UNIVERSITY OF OKLAHOMA

DEPARTMENT OF METEOROLOGY

Norman, Oklahoma 73069

ON THE LOW-LEVEL INFLOW INTO THUNDERSTORMS; A CASE STUDY*

by

J. P. Charba and Y. Sasaki

Ref:ARL-1653-3 September 1968

---

[*] This study was supported by the Environmental Science Services Administration Research Grant No. E22-108-68(G).

ABSTRACT

The results of a feasibility study with efforts to define the three dimensional extent of the low and mid-level interaction of the severe storm and the environmental flow in which it is embedded are reported. Results from 16 Apr 1968 storm data indicate that an intense storm which moved from west-southwest to east-northeast along a path just north of Oklahoma City was characterized by a narrow, high speed inflow current which was detected over 40 nm upwind. Balloon transponder data suggest that the thunderstorm updraft was fed by this "mesojet". The mesojet current approaching the storm underwent horizontal deceleration and upward vertical motion.

Nocturnal thunderstorms and their relationship to the kinematic and dynamic properties of the low-level jet have been the object of many recent studies. [Means (1944), Blackadar (1957), Pitchford and London (1962), Bonner (1966) and others.] Means (1944) demonstrated the importance of the warm-moist air advection characteristic of the low-level jet in supplying the latent energy required for thunderstorm formation in the Great Plains. A three year statistical study performed by Pitchford and London (1962) shows excellent coincidence of the frequency maximum position of the composite jet axis and the line of maximum thunderstorm frequency. Bonner (1966) concludes that the crucial role of the low-level convergence and the associated vertical velocity fields of low-level jets is not in initiating convection at night but in extending the lifetimes of squall line thunderstorms which form during maximum instability in the afternoon hours.

Analysis of data from balloon-transponder systems [See Hart and Cooper (1968)] have revealed that single thunderstorms have low-level inflows which can be traced as far as 30nm away from the storm. This observation seems to suggest that each well organized convective cell has what could be called a mesojet associated with its inflow. Further observations by Hart and Cooper that some balloon transponders launched in the general upwind direction from a storm cell bypassed the storm without any apparent interactions leads one to believe that the mesojet is narrow and well defined.

This preliminary report is a discussion of results of a feasibility study, the object of which is to define the interaction of the low and mid-level flow of the environment with the internal circulation of the thunderstorm. In April, 1968 the authors with several graduate students of the University of Oklahoma meteorology and with a cooperating team from the National Severe Storms Laboratory (NSSL) prepared the Chickasha (CHK) rawinsonde site for successive rawinsonde soundings to about the 700-mb level. Then for specified two week period in April they watched for a weather situation which they hoped would produce scattered severe thunderstorms in the immediate vicinity of CHK. Unfortunately, the ideal situation did not develop. They made the first series of launches on a 16 April 1968 storm day. Even with some unduely technical difficulties our average time interval between launches was 34 min. This report is a discussion of the preliminary results of this sounding data in addition to discussions of surface mesonetwork, radar, and TV tower data provided by NSSL and balloon transponder returns provided by Weather Science Inc. (WSI).

Synoptic Weather Pattern of 16 April 1968

The 16 April 1968, 1800 CST surface map featured a well developed frontal system extending southward from just west of Lake Superior, through western Iowa, and northeastern Kansas. The front curved westward in southwest Kansas and extended westward into a 997-mb low in southern Neveda. Thunderstorms began developing in a surface trough ahead of the front by mid-afternoon and by 1800 CST they formed into a squall line oriented SW-NE from just east of Lubbock, Texas and Hobart, Oklahoma, to Wichita, Kansas, and to the northeast Kansas border. A strong southerly current of Gulf air, whose temperatures and dewpoints were in the low 70's and mid 60's respectively, over central Oklahoma, converged into the eastern half of the trough. Dewpoint temperatures in the west side of the trough were mostly in the low 20's.

The frontal and pressure features of the 1800 CST 850-mb map was very similar to the surface map. An 850-mb jet whose axis extended from central Texas, to central Oklahoma, and to eastern Kansas provided an abundant supply of warm, moist air with winds of 30 to 45 kts.

The 1800 CST 500-mb map featured a deep trough from Montana to southern California. A closed low was centered over extreme eastern Nevada. This 500-mb height pattern resulted in a 50 kt west-southwesterly current over Oklahoma. Only weak vorticity and cool air advection was indicated over central Oklahoma.

