SHORTER CONTRIBUTION

The Mean Wind and Temperature Distribution through a Flat Upper Ridge in Winter

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(Manuscript received 7 March 1950)

Abstract

A mean cross section is constructed from a number of individually analyzed daily cross sections through flat upper ridges, using the position of the maximum of the geostrophic zonal wind at upper levels as reference for the meridional coordinate. Computed wind velocity, wind shear, and vorticity distribution are discussed. A comparison of the results with the meridional cross section of PALMÉN and NEWTON is emphasized.

Introduction

Since PALMÉN and NEWTON (1948) published their work about the mean wind and temperature distribution in the vicinity of polar front, it has been widely referred to and used in the consideration of problems in connection with the general circulation of the atmosphere, although the authors did not claim that their result represented the general situation of the atmosphere. One of the purposes of their work was to study the structure of the polar front and its relation with the wind and temperature fields. Therefore, they selected cases with a well-defined polar front. As a result, the intensity of the wind and temperature fields shown in their cross section can represent only the situation in a meridional cross section through a well-defined front. Furthermore, the individual cases they selected to construct their mean picture are so chosen that the cross sections are near the mean trough at the east coast of North America (although cases of strong curvature were not used). For these reasons one might expect that the wind and temperature fields discussed by PALMÉN and NEWTON are more intense than those found at other longitudes and times.

In order to clarify our ideas about the distribution of wind and vorticity in the meridional cross section, the preparation of a mean cross section at the same longitude of 80° W through a 'flat' ridge would thus seem to be advisable. 'Flat' ridges are desirable in order that the effects on the gradient wind speed of the trajectory curvature be held to a minimum. The same longitude of 80° W is desirable because the location of aerological stations along this meridian is almost ideal.

An additional consideration in selecting these cases was the elimination of those where more than one jet was well developed. The nine cases are those at 0300 GCT on the following dates: 30 November and 2 December, 1948; 17 January, 10 February, 27 February, 21 March, 25 March, 7 December, and 17 December, 1949. Fig. 1 is the mean 500 mb

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[2] Published as a contribution of a research on the general circulation of the atmosphere, sponsored by the office of Naval Research.

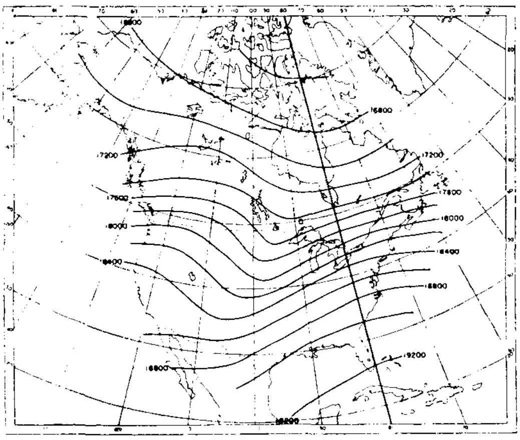

Fig. 1. Mean 500-mb surface of nine cases in winters of 1948 and 1949. Straight heavy line indicates the position of the mean cross section. Contours are drawn for 200-ft. intervals.

map for the 9 cases and gives a general impression of the situation. The flat ridge along the meridian of 80° W extends from the tropics up to about 55° N.

The mean cross section was determined in the same fashion as was that of PALMÉN and NEWTON, except for one difference—the position of the upper maximum wind (e.g. at 300 mb) is taken as the moving reference for the meridional coordinate instead of the polar-front layer. This was necessary because the variation of the slope of the polar front in the ridge region turned out to be greater than in the situation covered by the above authors.

Temperature and Wind Fields

The mean temperature and wind fields are shown in fig. 2[1] and potential temperature is shown in fig. 3. The mean front is not as distinct as in PALMÉN's and NEWTON's cross section, and its slope is smaller. Since the polar-front layer is not taken as the coordinate reference, the process of averaging may obliterate some of the frontal characteristics. Also, as generally recognized, the polar front is less distinct and has a smaller slope near the ridge than near the trough. Thus, in fig. 2 the polar front shows up as a broad transitional zone, and is quite indistinct near the surface.

Just as in their cross section, the baroclinity is not limited to the frontal zone, but exists in the cold and

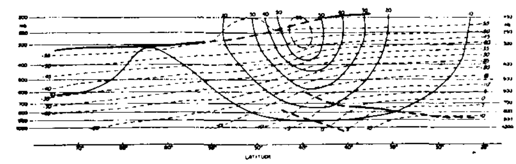

Fig. 2. Mean temperature and zonal component of geostrophic wind. Heavy lines indicate mean positions of frontal boundaries and tropopause. The dashed lines are isotherms (°C, *slanting numbers*) and the solid lines are lines of equal geostrophic zonal wind (m sec^{-1}, upright numbers).

