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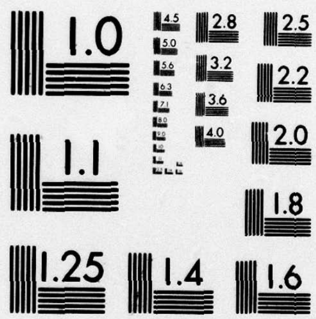
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MISCELLANEOUS PAPER EL-79-5

THERMAL MODELING OF BATTLEFIELD SCENE COMPONENTS

by

Lewis E. Link, Jr.

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

November 1979

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for U. S. Army Electronics Research and Development Command
Night Vision and Electro-Optics Laboratory
Fort Belvoir, Va. 22060

Supported in part by Department of the Army Project No. 4A762730AT42
Task A4, Terrain/Operations Simulation
Work Unit 003, Electromagnetic Target Surround
Characteristics in Natural Terrains

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper EL-79-5	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THERMAL MODELING OF BATTLEFIELD SCENE COMPONENTS.		5. TYPE OF REPORT & PERIOD COVERED Final report. 9 May-31 Dec 77
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Lewis E. Link, Jr		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project No. 4A762730AT42 Task A4, Work Unit 003
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Electronics Research and Development Command, Night Vision and Electro-Optics Laboratory Fort Belvoir, Va 22060		12. REPORT DATE November 1979
		13. NUMBER OF PAGES 100
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 12 118		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)

14 WES/MP/EL-79-5

18. SUPPLEMENTARY NOTES

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

Army-Wide Signature Program
Battlefield signatures
Climate
Electro-optical devices
Environmental models
Military operations
Sensors
Signatures
Target designators
Temperature
Terrain factors
Thermal models

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

The work reported herein addresses the battlefield signature modeling part of the Army-Wide Signature Program, and in particular the ability to consider quantitatively the effect of battlefield environmental conditions on the performance of electro-optical surveillance and target acquisition devices. An initial capability was developed to estimate the ranges of temperatures that can occur over the diurnal cycle for specific terrain features and climatic conditions. The capability consisted of formulating a generalized terrain data base

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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20. ABSTRACT (Continued).

for the Federal Republic of Germany (FRG), a representative climatic data base derived from measured weather data, and models for predicting time-dependent temperature histories for selected terrain surface conditions. The terrain and climatic data bases are presently interfaced with the temperature models (individual models for terrain surface features and vegetation components) by a matrix concept for selecting quantitative values for the model input parameters. A variety of model output products is presented for selected terrain features in the Fulda, FRG, area for winter and summer climatic conditions. A recommended plan for future research was formulated and is presented in the report.

PREFACE

The study reported herein was conducted by personnel of the U. S. Army Engineer Waterways Experiment Station (WES) from 9 May 1977 to 31 December 1977. The study was authorized in Project Order No. 27056, dated 9 May 1977, from the Commander, U. S. Army Electronics Research and Development Command, Night Vision and Electro-Optics Laboratory, Fort Belvoir, Virginia, to the Commander and Director, WES, and supported by Department of the Army Project No. 4A762730AT42, Task A4, Terrain/Operations Simulation, Work Unit 003, Electromagnetic Target Surround Characteristics in Natural Terrains.

The study was conducted under the general supervision of Messrs. W. G. Shockley, Chief of the Mobility and Environmental Systems Laboratory, and B. O. Benn, Chief of the Environmental Systems Division (ESD), and under the direct supervision of Dr. L. E. Link, Jr., Chief of the Environmental Research Branch (ERB). The ESD and ERB are now part of the Environmental Laboratory of which Dr. John Harrison is Chief. Dr. Link prepared this report.

Acknowledgment is made to Mr. J. R. Lundien for technical assistance in the conduct of the study and to Messrs. Erwin Baylot, ERB, Cary Cox, Instrumentation Services Division (ISD), WES, and Dan Kimes, Colorado State University, for their efforts in the temperature modeling aspects of the study. Mr. Alfonso Vazquez and SP5 George Radu, ERB, and Mr. Don Tingle, ISD, were responsible for the preparation of the inclosed terrain maps for West Germany.

Director of the WES during the conduct of the study and preparation of the report was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	0.555	Celsius degrees or Kelvins*
feet	0.3048	metres
knots (international)	0.514444	metres per second
miles (U. S. statute)	1.609344	kilometres
miles (U. S. statute) per hour	1.609344	kilometres per hour

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (0.555) (F - 32).

THERMAL MODELING OF BATTLEFIELD SCENE COMPONENTS

PART I: INTRODUCTION

Background

1. The Army has a fundamental need to develop advanced imaging and nonimaging electro-optical (E-O) sensors for surveillance, target acquisition, and terminal homing systems as well as for maintaining up-to-date criteria for countermeasures and camouflage. It is impractical to physically test the performance of existing and conceptual sensor systems against the variety of scenarios within which they are expected to operate. It is essential, however, that the worldwide tactical environment be considered over its complete spectral and spatial range for sensor design criteria and performance standards.

2. The Army-Wide Signature Program (AWSP) of the U. S. Army Materiel Development and Readiness Command is addressing the need for a target-surround (i.e., terrain background) design data base for sensor design and evaluation through a three-part program. The first part deals with the development of a battlefield signature model that will allow extrapolations of target and background signatures to varying environmental, climatic, and seasonal conditions throughout the world. The second area deals with updating a tactical signature library to fill critical gaps in the existing Army empirical signature data base that is used in equipment design or analyses studies. The third program area deals with susceptibility analyses and is designed to ensure that vulnerability of all Army missiles, aircraft, vehicles, and supporting tactical equipment is known so that effective means of camouflage can be brought to bear.

3. Work on the battlefield signature model part of the AWSP has resulted in considerable progress in the area of computer models and submodels for predicting the performance of surveillance, target acquisition, and terminal homing sensor systems and target signature

modeling. The target models have ranged from simple to complex. The more sophisticated approaches use combinatorial geometry concepts for providing realistic geometric descriptions of targets. Since both the target and target surround have to be dealt with simultaneously in a battlefield scenario, a compatible and equally capable target-surround modeling procedure is needed. To date, the target has received considerably more attention than its surrounding components.

Objective and Scope

4. The objectives of this study were to (a) define a research approach in developing a realistic target-surround signature data base for use in the design and evaluation of imaging and nonimaging sensors for surveillance, target acquisition, and terminal homing devices and (b) develop procedures for predicting terrain surface temperatures of typical components of battlefield environmental settings with special emphasis on the Federal Republic of Germany (FRG). The work consisted of formulating terrain and climatic data bases for the FRG, assembling computer models for predicting the diurnal temperatures of broad classes of terrain components as a function of climatic conditions, and developing a matrix for integrating the FRG data bases and the temperature models to provide the initial capability to predict expected temperature ranges for terrain surface features under a variety of battlefield scenarios.

5. The approach developed for use in this study is presented in Part II of the report and is followed by a discussion of the individual work elements accomplished (Part III). In some instances supplementary details on the work accomplished are presented in Appendixes A and B. Part IV of the report presents a demonstration of the utility of the products developed, and Part V is a plan that outlines recommended research requirements for future efforts. Funding and time estimates for the recommended research are included.

PART II: APPROACH

Overview

6. The approach presented herein is directed toward the capability to predict representative temperature ranges for general classes of terrain surface features from simplistic, but representative, terrain and climatic data bases. As such, it is an integral part of the larger concept of simulating battlefield environments for E-O sensor design criteria and performance evaluation. The logical extension of the products of this work is the integration of the temperature prediction capability with signature, atmosphere, and sensor performance models to allow simulation of the interaction of the battlefield environment and surveillance, target acquisition, and terminal homing operations.

Presentation and Discussion of Approach

7. Figure 1 presents a schematic representation of the approach followed in this work effort. The approach can be divided into four major parts for discussion: data base development (blocks 1 and 2), scenario definition (blocks 3 and 4), temperature modeling (block 5), and products (block 6). The following paragraphs discuss these major parts individually.

Data base development

8. Terrain and climate are the two basic categories of information required to predict temperature ranges for terrain surface features. The terrain features of interest are those that influence the appearance of the terrain to a thermal sensor system, i.e., those features that may have unique thermal histories over a diurnal cycle given some set of climatic conditions. The climatic data of interest are the time histories of the meteorological parameters that can significantly influence the temperatures of the terrain surface.

9. Terrain data (block 1). The terrain data base ideally should include the distribution of those terrain surface types expected to have

unique thermal properties. For example, a bare soil area and an area of pasture would be expected to have different temperature histories over the diurnal cycle because of their significantly different material properties. Grass-covered areas also have a more complex surface geometry than a bare surface--another important factor in the thermal energy balance. Woody vegetation would present an even more complex geometric situation and also introduces the added variables of stem spacing and density on a larger scale.

10. It is certainly not practical to obtain data for the complete diversity of terrain features that have different material and geometric properties (i.e., having different thermal properties). It is necessary to use some practical scheme that allows some of the variability to be collapsed into similar classes of features. The number of classes should be selected by considering the spectrum of conditions that can occur and lumping items that would be expected to have similar thermal characteristics. It is almost certain that all the tree species shown in Figure 2 would not have to be considered; however, presently there is insufficient data to make the assumption that deciduous and coniferous categories alone are adequate.

11. Constraints on developing a terrain data base include the extent of available data, resources for acquisition of new data, the size of the area of interest, and, of course, the specific needs of the analytical models used to predict temperature values. It is extremely important to note that although generalized terrain types may comprise the bulk of a data base for a large area, it is necessary to attach quantitative values for thermal coefficients and geometric descriptors to the specific components of each terrain type before meaningful temperature predictions can be attempted. In many instances, the lack of resources for acquiring new data makes the available data, regardless of its adequacy, the source of a bulk of the data base. This places a burden on the user to transform those data into the quantitative coefficients required by the temperature prediction models.

12. Climatic data (block 2). The energy budget of terrain surface features is strongly influenced by diurnal and seasonal

meteorological conditions. Parameters such as air temperature, solar insolation, wind speed, relative humidity, and cloud cover are the driving forces of the energy budget. The interactions of the meteorological phenomena and material and geometry characteristics of terrain features result in the thermal regime of the earth's surface. The meteorological parameters are, for the most part, strongly interrelated and, as such, must be considered in combination rather than individually. The climatic data base, then, requires correlative meteorological data over some time interval, not individual statistical averages such as mean monthly air temperature.

13. Temperature predictions require correlative meteorological parameters over diurnal cycles. The diurnal cycle variation is needed because of the significant changes in meteorological conditions, and hence, terrain surface temperatures that characteristically occur over that time frame. The diurnal cycle data should be representative of monthly or seasonal conditions that occur in the area of interest for temperature predictions. The useful range of variability would probably be encompassed by three sets of meteorological data, each consisting of all factors through a diurnal cycle. Each set would consist of a "maximum," an "average," and a "minimum" condition for each month. These data would provide one "typical" and two "extreme" conditions for each month, thus ensuring that all significant variability within a yearly cycle would be incorporated in predicted temperature values for terrain features.

14. Ideally, meteorological data recorded in the immediate area of interest would provide the best information for temperature predictions. This constraint can seldom be satisfied, resulting in the need for a methodology to acquire the most representative data available. The first step in this process is to locate and catalog available meteorological data sources (i.e., weather stations). Given the locations of the weather stations, it is then useful to have a summary of the types of data available for each and a statistical summary of the meteorological parameter values. The statistical data summary coupled with the terrain data (block 1) would allow cross-comparisons of

available meteorological data to acquire those data most meaningful for predicting temperatures of selected terrain components.

Scenario definition (blocks 3 and 4)

15. Scenario definition concerns the interface between the generalized terrain and climatic data bases (blocks 1 and 2) and the temperature prediction models (block 5). It involves both defining the specific terrain features and climatic conditions for which temperature histories need be predicted and formulating the quantitative inputs to the models from the quantitative and qualitative information in the data bases. Both steps at times require information beyond that provided in the generalized terrain feature distribution and climatic data bases.

16. Terrain feature selection-quantification (block 3). The terrain features (or conditions) for which temperature predictions need be made are those that dominate the landscape and those that might mask or be mistaken as a tactical target. Selecting these features requires (a) combining the individual terrain surface descriptors (required in the temperature prediction models) available in the terrain data base, (b) determining which individual features (e.g., trees, roads, buildings, etc.) and associations of features occur most frequently, and (c) determining those that appear to be tactical targets. The latter process can be accomplished to a large extent from a study of topographic maps and large-scale aerial photographs. However, specific features may have to be inferred from more general terrain classes. For example, the general terrain class "forest" may be interpreted to mean coniferous trees of a specific species for a given portion of the world where that species is dominant. The knowledge leading to that decision may or may not be included formally in the data base.

17. Quantification of terrain feature descriptors is essential to the analytical modeling effort. A sandy loam soil area, for example, must be described in terms of its thermal properties (conductivity and diffusivity) and geometry (roughness and thickness) for modeling. Thus, a methodology must be available to make these conversions in a consistent and realistic way.

18. <u>Meteorological conditions--selection-quantification (block 4)</u>. The ideal situation would be to select a specific, "representative" set of meteorological inputs to the temperature prediction models for each terrain-climate scenario to be modeled. This implies the availability of representative data for any location and climatic situation (season and weather). Of course, these data are not usually available. The task then becomes selecting from the available meteorological data those data most representative of the conditions to be modeled. If a weather station is located in the immediate vicinity of the area of interest, the selection is easy, unless that station cannot provide all the necessary information. In that case, the surrounding weather stations and those in similar terrain situations become candidates for sources of data. Selection of the specific data used from these "secondary" sources must be done carefully to ensure, as much as possible, that "correlated" model inputs are obtained. For example, solar insolation data obtained from a station for a day with partially cloudy skies would not correlate well with clear sky meteorological parameter values.

19. Specific meteorological conditions selected for modeling should represent the range of conditions that can occur in the location of interest for specific times of interest (i.e., times of the year). The number of times-of-year used should be selected on the basis of the magnitude of the changes in meteorological conditions over the yearly cycle, and, as such, is site-dependent.

20. If all meteorological data inputs to the temperature prediction models are not available in the data base (block 2), specific "likely" values that can be related to the values of the known parameters could be substituted. A prepared set of likely diurnal cycle situations would be most advantageous for this purpose and would promote consistency in the model predictions.

<u>Temperature modeling (block 5)</u>

21. The ability to transform the basic data inputs to predicted temperatures rests within the mathematical relations that comprise the temperature prediction models. The quality of the temperature

predictions will be a function of both the quality of the inputs and the ability of the mathematical relations to describe (simulate) the energy budget of surface terrain features.

22. Two temperature prediction models are deemed necessary, one for the terrain surface itself and one for vegetation. Cultural features such as roadways and buildings may be modeled with the same code used for the terrain surface materials. Vegetation is separated from the other features because of the unique and complex geometric characteristics that influence the energy budget of vegetation.

23. Terrain surface model. The terrain surface materials temperature model should be structured to allow simulation of both simple and complex situations. A simple situation might be a nonvegetated area with deep uniform soil. A more complex situation might be a roadway with a paved surface underlain by a roadbed and, beneath that, natural soil. As such, the model should handle multiple layers and be able to simulate the energy transfer mechanisms that occur both at the air-terrain surface and between the subsurface layers.

24. Ideally, the model should use easily acquired or readily inferred input parameters. This may not be feasible with the multiple-layer requirement, nor with the need to consider all of the major energy exchange phenomena that can occur. For example, the ability to simulate shadowing caused by topography (and vegetation) will be especially important for the realistic portrayal of terrain feature associations as they would appear to a specific thermal infrared (IR) sensor system. Demands for hard-to-get inputs can be satisfied by prior consideration of the range of values that are possible for these parameters and guidance for selecting "approximate" values for input to the models when measured data are not available.

25. Vegetation model. A vegetation model must incorporate both material and complex geometry effects to simulate the major energy exchange phenomena that influence the thermal regime of vegetation. Grasses have fairly uniform material properties, but the multitude of blade orientations and sizes create a very complex geometry from two perspectives. First, each grass blade is surrounded by many other

grass blades that are potential sources of radiant energy, and, secondly, the grass blades together form a very complex and irregular surface that can affect the energy exchange phenomena in many ways. Going a step beyond temperature prediction, the complex geometry of vegetation can significantly influence its IR signature with respect to surrounding terrain materials.

26. Trees present a slightly different situation in that the leaves or needles can have different material characteristics than the woody branches and stems. The same canopy geometry phenomenon as discussed for grasses must be considered.

27. The vegetation temperature model should be multidimensional in that the temperature of the vegetation components at different positions (e.g., top, bottom, sunny side, shaded side) may be of interest. In a uniform forest, a two-dimensional, layered model may be sufficient; however, when trees occur in solitude or are widely spaced, a three-dimensional model will be required. The level of sophistication needed can be determined by comparison of predicted values with measured data and close scrutiny of the vegetation component temperature data.

Products (block 6)

28. The products derived from the temperature prediction models are, of course, a function of the inputs. A useful initial product is a plot of the expected diurnal temperature ranges that would occur for each specific terrain feature modeled, given the prescribed meteorological conditions. Figure 3 provides an illustration of such a product and illustrates how predicted ranges of target temperatures could be easily compared to derive potential target-surround temperature differences as a function of time of day. It should be emphasized at this point that time of day is a very important dimension to add to the target-surround comparison because of the rapid and significant temperature fluctuations that some terrain materials experience over the diurnal cycle.

29. The time frame of the products could be weekly, monthly, or seasonal depending on the resolution desired and the fluctuations in meteorological conditions that occur in the area of interest. A possible criterion would be the use of monthly predictions for "high" resolution

and seasonal predictions for "low" resolution, unless otherwise warranted. For example, climatic variations in tropical areas may not even require "seasonal" considerations.

30. For a given month or season, it is anticipated that diurnal temperature histories should be determined for the extremes of conditions that can occur and for some "typical" or "average" condition. The selection of the "typical" or "average" condition should be done with much care and consideration because this condition represents a "statistical" situation that perhaps does not occur frequently on a real-life basis.

PART III: DATA BASE DEVELOPMENT, SCENARIO DEFINITION, AND MODEL ASSEMBLY

Introduction

31. The following paragraphs discuss WES efforts to provide an initial capability for predicting representative temperature values for general terrain types with special emphasis on the FRG. The specific work elements were designed to provide an initial data base for the FRG, criteria for scenario definition, and temperature prediction models, as outlined in the approach in Part II of this report. Work accomplished with respect to these parts of the approach, blocks 1-5 in Figure 1, is discussed in the following paragraphs.

Data Base Development

Terrain data

32. A set of generalized terrain maps were prepared for the FRG using available information. As such, the resulting products are a compromise between data available and the specific terrain conditions or features considered to have the most impact on the terrain surface thermal regime. Nevertheless, the products, four 1:1,000,000 scale maps showing the distribution of landforms, soils, vegetation, and urban areas, were prepared to consolidate information from existing sources. This included combining information from several sources or collapsing map categories into fewer more meaningful (i.e., to thermal phenomena) categories for the final map products. The map legends for the individual maps are presented in Tables 1-4. The maps and details on their preparation are presented in Appendix A.

33. The major terrain classes of landforms, soil type, vegetation type, and urban area distribution were selected as those general features that would most influence the performance of an E-O sensor system. Within each major class, the individual map classes were chosen intuitively to consolidate the information available from all sources

and to show their variation over the area of interest (FRG). Data on maps such as those presented in Appendix A cannot be used directly in E-O sensor system simulation studies because of the general classes of information presented. For this reason, an effort was initiated to acquire information that can be used in conjunction with the general information on the maps to provide quantitative inputs for the temperature prediction models. For example, some of the primary physical parameters required to predict vegetation component temperatures are absorptivity, emissivity, leaf dimension in direction of wind flow, and leaf resistance to water vapor diffusion.

34. Acquisition of these types of detailed data involves preparing a tabular summary or "matrix" of values that can occur for those physical and thermal properties that must be modeled to predict surface temperature. Figure 4 shows an example of a matrix form developed for the vegetation parameters needed to predict the surface temperature of this terrain component. The vegetation element (column 1) is a unique grouping of the numerical quantities of all the properties required for a prediction of a qualitatively described vegetation type, e.g., grassland. The qualitative description should be relatable to a comprehensive vegetation classification system such as Küchler's.[2] The scheme provides for assembling the vegetation on single or multiple layers. Also, tables and figures can be used to describe complex parameters such as those identified in columns 5, 7, 16, and 17. The data shown for elements 11-15 are those parameters needed to predict leaf surface temperature. The remaining portion of the form would have to be completed if temperatures representative of total vegetation assemblages (e.g., a tree canopy) were to be predicted. The matrix must be compiled inferentially from the literature and field measurements. Table 5 presents some very general guidance for solar absorptivity (α) and thermal emissivity (ε) values for general vegetation types. Keep in mind that vegetation component (e.g., a leaf) values of α and ε will differ from such values for a vegetation canopy. Leaf dimension (or needle) data were not accumulated. Data on leaf resistance to water vapor diffusion are presented in Table 6.

35. Once the matrix is completed it will be simplified by grouping similar quantities of each parameter irrespective of the qualitative classification, providing this lumping does not result in significant changes in the predicted temperatures. Definition of optimum ranges to provide the desired information for E-O sensor studies will be accomplished by a systematic sensitivity study. The relation of the resulting vegetation elements to worldwide environments must be established by relating the qualitative classifications (column 18, Figure 4) to the legend description of available vegetation maps. For example, the vegetation characteristics listed in Element 2 (grassland), Figure 4, would probably closely parallel the grass portion of vegetation class No. 3, shown on the vegetation map prepared for West Germany, Appendix A.

36. A similar matrix is under development for terrain surface materials (see Figure 5). For example, soil type has significant influence on the terrain surface thermal regime, and a table (Table 7) was adapted from the literature[3] that relates general soil type, moisture content, and density to thermal conductivity and diffusivity. Thermal conductivity and diffusivity are the primary soil properties that influence the energy balance in soils. A similar but less detailed summary for common rock and soil types is given in Table 8. General values of emissivity for soils and rock are given in Table 9. The soil and rock classes used in Tables 7, 8, and 9 are not similar because they were derived from different sources. Absorptivity data for soils are somewhat difficult to portray because the absorptivity varies with wavelength with changes in the soil color and moisture content. A very generalized table of ranges of values for absorptivity of soils, rock, and other surfaces over the visible and near-infrared spectral band (0.4-1.0 μm*) are given in Table 10.

37. A similar matrix concept has not been formulated for landform and urban area data. However, the landform types are useful to quantify shadowing and the relative orientation of the terrain surface and

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* A table of factors for converting U. S. customary units to metric (SI) units is presented on page 3.

incoming solar energy for energy budget considerations; however, no quantitative transforms have been established, to date, to systematically include these effects in the modeling efforts. Urban areas in the FRG are rapidly expanding, and it is well known that urban landscapes will be extensively represented in any future conflict in that area. Target-surround data in this environmental setting should have much more emphasis.

Climatic data

38. The primary climatic data products produced were a map showing the location and distribution of all reporting weather stations for the FRG, a summary of the types of data available from each weather station, statistical summaries of previous meteorological data collected at selected stations, and correlative meteorological data from six selected stations for use in temperature modeling efforts.

39. Map and summary of meteorological data. A search was made to identify available meteorological data for the FRG. The result of this effort was a map showing the locations of 92 reporting weather stations in the FRG and a tabular summary of the types of data available from each weather station. A description of the search, the maps, the tabular data summaries, and a list of references and relevant discussions for each are presented in Appendix B.

40. Statistical data summaries. Statistical data summaries were acquired for the Bremenhaven, Hannover, Wasserkuppe, Grafenwohr, Ramstein, and Munich weather stations. The summaries were supplied by the U. S. Air Force Environmental Technical Applications Center (ETAC), Air Weather Service, Scott Air Force Base, Illinois. The summaries acquired were forwarded to the U. S. Army Night Vision Laboratory (NVL) for their retention.

41. Correlative meteorological data. Computer-compatible magnetic tapes containing detailed weather data for six weather stations (Kiel, Hamburg, Bremenhaven, Wasserkuppe, Stuttgart, and Munich) were acquired for the year 1975 from ETAC to provide the basic information for assembling a realistic climatic data matrix for FRG for use in the terrain surface modeling efforts. These data were analyzed over the

yearly cycle by plotting (for each station) the daily range (maximum, minimum, and average) for each variable, i.e. air temperature, humidity, wind speed, solar radiation, cloud cover, and rainfall. For example, Figure 6 shows a typical plot for air temperature showing the total variation occurring over the 1975 yearly cycle for the Wasserkuppe station.

42. The temperature data for all stations were then examined on a monthly basis (every 28 days on the Julian calendar)* to select correlative monthly meteorological data for use in the temperature modeling effort. The data were studied to determine the day (of each 28-day period) having the highest temperature (hottest day), the day with the lowest maximum temperature (the coldest day), and the day with the median daily maximum temperature (a "typical" day). The 24-hour temperature histories for these three days in each 28-day period and the associated data for the same three days were assembled. For most parameters the data were available at half hour intervals. Some parameters were recorded less frequently, and when a data point was missing or considered erroneous, the previous recorded value was used.

43. Figure 7 is a sample plot of the correlative data for the maximum condition (the day having the highest daily maximum air temperature) for the summer (July) in 1975 for the Wasserkuppe weather station. This type of correlated data provides the basic meteorological information needed to model expected ranges of terrain surface temperatures on a monthly basis for the locations adjacent to the stations listed in paragraph 41. Correlative data from these stations are expected to be adequate for the initial climatic data matrix for the FRG; however, other data can be assembled if subsequent study reveals the need.

Scenario Definition

Terrain feature selection and quantification

44. The determination of specific features for temperature

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* Julian calendar was used because it was compatible with the Air Weather Service data base from which the data were derived.

modeling is a two-step process. The first step involves examining the associations of terrain surface descriptors available in the data base to determine the terrain surface conditions (types) most prevalent or most relevant for the area of interest. The second step involves inference of specific terrain surface features that dominate the landscape (scene) and would influence thermal IR sensor system perception of targets or other items of interest.

45. The factor complex technique, previously developed at the WES and illustrated in Figure 8, was adopted as the means to examine associations of terrain types. The technique allows the user to display distribution of complex factors. Figure 8 shows how the technique is used to display the combinations of landform, soil type, vegetation type, and urban or rural area map classes by "stacking" the respective "thematic" maps to produce a "thematic complex" map. The resulting single map presents those combinations of landform, soil, vegetation, and urban-rural (associations) that are most prevalent in an area of interest.

46. The thematic complex map is a valuable aide for identifying key terrain type associations; however, because of the small scale of the thematic maps developed in this study, selection of specific features for temperature modeling must be accomplished by inference, aided by supplementary data on the detailed characteristics of the terrain in the area of interest. For example, a vegetation class of coniferous forest found in combination with a soil type of sandy loam, a landform class of rolling hills, and outside urban areas (rural) might contain specific features that would not occur if the class of the factors were changed. Through a literature and air photo study and perhaps prior knowledge of the area, the dominant species of conifer could be established, which would give additional clues to vegetation characteristics needed for temperature predictions (Figure 4). If cultivated areas occur adjacent to the forest, realistic combinations of bare soil from cultivation, pasture (grass), and standing crops can be inferred by considering the time of year and the crops associated with the general region. Common types of rural roads and buildings can be realistically

inferred. Further, the fact that the forest occurs in rolling hills would indicate that topographic as well as tree canopy shadow effect may be important. Therefore, modeling should include such features as:

Terrain Feature	Descriptors
1. Coniferous trees	Lodgepole pine 80 percent canopy closure
2. Bare soil	Sandy loam
3. Grass	Over sandy loam
4. Roadways	Asphalt--macadam type Gravel type
5. Farm building	Stone walls Metal roof

47. Quantification of inputs to the temperature prediction models involves relating the specific terrain features selected to the physical-thermal descriptors used as inputs to the models. As stated in paragraph 34, work was initiated to develop a terrain feature matrix to define the range of values that is associated with each thermal descriptor for a wide range of specific terrain features.

48. Work on the development of a systematic procedure for quantification of inputs for the terrain surface features as inferred from existing terrain data has not been processed sufficiently to be included in this report. It remains, however, a key step in the overall process for predicting representative terrain surface temperature values and should be given considerable attention in the future.

Meteorological conditions--
selection and quantification

49. A majority of the climatological data needed for input to the temperature prediction models should be available through the correlated data discussed in paragraph 41. Some parameters may not be adequately represented in the data to provide end members in temperature prediction, and alternates must be considered as necessary to develop a complete data base. For example, meteorological parameters that may not be adequately represented include cloud cover, cloud type, relative humidity, and solar insolation. Hourly values for descriptors of cloud cover and cloud type could be handled by establishing a number of prescribed alternative diurnal histories that might represent extremes

in the area of interest. One extreme might be a cloud-free, sunny day and the other a complete cloud cover (for 24 hours) with thick clouds. Intermediate alternatives might include the following:

- a. Clear morning, thin cloud buildup for afternoon, and clear night.
- b. Thin cloud cover all day and night.
- c. Clear morning, thick cloud cover in afternoon, moderate cloud cover at night.
- d. Moderate cloud cover all day and night.

Relative humidity diurnal histories could be fabricated in a similar fashion, but related to the cloud cover conditions and weather options.

50. Solar insolation is a variable that can be calculated if appropriate atmospheric attenuation and scattering effects are considered. A portion of an existing WES model for evaluating remote sensor performance[13] includes the capability to predict the solar energy reaching the terrain surface (in mw/cm^2) for clear and hazy (no clouds) conditions. The calculation procedure used can be adopted to estimate solar energy for any zenith angle (time-of-day, time-of-year, and latitude effects), two haze conditions (two aerosol distributions), and any segment of the atmosphere (to consider terrain surface elevation). An additional routine is available to correct for the relative incidence angle between the solar energy and the terrain surface. This computer code output could be a fall-back position for hourly solar insolation data.

Temperature Models

General

51. As discussed in paragraph 22, two temperature prediction models were deemed necessary, one for the terrain surface and one for vegetation. The terrain surface model should also be able to handle cultural items such as roadways, and to a limited extent, buildings. The following paragraphs discuss a terrain surface temperature model obtained from the literature and a vegetation component temperature

model developed by Colorado State University (CSU) personnel as a portion of a contract effort to the WES.

Terrain surface temperature model

52. Source of model. The computer model adopted for an initial terrain surface temperature prediction capability was developed in 1969 for the Rome Air Development Center, Griffiss Air Force Base, New York, by the Infrared and Optics Laboratory, Willow Run Laboratories, University of Michigan. Details on the model are given in Reference 14.

53. Description of model. The model was designed to predict time-dependent surface temperatures and radiances of planar targets and backgrounds. It accounts for the effects of (a) solar insolation, (b) radiative transfer, (c) natural and forced convection, (d) rain evaporation, (e) thermal properties and physical configuration of the target, and (f) internally generated heat fluxes.

