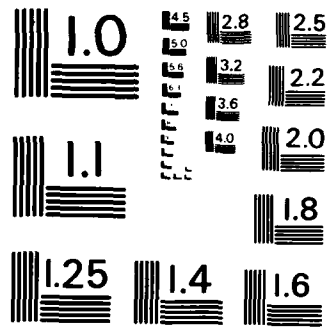END
FILMED
DTIC

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS - 1963 - A

US Army Corps
of Engineers

AD-A160 615

MILITARY HYDROLOGY

Report 8

FEASIBILITY OF UTILIZING SATELLITE AND RADAR DATA IN HYDROLOGIC FORECASTING

by

Bruce T. Miers

US Army Atmospheric Sciences Laboratory
White Sands Missile Range, New Mexico 88002

and

George L. Huebner

Texas A&M University
College Station, Texas 77843

DTIC
ELECTE
OCT 2 9 1985
S   D
A

Report 8 of a Series

September 1985

DTIC FILE COPY

MILITARY HYDROLOGY REPORTS

Report No.	No. in Series	Title	Date
TR EL-79-2	–	Proceedings of the Military Hydrology Workshop, 17-19 May 1978, Vicksburg, Mississippi	May 1979
MP EL-79-6 (Military Hydrology Series)	1	Status and Research Requirements	Dec 1979
	2	Formulation of a Conceptual Concept for Streamflow Prediction Capability	Jul 1980
	3	A Review of Army Doctrine on Military Hydrology	Jun 1981
	4	Evaluation of an Automated Water Data Base for Support to the Rapid Deployment Joint Task Force (RDJTF)	Nov 1981
	5	A Quantitative Summary of Groundwater Yield, Depth, and Quality Data for Selected Mideast Areas (U)	Mar 1982
	6	Assessment of Two Currently Exploitable Geophysical Methods for Military Ground-Water Detection	Oct 1984
	7	A Statistical Summary of Ground-Water Yield, Depth, and Quality Data for Selected Areas in the CENTCOM Theatre of Operations (U)	Oct 1984
	8	Feasibility of Using Satellite and Radar Data in Hydrologic Forecasting	Sep 1985
	9	State-of-the-Art Review and Annotated Bibliography of Dam Breach Forecasting	Feb 1985
Unnumbered		Proceedings of the Ground Water Detection Workshop, 12-14 January 1982, Vicksburg, Mississippi	Dec 1984

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper EL-79-6	2. GOVT ACCESSION NO. AD-A160 615	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MILITARY HYDROLOGY; Report 8, FEASIBILITY OF UTILIZING SATELLITE AND RADAR DATA IN HYDROLOGIC FORECASTING		5. TYPE OF REPORT & PERIOD COVERED Report 8 of a series
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Bruce T. Miers George L. Huebner		8. CONTRACT OR GRANT NUMBER(s) Intra-Army Order for Reimbursable Services No. WES-81-71
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Atmospheric Sciences Laboratory White Sands Missile Range, New Mexico 88002 and Texas A&M University College Station, Texas 77843		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project No. 4A762719AT40 Task Area B0, Work Unit 042
11. CONTROLLING OFFICE NAME AND ADDRESS DEPARTMENT OF THE ARMY US Army Corps of Engineers Washington, DC 20314-1000		12. REPORT DATE September 1985
		13. NUMBER OF PAGES 65
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) US Army Engineer Waterways Experiment Station Environmental Laboratory PO Box 631, Vicksburg, Mississippi 39180-0631		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

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The army that has the capability of predicting hydrologic conditions throughout the battlefield area would have a tactical advantage on both offense and defense. Such a capability, though, is dependent on a means for accurately monitoring and forecasting precipitation, the dominant driving element for dynamic hydrologic phenomena such as soil moisture and streamflow.

(Continued)

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

20.   ABSTRACT (Continued).

In the context of a tactical environment with its associated constraints, the potential utility of satellites and radars was evaluated. It was concluded that, in the 1980s time frame, only the weather radar can provide rainfall estimates meeting requirements of the military hydrologist.

Common components and operational characteristics of existing radar systems are discussed, and a set of general specifications for a tactical weather radar system is included.

PREFACE

Work for this report was conducted for the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., under Intra-Army Order for Reimbursable Services No. WES-81-71, Department of the Army Project No. 4A762719AT40, "Mobility and Weapons Effects Technology," Task Area BO, "Military Hydrology," Work Unit 042, "Integration of Intelligence Data into Hydrologic Forecast Procedures." The study was sponsored by the Assistant Chief of Engineers, Office, Chief of Engineers (OCE). Mr. Walter M. Swain and Dr. Clemens A. Meyer were Technical Monitors for OCE during the conduct of the study and preparation of this report.

The study was conducted by the US Army Atmospheric Sciences Laboratory (ASL), White Sands Missile Range, N. Mex., during the period of 8 June through 31 December 1981. Mr. Bruce T. Miers, ASL, and Dr. George L. Huebner, Texas A&M University, College Station, Tex., wrote the report. Drs. Colleen A. Leary, Texas Tech University, Lubbock, Tex., and Vernon T. Rhyne, Texas A&M University, also contributed significantly to the effort.

The contract was monitored at WES by Mr. John G. Collins, Environmental Constraints Group (ECG), Environmental Systems Division (ESD), Environmental Laboratory (EL), and Mr. Malcolm Keown, Chief, ECG, under the general supervision of Dr. Lewis E. Link, Chief, ESD, and Dr. John Harrison, Chief, EL.

During the preparation of this report, COL Tilford C. Creel, CE, and COL Robert C. Lee, CE, were Commanders and Directors of WES and Mr. F. R. Brown was Technical Director. At the time of publication, COL Allen F. Grum, USA, was Director and Dr. Robert W. Whalin was Technical Director.

This report should be cited as follows:

Miers, B. T., and Huebner, G. L. 1985. "Military Hydrology; Report 8, Feasibility of Utilizing Satellite and Radar Data in Hydrologic Forecasting," Miscellaneous Paper EL-79-6, prepared by US Army Atmospheric Sciences Laboratory, White Sands Missile Range, N. Mex., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

QUALITY
INSPECTED
4

CONTENTS

MILITARY HYDROLOGY

FEASIBILITY OF UTILIZING SATELLITE AND RADAR DATA IN HYDROLOGIC FORECASTING

PART I: INTRODUCTION

1. Under the Meteorological/Environmental Plan for Action, Phase II, approved for implementation on 26 January 1983, the US Army Corps of Engineers (USACE) has been tasked to implement a Research, Development, Testing, and Evaluation program that will: (a) provide the Army with environmental effects information needed to operate in a realistic battlefield environment, and (b) provide the Army with the capability for near-real time environmental effects assessment on military materiel and operations in combat. In response to this tasking, the Directorate for Research and Development, USACE, initiated the AirLand Battlefield Environment (ALBE) Thrust program. This new initiative will develop the technologies to provide the field Army with the operational capability to perform and exploit battlefield effects assessments for tactical advantage.

2. Military hydrology, one facet of the ALBE Thrust, is a specialized field of study that deals with the effects of surface and subsurface water on planning and conducting military operations. In 1977, the Office, Chief of Engineers, approved a military hydrology research program; management responsibility was subsequently assigned to the Environmental Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

3. The objective of military hydrology research is to develop an improved hydrologic capability for the Armed Forces with emphasis on applications in the tactical environment. To meet this overall objective, research is being conducted in four areas: (a) weather-hydrology interactions, (b) state of the ground, (c) streamflow, and (d) water supply.

4. Previously published Military Hydrology reports are listed inside the front cover. This report is the first which contributes solely to the weather-hydrology interactions research study area. The study area is oriented primarily toward the development of procedures for reducing the time required for obtaining and processing environmental data and using these data in making hydrologic forecasts in tactical environments. Although emphasis is

3

to be initially focused on the remote acquisition and subsequent processing of weather information, a comparable effort will be placed on terrain information in future years.

5. Under modern battlefield concepts, the ability to maneuver is essential; therefore, soil moisture and streamflow are important parameters in the intelligence preparation of the battlefield. The terrain team is the Army unit responsible for hydrologic data collection, interpretation, and analysis. To meet the requirements of today's Army, these terrain teams need equipment that is highly mobile and analysis techniques that are substantially automated, rapid, and accurate. Furthermore, results must be easily transmittable to and understandable by the battlefield commander.

6. Precipitation is the dominant driving element for most hydrologic phenomena of military significance. For the purpose of nowcasting hydrologic conditions in this area of operation and adjacent or nearby enemy held areas, the data of most interest to the military hydrologist are precipitation types and average amounts that occur over computational areas and time intervals. Often variability in precipitation is so great that instantaneous point values have little relation to the averaged values. It is also of significance to know where there is no precipitation. For short-term forecasting purposes, data on storm morphology, direction of movement, and rate of movement are required in addition to the data cited above.

7. Currently, there are three methods of estimating precipitation: through the use of rain gages, meteorological radars, and meteorological satellites. These methods and their attendant strengths and limitations with respect to military hydrology applications are the central topics of Part II of this report. The current status of meteorological support to military hydrology is discussed in Part III. Part IV is devoted to meteorological radar systems; specific topics addressed are common components and operational characteristics of existing radars. Part V presents specifications for a proposed ground-based mobile system to support Army Terrain team hydrologic functions.

PART II: METHODS OF RAINFALL MEASUREMENT

8. Accurate measurement of precipitation is an important but elusive
problem in military hydrology. Current techniques of measuring rainfall in-
clude the use of rain gages, weather radars, and meteorological satellites.
Of these the military is currently using only rain gages. The three tech-
niques and the representativeness of rainfall measurements made from them are
addressed in the following paragraphs.

Rain Gages

9. Rain gages are costly, troublesome, and time-consuming devices to
use. Furthermore, it should be noted that resultant precipitation values are
estimates, not exact measurements. Errors in the catch of a rain gage are due
to site location, gage height, large- and small-scale turbulences in air flow,
splash-in, and evaporation. Falling snow is particularly subject to wind ef-
fects which can result in underrepresentation of the true amount by 50 percent
or more.

10. Despite these problems, rain gages are known to present reasonably
accurate estimates of point rainfall except in very small time periods
(≤ 1 min) and areas (less than gage spacing). Huff (1970, 1971) indicated that
networks consisting of many rain gages accurately sample areal rainfall
amounts. In Illinois he investigated the accuracy of convective rainfall mea-
surements using networks of 49 gages in 100- and 1,500-km^2 areas. He compared
mean rainfall estimates on the basis of varying gage densities, measurement
periods, network areas, and precipitation intensities. His results were
summarized by a regression equation which indicated that the relative errors
in mean areal rainfall estimates increase with a decrease in gage density,
precipitation amount, or storm duration. He also showed that, for a given
sampling error, the gage density needed for warm season storms was two to
three times greater than that required in the colder part of the year. Among
synoptic storm types, air mass storms required the greatest sampling density.
During the warm season, storms producing unstable types of rainfall were found
to require twice as many gages as storms producing steady rainfalls. A con-
siderable difference in the magnitude of storm sampling errors was found be-
tween consecutive 5-year periods for the same network, as well as between

5

storms with apparently similar characteristics. Huff also determined that area mean gage rainfall measurements should be accurate to within about 5 percent for gage densities >1 gage per 50 km^2 with rainfall rates >10 mm hr^{-1}. In addition, area mean rainfall measurements should be accurate to within 10 percent for gage densities >1 per 160 km^2 with rainfall rates >4 mm hr^{-1}.

11. Huff's results indicate that, despite associated problems, rain gages at adequate densities can provide accurate mean areal rainfall estimates. Consequently, these gage rainfall estimates can be used as a standard of comparison in the evaluation of other techniques of measuring rainfall. Any deviation of other types of rainfall estimates from gage rainfall estimates must be interpreted as a deviation from a standard of known accuracy, but not necessarily as an indication of actual error. It is possible that other types of rainfall estimates may be more accurate.

Radars

12. Radar estimates of rainfall variability can be made on scales smaller than gage spacing or satellite coverage. Also, in tactical situations, the emplacement and monitoring of gages or sensors, especially in hostile territory or difficult terrain, are not practical.

Principles

13. Weather radars operate under the principle of backscatter and absorption of electromagnetic waves by particles of ice, snow, or water. The received power from particles varies with the dielectric and absorption properties of the particles, the refractive index of the intervening medium, and the atmospheric absorption. Thus, radar is capable of sensing precipitation in the form of water, ice, and snow. Phenomena such as tornadoes, blowing dust, and turbulence can also be detected by employing signature analysis of the returned signal.

14. The backscattered radar power from precipitation drops is proportional to the summation of the sixth power of drop diameters D_i^6 in a unit volume of air illuminated by the radar beams. Hence, the radar reflectivity factor (in units of $mm^6 \, m^{-3}$) is defined as:

6

$$Z = \Sigma_i \; N_i \; D_i^6 = \int_0^\infty N(D) \; D^6 \; dD \qquad\qquad (1)$$

where

N_i = number of drops with diameter D_i per unit volume of air

$N(D)$ = number of diameters between D and $D + dD$ per unit volume of air

15. Assuming that vertical air motions do not exist, rainfall rate R, the desired parameter, is related to D as shown in the following equation:

$$R = \frac{\pi}{6} \int_0^\infty N(D) \; D^3 \; V_t \; (D) \; dD \qquad\qquad (2)$$

where $V_t(D)$ is the terminal velocity of a drop of diameter D. In units of centimetres per second, terminal velocity can be approximated by the equation $V_t = 1400 \; D^{1/2}$ (Spilhaus 1948). By substituting the Marshall-Palmer (1948) exponential drop size distribution into Equations 1 and 2 and using the empirical relationship between V_t and D, the following expression relating Z and R is obtained:

$$Z = aR^b \qquad\qquad (3)$$

If in fact drop size distributions were exponential in form and known, and if vertical air motions were zero, the accuracy of radar rainfall estimates would not be limited by these error sources. However, the drop size distribution is rarely known and it varies in time and space. Also, vertical air motions are frequently of the same magnitude as the terminal velocities of the raindrops. Thus the Z-R relationship is not unique, and average relationships must be used. For this reason, numerous empirical values for the coefficient a and exponent b of the basic Z-R relationship have been derived over the years (Battan 1973).

