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ROCHESTER UNIV NY GRADUATE SCHOOL OF MANAGEMENT
EFFORTS IN MARKOV MODELING OF WEATHER DURATIONS.(U)
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AFGL-TR-82-0074

F19628-80-C-0003
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AFGL-TR-82-0074

**EFFORTS IN MARKOV MODELING OF
WEATHER DURATIONS**

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**Final Report
1 October 1979 - 30 September 1981**

15 February 1982

Approved for public release; distribution unlimited

AD A115793

**AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSON AFB, MICHIGAN 48801**

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JUN 1 1982

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-82-0074	2. GOVT ACCESSION NO. A115793	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EFFORTS IN MARKOV MODELING OF WEATHER DURATIONS		5. TYPE OF REPORT & PERIOD COVERED Final Report 1 Oct 1979 - 30 Sept 1981
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Julian Keilson		8. CONTRACT OR GRANT NUMBER(s) F19628-80-C-0003
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Rochester Graduate School of Management Rochester, New York 14627		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 667009AG
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Monitor/Irving I. Gringorten/LYD		12. REPORT DATE February 15, 1982
		13. NUMBER OF PAGES 6
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Ornstein-Uhlenbeck Cubic B-Splines Stationary Process Gaussian-Markov Passage Time		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A portable version of the algorithm for finding the maximum of Gaussian-Markov weather variates has been obtained employing cubic B-splines. Efforts to model and predict equipment response to temperature modified by the thermal lag of the equipment are described.		

FINAL REPORT

Contract No. F19628-80-C-0003
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United States Air Force
Air Force Geophysics Laboratory
Hanscom AFB, Massachusetts 01731

In the previous contractual period, the basic objective was the distribution of the maximum of the stationary Gaussian-Markov process over an interval of specified duration. This objective was achieved and presented in the Final Report [1], "The Maximum of the Stationary Gaussian-Markov Process Over an Interval of Specified Duration." (AFGL-TR-79-0282).

Even though the desired distribution was available with great accuracy, an improved portable version of the software was requested as a simple operational tool to be used for mission planning. The portable version requested was provided [2] in Scientific Report No. 1 (AFGL-TR-81-0068), "An Algorithm for $F_0(y)$ Using Cubic B-splines", and the software needed delivered to AFGL. The B-spline approach encapsulates the basic two-parameter tables into a simpler representation form approximating the tables with great accuracy. This portable form requires only a microcomputer and gives very quick response times.

The next problem addressed was the following: Consider the temperature at a specified geographical location and specified time of year. An item of military equipment such as a bulldozer has a substantial thermal inertia which "sees" the average value of the temperature over a given period rather than the instantaneous temperature. The following question then arises. Suppose the temperature is modeled by a stationary Gaussian-Markov process $X(t)$, and suppose that the average temperature $Y_\theta(t)$ is an exponentially weighted average of $X(t)$, i.e.,

$$(1) \quad Y_\theta(t) = \int_{-\infty}^t \theta e^{-\theta(t-t')} X(t') dt' .$$

Here θ is the reciprocal of the mean response time to $X(t)$. Such exponential weighting represents fairly the thermal lag response of equipment. Then $Y_\theta(t)$ is also stationary, and it is easy to show that $EY_\theta(t) = E[X(t)]$. The long-term average equipment temperature is therefore independent of the thermal mass of the equipment.

On the other hand, the variability of the equipment temperature is reduced by the averaging and the greater the thermal inertia, the smaller is the variability. The distribution of $Y_\theta(t)$ is known to be normal, and its variance is readily available. One can show that

$$(2) \quad \text{Var}[Y_\theta] = \text{Var}[X] \frac{1}{1 + \frac{\tau_\theta}{\tau_{\text{REL}}}}$$

where $\tau_\theta = \frac{1}{\theta}$ is the mean time to thermal equilibrium of the equipment and τ_{REL} is the relaxation time of the process $X(t)$ describing the temperature at the site of interest (cf. [1]). It is clear that

$$(3) \quad \text{Var}[Y_\theta] < \text{Var } X$$

as expected. Of considerable meteorological interest is the distribution of the maximum of $Y_\theta(t)$, i.e., of

$$(4) \quad M_\theta(t) = \max_{t \leq t' \leq t+\Delta} Y_\theta(t'),$$

the counterpart with averaging of the previous maximum obtained, for which $\tau_{\text{REL}} = 0$.

To address such a problem one must examine the time-dependent behavior of the joint distribution of $X(t)$, $Y_\theta(t)$ and, in particular, one must solve the following first passage problem related thereto. One requires, as in [1], the ergodic exit time from the subset $S = \{-\infty < x < \infty, -\infty < y < Y\}$ of the state space R_2 of the joint process $X(t)$, $Y(t)$. This is a very difficult problem, for which, ideally, an analytical solution is needed as a basis for algorithmic evaluation. Despite great effort, however, such a solution has not been found. It has therefore been necessary to consider processes which approximate the desired processes $Y_\theta(t)$ and $M_\theta(t)$, and which lend themselves to algorithmic methods.

Two papers were written with this objective in mind. Both [3,4] have been submitted as Scientific Reports. The first, "Row-continuous finite Markov chains, structure and algorithms," considers a bivariate Markov chain $[J(t), N(t)]$ on a rectangular lattice of integers $N = \{(j,n); 0 \leq j \leq J, 0 \leq n \leq M\}$ which has the property of row-continuity, i.e., is such that $M(t)$ changes by at most one in any transition. Algorithmic procedures are developed to find the ergodic distribution on the chain and expected sojourn times and ergodic exit times on subsets of state space are of interest.

The second paper, "The Ehrenfest chain as an approximation to the O-U process," develops a truncated birth-death process $N(t)$ which approximates the desired process. The hope is to employ this Ehrenfest chain approximation as the marginal process $J(t)$ of a bivariate chain $[J(t), M(t)]$ in which $M(t)$ would mirror the behavior of the desired $M_\theta(t)$.

The effort continues as a dissertation study of a graduate student, even though the contract has been terminated. The algorithms provided by the row-continuous approach are burdened by the need for large values of J and M to have any accuracy. These large J, M values in turn lead to long computer run times and the feasibility of the algorithmic approach and its accuracy must be established.

Julian Keilson
Julian Keilson
Principal Investigator

Date: February 15, 1982



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