54. The basis of the model is a one-dimensional heat-diffusion equation that can accommodate a one-dimensional object composed of from one to six layers of differing thermal properties. Inputs to the model include material properties, time-dependent environmental properties, constant environmental properties, and boundary conditions.

55. The material properties inputs are the thermal conductivity and thermal diffusivity for each layer and, in addition, the solar absorptivity, thermal emissivity, and surface roughness for the surface layer. Figure 9 is a general source of information for estimating the surface roughness value.[5] Solar absorptivity (1.0-reflectance) and thermal emissivity data are presented in Table 5.

56. The time-dependent environmental data items required as inputs to the model and their respective definitions (from Reference 14) are as follows:

a. Cloud Cover Intensity. This quantity is the measure of the fractional portion of the sky hemisphere obscured by clouds. The possible range is from 0 (clear) to 1 (overcast).

b. Sun Magnitude. This quantity specifies the magnitude of the solar radiation intensity at the ground. If arbitrary specifiable cloud shadowing is to be modeled, this quantity is specified as a function of time. Up to 300 time points may be specified.

c. Atmospheric Temperature. This quantity specifies the time-varying air temperature above the surface, ideally at 160 cm above the surface.

d. Horizontal Wind Speed. This quantity specifies the time-varying horizontal wind speed above the surface, again ideally at 160 cm.

e. Relative Humidity. This quantity specifies the time-varying fractional relative humidity of the air above the surface. The normal range of this quantity is 0-1.

f. Rain Intensity. This quantity specifies the time-varying intensity of rainfall upon the surface.

g. Lower Boundary Heat Source. This quantity can be used to specify in tabular form a heat flux on the lower boundary.

57. Constant environmental data inputs include the meteorological measurement height (height above the ground surface at which atmospheric temperature, wind velocity, and relative humidity are measured), cloud type, and rain temperature. The cloud type variable accounts for differing back-radiation properties among different cloud types when the cloud cover intensity (paragraph 56) is the same. It varies from approximately 0.2 for high, thin clouds to 0.9 for very low, dense clouds.

58. The boundary conditions include an initial temperature distribution in the material being modeled, a net heat flux on the lower boundary (or prescribed as a constant temperature), and the approximate solid angles subtended by the radiating surface and lower boundary. In addition, two parameters, a canopy characteristic factor and the probability of a clear line-of-sight through tree canopy at the zenith, are used to define the shading effects of tree canopies.

59. Model evaluation by WES. A Fortran listing of the computer program was obtained from the University of Michigan, Ann Arbor, Michigan. The program was segmented into modules according to the "top down structured" programming technique. Each module performs a particular function in the program. Comment statements were placed at the beginning of each module identifying the module and referencing the previous module wherein the command was given to access that module (all references are by program page number). The end of each module has a

comment statement listing the module the program goes to next. Two pages of comments were added to the end of the program giving definitions of pertinent variables and the page numbers (modules) in which they were used. The program was restructured and debugged using this procedure, starting with the first module and continuing the sequence until the entire program was on-line and working.

60. Evaluation of the model required a body of measured input parameters and measured terrain surface temperature values for comparison with the predicted values. These data were acquired in three locations (Vicksburg, Mississippi; Leadville, Colorado; and Fort Collins, Colorado) using a WES portable field data collection station. The station consists of a package of sensors (of variable composition) and an automatic data recorder. Sensors used for this study included wind speed, wind direction, solar insolation (sun and shade situations), rainfall, air temperature, atmospheric pressure, relative humidity, and contact temperature thermistors for terrain surface materials. The recorder, which can remain unattended for up to four weeks, was set to sample each data channel on an hourly basis and record the sensor outputs on a 6.4-mm magnetic tape cassette. The specific types of terrain surface feature temperature data collected are illustrated by the listing of thermistor locations for the Leadville, Colorado, data collection effort as shown in Table 11. Cloud cover intensity was the only model input variable not measured during the field experiments.

61. The Vicksburg site is located to the east of the main WES cantonment area on property owned by the WES. The site, shown pictorially in Figure 10, was comprised of an oak tree surrounded by low grass with an adjacent unpaved road. The Leadville site, shown in Figure 11, is located in the mountains of Colorado. The predominant vegetation type is lodgepole pine with randomly spaced areas of sparse grass. The Fort Collins site, shown in Figure 12, is located near the Foothills campus of the Colorado State University in the Colorado State Forest Service Nursery. The primary vegetation types are Russian olive trees and prairie grass.

62. Correlative meteorological and surface temperature

measurements were obtained during the 13-20 May 1977 period in Vicksburg, the 11-16 July 1977 period in Leadville, and the 21-26 October 1977 period in Fort Collins. These data were input to the model along with appropriate descriptors for the bare soil conditions at each site (e.g., contact thermistor No. 2 in Table 11); Table 12 lists the material property inputs used for the modeling at each site.

63. Predictions of soil surface temperatures were made for six-day periods using the measured inputs from Leadville and Fort Collins. The resulting predicted values are plotted with the measured soil surface temperature values in Figures 13 and 14 for Leadville and Fort Collins, respectively. Examination of the predicted and measured data for Leadville shows the impact of considering the material descriptors as static parameters during a period of changing climatic conditions, two partially cloudy days followed by three cloudy days with some rainfall, followed by a rainfall, followed by a relatively clear, sunny day. Since changes in soil moisture can significantly change parameters such as absorptance, conductivity, and diffusivity, a single specification of input values for these parameters is not sufficient. Use of values to obtain a best overall fit of the predicted to measured data produces less than optimum results for both clear and rainy conditions.

64. Comparison of the predicted and measured bare soil surface temperatures for Fort Collins shows considerably better agreement because climatic conditions were much less variable over the data collection period than they were for the Leadville data collection. As such, a static assumption for the material descriptors is more realistic, and the predicted temperature data are more representative of the actual conditions that prevailed.

65. A one-day (24-hour) period was selected from the Vicksburg data to obtain predictions with input data optimized to the conditions that occurred during that day. The results are shown in Figure 15 and confirm the capability of the model to predict realistic soil surface temperature values given approximate input descriptors. The slight time lag observed in the predicted and measured data in Figure 15 is due to an offset in the time between that assumed by the model (based on the

sun always rising at 0600 hrs) and the actual timing for the solar insolation as depicted in the measured data. This situation will be corrected in future applications.

66. Model status. The University of Michigan temperature prediction model is considered a viable initial capability for predicting terrain surface temperatures. The six-layer capability and inclusion of the major pertinent meteorological and physical phenomena make it very useful. The model inputs can be acquired from a meteorological data base such as that for the FRG discussed in this report, a terrain data base and appropriate means to specify quantitative material properties, and previously prepared input parameter values that represent prescribed battlefield scenarios.

67. An object deck and test data for the temperature prediction model were supplied to NVL personnel for their use.

Vegetation component temperature model

68. Source of model. The vegetation component temperature prediction model was generated by CSU personnel on contract to the WES. A report "Temperature Simulation of Scene Components in a *Pinus contorta* Stand, September, 1977"[15] discusses the model in detail and presents examples of its application to lodgepole pine needles, shrubs, and grasses using the Leadville, Colorado, meteorological data collected with the WES field data collection station (as previously discussed in the terrain surface temperature model evaluation portion of this report).

69. Description of model. The vegetation component temperature prediction model is based on physical principles developed by Gates.[16] Only a single vegetation element horizontal to the ground surface is considered. Flows of energy (illustrated in Figure 16) to and from the leaf are expressed as flow rates in difference equation form. A steady-state condition is assumed for each time interval. The model considers (a) direct solar irradiance, (b) diffuse solar irradiance, (c) atmospheric thermal exitance, (d) ground thermal exitance, (e) reflected direct solar irradiance from the ground, (f) reflected atmospheric thermal exitance from the ground, (g) advective heating, (h) convection,

(i) transpiration, and (j) leaf thermal exitance.

70. The following variables are model inputs:[15]

a. Local latitude (deg).

b. Sun declination (deg).

c. Normal solar irradiance outside the earth's atmosphere (w/m^2).

d. Atmospheric transmittance for a given solar zenith angle.

e. Shortwave (0.4-1.0 μm) leaf absorptivity.

f. Thermal (3-15 μm) leaf absorptivity.

g. Thermal emissivity of leaf.

h. Shortwave ground reflectance.

i. Thermal reflectance of ground.

j. Thermal emissivity of ground.

k. Air temperature (°C).

l. Horizontal wind velocity (cm/sec).

m. Width of leaf in direction of wind flow (cm).

n. Relative humidity of air.

o. Leaf resistance to water vapor diffusion (min/cm).

71. Model evaluation. The model was used to predict 24-hour temperature histories for a lodgepole pine needle cluster, shrubs, and grasses using the WES-measured data from Leadville, Colorado. The input constants for these model predictions are given in Table 13. Outputs of the model and measured temperature data for the above cases are given in Figures 17-19 for a needle cluster, shrub, and grass, respectively. No attempt was made to adjust the initial model input parameter values for a better fit to the measured data.

72. Examination of the curves in Figures 17-19 shows the most immediate limitation of the model. The author of the model points out that the model does not consider the effects of emitted thermal radiation by neighboring needles and branches; this is the probable cause of the predicted nighttime needle temperatures so consistently falling below the measured data. Radiated energy from neighboring materials could be a dominant source of energy for keeping individual needles warm at night. A detailed discussion on the model outputs is given in the CSU report.[15]

73. In a second report from CSU, "Scene Radiation Dynamics," January 1978,[17] it is stated that the vegetation component temperature model would be more representative if functions were incorporated to consider ground temperatures, leaves with low vapor-diffusion coefficients, and leaf vapor diffusion resistance as a variable with time of day. The major omissions from the model are (a) not accounting for thermal emissions of neighboring vegetation components and (b) not considering geometric effects such as shading by surrounding vegetation.

74. Model status. The CSU vegetation component temperature model has been placed on the WES computer and successfully executed using WES-measured inputs. Because of the inability of a single component model to simulate a complex feature such as a grass or tree canopy, this model is considered only an interim product for scene thermal analyses. As such, additional efforts were deemed necessary to form a more sophisticated vegetation canopy thermal model. The following paragraphs present initial efforts in developing this modeling capability.

Vegetation canopy thermal model

75. Model source. An attempt was made by CSU personnel to generate a geometric, layered, thermal canopy model. The following paragraphs briefly describe this work and its results.

76. Model description. The objectives of the model were to (a) simulate the true average temperature of scene components in a forest canopy, (b) predict the thermal signature of a vegetation canopy for varying view angles including horizontal positions within the canopy, (c) account for decreased direct/diffuse solar radiation absorption due to scattering by neighboring canopy components, and (d) account for the increased thermal absorption due to the thermal emissions of neighboring canopy components.

77. The model considers three horizontal infinite layers, and the absorbed solar radiation in each layer is simulated by a modified Monte Carlo canopy model previously developed by CSU personnel for optical wavelengths. The assumption of steady-state energy exchange between the canopy components and the surrounding environment is maintained as in the vegetation component model previously described. Since the model

assumes an infinite horizontal extent for the canopy, there is no provision for theoretically accounting for tree clumps that are surrounded by grasslands or shrubs.

78. Model evaluation. The meteorological data collected by the WES at Leadville, Colorado, and input parameters describing the forest canopy at the Leadville site were input to the model. The model outputs and associated measured data are presented in Figure 20, extracted from a CSU report.[17] It should be noted that this is the first time (to our knowledge) that this type of calculation has been accomplished, and the difference in predicted and measured data shown in the figure can probably be decreased in subsequent calculations and should not be considered as a fair appraisal of the model's capabilities. However, the model requires considerably more evaluation with measured data prior to recommendations for operational use. As structured, it takes a large step forward toward a realistic simulation of thermal phenomena in vegetation canopies and is a necessary step for simulating accurately the electromagnetic (EM) energy field radiated from vegetation canopies.

PART IV: TERRAIN TEMPERATURE PREDICTION

Introduction

79. The following paragraphs illustrate the type products obtainable using the data matrices and models discussed in Part III of this report in concert with the approach outlined in Figure 1. The site selected as the area of interest for this effort, as outlined in Figure 21, is in the Fulda Gap region of the FRG and includes a recording weather station (Wasserkuppe) from which correlative meteorological data have been derived and incorporated into the climatic data base. The subsequent discussion is divided into scenario definition and temperature modeling.

Scenario Definition

General

80. Scenario definition encompassed selection of key terrain features for temperature modeling and quantification of model input parameters. The selection of key terrain features for this study was done with the use of the factor complex concept previously discussed and some knowledge of the terrain conditions in the Fulda area acquired from previous field data collection efforts. Quantification of model inputs for the temperature prediction models was accomplished entirely by extracting parameter values from the literature. Meteorological inputs not readily available from the Wasserkuppe weather data were fabricated in a rational manner as described in subsequent paragraphs. Climatic data for the month of July were used to represent "summer" conditions and data for January were used to represent "winter" conditions.

Selection of terrain features

81. The factor complex concept as illustrated in Figure 8 was used to examine the dominant terrain conditions for the area of interest. Figure 22 presents the individual thematic maps (Appendix A) of the area of interest for landforms, soils, vegetation, and urban area

distribution. Figure 23 shows the thematic complex map for the area of interest with the associated legend.

82. A visual inspection of the thematic complex map in Figure 23 shows that map unit 17 covers a significant portion of the area of interest. For this illustration, only the terrain conditions for this map unit will be considered. However, all of the dominant map units could be considered in the same fashion. From Tables 1-4, it can be seen that the thematic complex map unit 17 is predominantly located in hilly terrain with slopes of 20-60 percent and the relief is from 50 to 300 metres. The soil is loamy sand and sandy loam with rock fragments derived from conglomerate, sandstone, or limestone. The vegetation is grass turf with patches of forest and woodlands, and it is a predominantly rural area.

83. The next step, relating these conditions to key terrain features, lacks a rigorous methodology, but the following list is realistic and sufficient to illustrate the procedures.

Feature	Rationale
Bare soil	Agricultural cropland often has considerable areas of exposed bare soil
Asphalt road Concrete road Gravel road	Various types of roadways occur in rural areas; these three are typical
Grass	Agricultural areas often have pastures or open grass areas
Shrubs	The vegetation class indicates possible transitions from grass to forest; shrubs may occur along such borders
Trees	Patches of woods are included in the vegetation class description; conifers are considered the main tree type for this illustration

Quantification of model inputs

84. Figure 5 lists the basic material descriptor input parameter values used for modeling the bare soil and roadway features (using the terrain surface thermal model) listed in the previous paragraph. These values were derived from the literature sources and the tables included in this report. Note that the roadways were modeled as multiple layer

systems and bare soil as a single layer. A concrete roadway was modeled as a 15-cm layer of concrete over a 30-cm-thick layer of gravel, over a 100-cm-thick layer of soil. The macadam roadway was modeled similarly, and the gravel roadway was modeled as a 30-cm-thick layer of gravel over a 100-cm-thick layer of soil.

85. The input descriptors for vegetation features are listed in Figure 4. These numerical data were obtained directly from work done by CSU to evaluate the vegetation component temperature model; no attempt was made to modify the descriptor values to better represent the particular vegetation species that occur for the Fulda area.

86. Meteorological data (Figure 6) were obtained directly from the (Wasserkuppe) correlative weather data in the climatic data base with the exception of solar irradiance. Solar irradiance values measured on a clear, summer day in Vicksburg were modified to correct for latitude and sun angle (geometric) effects and to create representative winter and summer solar insolation data for the Fulda area. Solar irradiance values computed for Fulda, FRG, were considered slightly greater than levels that actually occur, because factors such as the increased path length through the atmosphere (due to greater solar zenith angles for a given time) were not accounted for in the modifications of the Vicksburg data. In addition, the vegetation component temperature model does not consider cloud cover, and the terrain surface temperature model only considers cloud cover for net radiative heat transfer computations, not for computation of the net solar energy absorbed by the terrain surface. As such, cloud cover impact on solar energy absorbed was not considered. These phenomena would tend to cause higher predicted temperature values than would result if they had been considered in the energy balance computations. Tables 14-17 present the summer maximum correlative meteorological data used for the temperature modeling effort.

Temperature Modeling

Terrain surface features

87. Diurnal (measured hourly) temperature values for bare soil,

concrete roadway, asphalt roadway, and gravel roadway were predicted for the "minimum" and "maximum" daily climatic conditions in July (summer) and January (winter) as depicted by the correlative climatic data derived from the Wasserkuppe weather station data records. The expected temperature ranges predicted for the above features are presented in Figures 24-27 with both winter and summer conditions plotted on the same figure for each feature. The terrain surface temperature model was used for these predictions using the inputs previously described.

88. It is essential to note that the temperature ranges shown in Figures 24-27 were calculated with model input parameter values that may not be representative of the actual terrain surface conditions in the Fulda area. The predictions were made to demonstrate the products obtainable from the coordinated use of a terrain/climatic data base and analytical models such as those described in this report.

Vegetation component features

89. Diurnal (hourly) temperature values for grass, shrubs, and coniferous trees were predicted for maximum and minimum daily climatic conditions in July (summer) and January (winter) as depicted by the correlative climatic data derived from the Wasserkuppe weather station data records. The expected temperature ranges predicted for the above features are presented in Figures 28-30, with both winter and summer conditions plotted on the same graph for each feature. The vegetation component temperature model (paragraphs 68-74) was used to make the predictions and, as such, the curves shown in the figures represent individual vegetation components, without considering the influence of surrounding biomass. Based on preliminary comparison of the temperature predictions for a lodgepole pine needle cluster for a given time, the predicted temperatures from the vegetation component model are slightly lower than those from the vegetation canopy model for the uppermost layer of the canopy and slightly higher than those for the middle and lower canopy layers (in a three-layer canopy model).

90. As was the case for terrain surface features, the model input parameter values were derived from "in-hand" data for illustration purposes. An effort was made in all cases to use values as realistic

as possible; however, verification of the temperature predictions is necessary before they can be considered to represent the true conditions that occur in the Fulda area. The curves in Figure 31, presented for comparison purposes, represent radiation temperatures for very general classes of terrain surface conditions in Essen, FRG, on 7 and 8 August 1975.[18] Essen is not located close to Fulda but is within about one deg of latitude (see map in Figure 21). Comparison of the predicted temperature values for summer conditions present in Figures 24-30 with the measured Essen data in Figure 31 shows that the model-predicted values are indeed reasonable in trend and magnitude.

PART V: CONCLUDING COMMENTS AND RECOMMENDED RESEARCH

Concluding Comments

91. The user of a signature data base generally requests very simple pieces of information that may seem available from even the most basic study program, e.g., the temperature contrast between target and background. The data user has, in fact, asked for a single number (or small range of numbers) to represent a dynamic phenomenon with many complex geometric and atmospheric overtones. The user need for simplistic information is important; however, the realism of the information provided to the user must be paramount and should in all cases govern the methods used and products delivered.

92. An effective data base-modeling procedure system for EM signatures must contain data over wider extremes and at higher resolution than that required by the most sophisticated user, to effectively serve the full range of users. Formulation of the multiple-user capability is certainly more time-consuming and requires considerably more resources to implement initially; however, the future returns are most beneficial. Once set up, the system can serve many users with different needs. The data base portion of the system can be used at the resolution desired and would be quite easy to modify or update.

93. The work conducted during this study effort and discussed in this report was focused on gaining an initial foothold in the development of the desired comprehensive data base-modeling capability for E-O sensor development and evaluation. The work accomplished (Part III) provides an initial framework, however cursory, for estimating thermal regimes of terrain surface features in an area of interest and for specific climatic conditions, as demonstrated in Part IV of the report. Although the system framework is considered valid and the components of a data base-modeling system have been assembled, many gaps, both data and analytical, are evident. These gaps and the perceived capabilities needed, beyond predicted ranges of terrain feature temperatures, to allow complete appraisal of the performance of E-O systems in prescribed

battlefield environments were the impetus for definition of future work requirements. The work requirements identified are presented in the following paragraphs. They address the data base development, scenario definition, and modeling parts of the approach outlined in Figure 1 and also address signature simulation, sensor performance evaluation, and scene analysis efforts deemed necessary for a comprehensive E-O design/ evaluation capability that will realistically consider the impacts of the spectrum of battlefield environments within which such systems must perform. The work is described in a phased approach that will allow user representatives to periodically evaluate and modify the study efforts, focusing resources on the products and capabilities most relevant to their needs. The work presented in each phase is considered to be a logical extension of the products of efforts in previous phases and, as such, requires completion of the preceding phases before it can be effectively initiated.

Recommended Research

Phase I: Terrain Temperature Simulation

94. The objective of the Phase I research is to solidify the capability to predict representative temperature ranges for specific terrain features in the FRG as illustrated in Part IV of this report. This involves some additional work in the areas of data base development, scenario definition, and modeling, as outlined in Part II of the report and in Figure 1. The specific items to be addressed are as follows.

95. Item 1: Data Base Development. The terrain and climatic data bases established in the initial WES study effort reported herein were fabricated from available information and formatted without the benefit of the modeling efforts conducted as a part of this study. As such, considerable insight has been gained that can be used to streamline and broaden the applicability of those data. Two things are considered necessary for the terrain data base; first, updating the information on vegetation types and urban areas to reflect present conditions,

and second, combining map classes, particularly in soils and vegetation, to streamline the map products for thermal analyses of battlefield environments.

96. The climatic data base requires considerable attention to increase the number of weather stations for which statistical and correlated weather data are available for modeling efforts. This will involve acquisition of additional raw data and processing of those data to acquire the desired products.

97. The terrain surface vegetation and the correlated weather data must be placed into formats that permit more rapid access and direct input to the temperature prediction models.

98. Item 2: Scenario Definition. A very significant amount of work is needed to systematize the transition from the terrain and climatic data bases to the quantitative values for model input parameters. The work reported herein included an attempt to provide some of the necessary pieces for the transition; however, the job must be finished to provide the needed capability. The most important long-term need is to conduct matrix analyses such as the one illustrated in Figures 4 and 5 to determine the detail and scope required for a comprehensive data base and the appropriate quantitative values for physical and thermal descriptors of terrain feature materials. The matrix analysis for vegetation, soil and rock, cultural features, and climate would define the number of classes that are needed to consider the spectrum of conditions for each category in world environments. In addition, descriptor values for each class would be defined and systematized for ready access to the models. These two products would significantly aid the transition from generalized terrain conditions as depicted on a thematic complex map (Figure 23), to specific terrain surface features, to quantitative values of descriptors used as inputs to the temperature prediction models. An immediate improvement in capability can be gained by additional literature review and by collapsing all available data on physical and thermal descriptor values for terrain features.

99. Item 3: Modeling. A small effort is necessary to streamline and modify the terrain surface temperature model. This will involve

minor modifications to the computational algorithms and establishing set values for various parameter options. For example, specific cloud cover and cloud type combinations could be made options in the program rather than a requirement, since these values are difficult to obtain for an area of interest. The emphasis will be on making the model easier to use and reducing the input data that must be supplied by the user by making available specific options as described above for cloud characteristics.

100. A significant amount of effort is needed to continue evaluation and modification of the vegetation canopy thermal model (paragraphs 74-78). Prediction of temperature values for a number of vegetation types should be made and compared with measured data to identify any weaknesses in the model. The model can then be tuned to provide the most representative estimates of canopy temperatures. A sensitivity analysis is needed to determine the input parameters that most influence model predictions and to allow scenario definition and data base development efforts to focus on those parameters.

101. Item 4: Demonstration Products. Following the completion of items 1-3, it would be beneficial to exercise the entire system to produce specific demonstration products for an area of interest specified jointly by WES and NVL personnel. The products would be somewhat similar to those presented in Figures 24-30 but with additional phenomena such as shading and slope effects included. In addition, predictions will be closely compared to specific ground measurements to evaluate how well they represent actual conditions. Note that these products will be useful for E-O system design and evaluation.

Phase II: Signature Simulation

102. The objective of the Phase II effort is twofold: first, to extend the modeling capability to include prediction of electromagnetic signatures of terrain features based on atmospheric conditions and predicted feature temperatures; and second, to demonstrate that capability for a spectrum of conditions in the FRG. Specific items to be addressed are as follows:

103. Item 1: Signature Modeling. The terrain surface

temperature model and vegetation canopy thermal model must be expanded to allow prediction of terrain signatures as they would be received by a sensor at any prescribed position and as a function of atmospheric conditions. This will require only minor additions of the terrain surface temperature model in that a signature routine, although not evaluated, is available as a part of the overall package. Some modification will be necessary to enable incorporation of atmospheric transmission effects. Modeling work is currently ongoing through the U. S. Army Atmospheric Sciences Laboratory to create an engineering type model that handles the complex multiple scattering phenomenon that would be significant in battlefield environments because of dust and smoke. This model will be built into the signature prediction process.

104. The vegetation canopy thermal model will require considerable expansion to account for complex canopy geometric effects on radiated energy from the canopy. It is anticipated that the work done to allow prediction of canopy temperatures, which includes the framework to account for radiated energy from neighboring vegetation components (e.g., other needles, leaves, branches, etc.), will provide a valid basic framework for the canopy signature modeling capability.

105. Item 2: Demonstration Products. The signature modeling capability and previous data base development and scenario definition work will be combined to produce a spectrum of products for specified terrain conditions in the FRG. The predicted signature values as well as the temperature predictions from which they were derived will be selectively field-validated to provide confidence levels for the model products. Note that the results obtained at this point represent a viable product that can be used as a design tool and as an extrapolation device when used with measured field data.

Phase III: Scene Analyses

106. The objective of Phase III efforts is to formulate the capability to evaluate scenes in the entirety, including the synergistic effects of the distribution of terrain surface features and terrain surface geometry on the performance of E-O sensors for surveillance and target acquisition operations. Implicit in this capability is the

ability to realistically embed a target in the terrain scene. This, therefore, brings a number of diverse AWSP analytical efforts together into a total scene/target simulation capability. This is a considerable step beyond the capabilities developed in previous tasks, which were limited to the prediction of temperatures and signatures of individual terrain features. During this phase it is proposed to use those modeling capabilities and a data management system to realistically portray, statistically or graphically, the target-surround relations and contrasts as perceived by a sensor for selected battlefield scenarios. The specific items proposed are as follows:

107. Item 1: Data Management System. The key item in Phase III is the development of an overall data management system that allows the user to consider variations (in a three-dimensional sense) of terrain feature distributions and geometry. As such, the user must be able to consider a known surface geometry situation or to fabricate synthetic situations to suit individual evaluation criteria. The user must also be able to distribute terrain features realistically on the landscape and assign appropriate physical and thermal descriptors to each feature for subsequent modeling. The previous temperature-signature modeling capability could then be applied to depict the electromagnetic energy radiating from respective features and incorporating shadowing, obscuration, atmospheric phenomena, and sensor descriptors to arrive at sensor performance indexes. This management system should be equally useful for subsequent modeling of optical wavelength phenomena.

108. Item 2: Statistical Scene Analysis. Paramount to any modeling or simulation effort is the need to present a meaningful and easy to use end product. Statistical scene analysis has the advantage of mathematically considering the synergistic target-surround relationships for an entire scene (i.e., being able to examine target-surround contrasts in a variety of situations that could occur within a given terrain scene) without going completely through the rigorous procedures necessary to display a scene pictorially. This item concerns formulation of procedures (to be used in conjunction with the overall data management system) for statistical analysis of target-surround relations

in a scene. The products envisioned are probability functions defining the target-surround contrast (for specific sensors) for a significant sample of situations within a given scene. In this instance a "scene" is a specific portion of the earth's surface (an area of interest) or a synthetic landscape designed to test user-prescribed hypotheses.

109. Item 3: Scene Synthesis. The most realistic and perhaps most effective E-O system evaluation capability would be the ability to synthesize a pictorial image of a scene as it would be perceived by a given sensor under prescribed terrain/atmosphere/point-of-view conditions. This capability would effectively place the user "inside the sensor system looking out" to observe the performance for specific operational tasks. The ability to visualize the appearance of the target within a complex terrain would provide the ultimate information for E-O sensor designers and evaluators. The work in this item concerns development of the scene display algorithms that could be used within the framework of the overall data management system.

Phase IV: Technology Transfer

110. The object of Phase IV is technology transfer and demonstration of the products developed in Phase III. Documentation of the simulation models, data management system, and scene analysis procedures will be produced to ensure adequate reference material for system users. In addition, specific demonstrations of system capability will be held both for AWSP agency observation and subsequent documentation of example applications. This phase also concerns any final polishing needed to make the developed tools better serve the E-O sensor design and evaluation user community.

RERERENCES

1. "Foresters Guide to Aerial Photo Interpretation," Handbook 308, Oct 1966, U. S. Department of Agriculture, Forest Service, Washington, D. C.

2. Küchler, A. W., "A Physiognomic Classification of Vegetation," Annals of Association of American Geographers, Vol 39, 1949.

3. "Remote Sensing with Special Reference to Agriculture and Forestry," 1970, National Academy of Sciences, Washington, D. C.

4. Reifsnyder, W. E. and Lull, H. W., "Radiant Energy in Relation to Forests," Technical Bulletin No. 1344, Mar 1966, U. S. Department of Agriculture, Forest Service, Washington, D. C.

5. Geiger, R., The Climate near the Ground, Harvard University Press, Cambridge, Mass., 1965.

6. "Handbook of Military Infrared Technology," 1965, Office of Naval Research, Department of the Navy, Washington, D. C.

7. Idso, S. B. et al, "A Method for Determination of Infrared Emmittances of Leaves," Ecology, Vol 50, No. 5, 1969.

8. Jumikas, A. R., Thermal Geotechnics, Rutgers University Press, New Brunswick, N. J., 1977.

9. "Manual of Remote Sensing," American Society of Photogrammetry, Falls Church, Va., 1975.

10. Buettner, C. J. K. et al, "Consequences of Terrestrial Surface Infrared Emissivity," Proceedings of the Third International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, Mich., Oct 1964.

11. Robinson, N., Solar Radiation, Elsevier Publishing Co., New York, 1966.

12. Watson, R. D., "Spectral Reflectance and Photometric Properties of Selected Rocks," Remote Sensing of Environment, Vol 2, No. 2, Feb 1972.

13. Link, L. E., "Procedures for the Systematic Evaluation of Remote Sensor Performance and Quantitative Mission Planning," Technical Report M-76-8, Aug 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

14. Bornemeier, D. et al, "Target Temperature Modeling," Final Technical Report RADC-TR-69-4041, 1969, Rome Air Development Center, Griffis Air Force Base, N. Y.

15. Kimes, D., "Temperature Simulation of Scene Components in a Pinus contorta Stand" (Unpublished Report), Colorado State University, Sep 1977.

16. Gates, D. M., Energy Exchange in the Biosphere, Harper and Row, Inc., New York, 1968.

17. Ranson, K. J. and Kimes, D., "Scene Radiation Dynamics," Technical Progress Report and Prospectus to the U. S. Army Engineer Waterways Experiment Station, Colorado State University, Fort Collins, Colo., Jan 1978.