At 1600 CST, isolated thunderstorms appeared on the WSR-57 radar scope at NSSL, 90 nm northwest of Norman (NRO). The storms moved toward the east-northeast at 25 kts. By 1830 CST, radar showed a broken line of storm cells from 60 nm northwest to 90 nm north of NRO. High wind, large hail, and heavy rain accompanied these thunderstorms. Guthrie, Oklahoma received wind damage from an apparent tornado at 2215 CST.

Storm Data Obtained

As the storms moved from west-southwest to east-northeast just north of the northern edge of NSSL's surface beta network, seven rawinsonde soundings were made at CHK; the first launch was at 1935 and the last at 2257 CST. WSI launched two balloon transponders from NRO, one at 2105 and another at 2208 CST. Data from the mesonetwork and the TV tower was available for the entire period and the WSR-57 scope was photographed to 2231 CST.

Results of Data Analysis

Fig. 1 is a map which includes most of the NSSL's surface network for the 1968 storm season. Plotted at each network station is the wind, temperature, and dewpoint for 1945 CST. The temperature and dewpoint are reported in deg F and one wind barb represents 10 kt. The intensity contoured radar echoes drawn at times indicated are the full gain zero degree elevation scope representations. Range circles (solid) are shown at 20 nm intervals. The pressure field was not plotted since since an inspection of the barograms indicated no significant pressure disturbances over the network (weak to moderate pressure fluctuations were noted at stations 1D, 1E, 1F and 2C). The surface winds in Fig. 1 are shown to be uniformily from the south at about 20 to 25 kt in the southern half of the network, decreasing to 15 to 20 kt at stations nearest storms A and B. There is no major temperature or dewpoint variation over the data field. The 2115 CST picture of the network is shown in Fig. 2. The southern part of the network data field is virtually unchanged over the 1945 CST map. The winds at the northern network stations decrease even more as storm B edges closer to them. The temperature field remains uniform. [Ignore for the moment the balloon transponder tracks shown in Fig. 2]

Fig. 3 is a time section of the CHK soundings. One wind barb is 5 m sec^{-1}; a flag is 25 m sec^{-1}. Temperature and dewpoint is plotted in deg C. Dashed isotherms are drawn at 2½°C intervals and isodrosotherms (eg. heavy solid lines) are drawn at 10° intervals. The section of dewpoints greater than 15° is hatched. The temperature inversion layer is shaded. The spacing of the vertical soundings along the abcissa is proportional to the time interval between launches. At 1935 CST the winds are very uniform in speed from the surface to 660-mb; the moderate wind veer is shown to be smooth. The 2011 and 2040 CST soundings show a downward propagation of winds greater than 25 m sec^{-1}. Then from 2040 to 2118 CST, the winds near the 900-mb level increase dramatically, from 27 to 42 m sec^{-1}. Later soundings show this low-level jet propagating upward and diminishing in speed. Also, the lower-level winds change to a more westerly direction at 2218 and 2257 CST. Except for a slight wind maximum at 900-mb, the last sounding, similar to the first, shows winds of uniform velocity throughout the lower troposphere.

The thermal structure of the atmosphere is shown to be nearly dry adiabatic in the layer adjacent to the surface at all soundings, with a near-isothermal layer above in the earlier soundings. At 2011 CST, the lapse rate of temperature and moisture is steep, above 870-mb, resulting in a dry, cool pocket in the mid-tropospheric levels. After the appearance of the low-level jet maximum at 2148 CST a thick temperature inversion layer is observed to be forming over CHK. The air drys out rapidly with time in and immediately above the developing inversion. The height of the 15°C isodrosotherm does not show a large variation with time, being highest at the initial sounding and lowest at the final sounding.

The wind and temperature was also analyzed at all levels from the WKY-TV tower data (Fig. 4). Isotherms are drawn at 0.5°C intervals; a wind barb is 10 kts. The maximum wind velocity at the 146 ft level is centered around the 1850 CST reading; at 1458.5 ft, the maximum wind occurs about 2000 CST. There is a similar time lag in the wind change between the base and the summit (not as large however) for a wind shift which occurs at 2240 at the bottom and 2300 CST at the top of the tower. The near-invariant thermal structure through the depth of the tower during this time offers no hint as to the windshift cause.

The temperature reaches an apparent maximum at all levels between 1700 and 1800 CST and decreases uniformily to a virtually constant value at 2000 CST. A slight inversion appears at the upper levels at 1900 CST.

The winds at the tower top (910-mb) do not equal the correspondingly high values observed at CHK. The strongest sustained wind at the tower was 42 kt. The lowest 910-mb wind speed at CHK was 45 kt, the highest was almost 70 kts.

