A case study of winter cyclogenesis over Central Asia

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(Manuscript received January 12, 1970; revised version March 2, 1970)

ABSTRACT

This paper discusses the processes associated with the Central Asian trough in the winter system of planetary long waves. The case study has suggested that air from the convection layer over the Plateau of Iran ascended into the upper troposphere on the eastern side of a deep trough over Soviet Central Asia but the major process associated with the trough appears to have been the invasion of cold air masses from the north.

Introduction

It is well-known that Central Asia is a preferred location for one of the three major cold troughs in the winter system of planetary long waves and that the trough is a westward extension of the cold Low in the middle and upper troposphere over the Siberian region; the trough-lines show a marked tendency to occupy a region extending from the Caucasus–Caspian Sea area north-eastwards towards central Siberia. The mean positions of the major troughs over eastern Asia and over eastern North America are well-marked but the Central Asian trough is somewhat diffuse, which may indicate greater inter-annual mobility and a different formation mechanism. The Japanese and American troughs are both associated with intense polar front activity and prevalent ascent over, and to the east of, the continents, but the character of the Central Asian trough is rather different, the mountains of southern Asia exerting a considerable modifying in-influence on air-flows from both north and south. Walker (1967) has discussed the influence of these mountains on airflows from the south and suggested that cumulonimbus convection occurs when southerly airstreams are orographically lifted along the coasts of Iran and West Pakistan.

Commenting on the atmosphere over the deserts of Central Asia (south of the Aral Sea) Borisov (1959) says that "depressions sometimes bring cloud and precipitation and rather immobile depressions develop as a result of wave activity in the south of the desert". He further states that two zones of cyclonic activity are distinguishable over Soviet territory in winter; one zone is situated along the Arctic coast, whilst, in the other zone, depressions travel north-eastwards from the Black Sea area and give the plains of Central Asia most of their precipitation (usually snow).

These plains receive only small amounts of precipitation and, in January, two areas, one to the south of the Aral Sea and the other to the north of Lake Balkhash, record less than 10 mm. It may seem surprising that the plains are so dry, considering that Borisov states that a depression track passes through the area; however, sources of air for frontal cloud are cold and so possess a small mixing-ratio.

Atmospheric convection

Green, Ludlam & McIlveen (1966) have described how small-scale and large-scale slope convection collaborate in extra-tropical trough-ridge systems. They have shown that in the layer of small-scale convection (containing the tropical trade cumulus of low latitudes) subsiding air has its wet-bulb potential temperature (θ_w) raised, becomes potentially unstable, and is prepared for ascent; air from this layer enters large-scale circulations and rises on the eastern flanks of travelling troughs into the vicinity of the jet streams near the 300 mb level farther north. According to these investigators, the air which arrives near the jet stream,

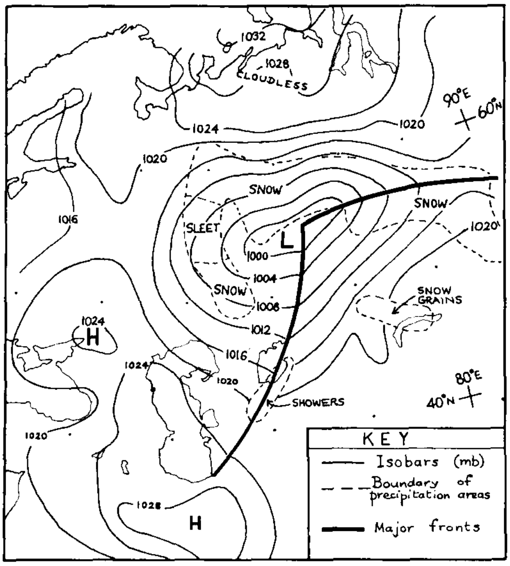

Fig. 1. Surface analysis over Central Asia at 0600 GMT on 21 December 1958.

