UDK: 551.515
Originalni znanstveni rad

The Role of Hydrodynamic Instability in a Weather Prediction

Uloga hidrodinamičke nestabilnosti u prognozi vremena

Marta Mann

Geofizički zavod Prirodoslovno-matematičkog fakulteta
Sveučilišta u Zagrebu

Primljeno 16.10. 1990, u konačnom obliku 03.06. 1991

Abstract

The aim of this paper is to answer the question why our weather prediction for Croatia failed on June 22, 1990? It deals with the application of the meridional wind profile in estimating the direction of movement of a cyclone in a hydrodynamically unstable atmosphere. Nonlinear meridional variation of zonal flow - barotropic wind shear - has been proved to govern the movement of cyclones and to support their amplification in the vicinity of the inflexional parts of the zonal flow meridional profiles.

Key words: hydrodynamic instability, baroclinic and barotropic instability, meridional profiles of zonal flow, barotropic governing

Sažetak

Članak promatra pitanje: zašto prognoza vremena dne 22. 06. 1990. za Hrvatsku nije bila točna? Promatrana je efikasnost meridionalnog profila zonalne struje u dijagnosticiranju pomicanja atmosferske ciklone u hidrodinamičko nestabilnoj atmosferi. Potvrđeno je da nelinearna meridionalna promjena zonalne struje - barotropno smicanje - upravlja pomicanjem ciklonalnih polja, podržavajući njihov razvoj u blizini infleksionih područja meridionalnog profila zonalne struje.

Ključne riječi: hidrodinamička nestabilnost, baroklina i barotropna nestabilnost, meridionalni profili zonalne struje, barotropno upravljanje

1. Introduction

Hydrodynamic instability (HI) is caused by nonlinear space -vertical (baroclinic HI) and horizontal (barotropic HI)- variations of the air flow in a statically stable free atmosphere. Charney's investigations to derive a criterion for the onset of the entire HI (Charney, 1947, Charney and Stern, 1962), based on the integral meridional variation of potential vorticity, q, show that the barotropic and baroclinic shear are in balance, and for the maintenance of HI they should not be greater than the meridional change of the Coriolis parameter (β).

A quasi-geostrophic two-level model combined with a field of the meridional nonlinear variation of the zonal flow was used to formulate a criterion for the offset of HI in the atmosphere (Mann and Šinik,

1990), which was given in the form of a critical meridional temperature gradient:

$$\left(\frac{\partial \bar{T}}{\partial y}\right)_c = \frac{f_o\, p}{R\, \delta\, p}\, \frac{1}{k^2\left[1-(k^2/M^2)^2\right]^{1/2}} \left(\beta - \frac{\partial^2 |U|}{\partial y^2}\right) \quad (1)$$

where $M^2 = \dfrac{8\, f_o^2\, p}{R\, p_o^2\, (\delta-\gamma)}$

is the parameter of static stability, with R-gas constant, δ-dry adiabatic lapse rate and γ-vertical lapse rate in the (x, y, p) coordinate system, p_o= 1000 hPa, f_o- the constant value of the Coriolis parameter and β-the meridional change of the Coriolis parameter. This investigation was done on the p isobaric plane, where the meridional change of the zonal mean temperature was defined ($\partial\bar{T}/\partial y$, $\bar{T}$ - zonal mean temperature, relevant for the whole layer whose width is δp between the upper and lower levels). Eq. (1) illustrates the dependence of baroclinic HI on the zonal flow meridional nonlinear variations -barotropic shear ($\partial^2|U|/\partial y^2$) (and also on δp, k, M and β parameters). Investigation has proved -according to the theory- that a barotropic shear may support as well as disturb the baroclinic HI (Brown, 1968, Mann and Šinik, 1990) depending on the magnitude of the zonal flow nonlinear shear in the β-plane. In such a context, the meridional profiles of the zonal flow can clearly indicate the barotropic supporting regions and also the regions where the baroclinic amplification is suppressed by the influence of a barotropic shear.

This work intends to find the answer to the question why the weather prediction failed on June 22, 1990, and to prove the importance of the atmospheric HI in weather prediction.

