

On the small-parametric nonlinear model of a hurricane life cycle

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Abstract. It is supposed the generalization of early developed small-parametric mathematical model to describe the hurricane full life cycle. The new model allows on the basis of self-consistent nonlinear equations for the wind velocity and the ocean surface temperature to study the typhoon full life cycle including both its development stage and damping one.

1. Introduction

The development of simplified physico-mathematical models of the life cycle of powerful large-scale atmospheric vortices like tropical hurricanes is of the great interest for a number of applications, for example, to study features of large-scale regional cyclogenesis, to elaborate methods of its forecasting, to investigate the role of solar-terrestrial relationships in the dynamics of natural crisis processes, at the analysis of tropical hurricanes influence on the large-scale circulation of atmosphere. Early in paper [1] for calculations of parameters, characterizing the life cycle dynamics of tropical hurricanes, the simple mathematical models based on observations data were considered. In papers [2,3] in analogy with the models of electromagnetic radiation generation in lasers the nonlinear model of hurricane development was suggested. This model takes into account pumping of energy in the ocean-atmosphere system, threshold conditions for powerful vortice forming and its interaction with an environment. In this model, the system of coupled nonlinear equations for the maximum wind velocity in hurricane and the ocean surface temperature in it, describes sufficiently really the hurricane forming from a small perturbation and the following vortice quasistationary stage.

In the present paper the generalization of nonlinear model [2] is done, which allows to describe the hurricane damping stage connected with its going on a coast or its displacement in the region of more cold ocean surface. For that one of parameters of environment determining the conditions of vortice generation is taken to be the time dependent. So its decreasing lower the some threshold value causes the typhoon damping. The calculations made on the basis of this modified self-consistent model show that at new conditions (decrease of governing parameter lower than threshold value) the generation properties in system studied are absent and the tropical hurricane damps.

Thus the modified nonlinear model reproduces sufficiently really the dynamics of development and damping of tropical hurricanes. The choice of parameters of the model studied gives us the possibility to govern, in particular, the duration of the stages of hurricane life cycle, the maximum wind velocity and so on. As the correlation analysis shows the presence of the influence of solar-terrestrial relationships on the atmosphere processes parameters (see, e.g., papers [4,5]), the model considered can be used in the investigations of the large-scale tropical cyclogenesis relationships with solar activity, as well as at the development of nonlinear analytic models for large-scale regional cyclogenesis, in the analysis of its statistical properties and possibly in the forecasting models elaboration.

2.BASIC EQUATIONS AND THEIR ANALYSIS.

First of all, to take into account obviously the presence of instability caused to the formation of large-scale vortice, let us modify the equation suggested in paper [1] for the maximum wind velocity in tropical cyclone V like this

$$dV / dt = \gamma \cdot (T - T_*) \cdot V - \sigma \cdot V^2, \quad (1)$$

where T is the temperature of ocean surface at the tropical cyclone (TC) region, T_* is its threshold value higher which the amplification of perturbations and the vortice formation take place, the term $-\sigma \cdot V^2$ determines energy losses due to dissipative processes increasing with the growth of vortice intensity. We take below that the wind velocity V is measured in m/sec, temperature T is in $^{\circ}\text{C}$, time t is in days. Then according to paper [2] characteristic values of parameters in eq. (1) are as the following: $T_* = 26.5$, $\sigma = 3 \cdot 10^{-3}$, $\gamma \leq 1$.

For the ocean surface temperature we use the equation from the paper [2]

$$dT / dt = -\beta \cdot (T - T_1) \cdot V^2 + (T_f - T) / \tau. \quad (2)$$

Here T_1 is the temperature of cold water, raising in TC from lower ocean levels to its surface (its typical magnitude is $T_1 = 23$), T_f is the equilibrium background temperature in the absence of perturbations conditioned by TC, the value of which is determined by heat balance in the season considered, τ is the typical time of equilibrium temperature establishment. Hereafter according to recommendations of paper [2] we take $\beta = 3 \cdot 10^{-4}$, $T_f = (28 \div 30)$, $\tau = 10$.

We take into account the hurricane damping due to, e.g., its going out into the cold water region by the choice of alternating parameter T_f as the time dependent function $T_f(t)$. At calculations below we use the following function

$$T_f(t) = T_{f1} - 0.5 \cdot \delta T_f \cdot \{ 1 + \text{th} [(t - t_1) / \tau_d] \}, \quad (3)$$

where T_{f1} is the background equilibrium temperature at the TC forming stage and the following quasistationary stage of vortice, t_1 determines the time of TC going out into the region with colder water with the temperature decreasing by δT_f , τ_d is the typical time of TC displacement in the colder water region.