Applications

16. Radars by themselves have not been proven an adequate substitute for rain gages in all applications. In addition to the reasons listed above,

there are slight errors in radar calibration which, when combined with the Z-R relationship errors, at times make the radar-derived rainfall estimates accurate to only within about 50 percent (Atlas 1964).

17. Difficulties with radar estimates and the cost of gage rainfall measurements have led investigators to develop gage adjustment procedures for radar data to derive mean areal rainfall estimates. Brandes (1975), for example, developed a technique of calibrating radars on the basis of gage measurements. His technique was designed to take advantage of both the point accuracy of gage measurements and the spatial coverage of radar measurements. The technique is outlined below:

a. Gage rainfall-radar rainfall ratios (G/R ratios) are calculated at gage locations using evenly weighted radar data within a fixed radius from the gage. The radius chosen is small with respect to gage spacing.

b. Radar rainfall data, exceeding some selected threshold value, are converted to a Cartesian grid having a grid spacing roughly equivalent to the radar resolution data.

c. The gage rainfall data and G/R ratios are transformed to the same Cartesian grid as the radar data using the objective analysis method of Barnes (1964). The weighting factor used reflects gage density.

d. An adjusted radar rainfall field is obtained by a grid-by-grid multiplication of the G/R ratio and its associated radar rainfall.

e. The final rainfall field is constructed using the gage and adjusted radar rainfall fields. The final rainfall estimate is set to 100 percent of the gage value at gage locations and linearly interpolated to 100 percent of the adjusted radar value at some fixed radius away from the gage locations.

18. Using Brandes' technique and two data sets derived from densely gaged areas that were also covered by radar observations, Hildebrand et al. (1979) found that for measurement of area mean convective rainfall, combinations of rain gage and radar data are no more accurate than gage only data for gage densities >1 gage per 100 km^2. For densities of one gage per 250-300 km^2 in a mid-western US climate, they found that combinations of gage and radar data may be more accurate than gage only mean convective rainfall measurements. Table 1 shows some radar areal estimates of rainfall using rain gages for calibration; data were adapted from Wilson (1979). These rainfall estimates all have associated errors of 30 percent or less, adequate for most hydrologic purposes, particularly in the tactical environment.

8

Satellites

19. Several techniques have been developed for making rainfall esti-
mates utilizing various detector systems on board meteorological satellites.
These techniques make use of satellite measurements at the primary visible,
infrared, or radio window frequencies of the earth's atmosphere. The tech-
niques for rainfall determination can be divided into three categories:
(a) microwave models, (b) cloud growth rate models, and (c) cloud characteris-
tics models. Included in Table 2 is a list of some of the satellite precipi-
tation estimation models, their design applications, and the satellites and
detectors involved. Advantages and disadvantages of the various satellite
techniques are summarized in Table 3. In general, space and time integrations
required for existing satellite systems prohibit the determination of instan-
taneous, precisely located rainfall intensities. Also, nonradiometric ap-
proaches do not generally provide a sound physical basis for rainfall
measurements.

Microwave models

20. The microwave model became a viable technique with the launch of
NIMBUS-5, which carried the first microwave radiometer (ESMR) on a US earth-
orbiting satellite. Measurement of rainfall over the oceans using the
19.3-GHz satellite microwave data are based on three physical phenomena:
(a) the atmosphere is very transparent to millimetre and longer wavelengths,
except for certain frequencies such as the 5-mm oxygen and the 1.6- and
13.5-mm water vapor bands; (b) the ocean has a low emissivity (0.4 at 15.5 mm)
and thus appears cold; and (c) raindrops interact strongly with radiation
wavelengths comparable to drop circumferences. Against the cool background of
the ocean, rain areas appear hot. Brightness temperature increases with rain
rate until, at some point, backscatter causes the brightness temperature to
decrease. Estimates of rain rate from the ESMR instrument represent instanta-
neous measurements. Since the satellite is in a sun synchronous polar orbit,
only two rainfall estimates per day over a given region can be made. This
makes interpretation difficult because the proper integration time for the
rate estimates cannot be determined directly. Also, the field of view (FOV)
of the ESMR is so large ($\sim$900 km^2) that, if rainfall occurs in only a portion
of the FOV, it is necessarily underestimated for the FOV as a whole. The
estimation of precipitation over land areas has been studied by Savage (1976)

9

using an ESMR at the 37-GHz frequency. He found that raining areas over land can be detected, but a clear measure of rain rate over a light to heavy rain rate scale is difficult to ascertain because the brightness temperatures of the land and the raining areas are very nearly the same.

Cloud growth rate models

21. Nonradiometric approaches have been used with some success for estimating rainfall; however, these techniques generally lack a clear physical basis and can thus not be universally applied to all meteorological conditions. A technique in this category that does address the process of precipitation development has been devised by Griffith et al. (1978). Briefly, the technique is as follows. The life history of a cumulonimbus cloud is determined from a sequence of satellite images. By use of an empirical relationship, volumetric rainfall is inferred for every image taken during the cloud's life history. The inferred rainfall is proportional to cloud area and to vertical growth and is inversely proportional to cloud top temperature. Thus, all other parameters being equal, a growing cloud has a greater inferred rainfall than a cloud whose area has been shrinking. Similarly, for two clouds with identical sizes and growth histories, the colder cloud will be assigned a larger inferred rainfall. Depending upon climatic region, various albedo and temperature thresholds have been used for convective areas. This is due to the difference in the cloud physics of convective systems and the varying atmospheric structure in which convection takes place.

22. Shown in Table 4 are error statistics compiled by several investigators who have used cloud growth approaches to estimate rainfalls in various regions. A major difficulty exists in evaluating the different approaches for estimating rain areas and amounts, the difficulty involving how to describe accuracies statistically. In Table 4, the bias B is the sum of the ratios of accumulated satellite to accumulated ground truth rainfall divided by the number of days. Accordingly, the mean error factor E_R is defined to be the sum of the ratios of satellite to ground truth rainfall or the inverse (ratio will always be greater than 1.00) divided by the number of days. As indicated in Table 4, estimates made from infrared (IR) data tended to overestimate by a greater amount than did the estimates made from visible (VIS) data. This is probably due to the presence of cirrus clouds (nonprecipitating clouds), which contaminate the IR data to a greater extent than the visible data. E_{rms} is defined as the root mean square of the deviation of the satellite quantity

from the radar quantity divided by the mean radar quantity. For a perfect technique, $B = E_R = 1$ and $E_{rms} = 0$. Lovejoy and Austin (1979) concluded that, for independent processes, the rms error of the satellite rainfall estimation technique was about 49 percent. It should be noted that weather radar estimates of rainfall were usually used as ground truth data for the satellite estimation techniques instead of rain gages.

Cloud characteristics models

23. The third technique of rainfall estimation using satellite data is based on empirically derived relationships between various cloud characteristics and raining areas. Cloud parameters used in these types of analyses have included cloud brightness or temperature, brightness or temperature gradients, cloud height, thickness, and areal coverage. Some of the procedures included in this general technique are not designed for the estimation of instantaneous rainfall, but instead are used to compile rainfall statistics for extended time periods.

24. Schofield and Oliver (1977) have developed a cloud characteristics model which entails a decision tree technique based on synoptic features and the dynamics of convective systems. This technique is used primarily for severe weather forecasts. However, it has been modified to account for various types of convective activity and can thus be effectively used for forecasting local convective rainfall.

PART III: MILITARY HYDROLOGY METEOROLOGICAL SUPPORT

25. Three main topics are briefly addressed in this section. The first
is military hydrology doctrine; responsibilities for hydrologic activities,
and meteorological support are set forth. Current meteorological programs
relevant to military hydrology are presented next. Finally, meteorological
support requirements for military hydrology and methodologies for fulfilling
these requirements are discussed.

Doctrine

26. The responsibility for providing hydrologic support to military
units resides in the Army by JCS Memorandum of Policy 46 and is outlined by
joint regulations AR 115-10/AFR 105-3 and AR 115-21/AFR 105-10. Meteorologi-
cal support to the Army for soil trafficability, river stage, and flood fore-
casts is the responsibility of the Air Force as outlined in AR 115-10/
AFR 105-3, AR 115-12, and delegated by JCS Memorandum of Policy 46.

27. The military hydrologist, in addition to providing streamflow fore-
casts, is required to provide trafficability forecasts, advisability of
bridging at certain locations and times, and dam breaching consequences. The
technology is already available to upgrade Army hydrologic procedures in soil
moisture and streamflow estimation. However, the best hydrologic procedures
and technologies will be of little value if they are not supported by adequate
meteorological data. At this time, it is not known what priorities meteoro-
logical data would carry on communication networks under crisis situations.
However, under current Air Force staffing and tactical communication proce-
dures, it appears that the Army terrain units with a direct support mission
would be without the needed meteorological data to carry out their assigned
hydrologic mission in crisis situations. If the direct support teams were to
supply their own meteorological data, the Tables of Organization and Equipment
(TOE's) would have to be expanded and the Army's training and doctrine would
have to be revised to allow for the added responsibility.

Current Programs

28. An original requirement (Air Force, TAC ROC 28-69, dated 21 Apr 69) identified a radar to be used for observing rainfall areas and amounts, movements, and intensities of severe storms and nuclear fallout areas in advanced operational/battle areas. Because of technical delays and cost overruns, this tactical unit has just recently been made available for field testing by the Air Force. All data requirements for military hydrology, however, cannot be met because the radar (TPS-68) does not have a digital video integrator processor unit and minicomputer for quantifying precipitation over small areas. Only six of these units have been produced, and their planned deployment will not meet Army tactical requirements. According to plans (Op Digest 1981), the Air Force assigns these radars as follows: (a) Tinker AFB, Okla. (one for mock-up training; one for contingency); (b) Robins AFB, Ga. (one for contingency/exercises); (c) 2nd Weather Wing US Air Force Europe (two for contingency/exercises); and (d) 1st Weather Wing Pacific Air Force (one for contingency/exercises). These are the only tactical mobile weather radars the Air Force plans to field because it is committed to purchase about 40 doppler radar systems in a joint effort with the Departments of Commerce and Transportation. These doppler radars are fixed installations, cost approximately $2 million each and will not be operational until the late 1980's.

29. The Air Force has two programs under development that could eventually benefit the Army hydrologist, the Pre-Strike Surveillance/Recon System (PRESSURS) and the Precipitation and Soil Moisture Mapping (PREAMP) system. However, PREAMP is not envisioned as a tactical observing aid; PRESSURS will not be employed as a response to Army requirements; and neither will be available until the late 1980's.

Requirements

30. Meteorological data requirements for Army tactical streamflow forecasting are stated in a letter from the Corps of Engineers given as Appendix A. Precipitation is required in units of millimetres per hour with an accuracy of ±25 percent of actual accumulation. Areal coverage for precipitation is required over a 100-km radius with a spatial resolution of ±20 percent or 5 km^2.

13

31. As summarized in previous sections, only a dense network of rain gages can provide data this accurately. However, in tactical situations, the placement, maintenance, and monitoring of numerous rain gages is unrealistic. In addition, because the flow of information is often interrupted in tactical situations, it is essential that the field element responsible for hydrologic support possess or have immediate access to capabilities for both localized observing and short-range forecasting of weather. Therefore, some method other than rain gages for estimating precipitation must be employed if highly useful data are to be obtained. The best procedure might involve the melding of radar and satellite observations into a common database and transferring subsequent analyses to the user in simple, understandable formats. Unfortunately, such a procedure would prove costly and time-consuming. Furthermore, an elaborate ground station would be required, a target both easily identifiable and vulnerable.

32. The major difficulties in using data solely from meteorological satellites for rainfall estimates are fourfold, namely: (a) errors in estimated rainfall amounts are large, (b) spatial resolutions are poor, (c) microwave sensors carried on sun synchronous orbital satellites provide only twice daily data, and (d) nonradiometric approaches generally lack a clear physical basis.

33. To satisfy Army hydrologic requirements in the near term, radar procedures similar to those employed by the National Weather Service (NWS) should be adopted. From its weather radars, the NWS utilizes data to accurately estimate current precipitation and precipitation accumulations, which in turn are used in compiling river stage predictions and flash flood warnings. Several basic parameters are estimated by the NWS from weather radar data, namely: (a) type of precipitation, (b) change of precipitation intensity, (c) movement of precipitation areas, (d) precipitation rate, (e) cumulative precipitation, (f) rate of areal growth, (g) rate of vertical growth, and (h) duration.

34. Radar shows a distinct advantage in determining precipitation types. Not only can convective storms be identified, but snow from stratiform clouds and the melting level in clouds can be observed and used in forecasting. Snow has a major impact on runoff events. For example, hydrographs should be adjusted when rain changes to snow or snow to rain. Also, snow could be falling at the higher elevations of a basin and rain at the lower

14

levels. On an areal basis, these events can best be detected by a weather radar.

35. The fact that the NWS plans to upgrade their radar systems by purchasing about 120 new ones costing about $2 million each is a testimonial to the effectiveness of weather radars to provide useful information on meteorological events. It might be noted at this point that the precipitation input to hydrologic models consists of areal means rather than point amounts. As noted in the previous sections, a weather radar may do a better job in estimating areal precipitation than rain gages when the density of rain gages is less than approximately one per 300 km^2. Even for convective storms, the radar observation is superior because uniform cirrus clouds often form over areas of interest and mask out any detail one might see from satellite imagery alone.

36. Another advantage of radar is mobility. New systems allow radar power output levels to be significantly reduced through the use of a frequency-stable, narrow bandwidth transmitting device and a coherent receiver. At reduced power outlet levels, a solid state transmitter is feasible, thus eliminating the magnetron. Lightweight, flat-plate antennas and high quality digital processors designed to take advantage of the lower power receiver/transmitter are also available. All of these elements can be integrated into a system that yields an adequate level of calibrated, controlled performance.

37. A weather radar of the TPS-68 type with an operating radius of 150 km and housed in a van could be sited well behind the forward edge of the battle area (FEBA), perhaps at the Corps level. In this case, position itself affords a degree of protection; further protection against targeting by hostile forces through signal tracing measures can be ensured by operating the radar only for brief, intermittent, and random periods. If vulnerability of a ground-based system is found to be an overwhelming disadvantage, an alternate system is the airborne weather radar. An airborne capability would ensure that the weather radar could be quickly moved to almost any location and not become a fixed target. Lightweight antennas and all solid state electronics also make the airborne system attractive. The airborne radar, with only minor modifications (addition of signal processing equipment), can be installed in a helicopter of the UH-1 variety. Size restrictions on the antenna though, when mounted on a helicopter of the UH-1 type, will restrict the beamwidth and thus

make difficult the attainment of a narrow beamwidth at 5.5 cm operating wavelength.

