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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

STOCHASTIC MATHEMATICAL MODEL OF A CHEMILUMINESCENT ARTIFICIAL CLOUD IN THE UPPER ATMOSPHERE

by

Ye. G. Slekenichs

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EDITED TRANSLATION

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ë in Russian, transliterate as yë or ë.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

STOCHASTIC MATHEMATICAL MODEL OF A CHEMILUMINESCENT ARTIFICIAL CLOUD IN THE UPPER ATMOSPHERE

[redacted]

Obninsk Branch of the Moscow Engineering Physics Institute

A prevalent method of studying the upper atmosphere today involves observing the behavior of artificial luminescent clouds in it. Specifically, observations of artificial chemiluminescent clouds allow determining the concentrations of the minor components of the atmosphere. The conduct of actual physical experiments on creating artificial luminescent clouds entails such substantial difficulties as the need for extensive preparatory work, considerable material expenditures, and complexity in processing the results. This leads to the necessity of creating mathematical models of artificial luminescent clouds that can be used in attempts to estimate the results of future experiments, ascertain the optimal conditions for conducting them, and interpret the results of past experiments.

This article examines a stochastic mathematical model of a spherical chemiluminescent cloud formed by ejection of a reagent at an altitude of over 120 km. The cloud expands under the influence of molecular diffusion.

The following simplifications are used in the model:

1. A temperature equilibrium is established between the contaminant particles of the cloud and the atmospheric constituents.

2. The diffusion coefficient is considered constant and assumed equal to the diffusion coefficient at the altitude corresponding to the center of the cloud, so that the distribution of contaminant material in the atmosphere is spherically symmetric.

3. There is no wind shear at the cloud-formation altitudes.

4. The cloud is assumed optically fine, and its brightness at the point of projection to the image plane is proportional to the total number of particles in the cloud along the line of sight.

5. Changes in the concentrations of the contaminant substance resulting from reaction with the atmosphere are small in comparison to changes in the concentration of contaminant material because of molecular diffusion.

The source of the artificial cloud's luminescence is thought to be the chemical reaction:

$$(\text{cloud})+(\text{environment})\xrightarrow{k}(\text{product})+h\nu, \qquad (1)$$

where k is the rate constant of the chemical reaction.

Thus a quantum of light is emitted because of collision between certain atoms or molecules of the cloud's contaminant material and the atmospheric components and the genesis of a chemical reaction between them. The probability of collision of reagents depends on the concentration of the cloud's contaminant material and of the atmospheric components. The concentration of contaminant particles in the cloud spreading by diffusion in our case is subject to Gauss' law and written in the form [5]

$$n(r,t)=\frac{N_0}{\pi^{3/2}(r_0^2+4Dt)^{3/2}}\exp\left(-\frac{r^2}{r_0^2+4Dt}\right). \qquad (2)$$

where r is the radial coordinate, D is the diffusion coefficient, t is time, r_0 is the initial effective radius, and N_0 is the total number of particles in the cloud.

Since the artificial cloud represents a spherically symmetric formation with a heterogeneous distribution of contaminant-material concentration by radius, but n in formula (2) depends on fixed r and t, the entire cloud is approximated by a piecewise homogeneous medium, i.e., it is divided into spherical sectors, in each of which the concentration of the contaminant material is assumed constant.

To calculate the change in the concentration of atmospheric components with altitude, we shall divide the cloud sphere into horizontal layers, in each of which the concentration of the atmospheric components is assumed constant. Then the probability of a reaction occurring and a quantum of light being emitted is written as follows for each level of all spherical sectors (Fig. 1):

$$P = \frac{K n_a n_0 P_a}{\Sigma \pi (r_i + r_j)^2 \bar{u}_{ij} n_j n_i P_j}, \qquad (3)$$

where n_a is the numerical density of the reacting atmospheric particles, n_0 is the numerical density of the reacting cloud particles; n_j and n_i are the concentrations of the atmospheric components and the contaminant material of the cloud; $\bar{u}_{ji}$ is the mean relative rate of movement of the atmospheric components and the cloud's contaminant material in its classic expression; r_j and r_i are the effective radii of the atmospheric components and the cloud's contaminant material; $P_j = \frac{n_i}{\Sigma n}$, $P_a = \frac{n_a}{\Sigma n}$ (Σn is the total concentration of all components of the atmosphere and contaminant material of the cloud).