18. Stock, P., "The Application of IR- and MSS-Data in the Ruhr District, Germany," Proceedings of the Eleventh International Symposium on Remote Sensing, University of Michigan, Ann Arbor, Mich., Apr 1977.

Table 1

Legend for Soils of West Germany

Class No.	Description
1	Unconsolidated sand and loamy sand found on wind-blown (e.g., dunes) and quaternary sand deposits
2	Alluvium (loam and clay)
3	Alluvium (sand and gravel)
4	Loamy sand and sandy loam found on terrace deposits
5	Loamy to silty sand and silt loam derived from loess or alluvium
6	Loamy sand and silt loam derived from loess
7	Sand and loamy sand derived from glacial deposits
8	Loamy sand and loam derived from glacial deposits
9	Sand and silt loam derived from glacial deposits
10	Loamy sand derived from sand and gravel of unspecified origin
11	Sand and loamy sand with rock fragments derived from sandstone or quartzite
12	Loamy sand and sandy loam with rock fragments derived from conglomerate, sandstone, or limestone
13	Loamy sand and loam with rock fragments derived from calcareous gravel, calcareous sandstone, and marl
14	Loam and silt loam with rock fragments derived from limestone
15	Loam and clay with rock fragments derived from dolomite, limestone, and other calcareous rocks
16	Loamy sand and loamy clay with rock fragments derived from various sedimentary rocks
17	Unspecified stony soils derived from limestone or dolomite
18	Sand and loamy sand with rock fragments derived from igneous rocks
19	Loamy sand and sandy loam with rock fragments derived from igneous rocks
20	Loamy sand and sandy loam with rock fragments derived from metamorphic rocks
21	Loamy sand and loam with rock fragments derived from metamorphic rocks
22	Exposed limestone and dolomite rocks
23	Gley soils
24	Moor or peat bog
25	Marsh land
26	Indurated, relict clay soils
27	Mined area

Table 2

Legend for Map of Geographic Distribution of Urban Areas

Class No.	Population
1	1,000,000 and over
2	500,000 to 999,000
3	100,000 to 499,000
4	50,000 to 99,000
5	25,000 to 49,000
6	No data, primarily rural

Note: The area of each circle is equal to the area of each city.

Table 3

Legend for Landform Map of West Germany

Class No.	Landform Types	Average Slope, Percent	Relief, m
1	Marsh lands	Less than 3	Less than 3
2	Level plains	Less than 8	Less than 25
3	Rolling plains and hills	8-20	25-50
4	Hills	20-60	50-300
5	Mountains	Greater than 30	Greater than 300

Table 4

Legend for Vegetation Cover Map of West Germany

Class No.	Description
1	Marsh with halophytic vegetation (e.g., marsh grass). Some marshes have been reclaimed and are now in grass turf or crops
2	Bog or moor with reeds, grasses, and sedges. In drier places, woods (e.g., alder) and shrubs may grow. Some moors have been reclaimed and are now in crops (e.g., wheat)
3	Grass turf with patches of woods and/or crops
4	Crops and grass turf complex with patches of woods
5	Crops, mainly wheat and sugar beets
6	Crops, mainly potatoes, rye, and barley
7	Crops, mainly vegetable gardens (e.g., cabbage), fruits, and flowers
8	Vineyards and hops predominate, frequently interspersed with other crops
9	Forest and woodlands

Table 5

Absorptivity and Emissivity Values for Vegetation

(Adopted from References 3, 4, 5, 6, and 7)

Feature	Absorptivity Sunny day	Absorptivity Cloudy day
Cottonwood	0.60	0.70
Prickly pear cactus	0.70	0.67
Chollas cactus	0.62	0.69
Pincushion cactus	0.59	0.66
Creosote bush	0.83	0.81
Holly (Chinese)	0.57	0.69
Quackgrass	0.60	0.73
Bamboo	0.60	0.72
Northern white-cedar	0.88	0.88
Eastern white pine	0.89	0.88
Oak woodland	0.82	
Grass, high, dry	0.67-0.69	
Meadows	0.70-0.88	
Rye and wheat fields	0.75-0.90	
Deciduous forests	0.80-0.85	
Coniferous forests	0.85-0.90	

Feature	Emissivity by Wavelength band, μm 3.0-5.5	Emissivity by Wavelength band, μm 8.0-14.0
Green mountain laurel	0.90	0.92
Young willow leaf (dry, top)	0.94	0.96
Holly leaf (dry, top)	0.90	0.90
Holly leaf (dry, bottom)	0.86	0.94
Pressed dormant maple leaf (dry, top)	0.87	0.92
Green leaf winter color - oak leaf (dry, top)	0.90	0.92
Green coniferous twigs (jack pine)	0.96	0.97
Grass - meadow fescue (dry)	0.82	0.88
Bark - northern red oak	0.90	0.96
Bark - Northern American jack pine	0.88	0.97
Bark - Colorado spruce	0.87	0.94
Corn		0.94
Indian-fis cactus		0.96
Prickly pear cactus		0.96
Cotton (upland)		0.96
Tobacco		0.97
Blind-pear cactus		0.98
Fremont cottonwood		0.98
Philodendron		0.99
Sugarcane		0.99

Table 6

Approximate Values for Leaf Resistance to Water Vapor Diffusion (Adopted from Reference 3)

Species	Common Name	Resistance to Water Vapor Diffusion sec/cm^{-1}
Acer rubrum	Red maple	11.0
Ammophila breveligulata	Beachgrass	3.0
Arctostaphylos Uva-ursi	Bearberry	5.0
Betula papyrifera	Paper birch	5.5
Chamaedaphne calyculata	Leatherleaf	8.5
Picea mariana	Black spruce	43.0
Pinus resinosa	Red pine	20.0
Pinus strobus	Eastern white pine	30.0
Populus tremuloides	Quaking aspen	
Wet site		2.2
Dry site		3.6
Thuja occidentalis	Northern white-cedar	70.0

Table 7

Physical and Thermal Properties of Soils

(Adopted from Reference 8)

Soil Physical Characteristics		Soil Thermal Characteristics			
Dry Density kg/m^3 × 10^{-3}	Moisture Content by Weight Percent	Conductivity cal/cm-hour-°C		Diffusivity cm^2/hour	
		Thawed	Frozen	Thawed	Frozen
		Sandy Soils			
1.08	2.0	2.6	2.8	13.0	14.7
1.05	4.0	3.8	4.2	17.3	21.0
1.00	8.0	5.0	6.2	19.2	28.2
1.18	2.0	3.4	3.8	15.5	18.1
1.15	4.0	4.5	5.3	18.0	24.1
1.10	8.0	6.1	7.6	21.0	31.7
1.27	2.0	4.2	4.8	16.8	20.9
1.25	4.0	5.4	6.4	20.0	26.7
1.20	8.0	7.1	9.0	22.2	34.6
1.10	15.0	7.7	10.5	19.2	36.2
1.37	2.0	5.2	5.9	19.2	23.6
1.35	4.0	6.5	7.6	21.7	25.3
1.30	8.0	8.4	10.7	24.0	38.2
1.20	15.0	8.9	12.3	21.2	41.0
1.20	20.0	9.4	13.3	20.0	41.6
1.47	2.0	6.3	7.1	21.7	26.3
1.45	4.0	7.7	9.0	23.3	32.1
1.40	8.0	9.6	12.3	24.6	39.7
1.30	15.0	10.3	14.5	22.9	43.9
1.25	20.0	10.8	15.5	21.0	44.3
1.57	2.0	7.2	8.4	23.2	29.0
1.55	4.0	8.9	10.7	25.4	35.7
1.50	8.0	10.9	14.1	25.3	44.1
1.40	15.0	11.7	16.6	23.9	47.4
1.35	20.0	12.3	17.7	23.2	47.8
1.30	25.0	12.8	19.0	22.1	48.7
1.60	8.0	12.4	16.2	27.6	46.3
1.50	15.0	13.4	19.2	25.8	51.9
1.40	20.0	14.0	20.5	25.0	51.3
1.35	25.0	14.6	22.0	23.9	52.4
1.60	15.0	15.3	22.1	28.3	56.7
1.50	20.0	16.0	23.7	27.1	56.4
1.45	25.0	16.6	25.2	25.9	58.6
1.65	15.0	17.3	25.4	30.4	62.0
1.60	20.0	18.0	27.2	29.0	63.3
1.50	25.0	18.6	28.5	27.8	62.0

(Continued)

Table 7 (Concluded)

Soil Physical Characteristics		Soil Thermal Characteristics			
Dry Density $kg/m^3 \times 10^{-3}$	Moisture Content by Weight Percent	Conductivity cal/cm-hour-°C Thawed	Conductivity cal/cm-hour-°C Frozen	Diffusivity cm^2/hour Thawed	Diffusivity cm^2/hour Frozen
Sandy Soils (Continued)					
1.75	15.0	19.2	28.9	32.5	67.2
1.70	20.0	20.0	30.7	30.8	66.7
1.65	25.0	20.5	31.5	28.9	65.6
1.85	15.0	21.5	32.5	34.1	51.6
1.75	20.0	22.0	33.9	32.4	70.6
1.70	25.0	22.3	34.4	30.1	68.8
Clayey Soils					
1.00	8.0	3.4	4.0	12.1	16.7
1.10	8.0	4.2	5.0	13.1	19.2
1.20	8.0	5.0	6.0	14.3	20.7
1.10	18.0	5.9	7.5	12.8	22.7
1.30	8.0	6.2	7.3	16.3	23.5
1.20	18.8	7.3	9.3	14.9	25.8
1.10	27.0	8.1	10.9	15.0	28.7
1.40	8.0	7.3	8.8	17.4	25.9
1.30	18.0	8.5	10.8	16.3	28.4
1.20	27.0	9.3	12.8	16.3	32.0
1.10	40.0	10.1	14.3	14.9	32.5
1.50	8.0	8.6	10.3	18.7	28.6
1.35	18.0	9.8	12.8	17.8	32.0
1.25	27.0	10.6	14.8	17.1	35.2
1.15	40.0	11.4	16.2	15.8	35.2
1.60	8.0	9.7	11.9	19.4	30.5
1.45	18.0	11.2	14.5	19.3	34.5
1.35	27.0	12.0	16.8	18.2	37.3
1.20	40.0	12.9	18.3	17.2	37.3
1.50	18.0	12.5	16.5	20.5	36.7
1.40	27.0	13.4	18.9	19.4	40.2
1.30	40.0	14.3	20.3	17.9	39.0
1.60	18.0	14.2	18.8	22.2	39.2
1.50	27.0	15.0	21.3	20.5	42.6
1.35	40.0	15.8	22.5	18.8	40.9
1.70	18.0	15.9	21.4	23.7	42.8
1.60	27.0	16.6	23.6	21.6	42.9
1.45	40.0	17.2	24.4	19.5	42.1
1.60	18.0	17.8	24.0	25.8	48.0
1.65	27.0	18.3	26.0	22.6	47.3
1.50	40.0	18.5	26.3	20.1	43.8

Table 8

Thermal Properties of Common Geologic Materials

(Adopted from Reference 9)

Material	Thermal Conductivity cal/cm-hour-°C	Thermal Diffusivity cm^2/hour
Basalt	18.0	32.4
Clay soil (moist)	10.8	18.0
Dolomite	43.2	93.6
Gabbro	21.6	43.2
Granite (granite rocks)	27.0 23.4	57.6
Gravel	10.8	28.8
Limestone	17.3	39.6
Marble	19.8	36.0
Obsidian	10.8	25.2
Peridotite	39.6	61.2
Pumice, loose (dry)	2.16	14.4
Quartzite	43.2	93.6
Rhyolite	19.8	50.4
Sandy gravel	21.6	50.4
Sandy soil	5.04	10.8
Sandstone, quartz	43.2 22.3	46.8
Serpentine	22.7 25.9	46.8
Shale	15.1 10.8	28.8
Slate	18.0	39.6
Syenite	27.7 15.8	32.4
Tuff, welded	10.1	28.8

Table 9

Emissivity Values for General Soil and Rock Types

(Adopted from References 6 and 10)

Material	Emissivity by Wavelength Band µm 3-5.5	8-14
Granite, rough		0.89
Dunite, rough		0.89
Basalt, rough		0.94
Sand, large grains		0.91
Sand, large grains, wetted		0.93
Sand (monterey), small grains		0.92
Hainamanu silt loam - Hawaii	0.84	0.94
Barnes fine silt loam - South Dakota	0.78	0.93
Gooah fine silt loam - Oregon	0.80	0.98
Vereiniging - Africa	0.82	0.94
Maury silt loam - Tennessee	0.74	0.95
Dublin clay loam - California	0.88	0.97
Pullman loam - New Mexico	0.78	0.93
Grady silt loam - Georgia	0.85	0.94
Colts neck loam - New Jersey	0.90	0.94
Mesita negra - lower test site	0.75	0.92

Table 10

Solar Absorptivity Values for Soils, Rocks, and Other Surfaces

Solar Absorptivity - Soils (Adapted from Reference 11)

Soil	Absorptivity
Black soil, dry	0.86
Black soil, moist	0.92
Grey soil, dry	0.70 - 0.75
Grey soil, moist	0.88 - 0.90
Blue loam, dry	0.77
Blue loam, moist	0.84
Fallow, dry	0.88 - 0.92
Fallow, moist	0.93 - 0.95
Ploughed field, moist	0.86
Desert, loamy surface	0.69 - 0.71
Sand, yellow	0.65
Sand, white	0.60 - 0.66
Sand, river	0.57
Sand, bright, fine	0.63

Solar Absorptivity - Rock (Adapted from Reference 12)

Rock Type	Absorptivity
Quartz sandstone (fresh)	0.30 - 0.40
Granite (fresh)	0.55 - 0.65
Granite (lichen covered)	0.60 - 0.70
Limestone (weathered)	0.70 - 0.80
Granite (weathered)	0.75 - 0.85
Dolomite (weathered)	0.80 - 0.85

Solar Absorptivity - Other Surfaces (Adapted from References 3 and 4)

Feature	Absorptivity
Fresh snow cover	0.05 - 0.25
Old snow cover	0.30 - 0.60
Clean firn snow	0.35 - 0.50
Clean glacier ice	0.54 - 0.70
Dirty firn snow	0.50 - 0.80
Dirty glacier ice	0.70 - 0.80
Density built-up areas	0.75 - 0.85
Water surfaces	0.90 - 0.97

Table 11

Summary of Leadville, Colorado, Contact Thermistors Locations

Contact Thermistor Number	Thermistor Location
	Cover Site
1	Flat rock close to path in cover area
2	Bare spot in soil close to flat rock
3	Base of tree trunk, 50 cm above ground, south side
4	Tree branch, 2/3 out from trunk, 1 m, E-SE
5	Branch tip, in needles, 1.5 m, north side
6	Tree branch, 1/2 out from trunk, bottomside, 2.5 m, S-SW
7	Tree branch, in needles, ≈ 2.5 m+, south side
8	Branch tip, in needles, 4 m, east side
9	Tree trunk, 4 m, south side
10	Tree top, branch tip, under branch, 2.5 m, north side
	Glade Site
1	Shrub in glade, ≈ 0.4 m
2	On soil surface in grass
3	In grass, 5 cm above surface
4	Tree at glade edge - branch tip, 1 m, west side
5	Tree at glade edge - branch tip, 2 m, west side
6	Tree at glade edge - branch tip, tree top, west side

Table 12

Input Descriptors for Bare Soil Predictions of Temperature at Vicksburg, Leadville, and Fort Collins

Site	Conductivity (g-cal/cm-hour-°C)	Diffusivity (cm^2/hour)	Absorptance Percent*	ε*	Surface Roughness**
Vicksburg**					
Layer 1	13.0	19.2	0.3	0.9	0.05
Layer 2	8.6	21.2	--	--	--
Leadville					
Layer 1	6.2	14.0	0.5	0.85	0.1
Layer 2	9.0	19.0	--	--	--
Fort Collins					
Layer 1	9.2	17.0	0.5	0.9	1.0
Layer 2	8.6	19.2	--	--	--

Note: ε = emissivity.
* Values needed for surface layer only.
** Each site was described as a two-layer system.

Table 13

Input to Vegetation Component Thermal Model for Leadville, Colorado, Site

Parameter	Pine Tree	Shrub	Grass
Shortwave leaf reflectance	0.4	0.4	0.4
Thermal leaf absorption	0.96	0.96	0.96
Emissivity of leaf	0.96	0.96	0.96
Thermal ground reflectance	0.04	0.04	0.04
Shortwave ground reflectance	0.2	0.2	0.2
Emissivity of ground	0.96	0.96	0.96
Leaf dimension, cm			
Run 1	2.0		
Run 2	0.1		
Run 3	4.0	1.0	1.0
Leaf resistance to water vapor diffusion, min/cm			
Run 1	0.33		
Run 2	0.66	0.08	0.02
Run 3	0.66		

Table 14

Correlative Meteorological Data for Summer,

Maximum Condition Fulda, FRG

Time hr	Solar Irradiance w/m^2	Relative Humidity	Wind Velocity cm/sec	Atmospheric Temperature °C	Cloud Cover Intensity
0.0	0.0	0.72	6.70	15.00	0.06
0.5	0.0	0.72	6.70	15.00	0.06
1.0	0.0	0.77	5.10	15.00	0.06
1.5	0.0	0.77	5.10	15.00	0.06
2.0	0.0	0.82	3.60	14.00	0.06
2.5	0.0	0.82	3.60	14.00	0.06
3.0	0.0	0.82	2.60	14.00	0.06
3.5	0.0	0.82	2.60	14.00	0.06
4.0	0.0	0.77	1.50	15.00	0.06
4.5	0.0	0.77	1.50	15.00	0.12
5.0	0.0	0.82	1.50	15.00	0.12
5.5	0.0	0.82	1.50	15.00	0.19
6.0	0.0	0.83	2.60	16.00	0.19
6.5	0.0	0.83	2.60	16.00	0.25
7.0	188.0	0.72	3.00	17.00	0.25
7.5	188.0	0.72	3.00	17.00	0.31
8.0	418.0	0.72	3.00	17.00	0.31
8.5	418.0	0.72	3.00	17.00	0.31
9.0	454.0	0.68	4.10	18.00	0.31
9.5	454.0	0.68	4.10	18.00	0.31
10.0	672.0	0.64	4.60	19.00	0.31
10.5	672.0	0.64	4.60	19.00	0.46
11.0	688.0	0.64	4.60	19.00	0.46
11.5	688.0	0.64	4.60	19.00	0.66
12.0	824.0	0.60	5.70	19.00	0.66
12.5	824.0	0.60	5.70	19.00	0.75
13.0	780.0	0.56	5.60	20.00	0.75
13.5	780.0	0.56	5.60	20.00	0.75
14.0	734.0	0.56	5.10	19.00	0.75
14.5	734.0	0.56	5.10	19.00	0.75
15.0	660.0	0.56	6.70	20.00	0.75
15.5	660.0	0.56	6.70	20.00	0.75
16.0	398.0	0.56	6.70	20.00	0.75
16.5	398.0	0.56	6.70	20.00	0.75
17.0	124.0	0.60	6.60	19.00	0.75
17.5	124.0	0.60	6.60	19.00	0.81
18.0	130.0	0.52	7.20	18.00	0.81
18.5	130.0	0.52	7.20	18.00	0.88
19.0	0.0	0.45	7.70	16.00	0.88
19.5	0.0	0.45	7.70	16.00	0.69
20.0	0.0	0.59	7.70	15.00	0.69
20.5	0.0	0.59	7.70	15.00	0.50
21.0	0.0	0.67	6.70	14.00	0.50
21.5	0.0	0.67	6.70	14.00	0.68
22.0	0.0	0.72	5.10	14.00	0.68
22.5	0.0	0.72	5.10	14.00	0.94
23.0	0.0	0.72	6.10	14.00	0.94
23.5	0.0	0.72	6.10	14.00	0.94

Table 15

Correlative Meteorological Data for Summer,

Minimum Condition Fulda, FRG

Time hr	Solar Irradiance w/m^2	Relative Humidity	Wind Velocity cm/sec	Atmospheric Temperature °C	Cloud Cover Intensity
0.0	0.0	0.80	5.70	2.00	0.06
0.5	0.0	0.80	5.70	2.00	0.06
1.0	0.0	0.80	5.10	2.00	0.06
1.5	0.0	0.80	5.10	2.00	0.06
2.0	0.0	0.93	6.10	1.00	0.06
2.5	0.0	0.93	6.10	1.00	0.06
3.0	0.0	0.93	6.20	1.00	0.06
3.5	0.0	0.93	6.20	1.00	0.12
4.0	0.0	0.92	5.60	0.00	0.12
4.5	0.0	0.92	5.60	0.00	0.12
5.0	0.0	0.86	5.10	1.00	0.12
5.5	0.0	0.86	5.10	1.00	0.19
6.0	0.0	0.93	5.10	1.00	0.19
6.5	0.0	0.93	5.10	1.00	0.32
7.0	188.0	0.87	5.10	2.00	0.32
7.5	188.0	0.87	5.10	2.00	0.38
8.0	418.0	0.74	3.00	2.00	0.38
8.5	418.0	0.74	3.00	2.00	0.42
9.0	454.0	0.68	4.60	3.00	0.42
9.5	454.0	0.68	4.60	3.00	0.56
10.0	672.0	0.60	4.10	5.00	0.56
10.5	672.0	0.60	4.10	5.00	0.62
11.0	688.0	0.60	5.10	5.00	0.62
11.5	688.0	0.60	5.10	5.00	0.62
12.0	824.0	0.60	4.10	5.00	0.62
12.5	824.0	0.60	4.10	5.00	0.69
13.0	780.0	0.56	5.10	6.00	0.69
13.5	780.0	0.56	5.10	6.00	0.75
14.0	734.0	0.48	4.10	7.00	0.75
14.5	734.0	0.48	4.10	7.00	0.69
15.0	660.0	0.44	3.10	7.00	0.69
15.5	660.0	0.44	3.10	7.00	0.69
16.0	398.0	0.44	4.10	7.00	0.69
16.5	398.0	0.44	4.10	7.00	0.62
17.0	124.0	0.44	4.10	7.00	0.62
17.5	124.0	0.44	4.10	7.00	0.44
18.0	130.0	0.56	3.60	6.00	0.44
18.5	130.0	0.56	3.60	6.00	0.32
19.0	0.0	0.55	3.60	5.00	0.32
19.5	0.0	0.55	3.60	5.00	0.19
20.0	0.0	0.64	4.60	4.00	0.19
20.5	0.0	0.64	4.60	4.00	0.12
21.0	0.0	0.59	3.60	4.00	0.12
21.5	0.0	0.59	3.60	4.00	0.07
22.0	0.0	0.68	4.10	3.00	0.07
22.5	0.0	0.68	4.10	3.00	0.07
23.0	0.0	0.74	3.60	2.00	0.07
23.5	0.0	0.74	3.60	2.00	0.07

Table 16

Correlative Meteorological Data for Winter, Maximum Condition Fulda, FRG

Time hr	Solar Irradiance w/m^2	Relative Humidity	Wind Velocity cm/sec	Atmospheric Temperature °C	Cloud Cover Intensity
0.0	0.0	0.61	9.30	7.00	0.00
0.5	0.0	0.61	9.30	7.00	0.00
1.0	0.0	0.47	7.20	6.00	0.00
1.5	0.0	0.47	7.20	6.00	0.00
2.0	0.0	0.47	7.20	5.00	0.00
2.5	0.0	0.47	7.20	5.00	0.00
3.0	0.0	0.50	5.10	5.00	0.00
3.5	0.0	0.50	5.10	5.00	0.00
4.0	0.0	0.43	7.20	5.00	0.00
4.5	0.0	0.43	7.20	5.00	0.00
5.0	0.0	0.43	7.20	5.00	0.00
5.5	0.0	0.43	7.20	5.00	0.00
6.0	0.0	0.43	6.20	5.00	0.00
6.5	0.0	0.43	6.20	5.00	0.26
7.0	130.0	0.44	4.60	6.00	0.26
7.5	130.0	0.44	4.60	6.00	0.56
8.0	290.0	0.47	5.10	5.00	0.56
8.5	290.0	0.47	5.10	5.00	0.69
9.0	314.0	0.47	6.20	6.00	0.69
9.5	314.0	0.47	6.20	6.00	0.69
10.0	466.0	0.47	6.20	6.00	0.69
10.5	466.0	0.47	6.20	6.00	0.57
11.0	476.0	0.44	6.10	7.00	0.57
11.5	476.0	0.44	6.10	7.00	0.62
12.0	570.0	0.36	4.60	10.00	0.62
12.5	570.0	0.36	4.60	10.00	0.78
13.0	540.0	0.36	4.60	10.00	0.78
13.5	540.0	0.36	4.60	10.00	0.85
14.0	508.0	0.41	3.60	8.00	0.85
14.5	508.0	0.41	3.60	8.00	0.88
15.0	458.0	0.41	6.20	8.00	0.88
15.5	458.0	0.41	6.20	8.00	0.88
16.0	276.0	0.41	6.20	8.00	0.88
16.5	276.0	0.41	6.20	8.00	0.88
17.0	6.0	0.50	5.60	5.00	0.88
17.5	6.0	0.50	5.60	5.00	0.60
18.0	90.0	0.54	5.10	4.00	0.60
18.5	90.0	0.54	5.10	4.00	0.58
19.0	0.0	0.56	5.10	6.00	0.58
19.5	0.0	0.56	5.10	6.00	1.00
20.0	0.0	0.55	6.10	5.00	1.00
20.5	0.0	0.55	6.10	5.00	1.00
21.0	0.0	0.55	5.10	5.00	1.00
21.5	0.0	0.55	5.10	5.00	1.00
22.0	0.0	0.60	8.70	5.00	1.00
22.5	0.0	0.60	8.70	5.00	0.52
23.0	0.0	0.60	8.70	5.00	0.52
23.5	0.0	0.60	8.70	5.00	0.52

Table 17

Correlative Meteorological Data for Winter,

Minimum Condition Fulda, FRG

Time hr	Solar Irradiance w/m^2	Relative Humidity	Wind Velocity cm/sec	Atmospheric Temperature °C	Cloud Cover Intensity
0.0	0.0	1.00	2.60	-4.00	0.48
0.5	0.0	1.00	2.60	-4.00	0.48
1.0	0.0	1.00	2.50	-4.00	0.48
1.5	0.0	1.00	2.50	-4.00	1.00
2.0	0.0	1.00	1.50	-4.00	1.00
2.5	0.0	1.00	1.50	-4.00	1.00
3.0	0.0	1.00	2.10	-4.00	1.00
3.5	0.0	1.00	2.10	-4.00	1.00
4.0	0.0	1.00	1.50	-4.00	1.00
4.5	0.0	1.00	1.50	-4.00	1.00
5.0	0.0	1.00	1.50	-4.00	1.00
5.5	0.0	1.00	1.50	-4.00	1.00
6.0	0.0	1.00	2.10	-5.00	1.00
6.5	0.0	1.00	2.10	-5.00	0.68
7.0	130.0	0.92	2.50	-5.00	0.68
7.5	130.0	0.92	2.50	-5.00	0.43
8.0	290.0	0.92	3.60	-5.00	0.43
8.5	290.0	0.92	3.60	-5.00	0.38
9.0	314.0	0.92	6.20	-5.00	0.38
9.5	314.0	0.92	6.20	-5.00	0.25
10.0	466.0	0.92	6.10	-4.00	0.25
10.5	466.0	0.92	6.10	-4.00	0.25
11.0	476.0	0.85	6.10	-3.00	0.25
11.5	476.0	0.85	6.10	-3.00	0.30
12.0	570.0	0.92	5.10	-3.00	0.30
12.5	570.0	0.92	5.10	-3.00	1.00
13.0	540.0	0.92	4.10	-3.00	1.00
13.5	540.0	0.92	4.10	-3.00	1.00
14.0	508.0	0.92	3.00	-2.00	1.00
14.5	508.0	0.92	3.00	-2.00	1.00
15.0	458.0	1.00	4.10	-2.00	1.00
15.5	458.0	1.00	4.10	-2.00	1.00
16.0	276.0	1.00	5.10	-2.00	1.00
16.5	276.0	1.00	5.10	-2.00	1.00
17.0	6.0	1.00	4.60	-2.00	1.00
17.5	6.0	1.00	4.60	-2.00	1.00
18.0	90.0	1.00	4.60	-1.00	1.00
18.5	90.0	1.00	4.60	-1.00	1.00
19.0	0.0	1.00	5.10	-1.00	1.00
19.5	0.0	1.00	5.10	-1.00	1.00
20.0	0.0	1.00	4.10	-1.00	1.00
20.5	0.0	1.00	4.10	-1.00	1.00
21.0	0.0	1.00	4.60	-1.00	1.00
21.5	0.0	1.00	4.60	-1.00	1.00
22.0	0.0	1.00	5.10	-1.00	1.00
22.5	0.0	1.00	5.10	-1.00	1.00
23.0	0.0	1.00	5.10	.00	1.00
23.5	0.0	1.00	5.10	.00	1.00

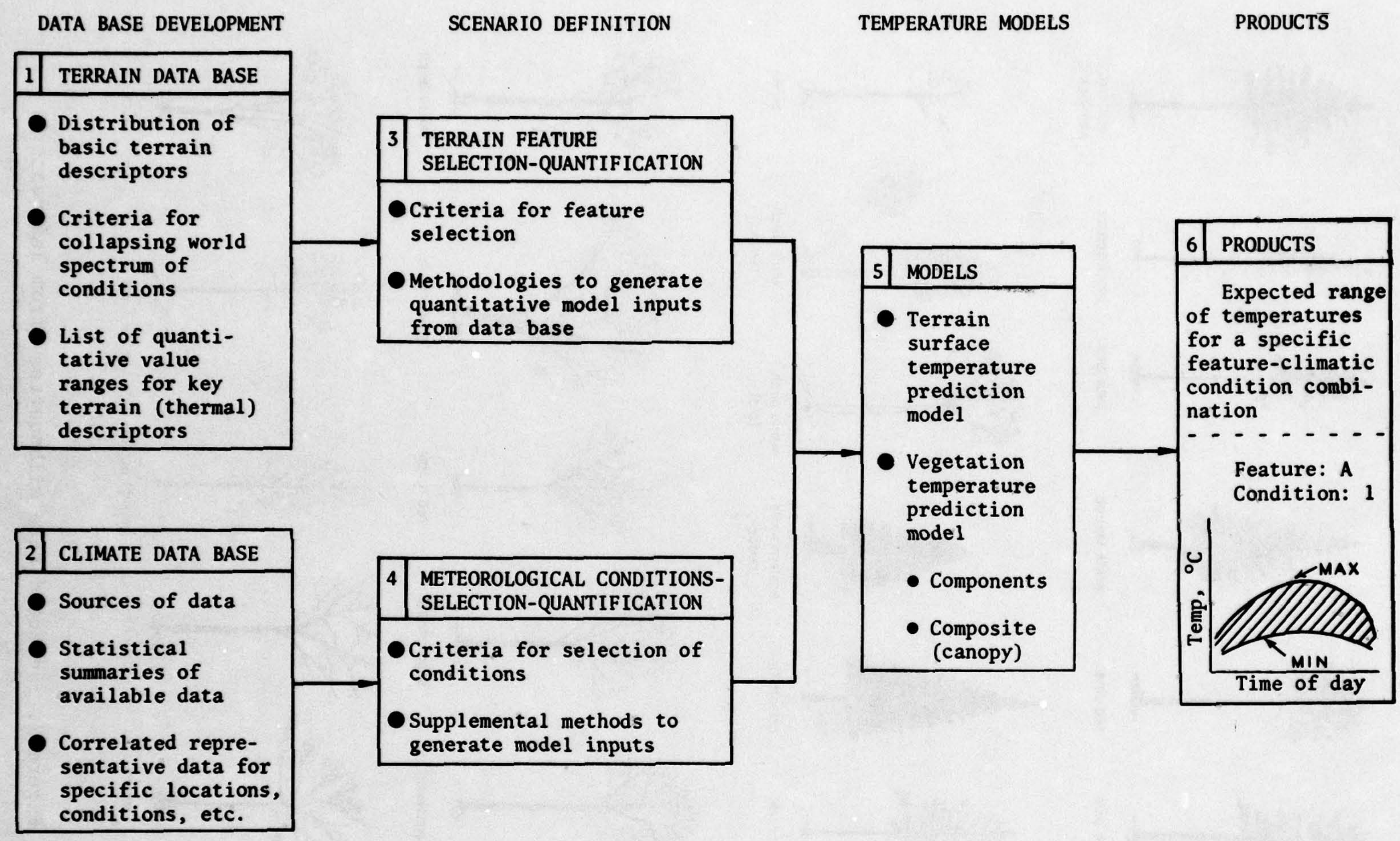


Figure 1. Major components in the approach used to develop an initial capability to predict terrain surface temperatures