38. Thus, weather radar systems appear feasible, either ground based or possibly airborne. The airborne system is mobile and perhaps less vulnerable. On the other hand, the ground-based system can provide better rainfall esti- mates, is easier to use and deploy, and is less expensive in that an aircraft is not integral. All of the hardware for these systems is currently available and either radar could be operational within approximately 6 months of a de- livery order. For example information and data on an airborne radar system, the reader is referred to promotional material and system specifications pub- lished by Collins Air Transport, a subsidiary of Rockwell International. Pro- posed specifications for a tactical ground-based meteorological radar system are included in Part V of this report.

PART IV: WEATHER RADARS

39. Topics addressed in this section include major components and operational characteristics of existing radar systems.

Major Components

40. Regardless of the design purpose, physical size, power, or weight of available weather radar systems, they have major components performing common functions.

41. The trigger generator or timer determines the pulse repetition frequency (PRF) and more or less controls the action of the entire radar system. The trigger is used to initiate the sweeps on the cathode ray tubes of the indicator units. Because time, and thus range, is measured from the start of a sweep out to a target appearing on a screen, it is essential that the emission of a pulse of energy sent from the antenna occur simultaneously with the start of the cathode ray tube (CRT) sweep if accuracy is to be ensured. For example, if the PRF of the equipment is 500, the trigger generator will turn the modulator on 500 times each second, and the modulator will pulse the transmitter 500 times per second. Simultaneously with the start of each transmitted pulse, the trigger generator will also initiate a sweep on the CRT of each indicator unit. The trigger generator also provides a trigger for gating the signal processor (enabling or disabling the circuits for certain precise periods of time) and to operate receiver-connected circuits such as sensitivity time controls (STC).

42. The trigger generator feeds a trigger to the modulator. A pulse of power from the modulator operates the transmitter. The modulator must produce a continuous pulse for the desired pulse length of the emitted signal, and at a voltage sufficiently high to operate the transmitter oscillator, which actually produces the bursts of radio frequency energy. The output of the modulator is fed to the transmitter. The transmitter then produces the radio frequency pulses while being powered by the modulating pulse. The essential unit of the transmitter is the magnetron, a special type of electronic tube capable of producing the radio frequency bursts at the desired frequency and at relatively high power.

17

43. It should be noted that low power, all solid state weather radars have been developed for aircraft and outperform conventional 50-kW systems by using state-of-the-art electronics and signal processing techniques. The use of an all solid state amplifier design reduces the radar power consumption (Klass 1979).

44. In pulsed radar systems, only one antenna is used for both transmission and reception. The receiver circuits must be connected to the antenna as soon as possible after the completion of the emitted pulse in order to receive and amplify the weak reflected echoes from targets during the silent period. Furthermore, the transmitter circuits should be disconnected from the antenna during the silent period to prevent absorption of the reflected signals from the receiver. These switching functions are accomplished electronically by the duplexer or transmit-receive-switch (Hiser 1973).

45. From the transmitter, the pulsed wave is sent to the antenna via the duplexer and a waveguide system. The antenna focuses the energy into a pulsed directive beam, with the shape of the beam dependent upon the geometric parameters of the antenna. The antenna also acts as a collector of echoes reflected from targets, and sends these echoes to the receiver via the duplexer.

46. The reflected waves from targets are fed to the receiver where they are amplified, detected, and further amplified to a power and voltage level suitable for display or recording. The receiver is usually of the fixed frequency type. It must be extremely sensitive to permit amplification and detection of reflected waves with a power as low as 10^{-14} watts. The inherent noise in any receiving system must be kept to a very low level in order that a reflected echo of such low power will not be obliterated, but will pass through the receiver and be detected above any noise present.

47. The receiver system also receives a trigger from the timer unit that can be used to control or "gate" the receiver output for displays. The trigger is also used to initialize activity in an STC circuit that changes the sensitivity of the receiver so that echoes at different ranges but of the same intensity are displayed equally.

48. Target information such as range, height, azimuth, areal extent, and intensity is displayed in some fashion. Some systems process the radar receiver output directly and convert it to a color television signal while at

18

the same time sending the output to a minicomputer for meteorological analysis and subsequent display using computer graphics.

49. A scanner is a precision electro-mechanical device for rotating the radar antenna in azimuth or elevation or both. Usually the speed of such rotation can be very finely controlled. The mechanical rotating features of the scanner are usually coupled directly by means of a synchro-system to an antenna control unit for movement of the antenna at the discretion of the operator. This system is also connected electronically to the indicator unit to permit portrayal of bearing or elevation on a display device.

Operational Characteristics

50. The four frequency bands commonly used in weather radar are as follows:

Band	Frequency Range (GHz)	Wavelength (cm)
S	1.5-3.7	11
C	3.7-6.2	6
X	6.2-10.9	3.5
K	10.8-18.0	2

The "C" and "S" band radars have proven superior because of their ability to penetrate intervening rainfall and detect rainfall beyond the first echo. The "S" band radar is the best in that the attenuation due to precipitation is very minimal. It does suffer, however, in its inability to detect very light precipitation unless a larger antenna, more power, or greater sensitivity is employed. Because of these and other considerations, a "C" band radar would be best suited for tactical hydrologic applications.

51. The performance of a weather radar can be determined from the basic range equation modified to account for the unique backscattering characteristics and resulting target cross section of hydrometeors such as raindrops, snowflakes, and hailstones. The equation has the form:

$$R^4 = \frac{P_t A_e c\tau}{32 \bar{P}_r} \sum_{i=0}^{n} \sigma_i \qquad (4)$$

where

R = maximum detection range

P_t = transmitter peak power

A_e = effective antenna aperture

c = speed of light

τ = pulse width (in time)

$\overline{P}_r$ = average received power level

σ_i = backscatter cross section of a single hydrometeor

The summation term of the equation represents the total backscattering cross section of all the hydrometeors within the illumination volume of the radar transmitter pulse and is derived through a statistical process. Figure 1 shows the maximum detection range versus rainfall rate for a typical "C" band radar.
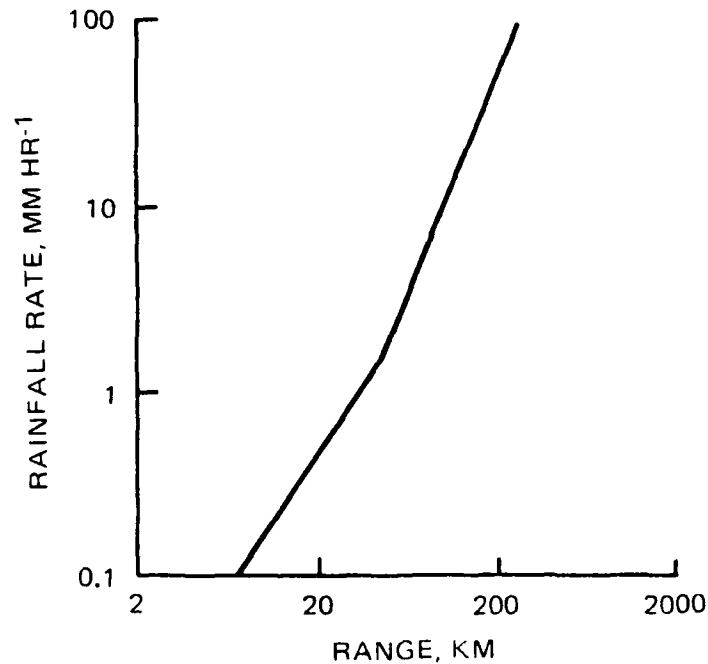
Figure 1. Maximum detection range versus rainfall rate for a typical "C" band radar

52. Since the echo signal level from a storm is related to the number and size of the individual raindrops in the illuminated volume, one would expect to be able to use the radar to measure the rate at which rain is falling. Various studies have been made to test the validity of the equation relating backscattered power to rainfall intensity. Direct observations of rainfall have been compared with calculations made from simultaneous radar

20

observations. In general, it has been shown that properly calibrated radars can make reasonably accurate measurements of rainfall intensity. These studies have used the equation:

$$Z = aR^b \qquad (5)$$

where

      Z = reflectivity factor

      R = rainfall rate

The coefficient a and the exponent b depend on the raindrop size distribution. Numerous coefficient and exponent values have been derived over the years depending mainly upon the type of rainfall being observed (Battan 1973). Some of the problems involved in using a radar as a rainfall estimator are: (a) the radar samples a volume surrounding the calibration rain gage, (b) the volume sampled is aloft and rain could drift before reaching the ground, (c) the rain aloft may not be reaching the ground due to updrafts or evaporation, and (d) variations in the raindrop size spectra occur that invalidate the assumption inherent in the equation of homogeneity of the spectra. Each radar must be accurately calibrated internally (transmitter power, receiver sensitivity, etc., must be known) and externally (compared with gage measurements) before being used to estimate rainfall over a watershed.

53. A very useful and desirable feature to measure rates of rainfall is employed on many weather radars. The "iso-echo contour" feature takes the digitized radar echo signals and puts them through level gates to display the picture in shades of gray corresponding to rates of rainfall. The range normalization in this feature eliminates range as a factor and the gray scales are only a function of the radar backscatter signal strengths.

54. Ground clutter (spurious signals) usually poses some problems in weather radar systems. Ground clutter returns are caused not only by the main beam but more likely by the sidelobes striking the ground at large enough angles of incidence to cause detectable reflections. The effect can be minimized by changing the antenna design (flat plate phased array antennas have fewer sidelobe problems) or by electronic suppression (blanking the display for a certain distance).

PART V: SPECIFICATIONS FOR A PROPOSED TACTICAL
WEATHER RADAR SYSTEM

55. The purpose of the effort discussed in this section was to develop a set of general specifications for a tactical or field type of weather radar system for providing data to Army terrain teams. The discussions will detail the rationale for each major portion of the specifications. As can be appreciated, many possible combinations are suitable but many years of experience plus an understanding of the nature of the desired operational conditions resulted in a derived set of parameters that will produce desirable operational characteristics.

56. The system must be completely self-contained, portable, and suitable for operations in several extremes of environmental conditions. There are several trade-offs between an optimum weather research type of radar and one designed for essentially rainfall or snowfall use in field operational conditions. The discussions are centered around the principal subsystems and/or design philosophy. No effort has been made to include Military Specifications in that the effort is better left to those in procurement. The general plan dictates a design suitable for all-weather operation with proper requirements for crew comfort and ease of maintenance under weather extremes.

57. The requirement for real-time analysis of total rainfall over areas dictates, for accuracy, a radar system equipped with a suitable minicomputer with graphic plotting capability. The overall operational criteria call for integration of rainfall rate, with respect to time, over a matrix of 5 km, i.e., 5- by 5-km grids. The resultant patterns, consisting of a total of many area increments, will then be displayed at regular intervals in the form of values of total rainfall for each grid. The display could be to any desired computer-generated scale and area suitable for overlays on general tactical operational charts.

58. For field reliability it is felt that additional real time displays are necessary. A color scan-converted updated type of television display is very desirable for real-time viewing of the situation. In addition, a contoured PPI (Plan Position Indicator), an A-Scope, as well as an RHI (Range Height Indicator) are very desirable. These displays not only add to the general effectiveness but serve as backups for the principal computer-generated products.

59. Other thoughts have been expressed regarding specific selectable
radar parameters, such as wavelength of operation, pulse-length, antenna beam-
width, peak power, pulse repetition rate, maximum display range, contoured
intervals on both the standard displays as well as the color displays, and the
general signal integration requirements.

60. The radar system is described by discussions relative to the re-
quirements for each major subsection. These include the selection of proper
wavelength of operation with allowable attenuation, the antenna/beamwidth re-
quirements, the transmitter/receiver, digital video processing, special con-
trol circuit requirements, and finally the required computing facilities.

Wavelength Considerations

61. One design consideration of utmost importance is the intended
wavelength of operation and the resulting antenna size. Several interacting
parameters determine the optimum combinations. The major parameters to be
considered are attenuation due to likely intervening rainfall, beamwidth re-
quirements, allowable physical size of the antenna/radome system, and the
pedestal requirements for such an antenna system. In practice, other than
attenuation, the antenna size is the limiting factor.

Antenna

62. A rather long wavelength of 10 cm with an antenna providing near
1-deg beamwidth would be optimum for a weather type radar. Such an antenna
would be approximately 7.3 m (24 ft) in diameter, which is not very practical
for a portable field radar. Relaxing the beamwidth to 2 deg will help but
still results in an antenna of approximately 3.6 m (12 ft) in diameter. It is
believed that, if attenuation factors are acceptable, a 5.45-cm system with a
beamwidth of 2 deg will provide the needed resolution for tactical hydrologic
forecasting. A determination must be made regarding the acceptability of the
2-deg beamwidth. If it is acceptable, an antenna approximately 2 m (6.5 ft)
in diameter will be required. Even with the addition of a radome, this size
antenna should prove entirely manageable insofar as portability and field
conditions are concerned. An arc-length distance is equal to the beamwidth in
radians times the distance from the radar. A tabulation of the arc-length of
a 2-deg (0.0349-radian) beamwidth antenna at various distances to a maximum of
150 km is shown below.

Distance, km	Arc-Length, km
20	0.70
50	1.75
100	3.49
150	5.24

63. If 5- by 5-km grids are used for display purposes, for example, the range at which the angular and distance resolutions are equal would be slightly less than 150 km. This is not an unreasonable range and is within a normal operational distance. A 1-deg beamwidth would be optimum, but with a 5.45-cm wavelength, this would require a 4.6-m (15-ft) antenna. A shorter wavelength, with its narrow beamwidth, cannot be used because of attenuation factors. It is therefore concluded that, with satisfactory attenuation characteristics, an operating wavelength of 5.45 cm and an antenna of approximately 2 m (6.5 ft) in diameter with a resulting 2-deg or less beamwidth is optimum for the intended use. It should be understood that the actual frequency of operation will satisfy the military weather radar frequency for this particular band. The actual frequency can vary from approximately 5,450 MHz to 5,650 MHz.

