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ON THE ROLE OF SOLAR-TERRESTRIAL RELATIONS IN THE DYNAMICS OF LARGE-SCALE ATMOSPHERIC CRISIS PROCESSES

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The solar activity influence on large-scale crisis processes in the Earth atmosphere, for example, tropical cyclones (TC) is considered. Firstly, the correlation coupling between Wolf numbers W(t), characterizing the solar activity intensity, and large-scale tropical perturbations amount T(t) occuring in the Earth atmosphere during the period (1983–1998) years is studied. A mutual correlation function for temporal sequences of Wolf numbers and TC amount shows a very complicated behaviour, in particular, there are temporal ranges of a well-defined correlation or anticorrelation of TC-events with the solar activity level. Regards to this, the model of oscillator driven by an external force is used which allows to explain the features of mutual correlation function. From the analysis performed it is follows that the consecutive mathematical model describing the solar activity influence on the tropical cyclogenesis must take into account a number of factors including the atmospheric perturbations triggering by an external forcing, the possibility of instability development, its nonlinear stabilizations and TC decay stage due to the change of background conditions. The elaboration of such model requires to investigate the tropical cyclogenesis phase plane using the experimental data when the number of events is small enough. For experimental data on the temporal sequence of TC intensity, the analytical approximation of each event by the differentiable function with free parameters is given. It takes into account the tropical disturbance forming, its quasistationary phase and the decay stage. To substantiate analytical approximations the modified typhoon nonlinear model was developed which includes equations for the maximum wind velocity and the ocean surface temperature and takes into account the nonstationary background. The model developed show the large-scale vortice forming, when the problem governing parameter exceeds its threshold value, the TC quasistationary phase and the following TC decay. Using the analytical approximation for a regional cyclogenesis the phase space structure of dynamical systems (T, Q), where Q = dT/dt, is considered. The phase space (T, Q) has complicated structure and includes both fast variations and slow trends. The approach developed allows to improve our understanding of the relations between large-scale crisis atmospheric processes and the space weather factors including the mechanisms of solar-terrestrial relations influence on the atmospheric hazards.

Correlation coupling between large-scale vortical perturbations amount occuring in the Earth atmosphere and Wolf numbers

The analysis of solar activity (SA) influence on large-scale vortical processes in the Earth atmosphere (LSVP), for example, tropical depressions, typhoons and hurricanes is the important part of natural hazards and Earth climate change investigations. In particular, the mutual correlation functions of solar activity (SA) characteristics and tropical cyclogenesis intensity are usually studied, the spectra of SA-events and LSVP-ones are compared and so on (see, for example, [1–4]). Let us consider the correlation coupling between Wolf numbers W(t) characterizing solar activity intensity with large-scale vortical perturbations amount T(t) occuring in the Earth atmosphere for the time interval from 1983 up to 1998 years. The plotts of functions W(t), T(t) for this time interval are shown in Fig. 1. A single point of these curves give the number of corresponding events during month period. So 192 points in the each data set were used. According to the Fig.1 the behaviour of oscillating functions W(t), T(t) is different, in particular, the growth of W(t) not always accompanied by the T(t) increase. Then the peaks of these functions have different position on t and so on. So far as W(t), T(t) oscillate the mutual correlation function Crf(n) was calculated where n is the temporal shift in monthes.

Let us determine the averaging W and T values on the data sets taken $\langle T\rangle = 1/192)\sum_j T_j$, $\langle V\rangle = 1/192)\sum_j V_j$, where $V_j = 0.02\ W_j$, and dispersions of temporal sequences V and T considered $\sigma_t^2 = (1/192)\sum_j (T_j - \langle T\rangle)^2$, $\sigma_V^2 = (1/192)\sum_j (V_j - \langle V\rangle)^2$, $0 \le j \le 191$. Now the mutual correlation function Crf(n) is determined by the following expression

$$\mathrm{Crf}(n) = \frac{1}{192-n}\sum_{J=0}^{191-n}(T_{j+n} - \langle T\rangle)(V_{j+n} - \langle V\rangle),\quad n=0, 1 \ldots N/2. \tag{1}$$

The plot of function Crf(n) is presented in the Fig. 1, *b*. We see that it shows obviously the absence of clear correlation between fluctuations $\delta T_j = T_j - \langle T\rangle$ and $\delta V_j = V_j - \langle V\rangle$. For example, there are wide intervals of δT and δV anticorrelations. The maximum of the first positive correlation in behaviour of considered events V(t), T(t) corresponds to temporal shift of the order of 6 days.