Note that the 2118 CST peak wind at CHK was observed when storm B was 45 nm away just slightly west of north. Storm B was 15-20 nm north of WKY at 2215 CST but no wind peak was observed there. In fact, a wind minimum was recorded at 2300 CST at the top of the tower.

With regards to this low-level wind structure, Fig. 2 shows the horizontal projection of the balloon transponder trajectories. The first balloon released at 2105 CST, was advected along a uniform northerly course up to the time it was permanently lost at 2153 CST. During the early period of its flight it attained speeds up to 48.5 kts; towards the end of its flight path it decelerated at 28.0 kts. At the time it was lost, the radar echo of storm B was located to the immediated west-northwest. The trace of altitude versus horizontal distance (Fig. 5a) showed that the equilibrium level (4200 ft above MSL or 3000 ft above the ground), initially attained at 2115 CST, was maintained up to the time the balloon was lost. This constant flight level indicates that no significant vertical motion was occurring in the low-level air current. The second transponder, released at 2208 CST, initially headed north, but soon deviated sharply towards the northeast, (Fig. 2). The balloon overtook the rear edge of storm B at 2245 CST. The horizontal speed ranged from as high as 61.5 kts in the bend region of the flight track to as low as 47 kts after the balloon had entered echo B. The altitude traced (Fig. 5b) showed that after reaching the equilibrium level at 2215 CST, the balloon maintained a near constant ascent rate of 1 m sec^{-1}. By the time it entered echo B it reached an altitude of 10,000 ft above MSL; thereafter the balloon height fluctuated widely.

[The altitude trace of the second transponder is not accepted without suspicion for several reasons: (1) no thunderstorms formed 10 to 20 nm south of the main line of storms as would be expected if 1 m sec^{-1} upward velocity existed in the area, (2) one is hard pressed to explain such vertical velocities on the basis of what is presently known about thunderstorm physics, and (3) no previously documented transponder flights have been observed to ascend as rapidly 10 to 20 nm away from a storm cell.

However, consultation with several members of the WSI research staff led to the conclusion that the data must be accepted as real because undetected transponder defects are highly unlikely.]

Conclusions

Combining the facts that the data for this research is somewhat fragmentary and unsychronized,(eg. especially since the thunderstorms were so far distant from the data sampling stations) and the analysis itself is not complete, no really conslusive statements can be made regarding interaction between the thunderstorms and the environmental flow. But questions and proposals can be raised in light of the findings of other researchers and the results obtained in this study.

Bonner's (1966) vertical velocity calculations indicate that maximum ascent should occur downstream from the jet maximum and to the left of the jet axis. A careful inspection of the facsimile maps for 1800 CST indicated that the jet axis was oriented along a north-south line, passing through central Oklahoma with the jet maximum between Oklahoma City and Fort Worth, Texas. Recall that the surface winds in the beta network decrease as one approaches the northern-most stations from the south. The winds at Chickasha were stronger than those at WKY for the same levels. And finally the balloon transponders reached their peak velocities far upwind from the convective cells. In fact, the second transponder clearly showed steady up motion and horizontal deceleration in the air current that fed storm B. These facts suggest that some of the horizontal momentum of the low-level jet maximum was converted into vertical momentum in the area of convective activity. This conclusion is, of course, in agreement with Bonner's results.

Bonner also suggests that the low-level jet is not a crucial requirement for thunderstorm development, but it is instrumental in maintaining their life times for long periods. The 16 April 1968 thunderstorm began developing about 1600 CST. Very little new-storm formation occurred after sunset. But existing cells developed to severe proportions at 2000 CST and rampaged into the early morning hours of April 17.

