CIRA

Cooperative Institute for Research in the Atmosphere

Colorado State University
Foothills Campus
Fort Collins, Colorado 80523

Colorado State University
National Oceanic and Atmospheric Administration

CIRA

A SYNOPSIS OF ACTIVITY

SEPTEMBER 1980 - DECEMBER 1981

1st Mid-year Report

February 1982

Thomas H. Vonder Haar
Director

PREFACE

This first "mid-year" report from the Cooperative Institute for Research in the Atmosphere (CIRA) is intended to communicate scientific results and information about current activities to NOAA and CSU scientists, students and staff as well as other interested parties. Falling as it does at a report time after the first full year of CIRA operations, it thus becomes the first CIRA summary report to carry scientific information. Each year we plan to issue this mid-year report as well as an annual report from CIRA.

TABLE OF CONTENTS

* * *

COOPERATIVE INSTITUTE FOR RESEARCH IN THE ATMOSPHERE

CIRA
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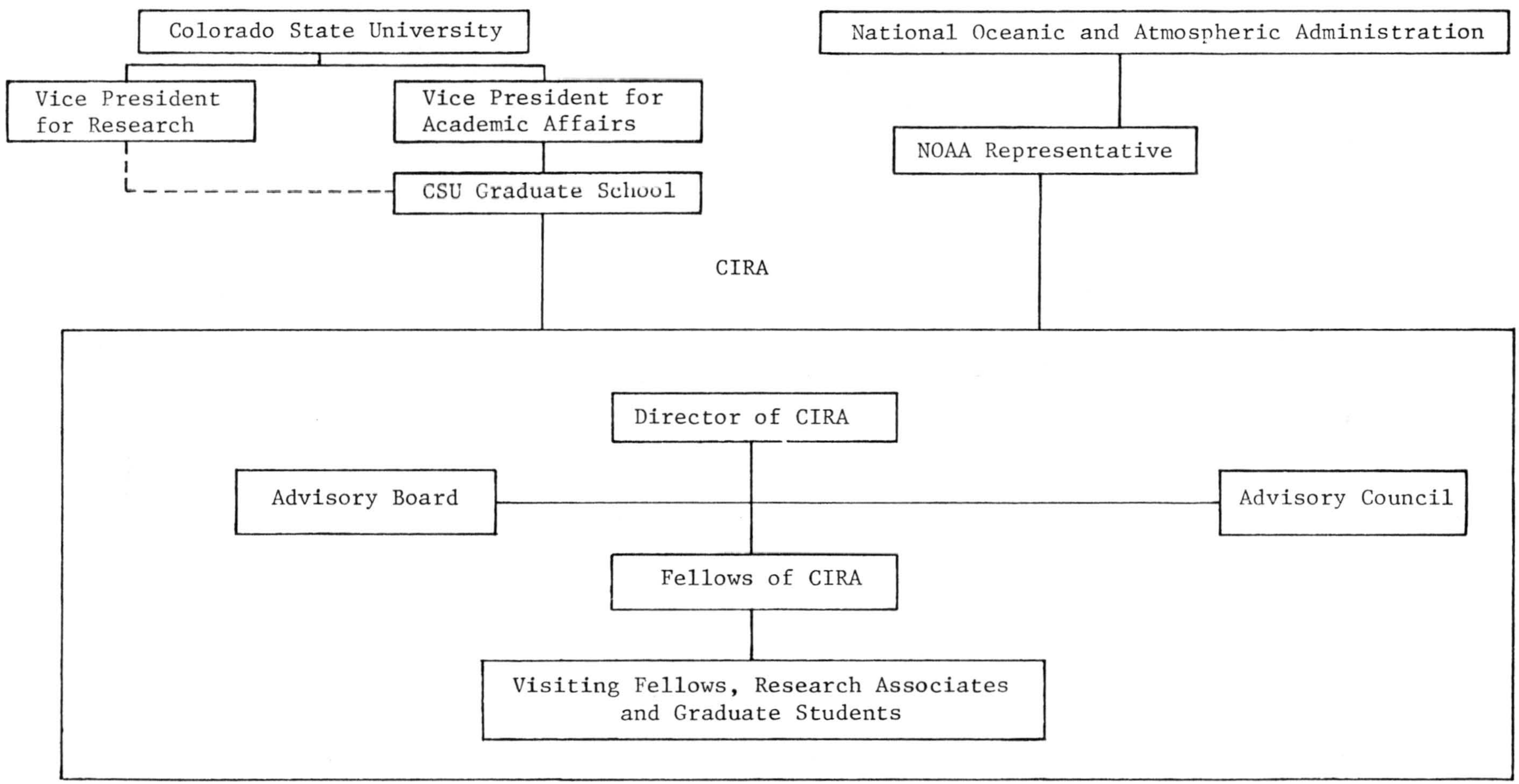
Thomas H. Vonder Haar, Director

The Cooperative Institute for Research in the Atmosphere (CIRA), under the auspices of the Office of the Vice President for Research, was formed in 1980 between CSU and the National Oceanic and Atmospheric Administration (NOAA) to increase the effectiveness of atmospheric research of mutual interest to NOAA, CSU, the state and the nation. Additional objectives are to provide a center for cooperation in specified research programs by scientists from Colorado, the nation and other countries, and to hasten the training of atmospheric scientists. All Colorado State University or NOAA organizational elements are invited to participate in the Institute's atmosphere research programs. Initial participation by NOAA has been through the Environmental Research Laboratories and the National Earth Satellite Service. At the University, the Departments of Atmospheric Science, Electrical Engineering, Economics, and Statistics are already involved in CIRA activities. As its initial research themes, the Institute has concentrated on global climate dynamics, local area weather forecasting, weather modification, and the application to meteorological field programs of a new atmospheric sounder system aboard NOAA's latest environmental monitoring satellite, GOES-4.