Attenuation

64. The probable attenuation characteristics of the 5.45-cm radar system must be satisfied. Attenuation due to precipitation depends upon the wavelength of the radar, the rainfall rate, and the distance the beam travels through precipitation. Battan (1973) tabulated the attenuation rates calculated by several investigators. The following relationships developed by Huebner (1977) summarize attenuation rates for three different radars in a simple analytic form:

$$3.2 \text{ cm} \quad A = dR/30.8$$
$$5.5 \text{ cm} \quad A = dR/130$$
$$10.0 \text{ cm} \quad A = dR/1111$$

In the above tabulation, A is the two-way attenuation in decibels, d is the distance the beam travels through precipitation in kilometres, and R is the rainfall rate in millimetres per hour.

65. For shorter wavelengths, attenuation due to precipitation becomes significant in two types of meteorological situations: first, in intense

convective precipitation systems with high precipitation rates (greater than 40 mm hr^{-1}); and second, in widespread precipitation where rainfall rates are more moderate but precipitation covers a wide area. In middle and higher latitudes (poleward of 35-deg latitude), the first situation is more typical of thunderstorms during the summer season, although the extratropical cyclones that give rise to moderate widespread precipitation can occur at any time of the year, particularly in northern Europe (Trewartha 1981).

66. To compare the importance of attenuation due to precipitation for rainfall measurements using radars of different wavelengths, idealized rainfall patterns were selected for each of the two meteorological situations described above. The idealized patterns were chosen so as to be typical of the sort of precipitation event that can be expected to occur at least once each year in middle and higher latitudes.

67. **Attenuation calculations.** The radar equation may be written in the following form to include attenuation due to precipitation:

$$\overline{P}r \ (dBm) = 10 \ \log_{10} \ f(radar) - 20 \ \log_{10} \ r + dBZ - \int_{o}^{r} A \ dr \qquad (6)$$

where

$$\overline{P}_r = \text{returned power}$$
$$f(radar) = \text{a function of the properties of the particular radar}$$
$$r = \text{range}$$
$$dBZ = \text{radar reflectivity factor}$$
$$A = \text{two-way attenuation due to rain, } dB \ (length)^{-1}$$

Rearranging gives:

$$dBZ = \overline{P}r \ (dBm) - 10 \ \log_{10} \ f(radar) + 20 \ \log_{10} \ r + \int_{o}^{r} A \ dr \qquad (7)$$

This same equation may be used to calculate an apparent dBZ value for cases when attenuation occurs but cannot be taken into account (usually because A depends on the rainfall rate, or radar reflectivity factor):

25

$$dBZ_{apparent} = \overline{P}r \ (dBm) - 10 \ \log_{10} \ f(radar) + 20 \ \log_{10} \ r \tag{8}$$

Combining the last two equations gives:

$$dBZ_{apparent} = dBZ - \int_{o}^{r} A \ dr \tag{9}$$

Converting dBZ to Z gives:

$$Z_{apparent} = 10^{-0.1 \int_{o}^{r} A \ dr} \ Z \tag{10}$$

Z can be expressed in terms of rainfall rate using a typical Z-R relationship:

$$Z = 200 \ R^{1.6} \tag{11}$$

where

R = rainfall rate, mm hr^{-1}

Z = radar reflectivity factor, $mm^6 \ m^{-3}$

Substituting for Z in the last equation gives:

$$R_{apparent} = 10^{-0.1/1.6 \int_{o}^{r} A \ dr} \ R \tag{12}$$

This equation is used to estimate the rainfall rates that radars of three different wavelengths would measure when observing a precipitation pattern for which R is specified.

68. Intense convection. Figure 2 shows the results of calculations to estimate the effects of attenuation of the radar beam as it travels through a line of thunderstorms oriented perpendicular to the radar beam. An intense cell (R = 50 mm hr^{-1}) is centered at 35 km from the radar. Debris from older cells gives rise to moderate rainfall rates at greater distances from the radar. This profile was chosen by examining the convective precipitation
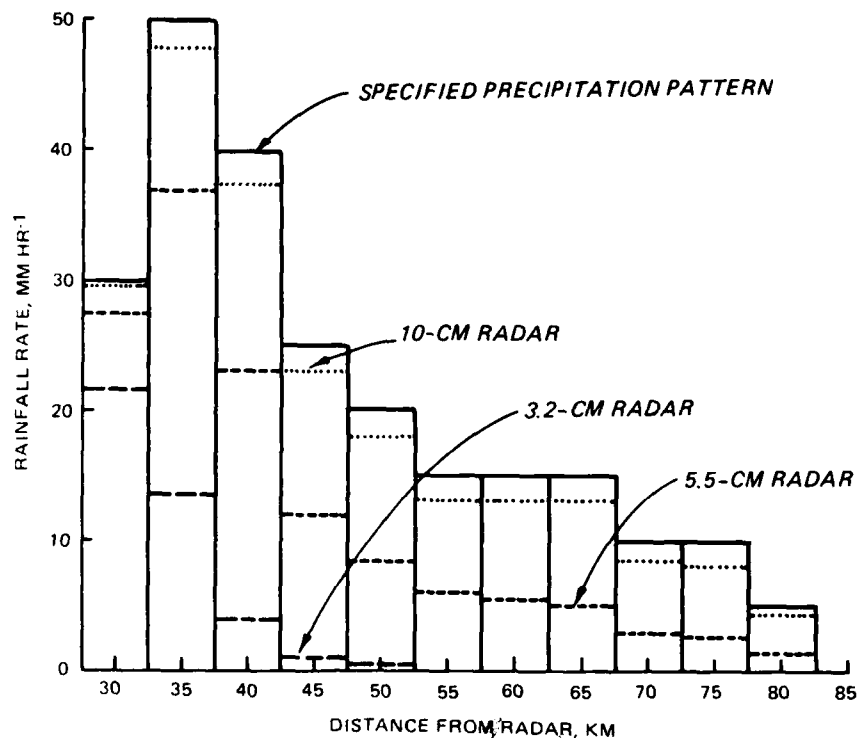
26

Figure 2. Results of attenuation calculations using a
specified precipitation pattern typical of intense con-
vection. Indications are for the rainfall rate shown
by the radars at the stated distance from the radar
location

patterns in Battan (1973) and reducing the rainfall rates to those that might
be observed north of 35 deg and in areas like northern Europe where convection
is not so intense as on the Great Plains of North America. Figure 2 shows
that the precipitation rates that a 3-cm radar would observe in this case are
an unacceptable estimate of the specified rainfall rates. The performance of
a 5.5-cm radar is a marked improvement, while the 10-cm radar shows little
degradation of the signal due to attenuation.

69. Precipitation associated with extratropical cyclones. Widespread
rain associated with extratropical cyclones is produced and organized in meso-
scale rainbands (Matejka et al. 1980), some of which may contain embedded
convection. For attenuation calculations, the cold frontal rainbands and the
warm sector rainbands and their associated rainfall rates as described by
Matejka et al. (1980) were selected.

70. In Figure 3 each radar sees a narrow band of heavier precipitation
at a range of 45 km coinciding with a cold front, with lower precipitation

27

Figure 3. Results of attenuation calculations using a
specified precipitation pattern typical of cold frontal
rainbands in an extratropical cyclone. When a radar's
performance is too close to the specified rainfall pat-
tern to be shown as a separate line, only the specified
rainfall is shown

rates in advance and to the rear of the center of the rainband. A second,
less intense rainband is centered at 125 km from the radar. Even with these
rainfall rates, much lower than those in Figure 2, the signal from the 3.2-cm
radar is severely attenuated and only 18 percent of the total rainfall is mea-
sured. The second rainband is scarcely detected at all. Performance at
5.5 cm is much better, with both a more accurate representation of the precip-
itation pattern and a greater percentage (62 percent) of the total rainfall
measured. At 10 cm, the effect of attenuation is minor.

71. <u>Warm sector rainbands.</u> Figure 4 shows the results of attenuation
calculations for a pair of warm sector rainbands. In spite of the low precip-
itation rates, the 3.2-cm radar measures only 56 percent of the specified
rainfall. Performance at 5.5 cm is again much better, with 87 percent of the
total rainfall measured by this radar. For the 10-cm radar, attenuation is
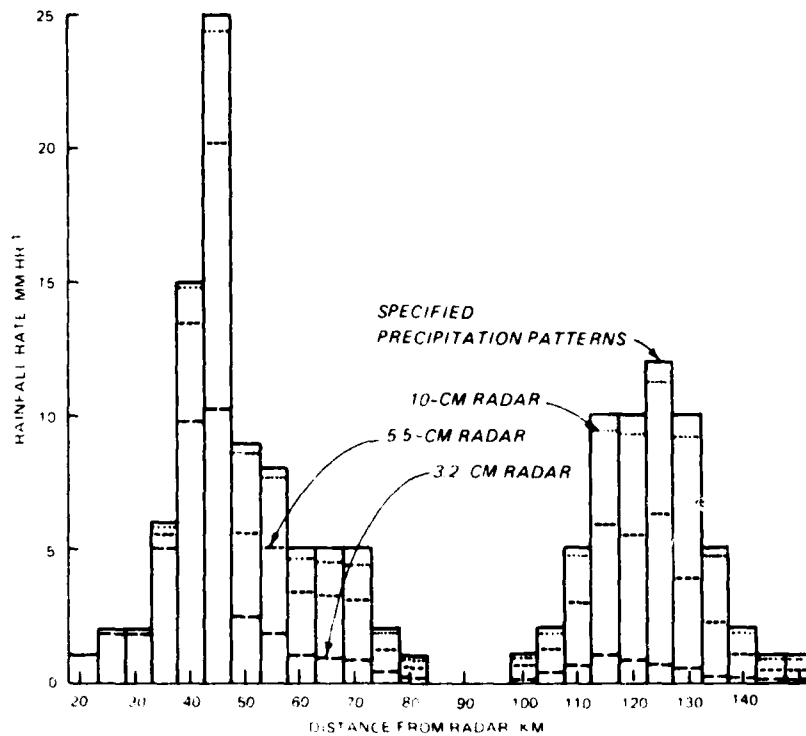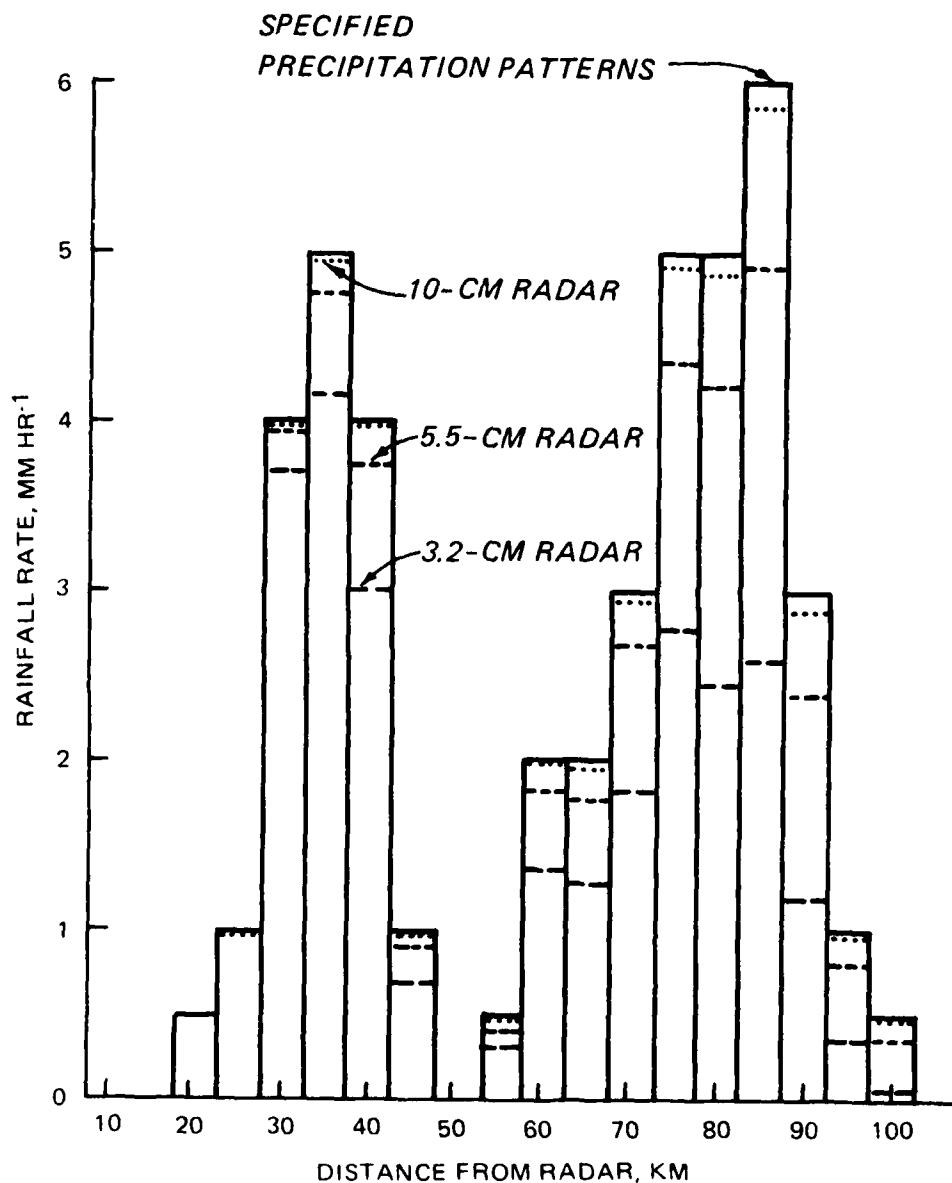negligible in this case.

28

Figure 4. Results of attenuation calculations using a specified
precipitation pattern typical of warm sector rainbands in an ex-
tratropical cyclone. Indications are for the rainfall rate shown
by the radars at the stated distance from the radar location

29

72. **Conclusions.** When rainfall rates exceed 3 mm hr^{-1} over areas with a linear dimension of 20 km or more, attenuation due to precipitation for a 3.2-cm radar is large enough to greatly obscure both the qualitative appearance of rainfall patterns and the total amount of precipitation falling in these areas. Performance is greatly improved with a 5.5-cm radar; however, a 10-cm radar is required for optimum estimates in intense convective situations. Dimensional constraints must be accounted for and the 5.5-cm radar accepted with a knowledge that the rainfall patterns, pattern depths, and rainfall rates are, on the average, probably less than used in the examples. Certain first-order corrections can be programmed for the computer contours. It should be recognized that, on the average, the probability that strong cells will align radially with respect to the radar is not great. The attenuation errors with the 5.5-cm radar are therefore manageable.