Probably the most interesting finding of this study is the strong low-level wind maximum appearing in the 2118 CST CHK sounding and the subsequent formation of an intense temperature inversion. If, indeed, this jet and inversion is related in any manner at all, it is not akin to the low-level jet associated with the diurnal osscilliation as treated by Blackadar (1957). Considering the short period of time in which the jet existed over CHK and the fact that its appearance preceeded the extreme intensification of a storm downwind from it, suggests that it was "mesojet" feeding the updraft of that storm. The analysis suggest this jet is narrow but well defined as also suggested by Don Hall of WSI in private communication. We propose that the synoptic low-level jet, larger in horizontal extent, is partitioned into several narrow mesojets, each flowing into its respective thunderstorm updraft. The concept of the mesojet is supported by the low-level wind maximum at CHK and the balloon transponder trajectories. We suggest that the mesojet feeding storm B and probed by the CHK sounding at 2118 CST, was of a size such that the 2105 CST transponder was not entrained into it and consequently did not enter the storm updraft. The second transponder was launched beneath the mesojet and was carried into the storm updraft itself. While it is true that no jet was observed at the TV tower top, this does not necessarily destroy the mesojet hypothesis. Since the air was converging as it approached the area of convective activity the horizontal speed decreased and furthermore the ensuing vertical velocity displaced the low-level wind maximum to an altitude above the tower top. [Should the vertical velocity, as indicated by the second transponder, be nonexistent we would still not be forced to abandon all of our conclusions. This restriction would only mean that the mesojet current was not ascending away from the storm.]

In the future we plan to test the validity of the mesojet hypothesis for this case. The data does allow one to make a rough estimate of the three dimensional extent of the mesojet and thus make mass flux calculations possible. It is also possible to make vertical velocity estimates for comparison with that measured by the second transponder as a further test.

REFERENCES

Blackadar, A.K., 1957 : "Boundary layer wind maxima and their significance for the growth of nocturnal inversions." Bulletin of American Meteorological Society, 38, 283-290.

Bonner, W.D., 1966 : "Case study of thunderstorm activity in relation to the low-level jet." Monthly Weather Review, Vol. 94, pp 167-178.

Hart, H.E. and L.W. Cooper, 1968 : "Thunderstorm airflow studies using radar transponders and super pressure balloons," Proceedings of the 13th Radar Conference, McGill University, pp 196-201.

Means, L.L., 1952 : "On thunderstorm forecasting in the central United States," Monthly Weather Review, Vol. 80, no. 10, pp 165-189.

Pitchford, K.L. and J. London, 1962 : "The low-level jet as related to nocturnal thunderstorms over mid-west United States," Journal of Applied Meteorology, Vol. 1, pp 43-47.