Thus the modified nonlinear model includes the three additional governing parameters δT_f , τ_d , t_1 .

The system of nonlinear equations (1), (2) with the nonstationary background temperature (3) was calculated numerically for various values of incoming parameters. Fig.1 shows the plotts of dependence on time of the wind velocity and the ocean surface temperature at the typhoon stage forming for the model considered in paper [2] when the equilibrium temperature value is $T_f = 28$. At the framework of modified model (1), (2) the temporal dynamics of wind velocity and ocean surface temperature under the vortice forming process is shown at fig.2 for the following values of incoming parameters :

$$T_{f1} = 28, \delta T_f = 0, \tau = 10, \gamma = 0.5, \beta = 3 \cdot 10^{-4}, \sigma = 3 \cdot 10^{-3}, V(0) = 1, T(0) = T_{f1} = 28.$$

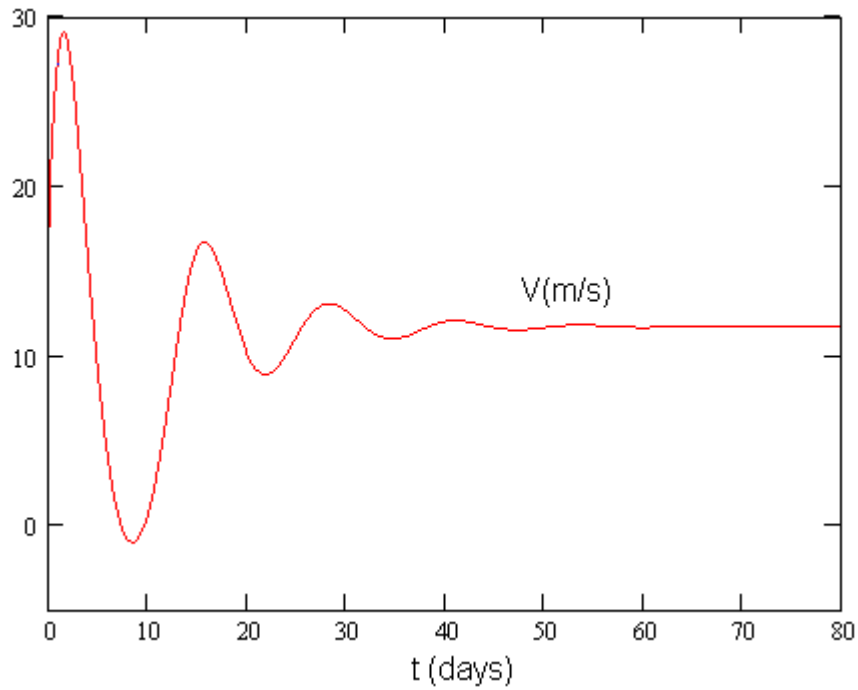


Fig.1a. The wind velocity dynamics in the hurricane at its forming stage.

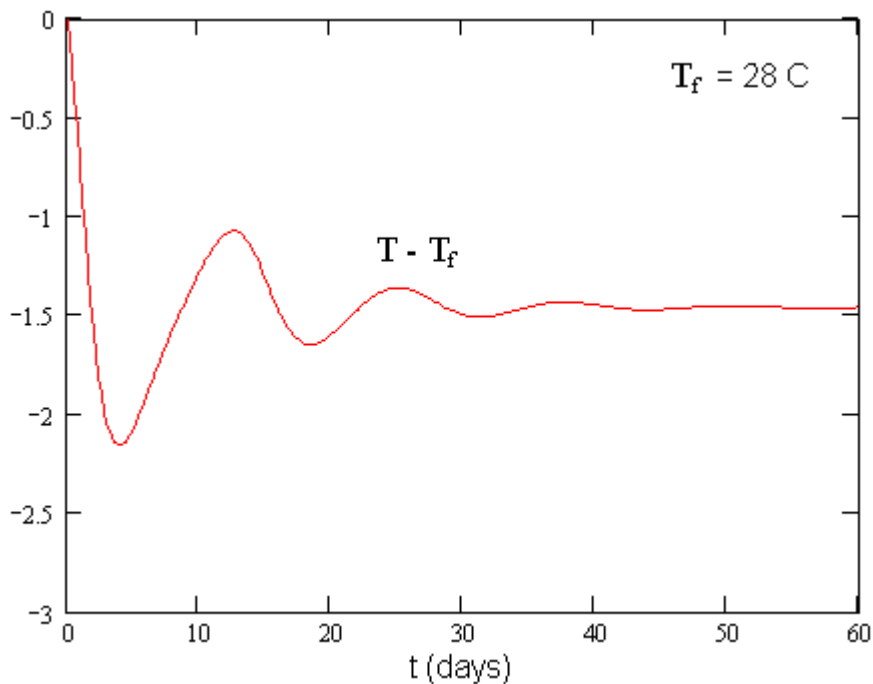


Fig.1b. The dynamics of ocean surface temperature T at the hurricane forming stage.