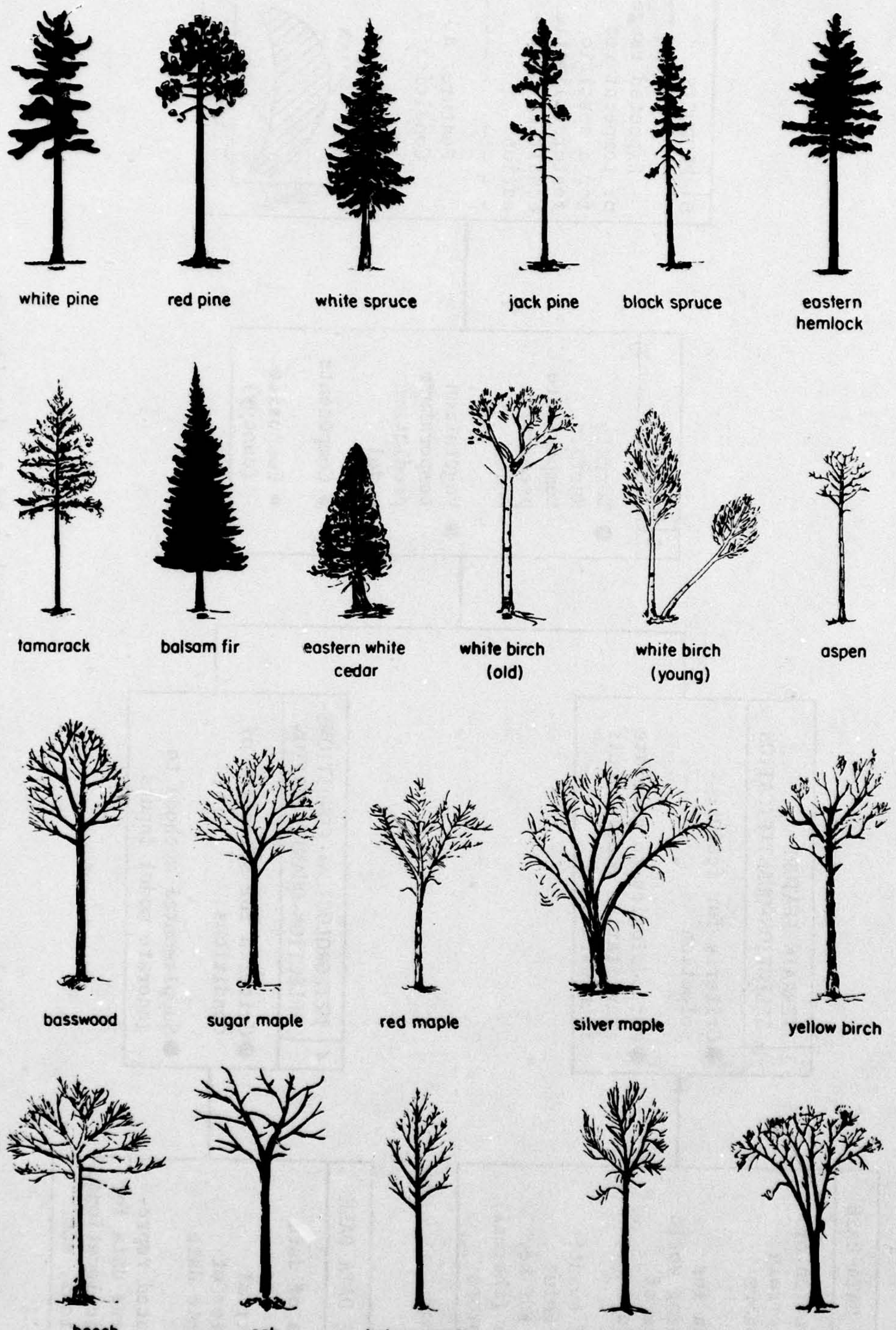


Figure 2. Selected tree silhouettes (from Reference 1)

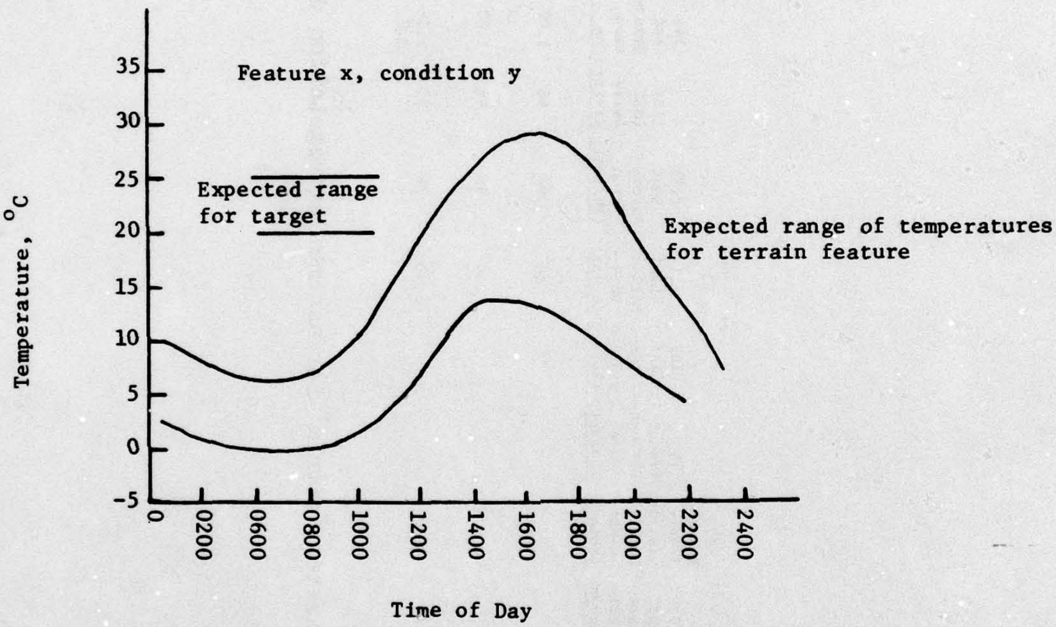


Figure 3. Illustration of temperature range product and comparison to target temperatures

(1) Vegetation Matrix Element	(2) Layer	(3) Layer Thickness	(4) Branch Area Index	(5) Branch Angle Inclination	(6) Leaf Area Index	(7) Leaf Angle Inclination	(8) Branch Transmission Coefficient (Solar)	(9) Branch Reflectance (Solar)	(10) Leaf Transmission (Solar)	(11) Leaf Reflectance (Solar)	(12) Leaf Absorption (Thermal)	(13) Leaf Emissivity	(14) Leaf Dimension cm	(15) Leaf Resistance to Water Vapor Diffusion	(16) Stem Size-Spacing Relation	(17) Stem Size/Height Relation	(18) Qualitative Descriptions
1										.40	.96	.96	1.00	0.02			Grass
2							0.0			.40	.96	.96	1.00	0.08			Scrub
3							0.0			.40	.96	.96	0.1-3.0	0.33-0.66			Pine Lodge Pole

Figure 4. Vegetation parameter "matrix" for assembling vegetation descriptors data

Terrain Surface Material Element	Layer	Layer Thickness cm	Thermal Conductivity cal/cm-hour-°C	Thermal Diffusivity cm^2/hour	Solar Absorption	Thermal Emissivity	Surface Roughness cm	Qualitative Description
1	1	15	15.6	55.0	.75	.99	1.0	Concrete Roadway
	2	30	10.8	28.8				
	3	100	11.7	22.0				
2			11.7	22.0	0.60	0.95	1.0	Soil
3			15.6	55.0	0.75	0.99	1.0	Concrete
4			14.0	19.4	0.92	0.95	1.0	Macadam
5			10.8	28.8	0.65	0.90	0.5	Gravel

Figure 5. Terrain surface parameter "matrix" for assembling terrain surface material descriptive data

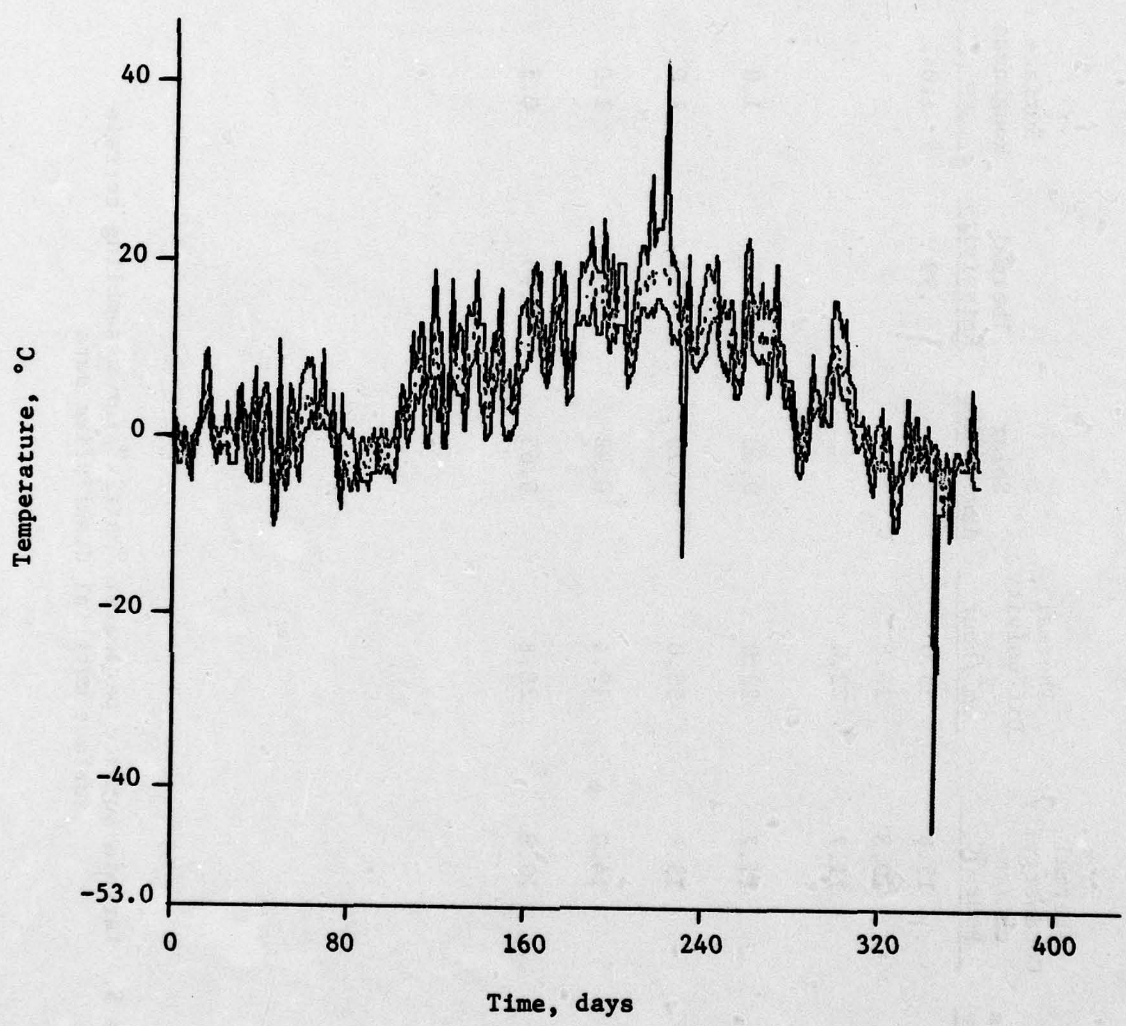


Figure 6. Plot of daily air temperature ranges from Wasserkuppe weather station for 1975

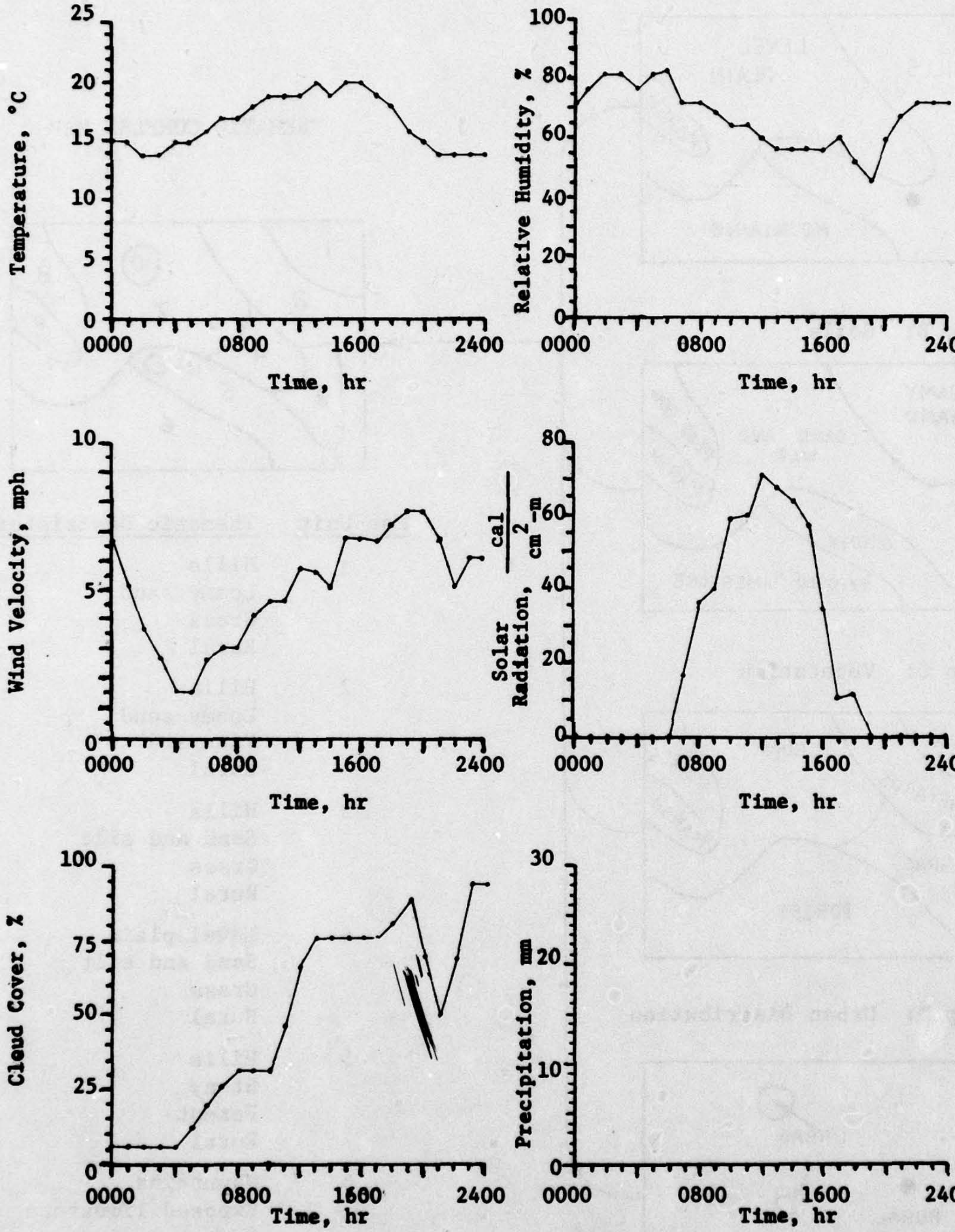
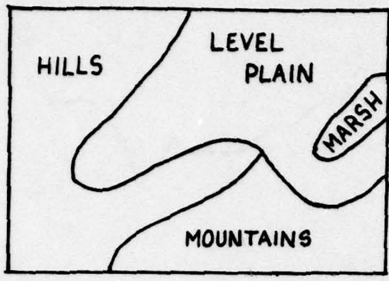


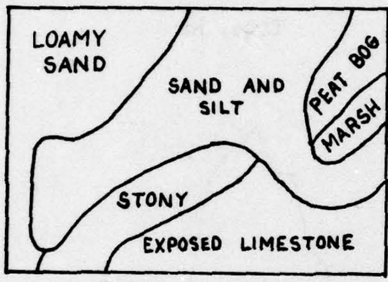
Figure 7. Example of correlative weather data for maximum (warmest day) condition in July 1975 at Wasserkuppe station

THEMATIC MAPS

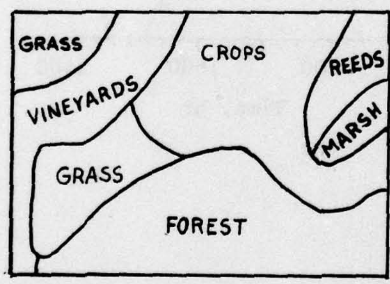
Map A: Landforms



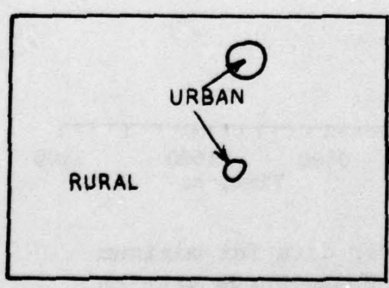
Map B: Soils



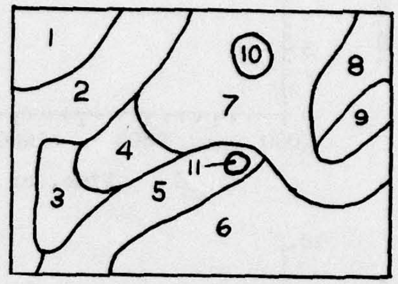
Map C: Vegetation



Map D: Urban Distribution



THEMATIC COMPLEX MAP



Map Unit	Thematic Descriptors
1	Hills Loamy sand Grass Rural
2	Hills Loamy sand Vineyard Rural
3	Hills Sand and silt Grass Rural
4	Level plain Sand and silt Grass Rural
5	Hills Stony Forest Rural
6	Mountains Exposed limestone Forest Rural
⋮	⋮

Figure 8. Principles of factor complex map methodology as applied to thematic terrain maps

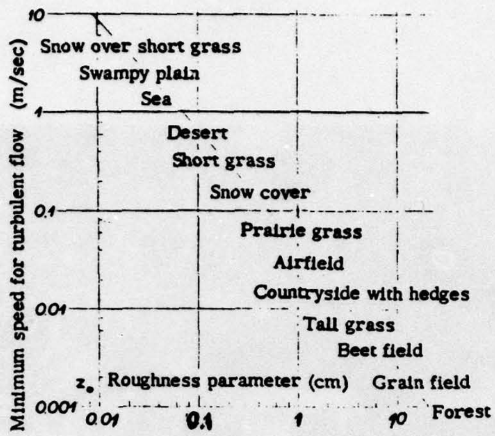


Figure 9. Information for estimating terrain surface roughness parameter (from Reference 5)

Figure 10. Photo of study site at Vicksburg, Mississippi

Figure 11. Photo of study site at Leadville, Colorado

Figure 12. Photo of study site at Fort Collins, Colorado

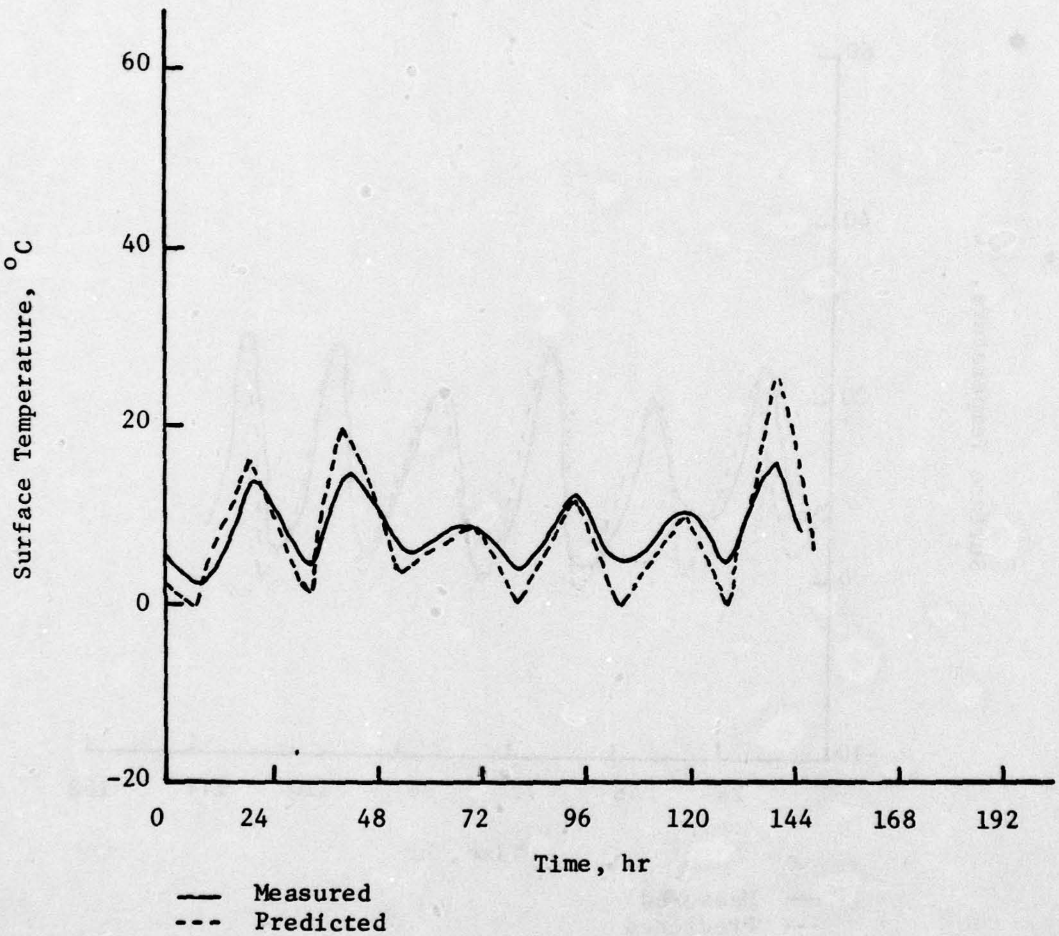


Figure 13. Predicted versus measured bare soil surface temperature data for 11-16 July 1977, Leadville, Colorado

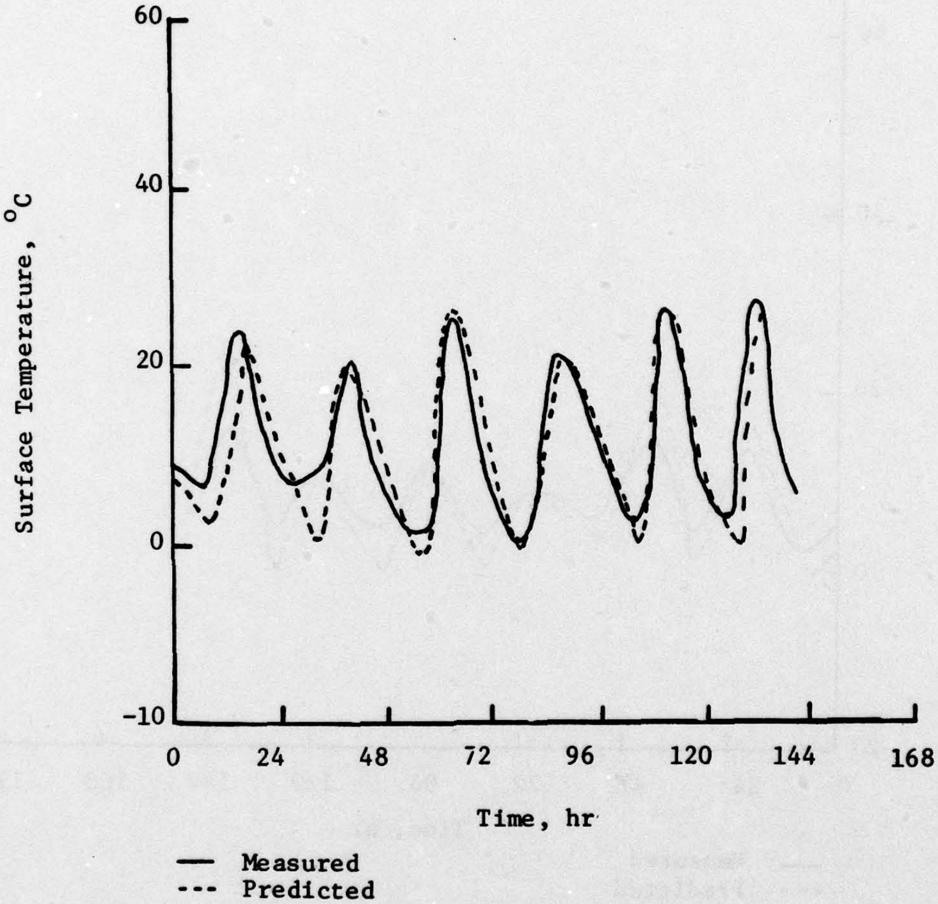


Figure 14. Predicted versus measured bare soil surface temperature data for 21-26 October 1977, Fort Collins, Colorado

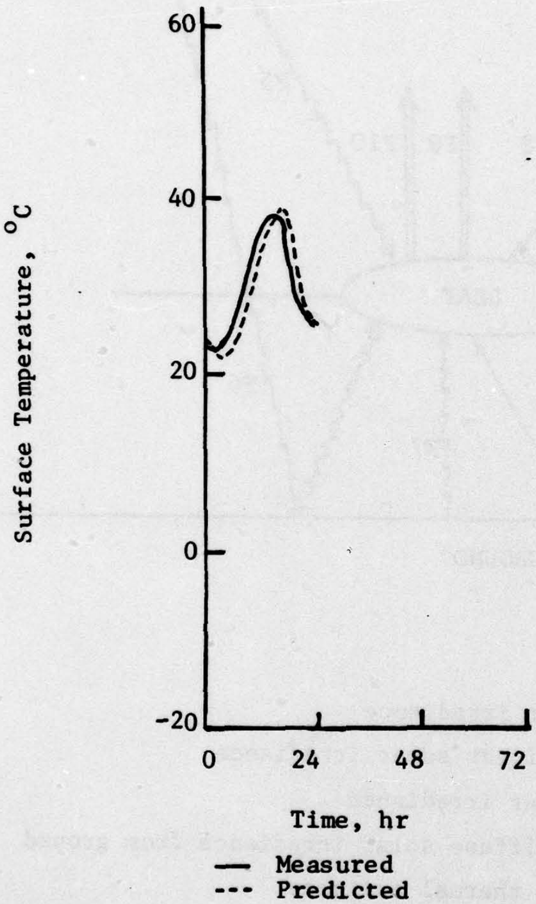
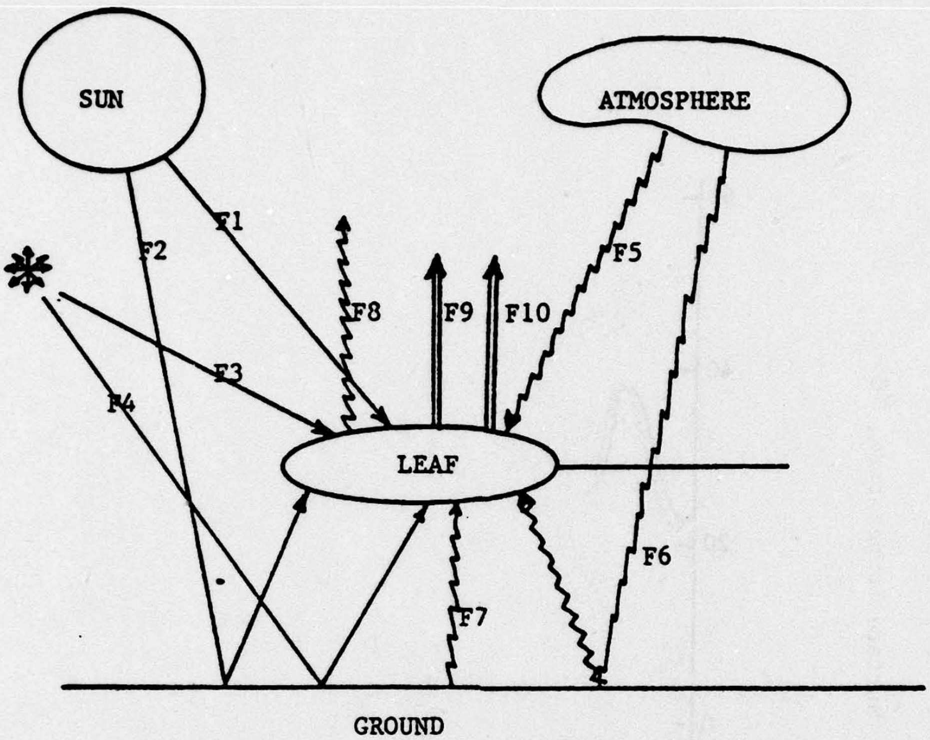


Figure 15. Predicted versus measured bare soil surface temperature for 16 May 1977, Vicksburg, Mississippi