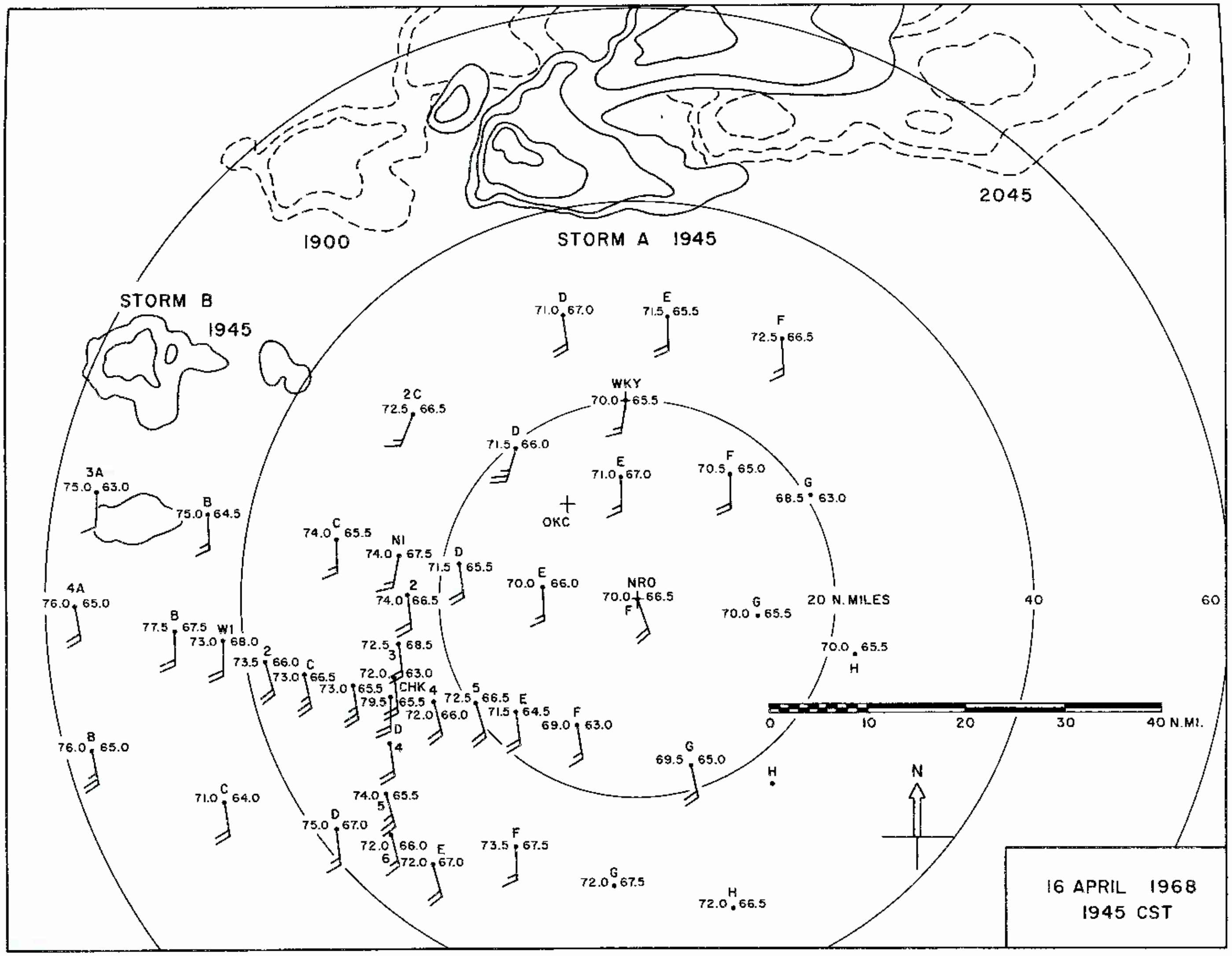

Fig. 1. 1945 CST plot of surface network wind, temperature, and dewpoint temperature. Intensity contoured radar echoes are shown for the times indicated.