2. Nonlinear meridional wind shear and meridional wind profiles of the zonal flow

The criterion for HI, $(\partial\bar{T}/\partial y)_c$ has been derived in such a way that a comparison with the observed $\partial\bar{T}/\partial y$ indicates the existence and intensity of total hydrodynamic instability, where the smaller value of $(\partial\bar{T}/\partial y)_c$ illustrates a greater possibility for a baroclinic perturbation to amplify, since in that case the observed mean meridional temperature gradient can sooner reach its critical value. The barotropic (horizontal) shear of the zonal flow generally suppresses the baroclinic development, except in the case of a small ($\sim\beta$) and positive $\partial^2|U|/\partial y^2$ (for more details refer to Mann and Šinik, 1990). This result suggests, that one should expect the development of a macroscale perturbation close to the inflexional parts of the zonal flow meridional profile (toward the side of the flow minimum), because in this regions barotopic shear may support baroclinic development. For this reason, the meridional profiles of the zonal flow may represent efficient tools for macroscale diagnostic, i.e. in cyclon development and the direction of the cyclonic movement on macroscale. Now, our intention is to illustrate this in practice.

3. Application of the meridional wind profile in weather prediction

The synoptic situation on June 22, 1990 has been used to illustrate the efficiency of the meridional wind profile in the forecast of the direction of movement of an atmospheric perturbation.

The situation is characterised by a deep trough over West, North-West Europe and the Northern part of the Atlantic ocean, with the trough axis over Great Britain (Fig. 1). *The regular weather prediction expected the cyclone to move away from that position and to come near Yugoslavia, and therefore pelting rain and thunder were predicted.*

The meridional wind shear has been determined by means of gridpoint values of U on the AT 700 hPa. Thermal wind and static stability have been computed by means of temperature date on AT 500 hPa and AT 850 hPa (Fig. 1).

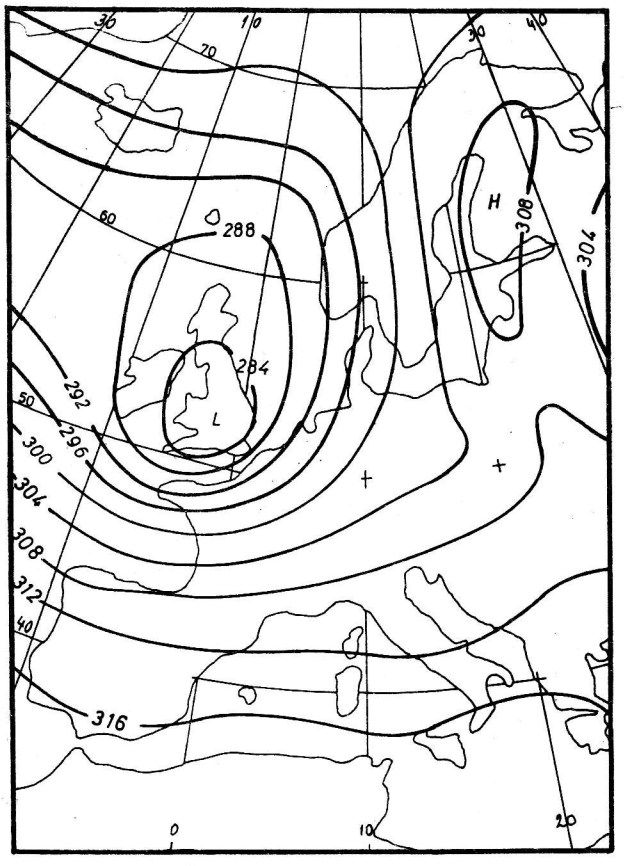

Fig. 1. AT 700 (gpdam) 00 UTC, 22 June 1990.
Sl. 1. AT 700 (gpdam) 00 UTC, 22.06.1990.

The question is, what will the cyclone development and movement direction be, or what region of the flow pattern will it choose? Furthermore, what does our wheather prediction - based on meridional profiles - give?

To the south of the centre of the cyclone we see a strong wind, connected with "barotropic governing" (James, 1987) and we expect that this region will "push" the perturbations away, toward regions where they can develop easier (Fig. 2). North of the cyclonic centre the flow is moderate and varies slowly in the meridional direction (λ=6°, 2°W and 2°, 6°E). We see regions of slowly variating zonal flow with minimuma and maximuma of flow, without large differences in their absolute values. Between these relatively small extreme values we can find inflexional regions. The gradual meridional changes of the zonal flow "elongates" the barotropic supporting zone of development, or the movement, of a hydrodynamically unstable atmospheric macroperturbations. The fact, that the differences between the minimum and maximum values of the zonal flow are small indicates that the minimums do not have a strong dissipative influence and also that the maximums do not mean a strong strengtening of the barotropic jet, i.e. they do not have a strong disturbing effect on the baroclinic development. This means that we can expect the centre of the cyclone to move slightly away from the original position to the North - Northeast i.e. far away from Yugoslavia. The expected position is denoted with a dashed line on Fig. 2.

