APPLICATION OF THE OBJECT-RESOURCE SYSTEM DEVELOPMENT MODEL FOR EXPLANATION OF SPECIFIC FEATURES OF EVOLUTION OF A CONVECTIVE CLOUD (CONVECTIVE CELL)

G.S. Burundukov, E.I. Potapov, I.A. Garaba, S.D. Plyusnin, E.A. Zasavitsky, M.T. Abshaev*, and A.M. Abshaev*

Institute of Electronic Engineering and Industrial Technologies, Academy of Sciences of Moldova, 3/3, Academiei str., MD-2028, Chisinau, Republic of Moldova
E-mail: efim@lises.asm.md
**High Mountain Geophysical Institute of ROSHYDROMET, 2, Lenina ave., 360020, Nalchik, Kabardino-Balkaria, Russian Federation*
E-mail: abshaev@mail.ru
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In terms of the general systems theory, we consider a possibility to apply the Lotky-Volterra model that reflects behavior of the consumer-resource (object-resource) system for biological populations in description of the elements of evolution of a convective cloud (convective cell). On the basis of obtained results, a conclusion is made that the given approach may be applied for these purposes.

Introduction

One of the basic postulates of the general systems theory is the isomorphism principle; it implies that the theoretical models developed for description of a certain system may be applied, with various levels of detail, in other fields of scientific knowledge [8]. Therefore, in the present work, we have made an attempt to consider evolution of a convective cloud (convective cell) by means of the Lotky-Volterra model, which is applied for description of development of biological populations in the context of the consumer-resource system (hereinafter, object-resource system). The term "resources" in biology is understood as various sources of energy and matter that determine specific features of existence (evolution) of such "objects" as biological populations. The object-resource system is described by means of equations (1) and (2) [5, 11]

$$dR/dt = -a \cdot R \cdot M + f \cdot R', \tag{1}$$

$$dM/dt = b \cdot R \cdot M - c \cdot M, \tag{2}$$

where dR/dt and dM/dt are the temporal variation in the resource amount R in the system and the respective variation in the mass M of the object (resource consumer); a and b are the coefficients that determine the efficiency of the resource assimilation by the object; c is the specific velocity of the natural dissipation of the object; $f \cdot R'$ are the advective (and/or vergence) and transformation variations in the resource amount.

Henceforth, in the simulation experiments, it is assumed that the coefficients a, b, and c are constants - they do not vary with time and do not depend on object evolution stage. In the case of a fixed (nonrenewable) resource, the coefficient $f = 0$ and variation (decrease only) in the resource amount occurs as a result of its removal from the system by an evolving object.

In this context, a convective cloud may be formally considered as an object - consumer of the energy resource of atmosphere. In order to specify the simulation conditions, we introduce the following notions and definitions:

– *Convective cloud* is not only a process but also an object localized in space and time (for an isolated cloud), existing (evolving) due to consumption (assimilation) of certain atmosphere resource. In this aspect, a cloud is an open dissipative system that keeps itself in being due to internal and external sources of energy and matter.
– *Resource* is a moist air of the subcloud layer. Heat of phase transitions is a source of energy; condensed/sublimated vapor makes the cloud visible (registrable) allowing remote tool monitoring of its evolution. Distribution of the resource in the subcloud layer (in plan) may be qualitatively estimated according to distribution of the pseudopotential temperature (PPT) and PPT of a wet-bulb thermometer in the ground layer [6], although this does not give a comprehensive idea, with required spatial resolution (cloud scale), of the resource allowance because of low density of the net of meteorological stations (posts).
– *Ground air temperature* is a factor that determines the resource availability for a cloud (contributing/stimulating, restraining/suppressing). The cloud evolution results not only in probable precipitation but also in relative cooling of air in the ground layer (suppressing factor).
– *Simulation object* in the selected approach is the cloud-resource system [4].