having risen from the trade wind layer, possesses the highest θ_w involved in the trough-ridge system; they propose that θ_w in the trade wind air is determined mainly by the sea-surface temperature, being typically about 4°C less at ship's deck level and 8°C less at the 850 mb level. Further, Green, Ludlam & McIlveen present evidence in support of their thesis from trough-ridge systems over the Atlantic Ocean and Walker (1967) has shown how their ideas may be consistent with observations made on polar front jet streams between the Persian Gulf and India. However, mean winter values of θ_w in the middle and upper troposphere to the east of the Central Asian trough over Soviet territory are found to be much lower than would be anticipated if air of trade wind origin were a common constituent. Indeed, if, as Walker suggests, deep tropospheric convection is initiated by the Iranian mountains, then it would be surprising if trade wind air habitually entered jet streams over the plains of Central Asia. There is, though, no reason, per se, why the preparation for ascent must be performed by trade cumulus, or even cloudy convection. Carlson & Ludlam (1965) have discussed how small-scale and large-scale convection may collaborate to produce severe local storms and their work suggests that convection over arid elevated plateaux, which are notable for the creation of layers of cloudless air of high potential temperature (θ), may effectively replace trade cumulus for the mechanism by which θ_w is raised prior to ascent in large-scale circulations. The consequent jet streams, though, may be less vigorous than their counterparts of trade cumulus origin because of the smaller latent heat content of air in arid source regions.

According to the Iranian Meteorological Department (1966), from the experiences of the pilots of both aeroplanes and sailplanes, convection is strong over the arid Iranian plateau at all times of the year, and cumulus congestus is commonly observed in winter. Support for these observations of convection is provided by climatological charts which show that Iran is a region of high θ at screenlevel in winter.

Therefore, a case study, based on radiosonde ascents and surface synoptic observations on a date during a World Meteorological Interval in the International Geophysical Year 1957–8, was made of a deep trough over the plains of Central Asia to examine the role of the Iranian plateau in relation to the atmospheric events associated with the trough.

The case study

(i) *Synoptic details*

The first indication of cyclogenesis was the appearance of two shallow troughs at the 500 mb level, one over the Ukraine and one over

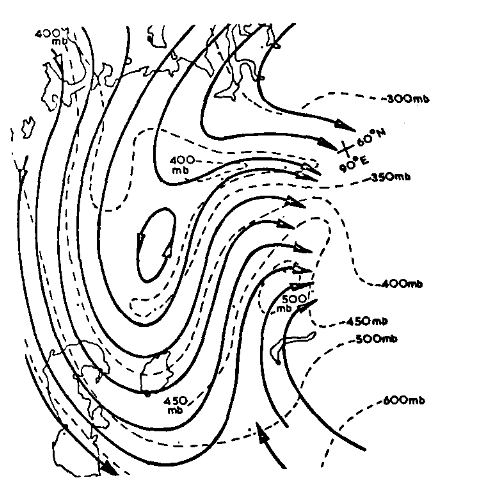

Fig. 2. Isentropic relative-flow analysis for $\theta = 34$°C at 1200 GMT on 21 December 1958.

the Caspian Sea. A day later the 500 mb analysis displayed only one trough, extending north from the Caspian Sea to about 60° N, and at the surface there was a corresponding Low (of 996 mb), accompanied by widespread rain, drizzle and snow. In the next 24 hours the 500 mb trough moved a little to the east of the Caspian Sea and became associated with a closed Low, whilst the surface Low first deepened and then began to occlude and fill slightly. Fig. 1 shows the surface analysis over Central Asia at approximately mid-day Local Time (0600 GMT, 21 December, 1958) when the Low was at its deepest. At the surface a warm front was easily located by the temperature contrast. The cold front, though, was obscure, the surface temperatures not indicating its position, and low stratus clouds covered most of the southern side of the Low. A front, which was subsequently identified from isentropic analysis as a confluence-line, was positioned from differences of wind direction and from a small area of rain south of the Aral Sea, and the air-mass boundary or cold front, revealed by later relative-flow analysis, lay farther east.

(ii) *Analysis*

The mid-afternoon screen-level values of θ over southern Central Asia and the 1200 GMT sounding from Teheran on 19 December 1958, showing an adiabatic layer from the surface (886 mb) to 850 mb, indicate that the Iranian plateau provided a source region of high θ. Morover, small cumulus clouds were reported from the majority of stations in western and southern Iran, the most mountainous part of the country. Thus, it is considered that, on 19th, convection was present over most of the plateau.

