DIVERGENCE, VERTICAL MOTION AND MOISTURE DISTRIBUTION OF HURRICANE "GRACIE" - SEPTEMBER 1959

by

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Submitted in Partial Fulfillment
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Degree of Master of Science

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Department of Meteorology, May 21, 1960

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Chairman, Departmental Committee on
Graduate Students

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ABSTRACT

Wind, temperature and specific humidity data of Hurricane "Gracie" were integrated, plus or minus 12 to 18 hours from 0000Z, 29 September 1959, to approach adequate coverage for an observed data evaluation of divergence, vertical motion and specific humidity distribution from 1000 to 500 mb.

The results are discussed in relation to a current mean data model, with emphasis on deviation from the mean.

A possible mechanism for intensification and recurvature of more northerly latitude storms (27-33°N) is presented.

ACKNOWLEDGEMENTS

I am grateful to Professor Victor P. Starr and Dr. Hsaio-Lan Kuo for their stimulating discussions and valuable assistance in the interpretation of significant features of Hurricane "Gracie" and for their critical review of this manuscript.

I also wish to express my appreciation to Mr. Joseph Levine, S.M., for his ideas concerning the approach to the problem, to Mr. John Bonzagni, USWB, Logan Air Port, Boston, Massachusetts, for his assistance in securing the necessary data and to Miss Jane Sinnott for the typing of this manuscript.

I will be eternally grateful to the USAF for my assignment at the Massachusetts Institute of Technology for the past two years which permitted my conquest of this S.M. degree.

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FIGURES

I. INTRODUCTION

Hurricane "Gracie" was the most intense tropical cyclone to cross the coast of the southeastern U.S. since "Hazel" in 1954. After forming in an "easterly wave" near the Island of San Salvador on 22 September her erratic movement for the next five days, which included most all directions of the compass, made forecasts nearly impossible. During the period 22-24 September the circulation in the upper troposphere was made up of many small-scale cyclonic and anticyclonic eddies. Between 12Z, 24 September, and 12Z, 25 September, the southern extension of a rapidly-moving, intensifying 700-mb trough, moved from the vicinity of Chicago, Illinois, to Washington, D. C. This southern extension assumed an E-W orientation as the trough passed Bermuda by 12Z, 26 September. It was at this time that "Gracie" began an eastward course. Anticyclonic development behind the trough rapidly resulted in an increase in low-level easterlies. This, plus development of the warm high aloft, caused a reversal of course to a westerly direction on 27 September.

By 00Z, 29 September, "Gracie" was located 220 miles SE of Charlestown, South Carolina. She had maintained near steady-state conditions for 24 hours in her movement to the WNW at approximately 12 mph. Recurvature to the NNW, with intensification were noteworthy by 12Z, 29 September.

All available current observations, with offtime reports, [+18 hours for peripheral stations (ie. Tampa, Florida, and Cape Hatteras, North Carolina), +6 hours for reconnaissance and ship data near the center and -12 hours for all data] were properly positioned with respect to the storm center. Storm movement was not subtracted out of these reports. Isotach charts, based on (u), (v) components of the observed winds and specific humidity (q) charts were analyzed for three levels (1000, 700 and 500 mbs).

Subjectivity enters the picture here, and errors arise dependent upon the quantity and quality of usable observations. We are almost completely dependent upon aircraft reconnaissance reports and scattered island rawinsonde data for analysis of storm structure during stages of development and maturity. Aircraft reconnaissance to date has been very restrictive to research because of three main factors: (1) altitude limitations (usual ceiling 500 mbs); (2) incomplete peripheral coverage at more than one level (usually 700 mbs) due to USAF procedure of flying to the storm center at 500 mbs from one quadrant, descending to 700 mbs for excellent coverage and finally ascending to 500 mbs for a homebound track via the initial quadrant; and (3) inadequate low-level (1000-850 mbs) coverage by Navy reconnaissance which normally results in one quadrant wind information as the aircraft tracks the storm, from a near stationary position, by radar. Because of these limitations, the opportunity has seldom arisen which has been conducive to individual storm study. The National Hurricane Research Project has realized this problem and has used two aircraft to collect simultaneous data at more than one level on at least seven occasions [1].

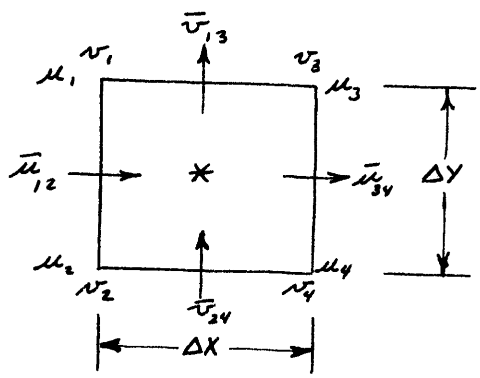
Hurricane "Ella", 1958, reached a position near the center of the Bahamas circle which permitted analysis of inflow-outflow of energy, heat and moisture through the walls of a cylinder of 4.5° lat. radius by Riehl and Gangopodahyaya [2]. The approximate interior area of 2.3×10^5 square miles of moisture and circulation details were analyzed by Levine [3] by supplementing the island rawinsonde reports with ship and aircraft reconnaissance reports. His approach, with a 60-mile grid size, was similar to this report, in that divergence, vertical motion and water-vapor flux were computed from 1000 to 500 mbs.

In this report, two grid sizes (Δx = 50 and 100 miles) were used in calculating divergence at 1000 mbs and the mean divergence from 1000 to 700 mbs and 700 to 500 mbs. The 100 mile grid was used for calculations of vertical motion, specific humidity distribution, and water vapor flux since it smoothed the divergent field while still maintaining significant features. It was assumed that with this smoothing plus the fact that in hurricane analysis, relatively large values of divergence are to be expected, minor errors in wind observations and isotach analysis would not substantially distort the significant divergence patterns.

II. DIVERGENCE

A. Computation of Horizontal and Mean Divergence

For the computation of the divergence field, two grid sizes were used (Δx = 50 and 100 miles) to show the variations in magnitude and smoothing effect with increase in size.

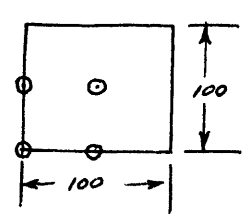


[Schematic picture of grid area and the mean ($\bar{\ }$) values of zonal and meridional wind components, $\Delta x = \Delta y$ = 50 or 100 miles]

For each grid area within the overall grid, the horizontal divergence "D" was determined by the equation

$$\text{"D"} = \frac{(\bar{u}_{34} - \bar{u}_{12}) + (\bar{v}_{13} - \bar{v}_{24})}{3600\ \Delta x} \qquad [10^{-5}\ \text{sec}^{-1}] \qquad (1)$$

Figures (1) and (2) represent the 1000-mb divergence for the 50 and 100 mile grid size respectively. Four grid displacements, with the storm center located at the center, corner and midpoints of the two adjacent sides were used with the 100 mile grid to insure an adequate representation of the significant features of the storm.



B. Comparison of Divergence with Mean

At first glance, fig (1) appears shocking to one accustomed to mean hurricane divergence charts and idealized models, but a comparison with Miller's [4] mean divergence, 0-1 km [fig 14a of his paper], will show a compatibility in the positions of salient features.

Two striking centers of convergence (-20 and -16 x 10^{-5} sec^{-1}), separated by divergent center (+9.5 x 10^{-5} sec^{-1}), weak convergence immediately east of the storm center and a second, strong divergent center (+16.1 x 10^{-5} sec^{-1}) south of the storm are noteworthy in fig (1). The features persist with the extension of the grid to 100 miles, fig (2), decreasing in magnitude to the point when the northern divergent and reverses sign to become an area of weak convergence separating two significant centers (-8± and -10+ x 10^{-5} sec^{-1}). The magnitudes of the convergence to the WNW and divergence to the south of the storm center were reduced by approximately 2/3 whereas the convergent center ENE and 2-1/2° distant from the storm center were reduced by 1/3.

Miller shows compatibility to the above, with a maximum convergent center (-4.4 x 10^{-5} sec^{-1}) NW of the storm center and a second center of convergence (-1.4 x 10^{-5} sec^{-1}) ENE and 4° distant from the storm center. These are separated by a significant decrease in convergence, to near divergence (-0.1 x 10^{-5} sec^{-1}), oriented N-S, immediately east of the storm. The convergent areas to the NW of the center compare favorably, even to magnitude considerations, <u>but</u> the significant deviation in magnitude of the ENE centers is worthy of comment.

The predominance of observations used by Miller were from Hazel '54; Connie, Diane, Ione, Janet '55; and Betsy '56; supplemented with reports dating back to 1946. One criteria for inclusion in his report was the location of the storm center south of 35°N latitude. This placed observations, geographically, along the Atlantic and Gulf coasts of the U.S., through the islands of the Caribbean, Bermuda, the Bahamas and Central America.

It is the belief of this author that a significant difference in characteristic peripheral structure exists, in that hurricanes in latitudes south of 27°N are surrounded by near homogeneous tropical air, whereas hurricanes north of 27°N, as in the case of "Gracie", are normally influenced by anticyclonic flow of modified polar air, <u>which</u>, when encountered by the peripheral northward flow of tropical air, will result in a strong convergent area. Advection of this area westward, with the prevailing lower level winds <u>might</u> result in its overtaking the slow moving storm circulation to cause intensification and recurvature. An indication of this progression of events is shown in the comparison of fig (1) with fig (3), which was computed and analyzed by Mr. Mike Simkowitz for the period 12Z, 29 September. The northern divergent area of fig (1) has been lost and the two centers of convergence appear to be rapidly converging. Between 06Z and 12Z, 29 September "Gracie" was observed to intensify (120 kt vs 90 kt maximum wind) and assume a NNW by direction of movement.

Mean charts, utilizing data from all storms, portray consistent features to all storms, including "Gracie" (i.e. maximum convergence immediately ahead and slightly to the right of direction of movement, divergence SW of and about 4° ahead of and right of storm, divergence in the right rear, and convergence in the left rear quadrants), but the convergent area of note to the ENE, in the case of "Gracie", will only be slightly reflected in the mean since it is characteristic of storms in more northerly latitudes, when circulation features of the anticyclone persist.