1. Evolution of a cloud (object) on a finite (nonrenewable) resource

For description of evolution of a cloud, we applied the system of equations (1) and (2), which was transformed into the form of recursions ($dt = 1$ and corresponds to the iteration step)

$$R_{i+1} = R_i - a \cdot R_i \cdot M_i + f \cdot R_i^{'}, \qquad (1')$$

$$M_{i+1} = M_i + b \cdot R_i \cdot M_i - c \cdot M_i . \qquad (2')$$

Figure 1 shows two variants of evolution of the cloud-resource system that reflect variations in the object mass and resource amount in the system for various initial volumes of a fixed resource specified by the model. For the case $\mathbf{M_1}$ the initial resource amount is twice as much as in the case $\mathbf{M_2}$. The analysis of the presented results on simulation of evolution of objects (cloud) shows the following:

i) Evolution of objects may be interpreted as evolution of single-cell clouds characterized by availability of one maximum of mass of the objects for the whole period of their existence.
ii) In the initial stage the growth of object masses is close to exponent; that is, the mass growth is of “explosive” behavior. It is known that this is the mode of development for systems with positive feedback. The result obtained by the simulation is confirmed by field studies that show that there is a stage of rapid development (growth) of a convective cloud, in particular:
   – in [13, 14] the following sequence of formation of cumulonimbus clouds is described: beginning of convergence in the ground layer; appearance of first visually observed clouds; *beginning of rapid growth of clouds* and appearance of first radio echo; convergence maximum, etc.;
   – in [15], the stages of the hail-cloud evolution are described: at first *Emerging*, then *Leap Increasing*, etc.

Let us note that in the course of evolution of a real convective cloud the feedback is realized in the following established sequence: process of cloud formation → simultaneous increase in cloud flotation ability due to natural stimulation of convection at water vapor condensation → inflow of a great amount of resource (subcloud air) into the cloud → great amount of condensed vapor → again increase in flotation ability, etc. This connection with time is broken either due to depletion of the resource from the subcloud layer or due to the influence of a suppressing temperature factor (cooling of the ground air by precipitation and, as a consequence, a decrease in access to the resource).

iii) An increase in the initial amount of the resource ($\mathbf{R_1} > \mathbf{R_2}$) leads to more rapid growth of the object. Thus, the object growth rate is proportional to the resource amount in certain environment of the object.

iv) According to the rate of growth of the object at initial stages of its development, it is possible to estimate also its maximal parameters: maximum rate of growth and maximum mass that the object achieves in its evolution. This fact was experimentally confirmed in [10], where it is shown that the rate of growth of the parameters that characterize the cloud power is in direct ratio to hail hazard of a cumulonimbus cloud in the stage of its maximal development; according to the rate of growth of these parameters, one can determine a capability of the cloud transiting into the prehail state [3].