Variable trends X_j for the function V_j and Y_j for the T_j one are given in Fig. 2, *a*. The mutual correlation function Crf1(n) of V and T fluctuations near these slow trends namely $\delta V_j = V_j - X_j$, $\delta T_j = T_j - Y_j$ determined by the formula $\mathrm{Crf1}(n) = \langle (T_{j+n} - \langle T\rangle)(V_{j+n} - \langle V\rangle)\rangle$ is presented in the Fig. 2, *b*. We see that the relationship of LSVP with SA has a quite complicated nature. So the consecutive mathematical model of relationship between the solar activity and large-scale vortical processes in the Earth atmosphere must take into account a number factors of principle like large-scale atmospheric instability triggering with the large vortices generation, the nonlinear stabilization of such instability, the perturbations dissipative decay at the end of their life cycle, the ratio between typical periods of both subsystems variability (SA and LSVP).

According to this we consider now the oscillator x(t) model allowing to explain the some observable features of mutual T(t)–W(t) correlations. The basic equation is written like this

$$d^2x/dt^2 + \nu dx/dt + \omega_0^2 x = f(t), \tag{2}$$

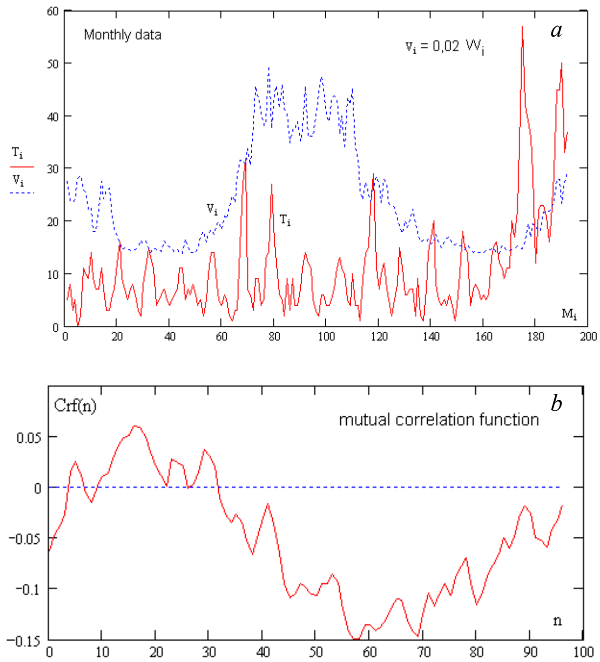


Fig. 1. Temporal behaviour of large-scale tropical disturbances number T_i over the World ocean and Wolf number W_i during period 1983–1998 years. So the year is $y_i = 1982 + M_i / 12$ where M_i is the monthy number (*a*). The mutual correlation function Crf(n) (*b*).

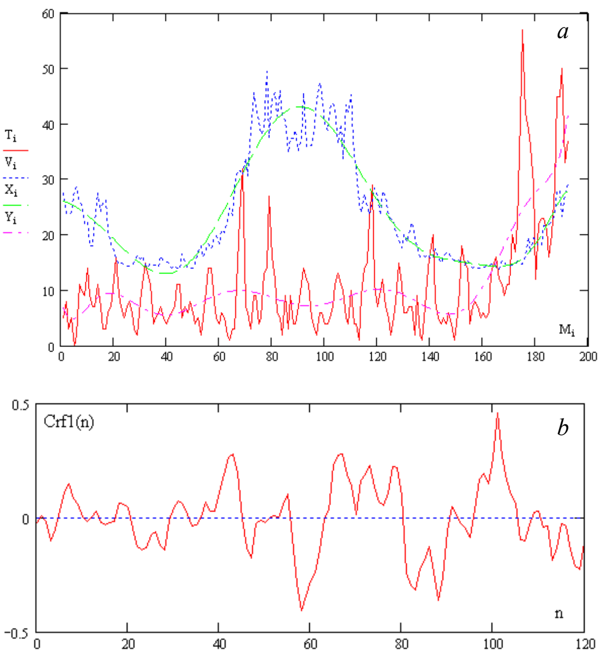


Fig. 2. Slow trends X_i, Y_i of sequences T_i, V_i (*a*). The mutual correlation function Crf1(n) for sequences ($T_i - Y_i$) and ($V_i - X_i$) (*b*).

