Constructive Modeling of Lightning Activity in Thunderstorm Front

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***Abstract*—Using the tools of constructive-synthesizing modeling, constructors of fractal time series which determine the location, magnitude and rate of damping of lighting discharges are developed. Model video images of lightning in the thunderstorm front are formed according to constructors' implementation. The adequacy of the model is verified by comparison of the model video image with the same produced by NASA satellite.**

Keywords—L-system; constrictive-synthesizing modeling; fractal; lightning activity; thunderstorm front; time series

I. INTRODUCTION

The study of patterns of spatial distribution of thunderstorms is the relevant and practically important problem for solving both the essential tasks of atmospheric electricity and lightning protection of engineering constructions and thunderstorm fire risk of forest areas. One of the sources of data on the spatial distribution of thunderstorms is WWLLN (World Wide Lightning Location Network) [1].

Lightning monitoring was performed by satellites using detectors OTD (Optical Transient Detector) and LIS (Lightning Imaging Sensor). They are recording short bursts of infrared radiation, which arise from the lightning discharge and can be seen from space even in daytime under the clouds.

The main directions of modeling and studying of lightning activity are associated with the study of spreading of currents from clouds to the ground [2], impact of lightning on electrical systems [3], isolation of zones of the lightning activity in specific geographic areas [4], and their impact on breaking-out of fires [5]. Much lesser number of works deals with the problem of modeling of lightning in the thunderstorm front, which is primarily due to its complexity. Typically, such works are limited to isolation of compact zones (clusters) of lightning formation [6].

This paper refers to modeling of lightning activity in the thunderstorm front based on the generated fractal time series which determine the time, coordinates and duration of flashes, and comparison of the model video images to video images received from the satellite.

II. CONSTRUCTIVE-SYNTHESIZING MODELING OF FRACTAL TIME SERIES

The basis of constructive-synthesizing modeling is the concept of generalized constructive-synthesizing structure [7-9], or generalized constructor (GC):

$$C = \langle M, \Sigma, \Lambda \rangle, \tag{1}$$

where M is the heterogeneous replenishable carrier, Σ is the signature of relations and relevant operations, such as linking, substitution, and inference, over attributes, Λ is the set of statements of the information support of construction (ISC) including: ontology, purpose, rules, restrictions, terms of starting and completion of construction.

Peculiarities of the constructive-synthesizing modeling are as follows [7-9]: attributiveness of elements and operations, replenishable carrier, model of performer in the form of its basic algorithms, relation of operations to the algorithms of their implementation.

Ontology of generalized constructor in its informal representation is given in [7, 8]; below we provide its part required for the subsequent presentation.

Signature Σ comprises sets of operations: Ξ – linking, Θ – substitution and inference, Φ – operations over attributes. The signature also contains the relations of substitution "$\rightarrow$".

$$\left\langle C_{TS}(\Omega_i(\mathrm{C}_{MS}),M_x,\mathrm{d}M_x,\mathrm{D}_x,\mathrm{m})=\left\langle M_{TS},\Sigma_{TS},\Lambda_{TS}\right\rangle,\right.$$
$$C_A=\left\langle M_A,\Sigma_A,\Lambda_A\right\rangle\rangle\ {}_I\mapsto$$
$$C_{A,TS}(\Omega_i(\mathrm{C}_{A,MS}),M_x,\mathrm{d}M_x,\mathrm{D}_x,\mathrm{d}D_x,\mathrm{m})=\left\langle M_{A,TS},\Sigma_{A,TS},\Lambda_{A,TS}\right\rangle.$$

III. Modeling of Lightning Activity in Thunderstorm Front

Based on the above constructors, the program modeling the lightning activity was developed.

Simulation results in comparison with the real thunderstorm, the video of which was obtained from the satellite are presented below. Fig.1 represents: frame of satellite video image (a) [11], the same with the removal of background (relief and cloudiness, b), with the flashes brought to the regular form (c), with all discharges (d).