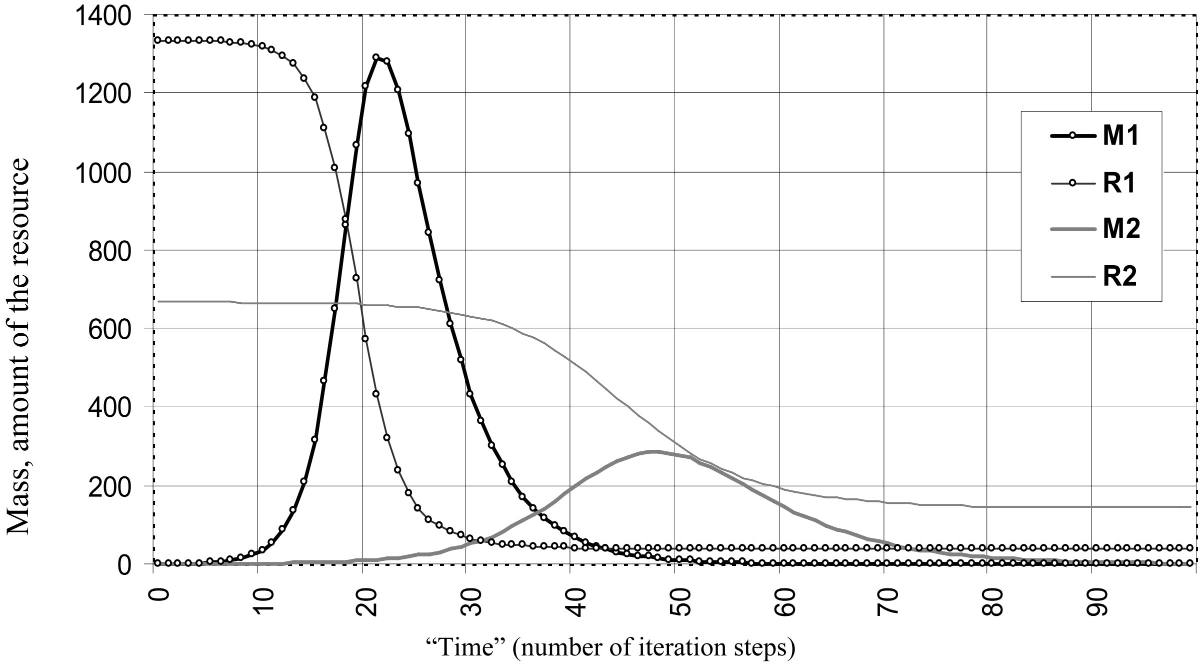

Fig. 1. Variations in masses of model objects evolving due to assimilation of a fixed (nonrenewable) resource. Vertical: the object mass **M** and the resource amount **R** (arbitrary units); horizontal: "time" (number of iteration steps).

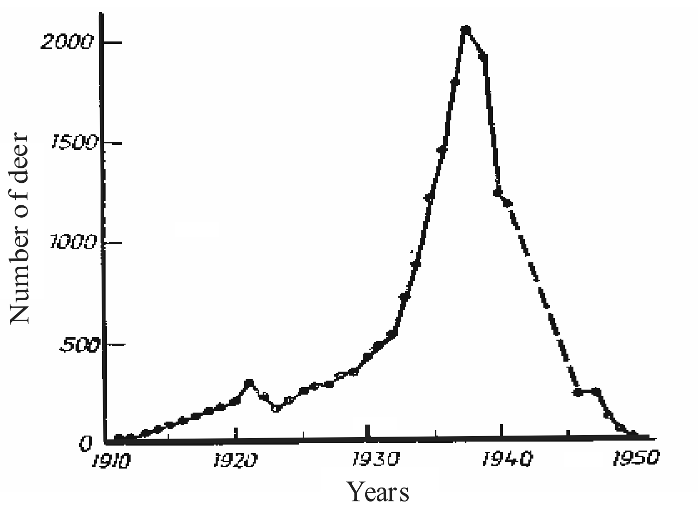

Fig. 2. Quantitative annual variations in the reindeer population at St. Paul island (Pribilof Islands, Alaska) [11].

Regularities of the evolution structure shown in Fig. 1 are also revealed in population ecology; this may count in favor of certain versatility of the exercised approach to application of the Lotky-Volterra model. Thus, Fig. 2 depicts results of an unintended experiment that demonstrate quantitative annual variations in an introduced deer population on one of the Alaska's islands [11]. The object of this example is a reindeer population (number of animal units, their total mass); the resource here is slowly reestablishing plant of the island (reindeer moss). The reindeer population failure (object dissipation) is caused by depletion of the resource reserves.

Figure 3 presents two variants of the object-resource system evolution:

i) in a specified volume of the resource, one object evolves (**M_1**);

ii) in the same volume of the resource, three simultaneously appeared objects evolve (**$M_{(2-4)}$**).

Results of the simulation experiment show that on one and the same amount of fixed resource, there may evolve either one object with greater mass and for longer time or several objects with less mass and with shorter lifetime of the complex. Experience of the long-term radar observations in hail protection in the Republic of Moldova shows that, in fact, the most intense rain storms and hail precipitate from powerful Cb (supercells), which evolve for a long time in a space being free from strong convective clouds for dozens of kilometers around. The same was found by radar observations of convective clouds in Northern Caucasia [1].

