TECHNICAL MEMORANDUM

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Some remarks on the effects of the Qinghai Tibet Plateau on weather developments

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1. SOME FACTS

The largest plateau in the world - Qinghai-Tibet Plàteau (or QTP for short) has thorough influences on weather developments. According to their physical characters these influences may be divided into two categories : dynamical and thermal. Dynamical influences are due to the blocking effect of QTP on the wind fields. QTP also produces a non-homogeneous distribution of friction force in the atmosphere. Thermal influences are due to the heat and/or cold sources generated by the different thermal characteristics of QTP, see ECMWF Workshop on Mountains and Numerical Weather Prediction (1979). According to the characters of the geographical distribution, the QTP induced errors may also be classified as local and global. Local errors are locally fixed around QTP. They are mainly connected with the reduction of pressure observation in situ to the sea level and the undue vertical motions caused by the mountain slopes in the model. Global spurious influences are embodied by the systematic errors in forecasting ultra-long waves, which are intimately connected with the low-order normal modes of the forecasting equations, see Quiby (1980).

These influences may be detected from the analyses of the results of numerical weather prediction. The systematic errors of the mean maps at day 7 in the ECMWF operational forecast show that there is a tendency for the semi-permanent centres of the atmospheric activity to be displaced eastwards by 10 to 15 degrees in the forecast field. The global picture is also more zonal for the forecasts than for the analyses. These indicate a reduced meridionality and show weaker standing eddies. These phenomena may be caused by the underestimation of the QTP effect, see Geleyn et al (1980).

Some case studies show that over the QTP there is always an anomalous strong cold centre on 1000 mb, not only at the initial analysis, but also in the entire 10-day forecasts. It seems that this anomalous phenomenon is purely a consequence of mutual interpolation from sigma- to p- coordinate and vice versa. The anomalous thermal field around QTP may also be explained as a result of the false adiabatic heating or cooling. The latter in turn is caused by the unrealistic vertical motion around QTP in the model.

2. MORE ACCURATE MOUNTAIN HEIGHT

One of the most important ways to improve the weather forecasting is to consider the QTP effect more properly and accurately. The orography used in numerical weather prediction models is usually over-smoothed, and has a large departure from the real situation. Then a possible way to improve the forecasting is to use a more realistic topographical pattern. Two case experiments carried out by Kondo and Nitta (1979) showed that the forecasts with the more realistic topography yield better results, and the temperature field in the lower troposphere being more accurate.

Tibaldi (private communication) recently has completed a series of comparative experiments with an old topography and a new topography. On the average better results are given by the new topography. In the new topography, in addition to the arithmetic mean, the dispersion in the mountain heights surrounding each grid point is also considered in calculating mountain height for each grid point. That is, the highest value nearby each grid point is also taken into account in the new topography.

Recently Bergthorsson (private communication) suggested a new concept - effective height. Its calculation is dependent on the wind direction, so it may be called "looking by the wind".

3. REDUCTION TO SEA LEVEL

All these efforts are aimed at obtaining better mountain height and, consequently, more realistic mountain influence on the weather development. There is still another problem : how to obtain sea level pressure charts or 1000 mb geopotential analyses in the Plateau region. Generally, surface pressure stations are recommended to reduce to sea level only when the surface height above sea level is less than 500 metres. Around the QTP the surface height is much greater than this figure. In China the analysis of sea level maps around the QTP had been mainly based on the twenty-four-hours pressure changes to avoid diurnal oscillations. But there is still the unsolved problem of how to choose an initial weather situation.

Recently, the following methods have been suggested in the Chinese Weather Service. For each station in the region around the Plateau the climatological mean of the surface pressure observations is calculated for each season. The deviation from the mean has also been calculated and normalised. Therefore, the range of the deviation is from -1 to 1, the same for every station. Then around the Plateau instead of isobars the isolines of these normalised deviations are analysed.

In order to obtain reasonable sea level (or 1000 mb) pressure (or height) contours in the region of the QTP, Chinese researchers had suggested to use a mean lapse rate of $0.45^{\circ}C/100$ m instead of $0.6^{\circ}C/100$ m in reducing ground level data to sea level. This figure is obtained by means of some preliminary statistical investigation. A series of stations with various elevations is chosen, and ordered according to the elevation. The ground pressure observation on each station is reduced to the elevation of the next station. It is found that on the average a lapse rate of $0.45^{\circ}C/100$ m will give the best results in the sense that there is a good agreement between the observed and reduced pressure values. Of course, further work may be done to classify the data set for each season and weather system.

4. GEOSTROPHIC ADAPTATION

The quasi-geostrophic relationship is widely used in pressure-wind analysis in middle and high latitude. This procedure has been well founded on the geostrophic adaptation theory in case of no mountain. The Plateau effect on the geostrophic adaptation procedure was also studied by Chinese meteorologists. The divergent barotropic, or shallow water equations are used in this study. Under the existence of the Plateau the two equations of motion remain unchanged, and the equation of continuity takes the following form:

$$\frac{\partial\phi}{\partial t} + u\frac{\partial\phi}{\partial x} + v\frac{\partial\phi}{\partial y} - g\left(u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y}\right) + g\,(H-h)\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = 0 \qquad (1)$$

Here H is the effective height of the atmosphere, h is the mountain height, and ϕ is the perturbation of geopotential. During this investigation the non-linear terms are neglected, and the Coriolis parameter f is considered as constant. The initial value problem is then solved, and the solutions approach stationary values when $t \rightarrow \infty$, i.e. a geostrophic relationship is established:

$$u = -\frac{1}{f}\frac{\partial\phi}{\partial y}, \qquad v = \frac{1}{f}\frac{\partial\phi}{\partial x} \qquad (2)$$

Substituting this relationship into the equation of continuity, we finally obtain:

$$u \frac{\partial h}{\partial x} + v \frac{\partial h}{\partial y} = 0 \qquad (3)$$

This means that the wind direction is parallel to the contour lines. So, the large scale atmospheric motion tends to detour the QTP, rather than to surmount it.