Transmitter and Receiver Requirements

73. There are certain design criteria, in addition to those dictated by good engineering requirements, that lead to adequate range resolution, sensitivity, ease of service, etc., that should be taken into account. This discussion is not in any way intended to detract from the freedom of design by the radar engineer, but additional comments are offered that may assist in meeting the requirements for the intended use.

74. One suggested set of design parameters, based upon several years of use of this general type of radar, is as follows:

Transmitter power output	250 kW
Pulse length	2 μsec
Antenna beamwidth	2 deg
Wavelength of operation	Approx. 5.45 cm
Minimum detectable signal	-108 dBm

75. The selection of the 2-deg beamwidth was discussed earlier so attention is given here to the -108 dBm signal sensitivity and the 250-kW peak power output.

76. It is recognized that a lower limit of interest in the rainfall exists. Therefore, within limits, there are trade-offs between power output and receiver sensitivity. A radar constant can be calculated if assumptions are made of: (a) a minimum detectable signal of -108 dBm at the receiver input

(one that is easily obtained without microwave preamplifiers), (b) a power output of 250 kW, (c) a pulse length of 2 μsec, and (d) an antenna beamwidth of 2 deg at 5.45-cm wavelength of operation. (The 2-μsec pulse length will be considered under the Digital Video Integrator Processor considerations).

77. The Probert-Jones form of the radar equation is as follows:

$$\overline{P}r = \frac{\pi^3 P_t G^2 \theta^2 h |K|^2 Z}{709.78 \; \lambda^2 r^2} \tag{13}$$

where the units and values of the specified parameters are:

$P_t = 250 \text{ kW} = 2.5 \times 10^8 \text{ mW}$ (Power output)

$G = 38.6 \text{ dB} \; (-2 \text{ dB for misc. losses})$ (Antenna effective gain
$= 36.6 \text{ dB} = 4571 \text{ gain}$ calculated as typical)

$\theta = 2° \equiv 0.0349 \text{ radian}; \; \theta^2 = 1.218 \times 10^{-3}$ (Antenna beamwidth)

$h = 2 \text{ μsec} \; (3 \times 10^{10} \text{ cm/sec}) = 6 \times 10^4 \text{ cm}$ (Pulse length in space)

$K = $ complex index of refraction

$Z = $ units of $\text{mm}^6 \text{ m}^{-3}$ (Reflectivity factor)

$\lambda = 5.45 \text{ cm}; \; \lambda^2 = 29.70 \text{ cm}^2$ (Wavelength)

$r = $ distance to target, km

78. The uncorrected radar constant is therefore

$$C = \frac{\pi^3 P_t G^2 \theta^2 h}{709.78 \; \lambda^2} \tag{14}$$

$$C = \frac{(31.0063)(2.5 \times 10^8)(2.089 \times 10^7)(1.218 \times 10^{-3})(6 \times 10^4)}{(709.78)(29.70)} \tag{15}$$

$$C = 5.611 \times 10^{14} \text{ mW/cm} \tag{16}$$

79. Because dimensional equality is needed, the above units of mW/cm must be converted to units of $\text{mW km}^2 \text{ m}^3 \text{ mm}^{-6}$. This gives a corrected radar constant of $5.611 \times 10^{-8} \text{ mW km}^2 \text{ m}^3 \text{ mm}^{-6}$.

80. If precipitation is assumed to be in the form of rain,

$$\overline{Pr} = \frac{5.611 \times 10^{-8} \ (0.93) \ Z}{r^2} \ mW \qquad\qquad \text{(Received power from} \qquad (17)$$
<div style="text-align:right">target)</div>

81. By substituting the -108 dBm minimum detectable signal proposed for this system and a maximum intended range of 150 km, a corresponding radar reflectivity factor A is computed as follows:

$$\overline{Pr} = -108 \ dBm = 1.585 \times 10^{-11} \ mW = \frac{5.611 \times 10^{-8} \ (0.93) \ Z}{150^2} \qquad (18)$$

$$Z = \frac{(150)^2(1.585 \times 10^{-11})}{(5.611 \times 10^{-8})(0.93)} = 6.83 \ mm^6 \ m^{-3} \qquad (19)$$

82. A common empirical equation included in the discussion on attenuation may be used to obtain the corresponding minimum detectable rainfall rate at the maximum distance of 150 km:

$$Z = 200 \ R^{1.6} \qquad (20)$$

$$R = \left(\frac{Z}{200}\right)^{0.625} = \left(\frac{6.83}{200}\right)^{0.625} = 0.121 \ mm \ hr^{-1} \ or \ 0.0048 \ in. \ hr^{-1} \qquad (21)$$

This amount of rainfall, which corresponds to a minimum detectable limit, is very small and below that of use in hydrologic forecasts. For signal processing, a 3-dB greater signal that will result in a rainfall rate of 0.190 mm hr^{-1}, still a very small value, is needed. It is quite easy to employ a lower noise receiver to reduce the minimum detectable rainfall rate. This is not felt necessary. With this result, it is clear that the general specifications listed earlier are sufficient for the intended use.

83. A modern coaxial magnetron operating at approximately a 5.5-cm wavelength will provide thousands of hours of trouble-free operation at an output of 250 kW. This size tube (magnetron) is in common usage and is well developed. For several reasons there should be no compromise on the selection of a coaxial magnetron over other types of magnetrons.

84.   The transmitter should have, in the output waveguide assembly, a bidirectional coupler with output jacks on the transmitter control panel. The coupler should be accurately calibrated with regard to coupling dB with the forward and reverse coupling loss provided on graphs as functions of frequency of operation. This will allow measurements of output power as well as standing wave ratio.

85.   Tuning stubs should be provided in the output waveguide assembly to enable correction of the load as seen by the magnetron. Good engineering would dictate the use of at least a 10-dB load isolator on the output of the magnetron.

86.   The transmitter/receiver should have both a logarithmic intermediate frequency (IF) amplifier for use with the Digital Video Integrator Processor (DVIP) as well as a linear type amplifier for calibration and display upon request on all scopes. The linear amplifier should be routed through an IF attenuator of at least 100-dB maximum attenuation with 1-dB increments. Both IF amplifiers should have a minimum of 80-dB dynamic range. The logarithmic IF amplifier should be accurate to within ±0.5 dB over the 80-dB dynamic range. Good engineering would dictate the use of line driver amplifiers on the outputs of the IF amplifiers.

87.   As was mentioned earlier, the receiver should have at least a -108 dBm minimum detectable signal at the input to the receiver.

88.   Good practice, considering the possible operating environment, would call for receiver Radio Frequency (RF) band-pass filters in the input to the receiver.

89.   There are developments in solid state technology that allow pulse generation of approximately 200 W in the "C" band area. This is approximately 30 dB less output than normally used for radar transmitters, but with signal processing at least a portion of this reduction can be regained.

90.   Modern aircraft are using, in some cases, solid state radar transmitters with stable oscillators that enable a receiver with a relatively narrow bandwidth to be used.

91.   In order to enhance the return power, a long pulse length as well as integration across the entire beamwidth of the antenna are used with solid state integration radars. This action degrades the target definition making it doubtful that required definition can be achieved at this time.

33

State-of-the-art design is borderline in terms of performance required for the ground-based weather radar system of the type being described. This does not suggest that solid state units do not have potential; as the state of development changes, it is entirely possible that such a system would be preferable.

92. Several test instruments should be mounted near the transmitter. To a great extent this listing will be determined by the radar design engineer, but several standard instruments include a good quality, calibrated, cavity wavemeter; a signal generator; a milliwatt-range rms power meter for the transmitter and coupler power range; a digital counter for the PRF measurements, etc.; and a portable oscilloscope of at least 100 MHz high frequency range. The power meters, wavemeter, scopes, etc., should be mounted such that adjustments to the waveguide filters, magnetron frequency, standing wave adjustments, etc., are possible while reading the instruments.

93. Although discussed under the next chapter on the DVIP unit, it is suggested that a PRF of near 414 per second be used. This will result in a duty cycle of 0.000828 for the magnetron (at 2-μsec pulse length) and is well within range for most tubes. It also allows the full required range with ample retrace time for all circuits, displays, etc. Although not suitable for the computer use, it is suggested that a switchable 414/207 PRF be used to allow the PPI scope to look at additional ranges (up to about 500 km). This would not be put into the computer circuitry but could be used for survey of larger areas. This maximum range of near 500 km would be of use in monitoring incoming fronts, etc.

94. A "once-around" active transmission should be provided. This would allow a silent transmitter with transmission only during one timed sweep around the azimuth. The information with this type of sweep would fit the input data format for the computer and would store data in the television scan-converter for constant display in color until the next time the antenna scanned. Tactical situations may well need this feature.

Digital Video Integrator Processor

95. In order to process radar data with any acceptable accuracy and speed, it is necessary that the data be processed in digital form. The common method for doing this is to convert range segment returns into digital form, average several of them for an average value for one unit of range, such as a

kilometre of range (bin size), and then integrate many of these returns over time. These are range normalized to provide data to the intensity gates. These values are normally 8-bit words and are gated to obtain threshold values for rainfall rates or values of dBZ . In general, this is the type of DVIP that is specified for this radar system.

96. In considering the factors that determine the accuracy to which radar data can be quantified, there are two main items in the system chain that contribute greatly. These are the radar and the quantizer. In the video chain of the radar there are many places where inaccuracies can be produced, and it is sufficient to say that the best that can be done practically in most radars is approximately ±1 dB. This does not include the additional uncertainty of whether or not the antenna beam is filled nor the effects of other physical irregularities.

97. According to the generally accepted theory relating to noncoherent radar targets, such as precipitation, the standard error of a single measurement from one radar return pulse is 5.57 dB.

98. If a single radar pulse (one sample) is accurate at one standard deviation (σ) to 5.57 dB, then an average of N samples will improve the accuracy such that:

$$\sigma = \frac{5.57}{\sqrt{N}} \qquad (22)$$

With a known uncertainty in the radar, this relationship can be used to calculate the number of independent samples that must be integrated in a video processor to produce an overall accuracy of 2.5 dB at the 95 percent confidence level for digitizing quantitative radar to 1/2 log Z. If 2.5 dB at the 95 percent confidence level is required, then one σ is 1/2 this, or 1.25 dB; if the radar is 2 dB at the 95 percent confidence level, then σ = 1 dB.

99. The variance of system error is equivalent to the sum of radar error and integrator error variances. Thus,

$$(\sigma_s)^2 = (\sigma_i)^2 + (\sigma_r)^2 \qquad (23)$$

35

where

σ_s = standard deviation of system error = 1.25 dB

σ_i = standard deviation of radar error = 1 dB

σ_r = standard deviation of integrator error

For conditions set forth in the above paragraph, then,

$$(1.25)^2 = (\sigma_i)^2 + 1$$

$$(1.25)^2 = \frac{(5.57)^2}{N} + 1$$

and $N = 55$. This is the number of independent 2-µsec samples that must be integrated to establish an overall system accuracy of 2.5 dB at the 95 percent confidence level.

100. The DVIP is designed such that dynamic integration is done in both range and azimuth. For a polar coordinate range bin of 2 km (6.6 µsec) by 2-deg azimuth and a given assumed PRF of 414 Hz, and a pulse-width of 2 µsec, the maximum slew rate can be calculated.

101. Since the range bins are specified as 2 km for our processor, there will be three independent 2-µsec samples in each range bin. If a total of at least 55 samples are needed, then 55/3 = 18.3 measurement samples per azimuth sample.

102. At 414 pulses per second, then 18.3/414 = 0.0442 sec per azimuth element. If our resolution elements are 2 deg apart in azimuth, then 180 × 0.0442 = 7.96 or about 8 sec per revolution (7.5 rpm). Rates less than this are preferred. If 31 time integrations are to be used, as is commonly recommended, an antenna scan rate of 4 rpm will improve accuracy in that a greater number of samples will be obtained, not all of which will be completely independent. Integration accuracy will therefore be better than 1 dB, and accuracy will be dependent upon uncontrollable factors such as beam filling.

103. As suggested for the specified radar system, a total of 31 time integrations will be made. If the system design is such that at least 8 digital conversions are averaged for the 2-km bin sizes and 31 time integrations are made for the 8-bit data for each 2-km bin, the system will be as nearly

independent as practical of the signal processing with the specified parameters.

104. The preceding discussion can be summarized by listing requirements as follows: 8 averaged samples per 2-km range bin, 31 time integrations averaged to produce a processor standard deviation of less than 1 dB, a PRF of 414, and an antenna speed of 4 rpm.

105. There are several additional requirements for a suitable DVIP unit, most of which are obvious to the radar system engineer. These requirements plus those mentioned earlier are summarized in Table 5.

Special Control Features

106. In addition to the standard displays of a PPI, range height indicator (RHI), A-scope, and color display, there should be a control panel that will allow the setting of the time interval for input of the digital low-level scan data to the computer. As will usually be the case, the input digital data to the computer will be at intervals of 5 min, but other intervals should be provided. Thirty seconds before the selection time or interval for the preset low-level scan, a tone should sound to alert the operator of the fact that an automatic scan will take place. This feature will allow the operator to use the radar to make height measurements, etc., for about 4 min out of every 5-min interval. At the preset time the antenna should disconnect from the hand-operated azimuth and elevation controls and revert to the preset elevation for the automatic scan. There must, therefore, be a control to preset the elevation of automatic scan, and it should be adjustable in 1/2-deg increments from 0 deg to approximately 10 deg in elevation.

107. It is important that any digital input to the computer not be supplied until the antenna reaches the correct preset elevation level. It might, therefore, be convenient to have the digital data begin at 359-deg azimuth and turn off at the next 359-deg azimuth reading. This is dependent upon the individual digital design.

108. The panel may also contain other controls such as the system switches, manual start for a low-level scan, override controls to eliminate the automatic scan sequence, as well as the previously mentioned "once-around" controls.