It seems natural to assume that this convergent area would develop rapidly as the southerly peripheral winds first break through the induced "buffer" ridge north of the storm to encounter the E to ESE winds of the anticyclone. Maximum magnitude would be attained perhaps 8-12 hours before recurvature, thereafter possibly decreasing in magnitude, but persisting as a significant feature, as it is advected with the lower tropospheric wind into the right and right front quadrant of the storm, causing intensification and recurvature as it influences the already present hurricane convergence area ahead of the storm.

In the case of "Gracie", the left rear quadrant is not totally convergent because of inflow interruption to the SE of the storm. Increased ridging, oriented NNE-SSW, from Bermuda to the Dominican Republic, occurred with the development of Hurricane "Hannah", located near 25N 58W at 29/10Z. The result of this ridging shows as two convergent inflow streams, one from the ESE and a stronger one from the south, separated by slight divergence.

In summary, it can be said that salient features of the mean hurricane are observed, but the characteristic features of "Gracie" are extremely graphic in representation.

Comparison of mean divergence; 1000–700 mb, fig (4) with Miller's 1–3 km [Fig 14b of his paper] shows excellent compatibility, excepting magnitudes and features noted before. Divergence immediately east of the storm, including orientation, compare well. In the extension of the grid from 50 to 100 miles, the convergent center to the ENE computed as the dominant feature of the storm, with strong convergence extending southward from the center.

Comparison holds for the 700–500 mb, fig (5), versus 3–6 km [Fig 14c], with the exception of the convergence-divergence near the storm center. "Gracie" showed a shift of the convergence to the SW of the storm center, with divergence oriented WNW-ESE north of and over the center, whereas the mean still maintains convergence to the right front and divergence over and to the rear of the storm center. The convergence ENE of the center is again dominant for the 100 mile grid.

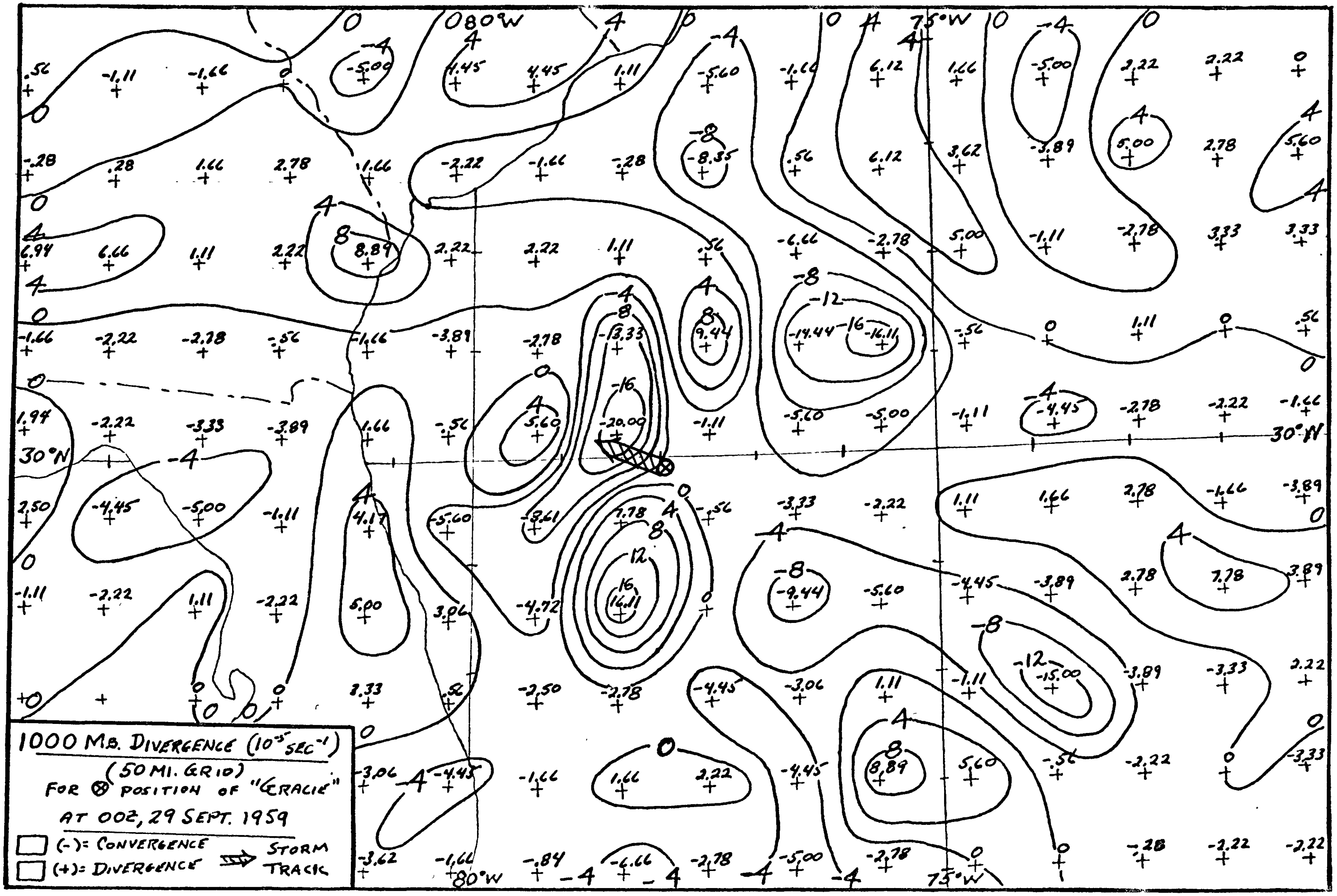

1000 MB. DIVERGENCE (10^{-5} SEC^{-1})
(50 MI. GRID)
FOR ⊗ POSITION OF "GRACIE"
AT 00Z, 29 SEPT. 1959
(-)= CONVERGENCE
(+)= DIVERGENCE
STORM TRACK
080°W
75°W
80°W
30°N

FIG 1

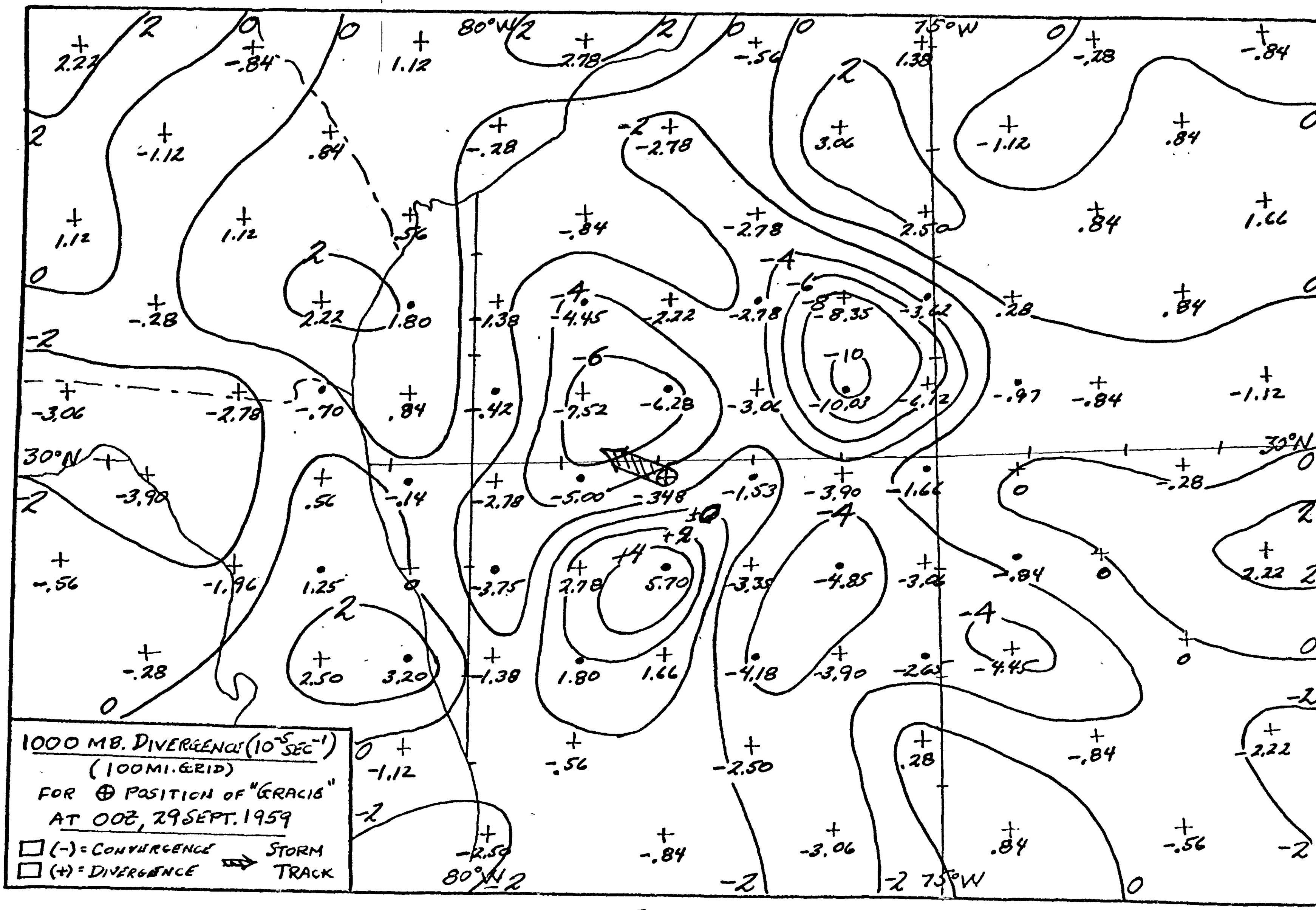

1000 MB. DIVERGENCE (10^-5 SEC^-1)
(100 MI. GRID)
FOR ⊕ POSITION OF "GRACIE"
AT 00Z, 29 SEPT. 1959
(-) = CONVERGENCE
(+) = DIVERGENCE
STORM TRACK
80°W
75°W
30°N