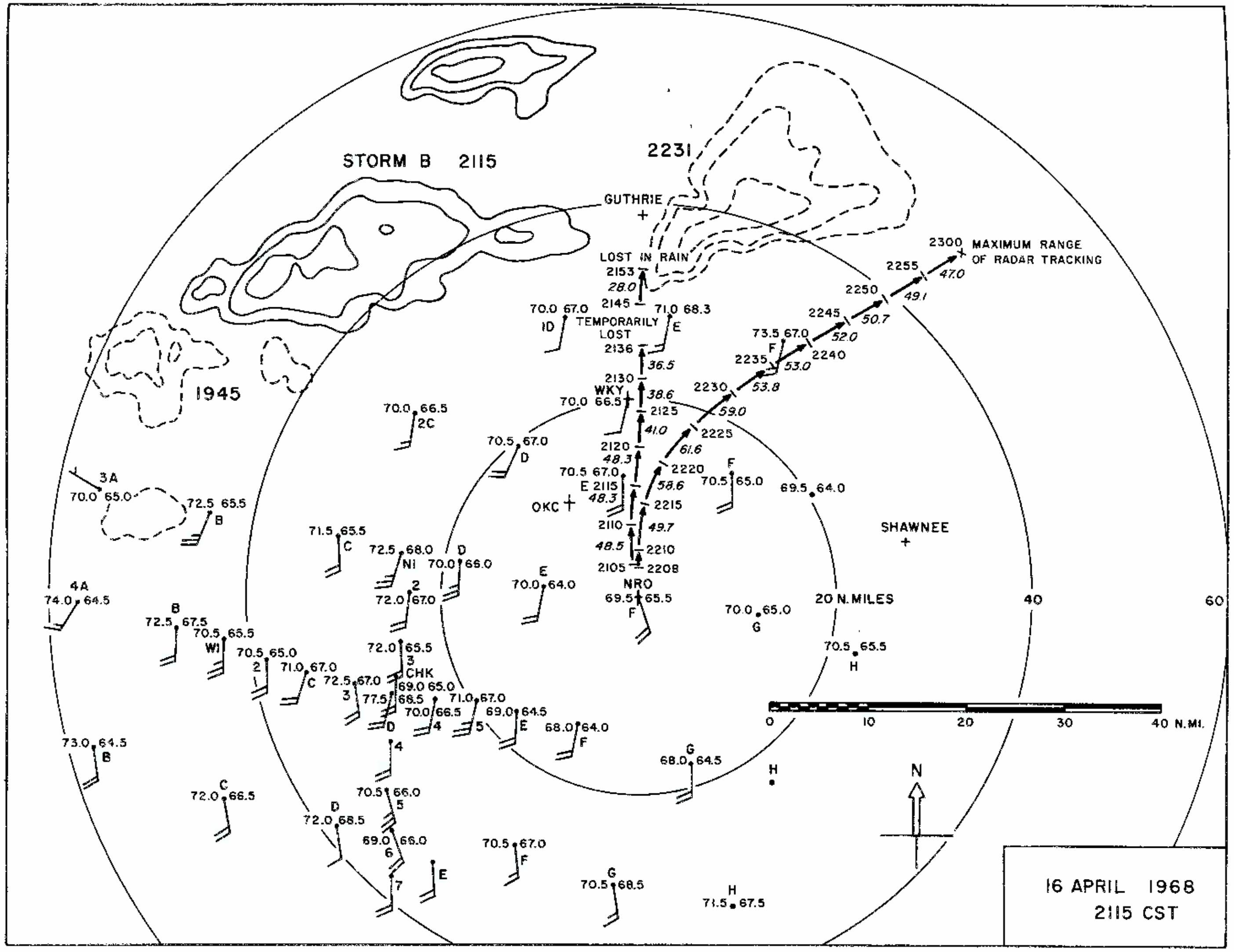

Fig. 2. Same as Fig 1 with the addition of balloon transponder trajectories. Time (CST) and balloon speed (kt) are plotted at indicated times.

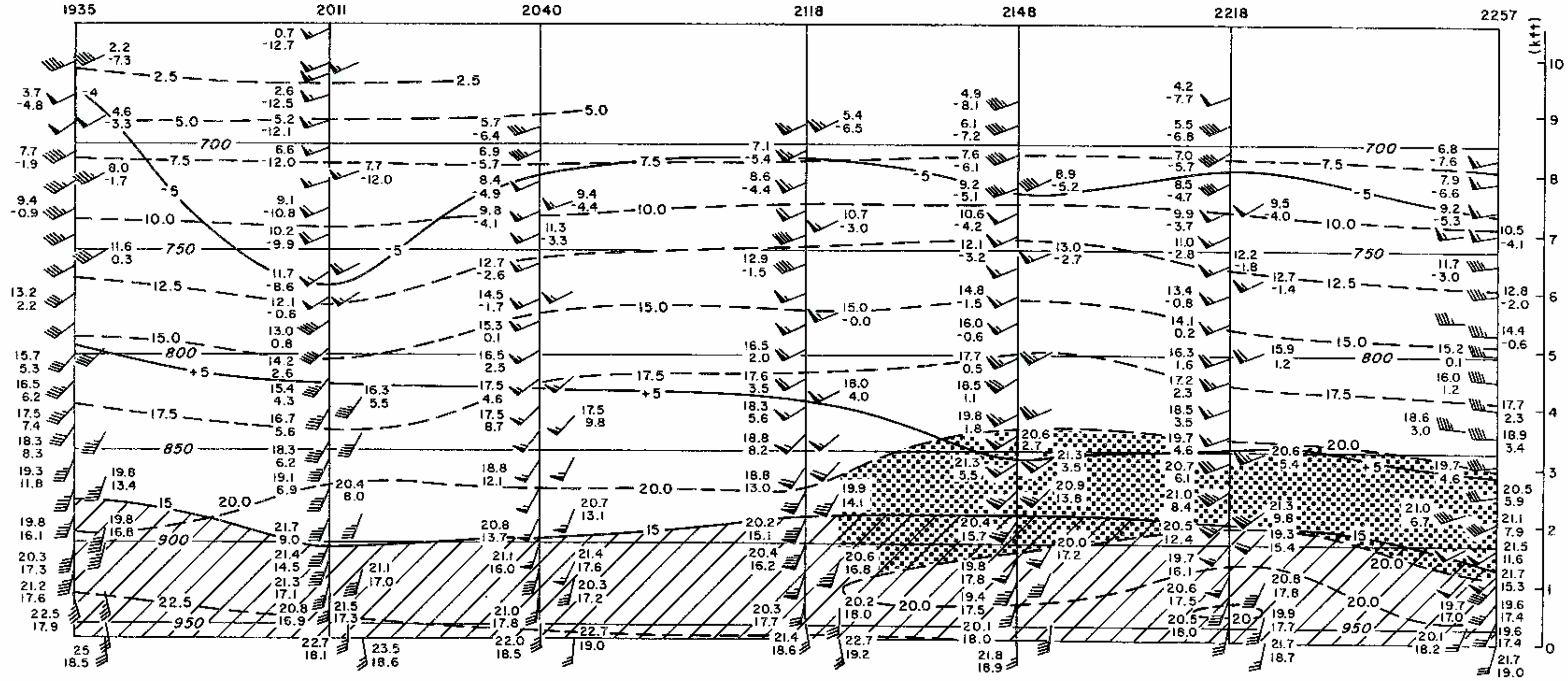

Fig. 3. Time section of the Chickasha soundings.

