Comments on "Modulation of Convective Activity by Large-Scale Flow Patterns Observed in GATE"[1]

ROBERT M. LEWIS AND RICHARD J. REED

Department of Atmospheric Sciences, University of Washington, Seattle, WA 98195

4 May 1983

Chen and Ogura (1982, denoted as CO) presented a diagnosis of the mean vertical velocity during Phase III of GATE. The purpose of our communication is to present an alternate diagnosis of vertical velocity which differs appreciably from theirs and to examine associated divergence fields.

Our results were obtained as a by-product of the recent study of Lewis (1983). Three-dimensional fields of divergence were computed at 6-hourly intervals during Phase III. Wind data from all of the ships in the A/B rawinsonde network were used, except from the *Meteor*. The u and v wind components were objectively analyzed using the method of Cressman (1959), modified with a density weighting factor (Bergthorsson and Doos, 1955). The grid network was 8×8, with 1.1° spacing in x and y, bounded at 19.65°N, 27.35°W, 4.65°N and 12.35°N. Divergences were calculated on a 6×6 grid by means of centered differencing. Corrections were applied to the divergence profiles assuming zero vertical velocity at 100 mb (O'Brien, 1970). This scheme utilized two simple hypotheses: 1) that errors in the wind data obtained by OMEGA/VLF navigation are constant with height, and 2) that errors in the data obtained by conventional methods of navigation increase vertically as a linear function of pressure. The major difference in methodology between this study and CO, who also used the Cressman method, is the inclusion of the OMEGA/VLF winds in our analysis.

Shown in Fig. 1 are the vertical velocity patterns found by each study in the vicinity of 23.5°W. CO diagnose two local maxima in the lower troposphere near 6.8°N and 10.2°N. Our diagnosis exhibits one maximum ($-1.7\ \mu b\ \mathrm{s}^{-1}$) at 7.9°N and 720 mb. The axis of greatest vertical velocity tilts from 7°N at 900 mb ($-1.4\ \mu b\ \mathrm{s}^{-1}$) through the primary maximum to reach a secondary maximum ($-1.3\ \mu b\ \mathrm{s}^{-1}$) at 8.2°N and 360 mb. The intensity of the rainfall observed during GATE has been shown to be determined largely by the magnitude of upward motion in the lower troposphere (Frank, 1979; Thompson *et al.*, 1979; Reeves *et al.*, 1979; Albright *et al.*, 1981). On this basis, our vertical velocity pattern suggests the greatest rainfall to have occurred from 6 to 9°N with a maximum at 7–8°N. The results of CO suggest two precipitation maxima centered at 6.8°N and 10.2°N; this interpretation is confirmed by their diagnosis of the mean apparent moisture sink (their Fig. 11) which exhibits two distinct maxima at these same latitudes.

By way of comparison, we present in Fig. 2 the mean patterns of rainfall estimated from both satellite and radar data. The greatest rainfall is shown by Fig. 2a to be centered near 9°N for most longitudes within the A/B array. West of 24°W, the maximum rainfall splits into two bands. Usually centered near 7°N and 13°N, these two bands continue westward across much of the Atlantic (Woodley *et al.*, 1980). Values of rainfall between $\sim 22\frac{1}{2}$–$24\frac{1}{2}$°W can be compared to the two vertical velocity patterns. Greatest satellite-derived rainfall is found from 7 to 10°N. Greatest radar-derived rainfall appears to occur $\sim\frac{1}{2}$° farther south, being concentrated between $6\frac{3}{4}$ and $9\frac{1}{2}$°N. South of $6\frac{3}{4}$°N no radar rainfall values are available. But amounts must drop off rapidly, as shown by the satellite data and confirmed by raingages on board the *Zubov* and *Musson*, both located near 5°N, 23.5°W, which measured amounts of 3.3 and 4.1 mm d^{-1} respectively, for the period (Seguin and Sabol, 1976). Thus, the mean rainfall patterns suggest only a single maximum of lower-tropospheric vertical velocity centered near $8\frac{1}{2}$°N at the longitudes in question.