where ν, ω_0 – are the friction coefficient and the oscillator frequency respectively. Is is supposed also that f(t)=0, x(t) = 0 for $t \le 0$. The solution of (2) is determined by the following formula

$$x(t)=(1/\omega_1) \int_0^t d\tau\, f(t-\tau)\, \exp(-\nu\tau) \sin(\omega_1\tau),\ t>0. \quad (3)$$

Here the frequency ω_1 is determined by $\omega_1^2=\omega_0^2-\nu^2$. Let us take now T to be the temporal step so t_k=Tk, where k = 0, 1 ... (N–1). From the expression (3) relationship of oscillator displacement $x_k \equiv x(t_k)$ with the external force $f_j = f(t_j)$ follows as

$$x_k = B \sum_{J=0}^{k} f_{k-j} \cdot \exp(-\delta\, j) \cdot \sin(\gamma\, j), \quad (4)$$

where the following denotes are introduced $\delta = \nu T$, $\gamma = \omega_1 T$ and $B = T/\omega_1$. For the simplest case of problem considered the external force we take as the sum of two dispersed impulses

$$f_k = A_1 \cdot D_1(k) \cdot \sin \Psi_1(k) + A_2 \cdot D_2(k) \cdot \sin \Psi_2(k),$$
$$\Psi_1(k) = \Omega_1(k-m)+\varphi_1,\ \Psi_2(k) = \Omega_2(k-s)+\varphi_2, \quad (5)$$
$$D_1(k) = 1/[1+(k-m)^2/\tau_1^2],\ D_2(k)=1/[1+(k-s)^2/\tau_2^2],$$
$$0 < m,\ s < (N-1).$$

The plots of the external force f_k and oscillations x_k excited by it are given in the Fig. 3, *a* for the following case of incoming parameters choice

$$\delta = 0.01,\ \gamma = \pi/19,\ \Omega_1 = \pi/41,\ \Omega_2 = \pi/107,$$
$$A_1 = 1,\ A_2 = 0.7,\ \tau_1 = 40,\ \tau_2 = 90,$$
$$m = 400,\ s = 990,\ \varphi_1 = 0,\ \varphi_2 = \pi/3.$$

In this case the oscillator frequency γ is significantly larger of the external force frequencies Ω_1, Ω_2 and we see the strong correlation between f(t) and x(t) behaviours.

For the intermediate case when $\gamma = \pi/95$, $\Omega_1 = \pi/41$, $\Omega_2 = \pi/107$ and unchanged other parameters, when the oscillator frequency value is placed between the external force frequencies Ω_1, Ω_2, the plots of f_k and x_k are presented in the Fig. 3, *b*. It is clearly seen from this figure that the anticorrelation of functions x_k and f_k at the time t < 700 exists. But at the time t > 700 the correlated behaviours of oscillator displacement x_k and force f_k are observed.

The case presented in the Fig. 3, *a* corresponds to the so-called noninertial approximation in the equation (2) when the following approximation takes place:

$$x(t) \approx f(t)/\omega_0^2.$$

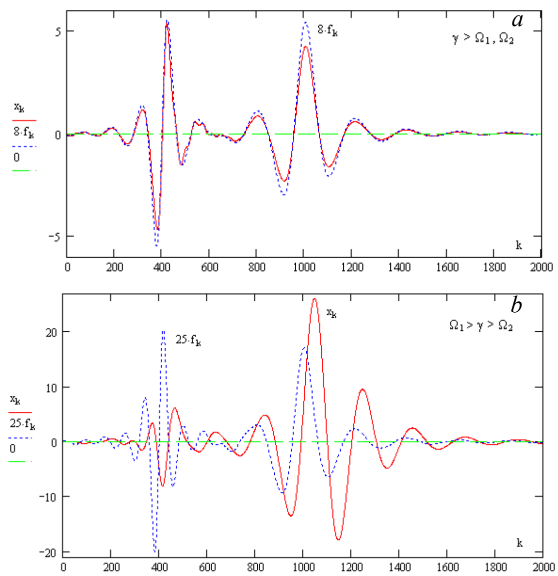


Fig. 3.