ORGANIZATION OF THE COOPERATIVE INSTITUTE FOR RESEARCH IN THE ATMOSPHERE



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CIRA PROJECT LISTING

September 1980 - December 1981

PRINCIPAL INVESTIGATOR(S)	TITLE	SPONSOR'S NUMBER*	DATES
L. Grant	A Design for Assessing On-going Operation Cloud Seeding Program	NA80RA-C-00017	10/1/79-3/30/81
P. Sinclair	Genesis and Development of Deep Convective Storms	NA80AA-D-00056	4/15/80-4/14/81
T. Vonder Haar/ T. Brubaker	Satellite Data Reception and Analysis Equipment and Support	NA80AA-D-00082	7/1/80-6/30/81
H. Cochrane	Estimating the Uses and Benefits Derived From PROFS	NA80RA-C-00183	8/1/80-9/30/82
T. Vonder Haar/ E. Smith	The Development of a Daytime Multispectral Radiative Signature Technique for Estimation of Rainfall from Satellites	NA80SA-C-00746	7/15/80-5/31/82
T. McKee	Surface Data Network Archives for PROFS	NA80RA-G-00201	8/1/80-5/31/82
T. Vonder Haar	Cooperative Institute for Research Visiting Members Program	NA81RA-H-00001	10/1/80-6/30/82
W. Bausch	Development of an Urban Lawn Irrigation Scheduling Program		7/1/81-6/30/82
L. Grant	Long-range Planning for Weather Modification	NA81RA-H-00001 Amendment 1; Item 2	11/1/80-3/31/82
G. Brier	Research on Statistical Techniques for Improvement on Long Range Forecasts	NA81AA-D-00039	2/1/81-7/31/83
T. Vonder Haar/ T. Brubaker	Satellite Studies & Focal Point Activities for PROFS	NA81RA-H-00001 Amendment 2; Item 4	2/1/81-9/30/82

PRINCIPAL INVESTIGATOR(S)	TITLE	SPONSOR'S NUMBER*	DATES
M. Carter	The Design of Improvements in Severe Weather Warning Programs Utilizing Concepts and Products Derived from PROFS	NA81RA-H-00001 Amendment 2; Item 3	10/1/80-10/31/82
T. Vonder Haar	Pilot Studies for the International Satellite Cloud Climatolcgy Project	NA81AA-D-00058	3/1/81-2/28/83
P. Mielke/ G. Brier	Development of Validation and Verification Techniques for Precipitation Estimation from Satellites	NA81RA-H-00001 Amendment 3; Item 5	4/1/81-4/30/82
L. Grant	Testing and Development of Ice Nucleation Materials and Generation Calibration	NA81RA-H-00001 Amendment 5; Item 7	2/1/81-9/30/82
W. Cotton	Numerical Simulation and Observational Analysis of the Dynamics Response of Towering Cumuli to Massive Seeding	NA81RA-H-00001 Amendment 4; Item 6	4/1/81-3/31/82
T. Vonder Haar	Mesoscale Research	NA81RA-H-00001 Amendment 6	8/1/81-7/31/82
T. McKee	Colorado Demonstration Intergovernmental Climate Project	NA80AA-D-00118	9/1/80-8/31/83

*To date all CIRA projects are funded by NOAA.

EXPANDED REPORTS - A SELECTION

THE DESIGN OF IMPROVEMENTS IN SEVERE WEATHER WARNING PROGRAMS UTILIZING CONCEPTS AND PRODUCTS DERIVED FROM PROFS

Dr. T. Michael Carter, CIRA Visiting Fellow

NA81RA-H-0001 Amendment 2; Item 3

10/1/80-10/31/82

ABSTRACT

The Automated Warning Data-Management System (AWADS) was designed to correct a number of serious shortcomings in the typical fan-out warning system used to relay warning messages of severe weather to local emergency service agencies. Using the underlying algorithm of AWADS, it was found that a number of related data-management problems faced by the operational forecaster could also be solved. A number of these functions have been integrated into a prototype version of AWADS, which will be operationally tested at the Denver Forecast Office of the National Weather Service during the summer of 1982.

THE AUTOMATED WARNING DATA-MANAGEMENT SYSTEM (AWADS)

When a local National Weather Service office observes a severe thunderstorm, or possibly the indication of a tornado, on their radar screen, their first responsibility is to issue a warning to local officials and the public in the affected area. In almost every case, these warnings are prepared and disseminated quickly and efficiently. But are these warnings actually received by local officials and the public? This question, among others, was the focus of a major National Science Foundation funded research project conducted by Dr. T. Michael Carter and his colleagues at the University of Minnesota.

