The Instability of Ultra-long Waves during the Formation of Long-term Weather Anomalies

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Abstract

The ultra-long waves of the main meteorological fields (geopotential, velocity, temperature, ozone) play a very important role in the formation of weather and climate regimes of the atmospheric circulation. There is a obvious correlation between the events of the blocking formation and the values of the amplitude of the first mode of geopotential. In this work we have investigated the relationship between the vortex formation in the Eastern Pacific and a blocking episode during 19/12-26/12/1996 near 180W. We have found that this blocking is associated with large amplitude of the wave with zonal number 4, and the formation the vortex is associated with this blocking. Arriving South America and interacting with the South Convergence Zone (SACZ) this vortex is converting into blocking vortex pair over South of Brazil. Very strong precipitation was generated over Southern Brazil at that time. In order to determine the role the baroclinic instability for the increasing of ultra-long waves we have used geostrophic equation type II and investigated stability of zonal flow in more common nonlinear formulation. We found that the growing of the amplitude of planetary waves in our case was not associated with this type of instability.

1 Introduction

In the case of a wave description of general atmospheric circulation any meteorologist can assert that ultra-long waves of the main meteorological fields (geopotential, velocity, temperature, ozone) play a very important role in the formation of weather and climate regimes of the atmospheric circulation. The greatest part of the kinetic and the available potential energy falls on first wavenumbers. The ultra-long waves are very important in a transfer as of the energy through the spectrum as of the heat to the stratosphere. The first three components are directly connected with the angular momentum behavior and as a consequence with El Niño events. There is a correlation between the blocking formation and the values of the amplitude of the first modes of geopotential. For example in summer 1995-1996 in SH it was observed high correlation between formation two blockings (in the South Pacific and over southern part of South America) (Fig.1) and growing of amplitudes of wavenumber 2 and 4 (Fig. 3). We want to note that formation blocking over South America was accompanied very strong rains. During 24 December over territory of Santa Catarina (Brazil) have fell 411.9 mm of precipitation (Climanálise,1995). By this reason the investigation of ultra-long behavior have not only academic interest.

The planetary waves are also responsible for low-frequency atmospheric circulation and as a consequence for the manner of temporary evolution of stochastic atmospheric regimes (James&James,1992; Kurganskiy et al,1996). Therefore the investigations of peculiarities of ultra-long wave behavior are important for understanding of climate processes and a construction of climate imitation models.

The base properties of ultra-long waves are connected with the problem of the stability of the zonal flow of the atmosphere. The growth rates and the height distribution of the ultra-long wave amplitudes are highly essential characteristic of planetary waves playing an important role in the dynamics of troposphere and stratosphere. In (Lynch,1979) the zonal flow instability respects to ultra-long waves was studying in linear approach by means of the planetary geostrophic equations of typeII (according to Phillips' terminology (Phillips,1963). First these equations for describing planetary scale motion was proposed by (Burger,1958) and later they was used in the works (Wiin-Nielsen,1961; Pisnichenko,1980; Williams,1984). Interesting results concerning the dependence of the growth rate from the wind shear were obtained.

But it is always interesting to solve the problem in more common nonlinear formulation and to evaluate the role of nonlinearity on the investigated phenomena.

2 Non-Linear Instability

Here we want to show that the problem on instability of the zonal flow to ultra-long wave disturbances can be solved i nonlinear considerations. In our investigations of ultra-long waves we also will use planetary geostrophic equations ty II for spherical Earth:

$$fu=-\frac{1}{\rho a}\frac{\partial p}{\partial\varphi};\quad fv=\frac{1}{\rho a\cos\varphi}\frac{\partial p}{\partial\lambda};$$

$$g\;=-\frac{1}{\rho}\frac{\partial p}{\partial z};\quad \frac{\partial\rho}{\partial t}+\nabla\cdot\rho\vec{v}=0;\quad \frac{ds}{dt}=0;\quad p=R\rho T.$$

Here u,v,w are respectively zonal, meridional and vertical velocity, p-air pressure, ρ-air density, s-entropy, T-temperature, $f=2\omega\sin\varphi$ -Coriolis parameter, $\omega-$ angular velocity of Earth's rotation, R-gas constant for dry ai g - gravitational acceleration. $\lambda,\varphi,z-$ respectively longitude, latitude and vertical coordinate, a - Earth's radius,

We will investigate the stability of stationary flow using Arnold's method according to scheme described in (Dikiy&Kurganskiy,1971).