FIG 2

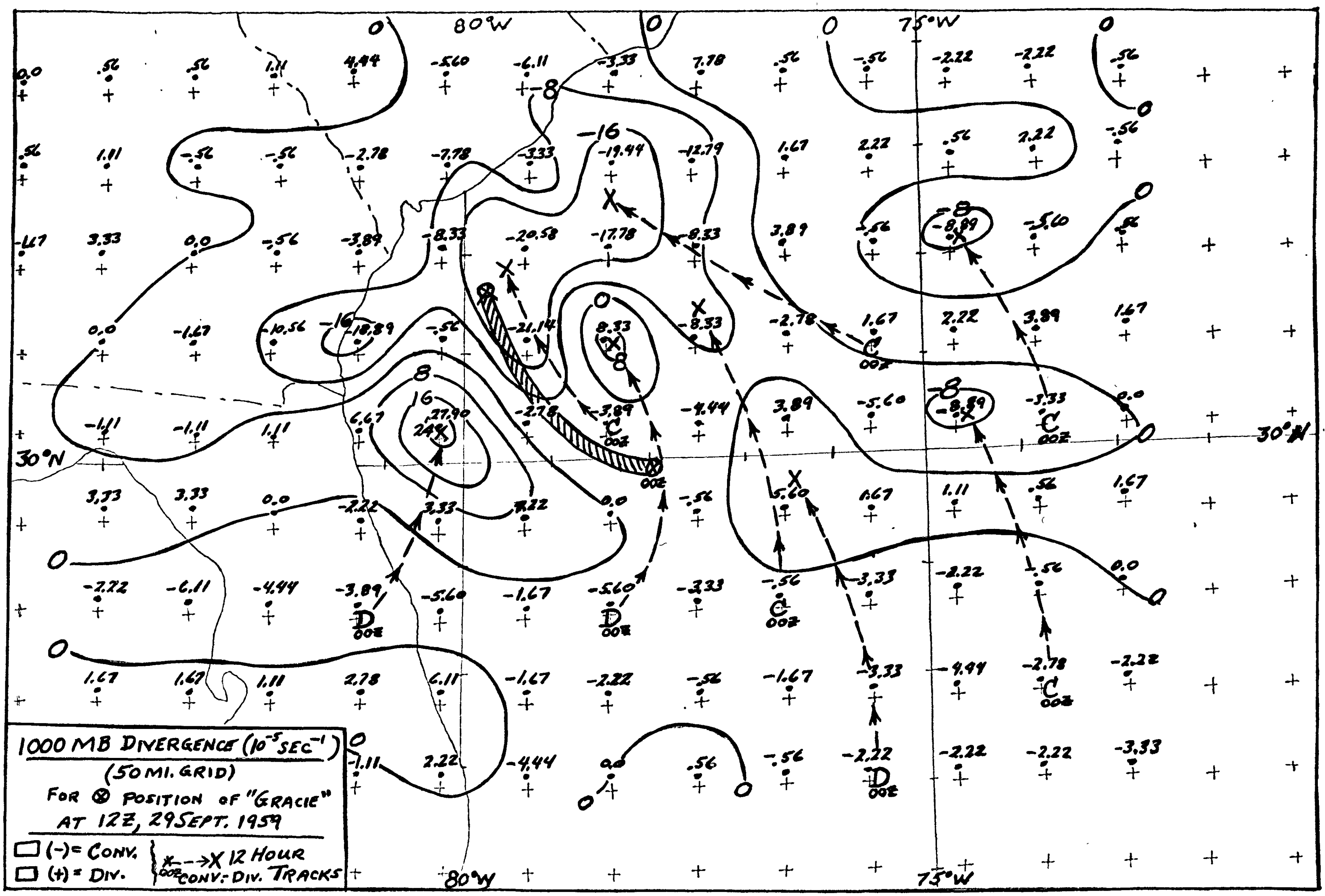

1000 MB DIVERGENCE (10^-5 SEC^-1)
(50 MI. GRID)
FOR ⊗ POSITION OF "GRACIE"
AT 12Z, 29 SEPT. 1959
(-) = CONV.
(+) = DIV.
X - - -> X 12 HOUR CONV.-DIV. TRACKS
80°W
75°W
30°N

FIG 3

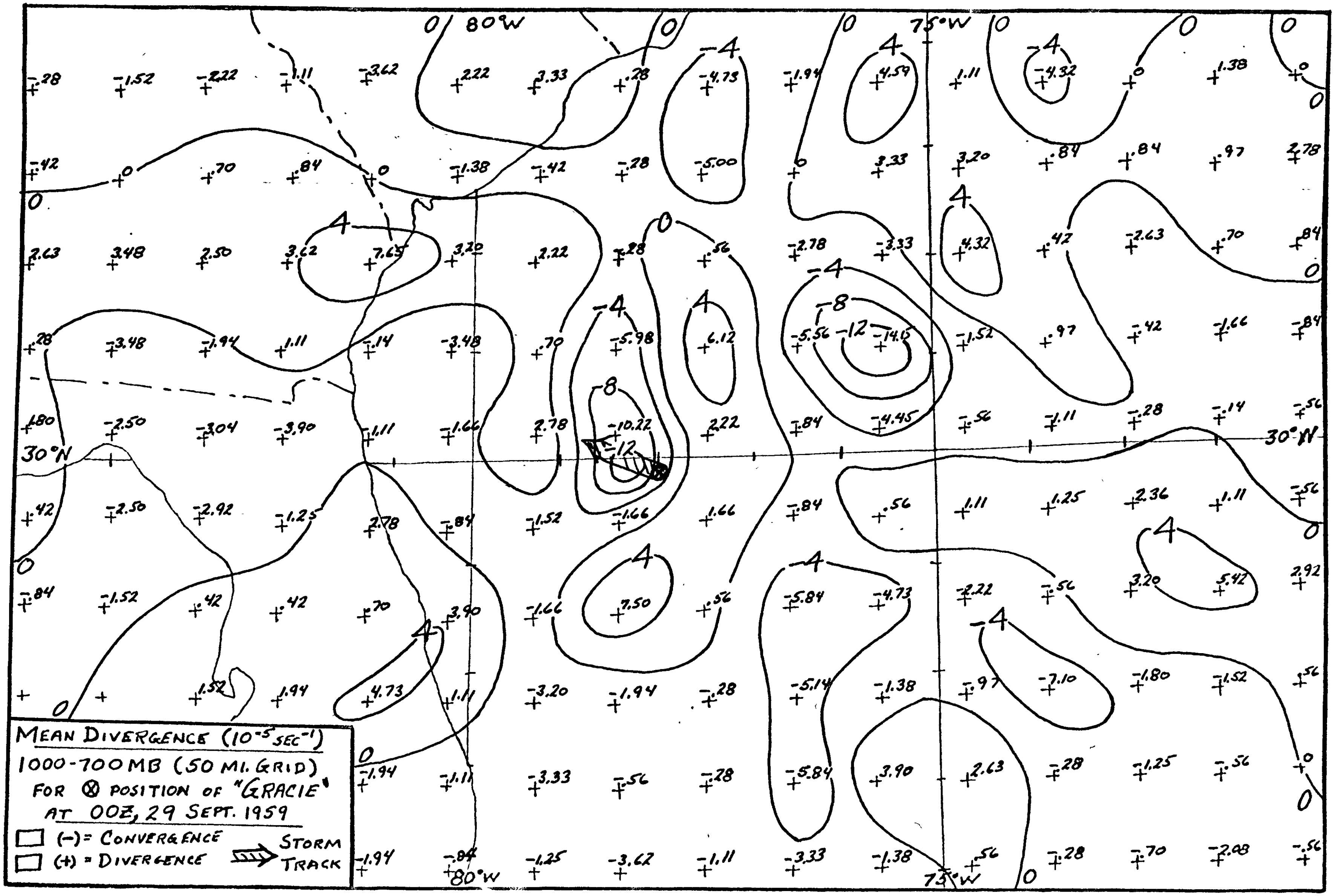

MEAN DIVERGENCE (10^-5 SEC^-1)
1000-700 MB (50 MI. GRID)
FOR ⊗ POSITION OF "GRACIE"
AT 00Z, 29 SEPT. 1959
(−) = CONVERGENCE
(+) = DIVERGENCE
STORM TRACK
80°W
75°W
30°N