It is instructive to compare our mean divergence pattern (Fig. 1c) to the mean A/B divergence profiles found by Thompson *et al.* (1979) and Reeves *et al.* (1979), who based their divergence measurements on least-squares second-order polynomial fitting of wind data from A/B and B-scale ships. Their studies found convergence layers centered centered at low levels and near 400 mb and divergence layers centered near 800, 520 and 250 mb. Our diagnosis exhibits all of these features in the south. In the north, however, only two divergence maxima are evident. If divergence layers

---

[1] Contribution Number 686, Department of Atmospheric Sciences, University of Washington.

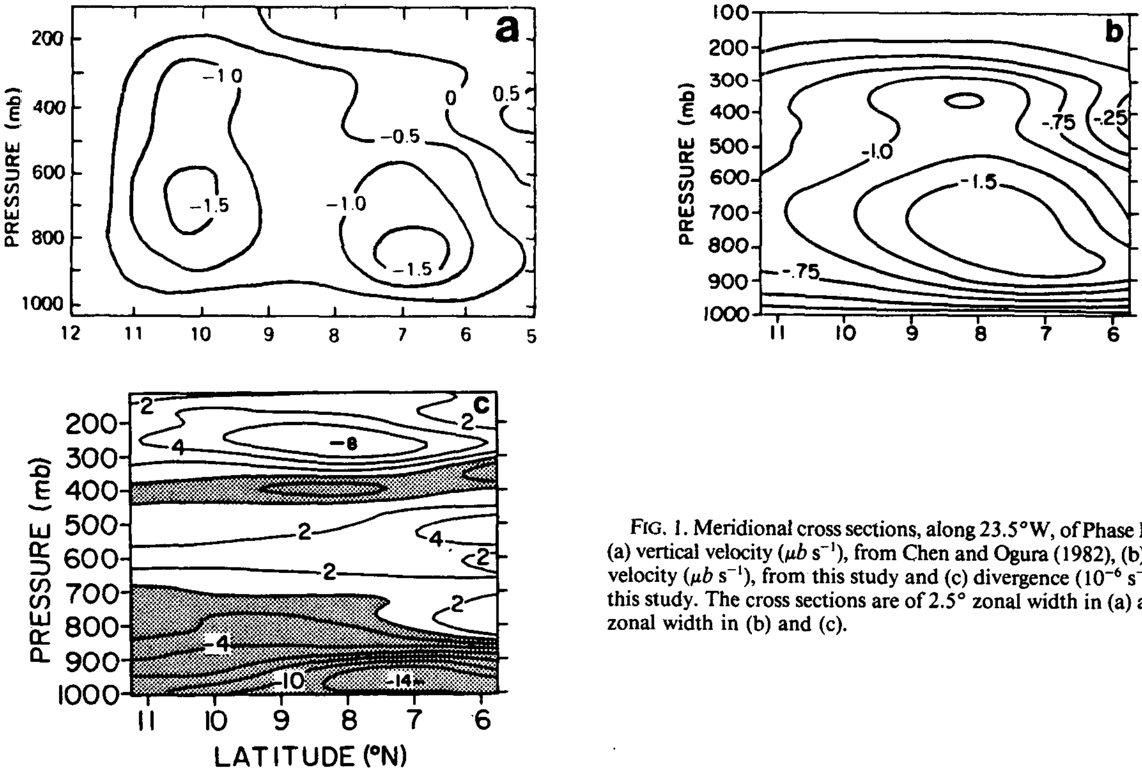

FIG. 1. Meridional cross sections, along 23.5°W, of Phase III mean (a) vertical velocity ($\mu b\ s^{-1}$), from Chen and Ogura (1982), (b) vertical velocity ($\mu b\ s^{-1}$), from this study and (c) divergence ($10^{-6}\ s^{-1}$), from this study. The cross sections are of 2.5° zonal width in (a) and 2.2° zonal width in (b) and (c).

represent regions of outflow from cumulus convection, as suggested by Thompson *et al.* (1979) and Albright *et al.* (1981), it is possible that the divergence pattern is revealing the existence of three main cloud populations on the southern flank of the intertropical convergence zone (ITCZ), but only two on its northern flank. These features have been shown previously by Chen (1980), whose mean divergence pattern is similar to ours except that it exhibits two maxima of both low-level convergence and upper-level divergence, consistent with the vertical velocity pattern of CO.

