SEMEP

Search for ElectroMagnetic Earthquake Precursors

Increment of parametric instability of drift type waves characterizing generation of zonal winds

Deliverable 6.1

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1 BACKGROUND AND MOTIVATION

Internal gravity waves (IGWs) have been the subject of intense research activity in recent years. There remain, nevertheless, a number of areas in which further progress is required to refine our understanding in order to describe and predict their influences in the middle atmosphere and the ionosphere. IGWs are associated with density and velocity perturbations of the atmosphere in the presence of equilibrium pressure gradients that are supported by the gravity force. The atmospheric particles within the perturbation oscillate owing to the restoring force of buoyancy.

IGWs play an important role in a large number of physical phenomena in the troposphere and the ionosphere. They provide an effective transport of energy and momentum from the lower layers of the neutral atmosphere to the ionosphere. Propagation of these waves through the atmosphere is characterised by an increase in the amplitude of the perturbation, caused by the decrease of density with altitude. As a result, IGWs may cause perturbations in the ionosphere. Satellite and ground-based electromagnetic sounding of the neutral atmosphere and lower layers of the ionosphere show a correlation between ground disturbances and those in the lower layers of the weakly ionized ionosphere. Theoretical and experimental studies have shown that IGWs in the ionosphere may originate from events such as earthquakes, volcanic eruptions, strong explosions, and powerful rocket launches. Therefore, warning and monitoring methods based on electromagnetic sensing are closely related to the IGW propagation.

During the period leading up to an earthquake many changes within the lithosphere occur. Two notable changes are the generation of low-frequency oscillations of the Earth’s surface and gas emanation. Modification of the atmospheric gas composition can induce a local green-house effect which results in the appearance of infrared radiation anomalies. Such anomalies, that can develop several days before EQs in some seismically active regions, have been detected by satellites. These thermal anomalies may generate a broad spectrum of IGWs. Although interpretation of the atmospheric response in terms of the IGW propagation is usually limited by consideration of the linear theory, there are a large number of observations that indicate the possible role of nonlinear processes.

2 GOAL

The problem of earthquake monitoring using electromagnetic sensing is closely related to IGW propagation. One of the most significant triggering forces for IGW in the atmosphere is wind shear. Dissipation of IGW usually results in the generation of large-scale nonlinear structures (convective cells) due to wave-wave and wave-mean flow interactions. Ground-based and satellite observations clearly demonstrate the permanent existence of zonal flows and vortex structures at different layers within the Earth's atmosphere. These flows have nonuniform velocities with respect to the height. The goal of this research task is the investigation of the generation of nonlinear large-scale zonal structures by IGW based on the parametric wave-wave instability.

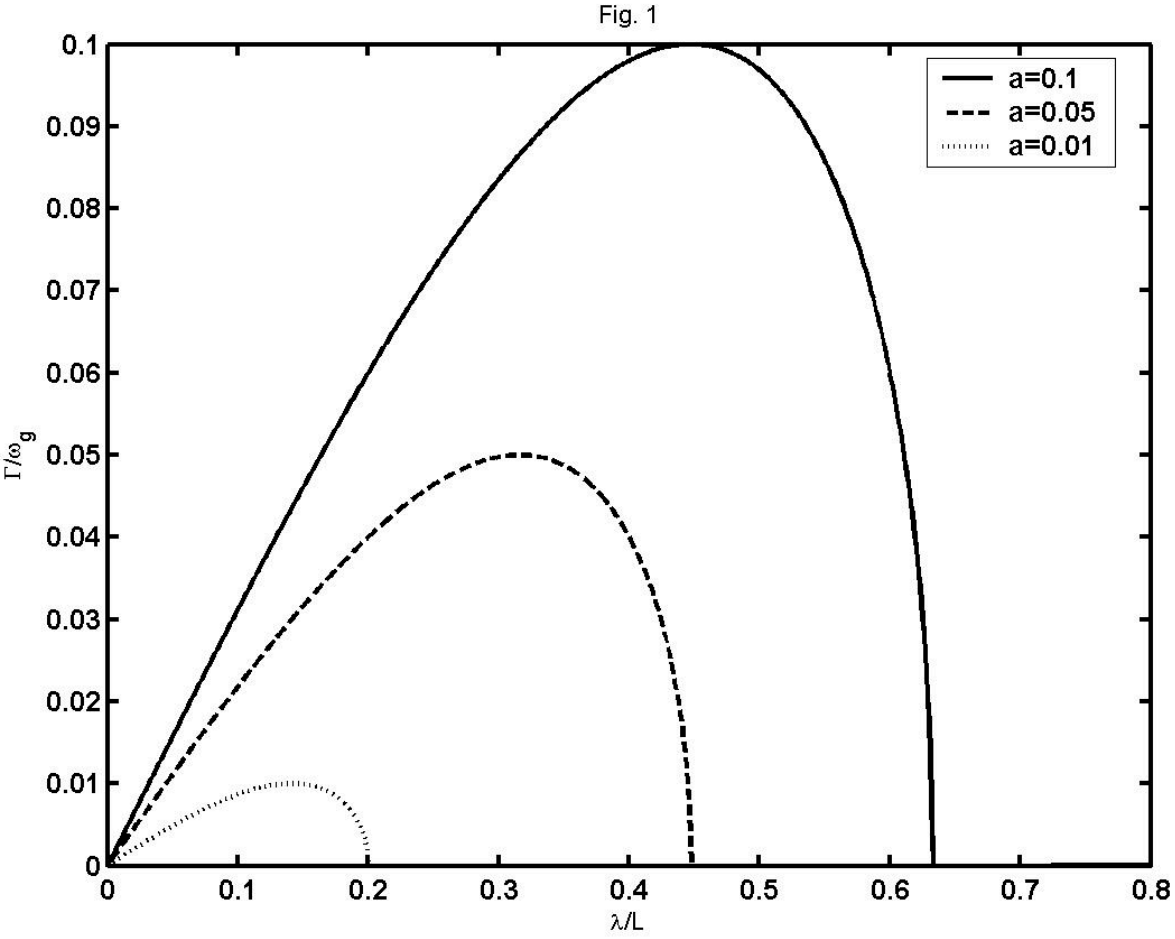
3 INCREMENT OF PARAMETRIC INSTABILITY OF IGW