Fig 4

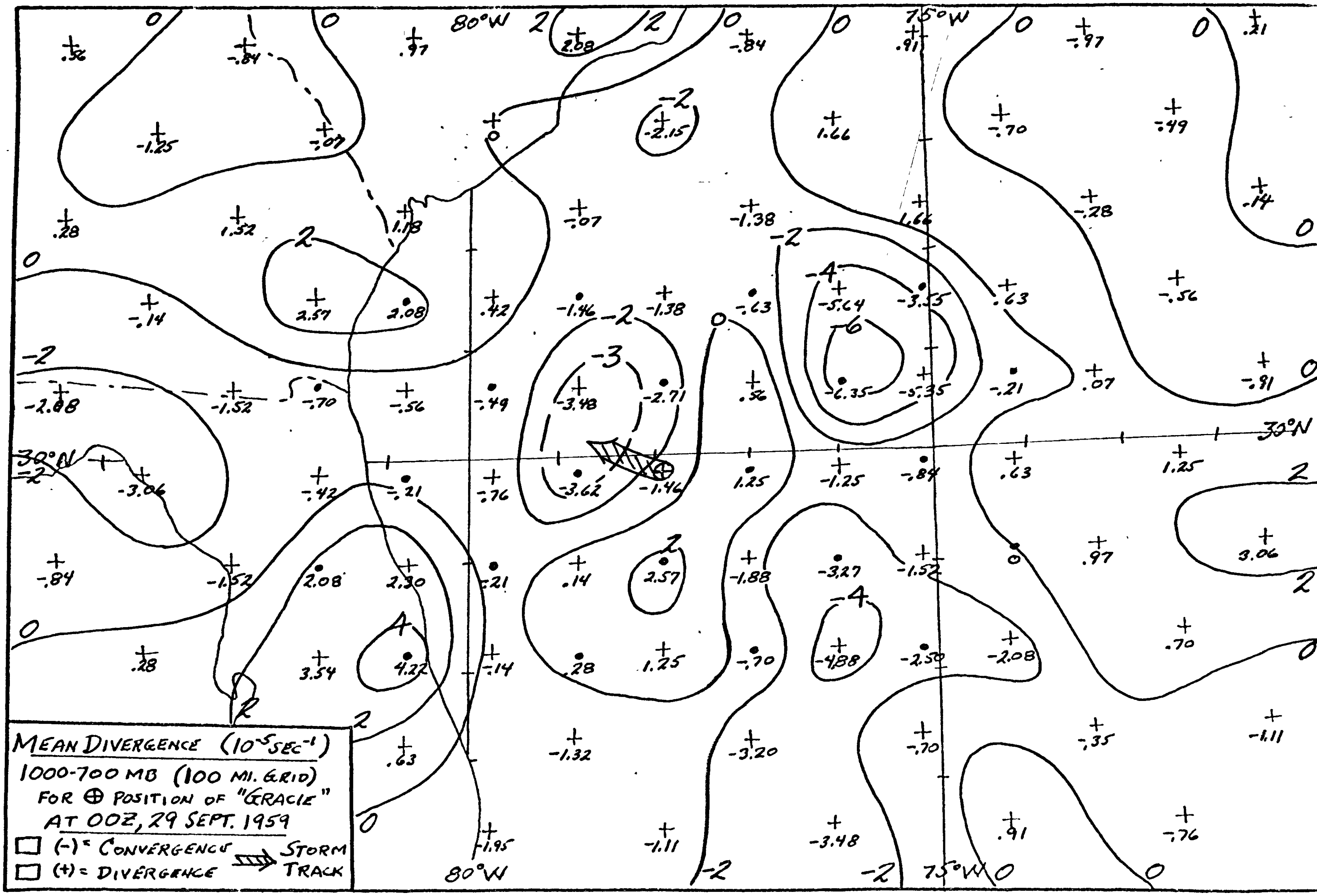

MEAN DIVERGENCE (10⁻⁵ SEC⁻¹)
1000-700 MB (100 MI. GRID)
FOR ⊕ POSITION OF "GRACIE"
AT 00Z, 29 SEPT. 1959
(-) = CONVERGENCE
(+) = DIVERGENCE
STORM TRACK
80°W
75°W
30°N

Fig 5

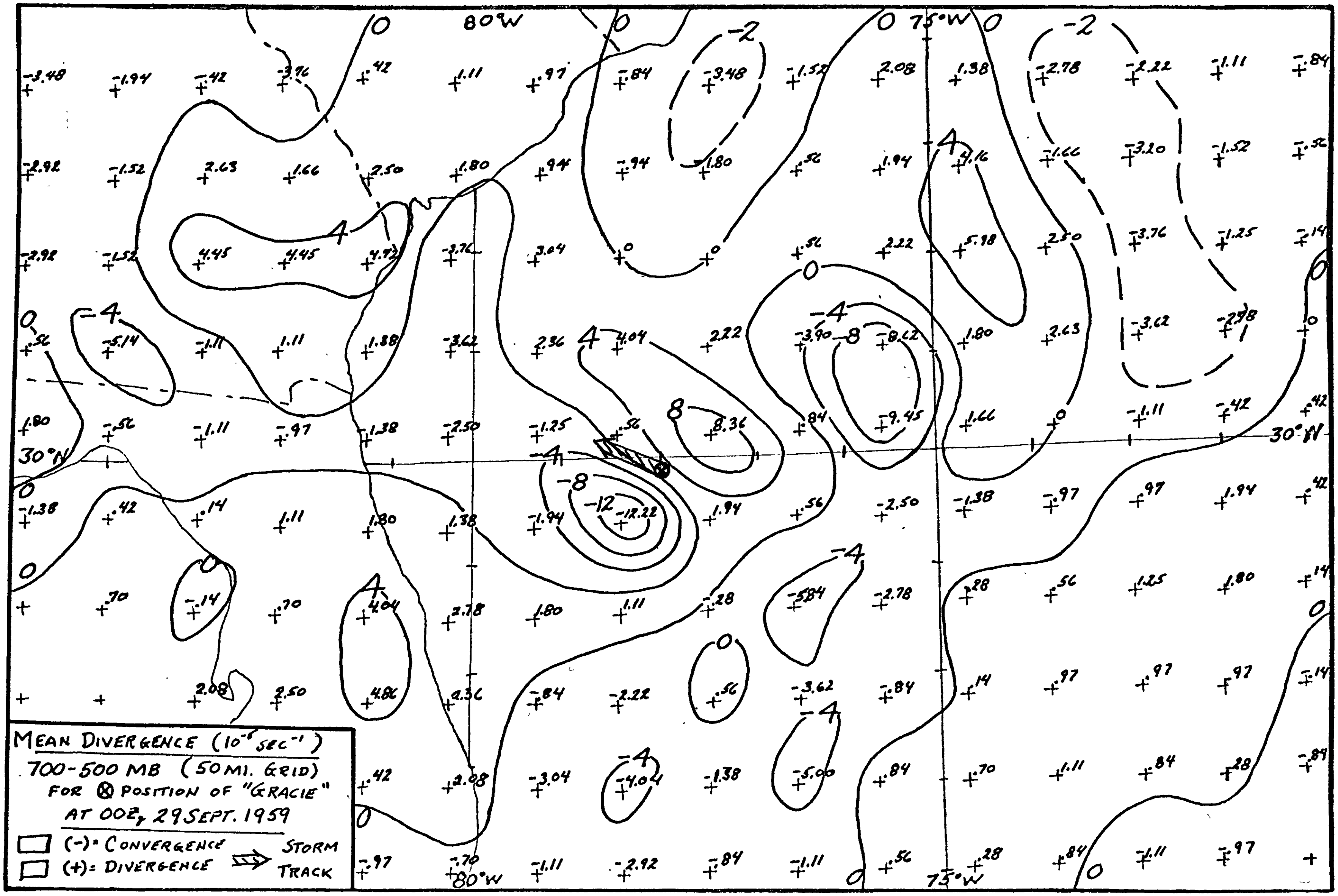

MEAN DIVERGENCE (10⁻⁵ SEC⁻¹)
700-500 MB (50 MI. GRID)
FOR ⊗ POSITION OF "GRACIE"
AT 00Z, 29 SEPT. 1959
(-)= CONVERGENCE
(+)= DIVERGENCE
STORM TRACK
80°W
75°W
30°N

FIG 6

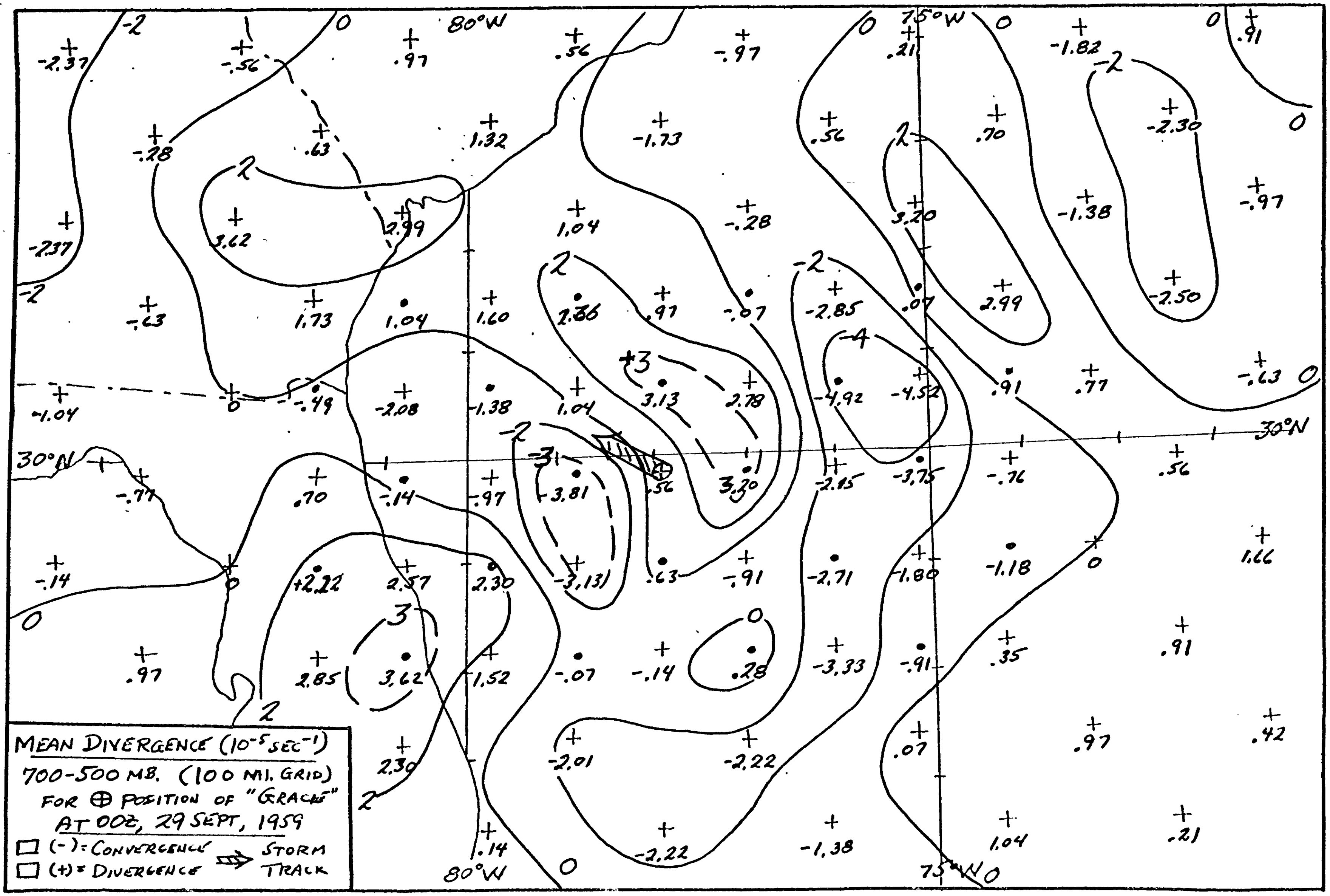

MEAN DIVERGENCE (10^{-5} SEC^{-1})
700-500 MB. (100 MI. GRID)
FOR ⊕ POSITION OF "GRACIE"
AT 00Z, 29 SEPT, 1959
(-) = CONVERGENCE
(+) = DIVERGENCE
STORM TRACK
80°W
75°W
30°N

