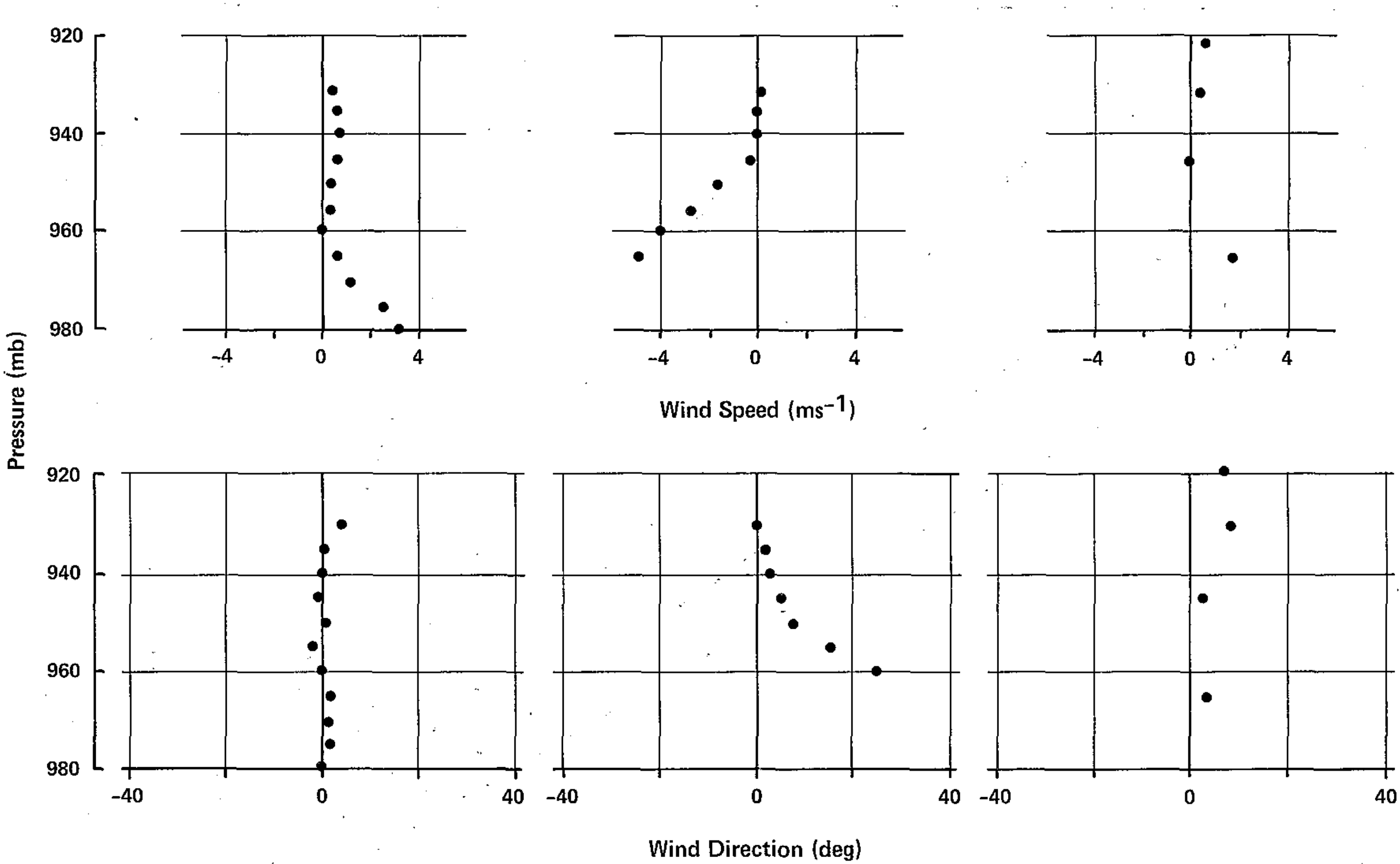


Figure 2.--Differences in wind speed and direction derived from three simultaneous Vanguard rawinsonde and Dallas BLIS flights.