A novel mechanism for the generation of large-scale zonal structures by IGW in the Earth's atmosphere is investigated (Onishchenko and Pokhotelov, 2012). The generation mechanism is based on the parametric excitation of convective cells by finite amplitude IGW. A set of coupled equations describing the nonlinear interaction of IGW and zonal flows is obtained. The generation of the zonal structures is due to Reynolds stresses produced by finite amplitude IGW. According to this process the energy is transferred from small scale IGW into large scale zonal structures (or convective cells). This process, which is an example of an inverse turbulent cascade as described by the theory of two-dimensional turbulence, creates large-scale structures out of turbulent chaos.

It is found that the maximum growth rate has a convective mode whose vertically directed wave vector corresponds to the periodic character of zonal structures in height. In this case, the zonal mode is purely growing with the growth rate (increment) Γ determined by equation (1)

$$\frac{\Gamma}{\omega_g} = \frac{\lambda}{L}\left(\frac{k^2\,|v_k|^2}{\omega_g^2} - \frac{\lambda^2}{4L^2}\right)^{1/2}. \qquad (1)$$

Here L is the spatial scale of the zonal structure, $k = 2\pi/\lambda$ is the wave number, λ is the wave length, $|v_k|^2$ is the square of the velocity fluctuations of the IGW averaged over small spatial and time scales, and ω_g is the Brunt-Vaisala frequency. In a stratified atmosphere at equilibrium $\omega_g^2 = (\gamma - 1)g/\gamma H$, where γ is the effective ratio of specific heats, g is the gravitational acceleration, and H the reduced atmospheric height. Equation (1) describes the initial stage of zonal flow generation due to the parametric instability of short-scale IGW. Figure 1 illustrates the dependence of the normalized wave increment as function of the ratio λ / L for typical values of $a = k^2 |v_k|^2 / \omega_g^2$, when $a = 0.1$, $a = 0.05$ and $a = 0.01$. For numerical estimations a typical value for the Earth's ionosphere is $\omega_g^2 = 4 \cdot 10^{-4}$ s^{-2}. According to equation (1), see also Figure 1, the optimal spatial scale of the zonal structure is determined by relation $L / \lambda = (2a)^{-1/2}$ at which the wave increment attains its maximum value of $\Gamma_{\max} = \omega_g a$. When $a = 0.05$ we have $\Gamma_{\max} = 2 \times 10^{-3}\,\mathrm{s}^{-1}$ and $L / \lambda = 3.2$. For waves with $\lambda = 3 \times 10^2\,\mathrm{m}$ the spatial scale of the zonal structures is $L = 1\mathrm{km}$. These estimates for spatial scales of nonlinear structures are consistent with Sindelarova et al., (2009) and existing Demeter observations (Pisa et al., 2011).



4 CONCLUSION

In the course of their propagation through the atmosphere in which the density decreases with altitude IGW may grow until self-organization effects start to become important and nonlinear solitary structures are formed. According to this process energy is transferred from small scale IGW into large scale zonal wind structures (or convective cells). This process is a paradigm for inverse turbulent cascade in the theory of two-dimensional turbulence, in which large-scale structures are created, out of turbulent chaos. We have demonstrated how zonal structures can be excited by finite amplitude IGW. The driving mechanism of this instability is due to the Reynolds stresses which are inevitably inherent for finite amplitude short-scale IGW. Our investigation provides an essential nonlinear mechanism for the transfer of spectral energy from short-scale IGW to long scale enhanced zonal structures in the Earth's atmosphere and ionosphere. Obtained estimates for spatial scales of nonlinear structures are consistent with Demeter observations.

5 REFERENCES

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