The numerator in formula (3) represents the rate of the chemical reaction which results in the emission of a quantum of light. Each term in the denominator sum defines the number of collisions in 1 cm^3/sec between any two atmospheric components or between atmospheric components and the contaminant material of the cloud [1].

Since a chemical reaction may occur at any point in the artificial cloud, stochastic calculation methods obviously can be used to

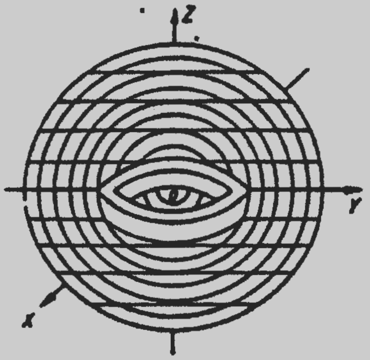

Fig. 1. Piecewise homogeneous structure of spherical cloud.

determine the point of interaction. To determine the point of interaction, we shall use the classic outline [3]

$$r = R^{3}\sqrt{\gamma_1};\ \cos\theta = 2\gamma_2 - 1;\ \varphi = 2\pi\gamma_3, \qquad (4)$$

where γ_1, γ_2, and γ_3 are random numbers with an even distribution law; R is the radius of the spherical cloud.

Further it is necessary to determine the possibility of an interaction act. The probability of such an event (we shall call it event A) depends on the distribution of the concentration of the cloud's contaminant material and of the atmospheric components (3). Random number γ, with a even distribution law, is used to model event A. We shall consider that if $\gamma < P$, event A has occurred; if $\gamma \geq P$, no event A took place. If event A did not occur, a new random point of interaction is modeled and the "draw" is repeated according to the outline indicated above. If event A did take place, the generated quantum of light is projected to the photographic image plane, then a new random point of interaction is modeled and the appearance of event A is further tested. Multiple repetition of this cycle of operations (on the order of $2.5 \cdot 10^6$) allows obtaining a qualitative pattern of the brightness of the artificial chemiluminescent cloud.

This probability algorithm was used to calculate the radiance brightness of a chemiluminescent ethylene cloud, the prototype of which was obtained experimentally [2]. An artifical ethylene cloud of spherical shape was created at an altitude of 141 km. It was a formation of two spheres, an inner and an outer, with a common center. The outer sphere expanded at a rate of 350 m/sec, the inner at 90 m/sec (Table 1).

Table 1.

(1) Сфера	(2) r_0 10^5 см	(3) R 10^5 см	(4) Δt с	(5) $D_{ср}$ $см^2/с$
Внутренняя (6)	0,93	0,93	8	$3{,}1 \cdot 10^8$
		2,00	30	
		2,30	55	
Внешняя (7)	0,93	0,93	8	$2{,}0 \cdot 10^{10}$
		7,5	18	
		14,2	30	
		20		

Key: (1) sphere; (2) r_0, 10^5 cm; (3) R, 10^5 cm; (4) Δt, sec; (5) D_{ave}, cm^2/sec; (6) inner; (7) outer.

The initial number of molecules in the cloud was taken as equal to $2.94 \cdot 10^{26}$ [2].

A cloud with these parameters was modeled in a YeS-1050 computer using the aforementioned outline. As a result, qualitative patterns of the ethylene cloud's brightness (Fig. 3) and of the concentration of ethylene in the cloud, represented as a piecewise homogeneous medium, were obtained. The values for the concentration of ethylene in the cloud, obtained experimentally and by calculation, are given in Table 2 for comparison [1].

Table 2.