F1 = Direct solar irradiance

F2 = Reflected direct solar irradiance

F3 = Diffuse solar irradiance

F4 = Reflected diffuse solar irradiance from ground

F5 = Atmospheric thermal exitance

F6 = Ground reflected atmospheric thermal exitance

F7 = Ground thermal exitance

F8 = Leaf thermal exitance

F9 = Forced convection

F10 = Leaf transpiration

Figure 16. Abstract energy flows to and from the leaf

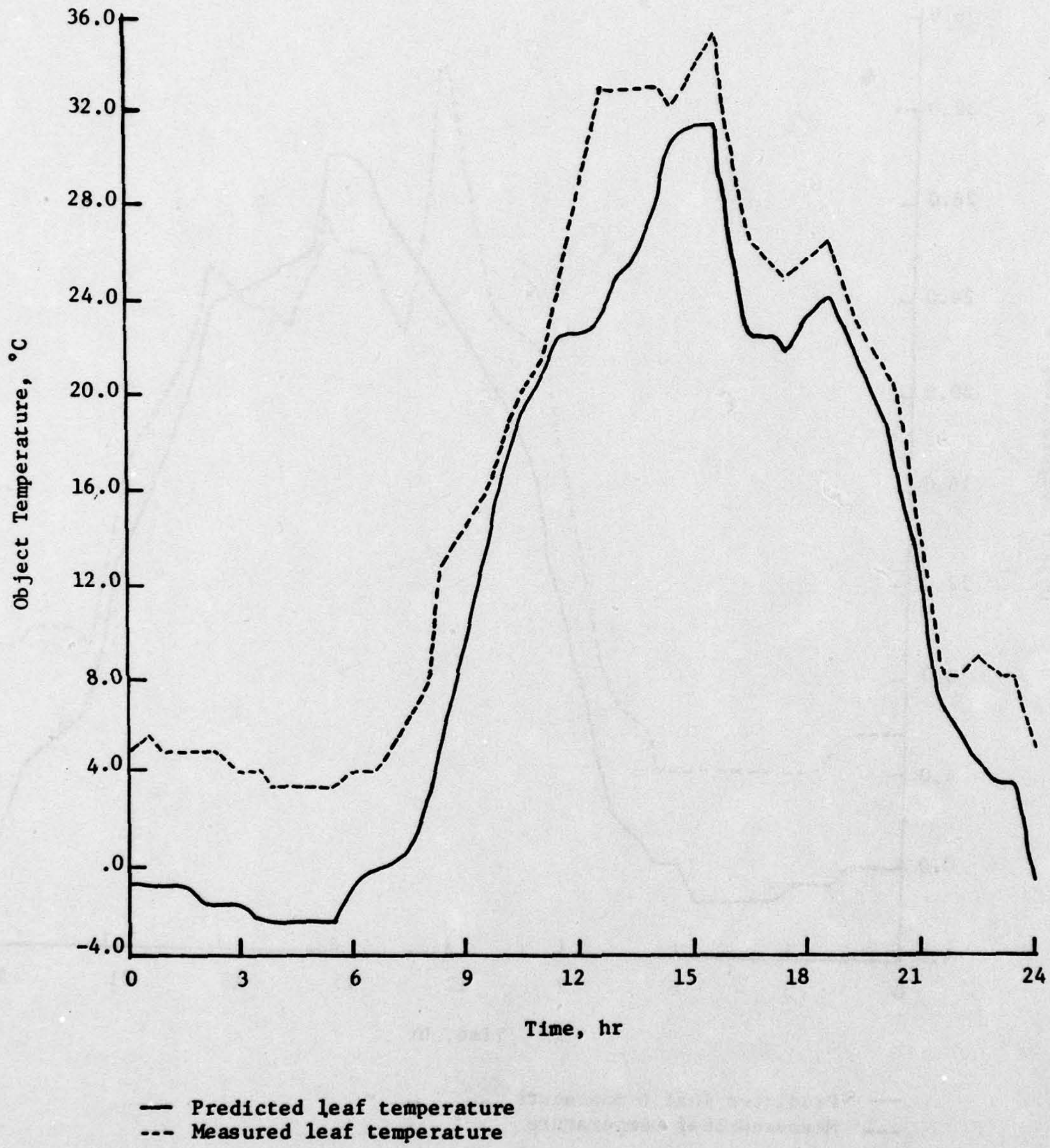
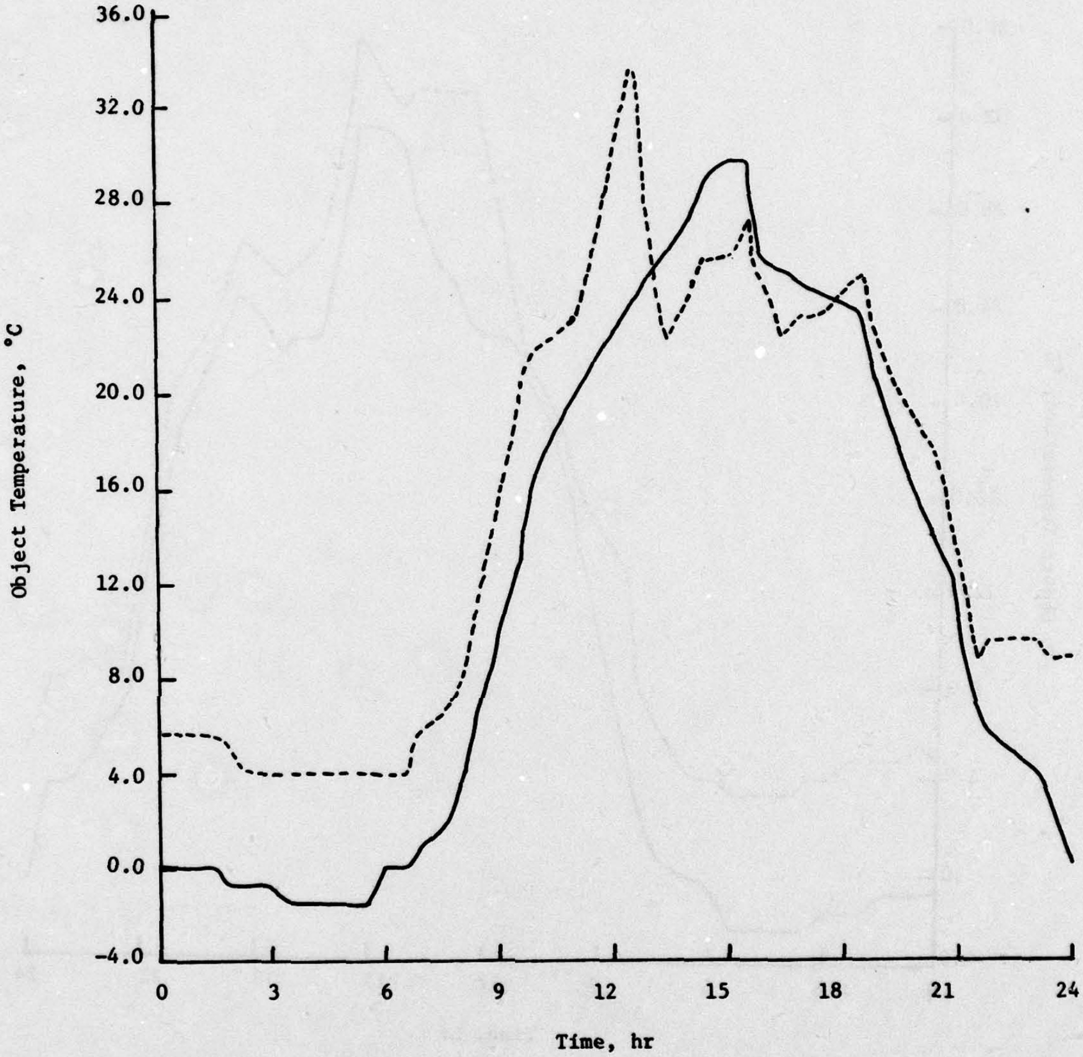


Figure 17. Vegetation component temperature model predicted and measured temperature data for a lodgepole pine needle cluster, Leadville, Colorado



— Predicted leaf temperature
--- Measured leaf temperature

Figure 18. Vegetation component temperature model predicted and measured temperature values for shrubs, Leadville, Colorado

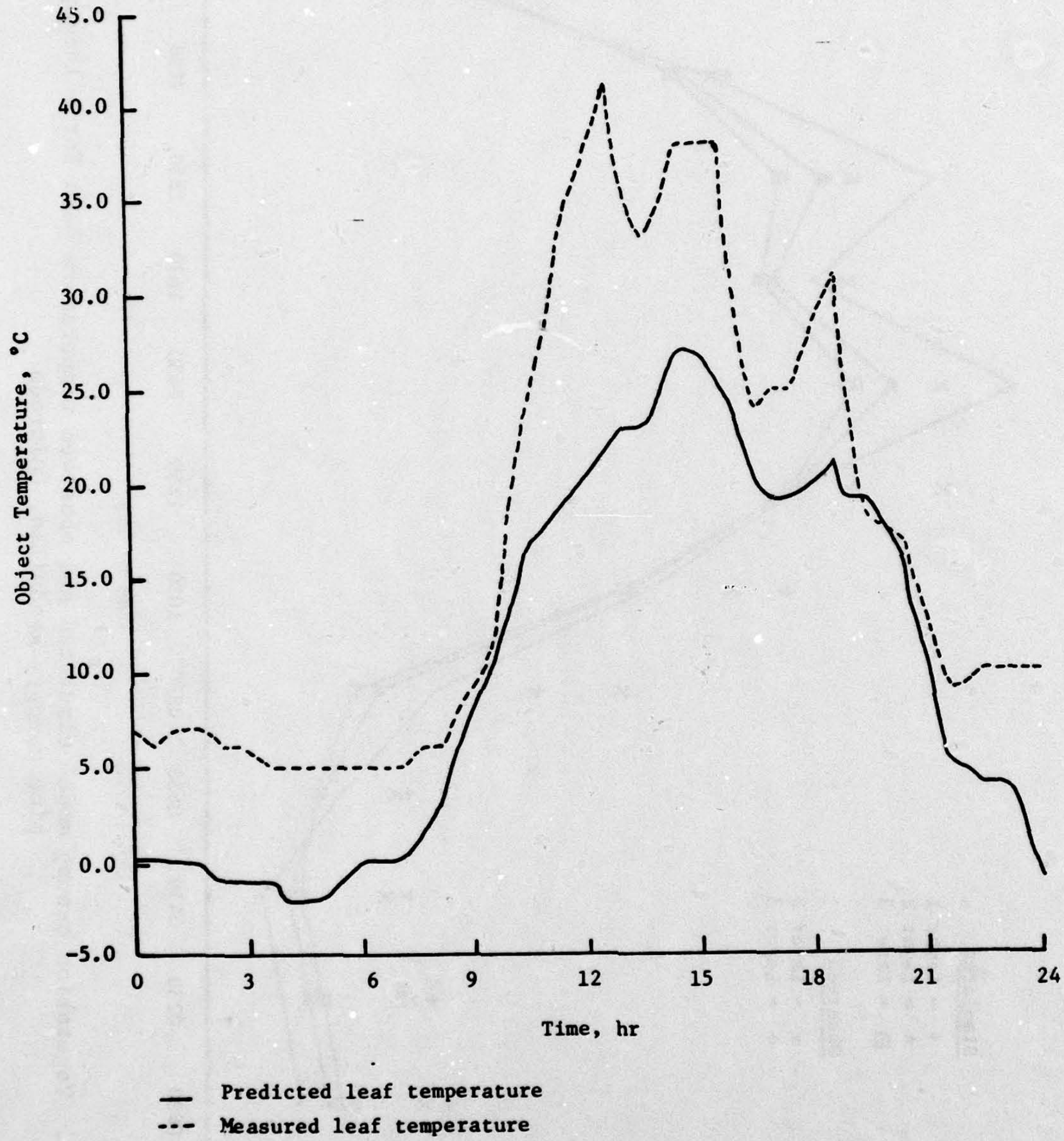


Figure 19. Vegetation component temperature model predicted and measured temperature data for grass, Leadville, Colorado

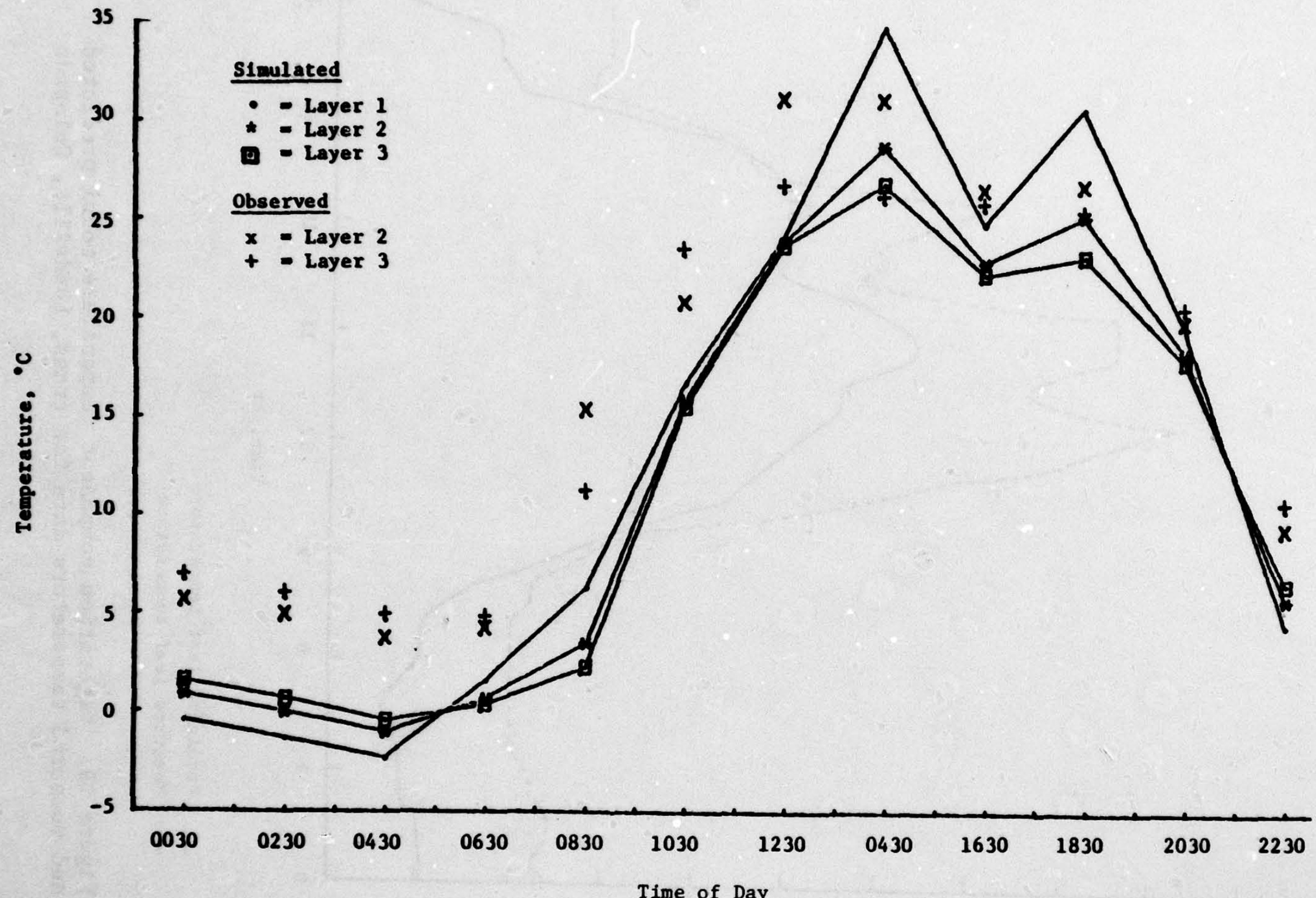


Figure 20. Vegetation canopy model simulated and observed temperature data for a lodgepole pine canopy, Leadville, Colorado

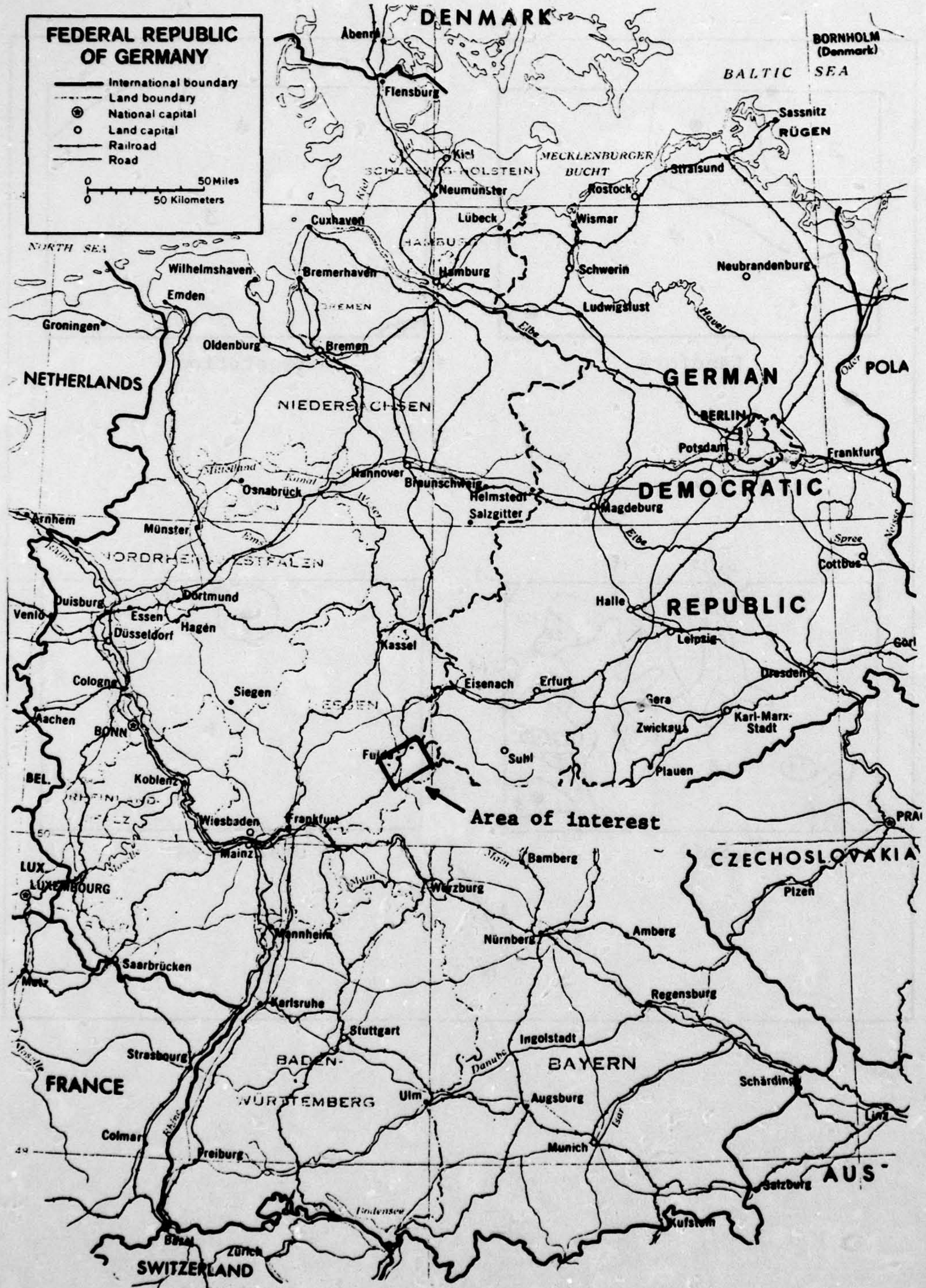


Figure 21. Map of the Federal Republic of Germany showing the study area of interest

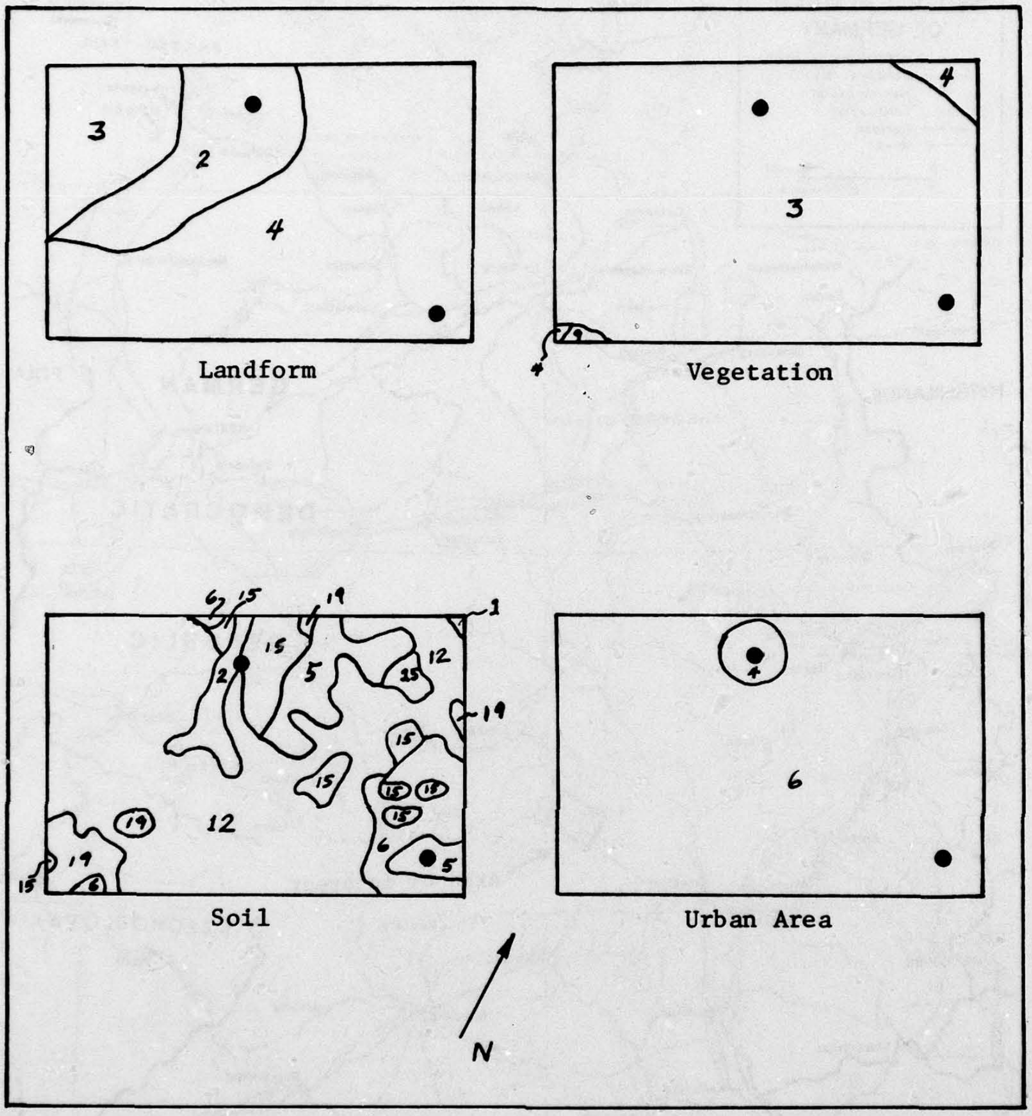


Figure 22. Thematic maps of area of interest; map classes are presented in Tables 1-4

Country: West Germany

Area: Fulda

Map Unit	Landform	Soils	Vegetation	Urban Distribution
1	02	02	03	04
2	02	02	03	06
3	02	05	03	06
4	02	06	03	04
5	02	06	03	06
6	02	12	03	04
7	02	12	03	06
8	02	15	03	04
9	02	15	03	06
10	03	12	03	06
11	03	12	09	06
12	04	01	04	06
13	04	02	03	06
14	04	05	03	06
15	04	06	03	06
16	04	06	09	06
17	04	12	03	06
18	04	12	04	06
19	04	15	03	06
20	04	19	03	06
21	04	19	04	06
22	04	19	09	06

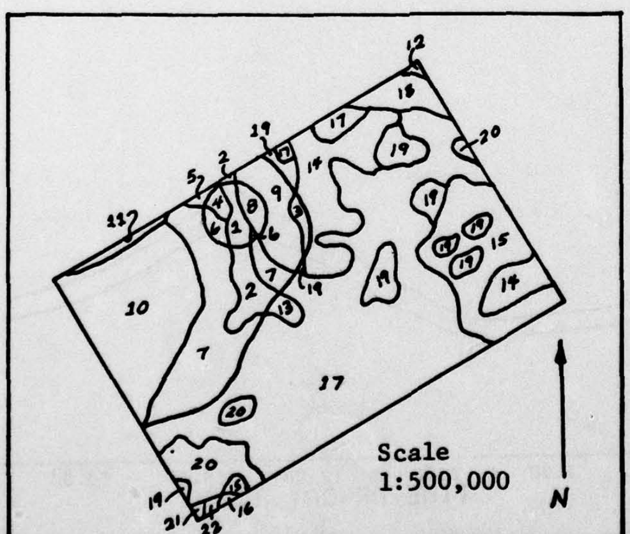
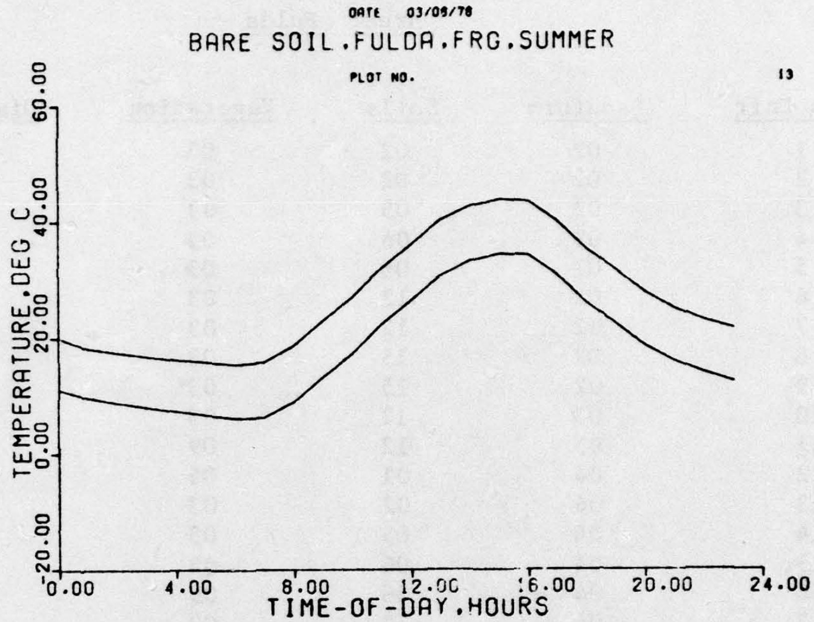


Figure 23. Thematic factor complex map and legend



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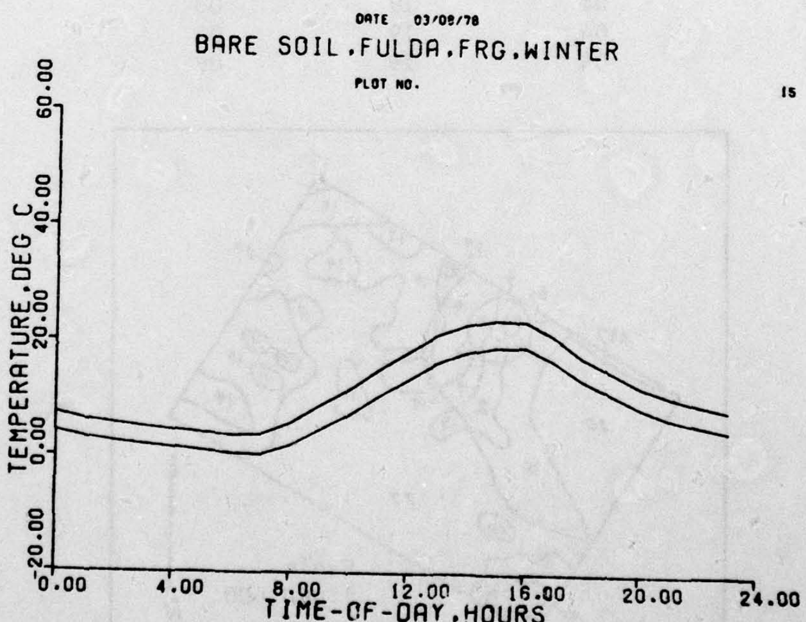
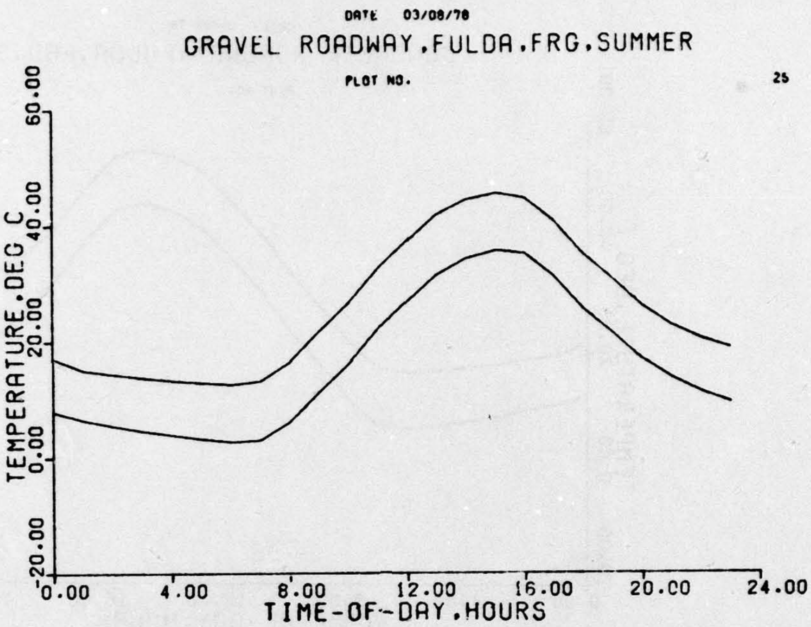


b.