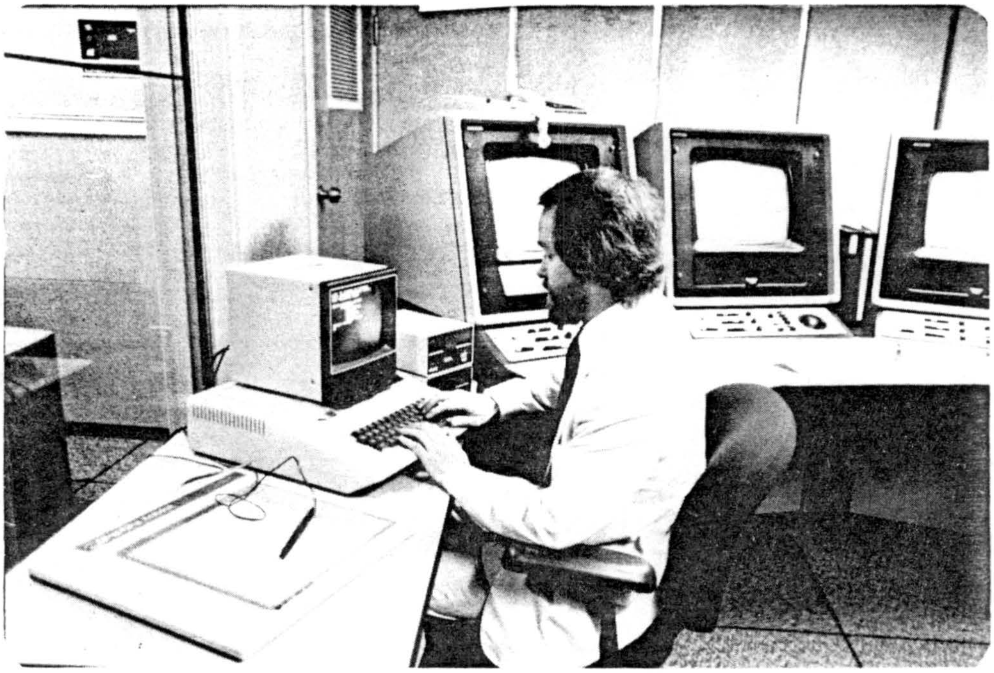
The answer was not comforting. After studying the dissemination of tornado and flash flood warnings in nine counties across the United States, it was found that an average of sixty percent of the affected emergency service agencies never received the warning issued by the National Weather Service. In exploring the reasons for this apparent widespread failure of warning systems, it was discovered that local National Weather Service offices are able to contact directly few, if any, emergency service agencies in the typical county. Instead they must rely heavily on those agencies they can contact to disseminate the warning to others--i.e., to "fan-out" the warning.

Further analysis revealed why these fan-out systems generally do not operate adequately; and, based on these analyses, four criteria which must be met in order to produce an effective fan-out warning system were developed. First, some means must be provided to identify the emergency service agencies which must be warned in each unique situation. Second, information on the interagency communication capabilities must exist in a readily available form. Third, this communication information must be analyzed to determine the optimal fan-out pattern. Finally, this optimal fan-out pattern must be reduced to a set of simple instructions which can be given to local law enforcement dispatchers. After reviewing data on a total of thirty counties nationwide, it was found that in none of these counties were these four requirements adequately met.

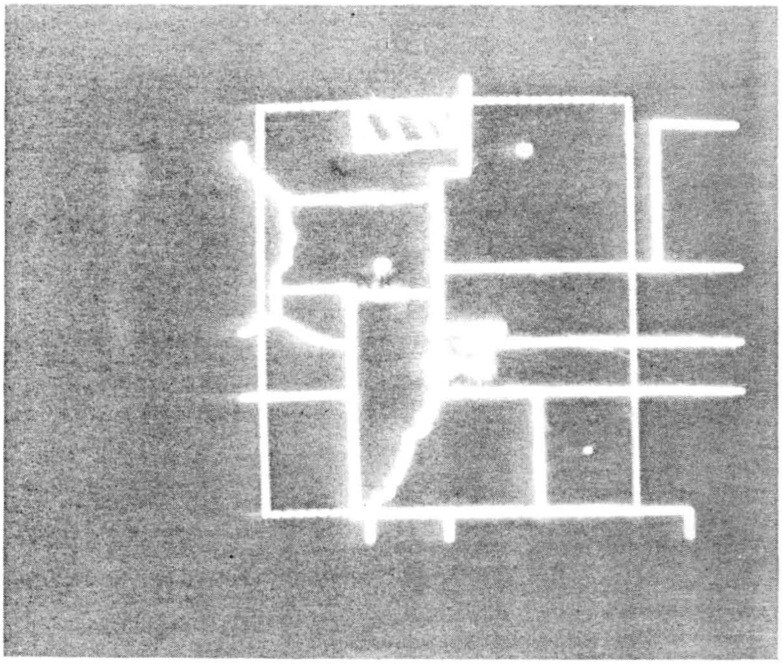
The Automated Warning Data-Management System (AWADS) is a direct outgrowth of this research. In September of 1980, Dr. Carter was brought to CIRA through a contract with the Prototype Regional Observing and Forecasting Service (PROFS) program of NOAA's Environmental Research Laboratories. The PROFS program had been given the task of focusing on the severe weather problem by the National Weather Service, and the focus of this contract was the related problem of how to increase the effectiveness of warning dissemination.