FIG 7

III. VERTICAL MOTION

A. Computation

From the equation of continuity,

$$\frac{d\rho}{dt} = 0 = \frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z}$$

1. Assume steady state so that $\frac{\partial \rho}{\partial t} = 0$

$$\frac{\partial \rho w}{\partial z} = -\rho\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) - u\frac{\partial \rho}{\partial x} - v\frac{\partial \rho}{\partial y}$$

2. Assume horizontal density constant in grid area

$$\frac{\partial \rho w}{\partial z} = -\rho_\ell\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = -\rho_\ell \text{"}D\text{"}$$

3. Integrate from z_1 to z_2

$$(\rho w)_{z_2} - (\rho w)_{z_1} = -\overline{\rho}_{1-2} \; \overline{\text{"}D\text{"}}_{1-2} \; \Delta z_{1-2} \quad [gm\ cm^{-2}\ sec^{-1}]$$

4. Solving for w_{z_2}, assuming $w_{1000} = 0$

700 mb vertical velocity

$$w_{700} = -\frac{\overline{\rho}_{10-7}}{\rho_7} \overline{\text{"}D\text{"}}_{10-7} \Delta z_{10-7} \qquad [cm\ sec^{-1}] \tag{2}$$

500 mb vertical velocity

$$w_{500} = \frac{\rho_7}{\rho_5} w_{700} - \frac{\overline{\rho}_{7-5}}{\rho_5} \overline{\text{"}D\text{"}}_{7-5} \Delta z_{7-5} \quad [cm\ sec^{-1}] \tag{3}$$

In this study, a uniform vertical density gradient was considered accurate for computation of vertical velocity, with

$$\rho_{1000} = 1.17 \times 10^{-3} \text{gm cm}^{-3} \qquad \rho_{700} = .87 \times 10^{-3} \text{gm cm}^{-3} \qquad \rho_{500} = .65 \times 10^{-3} \text{gm cm}^{-3}$$

$$\bar{\rho}_{10-7} = 1.02 \times 10^{-3} \text{gm cm}^{-3} \qquad \bar{\rho}_{7-5} = .76 \times 10^{-3} \text{gm cm}^{-3}$$

giving final equations for vertical motion

$$w_{1000} = 0$$

$$w_{700} = -1.18 \ \text{"}\overline{D}\text{"}_{10-7} \ \Delta Z_{10-7} \qquad [\text{cm sec}^{-1}] \qquad (2a)$$

$$w_{500} = 1.34 w_{700} - 1.17 \ \text{"}\overline{D}\text{"}_{7-5} \ \Delta Z_{7-5} \qquad [\text{cm sec}^{-1}] \qquad (3a)$$

Figure (8) and (9) represent the distribution of vertical motion through 700 mbs and 500 mbs respectively.

B. Comparison of Vertical Motion with Mean

The influence of the southerly inflow and the strong convergence area ENE of the storm center become more dominant as a major feature of "Gracie" as we go aloft to 500 mb. Strong downflow is indicated over South Carolina, Georgia, east-central Florida and immediately east of the storm center.

Features to the front and right front quadrant of the storm are reasonable when considering position and magnitudes, but in the left front quadrant (over Florida) the downflow is much more significant as is the upflow ENE of the storm, when compared to the mean.

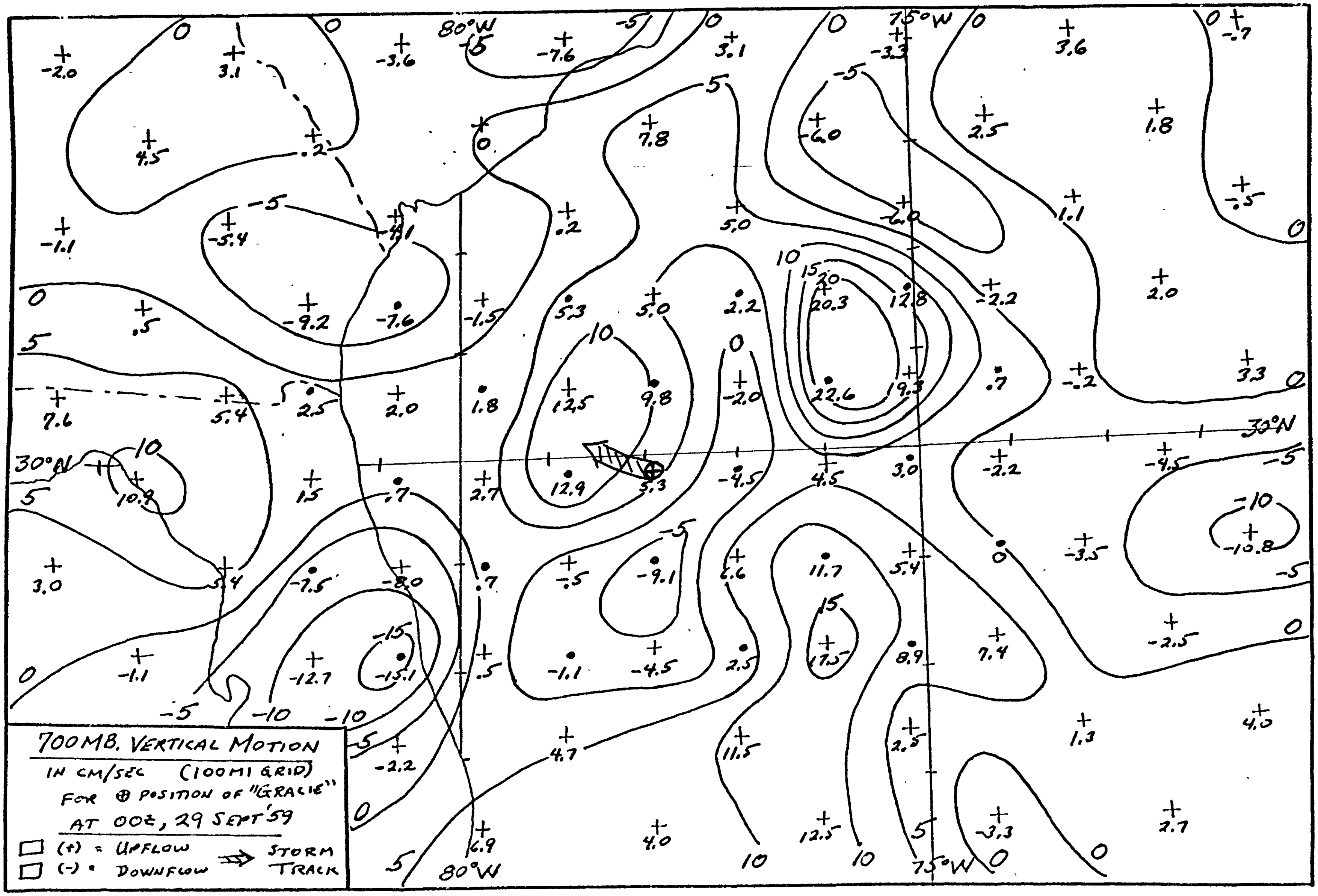

700 MB. VERTICAL MOTION
IN CM/SEC (100 MI GRID)
FOR ⊕ POSITION OF "GRACIE"
AT 00Z, 29 SEPT '59
(+) = UPFLOW
(-) • DOWNFLOW
STORM TRACK
80°W
75°W
30°N

FIG 8

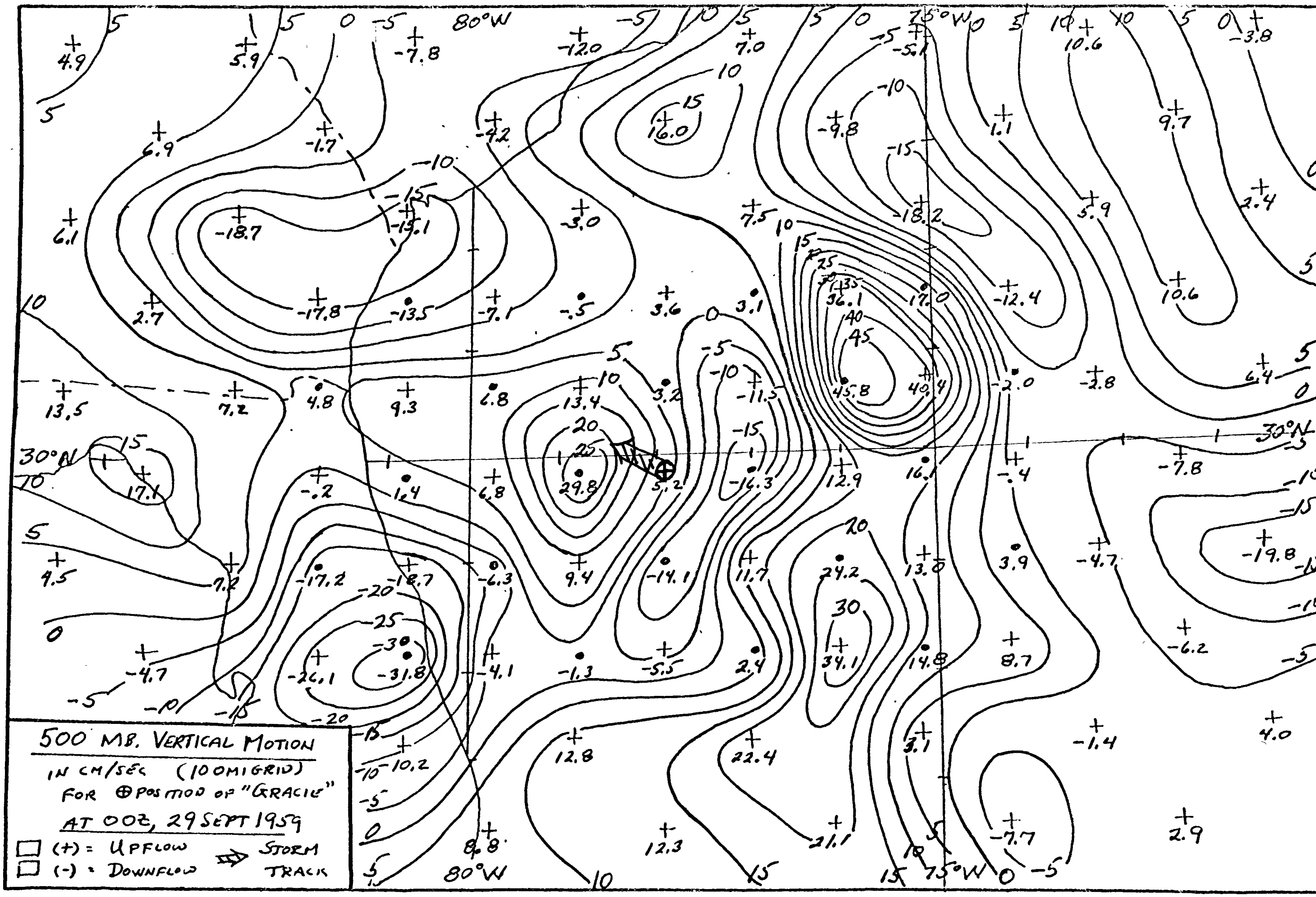

500 MB. VERTICAL MOTION
IN CM/SEC (100 MI GRID)
FOR ⊕ POSITION OF "GRACIE"
AT 00Z, 29 SEPT 1959
(+) = UPFLOW
(-) = DOWNFLOW
STORM TRACK
80°W
75°W
30°N