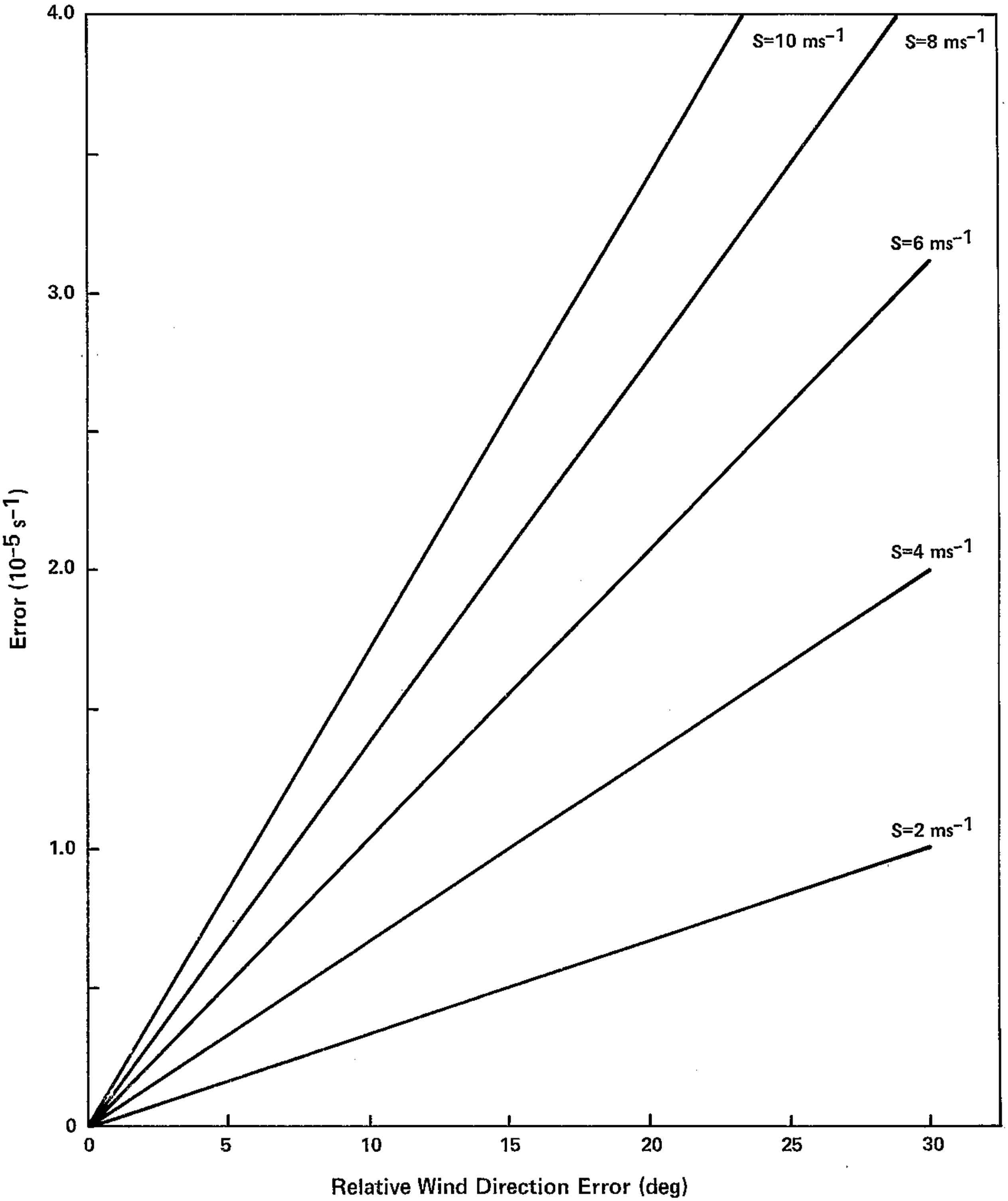


Figure 3.--Estimate of error in divergence and vorticity as a function of error in relative wind direction.

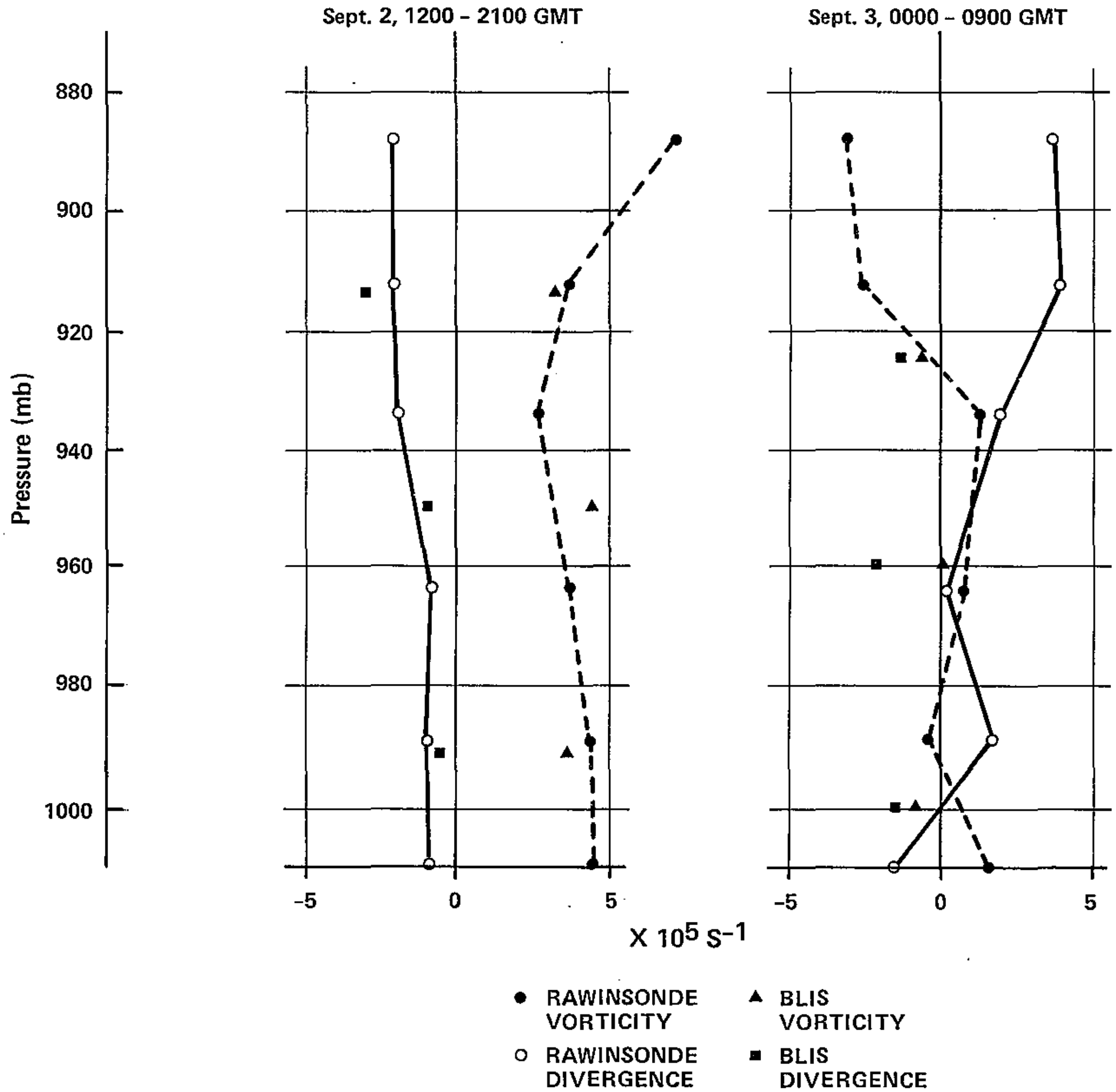


Figure 4.--Twelve-hour average vorticity and divergence profiles from rawinsonde, surface, and BLIS data.

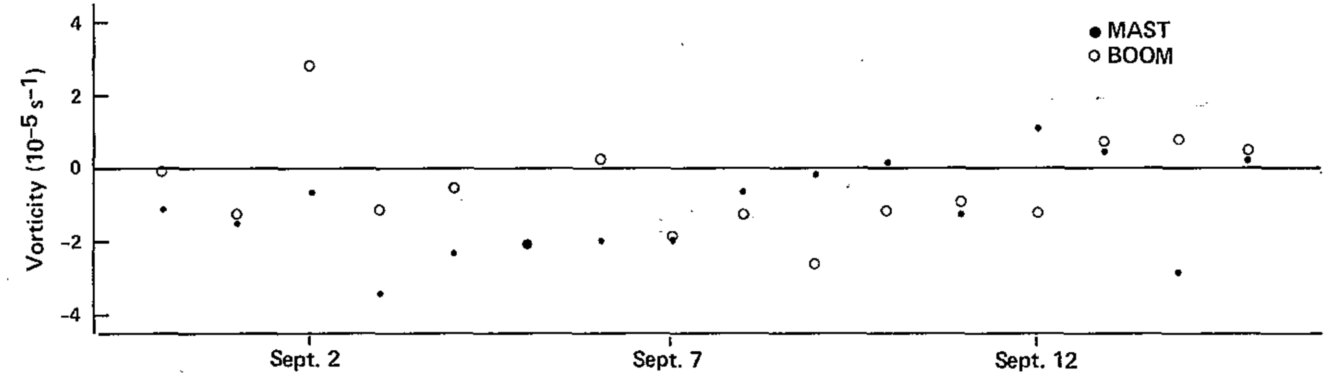


Figure 5.--Comparison of daily average vorticities based on continuous mast wind records and twenty-four 3-min boom averages.