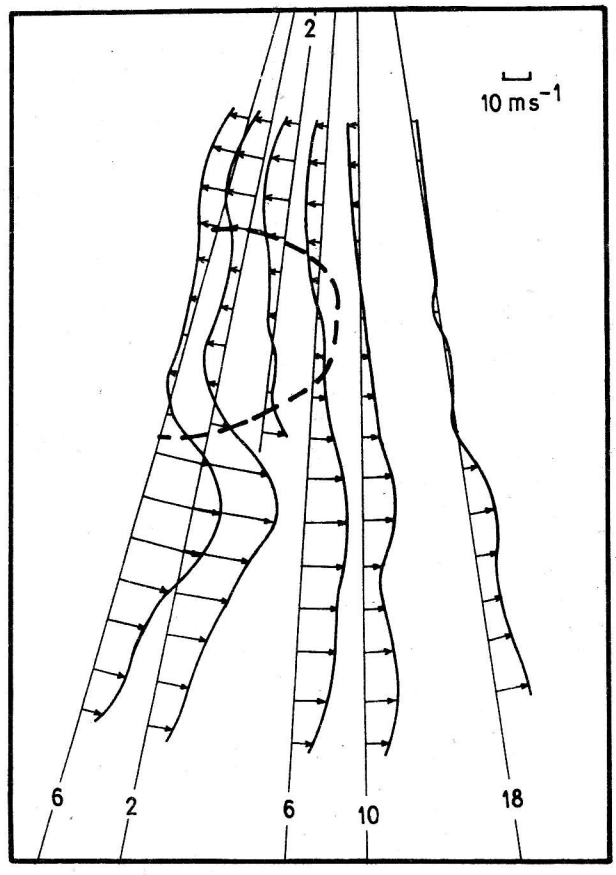

Fig. 2. Characteristic meridional wind profiles of zonal flow. The centre of the cyclone is expected to move to the region denoted with a dashed line.
Sl. 2. Karakteristični meridionalni profili zonalne struje. Crtkanom linijom naznačeno je područje očekivanog premještanja središnjeg dijela ciklone.

Finally let us take the characteristic wind profile for our country (λ=18°), which is important for the evolution of atmosphe-

ric situation over our region. This meridional profile appears not to offer any important information about the movement of the cyclone, because it is out of the cyclone region. For this reason we do not predict a weather change for our country.

Unlike the official weather forecast for June 23, 1990, *our weather forecast is: the broad, deep trough will stagnate over North - West Europe and the Northern part of the Atlantic ocean, with a slight movement of its centre to the North - Northeast and will remain over Great Britain. Thus, we do not expect the weather to change over our region.*