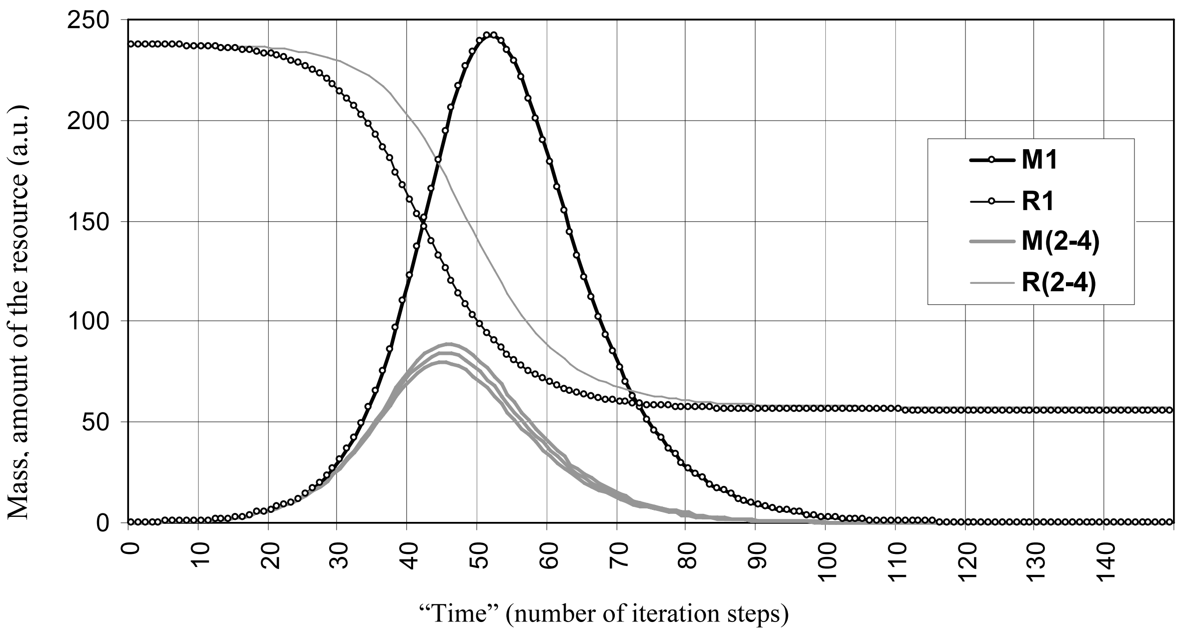

Fig. 3. Two variants of evolution of the object-resource system at identical initial amount of the resource: **M_1** - one object evolves; **$M_{(2-4)}$** - three objects evolve.

2. Evolution of a cloud (object) while moving over the field of uniformly distributed resource

The object motion, i.e., relative displacement of a cloud in the presence of wind shear in the atmosphere under the influence of steering flow (SF) over the field of immobile uniformly distributed resource, was simulated by us by means of introduction of an additional resource flow into the system (coefficient $f \rangle 0$)

$$R_{i+1} = R_i - a \cdot R_i \cdot M_i + f \cdot R_0 , \qquad (1'')$$

where (R_0) is the initial reserve of the resource in the system.

The result of the SF introduction into the model is that in certain time the object will shift into the region where the resource is not assimilated by it yet (providing the resource does not move at all or moves scantily). Two variants of the resource inflow into the system were calculated:

i) the resource removed from the system restores (in the absence of the object) up to the initial state after 100 iteration steps (per one iteration step, 1% initial resource reserve comes into the system);
ii) the resource restores after 50 iteration steps (that is, in the second variant the velocity of the object "displacement" is twice as much: $\mathbf{V_2 = 2V_1}$).

The results of calculations of variations in masses of the objects while their relative displacement over the field of uniformly distributed resource are presented in Fig. 4.