Figure 24. Predicted temperature ranges for the general terrain feature, bare soil, representing summer (a) and winter (b) conditions in the area of Fulda, FRG



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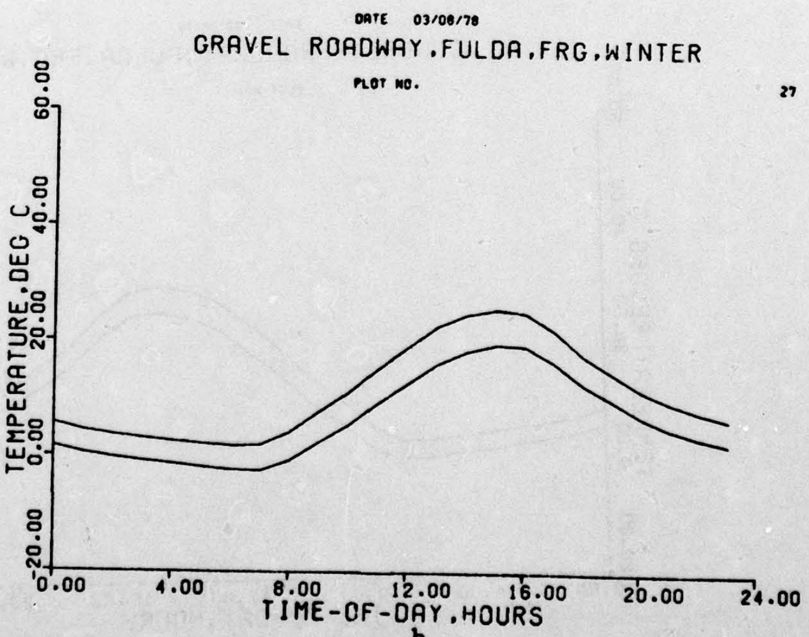
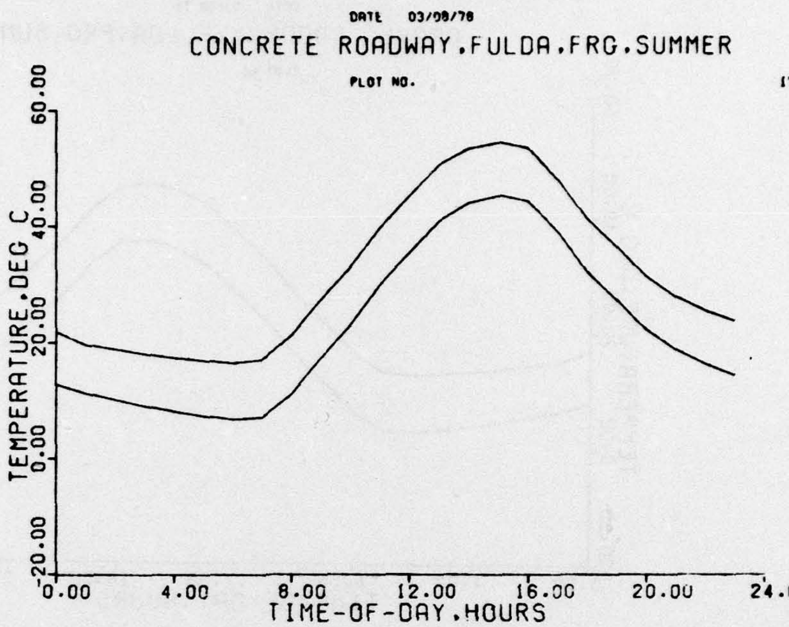


b.

Figure 25. Predicted temperature ranges for the general terrain feature, gravel roadway, representing summer (a) and winter (b) conditions in the area of Fulda, FRG



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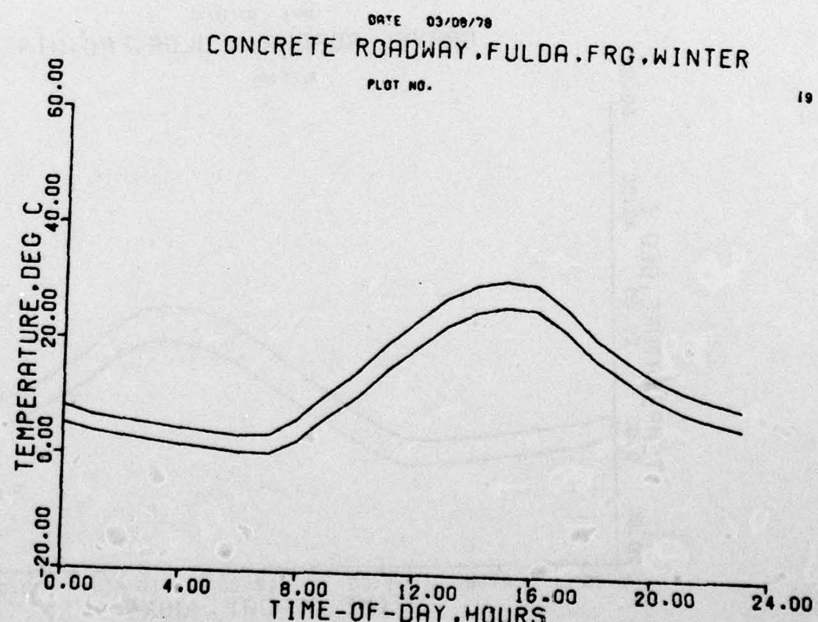
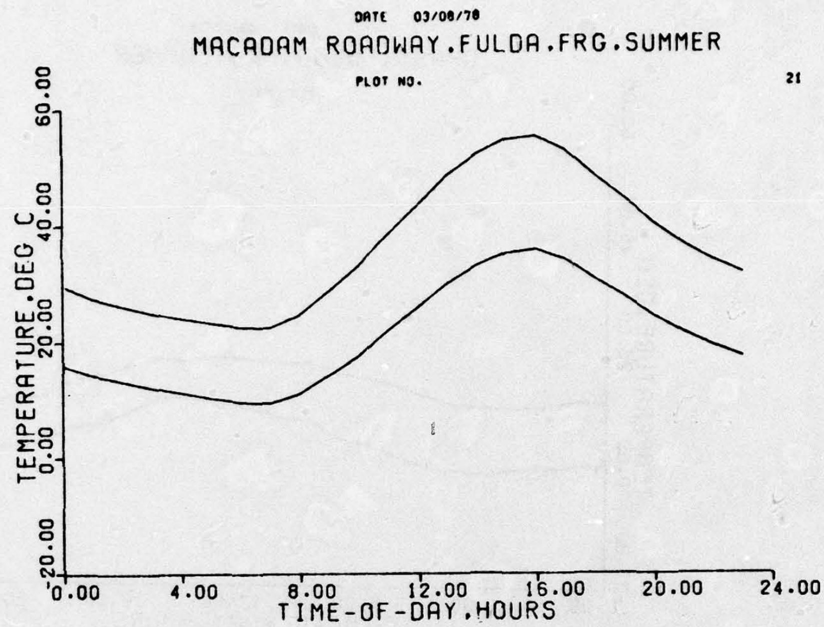


b.

Figure 26. Predicted temperature ranges for the general terrain feature, concrete roadway, representing summer (a) and winter (b) conditions in the area of Fulda, FRG



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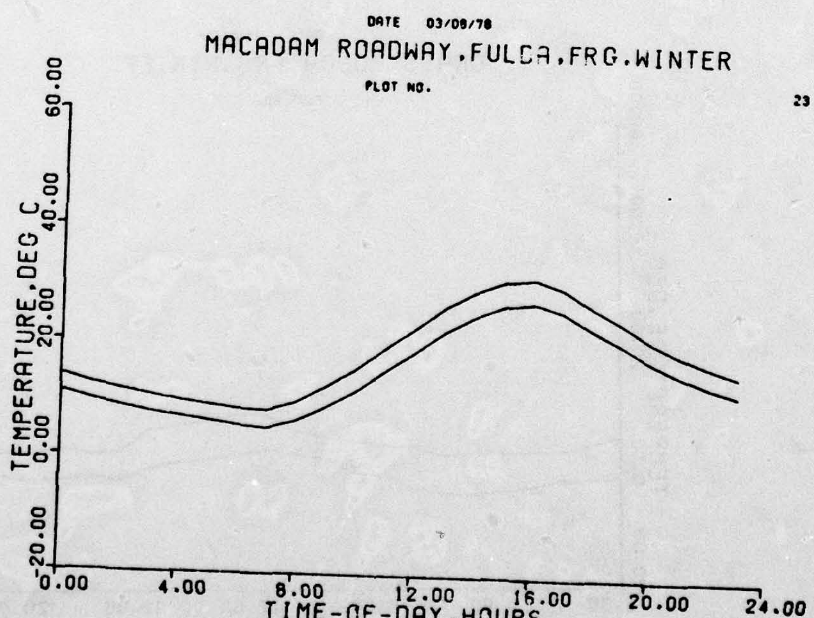

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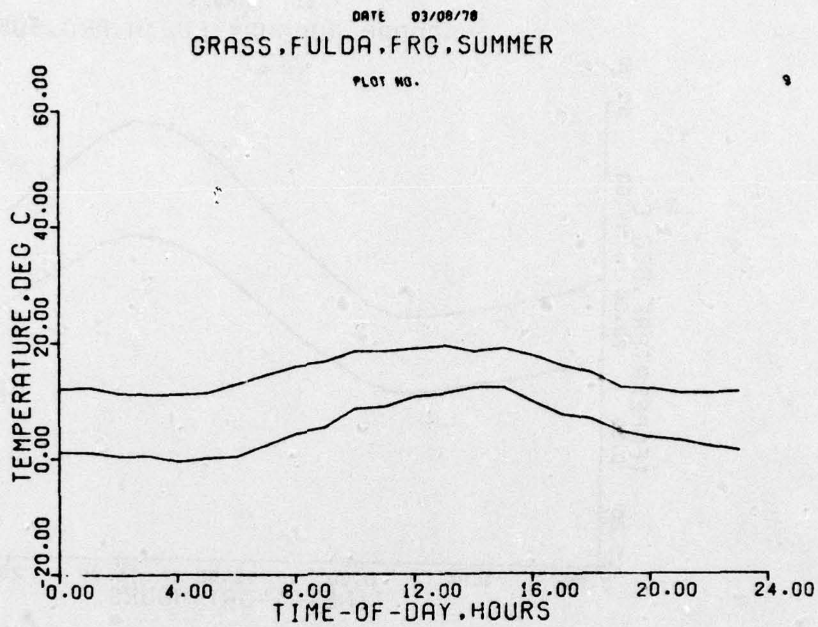
Figure 27. Predicted temperature ranges for the general terrain feature, macadam roadway, representing summer (a) and winter (b) conditions in the area of Fulda, FRG



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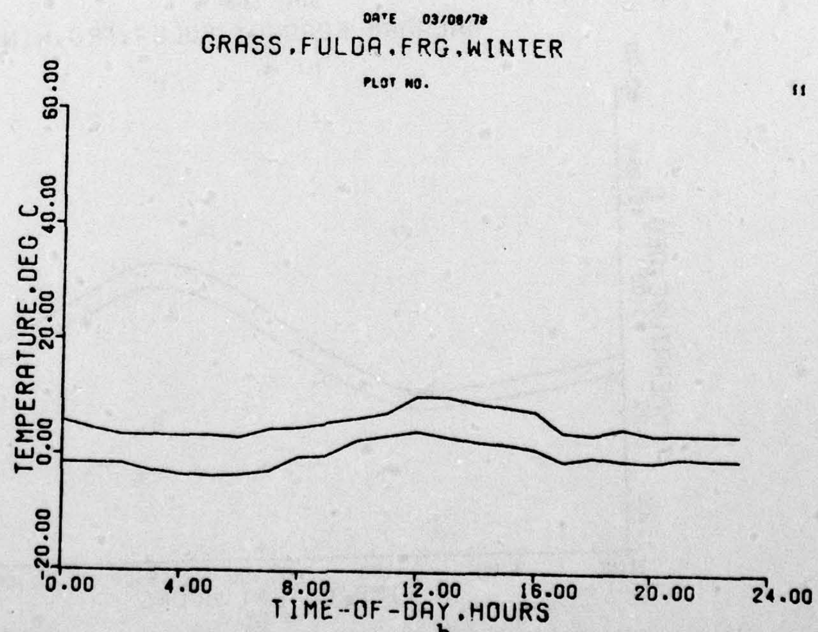
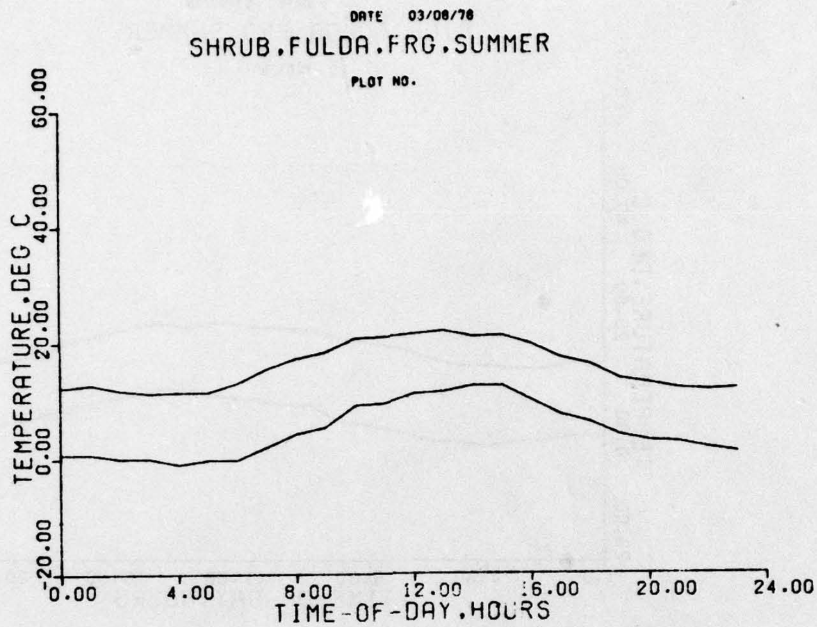


b.

Figure 28. Predicted temperature ranges for the general terrain feature, grass, representing summer (a) and winter (b) conditions in the area of Fulda, FRG



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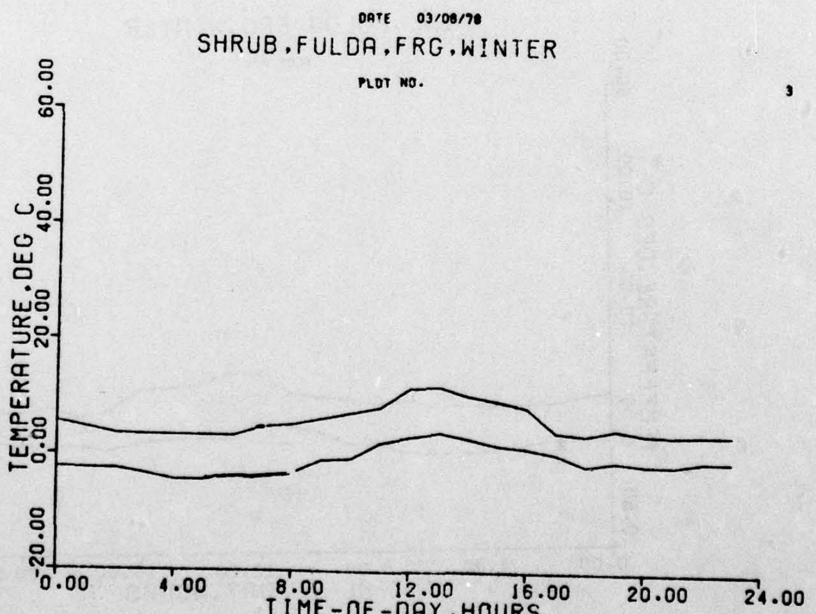
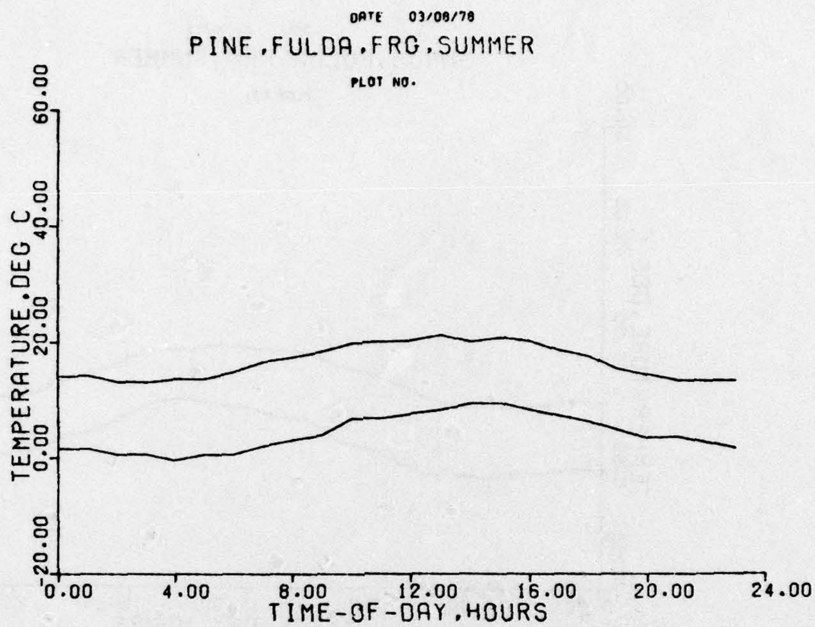


b.

Figure 29. Predicted temperature ranges for the general terrain feature, shrub, representing summer (a) and winter (b) conditions in the area of Fulda, FRG



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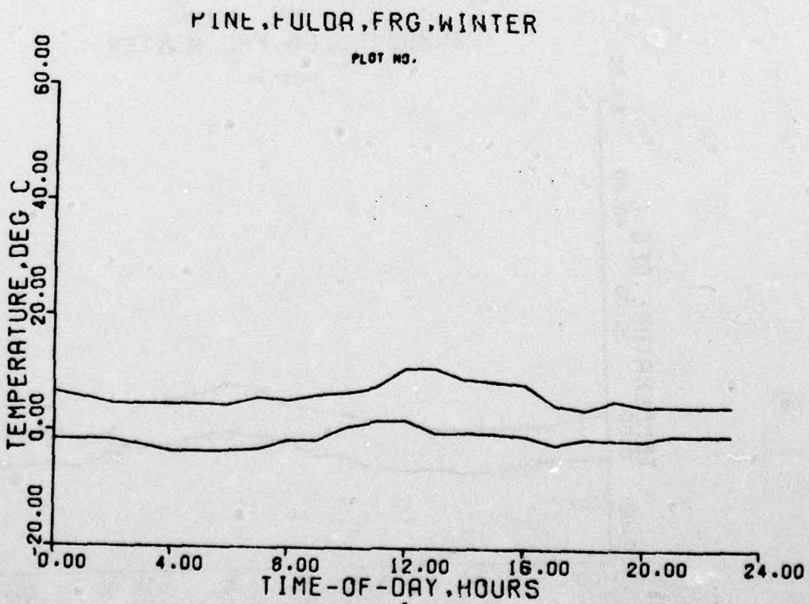

b.

Figure 30. Predicted temperature ranges for the general terrain feature, pine, representing summer (a) and winter (b) conditions in the area of Fulda, FRG

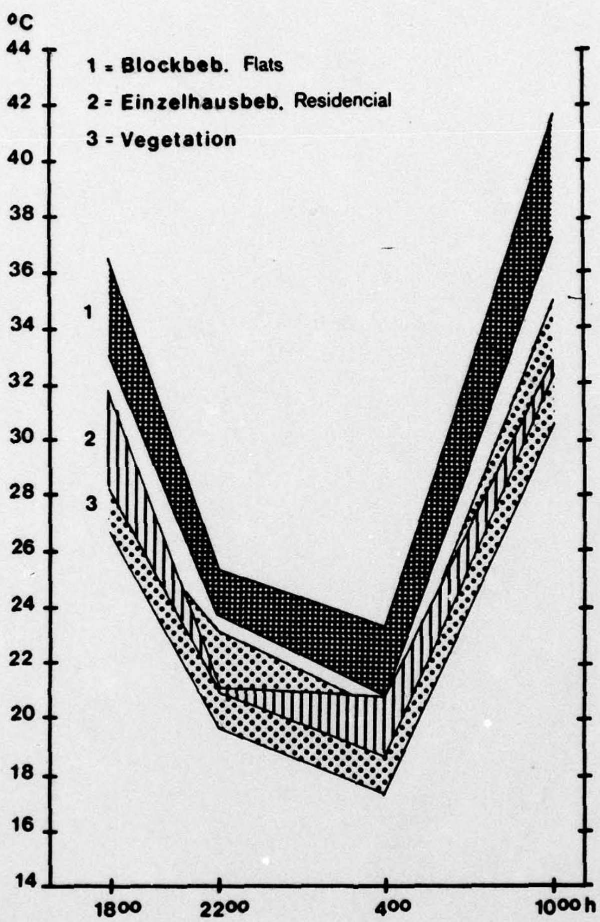

Figure 31. Radiometric temperature data for general terrain classes for Essen, FRG, on 8 August 1975 (Reference 1)

APPENDIX A: TERRAIN DATA BASE FOR THE FEDERAL REPUBLIC OF GERMANY: URBAN AND NONURBAN TERRAIN MAPS

An important part of the WES task in support of the Army-Wide Target Signature Program is the development and compilation of data pertinent to those environmental factors that affect the performance of field electrooptical sensors; initial emphasis has been given to environmental conditions in the Federal Republic of Germany (West Germany). Four 1:1,000,000 terrain maps of West Germany have been prepared. The base map used in this mapping project was derived from a 1:1,000,000 Soils Map of West Germany. This discussion provides background information on the sources and methods used to compile the four urban and nonurban terrain maps.

I: Geographic Distribution Map of Urban Areas

a. References or basic data used. This map was compiled from data obtained from the Defense Intelligence Agency (DIA), Washington, D. C. DIA provided information on the urban area (km^2), geographic coordinates, and population class of all urban areas in West Germany with populations greater than 25,000.

b. Comments. The purpose of this map is to graphically portray the geographic distribution, by population class and urban area (km^2), of urban areas in West Germany with populations of 25,000 or more. An intensive search for information on the areal extent of urban or built-up areas in West Germany failed to produce statistical data on the size or area of urban areas with populations less than 25,000. Quantitative data on the areal extent or size of cities under 25,000 could be obtained from the 1:50,000 (Series M745) topographic maps of West Germany; however, this would require a major mapping effort, and over 400 maps would be involved. Present funding limitations preclude such a task at this time. Also, most of the aerial photography used to compile these topographic maps was flown before 1965; this makes the data obtained from them obsolete, especially in the vicinity of metropolitan areas. A limiting factor of the urban area data provided by DIA is that these data include only urban areas within city limits and, therefore, do not include developed or built-up areas outside city limits. Also, the data provide no information or control on the actual geometric pattern or shape of the boundaries of cities. In this map, the area (to scale) of each circle equals the area (km^2) of each city as reported by DIA. This mapping scheme provides no control on the geometric pattern or shape of individual cities; because of this, a circle may overlap or fall entirely within the area of another circle. To obtain accurate control on the present areal extent and shape of urban or built-up areas, a more effective mapping effort is required. This creates the need for current and reliable data on the areal extent, geometric pattern, and configuration of all urban areas in West Germany.

c. Recommendations. A possible solution to the need for additional information on built-up areas in West Germany would be the use of LANDSAT (1:250,000) imagery to obtain current information on the actual area, geographic distribution, and shape or pattern of all urban areas.

II: Landform Map

a. References of basic data used.

(1) Military Engineering Geology Maps of West Germany, Series M5011, USAREUR, scale 1:250,000, which include terrain maps on a 1:1,000,000 scale.

(2) Bodenkarte der Bundesrepublik Deutschland, scale 1:1,000,000, Hannover, 1963 (Soils Map of West Germany).

(3) German Landscape Map (Structure and Form), scale 1:1,000,000. Borrowed from the USGS Library, Reston, Virginia.

b. Comments. This map was compiled mainly from the Military Engineering Geology Maps of West Germany. In compiling this map, mapping discontinuities and inconsistencies were found in the Series M5011 maps. The reliability of some of these maps is questionable, especially in the southern part of West Germany. The map discontinuities and inconsistencies were adjusted or corrected with data obtained from the Soils Map and the German Landscape Map.

c. Recommendations. This Landform Map provides the user with a general or regional view of landform types or conditions in West Germany. This might not suffice to meet the operational or mission planning requirements for specific target areas. Because various surface geometry factors will influence the performance of most electro-optical sensors, it is recommended that larger scale (1:50,000) landform maps of West Germany be prepared, especially for specific areas of interest.

III: Soils Map

a. References or basic data used. Bodenkarte der Bundesrepublik Deutschland, scale 1:1,000,000, Hannover, 1963 (Soils Map of West Germany).

b. Comments. The Soils Map of West Germany (referenced above) is one of the better maps available. The WES Soils Map was compiled from the German map, which uses 49 soil map units.

For this project, many of these map units were considered to be superfluous. For instance, the German map distinguishes between Pleistocene sands and Pleistocene and Holocene sands. To simplify the soils data, the 49 map units were reduced to 27 map units in the WES map.

c. Recommendations. For mission planning or operational purposes in specific target areas, larger scale (1:250,000) soils maps may be required. Because of the deficiencies noted in the Military Engineering Geology Maps of West Germany, referenced in II above, care must be exercised in the use of soils data obtained from these maps. Soils maps at 1:250,000 and larger scales, prepared by various West German agencies, are available for most of the country and should be referred to where more detailed soils data are required.

IV: Vegetation Cover Map

a. References or basic data used.

(1) Land Use Map by Central Intelligence Agency (CIA), Scale 1:5,000,000, May 1972.

(2) Bodenkarte der Bundesrepublik Deutschland (Soils Map of West Germany), scale 1:1,000,000, Hannover, 1963.

(3) Germany, A General and Regional Geography, by Robert E. Dickinson, Professor of Geography, University of Leeds, England, E. P. Dutton & Co., Inc., 2nd Edition, 1961.

b. Comments. There is a marked need for better and more detailed vegetation and land-use maps of West Germany. The *Vegetation Cover* Map prepared for this project was compiled from maps and information obtained after an intensive search for reliable data sources. This map was compiled primarily from the CIA Land Use Map. The information on marsh lands and peat bogs or moors was taken from the Soils Map of West Germany, referenced in a. above. The vegetation information was further improved by data obtained from the textbook by Robert E. Dickinson. The most important vegetation data gap found in this project was the lack of map information on the types or classes of forested areas, i.e., deciduous, coniferous, or mixed forests. Map information on the types of forest could be obtained from the 1:50,000 topographic maps (Series M745) of West Germany. However, as previously stated in I, b. above, this would require a major mapping effort that would produce vegetation data over 10 yr old.

c. Recommendations. There is a need for up-to-date reliable data on vegetation and land use in West Germany. A very general and recent land-use map of West Germany could be generated from 1:250,000 LANDSAT imagery; however, there still would be a need for more detailed land-use types or classes, i.e., cropland types, forest types, etc. A vegetation data search

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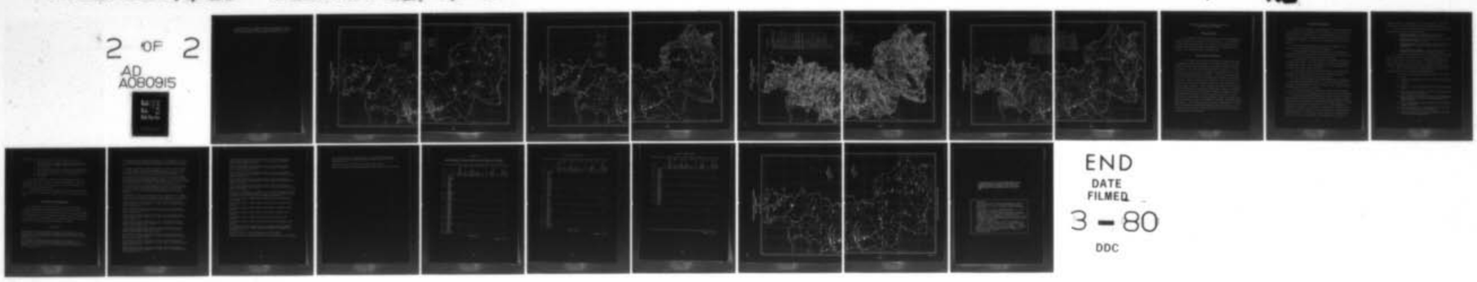

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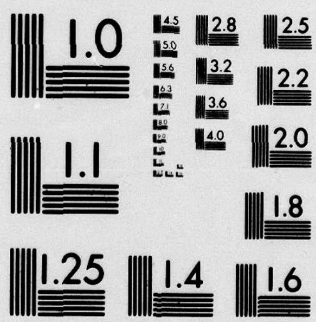
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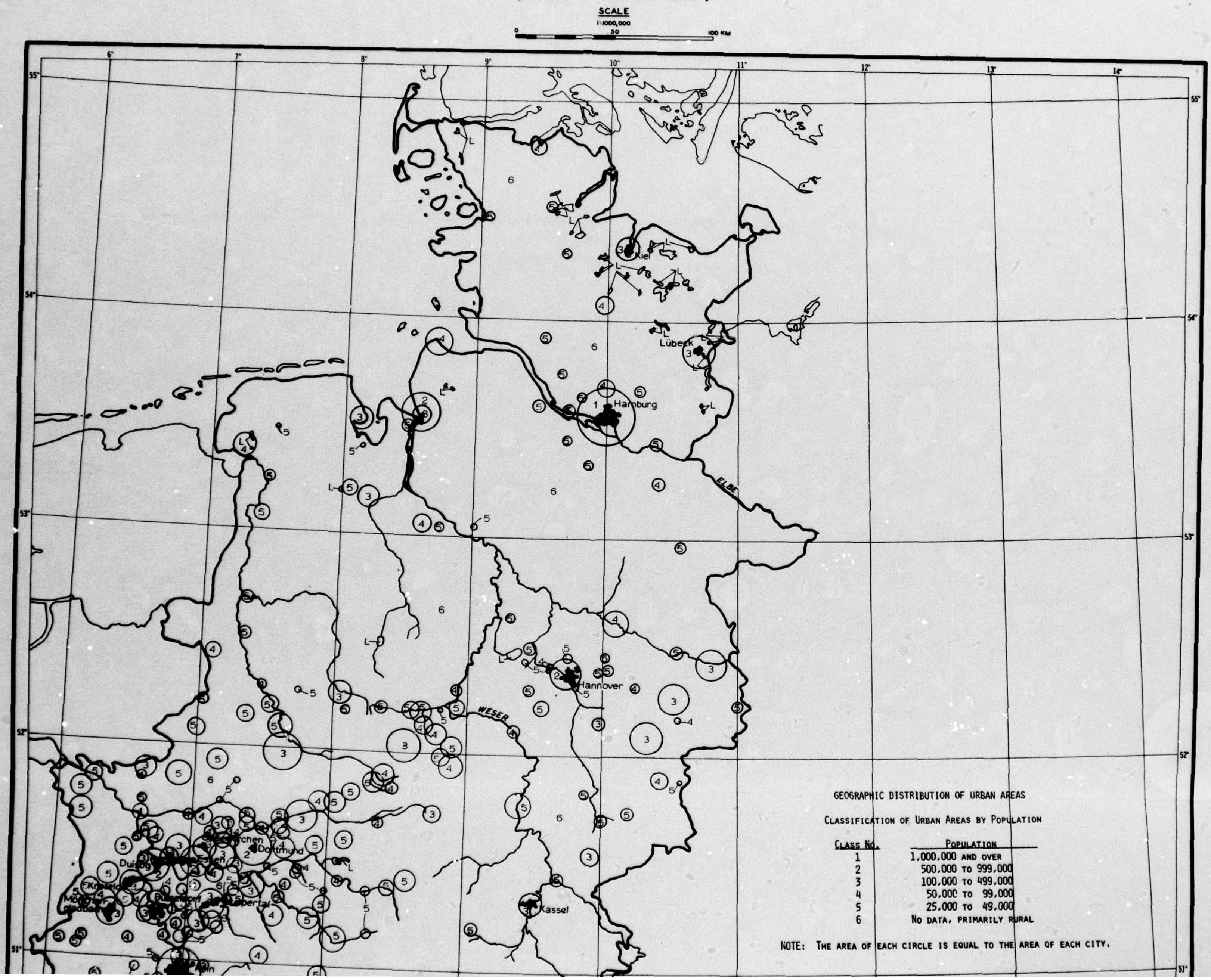
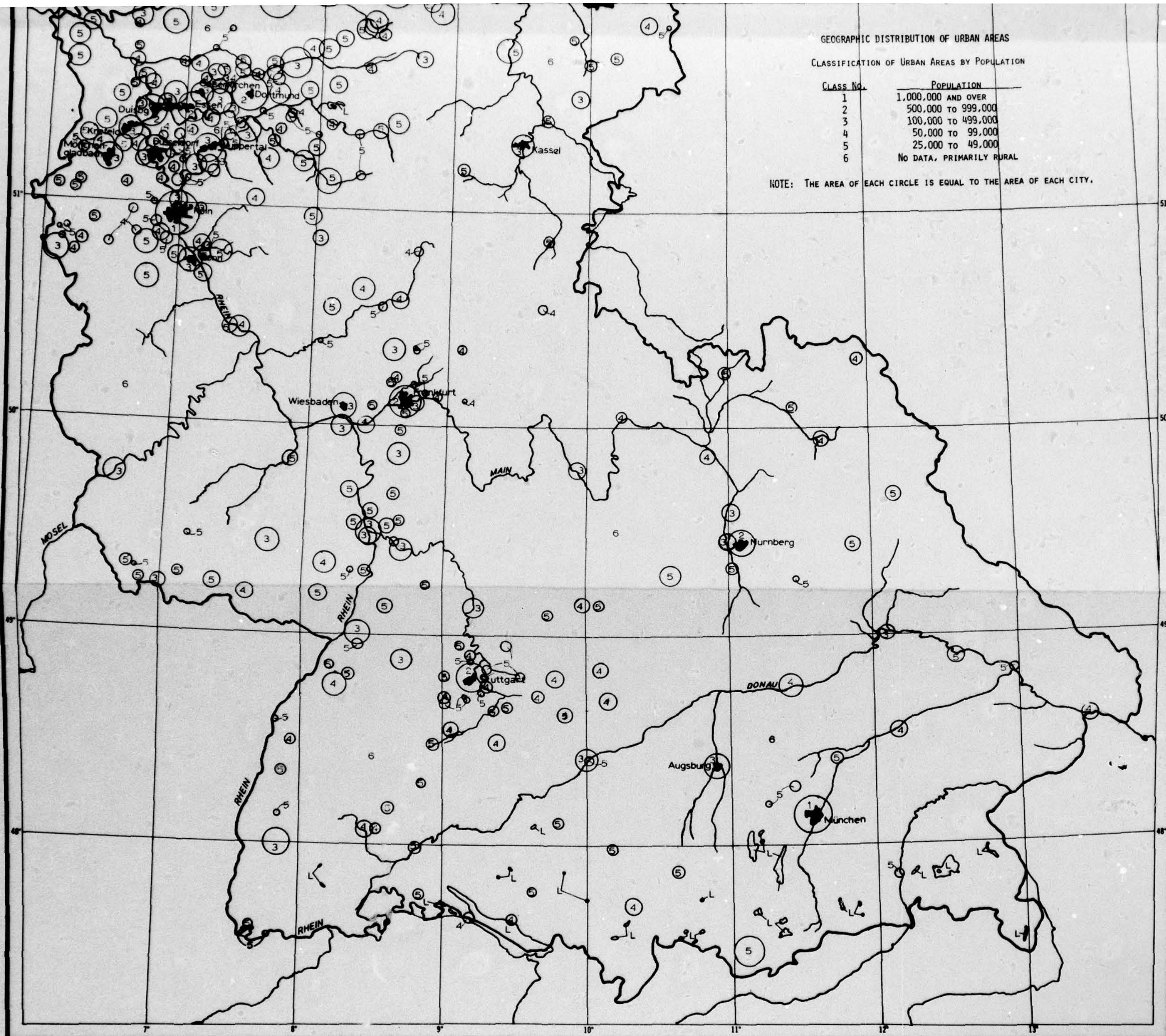
in West Germany is considered a prime requirement. A data search trip to West Germany is strongly recommended to improve the kind and quality of the available vegetation data base.