(1) Радиус облака, 10^5 см	(2) Δt с	(3) $(n_{C_2H_4})_{ср}$	
		(4) эксперимент [1]	(5) расчет
7	18	$2{,}1 \cdot 10^8$	$2{,}6 \cdot 10^7$
14	30	$2{,}7 \cdot 10^7$	$1{,}0 \cdot 10^7$

Key: (1) cloud radius, 10^5 cm ; (2) Δt, sec; (3) $(n_{C_2H_4})_{ave}$; (4) experiment [1]; (5) calculation.

As Table 2 shows, the results of the calculation agree satisfactorily with the experimental data for time t=30 sec. For t=18 sec they differ by a factor of 10.

Figure 2 shows curves of change in the concentration of ethylene by radius at various points in time. It is apparent that the difference between the concentrations in the central part and at the edge of the cloud decreases during the process of cloud development, which leads to cloud homogeneity.

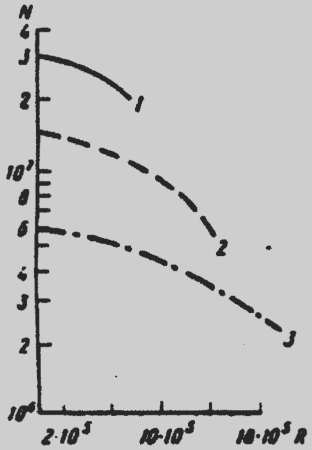

Fig. 2. Distribution of ethylene concentration along radius of cloud for various times:

1 -- t=18 sec; 2 -- t=30 sec; 3 -- t=55 sec.

Figure 3 gives a qualitative pattern of cloud brightness at various points in time, obtained using the model described above. The cloud-brightness pattern obtained from calculation corresponds to the experimental for time t=30 sec. As Table 1 shows, at times t=18 sec and t=55 sec the experimental cloud consisted of a single sphere. Patterns representing a cloud consisting of two spheres, an inner and an outer, were obtained by calculation, however, for times t=18 sec and t=55 sec.

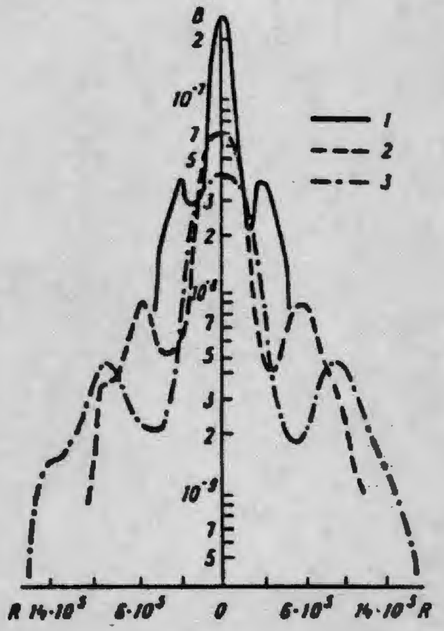

Fig. 3. Cloud brightness for various points in time:

For legend, see Fig. 2.

The suggested model can be used to obtain the qualitative and certain quantitative characteristics of chemiluminescent clouds before conducting an experiment, and can also be used to evaluate the results of experiments already conducted under different conditions.

The author expresses gratitude to the associates at the Computer Center of the Institute of Experimental Meteorology for their constant attention and assistance in the execution of calculation operations.

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[redacted]

I.c.(4) Cold Cloud (U)

~~(S/NOFORN/WNINTEL)~~ [redacted]

[redacted]

[redacted]

~~(S/NOFORN/WNINTEL)~~ There are no known towns, developed locations, or laboratories in the region of the cloud; however, the cloud appears to be the only known point source generated. [redacted]

[redacted]

~~(S)~~ Thus, only some information on the cold cloud enigma exists. It is not clear what the cloud was made of, what its purpose is, [redacted] In short, all that is absolutely known is that the cloud occurred, where and when it occurred, and that inferences can be made about its potential.