The key idea of this approach is to construct the functional which will be conserved during of investigated process. The conditions of sign-definitely of the second variation of this functional will correspond to the conditions of the stability of the considering flow.

Such functional can be constructed as a sum of the integrals of motion: potential energy, enstrophy and some one, describing the processes on underlying surface.

$$H=\iiint\limits_{V}\rho[c_v\,\mathbf{exp}(s/c_v)\,\rho^{\kappa-1}+gz+\Phi(s,\Omega(s_z,\rho))]\,d\tau+\iint\limits_{S}fG(s)\,d\sigma$$

(Φ, G are arbitrary functions, $\Omega=f/\rho\cdot\partial s/\partial z$ is potential vorticity for planetary scale, c_v is atmospheric specifi heat at constant volume.)

We have investigated here the stability of the zonal flow as respects to the ultra-long waves for the isothermal atmosphere ($\partial T/\partial z=0$) and linear with a height a profile of the wind $\partial\vec{v}/\partial z=\Lambda$. The second variation of functional has a form:

$$\delta^2H=\iiint\limits_{V}\{\frac{1}{\rho}[(\kappa-1)c_pT-\frac{\kappa^2g\;fu}{(\frac{\beta g}{f}+\frac{f\Lambda\kappa}{\kappa-1})}](\delta\rho)^2+2[(\kappa-1)T\;-\frac{gfu(1+\kappa(\kappa-1))}{R(\frac{\beta g}{f}+\frac{f\Lambda\kappa}{\kappa-1})}]\,\delta\rho\delta s+$$

$$\rho[\frac{T}{c_v}-\frac{fT\Lambda}{R(\frac{f\Lambda\kappa}{\kappa-1}+\frac{\beta g}{f})}-\frac{gfu}{c_v^{\,2}(\frac{f\Lambda\kappa}{\kappa-1}+\frac{\beta g}{f})}](\delta s)^2\}\,d\tau\;+\iint\limits_{S}\frac{(RT\beta+f^2u)\,f\,u\rho Tg}{f^2c_p\Lambda(\frac{f\Lambda\kappa}{\kappa-1}+\frac{\beta g}{f})}(\delta s)^2d\sigma$$

where c_p - is atmospheric specific heat at constant pressure, $\kappa=c_p/c_v$, $\beta=\partial f/\partial y$. If we assume that wind at the earth surface is equal zero than last integral is also equal zero and we can obtain the condition of stability for such model.

The flow will be stable if δ^2H will be sign-definite form. It follows from here that the zonal flow will be stable respect t ultra-long waves only for case when the zonal wind profile has the form $u=\Lambda z$ for $0\le z<Z_0$ and $u=\Lambda Z_0$ for $z\ge Z_0$ and defined from the formula:

$$Z_0=\frac{T\kappa(\frac{\beta g(2-\kappa)}{\kappa}+\frac{2f^2\Lambda}{\kappa-1}+(\frac{\beta^2g^2(\kappa+3)}{(\kappa-1)}+\frac{4f^2\beta g(\kappa^2+\kappa-1)\Lambda}{\kappa(\kappa-1)}+\frac{4f^4\Lambda^2}{(\kappa-1)^2})^{1/2}}{\frac{2f^2g\Lambda[(\kappa-1)^2+\kappa^2]}{c_v(\kappa-1)^2}}$$

In Fig. 2 it is given graphic of the height of velopause Z_0 (where the wind velocity stop growing with z) as a function o wind shear Λ. For parameters which are under this curve the flow is stable for ones which are upper the flow may be unstable and we can expect the growing of the ultra-long waves.