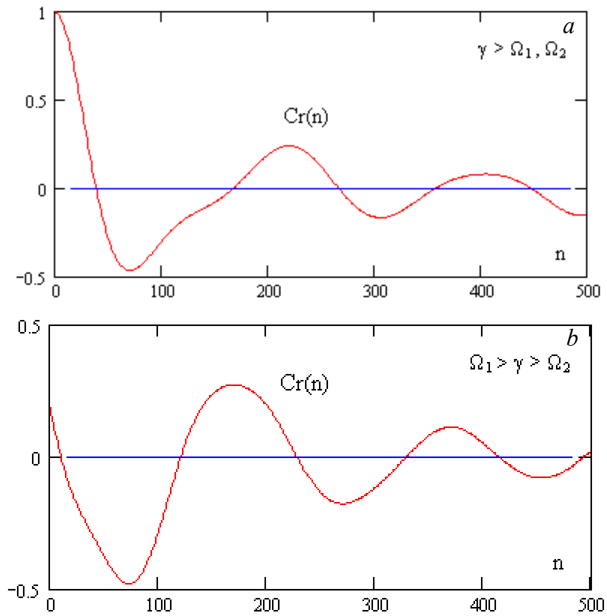


Fig. 4. The mutual correlation functions Cr(n) for the cases: $\gamma > \Omega_1$, Ω_2 (*a*); $\Omega_1 > \gamma > \Omega_2$ (*b*).

The mutual correlation functions for the both cases are shown in Fig. 4, *a* and Fig. 4, *b* respectively. Their comparison indicates that for the second case the level of mutual correlation x_k and f_k is less essentially.

Thus on the basis of the simple model considered it is possible to understand the complicated behaviour of mutual x_k, f_k correlations in the dependence on ratio between oscillator frequency and external force frequencies.

The analytical approximation of LSVP-events intensity and its phase plane

From the analysis given above it is seen the necessity to develop analytical model of LSVP-events intensity based on the differentiable functions. Such model will allows, for example, to describe correctly the phase space of LSVP-intensity and to improve our understanding of possible correlation relationships between large-scale vortical processes in the Earth atmosphere and solar activity variation, to study further the physical mechanisms of solar-terrestrial relationships realization in the large-scale atmosphere dynamics. Let us consider now (using as the example) the LSVP-intensity in the North-East part of Pacific Ocean for the August–October season of 1998 year. During this period 53 large-scale events (tropical depressions, storms and cyclons occured). Take into account that the each event with its ordering number k had the development period with its duration ε_k, the LSVP quasistationary phase $a_k \le t \le b_k$ and the decay stage with duration τ_k. The event development stage we may approximate by the following function

$$p_k(t) = 0.5\{1+(t-a_k)/[\varepsilon_k^2+(t-a_k)^2]^{1/2}\},$$

where t, a_k, b_k, ε_k – are measured in days. The decay stage of large-scale perturbation is approximated, in the analogy to given above, by the function

$$q_k(t) = 0.5\{1+(b_k-t)/[\tau_k^2+(t-b_k)^2]^{1/2}\}.$$

Therefore, the full life cycle of single LSVP-event with number k will be described by the function $f_k(t) = p_k(t)q_k(t)$,

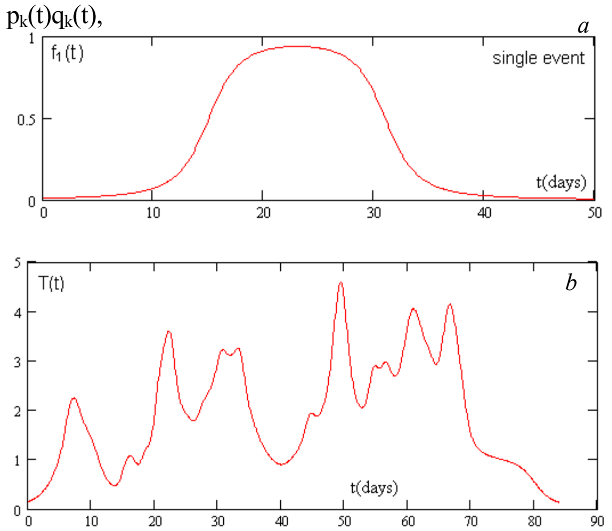
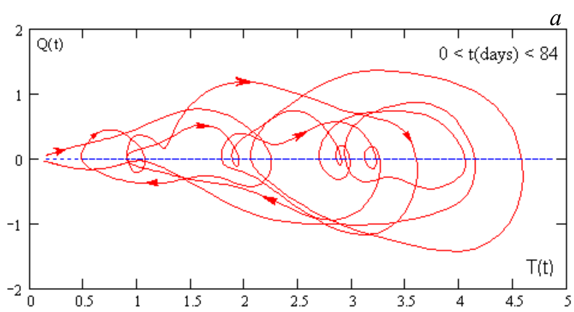