As we see it is rather the same as received in the paper [2]. At vortice quasistationary stage the temperature T is equal to 26.57 , which is slightly above than the threshold value $T_* = 26.5$. For the hurricane full life cycle (with allowance of its damping) the dynamics of maximum wind velocity and ocean surface temperature are shown at fig.3 for the following choice of incoming parameters: $T_{f1} = 28$, $\delta T_f = 2$, $\tau = 0.3$, $\gamma = 1$, $\beta = 6 \cdot 10^{-4}$, $\sigma = 3 \cdot 10^{-3}$, $V(0) = 0.3$, $T(0) = 28$, $t_1 = 14$, $\tau_d = 1$. Then at the TC quasistationary stage the maximum wind velocity equals to $V = 45.63$, the ocean surface temperature decreases to the value 26.64. At the end of hurricane damping stage the later becomes close to 24. Changing incoming parameters of system considered we can change the dynamics of process studied.

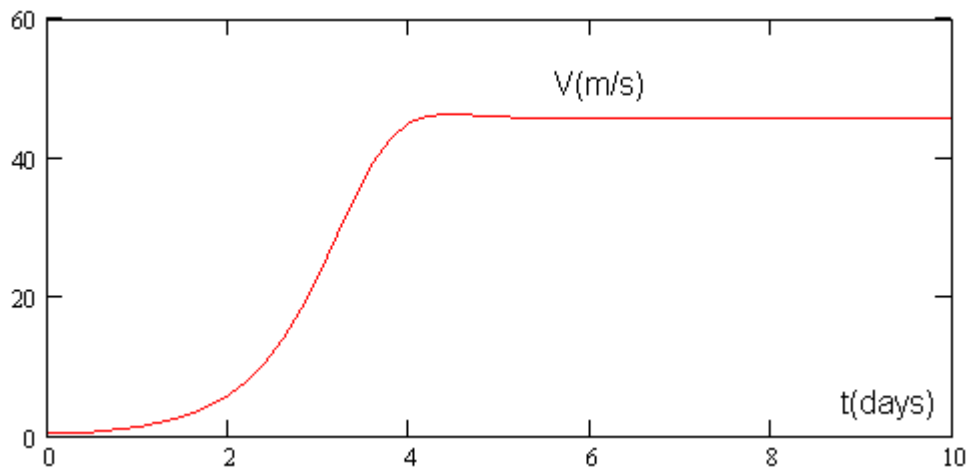


Fig.2a. The wind velocity dynamics at the hurricane forming stage for the modified nonlinear model.

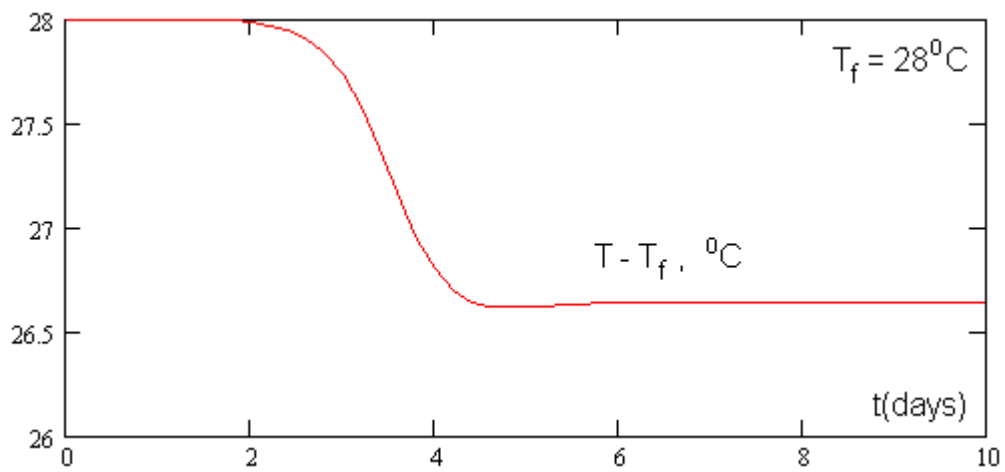


Fig.2b. The ocean surface dynamics at the hurricane forming stage for the modified nonlinear model.