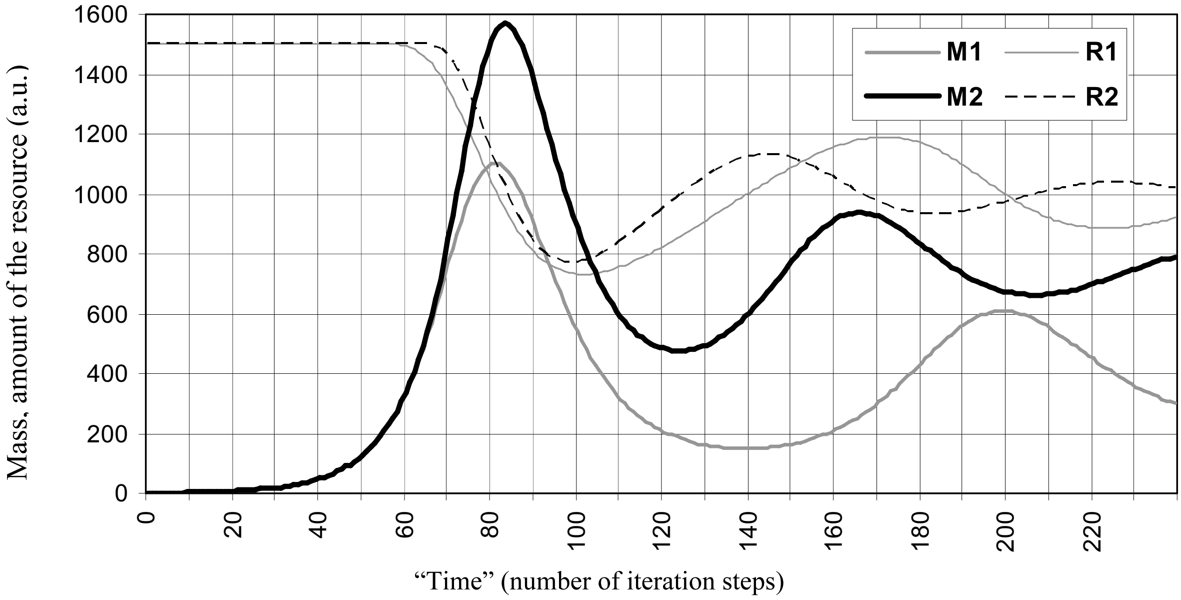

Fig. 4. Simulation of the evolving object displacement with the velocity $\mathbf{V}$ over the resource uniformly distributed in space. For the case $\mathbf{M_1}$ the velocity of the object displacement $\mathbf{V_1}$ is defined as the velocity at which the removed resource restores after 100 iteration steps. For $\mathbf{M_2}$ the resource restores after 50 iteration steps, $\mathbf{V_2 = 2 \cdot V_1}$.

Analysis of Fig. 4 has shown the following:

i) The basic specific feature of evolution of the object-resource system in the case under study is appearance of the mode of variations in object masses and amount of the resource in the system. Amplitudes of the temporal variations decrease with no change in period; constant object masses settle; amount of the resource in the system stabilizes (the figure depicts only initial stages of the system evolution). However, it is shown in [5, 11] that depending on ratio of the coefficient values in equations (1) and (2) and on type of the object trophic function (variation in the rate of resource consumption by the object depending on velocity of the resource inflow into the system), different variation modes of **M** and **R** are possible, both with amplitude decrease and increase.

Variations in the object masses ($\mathbf{M_1}$ and $\mathbf{M_2}$) are interpreted as manifestation of the time structure of the cloud with several cells: a multicell cloud with presence of several (by time) maxima of the radar-location parameters, i.e., with successive appearance of new cells and dissipation of old ones in the cloud. The phenomenon of object mass variations revealed by means of the model is similar to the temporal variations in the parameters that characterize intensity of a multicell convective cloud in its evolution; this is also confirmed by experimental studies of clouds in Northern Caucasia [1, 2]. Radar observations in Moldova have revealed different periods of appearance of new convective cells in multicell clouds: 15-25 min [7].

ii) As the resource inflow into the system increases, the absolute values of maxima in masses of the objects for the period of their development increase, as well as the frequency of variations in mass and amount of the resource in the object-resource system. The increase in the frequency of cell formation in the cloud and growth of its mass with increasing resource inflow may be interpreted as a transition of a multicell cloud into a supercell.

The velocity of the cloud motion with respect to the uniformly distributed resource in the ground layer may be determined by value of the vertical wind shear in the bottom half of troposphere. As shown in [12], with increasing vertical wind shear in the atmosphere (an increase in the relative rate of cloud displacement over the subcloud layer with the resource), intensification of cloud convection takes place.

It is shown in paper [9] that simulated precipitation falling from the fixed region of frontal clouds increase quantitatively at an increase in the velocity of their transfer (twofold at an increase in the SF velocity from 5-10 m/s to 15-20 m/s). This is an indirect confirmation of the fact that an increase in velocity of the cloud displacement leads to an increase in its parameters, in particular, mass.

Conclusions

The analysis of the results of calculation by the Lotky-Volterra model has shown that on its basis it is possible to unite heterogeneous factual materials, presented in literature by various authors, concerning observations of convective clouds, conditions of their formation, and evolution.

In the future, we plan to compare the data on evolution of convective clouds (cells) obtained by means of radar observations and the results of simulation experiments, to find predictive properties of the model with determination of range of its application, and to use the found specific features for solution of the problems of active influence on convective clouds for various purposes.

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