AWADS is a relatively simple data-management system--at least from the perspective of most meteorologists--since it was developed to operate on an Apple II Plus microcomputer. Using AWADS, a Weather Service forecaster can graphically outline the area he wants to warn, and the system will automatically perform each of the four tasks necessary for an effective fan-out system.

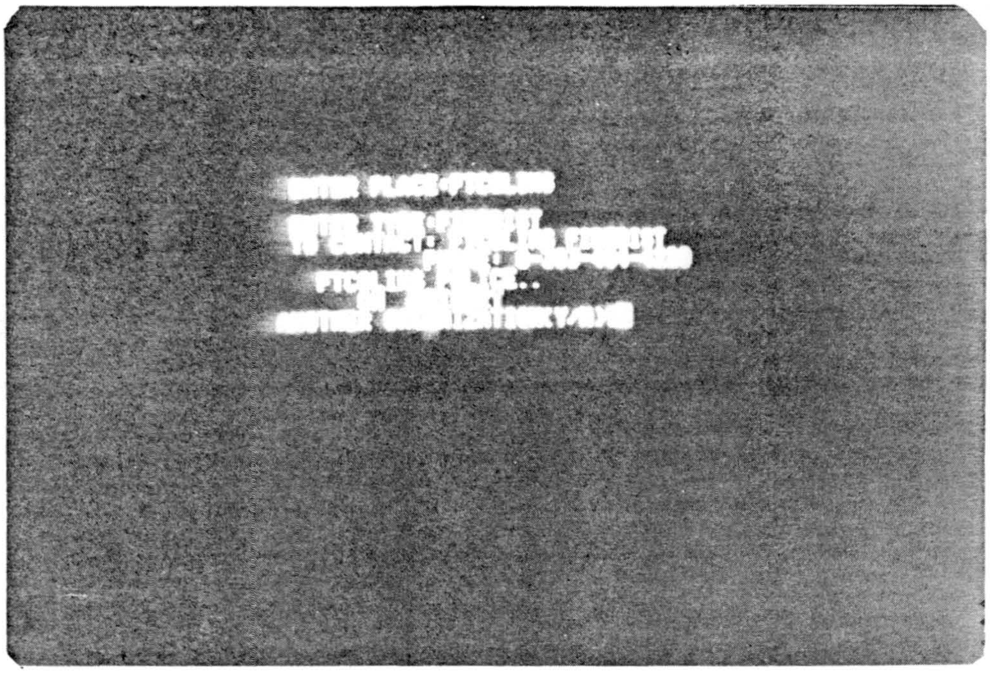
AWADS, of course, is not a magic black box. The majority of the initial development period during the past year-and-a-half has been devoted to developing the software and data bases for the system. The underlying algorithm of AWADS depends on a geographical grid system overlaid upon a Weather Service office's area of warning responsibility. By relating the operational areas of various emergency service agencies--law enforcement, fire, civil defense, and even



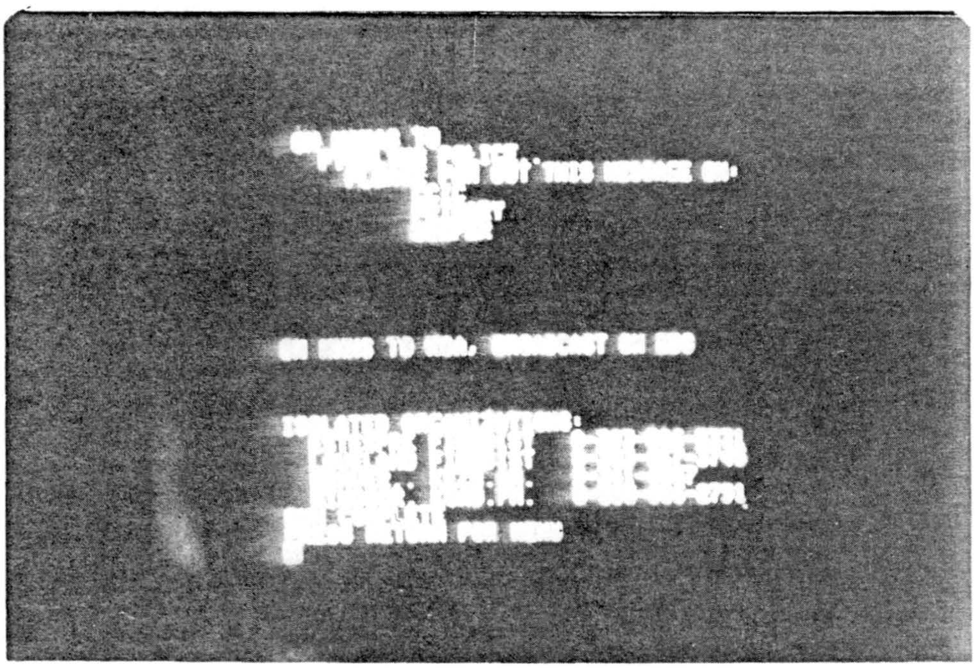
Dr. Carter demonstrating AWADS in the PROFS Forecast Office.