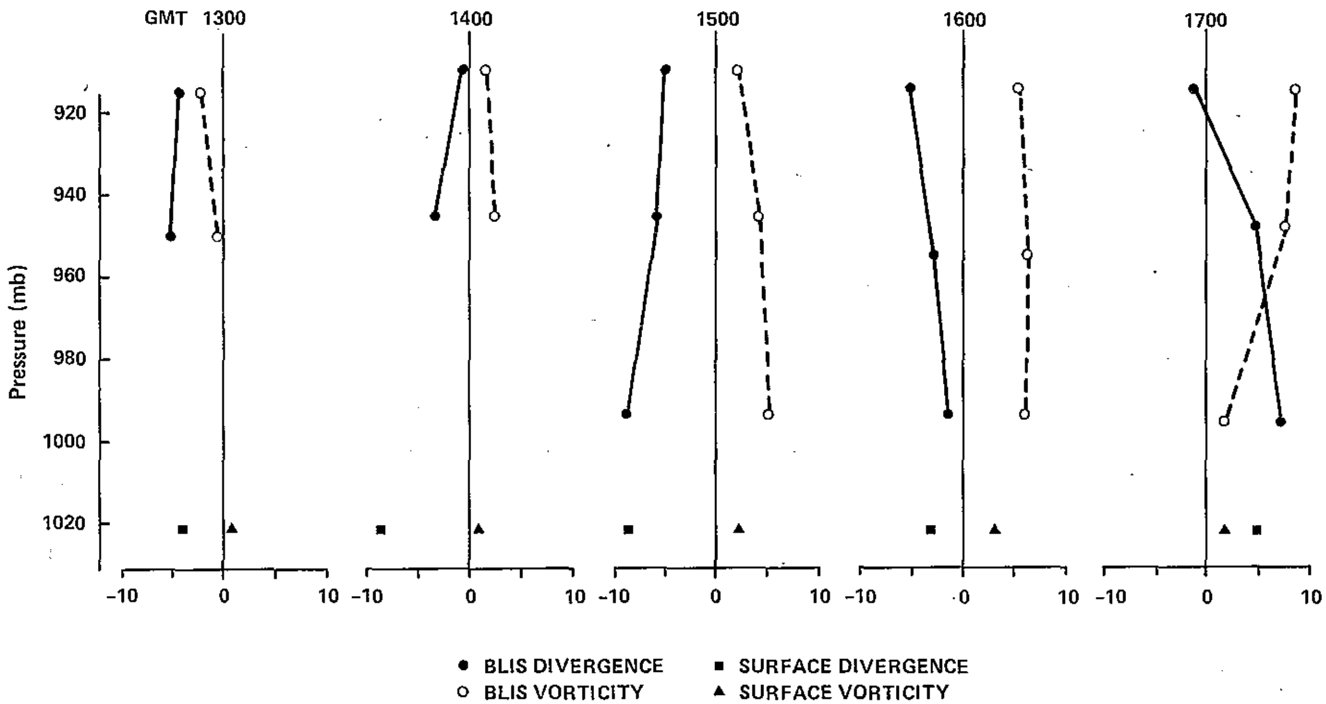


Figure 6.--Hourly vertical profiles of divergence and vorticity, September 2, 1974 (in units of 10^{-5} s^{-1}).

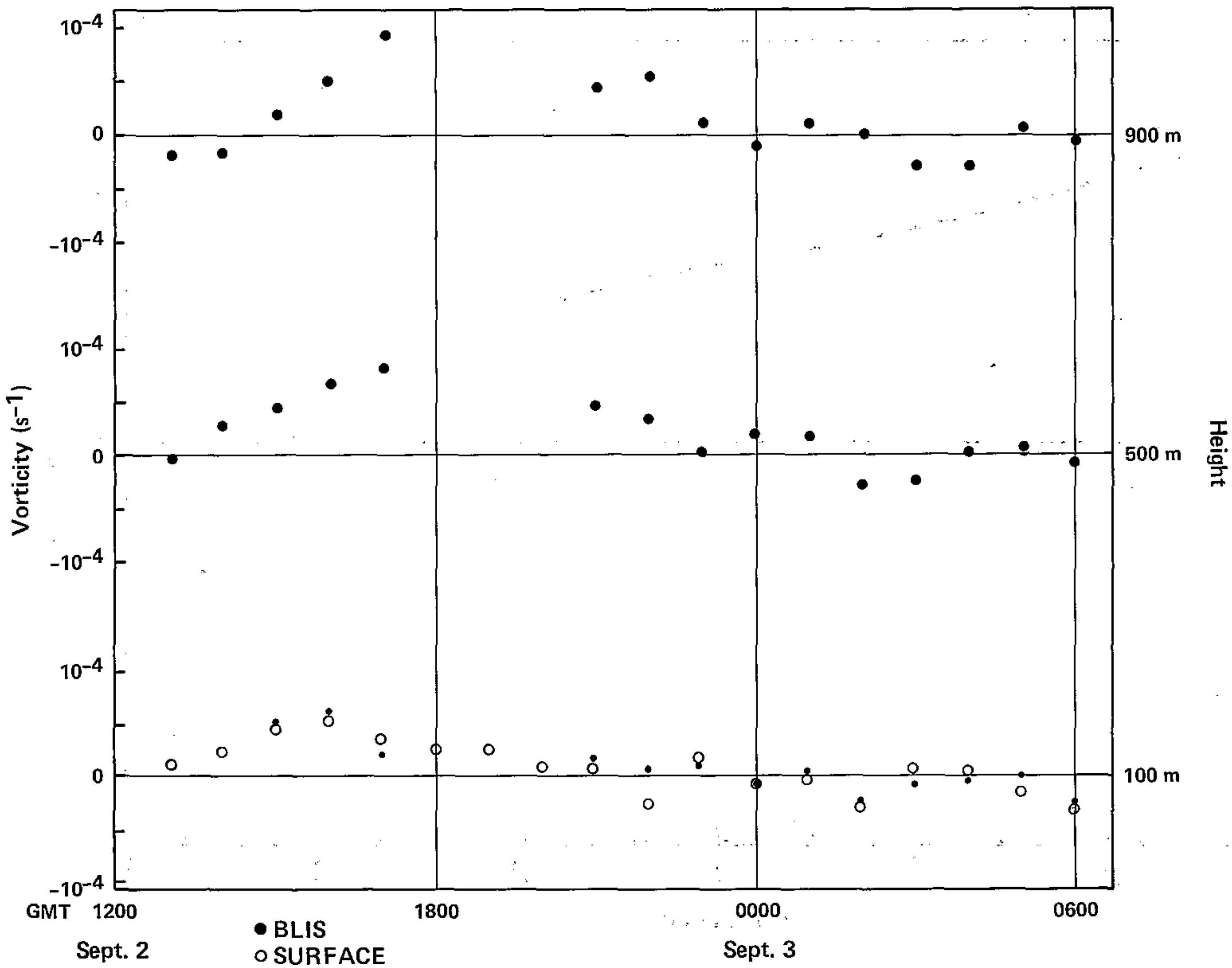


Figure 7.--Hourly average vorticity from surface and BLIS data, September 2-3, 1974.