At Ashkhabad, on the USSR–Iran border, there is evidence from the soundings (made every six hours), and from the cloud reports, that warm plumes emanating from the Iranian plateau, or air which had been moistened in the plateau convective layer, travelled northwards on the eastern side of the shallow trough over the Caspian Sea which was mentioned earlier; in particular, the sounding made at 1800 GMT on 19th shows, between 565 and 500 mb, a layer corresponding to $\theta = 34$°C and, above 500 mb, a deep layer corresponding to the saturated adiabatic $\theta_s \simeq 12.5$°C. Radiosonde observations made at Lenkoran, on the south-

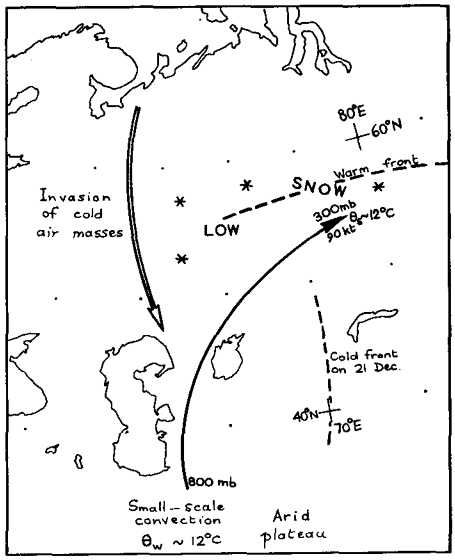

Fig. 3. Summary of analysis of the case study.

west side of the Caspian Sea, indicate that no warm plumes passed over that area.

The strongest wind identified in the upper troposphere on the eastern side of the trough, 250° 45 m sec^{-1}, occurred near 300 mb over Omsk at 1200 GMT on 21 December, when the station was within the area of snow associated with the warm front. The sounding made at Omsk at that time, besides showing a deep layer of saturated air containing the precipitating cloud, shows that there was a layer above, between 400 and 300 mb, which possessed a steep lapse rate (suggestive of ascent), corresponding to $\theta_s \simeq 12$°C. Moreover, it was shown, by isentropic analysis and by tracing the air back step-by-step southwards using soundings and reported winds, that the air in which θ_s was 12°C had originated over the plateau of Iran and risen over the cold front into the upper troposphere near to Omsk.

However, although the outbreak of convection over the plateau and the appearance of the trough over the Caspian Sea occurred almost simultaneously, suggesting a mutual connection, it is not considered that the convection was the dominant process in the maintenance of, and intensification of, the trough over the plains of Central Asia. The trough appeared to be in the steady state necessary for isentropic relative-flow analysis for only a short period of time. Furthermore, this isentropic analysis (see Fig. 2) showed that, on the western side of the trough, trajectories were more northerly than Green, Ludlam & McIlveen imply and the winds along these trajectories were quite strong, 30 to 40 m sec^{-1} being not unusual. Indeed, a study of the progress of the trough every six hours showed that the north and north-westerly flows became established very quickly. Rather it is considered that the invasion of cold air masses from the north, from the north-western side of the Siberian upper troposphere Low, was the dominant process in the development of the trough.

Fig. 3 summarizes the main features of the analysis.

Conclusion

Inspection of similar winter troughs over Central Asia suggests that the findings of this case study are broadly typical of the main processes associated with such troughs. It appears that the northward movement of warm plumes from the convective layer over the Plateau of Iran is responsible for initiating the troughs but that very cold northerly air-flows, induced on the western flanks of the troughs, are dominant in the development of the troughs.

It is perhaps pertinent to mention, too, that, in winter, the Plateau of Iran and the deserts south of the Aral Sea lie under a divergent region associated with the subtropical jet stream, a region in which cyclogenesis is favoured, consistent with the findings of this study.

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ПРИМЕР ЗИМНЕГО ЦИКЛОГЕНЕЗА НАД ЦЕНТРАЛЬНОЙ АЗИЕЙ

Обсуждаются процессы, связанные с ложбиной над центральной Азией в системе планетарных длинных волн зимой. Предположено, что воздух из слоя конвекции над Иранским нагорьем подымается в верхнюю тропосферу к востоку от глубокой ложбины над Советской центральной Азией, но основной процесс, связанный с ложбиной, повидимому, состоит во вторжении холодных масс с севера.