3 Blockings During Summer 1996 In Southern Hemisphere

We've considered time behavior of the first 15 components of the decomposition of geopotential in spherical harmonics and also of the wind shear in troposphere and stratosphere for the period December, 95 - January, 96. During 19/12-26/12/96 two blockings was observed in SH. For the same period strong growing of modes Y_6^4, Y_6^2, Y_4^2 took place. Analysis of the time behavior of the wind shear no give any hints on the possibility of the increasing of planetary wave amplitude from a baroclinic instability of zonal flow for this period. The height of velopause was approximately equal 12 km and Λ varied in the range $1.7 \cdot 10^{-3} - 2 \cdot 10^{-3}\ s^{-1}$ in troposphere and $-1.3 \cdot 10^{-3} - -1.7 \cdot 10^{-3}$ in stratosphere (Fig.3). However we have to note that we've used too artificial model for the atmosphere and that is why we obtained too large domain for stability. In reality wind profile and temperature stratification of atmosphere are strongly distinguished from ones which we used. Therefore we cannot confirm that mechanism of nonlinear instability didn't play any role in the increasing of ultra-long wave amplituides during December 95 blockings in SH. It is necessary further investigation with utilization more realistic parameters corresponding to the base atmospheric flow.

From the other side the mechanism of linear resonance of Rossby waves in the presence of vortex sources (heat sources and sinks) can be proposed as an alternative explanation of observed growth of ultra-long wave with zonal wave number 4 (Kurganskiy et al, 1987). During considering period ultra-long wave 4 was stationary. Condition of linear resonance for stationary Rossby waves is $u = -c$, u is mean zonal flow and $c = -\beta / k^2$ is Rossby wave phase velocity of resonance mode. For the latitude $\theta = 55^\circ$ (mean latitude for the band where ultra-long wave 4 was most expressed) wave number is approximately equal $k \approx 1.1 \cdot 10^{-6}\ m^{-1}$. Mean value for β is $1.6 \cdot 10^{-11}\ s^{-1} m^{-1}$ and consequently the resonance will be when the value of mean zonal wind will be equal approximately to 13 *m/s*. Fig.4 show temporary evolution of zonal wind in the belt $\theta = 40^\circ - 60^\circ$. One can see that in the period of blocking zonal wind abruptly decreased and condition of resonance for ultra-long wave number 4 was satisfied.

4 Conclusion

Arising of a system of two blockings in SH (over South Pacific and over south part of Brazil) is a rare but not single event. Apparently the presence of quasistationary ultra-long wave with zonal number 4 is essential condition for it. Further investigation with using more realistic theoretical models and for various periods have to help to understand this important phenomena.

5 Reference

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Legend to figures

Fig.1 Stream function (line) at 200mb and geopotential (shadowed) at 500 mb at 12 VTC for a)21/12/95, b)22/12/95, c)24/12/95, d)26/12/95.

Fig. 2 Diagram of stability as a function of a wind shear (s^{-1}) and a velopause height (*m*). Under the curve the flow is stable.

Fig.3 Temporary evolution of module of wind shear, averaging over the belt $65S-25S$ and for a) troposphere - 850mb-300mb and b) stratosphere 200mb - 20mb separately; c) temporary evolution of amplitude of wave Y_6^4 (------), Y_6^2 (—○—○—○), Y_4^2 (-●-●-●).