Fig 9

IV. SPECIFIC HUMIDITY

A. Computation of Divergence of Specific Humidity (q)

Referring to the schematic picture on page 8, values of (q) at each corner of the grid were used in conjunction with the (u), (v) components of the wind to compute the horizontal divergence of specific humidity from the equation

$$"qD" = \frac{\left[(\overline{qu})_{34} - (\overline{qu})_{12} + (\overline{qv})_{13} - (\overline{qv})_{24}\right]}{3600 \times 100} \quad \left[10^{-8}\,sec^{-1}\right] \qquad (4)$$

Mixing ratio (w) values were taken as equal to (q) since $(q) \sim (w) \sim .621\ e/p\ gm\ k\ gm^{-1}$. This permitted reading (q) directly from an adiabatic chart.

Mean values, $\overline{"qD"}_{10-7}$ and $\overline{"qD"}_{7-5}$ are represented in figs (10) and (11) respectively.

B. Comments

The most interesting features are the representation of the moisture, thus energy source through latent heat of condensation, extending from the south, northward to a definite maximum in the convergent area ENE of the storm center from 1000-700 mbs, and the significant divergence, oriented ESE-WNW, north and east of the storm from 700-500 mbs.

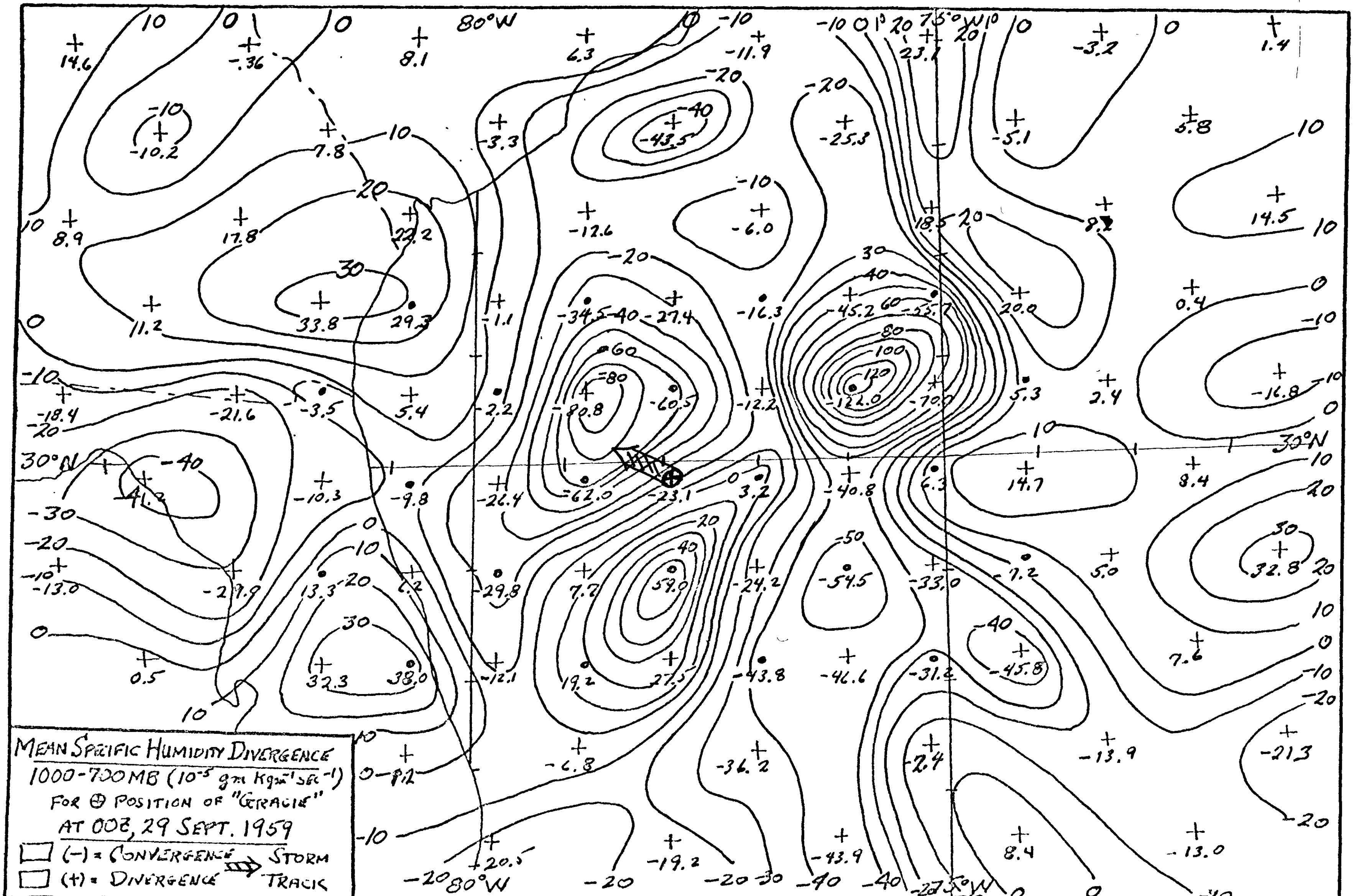
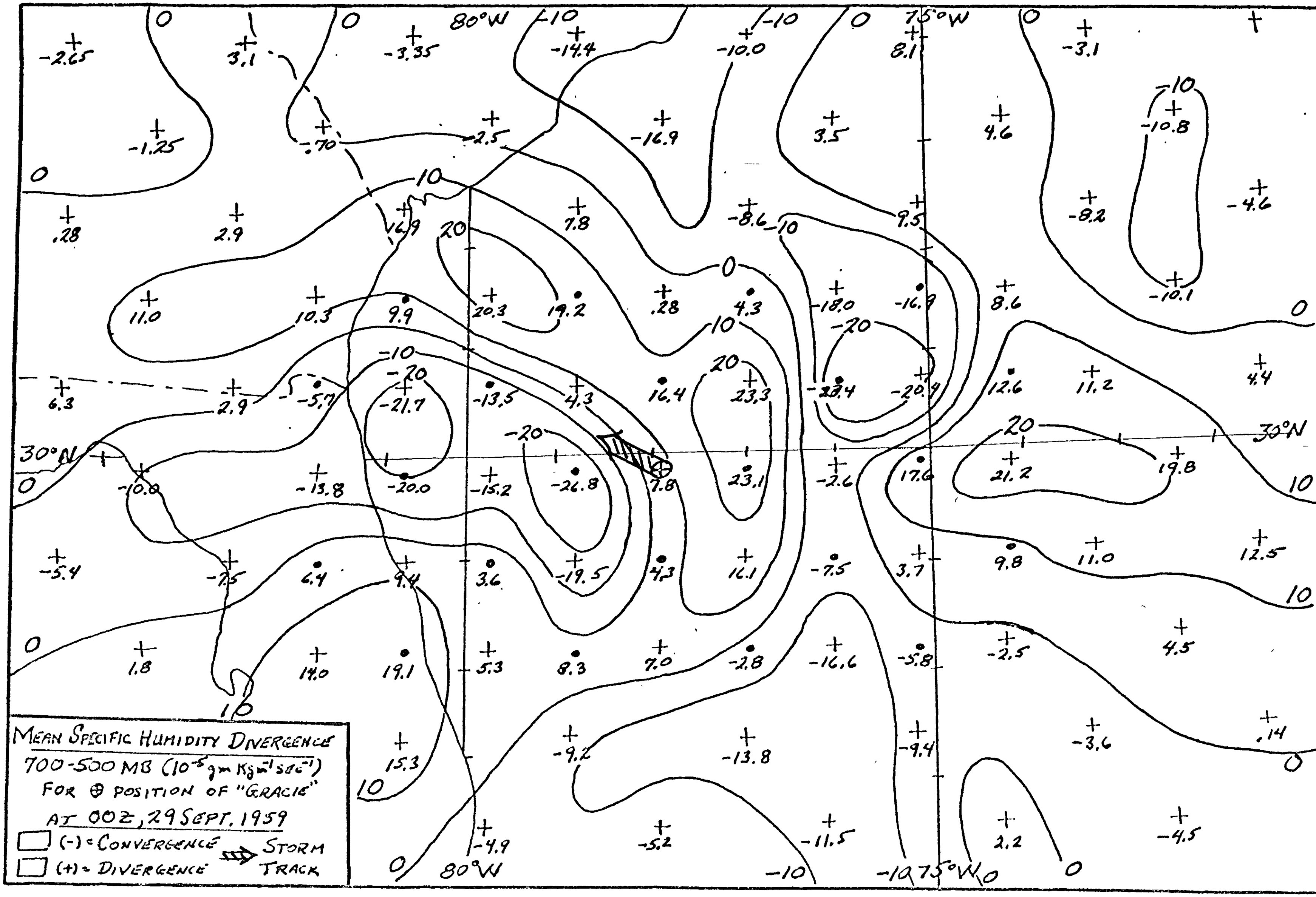

MEAN SPECIFIC HUMIDITY DIVERGENCE
1000-700 MB (10^{-5} gm Kgm^{-1} sec^{-1})
FOR ⊕ POSITION OF "GRACIE"
AT 00Z, 29 SEPT. 1959
(-) = CONVERGENCE
(+) = DIVERGENCE
STORM TRACK
80°W
75°W
30°N