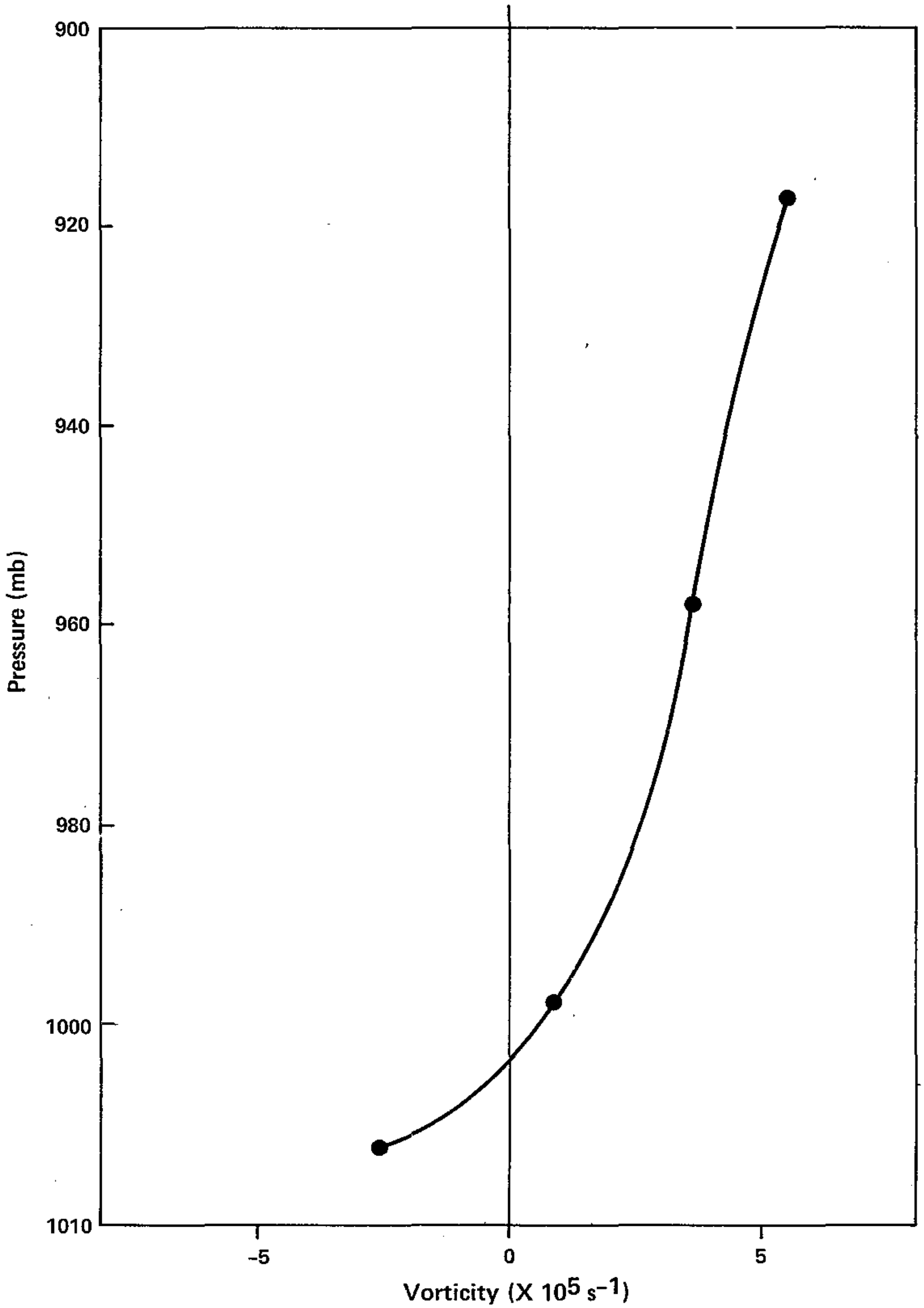


Figure 8.--Vorticity profile, 2200 GMT, September 2, 1974.