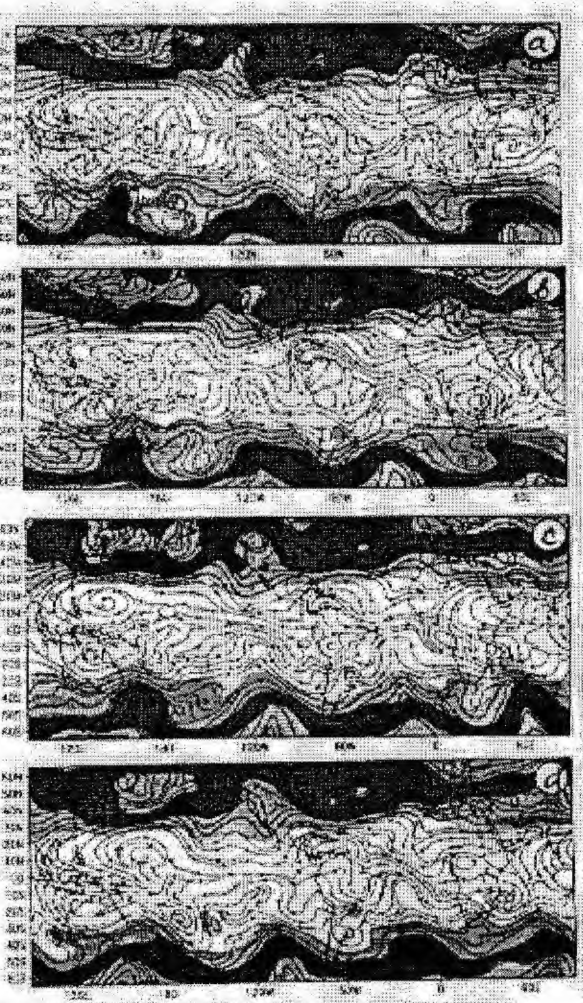

Fig. 1

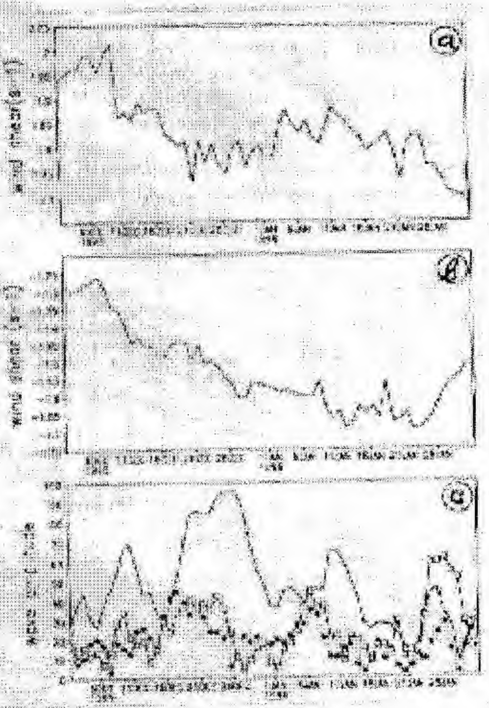

Fig. 3

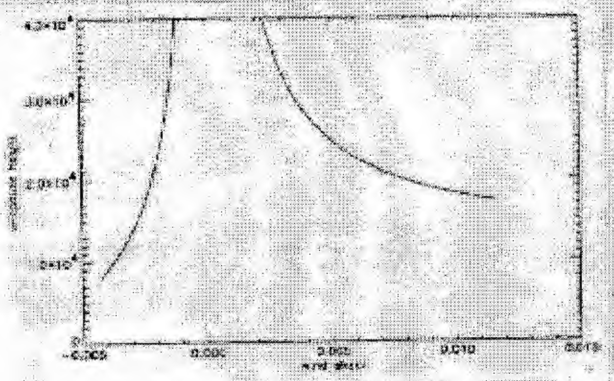

Fig. 2

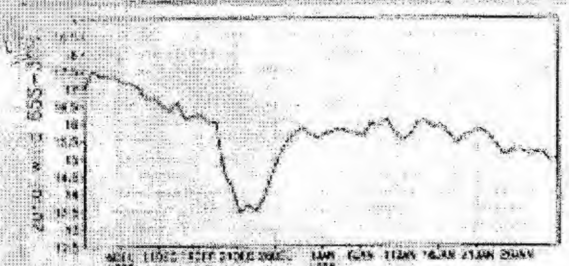

Fig. 4

Fig.4 Temporary evolution of geostrophic zonal wind averaging over the belt $65S-30S$ at 500 mb (units m/s).