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Small-Parametric Nonlinear Model to Study the Features of Regional Large-Scale Cyclogenesis

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Abstract. Small-parametric nonlinear model describing typical features of large-scale regional cyclogenesis including its seasonal behavior is suggested. The model allows also investigate the influence of solar-terrestrial relations on the tropical large-scale cyclogenesis. Our model includes a number of free parameters and their appropriate choice gives the possibility to control the temporal dynamics of the process studied. The developed model gives example of analytical description of large-scale regional cyclogenesis as sequence of cyclones and the full life cycle of each intense vortex may be taken into account.

Keywords: cyclogenesis, nonlinear model, vortices, seasonal behavior, temporal dynamics

Introduction

An important task in the problem of solar-terrestrial connections (STC) is the investigation of STC-role in the temporal dynamics of large-scale atmospheric crisis processes like tropical hurricanes, typhoons and extratropical cyclones. As it was suggested earlier [1-3], to describe the temporal dynamics of tropical hurricane (TH) it could be used the nonlinear model of TH based on the set of two coupled nonlinear equations for the maximum wind velocity and the ocean surface temperature inside a powerful vortices. This model describes realistically enough the full life cycle of hurricane including its formation from a large-scale synoptic perturbation, the following quasistationary stage and TH-damping conditioned by its displacement to the land or into the more cold water region.

The generalization of TH-models mentioned above takes into account the effective sources of atmospheric perturbations, the background conditions of non-stationarity, the ocean surface temperature variations and enables to study the role of solar-terrestrial connections in the dynamics of atmospheric crisis processes like TH.

It is possible to study the trigger start of the powerful vortex formation due to the atmosphere large-scale instability, its following damping after the quasistationary stage and the atmosphere preparation to the repeated generation of new TH due to the exceeding of its parameters at some threshold values. The suggested generalized model contains a numbers of free parameters. Their corresponding choice will allow us to control the temporal dynamics of processes studied, to change the seasonal behavior of large-scale regional cyclogenesis.

Numerical calculations performed using basis generalized model have shown that the free parameters mentioned above determined the regional cyclogenesis intensity, the duration and the power of individual event, the maximum of wind velocity in TH, the time necessary to prepare atmosphere for the large-scale vortices generation and the moments of their damping. The further generalization of this model which allows describing the simultaneous existence of two vortices in the region given and their competition as it was done in the paper [2].

Therefore by the use of nonlinear generalized model described in the present paper it is possible to study features of temporal dynamics of large-scale regional cyclogenesises and to analyze their dependences on some external factors like solar-terrestrial relationships, also the El-Niño phenomena and others which were described early in papers [4-8].

Further development of this approach taking into account experimental data on large-scale tropical perturbations and the investigation performed will allow elaborating the analytical model of seasonal behavior of a regional cyclogenesis. The results of this investigation have numerous applications like the elaboration of modern methods to forecast the large-scale crisis processes in the atmosphere, for investigations of tropical hurricanes influence on the global atmospheric circulations and for the search correlations between the solar activity and tropical cyclones.

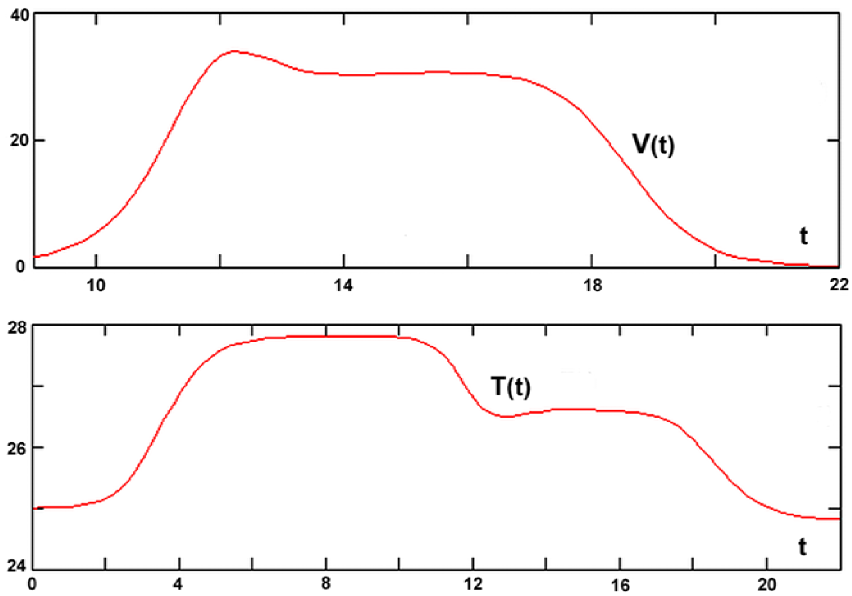

Fig.1. The results of numerical calculations for equations (1) with the function (2).

Basic equations and their analysis

The hurricane full life cycle could be studied using the small-parametric model based on the set of coupled nonlinear equations for the maximum wind velocity V(t) and the ocean surface temperature T(t) incide TH:

$$\frac{dV}{dt} = \gamma\left(T - T_*\right).V - \sigma V^2, \quad \frac{dT}{dt} = -\beta\left(T - T_1\right)V^2 + \frac{\left(T_f - T\right)}{\tau}. \qquad (1)$$

The choice of parameters γ, σ, β, τ, T_* , T_1 and the function $T_f(t)$ was substantiated in early papers [1-3]. In equations (1) the velocity V(t), the temperatures T(t), T_* , T_1 and the time *t* are measured in *m/sec*, °C and *days* respectively. Assuming the amplification of velocity V(t) of small perturbations begins when the temperature T(t) is above its threshold value T_* . According to [1] recommendation, it is supposed that T_* = 26,5 °C, T_1 = 23 °C.