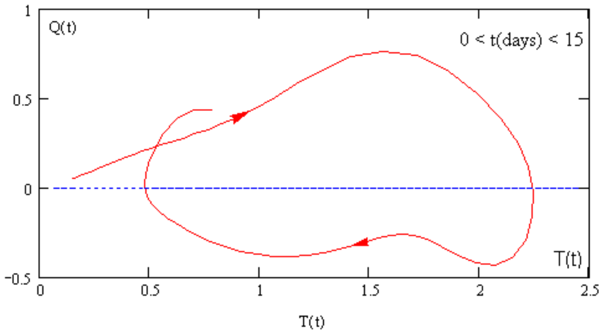
Fig. 5. The temporal profile of large-scale vertical single event (*a*). The plot of regional cyclogenesis intensity T(t) (*b*).

shown in Fig. 5, *a*. Consequently, the cyclogenesis intensity may be determined like this $T(t) = \sum_k f_k(t)$, where $1 \le k \le 53$. The plot of intensity T(t) for the choosen season is given in Fig. 5, *b*. It is important that we have now the analytical formula for LSVP-intensity in the form of differentiable functions. This allows us to study the phase plane of large-scale regional cyclogenesis (T, Q), where Q(t) = dT/dt or in the discrete form we obtain $Q_j = (T_{j+1}-T_j)/\Delta t$, where Δt–is the temporal step so $t_{j+1} = t_j+\Delta t$.

The phase plane (T_j, Q_j) is shown in the Fig. 6 for the entire season considered and in some time intervals. These figures indicate the complicated structure of phase plane studied. In particular, if we try to develop the oscillator model driven by the external force (for example, suppose $f_j = V_j$), to describe this plane then it is necessary to take into account the dissipation, the variable oscillator parameters like its frequency, a nonlinearity and so on which must determined by the background temperature, pressure, winds fields in the ocean-atmosphere system. The crite-



b



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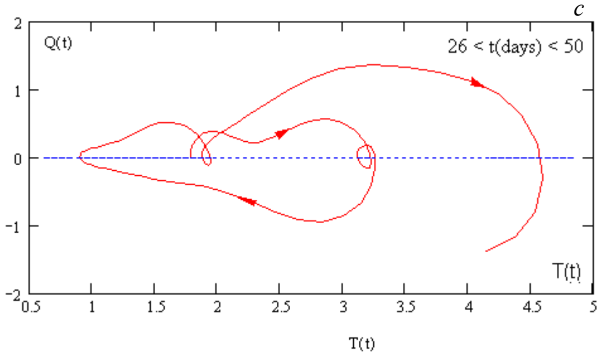

Fig. 6. The phase plane of regional cyclogenesis intensity: for the full season 0 < t (days) < 84 (*a*); for the period 0 < t (days) < 15 (*b*); for the period 26, t(days) < 50 (*c*).

rion of usefulness such model may be the correspondence of LSVP-intensity profile T(t) obtained to the experimental data existed. Such model is under development now. It is necessary to note also that besides the solar-terrestrial relationships there are other external factors influence on the LSVP in the Earth atmosphere, for example, cosmic rays.

The nonlinear model of life cycle for single LSVP event

To substantiate the analytical approximations of large-scale cyclogenesis intensity described above it is necessary to develope also simplified physico-mathematical models of life cycle of powerful atmospheric vortices like tropical cyclones (TC). It is of greate interest for a number of applications, in particular, for the analysis of solar-terrestrial relationships role in the dynamics of natural crisis processes, atmospheric electricity phenomena, for the studying of tropical cyclogenesis influence on the large-scale atmospheric circulations, for investigations of regional cyclogenesis features and for the elaborations of atmospheric crisis processes forecasting methods.

Previously the simple mathematical models based on observational data were used in [5] to calculate parameters which characterize the dynamics of tropical hurricane life cycle. In the analogy with electromagnetic radiation generation by lasers the nonlinear model of hurricane development was proposed in the paper [6]. This model takes into account the energy pumping in ocean-atmosphere system, the threshold conditions of powerful vortice forming and its interaction with the environment. The set of coupled nonlinear equations for the maximum wind velocity and the ocean surface temperature gives the realistic enough description of the hurricane development with the achievement quasistationary stage of vortice life cycle.