An area around Fort Collins is outlined for a Severe Thunderstorm Warning. The map background is produced from the National Weather Service's radar overlay.



The warning fan-out instructions produced by AWADS. The Fort Collins Police Department is the primary fan-out agency for Larimer County. Isolated organizations will not receive the warning unless they are called directly.



In the case of an emergency--e.g., a tornado report--AWADS can supply information to NWS forecasters on how to quickly contact any agency in the data base.

broadcast media stations--to this grid system, the crucial problem of how to easily identify which agencies had to be warned for each unique severe weather event was solved. Once conceived, the solution was rather simple: outline the area to be warned, determine which grid cells were contained inside the area, and sort the data base to select those agencies which operate in those grid cells.

Given that an agency's communication capabilities--two-way radio, teletype, hot-line telephone, etc.--are recorded in its data file, the remaining three tasks can be solved by rather standard matrix procedures: construct an adjacency matrix representing the communication links between the selected agencies, analyze this matrix for an optimal fan-out pattern, and produce a simple list of the communication channels to be used by each agency which disseminates the warning to others.

It soon became obvious, however, that this underlying algorithm could be used to attack a number of other data-management problems routinely encountered by Weather Service forecasters. With the appropriate data bases, for example, the forecaster could identify weather spotters in an area affected by a potential severe convective cell, or creek basins under a stationary convective cell, or towns or communities in the path of a severe thunderstorm or tornado.

These functions, and a few more to make the Weather Service forecaster's life easier, have now been integrated into a prototype version of AWADS which will undergo a thorough operational test at the Denver Weather Service Forecast Office during the summer of 1982. If the test results are successful--the crucial test is a significant reduction in the figure of sixty percent who do not receive the warnings--then the National Weather Service is committed to expanding the program to additional offices next year.

DEVELOPMENT OF VALIDATION AND VERIFICATION TECHNIQUES FOR PRECIPITATION ESTIMATION FROM SATELLITES

Dr. Paul W. Mielke, Jr. and Glenn W. Brier, CIRA Fellows

NA81RA-H-00001 Amendment 3; Item 5

4/1/81-9/30/82

ABSTRACT

Measures have been developed for comparing distinct multivariate estimates based on satellite data with corresponding estimates based on surface gauge network data and/or radar data. These measures involve a fourfold improvement over the common Pearson product-moment correlation coefficient since they (i) are capable of comparing one or more response measurements simultaneously, (ii) are able to relate two or more sets of data at once, (iii) are in correspondence with the ordinary Euclidean space rather than the incomprehensible non-metric space underlying the Pearson product-moment correlation coefficient, and (iv) involve inferences based strictly on permutational evidence, i.e., do not require absurd assumptions such as the requirement that all response measurements are obtained from a normally distributed population. The inferential techniques for these measures are analogous to recently developed multi-response permutation techniques for analyzing results of randomized block experiments (Mielke and Iyer, 1982).

DESCRIPTION AND DISCUSSION

Let $\underset{\sim}{x}'_{ir} = (x_{1ir}, \ldots, x_{cir})$ denote c response measurements (precipitation amounts) for c designated areas of a region where i identifies a particular time period (e.g., 15 minutes, hour or day) and r identifies a particular type of estimate (e.g., an estimate based on surface gauge network, radar or satellite data). If there are g time periods and b types of estimates, then the generalized measure of agreement which has been developed is given by

$$\rho = 1 - \delta/\mu_\delta$$

where

$$\delta = [n\binom{b}{2}]^{-1}\sum_{r<s}\sum_{i=1}^{g}\Delta(\underset{\sim}{x}_{ir}, \underset{\sim}{x}_{is}),$$

$\sum_{r<s}$ denotes the sum over all r and s such that $1 \le r < s \le b$, $\Delta(\underset{\sim}{x}_{ir}, \underset{\sim}{x}_{is})$ is a distance function of the differences between two types of estimates (e.g., an estimate based on surface gauge network data and an estimate based on a specific technique utilizing satellite data) for a particular time period, and μ_δ is the average value of δ for the $(g!)^{b-1}$ permutations over the g time periods within each of b-1 types of estimate (the ordered time periods of one estimate are fixed). Incidentally, if b=2, r=1, $\Delta(x_{i1}, x_{i2}) = (x_{i1} - x_{i2})^2$, and ranks replace the measurements of each type of estimate, then ρ is the well known Spearman rank correlation coefficient. As a consequence of recent concerns regarding the choice of a distance function (Mielke and Berry, 1982; Mielke _et al_., 1982; Mielke and Iyer, 1982), the choice of distance function is restricted to the ordinary Euclidean distance given by

$$\Delta(\underset{\sim}{x}_{ir}, \underset{\sim}{x}_{js}) = [\sum_{v=1}^{c}(x_{vir} - x_{vjs})^2]^{\frac{1}{2}}.$$