It is worth noting that for large scale analyses the relation (2) is equivalent to (3) under the above-mentioned assumptions. Since the observations around the QTP are not sufficient enough to make use of relation (2) properly, it may be worth trying to use relation (3) as an analysis tool. Based on this idea Kondo and Nitta used a manual modification of the mass field resulting in airflow moving around the mountain rather than over it. Encouraging forecasts were obtained with this manual initialisation.

Diagnostic equation (3) fully discards the pressure observations, assuming that there is an instant adaptation between the pressure and wind fields. This also has its theoretical explanation. In case of no mountain h = 0, there exists a critical horizontal scale $L_o = \frac{C_o}{f}$, where $C_o = \sqrt{gH}$. When the scale of motion $L > L_o$, the wind field adapts to the pressure field, when $L < L_o$, the pressure field adapts to the wind field. The time period required to accomplish the adaptation is so short, that from the view-point of synoptical analyses the adaptation may be regarded as instant. The existence of the QTP does not change the instant character of the adaptation and only reduces the critical scale to $L_h = \frac{C_h}{f}$, where $C_h = \sqrt{g(H-h)}$, see Yeh and Gao (1979).

5. SIGMA COORDINATE

The sigma coordinate system has outstanding advantages in considering mountain influences, and more and more numerical models have adopted it. But, in this coordinate system, the combination of steep orography and a sharp tropopause gives rise to a large truncation error in evaluating horizontal pressure force. When the horizontal mesh size of the grid is not more than several hundred km, the vertical truncation error seems to be more serious. This error also is created by large orographic slopes combined with sharp changes in lapse rate. Over the Himalayan slopes the vertical truncation error near the tropopause can reach values as large as those associated with a geostrophic wind of 10 m/s. This is not in balance with the initial wind field and thus gravity waves are created. Phillips (1979), has suggested an initialisation procedure to deal with the Himalayan source of these waves. A rectangular area (I) (of size) several thousand km on each side is centred over the Himalayas. A larger rectangular "buffer" zone (II) of width 1000 km is placed around area I. The initial data in area I are replaced by 12 horizontally uniform values of ϕ, each equal to a regional average in the Himalayan area from a weather situation typical of the season for which forecasts are to be made. A preliminary twenty-four successive 1-hour forecasts are run with this artificial initial condition. At the end of each hour, the grid point values outside of area II are set back to their initial values. The values in area II are progressively modified toward the initial values, proportional to the distance to its outer boundary. In this process, gravity waves are sent out by the Himalayas, and the repeated re-initialisation in the external region eliminates them. In the Himalayan region the variables are adjusted to one another, and the major travelling oscillation from the Himalayas is reduced by a factor of three or more. The Chinese numerical experiences are that the gravity waves are generated where the orographically forced vertical motion is large. To overcome this difficulty a variational calculation is suggested with the constraints to reduce the forced vertical motion.

6. NORMAL MODE INITIALISATION

It is quite reasonable to include mountain effects in normal mode initialisation procedures. In all the non-linear normal mode initialisation procedures, the atmosphere is assumed to be at rest, and temperature is a function of sigma only. In the case when the surface topography is non-zero, the assumed basic state is inconsistent, except in the special case of an isothermal atmosphere, in which the basic state temperature is independent of sigma. A topographic experiment was performed by Daley (1979) using an isothermal basic state for the initialisation process. The results were very similar to the case where temperature was allowed to vary with sigma. The initialised vertical motion was upward (downward) on the upstream (downstream) side of mountain barriers.

Needless to say, the QTP effects are associated with the atmospheric motion. Some research has been done to consider mean zonal wind profile in calculating normal modes. Preliminary results were obtained. The mean zonal wind shear has the effect to modify the existing normal modes both in frequency and amplitude. But these modifications are only of quantitative character, and qualitatively these waves remain the same as in the case of no motion. In the equatorial zone an eastward propagating Rossby wave can be induced by the easterly shear. Equation (1) in its linearised form, together with the two linearised equations of motion, may be used to investigate the mountain influence on horizontal normal modes, this work is now under way, see Du and Zhou (1980).

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REFERENCES

Daley, R. 1979 The application of Non-linear Normal Mode Initialization to an Operational Forecast Model. Atmosphere-Ocean, 17, 97-124.

Du, X., and Z. Zhou, 1980 On the effect of easterly shear on the atmospheric waves in the equatorial zone (presented at the International Conference on Preliminary FGGE Data Analysis and Results, Bergen, 23 - 27 June 1980).

Geleyn, J.-F., Nieminen, R. and Woods, A., 1980 ECMWF Forecast Report No. 1, Jan. 1980. Available from ECMWF library.

Kondo, H. and T. Nitta, 1979 A case study of the initialisation of the meteorological fields including topography. J.Met.Soc.Japan, 57, 300-307.

Phillips, N.A., 1979 The nested grid model, NOAA Technical Report NWS 22, April 1979.

Quiby, J. 1980 The response of a global barotropic model to forcing by large scale orography. ECMWF Technical Report No. 17, pp.29.

ECMWF Workshop on Mountains and Numerical Weather Prediction, 20 - 22 June 1979, pp.245.

Yeh, T.C. and Gao, Y.X. 1979 Meteorology of Qinghai-Tibet Plateau. 1-278, Beijing (in Chinese).