FIG 10



MEAN SPECIFIC HUMIDITY DIVERGENCE
700-500 MB (10^{-5} gm Kg^{-1} sec^{-1})
FOR ⊕ POSITION OF "GRACIE"
AT 00Z, 29 SEPT. 1959
(-) = CONVERGENCE
(+) = DIVERGENCE
STORM TRACK
80°W
75°W
30°N

FIG 11

V. MOISTURE (WATER VAPOR) FLUX

A. Computation of Flux Through 700 and 500 mb Surfaces

From the continuity equation, incorporation (q) values, we have

$$\frac{\partial \rho q w}{\partial z} = -\rho_k{}'' q D''$$

Integrating from z_1 to z_2, we have

$$(\rho q w)_{z_2} - (\rho q w)_{z_1} = -\bar{\rho}_{1-2} \; \overline{{}''qD''}_{1-2} \; \Delta z_{1-2} \qquad [gm\ cm^{-2} sec^{-1}]$$

Flux through the 700 mb surface per cm^{-2} becomes

$$(\rho q w)_{700} = -\bar{\rho}_{10-7} \; \overline{{}''qD''}_{10-7} \; \Delta z_{10-7} \qquad [gm\ cm^{-2} sec^{-1}]$$

with the total flux through the grid area at 700 mb being

$$F_{700} = -\bar{\rho}_{10-7} \; \overline{{}''qD''}_{10-7} \; \Delta z_{10-7} \; \Delta x^2 \qquad [gm\ sec^{-1}] \qquad (5)$$

and the total flux through the grid area at 500 mbs

$$F_{500} = F_{700} - \left[\bar{\rho}_{7-5} \; \overline{{}''qD''}_{7-5} \; \Delta z_{7-5} \; \Delta x^2\right] \qquad [gm\ sec^{-1}] \qquad (6)$$

In equation (5) and (6) $\bar{\rho}_{10-7} = 1.02 \times 10^{-3}$ gm cm^{-3}, $\bar{\rho}_{7-5} = .76 \times 10^{-3}$ gm cm^{-3}, $\Delta Z_{10-7} = .303 \times 10^5$ cm, $\Delta Z_{7-5} = .273 \times 10^5$ and $\Delta x^2 = (100\ mi)^2 = 2.59 \times 10^{14}\ cm^2$. The final equations for computing the flux are

$$F_{700} = -.80 \, \overline{"q D"}_{10-7} \qquad [10^8 \text{ gm sec}^{-1}] \tag{5a}$$

$$F_{500} = F_{700} - .54 \, \overline{"q D"}_{7-5} \qquad [10^8 \text{ gm sec}^{-1}] \tag{5b}$$

Figs (12) and (13) represent the total moisture flux through the 700 and 500 mb surface respectively.

B. Comments

In the steady state, with no loss of moisture from the top of the storm (all low level moisture influx is precipitated), the amount of rainfall can be computed.

From Riehl's model [5], which assumes that most of the outflow takes place above 10 km, the moisture loss at the top of the storm would be less than 5% of the low level influx, if we neglect liquid water loss. Assuming no evaporation in the areas of major convergence centers, the rainfall rate for the center ENE of the storm would be approximately 2.3+ inches per 6 hours or 9.52 inches in 24 hours, and ahead of the storm approximately 1.4+ inches per 6 hours or 6.4+ inches in 24 hours. This agrees substantially with Cline [6] when considering the moving storm, with a total rainfall value of 11 inches in 48 hours for a storm which passes overhead.

Charleston, South Carolina, in a summary of rainfall in 6 hourly amounts associated with "Gracie" reported the following:

28/18Z to 29/00Z	.01 inches
29/00Z to 29/06Z	.63 inches
29/06Z to 29/12Z	1.38 inches

29/12Z to 29/18Z	1.44 inches
29/18Z to 30/00Z	.35

This is an excellent verification of the convergent area ahead of the storm center, which computed at 1.4+ inches per 6 hours.

Columbia, South Carolina, and Charlotte, North Carolina, reported about 5 inches of rain from 29/12Z to 30/12Z. Richmond, Virginia, reported 9.10 inches of rainfall at Montebello, 7.70 inches at Balcony Falls and 6.38 inches at Buchanan. Heavy rains persisted into Pennsylvania.

Further evaluation will be made when complete rainfall data is available to this writer.

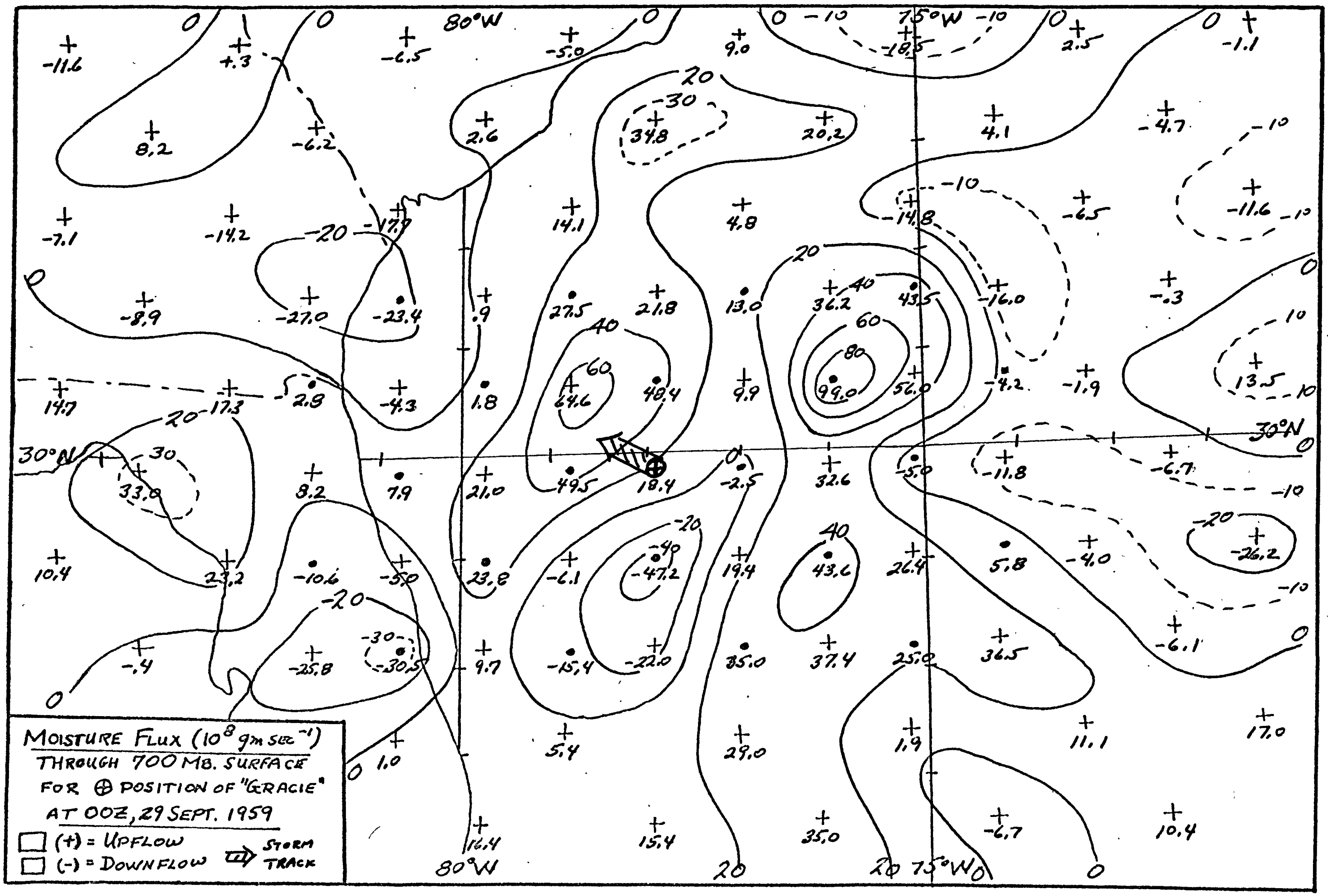

MOISTURE FLUX (10^8 gm sec^{-1})
THROUGH 700 MB. SURFACE
FOR ⊕ POSITION OF "GRACIE"
AT 00Z, 29 SEPT. 1959
(+) = UPFLOW
(-) = DOWNFLOW
STORM TRACK
80°W
75°W
30°N