109. The PPI and RHI displays should include digital readouts of digital azimuth and elevation values of 0.1-deg increments. These small increments are necessary for calibration of the antenna elevation and azimuth by reading the sun's noise at certain times, etc.

110. The antenna speed control should be located on this panel and a digital antenna speed readout in revolutions per minute should be included that indicates to within 0.1 rpm. This control should have a locking device to prevent accidental variations that will affect the data. Another possible method would involve a preset control associated with the servo speed readout that would hold the speed accurately while on automatic scan and then revert to a manual type of speed control for ordinary scanning. A manual control for elevation and azimuth is necessary to enable the placement of the antenna to any azimuth and elevation.

Scan Converter and Color Display

111. Although the contoured six levels of analog data from the DVIP system are displayed on the PPI and RHI displays, there is a decided advantage to having a color television type of display that is "updated" every antenna revolution. The primary objective of this type of display is to have a six-color-level TV display consisting of approximately 5- by 5-km pixels (picture elements) wherein the color of each pixel is representative of the highest DVIP level (1 through 6) within that pixel area.

112. There are several available techniques for accomplishing this procedure and most all are adaptable to the needs of this system. Basically, the methods consist of a scan conversion for azimuth-range to rectangular coordinates wherein the updated, stored pixels are scanned in a TV type raster scan. In this case the maximum 8-bit range bin value falling within a certain pixel would determine the value stored within that particular pixel's memory.

113. Inasmuch as a minimum effective 150-km range display is being considered, it is best that an actual range of more than 300 km be obtainable from the DVIP. In this way, the TV aspect ratio would allow a 300-km total display in the vertical while allowing a total display of a little more than 500 km in the horizontal. This would occur at the normal unexpanded TV display. If a maximum display of 450 km is obtainable from the DVIP, most all areas within the TV display can be utilized.

38

114. The azimuth information necessary for coordinate transformation would normally be obtained from a synchro-to-digital converter that would transform antenna synchro-azimuth data from degrees and tenths of degrees to sine-cosine functions. Range can, of course, be supplied by the range generator in the DVIP unit.

115. The video integrator and processor (VIP) levels, in this case six levels, can be supplied as binary words from the range normalized level gates or from the 8-bit data before being gated. If the six 8-bit levels are obtained before being gated, the gating will have to be a part of the scan conversion and digitally variable to track those values selected for the six VIP levels supplied to the PPI and RHI scopes. In either case, the transformation and data source must be at the 8-bit level if the input to the computer option is used. As will be mentioned later, there can be two options for computer input, directly from the updated 8-bit memory of the scan converter or directly from the normalized or unnormalized 8-bit range bin data of the DVIP. If the second option is selected, there is need for only six levels of resolution in the scan converted color pixel data. Only the computer needs the 8-bit resolution to utilize the dBm dynamic range of the signals. As will also be mentioned later, it is better to have the computer take its input from a source other than the converted pixel data. If the computer input is from the converted scan, an elaborate scan conversion with 8-bit accuracy that is stored for readout to the computer before being gated for color presentation will be needed. A separate computer input will free the design of the scan conversion and color display from some rather severe requirements. The system used is at the discretion of the designer, but it is necessary that the overall design include the proper computer input requirements.

116. There are several rather special requirements that will enhance the utility of the color TV display; these should be included as specified requirements.

117. There should be a scan expansion feature that will allow "overscan" of the pixel memories and effect an enlargement of the presented TV image. As was mentioned earlier, a 300-km maximum range (total vertical) is specified as optimum and this feature should enable a 150-km maximum range presentation to have a "times two" expansion on the TV screen.

118. A second feature that would be of benefit and is included as a requirement is the ability to effect an "offset" such that quarters of the original image as northeast and southeast can be made to be displayed over most of the screen. In all cases, the "center" point, i.e. location of the radar, should not shift position on the TV screen when the scale is changed.

119. The six distinct colors for the individual VIP levels should be fully selectable, e.g., red, green, blue, white, plus two selected contrasting mixtures. A black pixel would indicate that the particular pixel VIP level was turned off or there was no echo at the point. It must be possible to remove, or turn off, one or more VIP levels.

120. The actual dBZ threshold values for each color must represent the corresponding VIP level set within the DVIP unit. In the event a decision is made by the manufacturer to obtain the data for the scan converter before gating in the DVIP, 8-bit level gating within the scan converter must be possible. Whatever the source of data, the TV representation must be range normalized from 10 to at least 220 km. Range blanking of the screen should correspond to that being presented to the PPI and RHI screens and controllable.

121. The TV format should show pertinent registration data in white color or an outer screen area. Registration data should include the Julian day; the time in hours, minutes, and seconds; the antenna elevation in degrees and tenths of degrees; and the colors associated with VIP numbers 1 through 6.

122. There should be six movable white markers that can be programmed by the operator to indicate known points of reference on the TV screen. These should be movable over the entire screen display.

123. There should be a permanent program that will give segmented range rings at 50, 100, and 150 km.

124. The output to the TV monitor (monitor will be included) should provide two outputs of 1 V peak to peak (p-p) ± 0.2 V (p-p), 75 ohms, Sync. negative, and unbalanced line and should meet Electronic Industries Association standards and National Television Systems Committee color signals. The color monitor should have a 21-in. screen.

Computer Requirements

125. For realizing its full potential, an "on-line" minicomputer should be included in the system. There are backup displays, such as the color TV

contoured display as well as the standard rainfall rate contoured PPI dis-
plays. The backups do not, however, give the principal computer-derived dis-
play, which is a gridded matrix of 5 by 5 km with notations of rainfall rates
and integrated totals for each grid.

126. The preceding statement summarizes the need for "on-line" comput-
ing facilities. The backup displays are fully capable of giving contoured
displays of instantaneous rainfall rates in millimetres per hour, but for best
use of hydrological models, total integrated rainfall for each grid is needed
upon demand. This will allow transparent overlays to be used with Army charts
that have the necessary elevation contours.

127. A stored program can, upon demand, produce location and levels of
peak values of rainfall rate occurring during any interval of specified time.
In addition, it is anticipated that the unit will produce, during radar cali-
bration procedures, the coefficients for the third-order equation that will
relate power in dBm to the 8-bit values for the radar bins. This expression
will be generated from 5-dBm input signal increments and is of the form

$$dBm = A + BX + CX^2 + DX^3 \tag{24}$$

where

$\quad A$, B , C , and D = computer-derived coefficients

$\quad\quad\quad\quad\quad\quad\quad\quad X$ = the value of the 8-bit word at any range bin
displaying the signal supplied by an external
generator

A typical expression will be of the following type.

$$dBm = -0.1121E+03 + 0.2477E+00X + 0.6828E-03X^2 - 0.1531E-05X^3$$

The values of X derived from the display associated with the DVIP would be
entered, along with the dBm values for computation of the coefficients. The
completed third-order equation would then be entered again to enable calcula-
tions of the dBm values from the 8-bit values for each DVIP range bin.

Specific requirements

128. It is fully realized that there are many possible computer config-
urations that would be satisfactory. The following discussion will detail the
majority of the desired products with suggestions as to their handling.

129. Basically, it is necessary that the computer be equipped with a keyboard entry and CRT display. A disc memory will be necessary for data and program storage. Processing for the integrated plots will call for entry and retrieval of a rather large array. For any portion of the total radar range it should be possible to tabulate, in matrix form and upon demand, the final integrated rainfall data. This requirement calls for a stored plotting routine as well as a graphic plotter. Most Army tactical charts employ metric units and will be to the scale of 1:50,000 or 1:250,000.

130. Several things should be considered. It is doubtful that plotted rainfall for the complete coverage of the radar will prove desirable. It should be possible to enter the coordinates or area (along with scale factors) to be plotted before starting a plot routine. This could also be handled in quadrants. It is suggested that either the plot be made on transparent material or procedures be made for transfer of data to such material. This is necessary for Army tactical chart overlays.

131. In addition, it would be advisable to have a CRT display of entered and processed data as well as the entire contoured rainfall area or any portion of the contoured rainfall area. It would also be desirable to have a display of a "running total" type of contoured rainfall with provisions for a plot of the total (to that time) integrated values without terminating the integration procedure. This would allow the observer to monitor the total interim buildups as well as the total rainfall for any portion of the radar coverage. The conversion to plot contouring routine would therefore be at a suggested update of once every 5 min. The planned data entry from a 360-deg scan is once every 5 min (suggested) so the integration would be at a constant rate for the 5-min intervals.

Input data sources

132. There are two options for data sources for the computer input. The first option, but not one recommended, would be the memory storage of the TV scan converter. As specified earlier, the scan converter could store, in rectangular coordinates, 8-bit words for at least the array of 5- by 5-km pixels. These would be scanned and coded for color display on the TV monitor. A scan of these same 8-bit words can be entered, through a buffer, into the computer. This format would cover a 300- by 300-km area or a 60 by 60 (approximate) pixel array that is updated every 360-deg scan of the radar

antenna. In this way we can possibly eliminate the computer conversion from an azimuth/distance scan to a rectangular presentation.

133. It is felt that, under continuous scan conditions, the computer data will be updated every 5 min (Huebner 1981). This scan time should be under the control of the operator. Under certain tactical situations it would be advantageous for a single scan ("once-around") set of records to be entered. The scan converter would, with proper lockouts, hold and enter these values if no additional update data were available. This procedure would cause the computer to continue to integrate at 5-min intervals with the same rainfall rate patterns.

134. The computer would have a fixed input blanking of 10 km and would process the 60 by 60 (approximately) array of gridded data.

135. In addition to the 8-bit rectangular coordinate data, the year, Julian day, hour, minute, azimuth, elevation data, etc., should be entered through a formatter. The plots should show the time periods for the total integration period as well as the parameters mentioned previously.

136. A second, recommended option for the entry of data into the computer would be to supply the 8-bit word data for each DVIP bin directly from the DVIP unit. These 150-km maximum data will, of course, be delivered to a buffer/formatter for computer entry. The suggested format and data rate for such entry procedures should be examined.

137. The specified type of DVIP unit will, upon reception of the read command from the synchro-to-digital converter at every 2-deg azimuth interval (359, 1, 3, 5, etc.), deliver to the buffer approximately 112 bytes, of which 70 will be range bin data (range of 10 to 150 km at 5-km increments). In addition to the 70 bytes, information regarding the year, Julian day, time, azimuth elevation, etc., must be included. The azimuth synchro-to-digital converted should read to 1-deg increments while the elevation unit should be in 0.1-deg increments. These values are recommended values and are subject to changes by the design engineer as long as the end product is not changed.

138. For the suggested 31 integrations by the DVIP circuitry at a PRF of 414, an antenna speed of 4.45 rpm should be used if the data are read every 2 deg. For ease of calibration, this could perhaps be set at 15 sec per revolution or 4 rpm. This would not, however, distribute the 31 integrations over the complete 2-deg azimuth increment. This is dependent on the type of read trigger used in the particular design of the DVIP.

43

Data listing

139. For the case of an antenna speed of 4 rpm, 31 integrations, 2-km bins, readout every odd number of degrees, 90 bytes of bin data, and approximately 22 bytes of header information for each record, a data entry rate of approximately 112 bytes every 2 deg (1,344 bytes per second) will be needed. At any antenna speed, a 360-scan (once every 5 min) would input 20,160 bytes.

140. Provisions should be made for entry of keyboard comments. These should be printed on the output-contoured format. Such an entry might include points of reference to enable proper overlay of the tactical charts.

Computations

141. It has been suggested that the DVIP data be read to the computer on the odd degree intervals instead of the even intervals. This is done to eliminate confusion between 0 deg and 360 deg in some programs.

142. Each 8-bit word for each range bin of the DVIP is stored and identified with the particular bin number and azimuth reading. As was mentioned earlier, a third-order equation that was derived from calibration input signals is used to convert each bin value to a power value in dBm. These values are used in an equation of the following type for conversion to dBZ values:

$$dBZ = dBm + 20 \log r + 71.477 \tag{25}$$

where

$dBZ = 10 \log_{10} Z$

Z = radar reflectivity factor, $mm^6 m^{-3}$

r = distance to the particular range bin

$71.477 = 10 \log_{10}$ radar constant plus 2.7 dB for the DVIP correction for integration

The above equation takes into account the radar constant and normalizes the data for range. The data directly from the DVIP unit may or may not be normalized for distance. In the case of the first option of data input, we derived the data from the scan converter and it will be normalized; that input and the input from a normalized portion of the DVIP would not require the 20 log r term.

143. The values for rainfall rate can be derived with the use of an empirical equation of the form

$$Z = 200 \ R^{1.6} \tag{26}$$

where R is rainfall rate, mm hr^{-1}. This can be shown in the following form:

$$R = \left(\frac{10^{0.1} \ dBZ}{200} \right)^{0.625} \tag{27}$$

Dividing the above by 12 gives the rainfall for a 5-min interval between data entry events. These 5-min values of rainfall are stored as values for each range bin and added to subsequent 5-min totals. At the end of a specific time (to be entered), these are transformed into rectangular coordinates and transferred to a display and/or plotting routine that will denote the data on each grid.

144. A quadratic interpolation scheme, as used by Sieland (1977), can be used for conversion of the values of Z from azimuth/range units to rectangular coordinates.

145. The plotter should be selected to enable a plot of an area large enough to be of tactical use. With a 1:50,000 chart a plotter approaching 1-m width would be helpful, but for field meteorological use a better presentation could be done with a 1:250,000 scale. In this case, the plotter size is much smaller and easier to handle.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

146. The Army is assigned responsibility for river stage and flood forecasting, soil trafficability forecasting, and weather observations in battlefield areas forward of division command elements. To carry out these missions, some means must be available for the responsible units to receive and assimilate necessary meteorological data.

147. Accurate areal estimates of precipitation are best accomplished by using dense networks of recording rain gages. It has been shown that area mean gage rainfall measurements are accurate to within approximately 5 percent for gage densities greater than one gage per 50 km^2 for rainfall rates greater than 10 mm hr^{-1}, or to within 10 percent for gage densities greater than one per 160 km^2 for rainfall rates greater than 4 mm hr^{-1}. However, the emplacement, monitoring, and servicing of such dense networks of gages in tactical situations is totally unrealistic.