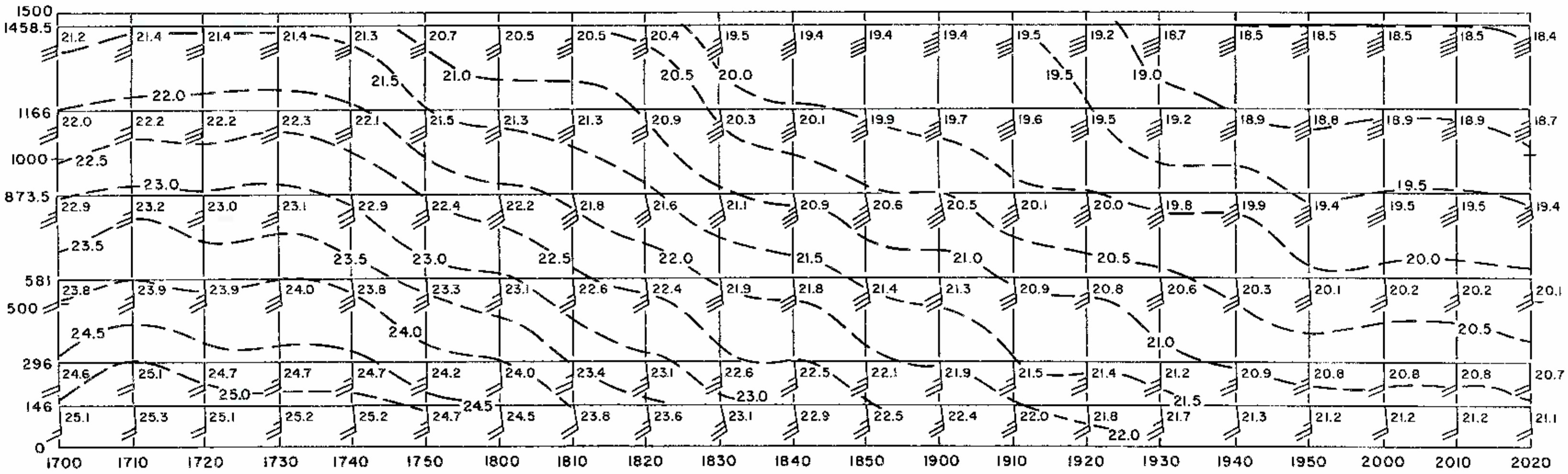

Fig. 4. Time section of the WKY-TV tower data.

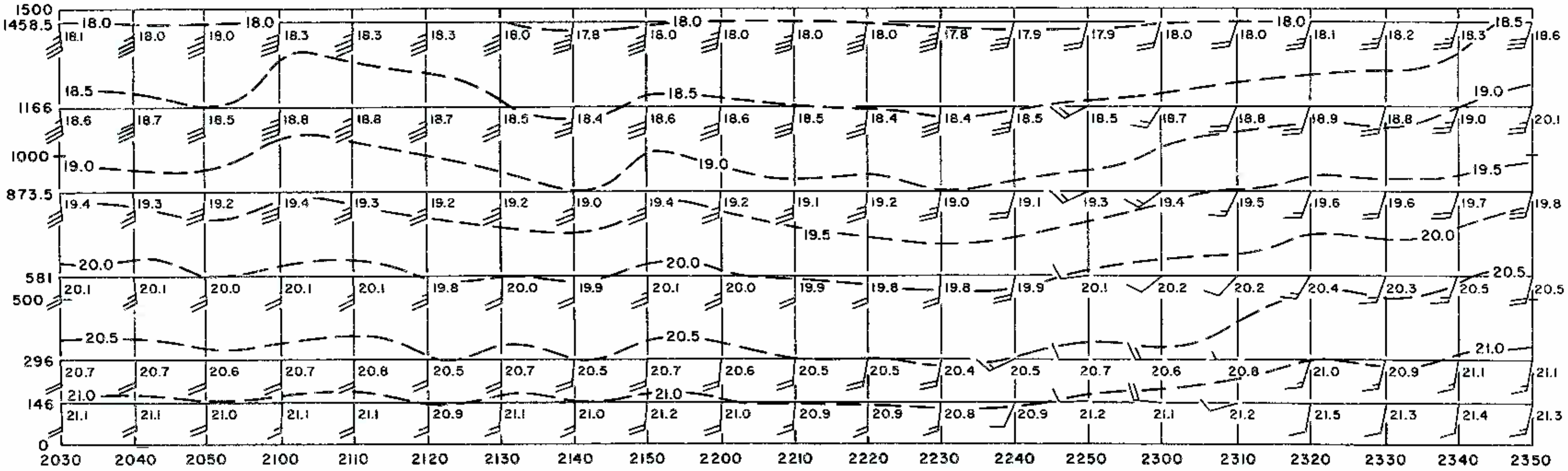

Fig. 4. Continued.