I.c.(5) Dome of Light ~~(S)~~

~~(S/NOFORN/WNINTEL)~~ [redacted] sightings of a very large dome of light have been made in counties along the [redacted] border of the Soviet Union. [redacted]

[redacted] Although reports differ, most observers describe the phenomenon as a small white sphere on the horizon that expands uniformly outward and upward while maintaining its dome-like shape. It is initially opaque, but as it expands it becomes transparent, and stars can be seen through the center of the dome. As it begins to fade, the outer boundary remains brighter forming a rainbow-shaped arc. At full extent it has been reported as being tremendously large, filling more than half of the sky. Approximate calculations [redacted] indicate it is on the order of 1,900 km wide, with its center 1,000 km high. Most Domes of Light are visible for about 20 minutes but events lasting up to 100 minutes have been reported. In almost all cases the Domes of Light have been seen while the observers were in darkness or twilight [redacted]

~~(S NOFORN WNINTEL)~~ The relationship between the Soviet SS-20 IRBM and the Dome of Light is not known, but during every known Dome of Light, there has also been an SS-20 launch at the same, or nearly the same, time. Some sightings were observed after the SS-20 launch, but on two or more occasions the Dome of Light was reported near full extent before the SS-20 was launched. The causal relation between the missile and the Dome of Light is further complicated by the fact there have been [redacted] launches for which no Dome of Light has been reported.

~~(S NOFORN WNINTEL)~~ To date, no satisfactory explanation exists that does not conflict with some portion of the reported observations. Speculations range from a naturally occurring phenomenon as a result of venting unused rocket fuel to the release of ion clouds to simulate a post-nuclear attack environment for the purpose of communication experiments. [redacted] Observations of the dispersion can then be used to calculate physical properties of the upper atmosphere such as density, temperature, and particle flow rates. These experiments differ from the reported Domes of Light observations in several respects, most importantly in appearance, size, and observed duration. The domes do not appear to contain charged particles since there is no striation or tendency for the particles to follow the magnetic field lines as in ion release experiments. Additionally, the domes are much larger and are visible for a longer period of time than any known ionization experiment. A second expla- [redacted] A Russian mathematician describes a computer model of "an ethylene cloud of spherical shape created at an altitude of 141 km." This unclassified article also states his model was the prototype of an actual experiment conducted in 1974. Unfortunately there was no discussion of any possible purpose for the experiment.

~~(S NOFORN WNINTEL)~~ [redacted].

~~(S)~~ Although the quality of the visual sitings have greatly increased our baseline knowledge of the Dome of Light, it is important that quantified observations be obtained. Spectroscopic measurements of the elements emitting the observed light would make a valuable contribution toward the final determination of the Dome of Light structure and composition.

[redacted]

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SDMEA-EM-90-17

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

ENGINEERING MEMO

SS-25 DOL FLIGHTS (U)

12 December 1990

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SS-25 DOL Flights (U)

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Chief, Performance and Analysis Branch	Chief, Missile and Space Engineering Division

TABLE OF CONTENTS (U)

ABSTRACT (U)

~~(S)~~ [redacted] when they rise during powered flight on various occasions. This phenomenology has been the center of much discussion, and various researchers have attempted to explain it with varying degrees of success. [redacted] Information not supplied in this memo includes weather data, although the environment for the simulations did use a standard atmosphere and a more-or-less physical, rotating Earth.

(U) This work was performed under TAN: ELMB.

INTRODUCTION

[redacted]

[redacted] By folding in sun and moon angular data, as well as weather data, one should be better prepared to unravel more of the DOL associated mystery.

DISCUSSION (U)

~~(S)~~ The computer model used [redacted] in this memo has been prepared to generate performance estimates of the SS-25 system for various scenarios. [redacted]

[redacted]

[redacted]

~~(S)~~ Particular information is given in APPENDIX I regarding, not only the vehicles flight path latitude, longitude and altitude histories, but also, perhaps relevant, vehicle velocity, flight path angle and azimuth. Since these simulations can forseeably be used for several different researcher's purposes, the full output capability [redacted] was used to provide outputs in a selected 10 second print interval. Upon special request, a more frequent print interval will be made available.

APPENDIX (U)

The remaining pages of this document are denied under Exp (b)(1)