148. Weather radars operate under the principle of backscatter and absorption of electromagnetic waves by particles of ice, snow, or water. Significant errors in radar estimates of precipitation can result from nonuniform drop size distributions, vertical air motions, and internal calibration errors. However, adjustments in the radar data can be made by calibrating to rain gage data. Errors after the adjustments range from 7 to 30 percent. These radar estimates are believed adequate for hydrologic purposes.

149. The techniques for rainfall estimation using satellite sensors can be divided into three categories: (a) microwave models, (b) cloud growth rate models, and (c) cloud characteristics models. The microwave model relies on the fact that raindrops interact strongly with radiation where wavelengths are comparable to drop circumference. Against a cool background, rain areas have higher brightness temperatures for these wavelengths. For microwave sensors, problems in rainfall estimation occur because: (a) backgrounds are not always cool (especially over land), (b) microwave sensors are currently on board satellites in sun-synchronous orbits that give only twice-per-day coverage of a given area, and (c) the field of view of the sensors is so large that underestimation of the total rainfall often occurs. Cloud growth rate and characteristic models have been used to estimate rainfall with some success. For the cloud growth rate approach to rainfall estimation, as an example, the root

46

mean square (rms) error is about 49 percent when compared with radar results. However, both techniques lack a clear physical basis and, consequently, cannot be universally applied to all meteorological conditions.

150.   After considering the meteorological data requirements for military hydrology and evaluating the precipitation estimation systems, it was concluded that a weather radar would provide the necessary data at the lowest cost in the needed time frame.   An original US Air Force requirement (TAC ROC 28-69, dated 21 Apr 69) identified a radar that could satisfy most hydrologic requirements.   However, because of technical delays and cost overruns, this tactical unit has just recently been fielded.   Even now, a DVIP and minicomputer need to be added to the system to satisfy hydrologic data requirements.

151.   General specifications for a tactical weather radar system that could be used by the US Army are set forth; these may be considered and treated as recommendations:

a.   Based on antenna considerations and attenuation characteristics associated with different storm configurations, it is recommended that a 5.45-cm system with a 2-deg beamwidth be utilized.   This will provide reasonable accuracies and resolutions to a distance of almost 150 km.

b.   To meet wavelength and beamwidth requirements, a parabolic antenna approximately 2 m in diameter will be necessary.   The antenna should be housed in a radome for protection.

c.   Within limits, there are trade-offs between power output and receiver sensitivity.   Based on theoretical, empirical, and practical considerations, a transmitter power output of 250 kW and a receiver minimum sensitivity of -108 dBm should prove ideal.

d.   To process radar data with acceptable accuracy and speed, it is necessary that it be done in digital form.   For this purpose, a DVIP must be incorporated in the system.   With a pulse rate frequency of 414 and an antenna speed of 4 rpm, the DVIP should be capable of averaging eight samples per 2-km range bin and averaging 31 time integrations to produce a processor standard deviation of less than 1 dB.

e.   A scan converted and color display should be incorporated. This will provide a six-color-level TV display consisting of approximately 5- by 5-km pixels with the colors being representative of DVIP (rainfall intensity) levels.

f.   For the radar system to develop its full potential, an on-line minicomputer is a necessity.   The computer should be equipped with a keyboard entry and CRT display for data and program

47

modifications. A disc memory will be necessary for data and program storage.

152. It is recommended that a weather radar like that specified in this report be used to satisfy the immediate military hydrology requirements for precipitation data. All of the components of such a system are currently available and could be assembled to form an operational unit within a relatively short time frame. Further investigations should be made to establish the feasibility of using airborne weather radar systems to provide weather data to Army terrain teams.

153. Finally, it is recommended that cooperative field studies be conducted utilizing US Air Force Air Weather Service and National Weather Service personnel and weather radar systems. The objectives of these studies would be to: (a) demonstrate the feasibility of integrating radar-rainfalls into hydrologic forecasts, (b) develop the procedures and techniques for effectively utilizing radar-rainfalls, and (c) develop first-generation automated data processing procedures required for the near real-time forecasting of hydrologic conditions (state-of-the-ground and streamflow parameters) on the basis of weather radar data.

REFERENCES

Adler, R. F., and Rodgers, E. B. 1977. "Satellite-Based Case Studies of
Latent Heat Release in a Tropical and an Extratropical Storm," Draft Report.

Atlas, David. 1964. "Advances in Radar Meteorology," Advances in Geophysics,
Vol 10, Academic Press, N.Y., pp 318-478.

Barnes, S. L. 1964. "Techniques for Maximizing Detail in Numerical Weather
Map Analysis," Journal of Applied Meteorology, Vol 3, No. 4, pp 396-409.

Barrett, E. C. 1973. "Forecasting Daily Rainfall from Satellite Data,"
Monthly Weather Review, Vol 3, pp 215-222.

Battan, Louis J. 1973. Radar Observation of the Atmosphere, The University
of Chicago Press.

Brandes, E. A. 1975. "Optimizing Rainfall Estimates With the Aid of Radar,"
Journal of Applied Meteorology, Vol 14, pp 1,339-1,345.

Cheng, N., and Rodenhuis, D. 1977. "An Intercomparison of Satellite Images
and Radar Rainfall Rates," M.S. Thesis, University of Maryland.

Collier, C. G., Harrold, T. W., and Nicholass, C. A. 1975. "A Comparison of
Areal Rainfall as Measured by a Raingage-Calibrated Radar System and Raingage
Networks of Various Densities," Preprints, 16th Radar Meteorology Conference
(Houston), American Meteorological Society, Boston, pp 467-472.

Follansbee, W. A., and Oliver, V. J. 1975. "A Comparison of Infrared Imagery
and Video Pictures in the Estimation of Daily Rainfall from Satellite Data,"
NOAA Technical Memorandum NESS 62, US Department of Commerce.

Griffith, C. G., Woodley, W. L., Browner, S., Teijeiro, J., Maier, M., Martin,
D. W., Stout, J., and Sikdar, D. N. 1976. "Rainfall Estimation from Geo-
synchronous Satellite Imagery During Daylight Hours," NOAA Technical Report
ERL 356-WMPO 7, US Department of Commerce.

Griffith, C. G., Woodley, W. L., Grube, P. G., Martin, D. W., Stout, J., and
Sikdar, D. N. 1978. "Radar Extinction from Geosynchronous Satellite
Imagery--Visible and Infrared Studies," Monthly Weather Review, Vol 106,
pp 1153-1171.

Harrold, T. W., English, E. J., and Nicholass, C. A. 1974. "The Accuracy of
Radar-Derived Rainfall Measurements in Hilly Terrain," Quarterly Journal of
the Royal Meteorological Society, Vol 100, pp 331-350.

Hildebrand, P. H., Towery, N., and Snell, M. R. 1979. "Measurement of Con-
vective Mean Rainfall Over Small Areas Using High Density Raingages and
Radar," Journal of Applied Meteorology, Vol 18, pp 1316-1326.

Hiser, H. W. 1973 (Dec). "An Operational Guide for the AN/TPS-41 Radar,"
ECOM-0218-1, US Army Electronics Command.

Huebner, G. L. 1977. Radar Meteorology Class Notes, Texas A&M University, College Station, Texas.

_____. 1981. "Studies of Variations of Cell Parameters to be Exceeded to Confirm Certain Seeding Hypotheses," Proceedings of the 20th Conference on Radar Meteorology, American Meteorological Society, Boston, Mass.

Huff, F. A. 1970. "Sampling Errors in Measurement of Mean Precipitation," Journal of Applied Meteorology, Vol 9, pp 35-44.

_____. 1971. "Evaluation of Precipitation Records in Weather Modification Experiments," Advances in Geophysics, Vol 12, Academic Press, pp 59-134.

Huff, F. A., and Towery, N. G. 1978. "Utilization of Radar in Operation of Urban Hydrologic Systems," Preprints, 18th Conference on Radar Meteorology (Atlanta), American Meteorological Society, Boston, pp 437-441.

Jatila, E., and Puhakka, T. 1973a. "Experiments on the Measurement of Areal Precipitation by Radar, Geophysica, Vol 12, pp 103-125.

_____. 1973b. "On the Accuracy of Radar Rainfall Measurements," Geophysica, Vol 12, pp 127-140.

Kidder, S. Q., and Vonder Haar, T. H. 1976. "A Comparison of Satellite Rainfall Estimation Techniques over the GATE Area," Proceedings of the Symposium on Meteorological Observations From Space: Their Contribution to the First GARP Global Experiment, June 8-10, 1976, Philadelphia, Pa., pp 123-125.

Kilonsky, B. J., and Ramage, C. S. 1976. "A Technique for Estimating Tropical Open-Ocean Rainfall from Satellite Observations," Journal of Applied Meteorology, Vol 15, pp 972-975.

Klass, Philip, J. 1979. "Collins Paces Weather Radar Efforts," Aviation Week & Space Technology, Nov 26, pp 58-60.

Lovejoy, S., and Austin, G. L. 1979. "The Sources of Error in Rain Amount Estimating Schemes from GOES Visible and IR Satellite Data," Monthly Weather Review, Vol 107, pp 1048-1054.

Marshall, J. S., and Palmer, W. M. 1948. "The Distribution of Raindrops with Size," Journal of Applied Meteorology, Vol 5, pp 165-166.

Martin, D. W., and Scherer, W. D. 1973. "Review of Satellite Rainfall Estimation Methods," Bulletin American Meteorological Society, Vol 54, pp 661-674.

Matejka, T. J., Houze, R. A., Jr., and Hobbs, P. V. 1980. "Microphysics and Dynamics of Clouds Associated with Mesoscale Rainbands in Extratropical Cyclones," Quarterly Journal of the Royal Meterological Society, Vol 106, pp 29-55.

Op Digest. 1981. AWS Operations Digest, AWS/DOOF, Scott AFB, Ill., 62225, AWSRP 105-1.

Rao, M. S. V., Abbot, W. V., III, and Theon, J. S. 1976. "Satellite Derived Global Oceanic Rainfall Atlas (1973-1974)," NASA SP-410.

Savage, R. C. 1976. "The Transfer of Thermal Microwaves Through Hydrometers," Ph.D. Dissertation, University of Wisconsin, Madison.

Savage, R. C., and Weinman, J. A. 1975. "Preliminary Calculations of the Upwelling Radiance from Rainclouds at 37.0 and 19.35 GHz," Bulletin American Meteorological Society, Vol 56, pp 1272-1274.

Schofield, R. A., and Oliver, V. J. 1977. "A Scheme for Estimating Convective Rainfall from Satellite Imagery," NOAA Tech Memorandum No. 86, US Department of Commerce.

Sieland, Thomas E. 1977. "Real-Time Computertechniques in the Detection and Analysis of Severe Storms from Digital Radar Data, A Dissertation," Department of Meteorology, Texas A&M University, College Station, Tex.

Spilhaus, A. F. 1948. "Drop Size, Intensity and Radar Echo of Rain," Journal of Applied Meteorology, Vol 5, pp 161-164.

Stout, J., Martin, D., and Sikdar, D. N. 1979. "Estimating Rain with Geosynchronous Satellite Images," Monthly Weather Review, Vol 107, pp 585-598.

Trewartha, G. T. 1981. The Earth's Problem Climates. 2nd ed., The University of Wisconsin Press, Madison.

Wilheit, T. T., Rao, M. S. V., Chang, A. T., Rodgers, E. B., and Theon, J. S. 1975. "A Satellite Technique for Quantitatively Mapping Rainfall Rates Over the Oceans," NASA/GSFC X DOC, 911-75-72.

Wilson, J. W. 1970. "Integration of Radar and Raingage Data for Improved Rainfall Measurement," Journal of Applied Meteorology, Vol 9, pp 489-497.

_____. 1975. "Radar-Gage Precipitation Measurements During the IFYGL," CEM Report 4177-4546, The Center for the Environment and Man, Hartford, Conn.

_____. 1979. "Radar Measurement of Rainfall - A Summary," Bulletin American Meteorological Society, Vol 60, pp 1048-1058.

Woodley, W., Olsen, A., Herndon, A., and Wiggert, V. 1974. "Optimizing the Measurement of Convective Rainfall in Florida," NOAA Tech. Memo. ERL-WMPO-18, Boulder, Colo.

Wylie, D. P. 1978. "An Application of a Geostationary Satellite Rain-estimation Scheme to an Extra-tropical Area," Report to Department of Space Science, University of Wisconsin, Madison.