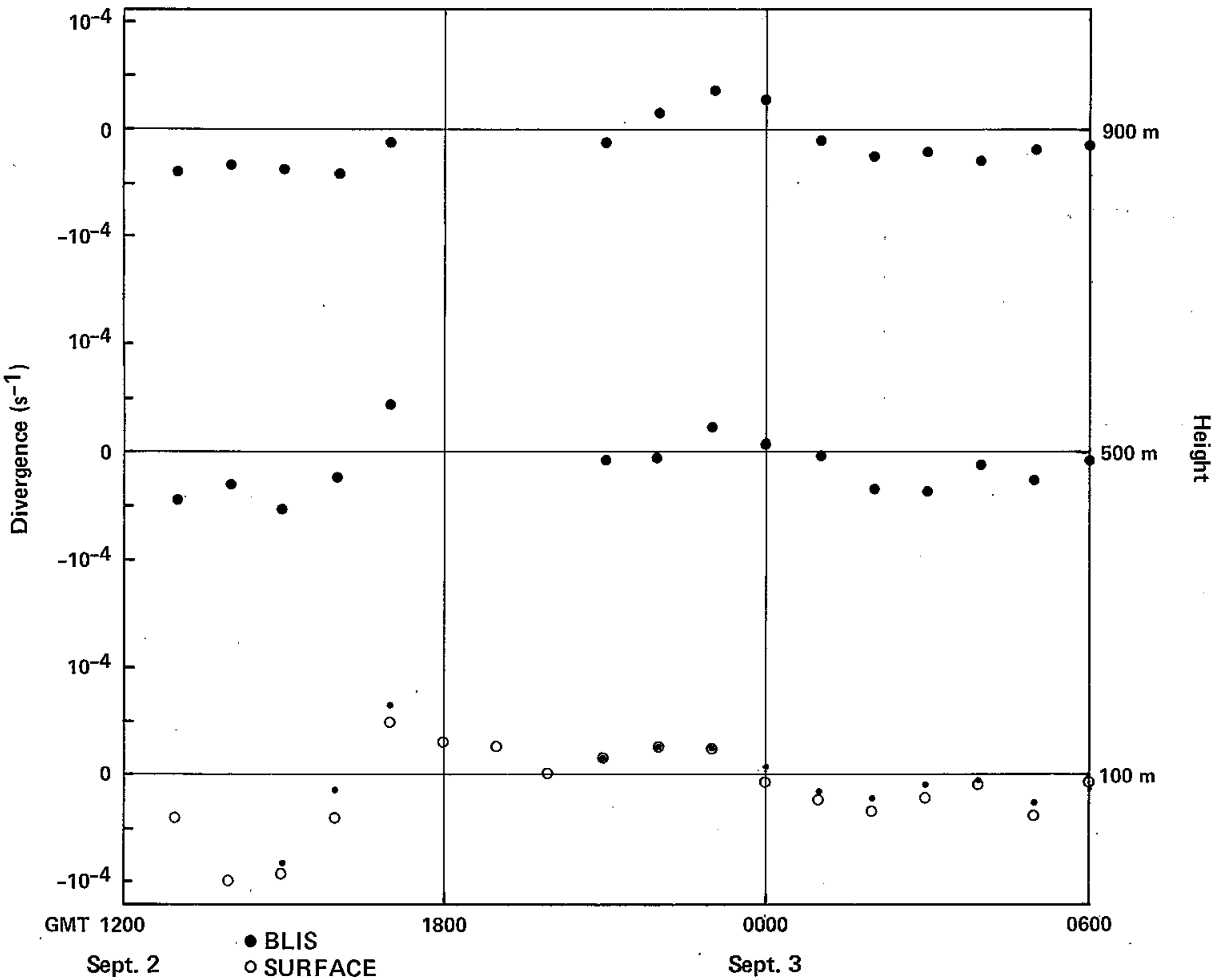


Figure 9.--Hourly average divergence from surface and BLIS data, September 2-3, 1974.

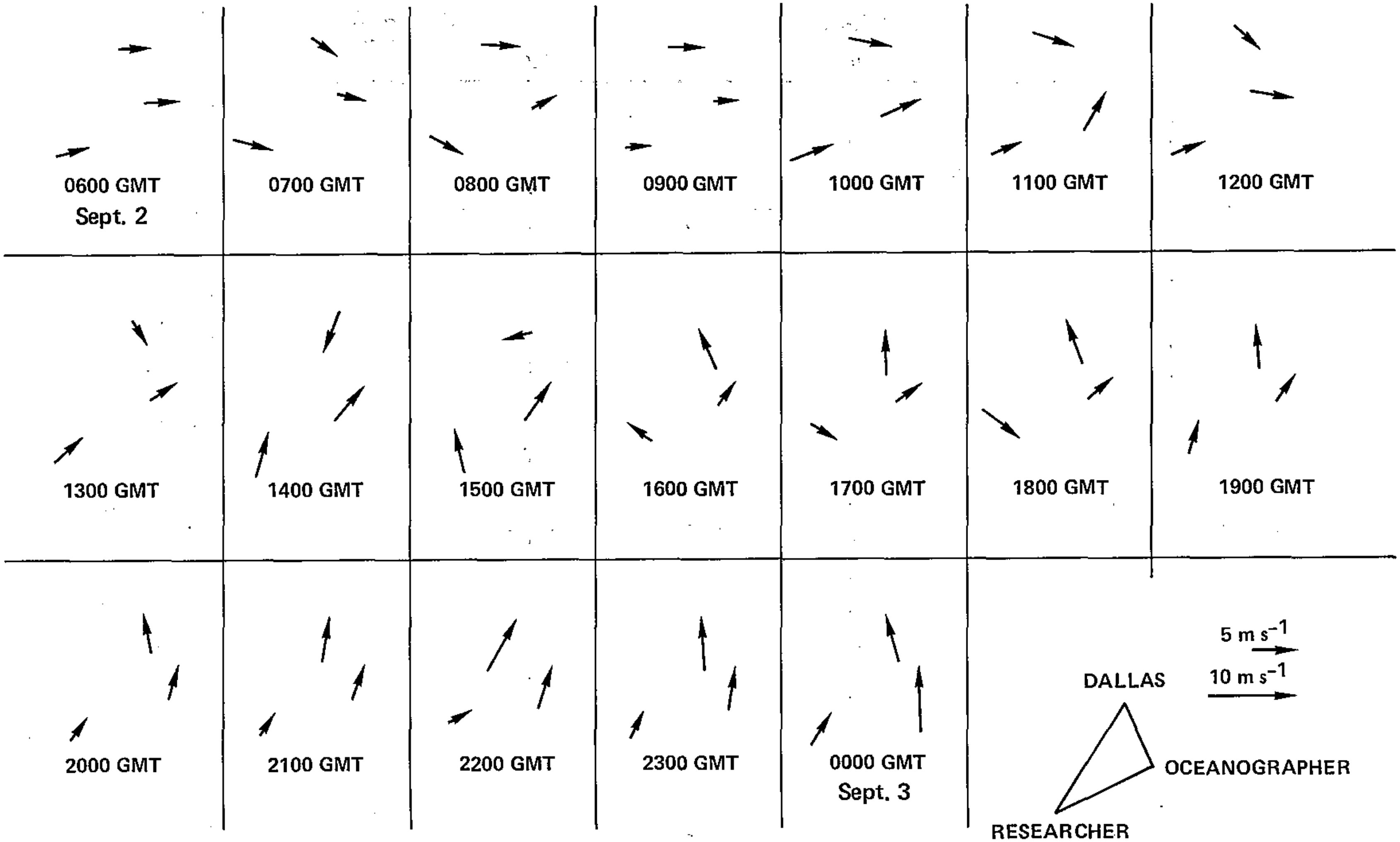
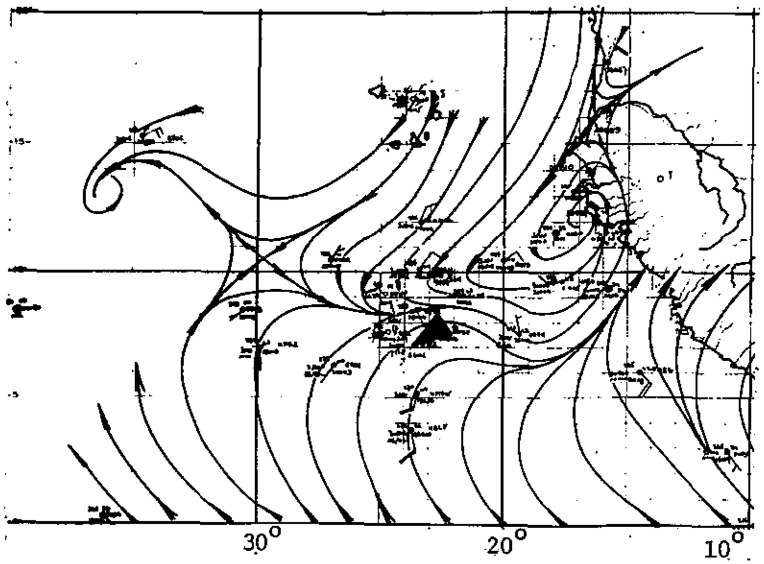
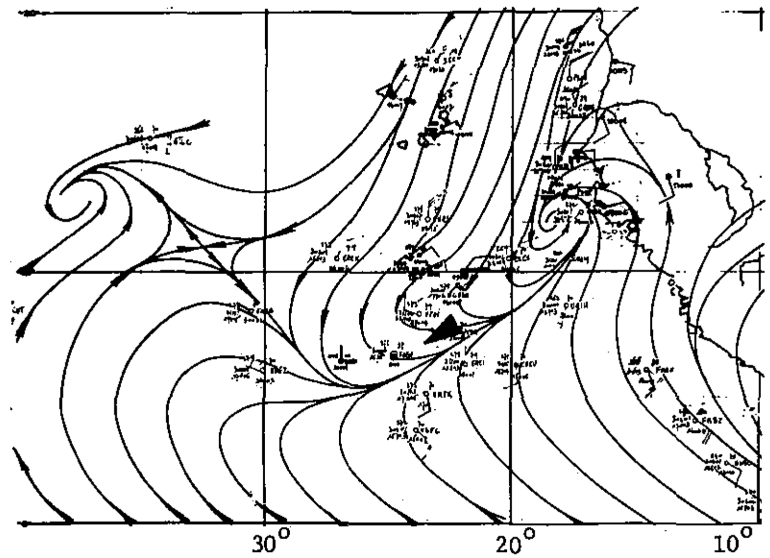