The statistical significance of ρ will be determined from the standardized test statistic given by

$$T = (\delta - \mu_\delta)/\sigma_\delta$$

where σ_δ is the standard deviation of δ for the $(g!)^{b-1}$ permutations over the g time periods within each of b-1 types of estimate (the ordered time periods of one estimate are fixed). The P-value associated with a realized value of T will be approximated by the Pearson type III distribution as described by Mielke et al. (1981) for a closely related class of permutation techniques termed multi-response permutation procedures (MRPP). Implementation of the Pearson type III approximation necessitates the further calculation of γ_δ, the skewness of δ for the $(g!)^{b-1}$ permutations over the g time periods within each of b-1 types of estimate (the ordered time periods of one estimate are fixed). In particular, T is presumed to follow the Pearson type III distribution with the density function given by

$$f(y) = \frac{(-2/\gamma)^{4/\gamma^2}}{\Gamma(4/\gamma^2)} [-(2+y\gamma)/\gamma]^{(4-\gamma^2)/\gamma^2} e^{-2(2+y\gamma)/\gamma^2}$$

where $-\infty < y < -2/\gamma$. If δ_0 is a realized value of δ, $T_0 = (\delta_0 - \mu_\delta)/\sigma_\delta$ and $\gamma = \gamma_\delta \leq -0.001$, then

$$P(\delta \leq \delta_0) \doteq \int_{-\infty}^{T_0} f(y)dy$$

is the approximate P-value (an approximate P-value based on the standard normal distribution is reported if $\gamma_\delta > -0.001$). The approximate P-value is evaluated with Simpson's rule over the interval $(T_0 - 9, T_0)$.

To obtain δ, T and the P-value for a realized value of δ, the determination of μ_δ, σ_δ^2 and γ_δ is essential. If $\Delta(i, r; j, s) = \Delta(\underset{\sim}{x}_{ir}, \underset{\sim}{x}_{js})$ and

$D(i, r; j, s) =$

$$\Delta(i, r; j, s) - g^{-1}\sum_{i=1}^{g}\Delta(i, r; j, s) - g^{-1}\sum_{j=1}^{g}\Delta(i, r; j, s) + g^{-2}\sum_{i=1}^{g}\sum_{j=1}^{g}\Delta(i, r; j, s),$$

then μ_δ, σ_δ^2 and γ_δ are conveniently expressed as

$$\mu_\delta = [g^2\binom{b}{2}]^{-1}\sum_{r<s}\sum_{i=1}^{g}\sum_{j=1}^{g}\Delta(i, r; j, s),$$

$$\sigma_\delta^2 = [g\binom{b}{2}]^{-2}\frac{1}{g-1}\sum_{r<s}\sum_{i=1}^{g}\sum_{j=1}^{g}[D(i, r; j, s)]^2,$$

$$\gamma_\delta = \kappa_3(\delta)/\sigma_\delta^3$$

and

$$\kappa_3(\delta) = [g\binom{b}{2}]^{-3}\frac{1}{g-1}[H(g) + L(b)]$$

where $g \geq 2$, $b \geq 2$,

$$H(g) = \begin{cases} 0 & \text{if } g = 2, \\ \frac{g}{g-2}\sum_{r<s}\sum_{i=1}^{g}\sum_{j=1}^{g}[D(i, r; j, s)]^3 & \text{if } g \geq 3, \end{cases}$$

$$L(b) = \begin{cases} 0 & \text{if } b = 2, \\ \frac{6}{g-1}\sum_{r<s<t}\sum_{i=1}^{g}\sum_{j=1}^{g}\sum_{k=1}^{g}D(i, r; j, s)D(i, r; k, t)D(j, s; k, t) & \text{if } b \geq 3; \end{cases}$$

and $\sum_{r<s<t}$ denotes the sum over all r, s and t such that $1 \leq r < s < t \leq b$. The following notation is useful for implementing a computer program to obtain μ_δ, σ_δ^2 and γ_δ. Let

$$\Delta(i, r; j, s) = \Delta(\underset{\sim}{x}_{ir}, \underset{\sim}{x}_{js}),$$