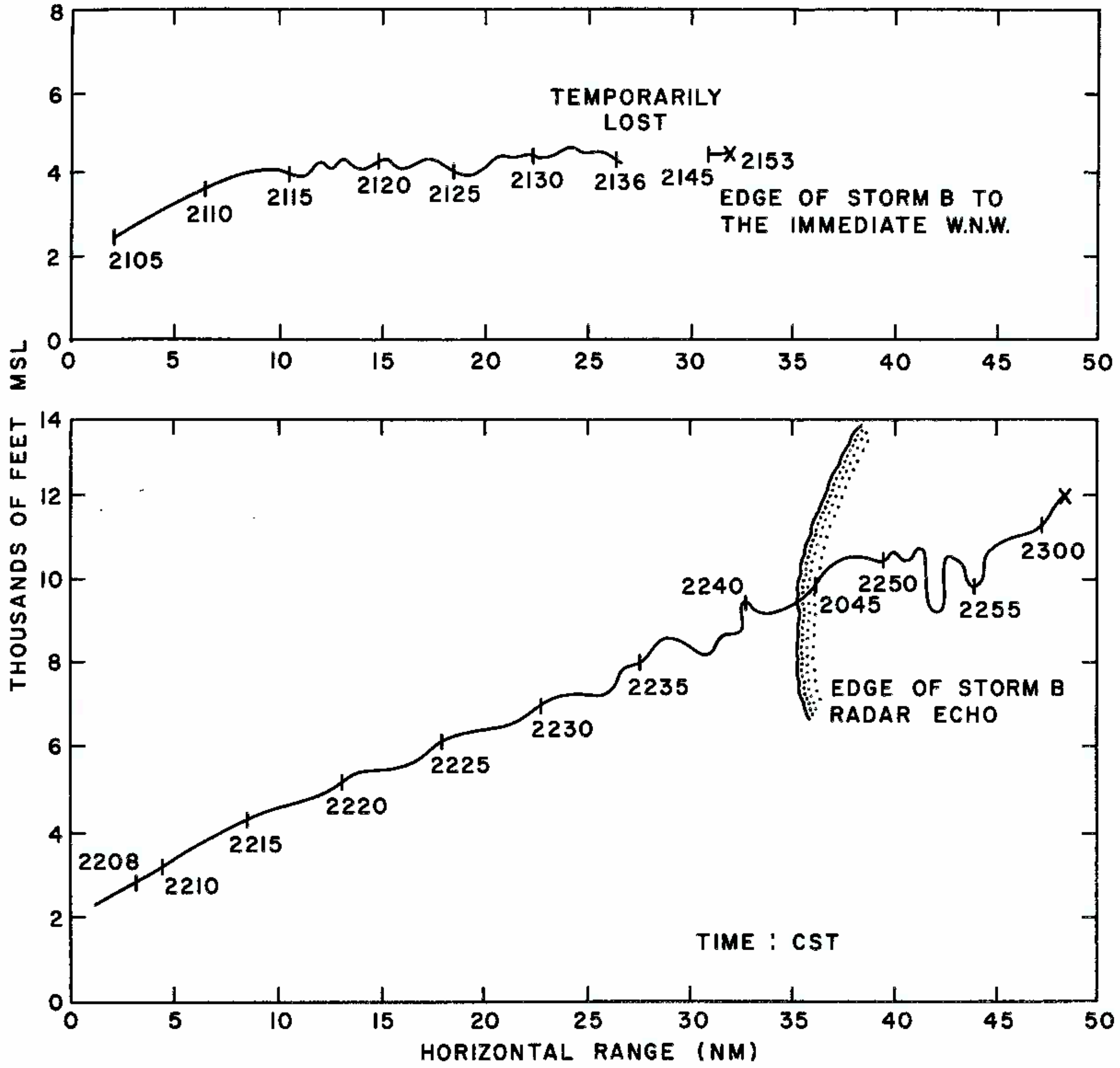

Fig. 5a (above) and b(below). Profile of altitude vs horizontal distance. CST time is indicated as shown.