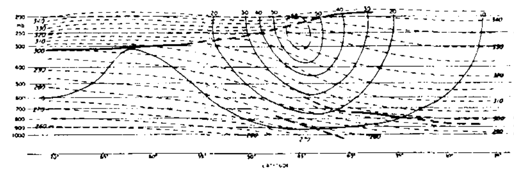

Fig. 3. Mean potential temperature (°K, dashed lines) and geostrophic zonal wind (m sec^{-1}, solid lines) for the same cross section shown in fig. 2.

warm air as well. The baroclinity in the warm air decreases rapidly towards the south so that almost barotropic conditions exist south of 35° N. However, the baroclinity in the cold air extends to high latitudes.

Although the details of the tropopause zone are damped out in the mean cross section, a gentle slope upwards from north to south is indicated, with a maximum slope above the northern extension of the polar front. It differs somewhat in this respect from PALMÉN and NEWTON's result, which shows the tropopause to reach its lowest elevation just above the northern extension of the polar front. The individual cases which make up the mean cross section show the same result. The jet stream shows a maximum wind of 55 m sec^{-1} at the 250-mb level. Since our front does not reach the 500-mb surface, nothing can be said about the relative positions of the jet stream at upper levels and the intersection of the polar front with the 500-mb surface. However, the upper jet is approximately above a temperature of —25° C at 500 mb, which agrees, in general, with the statement by PALMÉN and NEWTON that the jet is located above the intersection of the 500-mb surface and the polar front.

The location of the maximum wind velocity at approximately 45° N, the same as that of PALMÉN and NEWTON, must be considered as a coincidence. As they state, in their cases the jet was situated somewhat farther to the north than usual, and this fact is probably the explanation for the agreement in

[1] The references to latitude used hereafter are not intended to imply the actual mean latitudes of the elements referred. Latitudes are used merely for brevity in description, as done by PALMÉN and NEWTON.

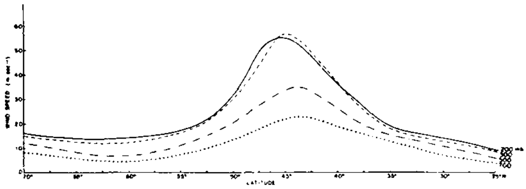

Fig. 4. Geostrophic wind profiles at various isobaric surfaces.

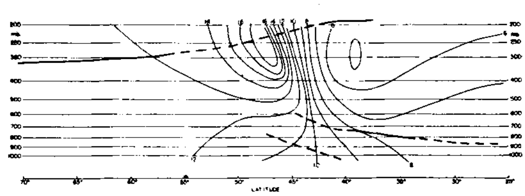

Fig. 6. Absolute vorticity (10^{-5} sec^{-1}).

latitude. It is, of course, evident from these two mean cross sections one cannot conclude that the maximum westerly wind will appear at 45° N in other meridional cross sections (for example, along the meridian of 5° W).

The wind distribution at different isobaric surfaces is shown in fig. 4. The position of maximum wind shifts toward north as height increases.

Wind Shear and Vorticity

Fig. 5 shows the values of horizontal wind shear for the same cross section. Strong shear appears on both sides of the jet, cyclonic to its north and anticyclonic to its south, although both the intensity and the concentration of the shear pattern are less than that shown by PALMÉN and NEWTON. In the past few years, the strong anticyclonic shear to the south of the jet has attracted much attention, particularly with respect to the instability of the horizontal flow in this region. KUO (1949) in a recent paper argued that if such strong shear happened only in a limited region, its effect should be damped by the influence of the much larger neighboring region with weak shear.

In our cross section, the absolute value of the shear of the computed geostrophic wind south of the jet is less than that of the coriolis parameter. As all the cases we have chosen are through a very weak ridge, and the computed geostrophic wind speed fairly agrees with the observed, the influence of the curvature may be considered as small. It seems reasonable then that south of the jet the actual value of the absolute vorticity in this case remains greater than zero. Therefore, the horizontal flow pattern is stable by the consideration of conservation of angular momentum.