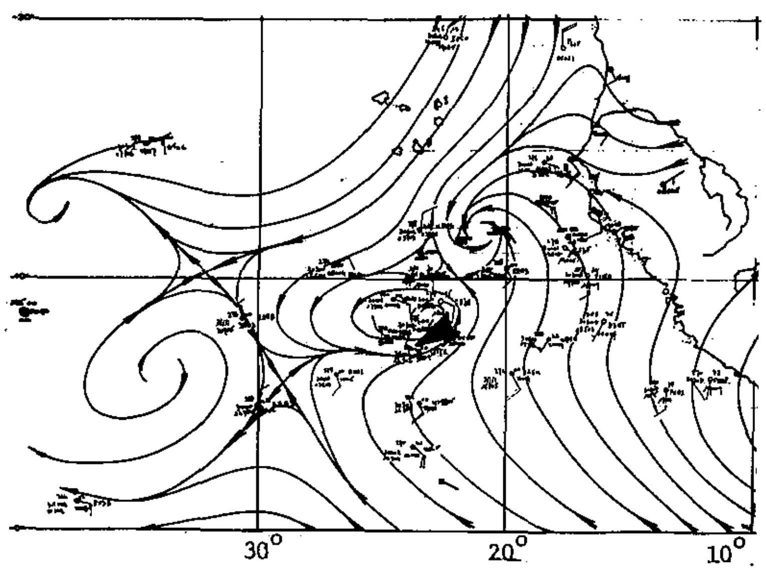
Figure 10.--Surface wind pattern for the Researcher-Dallas-Oceanographer triangle, September 2-3, 1974.



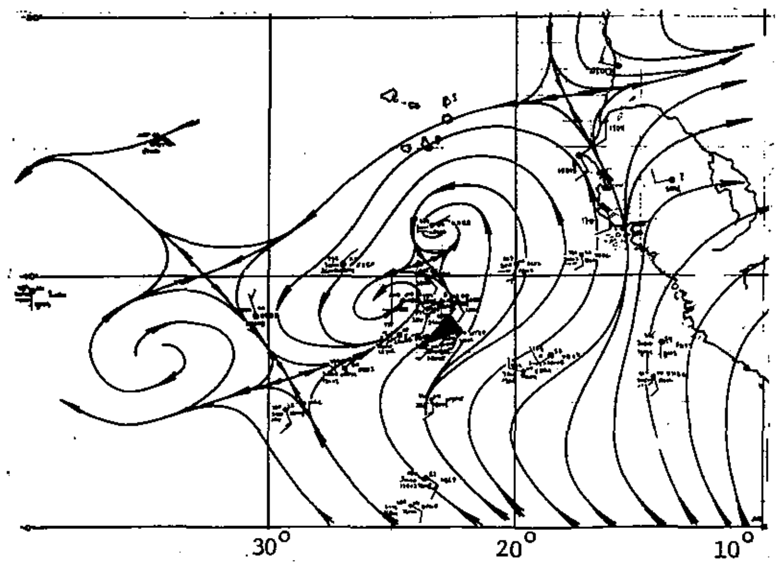
a. 0600 GMT, September 2, 1974.



b. 1200 GMT, September 2, 1974.

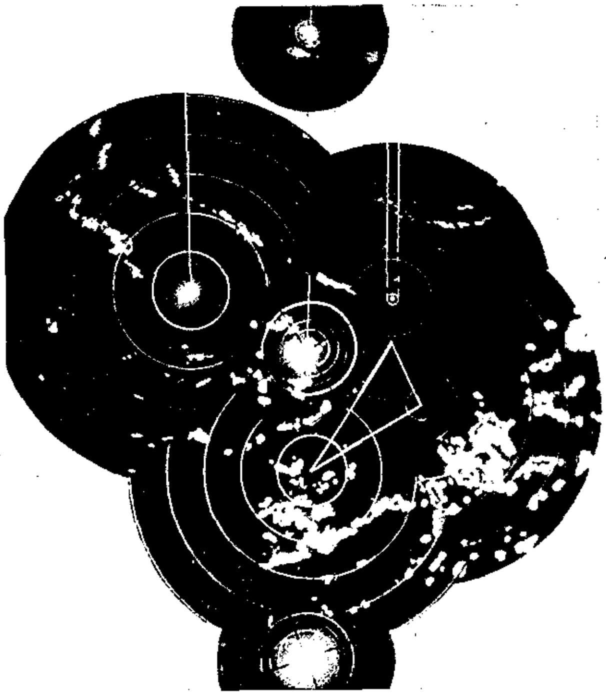


c. 1800 GMT, September 2, 1974.