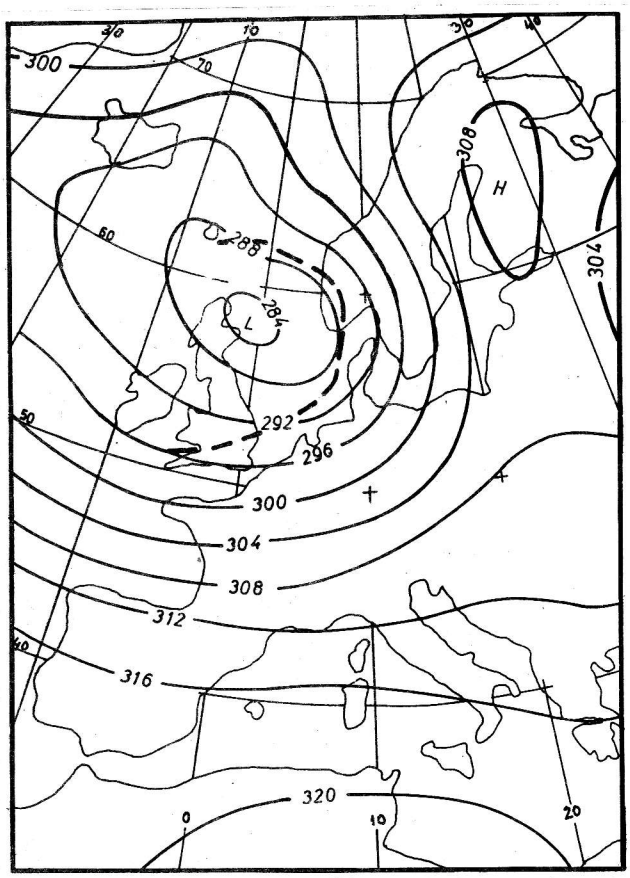

Fig. 3. AT 700 (gpdam) 00 UTC, 23 June 1990. The region of the expected new position of the cyclone middle part is denoted with a thick dashed line so that it can be compared to the real synoptic situation.

Sl. 3. AT 700 (gpdam) 00 UTC, 23.06.1990. Debelom, crtkanom linijom označeno je očekivano područje premještanja središnjeg dijela ciklone radi usporedbe sa stvarnom sinoptičkom situacijom.

A comparison of our weather forecast with the real synoptic situation, i.e. with the real movement of the cyclone (Fig. 3) is encouraging, sin ce only the middle part of the broad cyclone moved slightly to the North-East. On June 23, 1990 there was no weather change over Yugoslavia.

4. Conclusion

In this paper we have proved the influence of the meridional wind profile of the zonal flow on cyclone direction of movement, i.e. the barotropic wind shear influence on the movement of hydrodynamically unstable macroperturbations. It has been shown -in accordance with the results of Mann and Šinik (1990)- that the barotropic (horizontal) wind shear supports the baroclinic amplification of an unstable wave in the vicinity of inflexional part of the zonal flow meridional profile, and thus governs their movement. We have also answered the question why the weather prediction on June 22, 1990 was wrong. The successfulness of the weather prediction was essentally influenced by the hydrodynamic instability of the atmosphere and the barotropic wind shear of the zonal flow which governed the movement of the cyclone. This paper shows that the prognostic model failed to forecast the real position of this large cyclone over North-West Europe because it did not take into consideration barotropic influence.

References

Brown, J.A., 1968 a: A numerical investigation of hydrodynamic instability and energy conversions in the quasi-geostrophic atmosphere: Part I. Journal of the Atmospheric Sciences, **26**, 352-365.

Brown, J.A., 1968 b: A numerical investigation of hydrodinamic instability and energy conversions in the quasi-geostrophic atmosphere: Part II. Journal of the Atmospheric Sciences, **26**, 366-375.

Charney, J.G., 1947: The dynamics of long waves

in the baroclinic westerly current. Journal of Meteorology, 4, 1040-1053.

Charney, J.G. and Stern, M.E., 1962: On the stability of internal baroclinic jets in a rotating atmosphere. Journal of the Atmospheric Sciences, 19, 159-172.

James, I.N., 1987: Suppression of baroclinic instability in horizontally sheared flows. Journal of the Atmospheric Sciences, 44, 3710-3720.

Mann, M., and Šinik, N., 1990: Some properties of hydrodynamic instability in a quasi-geostrophic atmosphere. Geofizika, 7, 55-70.

Europäischer Wetterbericht, Amstblatt des Deutschen Wetterdienstes, Offenbach a.M., VI, 1990.

Kratak sadržaj

Pomoću našeg primjera potvrdili smo -u skladu sa teorijskim očekivanjima- efikasnost meridionalnih profila zonalne struje u pogledu pomicanja atmosferskih makro poremećaja, tj. utjecaj barotropnog smicanja u izboru najpogodnijeg područja za razvoj hidrodinamičke nestabilnosti atmosfere (HdN). Barotropno (horizontalno) smicanje zonalne struje može podržati baroklini razvoj u blizini infleksionog područja meridionalnog profila zonalne struje, zbog čega u stvari "upravlja" pomicanjem već postojećih poremećenja. Istovremeno dali smo objašnjenje razloga pogrešne prognoze na čiji je ishod -kako zapažamo- bitno utjecala HdN atmosfere, odnosno barotropno smicanje zonalne struje koje je djelovalo na smjer pomicanja prostrane ciklone. Ovaj rad ilustrira pogrešku prognostičkog modela u pogledu pomicanja prostrane ciklone iznad sjeverozapadne Evrope zbog neadekvatnog simuliranja barotropnog utjecaja.