$$SJ(i, r, s) = \sum_{j=1}^{g}\Delta(i, r; j, s),$$

$$SJ2(i, r, s) = \sum_{j=1}^{g}[\Delta(i, r; j, s)]^2,$$

$$SJ3(i, r, s) = \sum_{j=1}^{g}[\Delta(i, r; j, s)]^3,$$

$$SIJ(r, s) = \sum_{i=1}^{g}SJ(i, r, s),$$

$$SIJ2(r, s) = \sum_{i=1}^{g} SJ2(i, r, s),$$

$$SIJ3(r, s) = \sum_{i=1}^{g} SJ3(i, r, s),$$

$$TJ2(i, r, s) = [SJ(i, r, s)]^2 + [SJ(i, s, r)]^2,$$

$$TJ3(i, r, s) = [SJ(i, r, s)]^3 + [SJ(i, s, r)]^3,$$

$$TIJ2(r, s) = \sum_{i=1}^{g} TJ2(i, r, s),$$

$$TIJ3(r, s) = \sum_{i=1}^{g} TJ3(i, r, s),$$

$$U(i, r; j, s) = \Delta(i, r; j, s)SJ(i, r, s)SJ(j, s, r),$$

$$UJ(i, r, s) = \sum_{j=1}^{g} U(i, r; j, s),$$

$$UIJ(r, s) = \sum_{i=1}^{g} UJ(i, r, s),$$

$$V(i, r, s) = SJ(i, r, s)SJ2(i, r, s) + SJ(i, s, r)SJ2(i, s, r),$$

$$VI(r, s) = \sum_{i=1}^{g} V(i, r, s),$$

$$W(i; r, s, t) = SJ(i, r, s)SJ(i, r, t),$$

$$WI(r, s,) = \sum_{i=1}^{g} W(i; r, s, t),$$

$$\begin{aligned} Y(i, j; r, s, t) = {} & \Delta(i, r; j, s)SJ(i, r, t)SJ(j, s, t) \\ & + \Delta(i, r; j, t)SJ(i, r, s)SJ(j, t, s) \\ & + \Delta(i, s; j, t)SJ(i, s, r)SJ(j, t, r), \end{aligned}$$

$$YJ(i; r, s, t) = \sum_{j=1}^{g} Y(i, j; r, s, t),$$

$$YIJ(r, s, t) = \sum_{i=1}^{g} YJ(i; r, s, t),$$

$$Z(i, j, k; r, s, t) = \Delta(i, r; j, s)\Delta(i, r; k, t)\Delta(j, s; k, t),$$

$$ZK(i, j; r, s, t) = \sum_{k=1}^{g} Z(i, j, k; r, s, t),$$

$$ZJK(i; r, s, t) = \sum_{j=1}^{g} ZK(i, j; r, s, t),$$

and

$$ZIJK(r, s, t) = \sum_{i=1}^{g} ZJK(i; r, s, t).$$

Then μ_δ, σ_δ^2 and γ_δ are given by

$$\mu_\delta = [g^2\tbinom{b}{2}]^{-1}\sum_{r<s} SIJ(r, s),$$

$$\begin{aligned} \sigma_\delta^2 = [g^2\tbinom{b}{2}]^{-2}\frac{1}{g-1} \sum_{r<s}\{ & [SIJ(r, s)]^2 - gTIJ2(r, s) \\ & + g^2 SIJ2(r, s)\}, \end{aligned}$$

$$\gamma_\delta = \kappa_3(\delta)/\sigma_\delta^3,$$

and

$$\kappa_3(\delta) = [g^2\binom{b}{2}]^{-3}\frac{1}{g-1}\Big[\frac{1}{g-2}\sum_{r<s}\{4[SIJ(r, s)]^3$$
$$- 6gSIJ(r, s)TIJ2(r, s) + 6g^2UIJ(r, s)$$
$$+ 2g^2TIJ3(r, s) + 3g^2SIJ(r, s)SIJ2(r, s)$$
$$- 3g^3VI(r, s) + g^4SIJ3(r, s)\}$$
$$- \frac{6}{g-1}\sum_{r<s<t}\{SIJ(r, s)SIJ(r, t)SIJ(s, t)$$
$$- g[SIJ(s, t)WI(r, s, t) + SIJ(r, t)WI(s, r, t)$$
$$+ SIJ(r, s)WI(t, r, s)] + g^2YIJ(r, s, t)$$
$$- g^3ZIJK(r, s, t)\}\Big].$$

A value of ρ which is close to one (1) indicates that the estimates are in good agreement whereas a value of ρ which is near zero (0) indicates that the estimates are not in agreement with one another. However, a statistical inference concerning the significance of ρ (like the Pearson product-moment correlation coefficient) requires the evaluation of a corresponding P-value. Thus, if the estimates of two or more distinct satellite techniques are individually compared with an estimate based on the same surface gauge network data (i.e., b=2), then the estimate of the satellite technique that yields the smaller P-value is designated the better estimate relative to the empirical evidence. It should be mentioned that the value of $(g!)^{b-1}$ should be fairly large (perhaps no less than 10^8) when serious comparisons are made. A feature worth noting is that the value of c (the number of response measurements observed) has no effect on $(g!)^{b-1}$. This is simply because one multi-response measurement (c values) is associated with each estimate for each time period (i.e., one point in a c-dimensional Euclidean space). However, if more estimates (b) are compared at a time, then $(g!)^{b-1}$ can be made substantially larger. For example, if the estimates of two or more distinct satellite techniques are individually compared with two estimates (e.g., one based on surface gauge network data and the other based on radar data), then b=3 would be involved. In this instance ρ would be a measure of agreement between three distinct estimates. Table 1 presents values of $(g!)^{b-1}$ for representative values of b and g.

Table 1. Values of $(g!)^{b-1}$.

b	g	$(g!)^{b-1}$
2	6	7.2×10^{2}
2	12	4.8×10^{8}
2	18	6.4×10^{15}
2	24	6.2×10^{23}
2	30	2.7×10^{32}
3	6	5.2×10^{5}
3	12	2.3×10^{17}
3	18	4.1×10^{31}
3	24	3.8×10^{47}
3	30	7.0×10^{64}

In addition to only comparing estimates based on satellite techniques with estimates based on surface gauge network data and/or radar data, it would be informative to compare estimates based on surface gauge network data with estimates based on radar data.