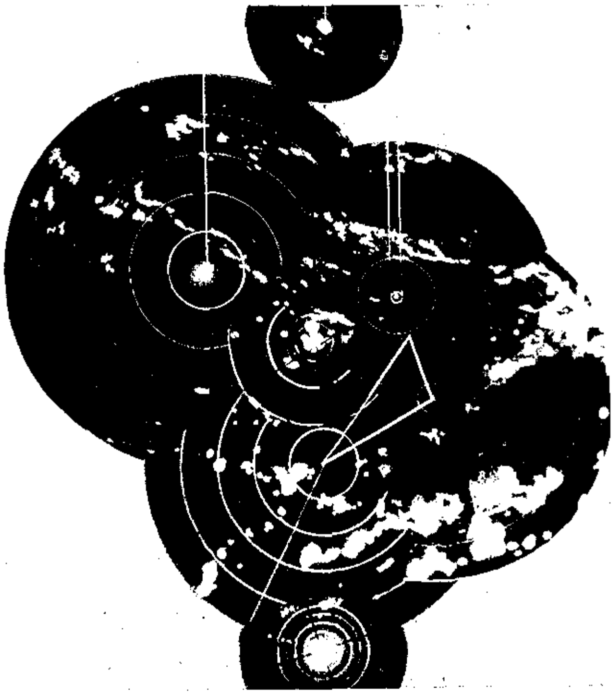


d. 0000 GMT, September 3, 1974.

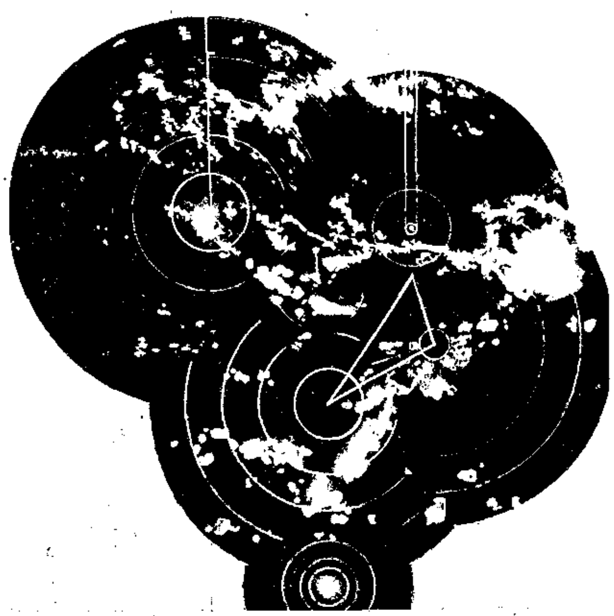
Figure 11.--Surface streamline analyses; note ship triangle near center.



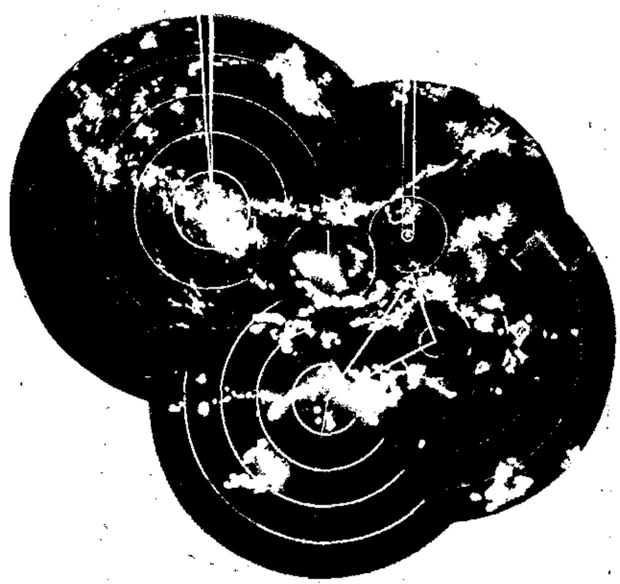
a) 0600 GMT.



b) 0900 GMT.

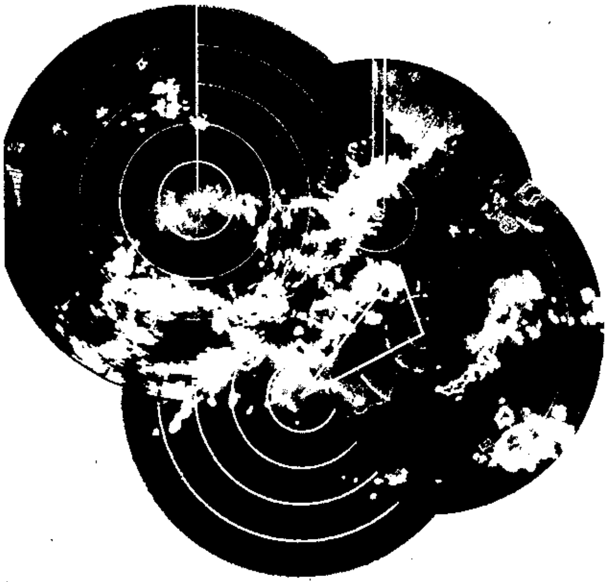


c) 1200 GMT.



d) 1500 GMT.

Figure 12.--Composite radar photographs, September 2, 1974.



e) 1800 GMT. f) 2100 GMT.

Figure 12.--Composite radar photographs, September 2, 1974 (continued).