Table 1

Radar Areal Estimates of Rainfall Using Gages for Calibration (Adapted from Wilson 1979)

Reference	Location	Rain Type	Z-R Relation	No. Cases	Radar OBS Frequency (min)	Radar Range (km)	Area Size (km^2)	Duration	Adjustment Type and Calibration Gage Density (km^2/gage)	% Error After Adjustment
Wilson (1970)	Oklahoma	Thundershowers	KR$^{1.6}$	23	5-10	35-100	3500	Storm	Average 1200	30
Brandes (1975)	Oklahoma	Thundershowers	200R$^{1.6}$	9	5	45-100	3000	Storm	Average 900	13
Woodley et al. (1974)	Florida	Showers Thundershowers	300R$^{1.4}$	39	5	85-115	570	24-hr	Average 1600	30
Wilson (1975)	New York	Showers Stratiform Thundershowers	200R$^{1.6}$	41	10	95-112	170	24-hr	Variable 275	22
Harrold et al. (1974)	England	Showers Stratiform	200R$^{1.6}$	27	1	12-48	50-100	1-hr	Average 500	19
Collier et al. (1975)	England	Showers Stratiform	200R$^{1.6}$	13	1	12-48	700	3-hr	Variable 233	7
Jatila & Puhakka (1973 a, b)	Finland	Showers Thunderstorms	200R$^{1.6}$	6	5	18-28	180	Storm	Variable 180	23
Huff & Towery (1978)	Illinois	Showers Thunderstorms	300R$^{1.35}$	67	3	20-100	5300	30-min	Variable 150	17

Table 2

Satellite Precipitation Estimation Models

Developer	Application	Satellite/Sensor
	Microwave Model	
Wilheit et al. (1975)	Instantaneous rainfall	Nimbus/ESMR
Rao et al. (1976)	Average oceanic rainfall	Nimbus/ESMR
Adler and Rodgers (1977)	Latent heat release in cyclones	Nimbus/ESMR
Kidder and Vonder Haar (1976)	Diurnal rainfall characteristics	Nimbus/ESMR
Savage and Weinman (1975)	Instantaneous rainfall over land	Nimbus/ESMR
	Cloud Growth Rate Model	
Griffith et al. (1976)	Space/time integrated rainfall totals applied to various meteorological conditions	ATS or GOES/SSCC or VISSR
Martin and Scherer (1973)	Same as Griffith	GOESS/VISSR
	Cloud Characteristics Model	
Schofield and Oliver (1977)	Severe rain effects	GOESS/VISSR
Kilonsky and Ramage (1976)	Monthly rainfall	NOAA/SR
Cheng and Rodenhuis (1977)	Instantaneous rainfall	NOAA/SR
Follansbee and Oliver (1975)	Daily rainfall	ATS-3/SSCC
Barrett (1973)	Daily rainfall	Nephanalyses

Table 3

Advantages and Disadvantages of Various Rainfall Estimation Techniques (Satellite Sensors)

Techniques	Advantages	Disadvantages
Microwave	Precipitation detection	Low time sampling rate
	Based on physical principles	Low spatial resolution
	Instantaneous measurement	Difficulties with land background
Cloud growth rate	High time and space sampling	Requires time and space integrations to reduce noise (volume weighted)
	Adjustable to varying meteorological conditions	Mass transport processes obscured by cloudiness
	Based on physical cloud model	Questionable accuracy
Cloud characteristics	Can be photographically based	Physical models are lacking
	Provides for dynamic interpretation	Difficult to automate
	Can provide point forecasts	Questionable accuracy

Table 4

Comparison of the Error Statistics Obtained by Various Researchers in Satellite Rain Estimation (Lovejoy and Austin 1979)

Author	Follansbee and Oliver (1975)	Schofield and Oliver (1977)	Griffith et al. (1978)	Wylie (1978)	Stout et al. (1979)
Technique	Nephanalyses	History & synoptic data	Lifetime measurements	Expanding anvils	Expanding anvils
Region	Alabama, Georgia, South Carolina	North Carolina	Florida	Montreal	Gate
Size of area (km²)	10^5	10^5	10^4 / 10^5	10^4	6×10^3
Number of sequences examined	255	1	8 / 5	5	2 / 4
Number of data points used	255	4	53 8 37 43 / 55	35	219 329 69 / 8
Time of accumulation	Daily	6 hr	Hrly Daily Hrly Hrly / Daily	30 min	30 min 1 hr 6 hr
Type of data used	VIS IR Both	IR & VIS	VIS VIS IR / VIS IR	VIS IR	VIS IR IR
E_{rms}	1.31 1.51 1.22	0.44	-- -- 2.70 / -- --	0.58 0.46	.62 .76 .32 .23
B	-- --	1.18	1.11 .83 1.15 / 1.13 1.90	-- --	-- -- -- --
E_R	-- --	1.86	2.61 2.61 2.38 3.71 / 1.39 1.95	-- --	-- -- -- --

Table 5

DVIP Specifications (Minimum)

Bin size	2 km
Maximum range	450 km
Number of bins	225
Integration factor	31
Accuracy	Better than 1 dB
Range blanking	Variable 0 to at least 30 km
Range normalization	Corrected for range over 20 to 230 km on displayed video. (Can also put corrected 8-bit words into computer if design calls for data input from this source.)
Digital outputs	To be determined by needs of entire system as designed. The normal digital products would include the following: - 8-bit transistor-transistor logic uncorrected integrated video - Data ready flag - Range interval monitor if needed - Time sample monitor if variable sample - IF attenuator bypass monitor - Sensitivity time control active monitor if needed - Test mode monitor
Displayed video	Normal log or contoured log
Displayed contoured log levels	2-cycle, 3-level form at: Level 1 - Gray Levels are Level 2 - White individually Level 3 - Black set to any Level 4 - Gray gate level Level 5 - White with 8-bit Level 6 - Black definition
Remote outputs	Separate from main video output
Inputs	Log video Radar system trigger
Test inputs (internal)	Necessary ramp, etc., signals for maintenance

APPENDIX A: METEOROLOGICAL DATA REQUIREMENTS LETTERS

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P.O. BOX 631
VICKSBURG, MISSISSIPPI 39180

REPLY TO
ATTENTION OF

DAEN-RDM

SUBJECT: Meteorological Research for Tactical Hydrological Forecasting

Commander
U. S. Army Materiel Development
  and Readiness Command
5001 Eisenhower Avenue
Alexandria, VA 22333

1. Reference:

    a. Joint Regulation AR 115-10/AFB 105-3, Weather Support to the
U. S. Army.

    b. AR 115-20, Statement of Requirements for Direct Weather Service
Support.

    c. AR 115-21/AFB 105-10, Military Hydrology.

    d. DF from DAEN-ZCM to DAMI-ISP dated 28 April 1980, subject, Meteorolog-
ical Data Requirements in Support of Army Tactical Hydrology (Incl 1).

2. The Chief of Engineers is assigned responsibility for providing military
hydrology information to the Armed Forces. This involves trafficability and
flood forecasts which require mesoscale (tactical) meteorological inputs. It
is critical that Army terrain units receive these meteorological data in a
timely fashion so that near real-time forecasts of the impact of hydrologic
conditions on military operations can be made. The specific meteorological
data requirements for tactical hydrological forecasting are presented in
reference d.

3. Currently, available meteorological support to Army terrain teams is not
adequate to provide the needed data. It is requested that the U. S. Army
Materiel Development and Readiness Command provide support to upgrade the Army
meteorological capability. Assistance is needed in the form of long-term
research on meteorological data acquisition and forecasting techniques and
short-term cooperative efforts with the Corps of Engineers to evaluate the
applicability of existing state-of-the-art meteorological measurement/
monitoring systems. Items of immediate interest include the applicability of
existing battlefield radar systems for meteorological applications, evaluation

DAEN-RDM
SUBJECT: Meteorological Research for Tactical Hydrological Forecasting

of an advanced Air Force Tactical Weather Radar (TPS-69) for providing Army
tactical precipitation data needs, evaluation of existing satellite capabili-
ties for estimating precipitation rates, advancement of satellite weather
monitoring capabilities, and remote measurement of surface weather conditions.

1 Incl
as

DISPOSITION FORM

For use of this form see AR 340-15; the proponent agency is TAGO

REFERENCE OR OFFICE SYMBOL	SUBJECT
DAEN-ZCM	Meteorological Data Requirements in Support of Army Tactical Hydrology

TO	FROM	DATE	CMT 1
DAMI-ISP	DAEN	28 Apr 80 Mr. Swain/52111/jl	

1. References:

    a. AR 115-10/AFR 105-3, Weather Support to the US Army.

    b. AF 115-20, Statement of Requirements for Direct Weather Service Support.

    c. AR 115-21/AFR 105-10, Military Hydrology.

2. The purpose of this memorandum is to provide a statement of meteorological data requirements to support Army tactical hydrological forecasting activities. It is requested that your office make arrangements with the Air Force to provide these meteorological data to the Army.

3. The references cited in paragraph 1 above assign responsibilities to: the Army Corps of Engineers for initiating hydrology support to the Services (to include R&D and support of operational elements); and, the Air Force for providing meteorological information that is needed to support the Army's hydrological efforts.

4. As you know, the Army is reorganizing its direct support terrain teams and forming new terrain teams for division support which are to be activated by September 1980. These teams, in carrying out their terrain analysis mission, will provide information on soil trafficability (cross country movement) and river crossing (bridging, fording sites) which requires mesoscale (tactical) meteorological and hydrological input. Inclosure 1 is a draft statement of Army requirements (SOR) for Air Force weather service data necessary to support the requirements of these terrain teams and Army tactical hydrological forecasting. This SOR will be expanded as necessary as we gain a better understanding of the total military hydrological requirements of field commanders. It is critical that Army terrain units receive these meteorological data which will be processed into near real time terrain intelligence products utilized by tactical commanders for planning and operations. Broadly speaking, these data requirements must, at a minimum, provide sufficient, timely information for an interpretation of weather forecasts, observations and climatological data in terms of impact on particular types of military operations.

5. Your assistance in making arrangements with the Air Force to provide the meteorological information outlined in Incl 1 in support of Army tactical hydrology is appreciated. Office Chief of Engineers (OCE) POC is Mr. Walter Swain, DAEN-ZCM, Telephone 695-1125.

FOR THE CHIEF OF ENGINEERS:

1 Incl   BERNARD C. HUGHES
as   Colonel, CE
                                                Chief, Military Engineering Division
CF: RDM, WES, ETL
    ASL

WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
PO BOX 631
VICKSBURG, MISSISSIPPI 39180

REPLY TO
ATTENTION OF

WESEN   22 MAY '80

SUBJECT: Meteorological Research for Tactical Hydrological Forecasting

HQDA (DAEN-RDM/Dr. Coke DePercin)
WASH DC 20314

1. Reference:

    a. Joint Regulation AR 115-10/AFR 105-3.

    b. DF from DAEN-ZCM to DAMI-ISP dated 28 April 1980, subject,
Meteorological Data Requirements in Support of Army Tactical Hydrology.

    c. WESEN MFR dated 27 September 1979, subject: Meteorological
Capabilities and Requirements in Military Hydrology.

2. Reference a places responsibility on the Army Engineer Field Units for the
forecasting of trafficability and river stage conditions. Pursuant to that
responsibility, the Corps of Engineers has established the Military Hydrology
Research Program being directed by the U. S. Army Engineer Waterways Experi-
ment Station (WES) for the purpose of upgrading Army doctrine and procedures
in Military Hydrology.

3. The research effort has identified certain shortfalls in the present doc-
trine and steps necessary for the elimination of these shortfalls. One of the
more serious shortfalls is the lack of adequate weather information available
to Engineer Terrain units. As a result, the field Army's capability for river
stage and flood forecasting is substantially inferior to that potentially fea-
sible with off-the-shelf technology. Specific meteorological data require-
ments for Army tactical hydrological forecasting are given in reference b.

4. As described in reference c, state-of-the-art technology in the form of
weather radar and satellite sensors can potentially provide useful data for
tactical hydrologic applications. In addition, work previously accomplished
at the Atmospheric Sciences Laboratory (ASL) concerning remote surface weather
measurement devices is relevant to engineer meteorological data needs. The
ASL has an in-house expertise to conduct both short- and long-term research in
the areas of tactical meteorology. It is recommended that the ASL be tasked
through the U. S. Army Materiel Development and Readiness Command (DARCOM) to

conduct the necessary research to investigate the applicability of existing
and emerging technology to upgrade Army meteorological capability and to
advance Army capabilities for the future. A draft letter to DARCOM is
attached (Incl 1) for your consideration.

5. Communications with the ASL personnel (Dr. Rachelle and Mr. Fred Horning)
indicate that the ASL is anxious to do this type of work and has a unique
expertise within the Army to do so. Point of contact at the WES for more
information is Dr. Lewis E. Link at telephone number 601 634-2606.

FOR THE COMMANDER AND DIRECTOR:

1 Incl   F. R. BROWN
as   Engineer
                                                Technical Director

REPLY TO
ATTENTION OF

DAMI-ISP   20 May 1980

SUBJECT: Meteorological Data Requirements in Support of Army
          Tactical Hydrology

Commander
US Army Training and Doctrine
  Command
ATTN: ATCD-IE
Fort Monroe, VA 23651

1. Attached statement of requirements (SOR) for meteorological data in support
of Army tactical hydrology was forwarded to this office by the Chief of Engi-
neers. It represents an attempt to define specific weather data, in terms of
parameters and accuracy, which is required now by field units to provide tacti-
cal hydrological forecasting for military operations.

2. This SOR has been forwarded to Headquarters, Department of the Air Force,
to inform Air Weather Service (AWS) of the data requirements, and to request
that AWS provide those portions of the data which are an Air Force
responsibility.

3. Data requested in Paragraph 1,B (Surface Weather Observations) is an Army
responsibility. Therefore, request TRADOC take action to establish a capabil-
ity for remote weather observations from silent, or enemy-held areas, if no
such capability presently exists. Capability for observation of Solar Insola-
tion should also be established.

4. Further information on this SOR may be obtained from Dr. L. E. Link, Water-
ways Experiment Station, Vicksburg, Mississippi, telephone commercial
(601) 636-3111, Ext 2606.

FOR THE DIRECTOR OF INTELLIGENCE SYSTEMS:

1 Incl   THOMAS J. HOGAN
as   Colonel, GS
                                  Chief, Imagery Intelligence
                                    Division
CF: USAASL
     USAEWES

STATEMENT OF REQUIREMENTS OF METEOROLOGICAL DATA
FOR ARMY TACTICAL HYDROLOGICAL FORECASTING

The following elements of meteorological data, in units, accuracies and timeliness as stated, are required for input to Army models of tactical hydrological conditions. These models will be used to produce tactical forecasts of river stage and flood, and soil trafficability. This meteorological data will also provide valuable input to Army terrain analysis teams production requirements.

1. Observations:

  A. Precipitation

    (1) Intensity, in terms of accumulation on the surface, mm/hr, with an accuracy of ±25% of actual accumulation.

    (2) Areal coverage, over a 100 $\overline{KM}$ radius, with spatial resolution of ±20% or 5KM².

    (3) Rate and direction of movement of areas of precipitation. Direction to the nearest 20° of azimuth. Rate of movement in meters per second, with an accuracy of ±10%.

    (4) Frequency of measurement, every 30 minutes.

    (5) Timeliness of information: Available to hydrologist in pictorial form, within 30 minutes after observation.

  B. Surface Weather Observations

    (1) Coverage: Weather observations currently available on the battlefield will provide adequate surface weather data, in terms of data elements and accuracy.

    (2) Solar Insolation: Measurements of solar insolation, in hourly averages, with an accuracy of ±25% are required.

2. Forecasts:

  A. Time Intervals: Forecasts for 4, 12, and 24 hours are required at 4 hour intervals.

  B. Areal coverage forecasts should cover the area within a 100 KM radius.

  C. Data Elements: Forecasts should include:

    (1) Those data elements normally included in Standard Surface Weather Observations, IAW Federal Meteorological Handbook #1.

    (2) Precipitable water content and potential precipitation.

Incl 1

(3) Air mass and frontal characteristics.

(4) Speed and direction of frontal movement.

(5) Temperatures for next 24 hours at 4, 12, and 24 hour intervals.

(6) Surface wind speed and direction.

END

FILMED

12-85

DTIC