Below the generalization of hurricane model [6] will be done which allows to describe additionally the vortice damping stage conditioned, for example, by its displacement to the region of more cold ocean surface or its passage on the coast. To obtain this, some environmental medium parameter, which determines the condition of vortice generation, is taken by the function of time. So this parameter decreasing below its threshold value results to the vortice damping. Numerical calculations performed in the reference frame of generalized self-consistent model have shown that our model reproduces realistic enough the temporal dynamics of tropical cyclones full life cycle.

Let us go to the typhoon nonlinear model description. First of all, to take into account in the clear form the presence of instability initiating the large-scale vortice generation, we modify the equation for maximum wind velocity V(t) proposed in the paper [6], to the following one

$$dV/dt = \gamma(T - T_*)V - \sigma V^2, \tag{6}$$

where T(t) is the ocean surface temperature inside tropical cyclone, T_* is its threshold value above which the perturbations are growing and the vortice generation is occurring. The term $-\sigma \cdot V^2$ determines the vortice energy losses (conditioned by dissipative processes) which are increasing under the vortice intensity growth. It is convenient to assume that the wind velocity V, the temperature T and the current time t are measured respectively by m/sec, °C and days. So, according to the estimate [5], the typical values of parameters entering to the eq.(6) are as the following:

$\gamma \le 1$, $T_* = 26.5$, $\sigma = 3 \cdot 10^{-3}$.

The ocean surface temperature T(t) is governed by the following nonlinear equation [6]

$$dT/dt = -\beta(T - T_1)V^2 + (T_f - T)/\tau. \tag{7}$$

Here T_1 is the temperature of cold water which rises inside TC from lower layers of ocean to its surface (T_1=23), T_f is the equilibrium background temperature of ocean surface in the TC-perturbations absence (its value is determined by the heat input-output balance in the season considered), τ is the typical time of equilibrium temperature establishment. Below according to recommendations of the paper [6] it is taken τ = 10, $\beta = 3 \cdot 10^{-4}$, $T_f = (28 \div 30)$.

The hurricane damping (conditioned, for example, by its passage to the more cold water region) is modeled in eq.(7) by the choice of variable parameter, namely $T_f(t)$. In the numerical calculations the following function $T_f(t)$ was used

$$T_f(t) = T_{f1} - 0.5\delta T_f\{1 + \mathrm{th}[(t - t_1)/\tau_d]\}, \tag{8}$$

where T_{f1} is the equilibrium ocean temperature at the stages of TC forming and its following quasistationary state, t_1 determines the time of TC passage to the cold water region where the temperature decreasing is δT_f, τ_d is the typical time of TC displacement into the cold water region. Thus our nonlinear model includes additional governing parameters δT_f, τ_d, t_1.

The set of coupled nonlinear equations (6), (7) with the nonstationary background temperature (8) was solved numerically for the different choice of incoming parameters. Plotts of temporal dependence of the maximum wind velocity V(t) and the ocean surface temperature inside typhoon T(t) are given in the Fig. 7 for the time interval, when the large-scale vortice is forming, under the following choice of incoming parameters:

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

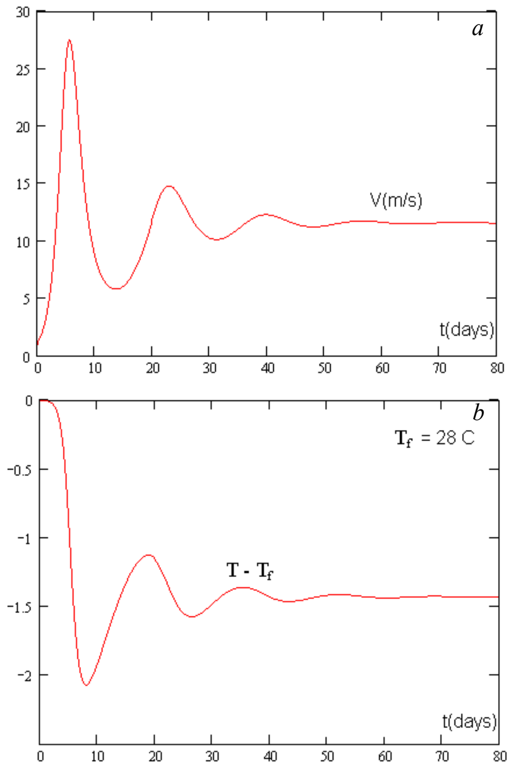

Fig. 7. Dynamics of the wind velocity *a*) and the ocean surface temperature *b*) in the forming typhoon.