FIG 12

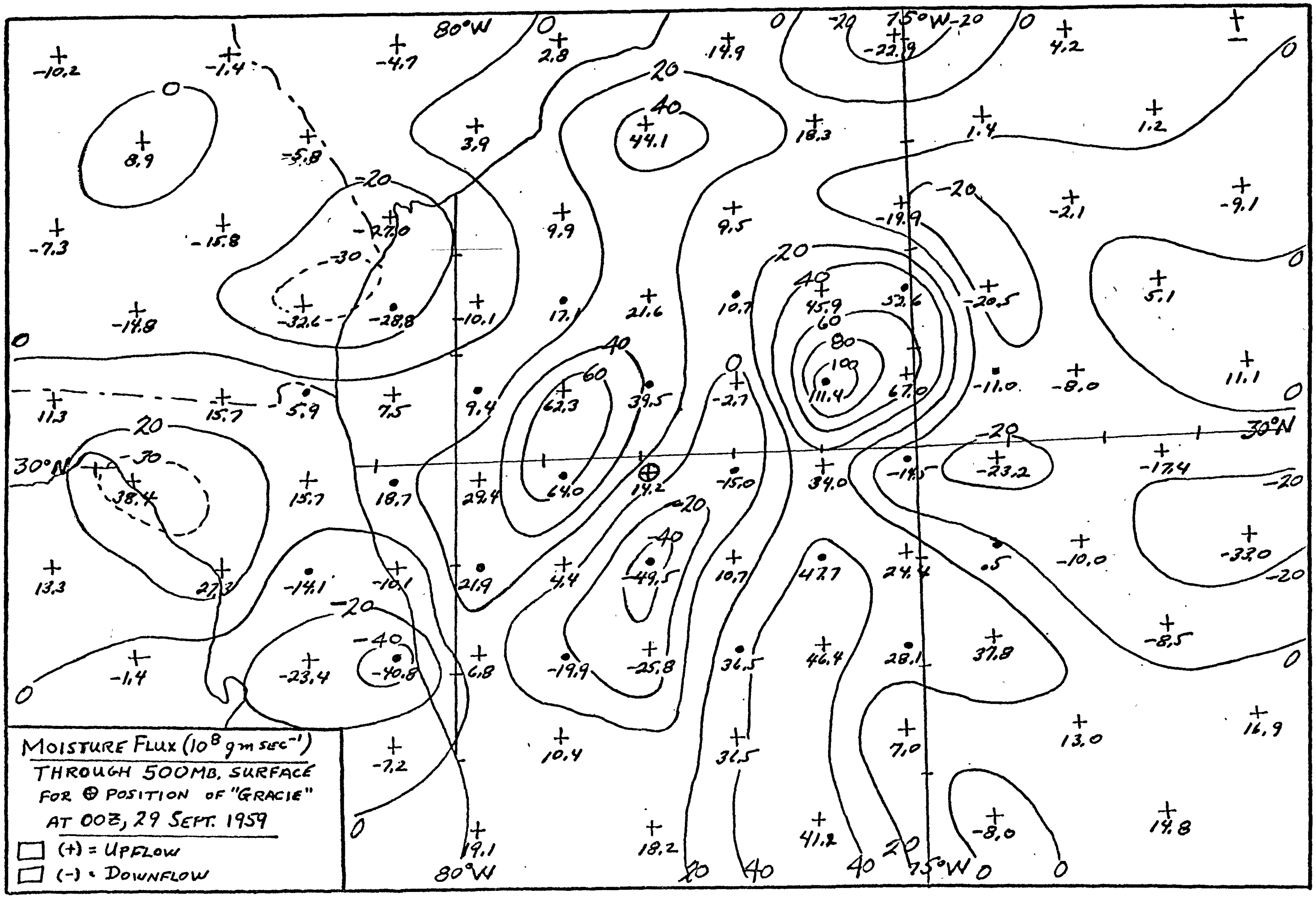

80°W
75°W
30°N
MOISTURE FLUX (10^8 gm sec^-1)
THROUGH 500MB. SURFACE
FOR ⊕ POSITION OF "GRACIE"
AT 00Z, 29 SEPT. 1959
(+) = UPFLOW
(-) = DOWNFLOW

FIG 13

VI. CONCLUSIONS AND RECOMMENDATIONS

This case report on Hurricane "Gracie" for 00Z, 29 September 1959, including comparisons of divergence features with those of 29/12Z, and divergence-vertical motion features with those of the "Miller" mean model, brings out the possible need of a classification of storm types, perhaps under two main headings; (1) storms with peripheral homogeneity and (2) storms with peripheral discontinuities. Characteristic features of individual storms, which are dependent upon the stage of development, location and peripheral synoptic influences, could be investigated more thoroughly with selective quadrant reconnaissance. The current procedures of routine hurricane reconnaissance, by the USAF and Navy, leave much to be desired, in that the flights, more often than not, are reporting information which is repetitious to that of previous flights into the storm area. Considering western Atlantic, Type (2) storms, control of flight track and altitude by a central agency would create an excellent opportunity to collect information on what appears to be critical features of any individual storm. Radar tracking of the storm center, plus one dropsonde or aircraft sounding in the center, per flight, would sufficiently indicate the movement and intensity of the storm at that time and free the aircraft for directed critical coverage elsewhere in the storm area. Since we normally have two flights per day into the storm area, from opposite directions, integrated triangular coverage, with a common side (say NW-SE through the storm center), might be considered as the basic flight track. Critical area coverage, perscribed by the central agency after careful synoptic analysis and study of earlier reconnaissance reports, could be accomplished following fulfillment of basic track coverage. Representation of this recommended basic track, plus area of interest are shown on Fig (14), 700 mb analysis based on integrated reports. [It is of interest to note that the ENE convergent area moved with the 700 mb wind at approximately 50% of the speed Fig (3), and "Gracie" intensified with convergence of noted convergent centers to a maximum estimated 175 mph wind east of Beaufort, North Carolina.]

More stress is needed on observed wind reports at reporting points plus significant wind shift-velocity variation along each leg of the track.

In closing, we must face the fact that flying time is the controlling factor to available storm coverage. This necessitates a close surveillance of reconnaissance missions to (1) assure fulfillment of normal mission requirements and (2) secure as much added, useful information as possible for future research of the structure and characteristics of hurricanes.

Recommendations for future research.

1. Deviations in the mean, of Type (1) versus Type (2) hurricane

models.

2. Case studies of Type (2) storms, in the light of advected peripheral convergence areas, intensification and recurvature, based on selected area as well as routine reconnaissance.

3. Deviations in characteristic features of case studies from the Type (2) mean and the synoptic significance of these deviations.

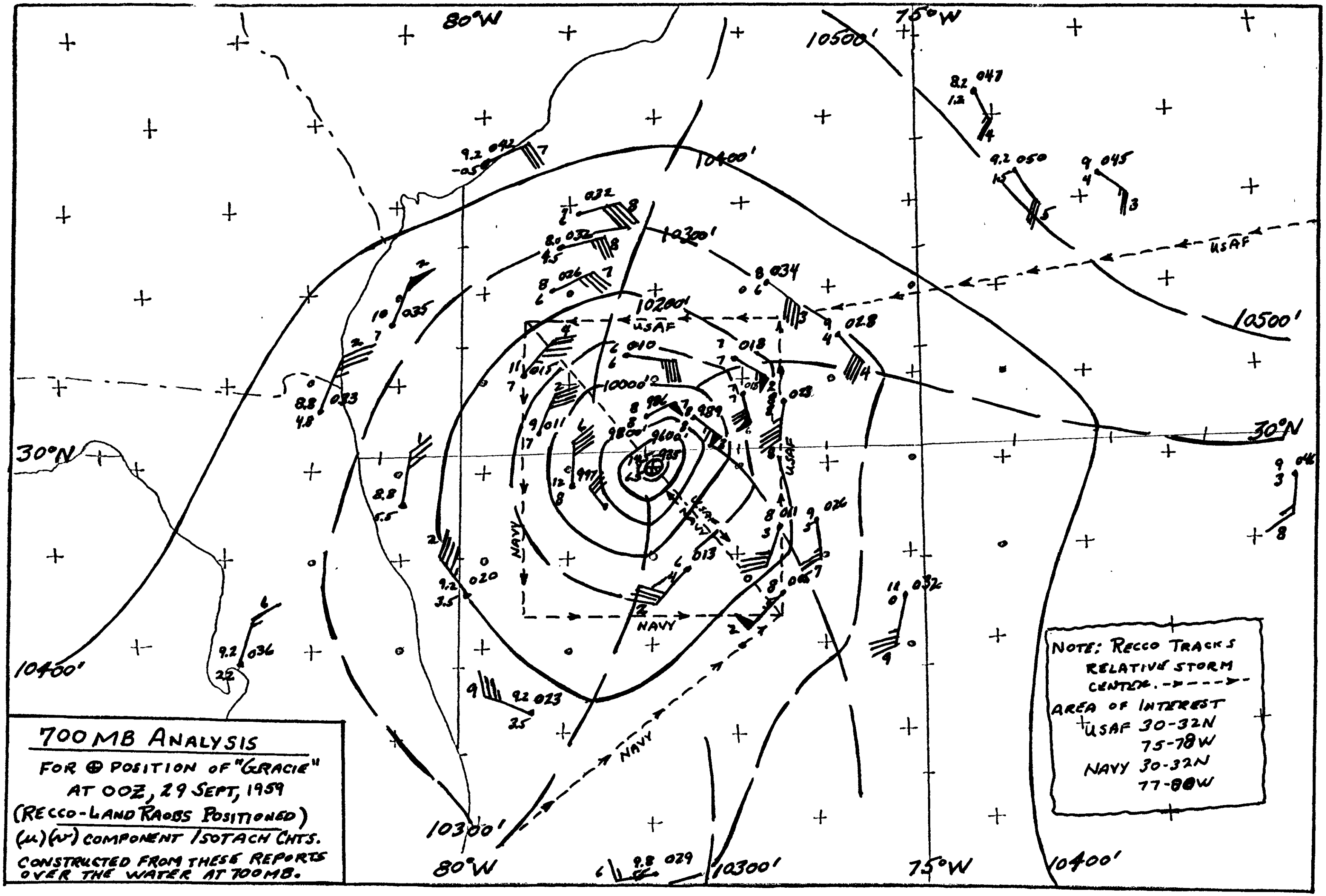

700 MB ANALYSIS
FOR ⊕ POSITION OF "GRACIE"
AT 00Z, 29 SEPT, 1959
(RECCO-LAND RAOBS POSITIONED)
(u)(v) COMPONENT ISOTACH CHTS.
CONSTRUCTED FROM THESE REPORTS
OVER THE WATER AT 700MB.
NOTE: RECCO TRACKS
RELATIVE STORM
CENTER.
AREA OF INTEREST
USAF 30-32N
75-78W
NAVY 30-32N
77-80W
80°W
75°W
30°N
10500'
10400'
10300'
10200'
10000'
9800'
9600'
USAF
NAVY

Fig 14

VII. BIBLIOGRAPHY

[1] Staff, NHRP, "Details of Circulation in the High Energy Core of Hurrican Carrie," NHRP Report No. 24, November 1958.

[2] Riehl, H., and Gangopodahyaya, M., "Exchange of Heat, Moisture, and Momentum between Hurricane Ella (1958) and its Environment," NHRP Report No. 29, April 1959, 12 pp.

[3] Levine, J., "Water Vapor Flux Divergence in Hurricane "Ella" and its Relation to Maintainance of a Hurricane's Kinetic Energy," to be published, June 1960, 17 pp.

[4] Miller, B. I., "The Three-Dimensional Wind Structure Around a Tropical Cyclone," NHRP Report No. 15, January 1958, 41 pp.

[5] Riehl, H., "A Model of Hurricane Formation," J. appl. Physics, 21, 1950, p. 917-925.

[6] Cline, J. M., "Tropical Cyclones," N.Y. Macmillan 1926, 301 pp.