In addition to substantial meridional structure exhibited by the divergence and vertical velocity, interesting zonal structure has also been found. Fig. 3 displays meridional cross sections of both quantities through the east and west thirds of the A/B region. The divergence patterns of Figs. 1 and 3 reveal that three layers of divergence are present at all longitudes

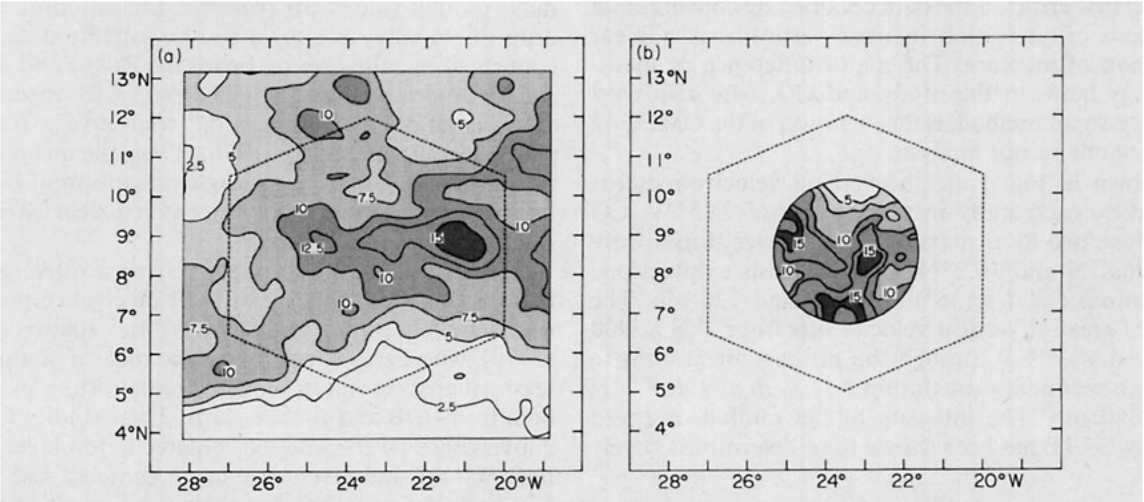

FIG. 2. Phase III mean estimated rainfall derived from (a) satellite data (Woodley *et al.*, 1980) and (b) radar data (Hudlow, 1979), covering the period 1800 GMT 30 August–0600 GMT 19 September. Contours are in mm d^{-1}. The dashed hexagon denotes the outer A/B array.

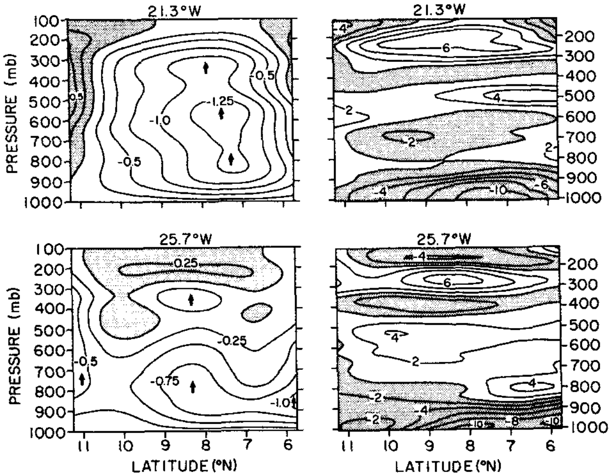

FIG. 3. Mean Phase III meridional cross sections of (left) vertical velocity (μb s^{-1}) and (right) divergence (10^{-6} s^{-1}), centered on the longitudes indicated, with a zonal width of 2.2°. Shading denotes downward motion (left) or convergence (right).