FEDERAL REPUBLIC OF GERMANY
(WEST GERMANY)




GEOGRAPHIC DISTRIBUTION OF URBAN AREAS
CLASSIFICATION OF URBAN AREAS BY POPULATION
CLASS NO. POPULATION
1 1,000,000 AND OVER
2 500,000 TO 999,000
3 100,000 TO 499,000
4 50,000 TO 99,000
5 25,000 TO 49,000
6 NO DATA, PRIMARILY RURAL
NOTE: THE AREA OF EACH CIRCLE IS EQUAL TO THE AREA OF EACH CITY.
Duisburg
Dortmund
Krefeld
Wuppertal
Köln
Kassel
Wiesbaden
Frankfurt
MAIN
RHEIN
MOSEL
Nurnberg
Stuttgart
DONAU
Augsburg
München
51°
50°
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FEDERAL REPUBLIC OF GERMANY
(WEST GERMANY)

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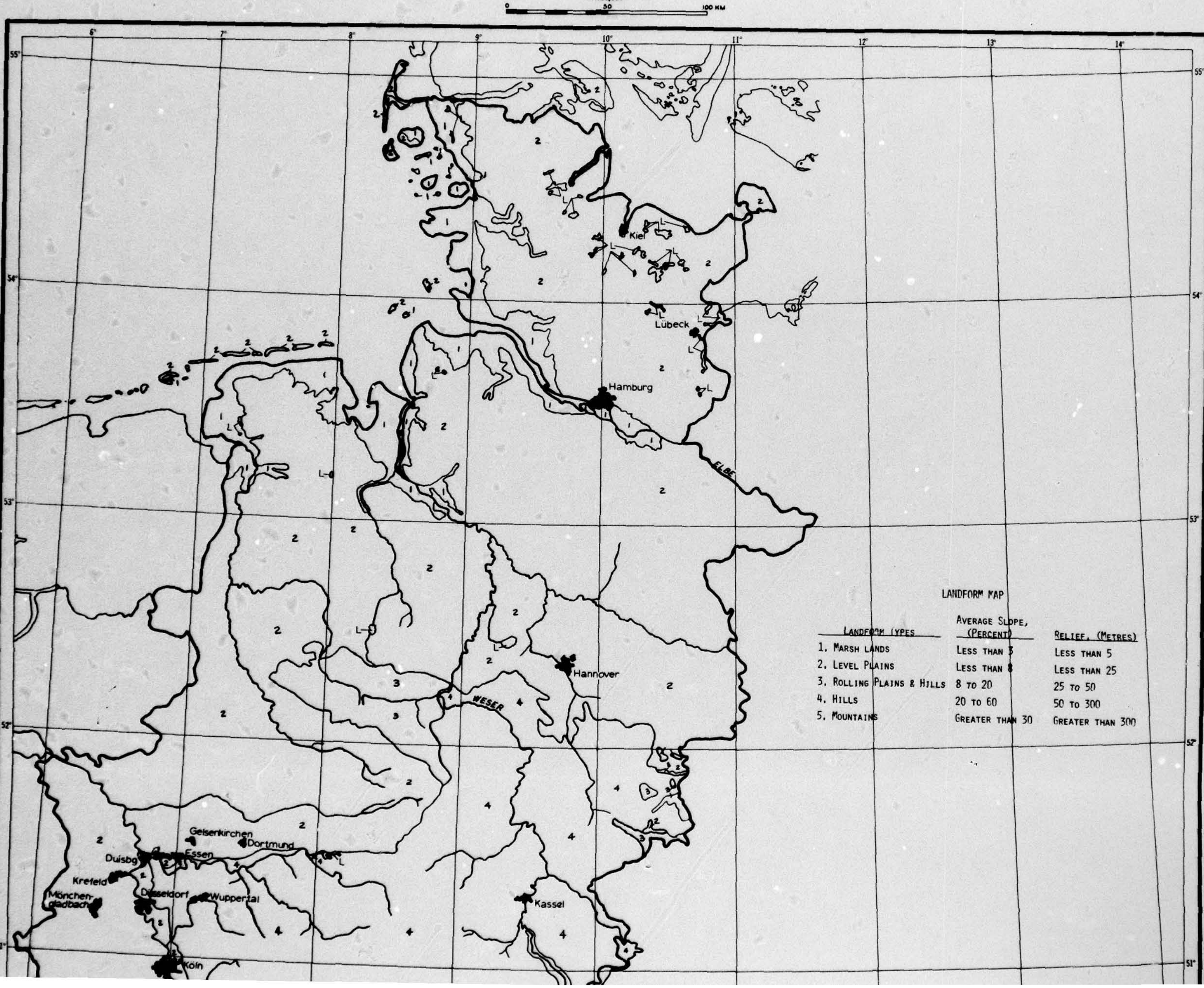

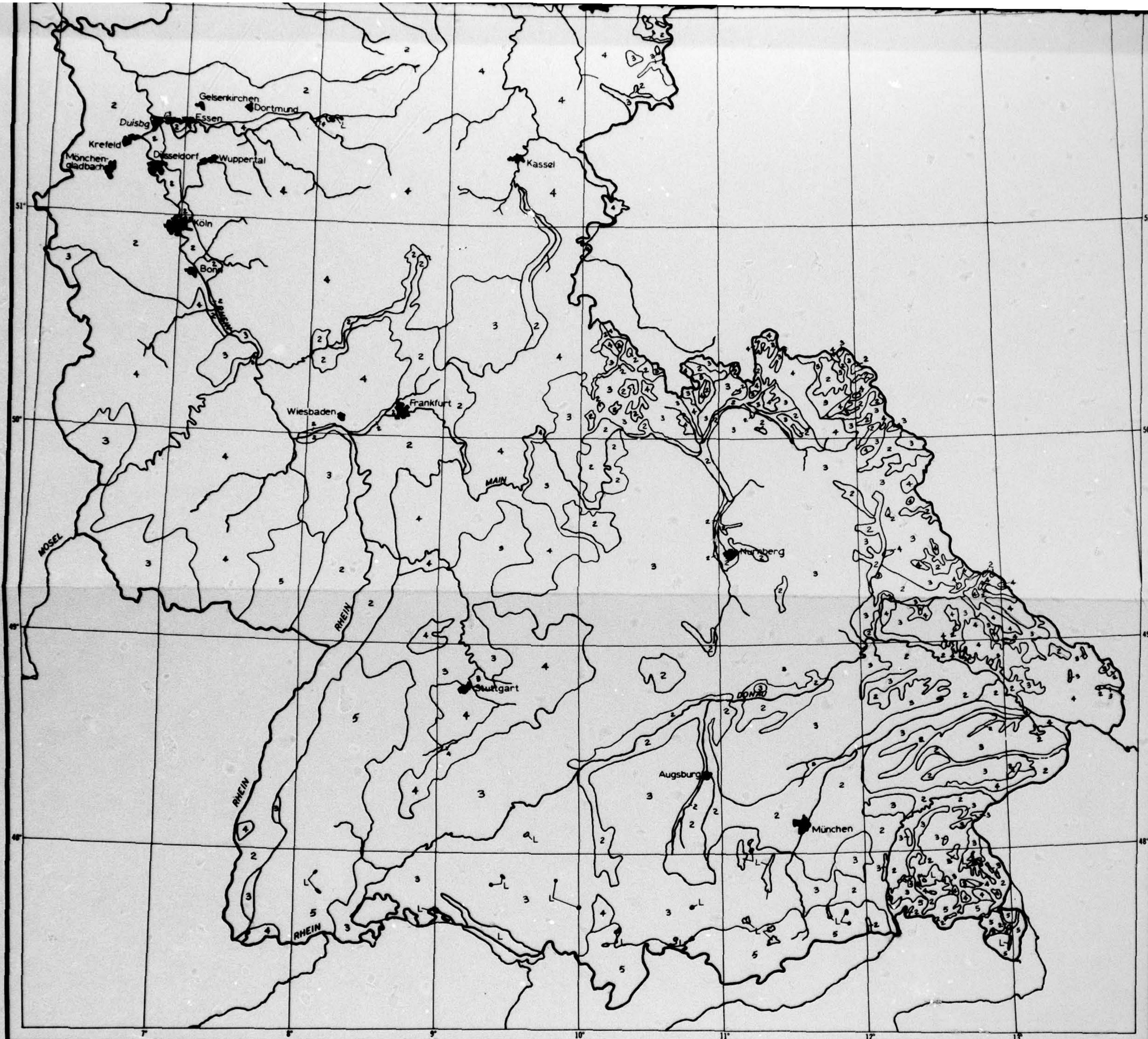
Gelsenkirchen
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Essen
Duisbg
Krefeld
Düsseldorf
Wuppertal
Mönchen-gladbach
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Bonn
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Wiesbaden
Frankfurt
MAIN
MOSEL
RHEIN
Nürnberg
Stuttgart
DONAU
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FEDERAL REPUBLIC OF GERMANY
(WEST GERMANY)

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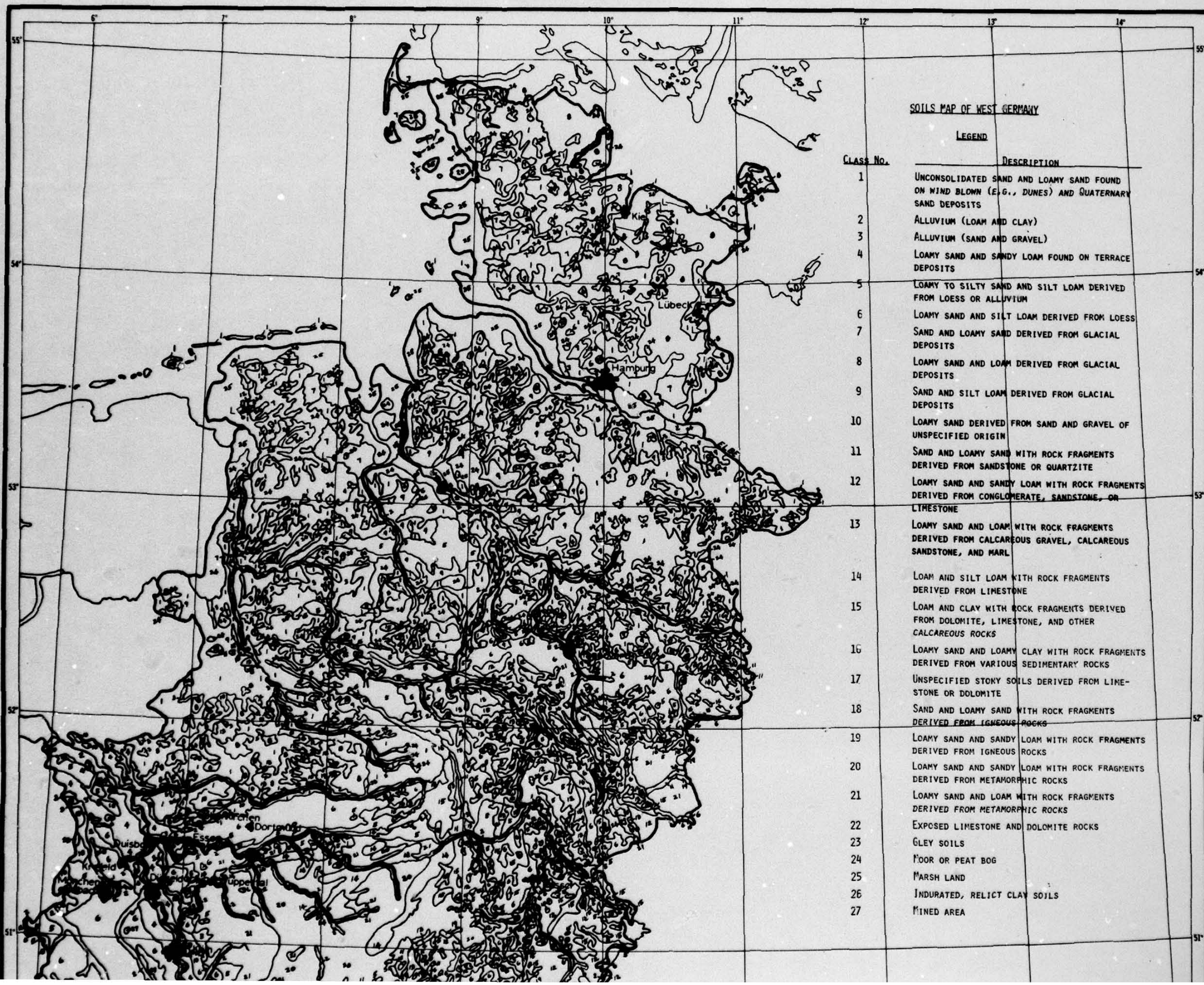
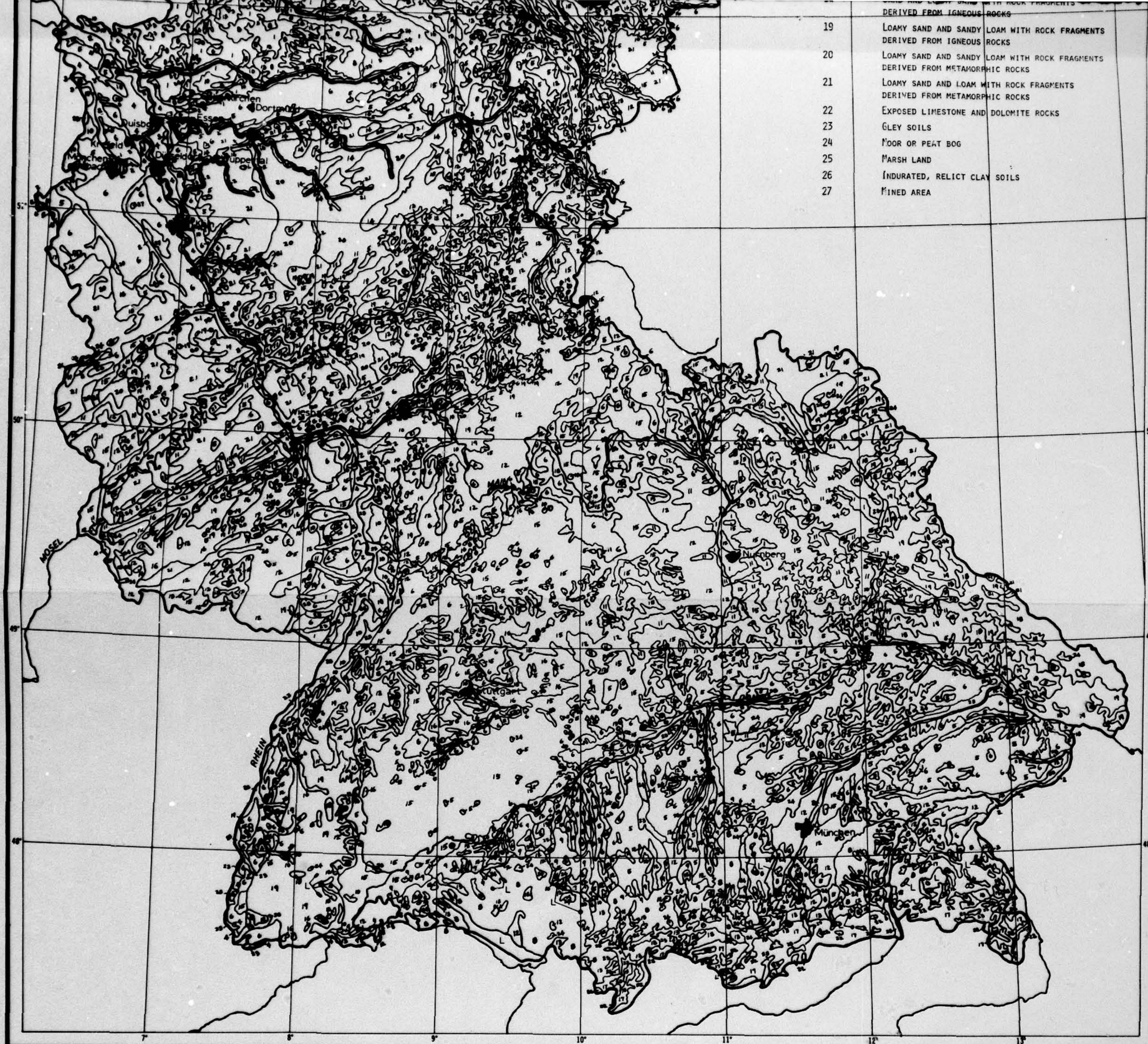


SOILS MAP OF WEST GERMANY

LEGEND

CLASS NO.	DESCRIPTION
1	UNCONSOLIDATED SAND AND LOAMY SAND FOUND ON WIND BLOWN (E.G., DUNES) AND QUATERNARY SAND DEPOSITS
2	ALLUVIUM (LOAM AND CLAY)
3	ALLUVIUM (SAND AND GRAVEL)
4	LOAMY SAND AND SANDY LOAM FOUND ON TERRACE DEPOSITS
5	LOAMY TO SILTY SAND AND SILT LOAM DERIVED FROM LOESS OR ALLUVIUM
6	LOAMY SAND AND SILT LOAM DERIVED FROM LOESS
7	SAND AND LOAMY SAND DERIVED FROM GLACIAL DEPOSITS
8	LOAMY SAND AND LOAM DERIVED FROM GLACIAL DEPOSITS
9	SAND AND SILT LOAM DERIVED FROM GLACIAL DEPOSITS
10	LOAMY SAND DERIVED FROM SAND AND GRAVEL OF UNSPECIFIED ORIGIN
11	SAND AND LOAMY SAND WITH ROCK FRAGMENTS DERIVED FROM SANDSTONE OR QUARTZITE
12	LOAMY SAND AND SANDY LOAM WITH ROCK FRAGMENTS DERIVED FROM CONGLOMERATE, SANDSTONE, OR LIMESTONE
13	LOAMY SAND AND LOAM WITH ROCK FRAGMENTS DERIVED FROM CALCAREOUS GRAVEL, CALCAREOUS SANDSTONE, AND MARL
14	LOAM AND SILT LOAM WITH ROCK FRAGMENTS DERIVED FROM LIMESTONE
15	LOAM AND CLAY WITH ROCK FRAGMENTS DERIVED FROM DOLOMITE, LIMESTONE, AND OTHER CALCAREOUS ROCKS
16	LOAMY SAND AND LOAMY CLAY WITH ROCK FRAGMENTS DERIVED FROM VARIOUS SEDIMENTARY ROCKS
17	UNSPECIFIED STONY SOILS DERIVED FROM LIMESTONE OR DOLOMITE
18	SAND AND LOAMY SAND WITH ROCK FRAGMENTS DERIVED FROM IGNEOUS ROCKS
19	LOAMY SAND AND SANDY LOAM WITH ROCK FRAGMENTS DERIVED FROM IGNEOUS ROCKS
20	LOAMY SAND AND SANDY LOAM WITH ROCK FRAGMENTS DERIVED FROM METAMORPHIC ROCKS
21	LOAMY SAND AND LOAM WITH ROCK FRAGMENTS DERIVED FROM METAMORPHIC ROCKS
22	EXPOSED LIMESTONE AND DOLOMITE ROCKS
23	GLEY SOILS
24	MOOR OR PEAT BOG
25	MARSH LAND
26	INDURATED, RELICT CLAY SOILS
27	MINED AREA


DERIVED FROM IGNEOUS ROCKS
19 LOAMY SAND AND SANDY LOAM WITH ROCK FRAGMENTS DERIVED FROM IGNEOUS ROCKS
20 LOAMY SAND AND SANDY LOAM WITH ROCK FRAGMENTS DERIVED FROM METAMORPHIC ROCKS
21 LOAMY SAND AND LOAM WITH ROCK FRAGMENTS DERIVED FROM METAMORPHIC ROCKS
22 EXPOSED LIMESTONE AND DOLOMITE ROCKS
23 GLEY SOILS
24 MOOR OR PEAT BOG
25 MARSH LAND
26 INDURATED, RELICT CLAY SOILS
27 MINED AREA
Nürnberg
München
RHEIN
MOSEL
MAIN
52°
51°
50°
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FEDERAL REPUBLIC OF GERMANY
('WEST GERMANY')

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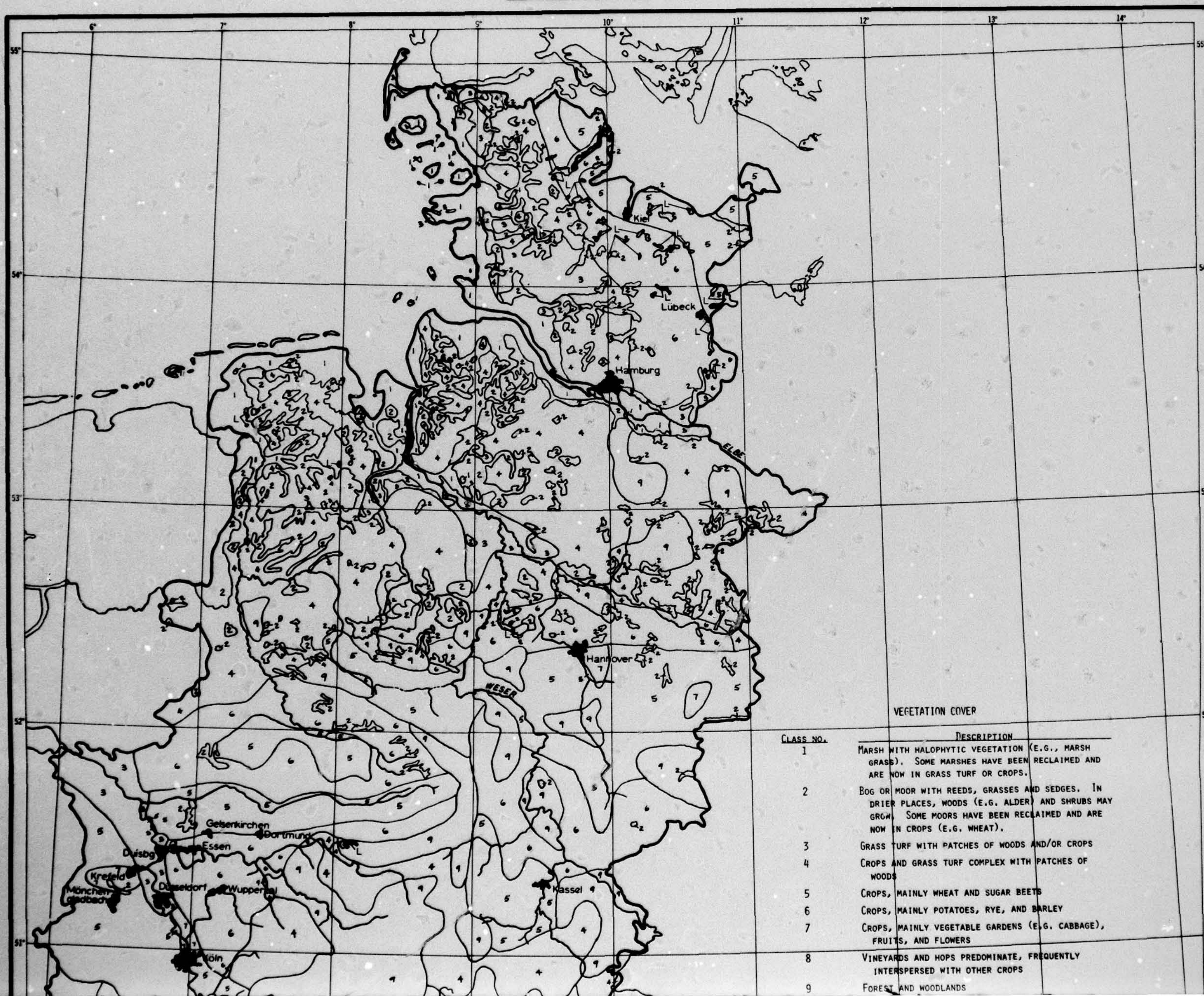
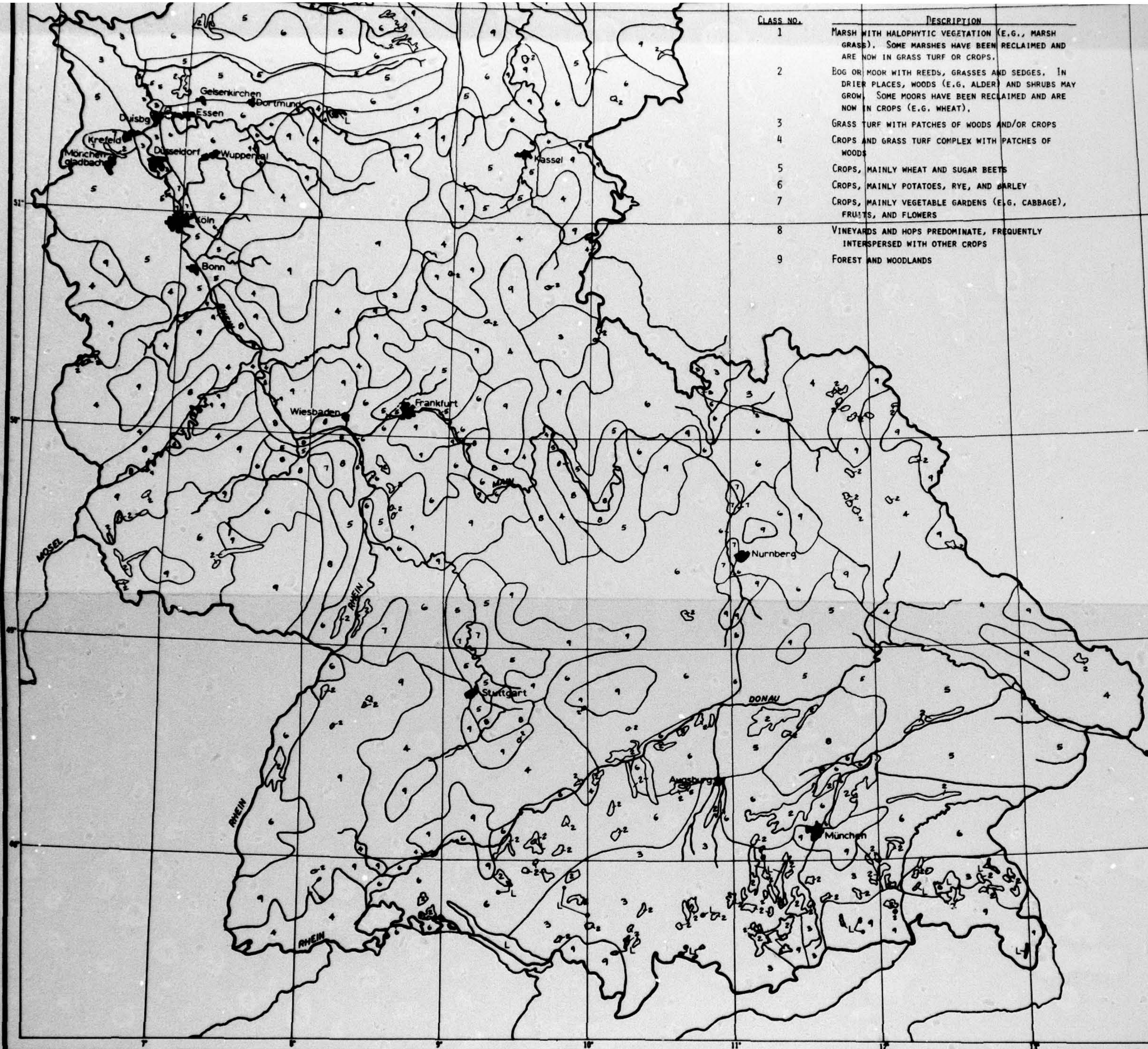




Class No.	Description
1	Marsh with halophytic vegetation (e.g., marsh grass). Some marshes have been reclaimed and are now in grass turf or crops.
2	Bog or moor with reeds, grasses and sedges. In drier places, woods (e.g. alder) and shrubs may grow. Some moors have been reclaimed and are now in crops (e.g. wheat).
3	Grass turf with patches of woods and/or crops
4	Crops and grass turf complex with patches of woods
5	Crops, mainly wheat and sugar beets
6	Crops, mainly potatoes, rye, and barley
7	Crops, mainly vegetable gardens (e.g. cabbage), fruits, and flowers
8	Vineyards and hops predominate, frequently interspersed with other crops
9	Forest and woodlands

2

APPENDIX B: SURVEY OF WEATHER DATA FOR THE FEDERAL REPUBLIC OF GERMANY

Purpose and Scope

1. The purpose of this survey was to review the on-hand meteorological references for definition of data content. It was considered of equal importance to prepare a map depicting the locations of all recording stations found within the references. The data search was limited to the Federal Republic of Germany (FRG).