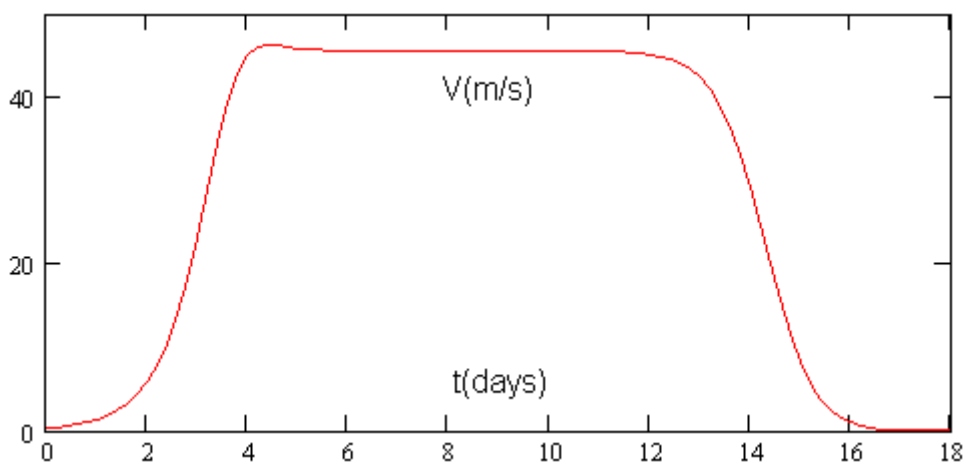


Fig.3a. The wind velocity dynamics for the hurricane full life cycle.

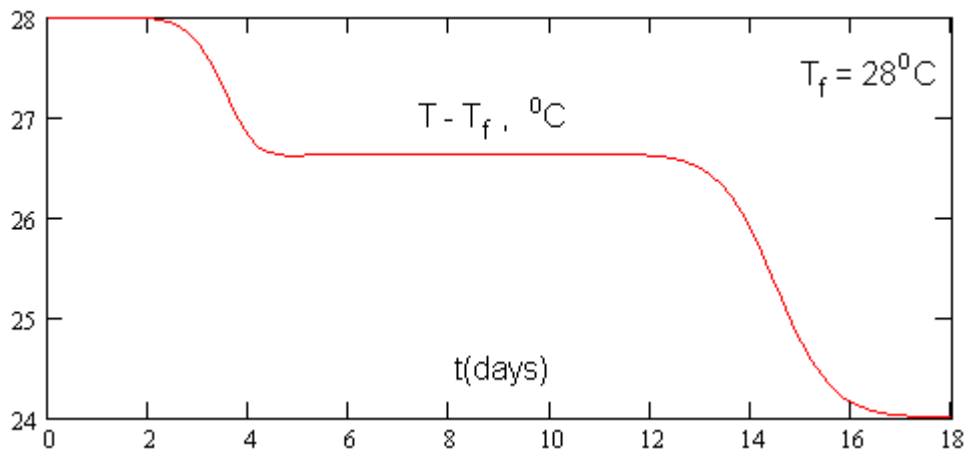


Fig.3b. The ocean surface dynamics for the hurricane full life cycle

According to the fig.3 for the problem parameters chosen the temporal behaviour of $T(t)$ is monotonous one. The maximum wind velocity $V(t)$ in typhoon during its development stage and damping one have also monotonous dependences on time.

CONCLUSION.

The results of investigation performed are as the following. Firstly, the modified nonlinear model of the temporal dynamics of large-scale atmosphere vortice like the hurricane is suggested. The stage of hurricane damping is taken into account with introducing in equations studied the time dependent parameter – the background equilibrium temperature $T_f(t)$.

Secondly, the numerical calculations of vortice temporal dynamics in the framework of modified nonlinear model are performed. The modified nonlinear model contains free parameters, changing which we can govern the processes of forming and damping of hurricane, the duration of its quasistationary stage.

The nonlinear, nonstationary model presented can be useful for the investigations of regional tropical cyclogenesis and for the analysis of the influence of solar-terrestrial relationships on the dynamics of large-scale crisis atmospheric processes. The further generalization of model presented may be done, in particular, by the taking into account more complicated background conditions describing their seasonal behaviour and by introducing a some external forcing connected, for example, with the solar activity influence.

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