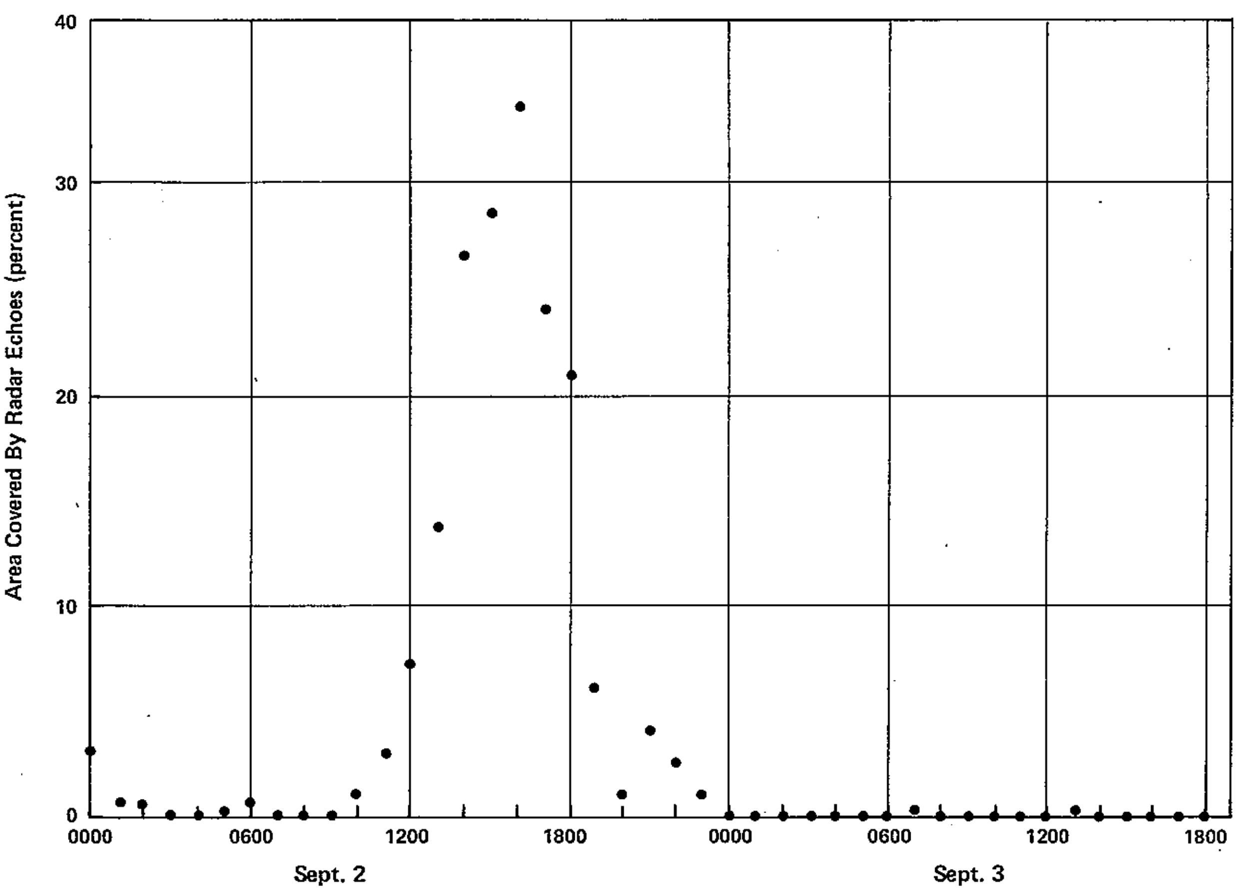


Figure 13.--Percent area covered by radar echoes.

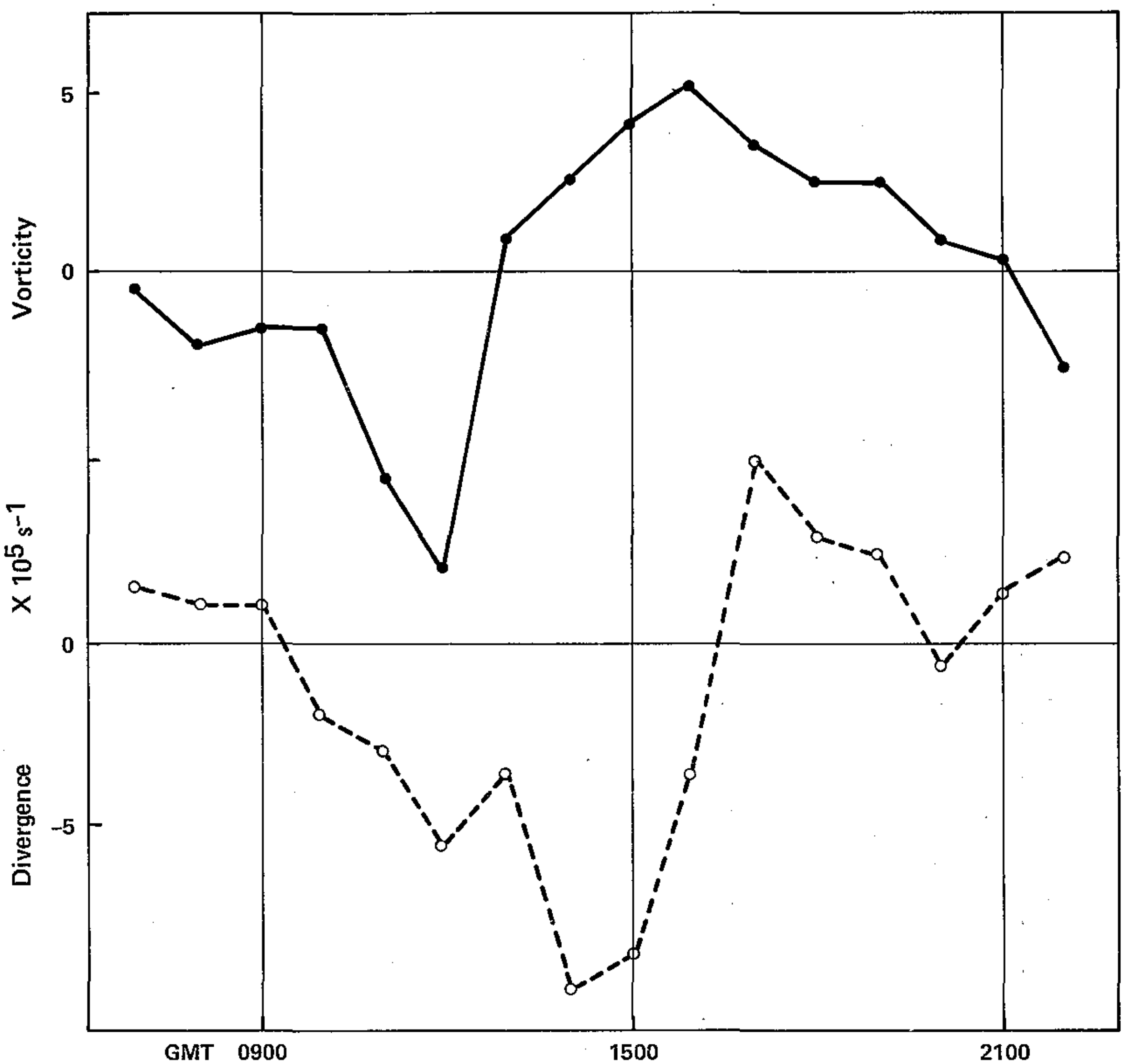


Figure 14.--Hourly average surface vorticity and divergence, 0700 to 2200 GMT, September 2, 1974.

(Continued from inside front cover)

EDS 16 NGSDC 1 - Data Description and Quality Assessment of Ionospheric Electron Density Profiles for ARPA Modeling Project. Raymond O. Conkright, in press, 1976.

EDS 17 GATE Convection Subprogram Data Center: Analysis of Ship Surface Meteorological Data Obtained During GATE Intercomparison Periods. Fredric A. Godshall, Ward R. Seguin, and Paul Sabol, October 1976. (PB-263-000)

EDS 18 GATE Convection Subprogram Data Center: Shipboard Precipitation Data. Ward R. Seguin and Paul Sabol, November 1976. (PB-263-820)

EDS 19 Separation of Mixed Data Sets into Homogenous Sets. Harold Crutcher and Raymond L. Joiner, February 1977.

EDS 20 GATE Convection Subprogram Data Center--Analysis of Rawinsonde Intercomparison Data. Robert Reeves, Scott Williams, Eugene Rasmusson, Donald Acheson, Thomas Carpenter, and James Rasmussen, November 1976.

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