For the calculations there is used the function $T_f(t)$ taking into account the change of background conditions on the hurricane path:

$$T_f(t) = T_0 + \delta T_1\{1 + th[s_1(t)]\} - \delta T_2\{1 + th[s_2(t)]\}, \qquad (2)$$

where δT_1, δT_2 are typical values of background temperature T_f changes, $s_1(t)=(t-t_1)/\tau_1$, $s_2(t)=(t-t_2)/\tau_2$. Considering the case when the initial temperature $T_f = T_0$ is below the threshold value T_* , then the increasing of T_f results in the development of instability and in weak perturbation growth with the powerful vortices formation. But the following displacement of TH into the more cold water zone ($T_f < T_*$) causes the strong vortices damping.

The results of numerical calculations for equations (1) with the function (2) and the incoming parameters choice T_0 = 25, δT_1= 1.4, δT_2 = 1.5, $\tau_1 = \tau_2$ = 1, t_1 = 3, t_2 = 18 and V(0) = 0.3 are given in the Fig.1 by the plots of velocity V(t) and temperature T(t). It is shown that under the vortices amplification the maximum wind velocity increases up to V = 33.79. At the TH quasi-stationary stage the ocean surface temperature is T ≈ 26.6. So, it is slightly above the threshold value T_* .

Therefore, the model used reproduces main features of large-scale tropical perturbation during its full life cycle. The choice of the incoming parameters allows modeling of the TH temporal evolution. Consequently, it is possible to modify this model to study the seasonal behavior of large-scale regional cyclogenesis.

$$\frac{dV}{dt} = \gamma\left(T - T_*\right).V - \sigma V^2 + \psi(t), \quad \frac{dT}{dt} = -\beta\left(T - T_1\right)V^2 + \frac{\left(T_f - T\right)}{\tau}, \quad \frac{dT_f}{dt} = f(t) - \nu\left(T_f - T_0\right), \qquad (3)$$

where $f(t) = A.[1 + \mu.\cos(\omega t)]$ is taking into account the external factors that have influence on ocean surface temperature and $\psi(t) = 0.3.[1 - \cos(0.03t)]$ describes the wind generation by small perturbation, for example, by the pressure weak gradient.

External factors may be used to study El-Niño events and others. The non-stationary background temperature $T_f(t)$ of ocean surface may be described by the function described in (4).

For the numerical calculation of equations (3) the incoming parameters values are chosen: t_4 = 1.2, t_6 = 88, t_3 = 1, μ =0.2, ν = 0.1, ω = 0.08.

$$T_f(t) = -1.5.\left[1+\tanh\left(\frac{t-t_4}{\tau_3}\right)\right].\left[1-\tanh\left(\frac{t-60}{\tau_3}\right)\right]-1.1.\left[1+\tanh\left(\frac{t-t_6}{\tau_4}\right)\right].\left[1-\tanh\left(\frac{t-120}{\tau_4}\right)\right] \quad (4)$$

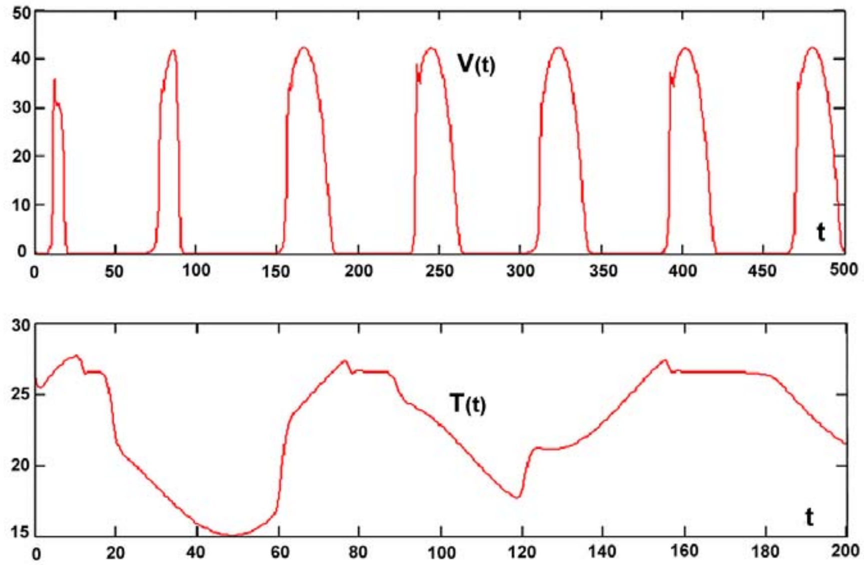

Fig.2. Generation of large-scale quasi-periodical vortical perturbations.

The results of calculations are presented in Fig.2 by plots of the wind velocity V(t) and the ocean surface temperature T(t).

According to the plots in the Fig.2 there is a quasi-periodical generation of large-scale vortical perturbations in the system considered. It is necessary to note that vortices amplitudes max V(t) are different ones. By variations of incoming parameters it is possible to change the life cycle duration for each vortex, the times of active season beginning and its end.

Conclusions

The main results from the investigation performed may be summarized as followings:

- The small parametric non-linear model generalization allows describing features of large-scale regional cyclogenesis (LSRC) during the active season;
- On the basis of LSRC model it is possible to study the external factors (like solar-terrestrial connections, El-Niño phenomena and others) that have influence on the LSRC seasonal behavior.
- The approach developed could be used for investigation of the influence of tropical hurricanes on the atmosphere global circulation, for elaborations of the modern methods to forecast large-scale crisis processes in the atmosphere and for analysis of correlations between solar-magnetosphere activity and tropical cyclones.

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