Data Content of References

2. A review of the collected meteorological references was made to determine the number and location of recording stations in the FRG. Ninety-two stations were identified and located on a map by geographic coordinates to show their distribution within FRG (Figure B1). Occasionally, more than one station occurred in the immediate area of each other with slightly different coordinates. Where the coordinates did not vary more than three min, the stations were located as one station on the map. After the stations were located on a map, a table was prepared to depict the type of meteorological data collected by each recording station (Table B1). Major headings presented on this table are the World Meteorological Observation (WMO) station number, map location number on base map, recording stations (arranged in alphabetical order with latitude and longitude), and meteorological parameters. These parameters are temperature, relative humidity, weather conditions, surface wind, visibility, sky cover, barometric pressure, and miscellaneous observations. Each of these parameters includes subparameters. A check mark (X) beneath the subparameters indicates meteorological data were collected and reported by a particular station and may be found in one of the entries in the references.

Discussion of Parameters

3. Most of the parameters and subparameters are self-explanatory, but some need further definition due to limiting factors or conditions placed upon them. Temperature in the bibliographical material was recorded in all cases as °F, except one where it was recorded as Celsius. No distinction, however, has been made on the table as to the unit of measure.

4. Relative humidity data are found in the N-summaries, the worldwide airfield summaries, and the E-summaries.

5. Each parameter under weather conditions is a tabulation of percentage-frequency of occurrence of various atmospheric phenomena and obstructions to vision derived from hourly observations.

6. Surface wind is recorded in knots with direction reported by 16 compass points most of the time; however, some data are referred to an eight-point compass. Also, direction and speed are presented as a percentage with a mean reported for both.

7. Visibility is based on hourly observations and is tabulated for classes of ceiling from zero to ≥20,000 ft versus horizontal visibility in 16 increments from zero to ≥10 miles.

8. Sky cover is prepared from hourly observations and presented as a percentage-frequency distribution of total sky cover either in tenths or eights, depending on the data source. Also, a mean sky cover and number of observations are given.

9. Barometric pressure is recorded at station elevation and/or at mean sea level and is expressed in in. of mercury or mb, respectively.

10. Several meteorological parameters are listed under the miscellaneous heading. Military operation defines flying conditions and the mean number of days favorable for a specific military operation. Flying conditions are presented as category A, B, or C. Under category A, visibility is limited to 2-1/2 miles or greater with a low cloud amount of 0-4/8, or 5-8/8 at a height of 1000 ft or greater. Category B has a visibility limit of 1-1.4 miles or greater with a low cloud amount of 0-4/8, or 5-8/8 at a height of 650 ft or greater, but not meeting

category A criteria. Category C has a visibility limit of less than 1-1/4 miles, or low cloud amount of 5-8/8 at heights below 650 ft.

11. Specific military operations and conditions when these operations may be performed are presented below:

a. Incendiary bombing: A surface wind of 17 knots or greater and with no precipitation occurring.

b. Parachute operations: Flying condition A with a surface wind speed of 10 knots or less.

c. Chemical warfare: A surface wind speed of 4-10 knots, a temperature of 33-89°F, and with no precipitation occurring.

d. Visual high-level bombing: A total sky cover of 2/8 or less with a visibility of 2-1/2 miles or greater.

12. Wind speed and temperature are a percentage-frequency distribution. Wind speed is tabulated in knots and is separated into 10 classes ranging from calm to >40 knots. Temperature recordings vary from 110 and higher to a -39°F and below. A total percentage and number of observations for each class and temperature range are given.

13. State of ground surface is identified by 10 codes, which identify surface cover conditions as presented below:

(0) Dry with no appreciable amount of dust or loose sand.

(1) Moist.

(2) Wet with standing water in small or large pools on the surface.

(3) Frozen.

(4) Glaze or ice on the ground but with no snow or melting snow.

(5) Snow or melting snow with or without ice covering less than one-half of the ground.

(6) Snow or melting snow with or without ice covering more than one-half of the ground but the ground not completely covered.

(7) Snow or melting snow with or without ice covering the ground completely.

(8) Loose dry snow, dust, or sand covering more than one-half of the ground, but not completely.

(9) Loose dry snow, dust, or sand covering more than one-half of the ground completely.

The above codes have further restrictive conditions which are:

(1) Where dust or sand is reported and the temperature is below 0°C, the word DUST or SAND is added to the end of the report.

(2) The definitions for codes 0-3 apply to representative bare ground and codes 4-9 to an open representative area.

(3) The highest code figure is to be reported in all instances.

14. Soil temperature tabulates mean and standard deviation of temperature at 2 cm, 5 cm, and 10 cm below ground surface. The soil temperature is a monthly report separated into three divisions--1-10 days, 11-20 days, and 21-30 days.

15. Data gathered for solar radiations are expressed in Langley units (cal/cm^2) per day whereas sunshine duration is expressed in hours/ day.

Conclusion and Recommendations

16. Meteorological data collected by the various recording stations are presented in many formats and are often inconsistent. With an overall review, data gaps between stations can be seen quite readily. It is recommended that a more consistent format be used for presentation of data such as a table whereby the various types of meteorological data collected by all stations can be determined at a glance.

Bibliography

Environmental Technical Applications Center, "N Summary Nos. 1, 6, 7, 14, 21, and 22, for January 1949 to November 1971, Bremerhaven, West Germany," U. S. Air Force, Data Processing Division, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "N Summary Nos. 1, 6, 7, 14, 21, and 22, for January 1949 to November 1971, München, West Germany," U. S. Air Force, Data Processing Division, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "N Summary Nos. 1 thru 31, for January 1949 to November 1971, Hannover, West Germany," U. S. Air Force, Data Processing Division, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "Revised Uniform Summary of Surface Weather Observations (RUSSWO), Parts A, B, C, D, E, and F, for January 1959 to December 1970, Grafenwohr, West Germany," U. S. Air Force, Data Processing Division Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "Revised Uniform Summary of Surface Weather Conditions (RUSSWO), Parts A, C, and D, for January 1966 to December 1976, Wasserkuppe, West Germany," U. S. Air Force, Data Processing Division, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "Revised Uniform Summary of Surface Weather Observations (RUSSWO), Parts C, D, and Portions of Part E, for March 1952 to December 1970, Ramstein Air Base, West Germany," U. S. Air Force, Data Processing Division Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "Summary of Soil Temperatures and State of Ground, 39 Stations, West Germany," U. S. Air Force, Data Processing Division, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Bitburg, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Buchel, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Giessen, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Gutersloh RAF, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Hamburg-Fuhlsbuttel, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Kassel, West Germany," U. S. Air Force, Air Weather Services Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Kitzingen, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Laarbuch, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Rhein-Main, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Schleswig, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Solingen, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Stuttgart, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Environmental Technical Applications Center, "World-Wide Airfield Summary, Wildenrath, West Germany," U. S. Air Force, Air Weather Service (MAC), Asheville, N. C.

Lof, G. O. G., Duffie, J. A., Smith, C. O., "World Distribution of Solar Radiation," Solar Energy Laboratory, Report No. 21, July 1966, College of Engineering, The University of Wisconsin, Madison, Wis.

Miscellaneous Report, DATSAV Surface Observations, Berlin/Templehof, West Germany.

Miscellaneous Report, DATSAV Surface Observations, Bremerhaven, West Germany.

Miscellaneous Report, DATSAV Surface Observations, Grafenwroh, West Germany.

Miscellaneous Report, DATSAV Surface Observations, Hannover, West Germany.

Miscellaneous Report, DATSAV Surface Observations, Kassel, West Germany.

Miscellaneous Report, DATSAV Surface Observations, Wasserkuppe, West Germany.

Naval Weather Service Command, "Guide to Standard Weather Summaries and Climatic Services," NAVAIR Publication 50-1C-534, January 1975, Asheville, N. C.

Unknown Publication, Erdbodentemperaturen, West Germany.

Unknown Publication, Globalstrahlung und Sonnenscheindaver, West Germany.

Naval Weather Service Command, "Guide to Standard Weather Summaries and Climatic Services," NAVAIR Publication 50-1C-534, January 1975, Asheville, N. C.

Unknown Publication, Erdbodentemperaturen, West Germany.

Unknown Publication, Globalstrahlung und Sonnenscheindaver, West Germany.

Table B1

<u>Meteorological Recording Stations, Federal Republic of Germany</u>

WMO Station Number	Location on Base Map	Recording Station \ Parameter	Temperature: Temperature	Absolute Max. and/or Min.	Mean Daily Max. and/or Min.	Daily and/or Monthly Mean	Mean Dew Point	Relative Humidity: Mean Percent	Absolute Minimum	Mean Wet Bulb	Dry Bulb	Weather Conditions: Precipitation	Thunderstorms	Rain and/or Drizzle	Freezing Rain/Drizzle	Snow and/or Sleet	Hail	Fog	Smoke and/or Haze	Blowing Snow	Snow Depth	Dust and/or Sand	Surface Wind: Direction	Speed	Max Speed	Visibility: Statute Miles/Meters	Ceiling	Sky Cover: Percent Frequency	Mean Sky Cover	Total Cloud Amount	Low Cloud Amount	Mean Total Cloud Amount	Pressure: Station	Sea Level	Miscellaneous: Military Operation	Wind Speed/Temperature	State of Ground Surface	Soil Temperature	Solar Radiation	Sunshine Duration
10501	55	Aachen N5047-E0606										X																										X		
10852	39	Augsburg/Kriegshaber N4823-E1051																																			X	X		
10658	28	Bad Kissingen N5012-E1006																																			X	X		
10971	44	Bad Tolz N4746-E1134																																			X	X		
10670	29	Bamberg N4953-E1052																																			X	X		
10997	45	Berchtesgaden N4738-E1300																																			X	X		
10381	33	Berlin/Dahlem N5228-E1318	X				X					X											X	X		X	X	X		X			X	X			X	X		
10610	77	Bitburg N4956-E0633		X	X	X	X	X						X		X								X		X	X	X					X			X				
	81	Bochum N5129-E0713																																					X	
	32	Braunlage/Harz N5143-E1037																																				X	X	
10348	22	Braunschweig/Voelkenrode N5218-E1027																																			X	X	X	X
10224	50	Bremen/Flughafen N5303-E0847																																				X		
10129	4	Bremerhaven N5332-E0835	X	X	X		X	X				X	X	X		X		X	X		X	X	X	X	X	X	X	X		X	X		X	X	X					
00001	7	Bremervoerde N5329-E0909																																			X	X		
10613	76	Buchel (Heidelberg)		X	X	X	X	X						X		X								X		X	X	X					X			X				
	61	Buchen/Odenwald N4931-E0920																																				X		
	64	Coburg N5016-E1057																																				X		
	63	Donaueschingen N4757-E0830																																				X		
	40	Edewechterdamm N5308-E0756																																				X		
00002	8	Eiberg N4820-E1203																																			X	X		
	59	Ensheim/Saar N4912-E0707																																				X	X	
10410	34	Essen/Mulheim N5125-E0657																																			X	X		
00003	9	Eutin/Eutin N5408-E1037																																			X	X		
10033	18	Flensburg N5448-E0926																																			X	X		
	62	Freiburg N4800-E0751												X																								X	X	
10934	42	Friedrichshafen N4739-E0929																																			X	X		
00004	10	Friesdorf N5042-E0708																																			X	X		
	57	Fulda N5033-E0942																																				X		
10628	27	Geisenheim N4959-E0758																																			X	X		
10532	36	Giessen/Liebigshohe N5034-E0842		X	X	X	X	X						X		X								X		X	X	X					X			X	X	X		
10444	25	Goettingen N5131-E0956																																			X	X		
34180	2	Grafenwoehr N4942-E1157	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				X	X						
10320	73	Guetersloh RAF N5156-E0819		X	X	X	X	X				X				X								X		X	X	X					X			X				
10616	87	Hahn N4957-E0716												X																										
10147	51	Hamburg-Fuhlsbuttel N5338-E0959		X	X	X	X	X						X		X								X		X	X	X					X			X		X	X	X

(Continued)

(Sheet 1 of 3)

Table B1 (Continued)

WMO Station Number	Location on Base Map	Recording Station	Temperature: Temperature	Temperature: Absolute Max. and/or Min.	Temperature: Mean Daily Max. and/or Min.	Temperature: Daily and/or Monthly Mean	Temperature: Mean Dew Point	Relative Humidity: Mean Percent	Relative Humidity: Absolute Minimum	Relative Humidity: Mean Wet Bulb	Relative Humidity: Dry Bulb	Weather Conditions: Precipitation	Weather Conditions: Thunderstorms	Weather Conditions: Rain and/or Drizzle	Weather Conditions: Freezing Rain/Drizzle	Weather Conditions: Snow and/or Sleet	Weather Conditions: Hail	Weather Conditions: Fog	Weather Conditions: Smoke and/or Haze	Weather Conditions: Blowing Snow	Weather Conditions: Snow Depth	Weather Conditions: Dust and/or Sand	Surface Wind: Direction	Surface Wind: Speed	Surface Wind: Mean Speed	Visibility: Statute Miles/Meters	Visibility: Ceiling	Sky Cover: Percent Frequency	Sky Cover: Mean Sky Cover	Sky Cover: Total Cloud Amount	Sky Cover: Low Cloud Amount	Sky Cover: Mean Total Cloud Amount	Pressure: Station	Pressure: Sea Level	Miscellaneous: Military Operation	Miscellaneous: Wind Speed/Temperature	Miscellaneous: State of Ground Surface	Miscellaneous: Soil Temperature	Miscellaneous: Solar Radiation	Miscellaneous: Sunshine Duration
10338	3	Hanover N5227-E0943	x	x	x	x	x	x				x	x	x		x		x	x		x	x		x	x	x	x	x		x	x	x	x	x	x	x			x	
00005	11	Herford N5207-E0847																																			x	x		
	82	Hoefchen N5106-E0706																																					x	
10685	30	Hof N5019-E1153																																			x	x		
10962	72	Hohenpei Benberg N4748-E1101																																					x	x
	68	Wull/Ndb. N4836-E1141																																				x		
00006	12	Kaisheir Neuhof K4844-E1048																																			x	x		
00007	13	Karlschuld N4840-E1118																																			x	x		
	83	Karlsruhe N4901-E0825																																					x	
	53	Kassel-Marleshausen N5120-E0927	x	x	x	x	x	x				x		x		x							x	x		x	x	x					x	x		x		x		
10946	43	Kempten N4743-E1020																																			x	x		
14010	75	Kitzingen N4944-E1012	x	x	x	x	x	x						x		x							x	x		x	x	x					x			x				
	92	Koblenz N5022-E0735										x																												
	84	Konigstein-Taunus N5011-E0829																																					x	
10405	78	Laarbruch N5136-E0608		x	x	x	x	x					x	x										x		x	x	x					x			x				
10305	21	Lingen N5231-E0719																																			x	x		
10253	20	Luchow N5258-E1111																																			x	x		
10729	32	Mannheim N4932-E0830																																			x	x		
10875	40	Muhldorf N4815-E1202																																			x	x		
	67	Muhldorf/Inn N4815-E1232																																				x		
10866	5	Muchen N4808-E1142	x	x	x			x					x	x		x		x	x		x	x	x	x	x	x	x	x			x				x				x	
	54	Munster N5158-E0736																																				x		
	60	Neustadt/Weinstrabe N4922-E0808																																				x		
10113	48	Norderney N5343-E0709																																				x		
10763	35	Nurnberg/Kraftshop N4930-E1105																																			x	x		
	69	Oberstdorf N4724-E1017																																				x	x	
10215	19	Oldenburg N5308-E0812																																			x	x		
10893	41	Passau/Oberhaus N4835-E1329																																			x	x		
00008	14	Peissenberg N4747-E1104																																			x	x		
34050	6	Ramstein	x					x			x	x											x	x	x	x	x	x												
10776	36	Regensburg N4902-E1204																																			x	x		
10636	74	Rhein-Main N5002-E0835		x	x	x	x	x						x		x								x		x	x	x					x			x				
00009	15	Rothenburg on the Tauber N4923-E1011																																			x			
	47	Schleswig/Wetterami N5432-E0933		x	x	x	x	x						x		x								x		x	x	x					x			x		x		
00010	16	Seligenstadt N4951-E1006																																			x	x		

(Continued)

(Sheet 2 of 3)

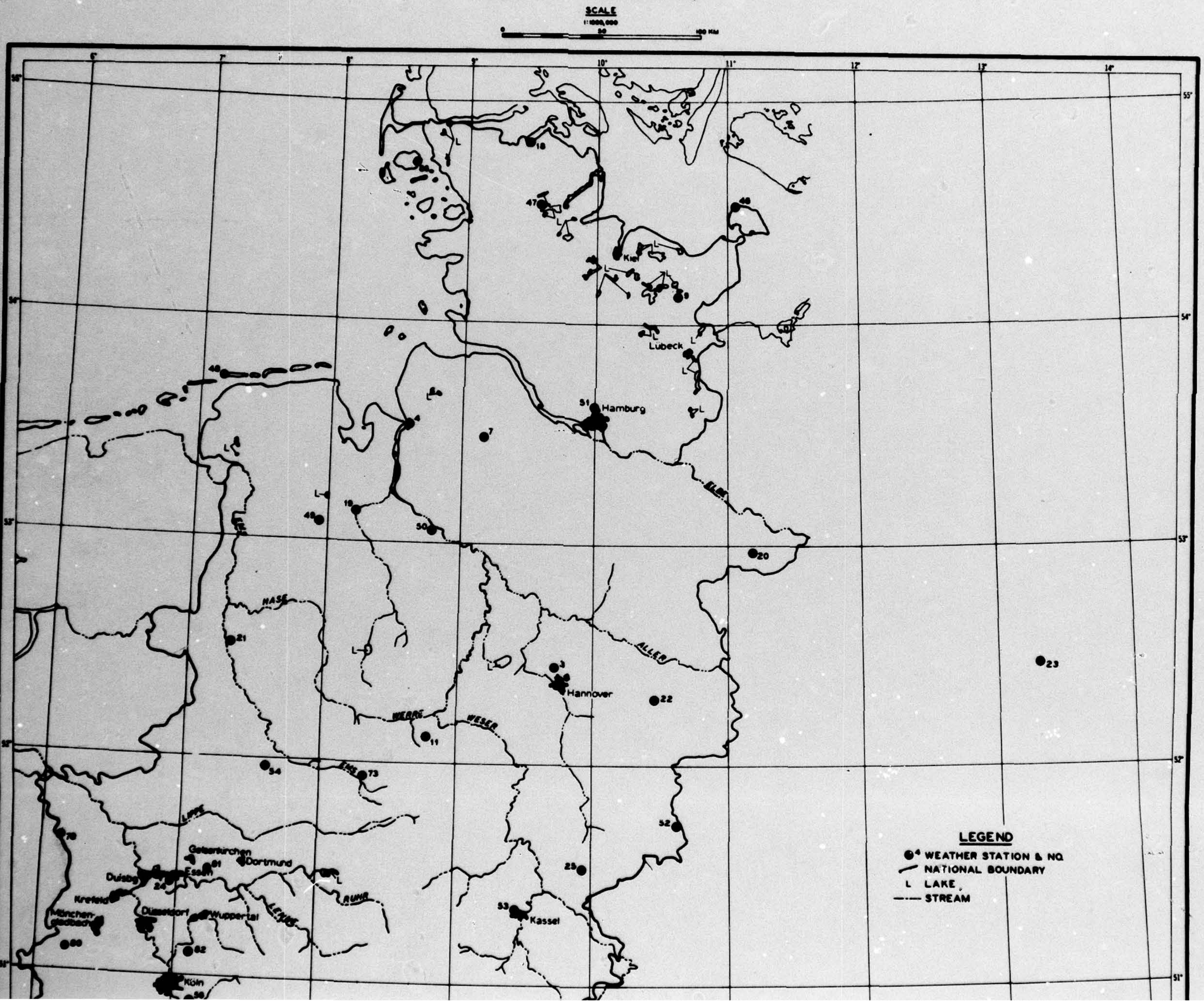
Table B1 (Concluded)

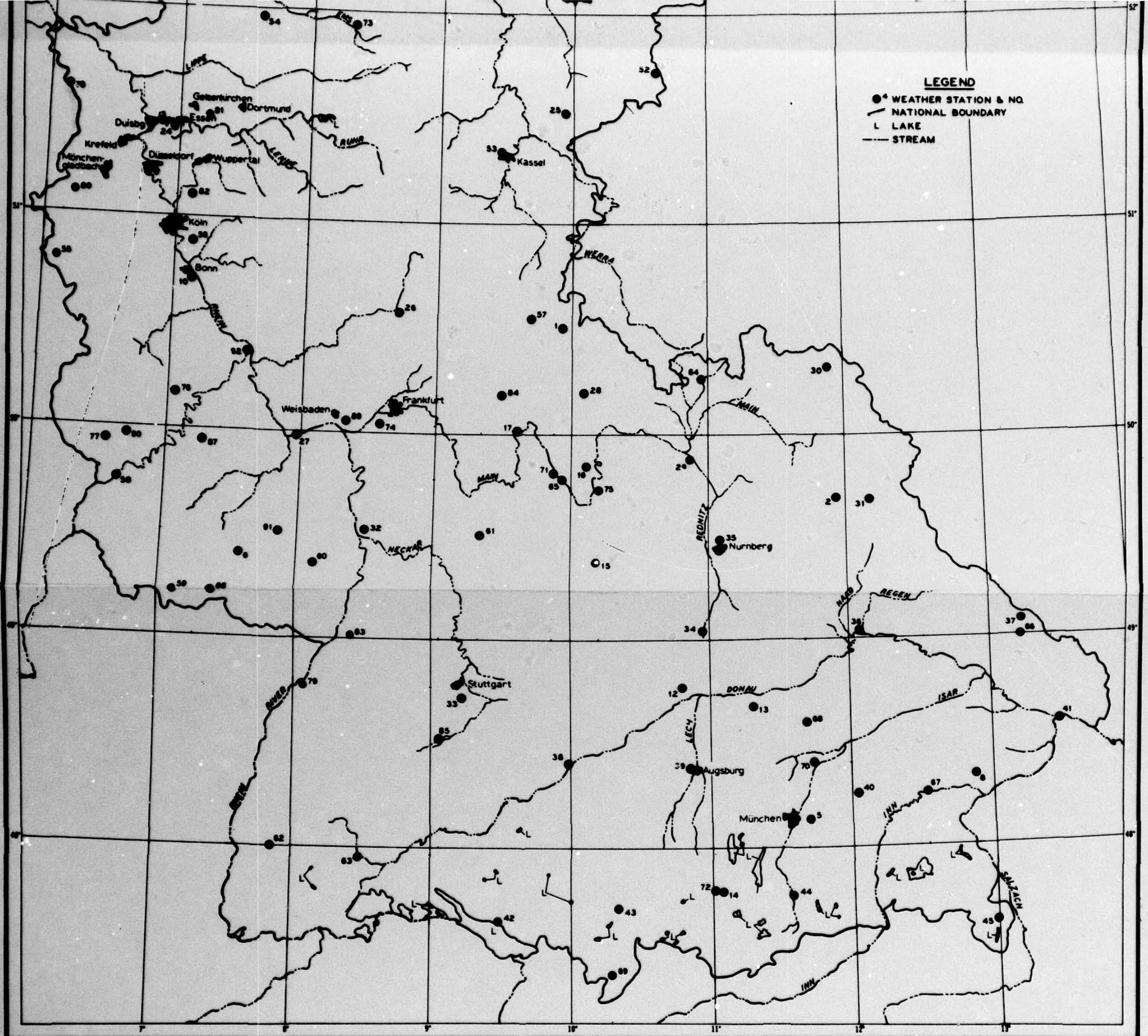
WMO Station Number	Location on Base Map	Recording Station (Parameter)	Temperature: Temperature	Temperature: Absolute Max. and/or Min.	Temperature: Mean Daily Max. and/or Min.	Temperature: Daily and/or Monthly Mean	Temperature: Mean Dew Point	Relative Humidity: Mean Percent	Relative Humidity: Absolute Minimum	Relative Humidity: Mean Wet Bulb	Relative Humidity: Dry Bulb	Weather Conditions: Precipitation	Weather Conditions: Thunderstorms	Weather Conditions: Rain and/or Drizzle	Weather Conditions: Freezing Rain/Drizzle	Weather Conditions: Snow and/or Sleet	Weather Conditions: Hail	Weather Conditions: Fog	Weather Conditions: Smoke and/or Haze	Weather Conditions: Blowing Snow	Weather Conditions: Snow Depth	Weather Conditions: Dust and/or Sand
10712	91	Sembach N4931-E0752										x										
10722	79	Sollingen N4846-E0804		x	x	x	x	x						x		x						
10607	90	Spangdahlem N4958-E0642										x										
00011	17	Steinbach N5001-E0936																				
10738	33	Stuttgart/Hohenheim N4843-E0913		x	x	x	x	x						x		x						
10609	58	Trier/Stadt N4945-E0639																				
	85	Tubingen N4831-E0903																				
10838	38	Ulm N4824-E0959																				
	56	Waln/Wald. N5053-E0708																				
108440	1	Wasserkuppe N5030-E0957	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x
10688	31	Weiden N4941-E1210																				
	70	Weihenstephan N4824-E1144																				
10761	34	Weissenburg N4902-E1058																				
	46	Westermarkelsdorf N5432-E1103																				
10633	89	Wiesbaden N5003-E0820										x										
10402	80	Wildenrath N5106-E0613		x	x	x	x	x						x		x						
10655	65	Wurzburg-Sud N4947-E0956																				
	71	Wurzburg-Zell N4949-E0952																				
	86	Wyk/Fohr N5443-E0835																				
10714	88	Zweibrucken N4913-E0724										x										
10791	37	Zwiesel N4905-E1314																				
	46	Zwieselberg N4900-E1313																				

WMO Station Number	Location on Base Map	Recording Station (Parameter)	Surface Wind: Direction	Surface Wind: Speed	Surface Wind: Mean Speed	Visibility: Statute Miles/Meters	Visibility: Ceiling	Sky Cover: Percent Frequency	Sky Cover: Mean Sky Cover	Sky Cover: Total Cloud Amount	Sky Cover: Low Cloud Amount	Sky Cover: Mean Total Cloud Amount	Pressure: Station	Pressure: Sea Level	Miscellaneous: Military Operation	Miscellaneous: Wind Speed/Temperature	Miscellaneous: State of Ground Surface	Miscellaneous: Soil Temperature	Miscellaneous: Solar Radiation	Miscellaneous: Sunshine Duration
10712	91	Sembach N4931-E0752																		
10722	79	Sollingen N4846-E0804		x		x	x	x					x			x				
10607	90	Spangdahlem N4958-E0642																		
00011	17	Steinbach N5001-E0936															x	x		
10738	33	Stuttgart/Hohenheim N4843-E0913		x		x	x	x					x			x	x	x		
10609	58	Trier/Stadt N4945-E0639																x	x	x
	85	Tubingen N4831-E0903																	x	
10838	38	Ulm N4824-E0959															x	x		
	56	Waln/Wald. N5053-E0708																x		
108440	1	Wasserkuppe N5030-E0957	x	x	x	x	x	x	x				x	x						
10688	31	Weiden N4941-E1210															x	x		
	70	Weihenstephan N4824-E1144																x		
10761	34	Weissenburg N4902-E1058															x	x		
	46	Westermarkelsdorf N5432-E1103																x		
10633	89	Wiesbaden N5003-E0820																		
10402	80	Wildenrath N5106-E0613		x		x	x	x					x			x				
10655	65	Wurzburg-Sud N4947-E0956																x	x	x
	71	Wurzburg-Zell N4949-E0952																x	x	
	86	Wyk/Fohr N5443-E0835																	x	
10714	88	Zweibrucken N4913-E0724																		
10791	37	Zwiesel N4905-E1314															x	x		
	46	Zwieselberg N4900-E1313																x		

(Sheet 3 of 3)

FEDERAL REPUBLIC OF GERMANY
(WEST GERMANY)





LOCATION OF WEATHER STATIONS

Figure B1

2

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Link, Lewis E
Thermal modeling of battlefield scene components / by Lewis E. Link. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
43, [65] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; EL-79-5)
Prepared for U. S. Army Electronics Research and Development Command, Night Vision and Electro-Optics Laboratory, Fort Belvoir, Va.
Supported in part by Department of the Army Project No. 4A762730AT42, Task A4, Terrain/Operations Simulation, Work Unit 003, Electromagnetic Target Surround Characteristics in Natural Terrains.
Includes bibliographies.
1. Army-Wide Signature Program. 2. Battlefield signatures. 3. Climate. 4. Electro-optical devices. 5. Environmental models. 6. Military operations. 7. Sensors. 8. Signatures. 9. Target designators. 10. Temperature. 11. Terrain factors. 12. Thermal models. I. Night Vision and Electro-Optics Laboratory. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; EL-79-5.
TA7.W34m no.EL-79-5