Fig. 6 gives the distribution of the absolute vorticity in the cross section. Since we have considered the curvature small, the absolute vorticity is taken as the sum of the shear and the coriolis parameter. There is a maximum value of vorticity of 17×10^{-5} sec^{-1} to the north of the jet stream, and a minimum value of 5×10^{-5} sec^{-1} to its south. The contrast between the maximum and the minimum values of the absolute vorticity is not as distinct as in the cross section shown by PALMÉN and NEWTON.

The distribution of absolute vorticity at different isobaric surfaces is presented in fig. 7. It shows clearly that the absolute vorticity is fairly constant to the south and north of the jet stream, and that on the south side this constant value is greater than zero. It remains almost constant at the southern part of the cross section. At the northern end it increases very slowly and approaches the polar vorticity of earth rotation.

Fig. 7 suggests that there exist three relatively distinct zones, each with characteristic type of vorticity distribution, a northern zone of almost uniformly high vorticity, a transition zone in which the vorticity decreases from a high to a low value, and a southern zone of almost uniformly low vorticity.

The idea of zonal distribution of vorticity has been used by PLATZMAN (1949) in a theoretical study of upper tropospheric disturbances. He based his con-

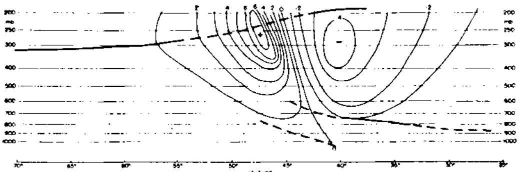

Fig. 5. Horizontal wind shear (10^{-5} sec^{1-}). Positive numbers indicate cyclonic shear, negative numbers anticyclonic shear.

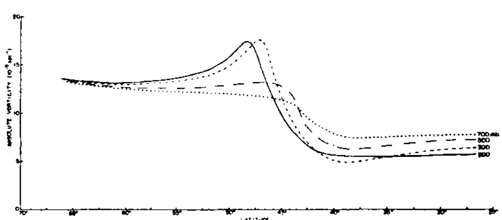

Fig. 7. Absolute vorticity profiles at isobaric surfaces.

sideration on PALMÉN and NEWTON's data and used a simplified model. ROSSBY (1947) has pointed out that a regime of uniform absolute vorticity within an extensive polar cap would tend to be established through the operation of large-scale lateral mixing. Fig. 7 indicates that there might be several zones with dominant large-scale lateral mixing processes and fairly constant vorticity separated by transitional zones with intensive meridional circulation and sharp change of vorticity.

Some Additional Remarks

The general characteristics of the mean distribution of the wind velocity, wind shear, and vorticity in the cross section through the flat ridges agree, in general, with that near troughs as shown by PALMÉN and NEWTON, but both the intensities and the contrast between the extreme values are less distinct than in the latter cross section. This is the situation when the geostrophic wind relationship is assumed to hold. If we consider the influence of curvature, even if we take a large radius of curvature, for instance 2,500 km (as the contours of the upper isobaric surfaces indicate), the situation may be reversed because of the great influence of the curvature on the wind speed for anticyclonic flow. A comparison of the geostrophic wind with the observed wind in the individual cases shows that they agree fairly well, although the computed geostrophic wind is usually about 5—10 per cent stronger than the observed. If we apply the gradient wind equation by using the curvature of the streamline, the result will give ridiculously high values for the computed wind speed in the high levels. It seems, therefore, that although the contours of the isobaric surfaces in our cases show some weak anticyclonic curvature, the trajectories are nearly straight because of the movement of the system, and furthermore that the curvature influence is probably compensated by the non-gradient flow.

Acknowledgements

The author wishes to express his appreciation for the benefit of many fruitful discussions with Profs. C. G. ROSSBY and E. PALMÉN, and Mr. C. W. NEWTON, and his gratitude to Mr. N. A. PHILLIPS for reading the manuscript.

REFERENCES

KUO, H. L., 1949: Note on the inertial stability of geostrophic zonal flow. *J. Meteor.*, **6**, 356—358.

PALMÉN, E. and C. W. NEWTON, 1948: A study of the mean wind and temperature in the vicinity of the polar front. *J. Meteor.*, **5**, 220—226.

PLATZMAN, G. W., 1949: The motion of barotropic disturbances in the upper troposphere. *Tellus*, **1**, 3, 53—64.

ROSSBY, C. G., 1947: On the distribution of angular velocity in gaseous envelopes under the influence of large-scale horizontal mixing processes. *Bull. Amer. Meteor. Soc.*, **28**, 53—68.