A similar result was obtained as a result of modeling. The model of thunderstorm front is specified by Bezier curve. The pair of constructors $C_{A,MS}(f,\{f\to f+f\},200)\ {}_R\mapsto\Omega_1(C_{A,MS})$ and $C_{A,TS}(\Omega_1(C_{A,MS}),13,50,20,10,200)\ {}_R\mapsto\Omega_1(C_{A,TS})$ forms the time series of the lightning discharge position along the curve $u_S(t)=\Omega_1(C_{A,TS})$ (fig.1, e). The other pair $C_{A,MS}(yxyxy,\{x\to+xf,y\to-yf\},200)\ {}_R\mapsto\Omega_2(C_{A,MS})$ and $C_{A,TS}(\Omega_2(C_{A,MS}),9,5,20,10,200)\ {}_R\mapsto\Omega_2(C_{A,TS})$ – distance from the curve $u_L(t)=\Omega_2(C_{A,TS})$. The third pair $C_{A,MS}(--\backslash\backslash\backslash\backslash\backslash\backslash ppmyuumxmxxmpmmxmpxmff,$ $\{y\to-yf,x\to+xf,f\to ff,p\to+p,m\to-m,d\to\backslash\backslash d,$ $u\to/u\},200)\ {}_R\mapsto\Omega_3(C_{A,MS})$ and $C_{A,TS}(\Omega_3(C_{A,MS}),6,30,30,$ $15,200)\ {}_R\mapsto\Omega_3(C_{A,TS})$ – value of the discharge $u_R(t)=\Omega_3(C_{A,TS})$. According to the constructed three time series, a video is created, all discharges of which are shown in the (fig.1, f).

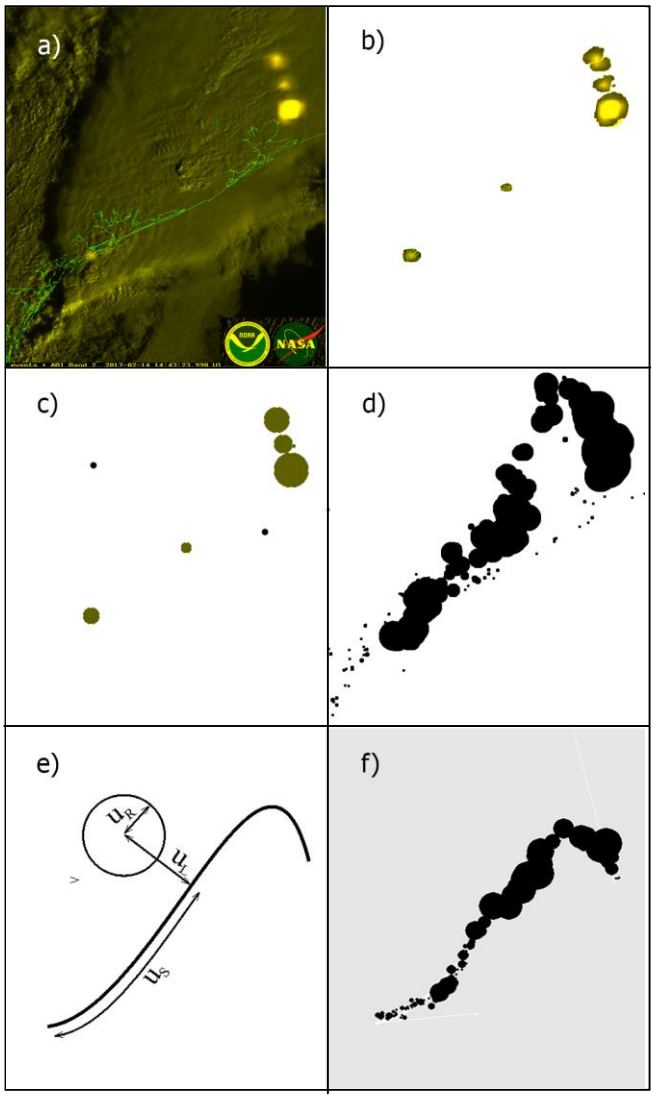

Fig. 1. Satellite and model images of thunderstorm front with lighning discharge

Conclusions

Usage of modeling in the formation of lightning discharges based on the constructive-synthesizing approach allows obtaining the realistic description of the thunderstorm front lightning activity. This approach can be the basis for solving the dynamic problem on lightning protection of engineering constructions and civil objects, and development of strategy of aircraft behavior in order to mitigate the risks of lightning strokes in the conditions of movement in the thunderstorm front.

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