south of the ITCZ. Only in the east does the three-layer structure persist in and north of the ITCZ. This result is in good agreement with the divergence layers inferred from the vertical derivative of the vertical velocity profiles shown at 6.5 and 10.5°N by Reeves *et al.* (1979), who also show three layers in the south and two in the north. Except in the east, the low-level layer of convergence is shown to deepen with latitude. A midtropospheric convergence layer is shown to exist in the east and to slope downward with longitude, merging with the low-level convergence layer near 22°W. One maximum of vertical velocity is found in the east, between 7 and 8°N, about 1° south of the satellite-derived rainfall maximum. West of 25°W, the vertical velocity is shown to become less intense and to exhibit greater meridional extent, in good agreement with the satellite-derived rainfall pattern.

In summary, we have diagnosed one distinct meridional maximum of vertical velocity to occur at 7–8°N everywhere in the A/B region except west of about 25°W, where the vertical velocity is found to be less intense and of broader meridional extent. It has been shown that a single maximum of upward motion is more consistent with the patterns of satellite and radar derived rainfall than is the double maximum found by CO. Diagnosed divergence patterns have revealed the existence of pronounced spatial variations in midtropospheric divergence in both the meridional and zonal directions. These and the similar temporal variations that occur in connection with both easterly wave passages (Thompson *et al.*, 1979) and the diurnal cycle (Albright *et al.*, 1981) are subjects of continuing interest.

Acknowledgments. This research was supported jointly by the National Science Foundation and the National Oceanic and Atmospheric Administration, under Grant ATM81-03697.

REFERENCES

Albright, M. D., D. R. Mock, E. E. Recker and R. J. Reed, 1981: A diagnostic study of the diurnal rainfall variation in the GATE B-scale area. *J. Atmos. Sci.*, **38**, 1429–1445.

Bergthorsson, P., and B. R. Doos, 1955: Numerical weather map analysis. *Tellus*, **7**, 329–340.

Chen, Y.-L., 1980: The relationship between organized convective systems and large-scale fields observed in GATE. Ph.D. thesis, University of Illinois, Urbana, 148 pp.

——, and Y. Ogura, 1982: Modulation of convective activity by large-scale flow patterns observed in GATE. *J. Atmos. Sci.*, **39**, 1260–1279.

Cressman, G. P., 1959: An operational objective analysis system. *Mon. Wea. Rev.*, **87**, 367–374.

Frank, W. M., 1979: Individual time period analyses over the GATE ship array. *Mon. Wea. Rev.*, **107**, 1600–1616.

Hudlow, M. D., 1979: Mean rainfall patterns for the three phases of GATE. *J. Appl. Meteor.*, **18**, 1656–1669.

Lewis, R. M., 1983: A study of vertical velocities associated with cloud clusters during Phase III of the GARP Atlantic Tropical Experiment. M.S. thesis, University of Washington, 190 pp.

O'Brien, J. J., 1970: Alternative solutions to the classical vertical velocity problem. *J. Appl. Meteor.*, **9**, 197–203.

Reeves, R. W., C. F. Ropelewski and M. D. Hudlow, 1979: Relationships between large-scale motion and convective precipitation during GATE. *Mon. Wea. Rev.*, **107**, 1154–1168.

Seguin, W. R., and P. Sabol, 1976: GATE convection subprogram data center: Shipboard precipitation data. NOAA Tech. Rep. EDS 18, 73 pp. [NTIS PB-263 820/3GI].

Thompson, R. M., Jr., S. W. Payne, E. E. Recker and R. J. Reed, 1979: Structure and properties of synoptic-scale wave disturbances in the intertropical convergence zone of the eastern Atlantic. *J. Atmos. Sci.*, **36**, 53–72.

Woodley, W. L., C. G. Griffith, J. S. Griffin and S. C. Stromatt, 1980: The inference of GATE convective rainfall from SMS-1 imagery. *J. Appl. Meteor.*, **19**, 388–408.