The measures of agreement introduced here provide a general technique that is applicable to a wide variety of similar problems. The fourfold improvement described in the Abstract for these new measures of agreement over commonly used measures (e.g., the Pearson product-moment correlation coefficient) indicates the potential use of these new measures. The measures of agreement required for the present comparisons of distinct estimates based on satellite techniques with estimates based on surface gauge network data and/or radar data did not previously exist. As a consequence, comparisons with previously existing techniques for the multivariate questions described here will be impossible. This feature further emphasizes the potential of these new measures of agreement for a multitude of other similar problems which are routinely encountered and simply not analyzed in an appropriate manner.

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LONG-RANGE PLANNING FOR WEATHER MODIFICATION

Professor Lewis O. Grant, CIRA Fellow
NA81RA-H-00001 Amendment 1; Item 2
11/1/80-3/31/82

INTRODUCTION

This is a brief letter-type progress report on the program of "Long-Range Planning for Weather Modification." The next section briefly summarizes the efforts to date. The last section briefly summarizes some of the tentative conclusions.

PROGRAM ACTIVITIES

A five-day workshop was held from April 11-15, 1981. This was attended by the following scientists, all of whom have extensive weather modification related experience: Dr. William Cotton (Colorado State University), Dr. Abraham Gagin (The Hebrew University of Jerusalem), Prof. Lewis Grant (Colorado State University), Dr. Paul Mielke (Colorado State University), Dr. Harold Orville (South Dakota School of Mines and Technology), Dr. Larry Davis (Colorado International Corporation), Mr. Robert Elliott (North American Weather Consultants), and Prof. Ray J. Davis (University of Arizona). A strong concensus was reached by the workshop attendees as to the components and priorities that should be included in a long-term, national weather modification program.

Working papers prepared at the workshop have been used to develop a first rough draft for a proposed national long-range plan of weather modification research. This first rough draft will be reviewed, modified, and refined by individual members of the working group. A reworked draft will then serve as a working document for a second workshop of the participants to be held later this fall. This workshop will provide an opportunity for reconsidering each of the conclusions, filling in details, and refining the text. The present draft has sections dealing with each of the following topics:

1. Rationale and purpose for a long-term weather modification research plan.
2. Goals for long-term weather modification research.
3. Research components for a long-term program.
4. Sequence for program development.
5. Societal considerations.
6. Resources requirements
    a. Scientists
    b. Laboratories
    c. Modeling
    d. Field equipment and instrumentation.
7. Issues for NOAA.
8. Differences and similarities to other plans for weather modification.

SOME TENTATIVE CONCLUSIONS

Tentative conclusions are listed below. These are very preliminary and are incomplete, both as to topics covered and specific details.

1. Problem focused research, as well as basic research, will be needed to make weather modification a viable, appropriate technology to address societal problems and minimize societal disbenefits.

2. Focused research will be needed to:

   a. Resolve key scientific questions.

   b. Provide models that can be used to facilitate field testing of the technology and ultimately serve to guide operational programs.

   c. Develop appropriate and efficient treatment and management systems that can be utilized in good field experiments and ultimately in operational programs.

   d. Conduct exploratory experiments to test specific hypothesis related to differing cloud systems.

   e. Conduct confirmatory experiments to verify, with a high degree of confidence, the finding of the exploratory experiments.

   f. Develop efficient application and assessment procedures for subsequent operational (non-research) type programs.

3. During the past ten years scientists have been trained, instrument systems have been developed for making the appropriate observations, and modeling approaches have been formulated for organizing all the complex variables. These developments will permit the conduct of the required focused research with a high degree of confidence of success.

4. Priority programs of focused research as seen by this group have been identified. For each type of weather modification, the priorities were established based on the following considerations:

a. Scientific feasibility

b. Technical feasibility

c. Definitions of research required

d. Specifications of the resources required to do the research

e. Considerations of the potential value of doing the research

f. Considerations of the social acceptability of each type of weather modification capability.

5. The highest priority of focused weather modification research should be on programs to augment precipitation.

A middle level of priority should be placed on focused research programs of radiation and visibility management.

The lowest priority for focused research in the initial stages of a long-term national program should be related to severe weather reduction and the modification of meso and synoptic scale weather systems. In these areas, considerably more basic research will be required before great emphasis is placed on focused research.

6. The general priority order for focused research being considered is listed below according to the type of modification involved:

a. Precipitation management from winter season orographic clouds.

b. Precipitation management from winter season rain and snow bands.

c. Precipitation management from summer convective cloud systems.

d. Clearing of wintertime stratus cloud cover.

e. Precipitation augmentation from wintertime stratiform clouds.

f. Clearing of supercooled fogs.

g. Clearing of warm fogs.

h. Precipitation management by modification of surface albedo.

i. Reduction in severe weather damage such as hail, lightning, etc.

j. Modification of large-scale weather systems, tropical or extra-tropical.

7. A significant NOAA issue concerns the agency's interest in pursuing research focused to the solution of specific problems of societal concern. NOAA's position in the Department of Commerce, and its relation to the National Weather Service, could include such a societally relevant role. If such focused research is not accepted as a role for NOAA, the research program at NOAA should be clearly defined and developed along basic research lines that could support focused research in other agencies.