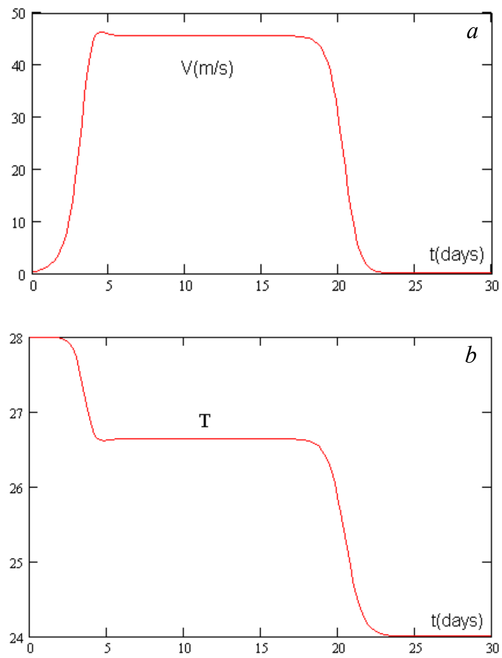

Fig. 8. The temporal dynamics of wind velocity *a*) and ocean surface temperature *b*) for the full life cycle of typhoon.

It is seen that the temporal dynamics of V(t), T(t) are quite similar to studied ones in the paper [6]. At the quasistationary stage of typhoon life cycle the value of temperature T is 26.57 °C which is slightly above the threshold magnitude $T_* = 26.5$ °C. The temporal dynamics of V(t), T(t) for the full life cycle of typhoon is shown in the Fig. 8. Calculations were performed under the following choice of incoming parameters:

$$T_{f1} = 28,\ \delta T_f = 2,\ \tau = 10,\ \gamma = 1,\ \beta = 6{\cdot}10^{-4},$$
$$\sigma = 3{\cdot}10^{-3},\ V(0) = 0.3,\ T(0) = 28,\ t_1 = 20,\ \tau_d = 1.$$

According to the Fig. 8 at the quasistationary stage of TC life cycle the wind velocity has the value $V_s = 45.63$, the ocean surface temperature decreases up to $T_s = 26.64$ °C. At the end of typhoon damping stage it is close to the value 24 °C.

It is necessary to note that by changing of system incoming parameters it is possible to govern the temporal dynamics of process considered.

Conclusions

1. It was considered the correlation relationships between the large-scale vortical processes intensity occured in the Earth atmosphere (the set on independent events) and the solar activty variations characterized by the Wolf numbers. The complicated dynamics of these correlations is explained on the basis of oscillator model under influence of the external force and the ratio between the force frequencies and oscillator one is taken into account.

2. The analytical approximation of LSVP-intensity based on the differentiable functions is developed and it is applied to the analysis of active cyclogenesis season August-October 1998 year for the North-East part of Pacific Ocean. The complicated structure of LSVP-intensity phase plane is obtained. Its approximation by the oscillator model beside the dissipation must take into account the variable system parameters like oscillator frequency and possible the system nonlinearity. The parameters variability corresponds naturally to the nonstationary background fields under LSVP-development.

3. It is proposed and substantiated the generalized nonlinear model of temporal dynamics of large-scale atmospheric vortice like a typhoon describing its full life cycle. It were performed numerical calculations the typhoon temporal dynamics. The model considered contains a number of free parameters which determine the durations of vortice forming process, its quasistationary phase and typhoon damping stage also. This model may be useful, in particular, for the analysis of large-scale regional cyclogenesis and its statistical properties, for the elaborations of typhoongenesis forecasting methods and in the studying of the solar-terrestrial relationships influence on crisis atmospheric processes.

4. The approach developed above allows to improve our understanding of the relations between large-scale crisis atmospheric processes (tropical cyclones, the thunderstorm clouds formation, atmospheric electricity

phenomena) with the various space weather factors including the mechanisms of solar-terrestrial relations influence on the atmospheric vortices.

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