(2)

# NAVAL POSTGRADUATE SCHOOL

## Monterey, California

# THESIS

A PROTOTYPE CLIMATE
INFORMATION SYSTEM

by

Terry K. Jarrett

June 1991

Thesis Advisor: Carlyle H. Wash

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## REPORT DOCUMENTATION PAGE

a. REPORT SECURITY CLASSIFICATION
JNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Naval Postgraduate School

6b. OFFICE SYMBOL *(If applicable)*
63

7a. NAME OF MONITORING ORGANIZATION
Naval Postgraduate School

6c. ADDRESS *(City, State, and ZIP Code)*
Monterey, CA 93943-5000

7b. ADDRESS *(City, State, and ZIP Code)*
Monterey, CA 93943-5000

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State, and ZIP Code)*

10. SOURCE OF FUNDING NUMBERS

| Program Element No | Project No. | Task No | Work Unit Accession Number |
|---|---|---|---|
| | | | |

11. TITLE *(Include Security Classification)*
A PROTOTYPE CLIMATE INFORMATION SYSTEM

12. PERSONAL AUTHOR(S) Jarrett, Terry K.

13a. TYPE OF REPORT
Master's Thesis

13b. TIME COVERED
From To

14. DATE OF REPORT *(year, month, day)*
June 1991

15. PAGE COUNT
83

16. SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17. COSATI CODES

| FIELD | GROUP | SUBGROUP |
|---|---|---|
| | | |
| | | |

18. SUBJECT TERMS *(continue on reverse if necessary and identify by block number)*
climatology, data base, information systems

19. ABSTRACT *(continue on reverse if necessary and identify by block number)*

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS REPORT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
Carlyle H. Wash

22b. TELEPHONE *(Include Area code)*
408-646-2295

22c. OFFICE SYMBOL
MR/Wx

**DD FORM 1473, 84 MAR**

83 APR edition may be used until exhausted
All other editions are obsolete

# A Prototype Climate Information System

by

Terry K. Jarrett
Department of the Navy
B.S., San Jose State University, 1978

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY

from the

NAVAL POSTGRADUATE SCHOOL
June 1991

Author: Terry K Jarrett
Terry K. Jarrett

Approved by:
Carlyle H. Wash, Thesis Advisor

Philip A. Durkee, Second Reader

Robert L Haney
Robert L. Haney, Chairman,
Department of Meteorology

# ABSTRACT

A prototype Climate Information System (CIS) is developed to manage and display climatic data as part of the Navy's Tactical Environmental Support System (TESS). The CIS reduces the time and effort required to locate, ingest and analyze climatic data. The CIS remedies accessibility problems of existing climatologies by using a Data Base Management System (DBMS) to manage on-line data sets. The CIS computer graphics improve data comprehensibility by remapping data to common projections.

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# ACKNOWLEDGEMENT

The author acknowledges the support of the sponsor, Space and Naval Warfare Systems Command, PMW-141, CAPT C. Hoffman, USN, Program Element 64230, for making this effort possible.

# I. INTRODUCTION

## A. CURRENT NEEDS

Naval officers who plan operations which are affected by climatic elements need more efficient support. These operations include logistics, ship and aircraft transits, training exercises and construction. Currently, the Navy oceanographers who provide climatological support to the operational planners must rely on manual, labor intensive procedures to obtain data. Improving the efficiency of climatological support requires enhancements to both the oceanographer's access to pertinent climatic data and the planner's ability to interpret this information.

Plans made for events which will occur a week or more into the future are defined here as contingency plans. The concept of operations for the United States Navy directs that tactical contingency plans which use climatic data will be updated with current and forecasted weather conditions as these observations become available (Roark, 1988). Since war may prevent the communication of the updated weather data, the previously developed contingency plans based on climatology may be the best available.

The Commander of the Naval Oceanography Command (CNOC) has published a list of requirements for oceanographic and meteorological climatologies which is shown in Table 1. Some of these requirements are explicitly stated as needs for computerized climatologies, while others are for the more traditional hard copy publications.

TABLE 1. VALIDATED CNOC CLIMATOLOGY REQUIREMENTS. The various climatic parameters listed below have been validated by CNOC as required for environmental support. This list is from CNOC letter 3140 (U.S. Navy, 1989a).

Ocean wave height, direction and period (primary and secondary)
Ocean front position/strength and eddy frequency
Ocean current direction and speed
Surface visibility
Sea ice boundaries and ice coverage
Cloud amount and base height (low, mid, high, and total cloud)

- Ocean profiles:
    - temperature
    - salinity
    - density
    - sound velocity

- Ocean acoustics:
    - below layer gradient
    - convergence zone range
    - sonic layer depth
    - shallow sound channel:
    - thickness, strength, depth
    - deep sound channel
    - critical depth
    - bottom loss
    - volume scattering
    - ice and volume reverberation

Sea State
Precipitation
Sea level atmospheric pressure
Optical water type (turbidity)
Radar duct height frequency distributions
Marine surface wind speed frequency distribution

- Atmospheric profiles:
    - geopotential height
    - temperature
    - dew-point
    - wind velocity

- Surf:
    - surf zone width
    - depth of breakers
    - breaker height
    - breaker angle
    - breaker period
    - currents

- Geophysics:
    - water depth
    - bottom materials
    - bottom slope
    - magnetic variations
    - tides

## B. SCOPE OF THE PROBLEM

Decades of climatological data collection have yielded numerous atlases, tables and reports summarizing the global and regional climates. Impediments to effectively using these data now center on accessibility, rather than availability. Once located, the climatic data typically are presented as tables and atlases. These static displays underutilize the large bandwidth of the eye/brain system. Inefficient procedures force climatic data users to spend excessive time on data retrieval and formatting at the expense of data analysis and application.

The meteorological spaces aboard naval ships are cramped. The space needed to store the bound volumes of applicable climatic data may be unavailable. For example, the Naval Eastern Oceanography Command (NEOC) has 214 climatology publications on-hand to support its mission (William Bentley, personal communication). Climatic publications, including atlases, occupy more than 37 bookcase shelves at the Fleet Numerical Oceanography Center (FNOC) research library. To place this much climatic data aboard naval ships requires an alternative to a paper publications.

Microfilm reproductions of paper based climatologies offer great space savings. This economy is somewhat offset, however, by the need for a bulky and single-purpose microfilm reader. Locating a desired microform may be even more difficult than finding its paper counterpart since a microform is easily lost. Lastly, finding specific data on microfilm is no less labor intensive than it is for paper publications.

The above data accessibility impediments are matched by usability limitations associated with both paper and microfilm. Such hard copies provide only static displays which do not facilitate data merging and comparison. For example, the analysis of data presented in various atlases may require paging back and forth, tracing or photocopying maps and manual adjustments to account for differing map projections and scales. Printing costs often limit the use of color in paper publications and most microfilm is monochromatic. Consequently, coloration (which may improve data comprehensibility) is generally unavailable in hard copy climatologies.

The computer revolution has provided a potential solution to the above accessibility and usability problems. Computer media are compact, hold large amounts of data and are easily reproduced and distributed. Personal and desktop computers are likewise compact and affordable. Many climatic data users already possess such multi-purpose computers. A large commercial software industry provides many useful programs which are economically priced, since the development costs are shared among numerous customers. Some of this software can automate the location and display of climatic data resident on the computer.

Recognition of these applications lead the Navy during the 1980's to deploy several computer systems which contain a limited number of climatologies. These developments include the Integrated Refractive Effects Prediction System (IREPS), the Integrated Carrier Anti-Submarine Warfare (ASW) Prediction System (ICAPS), and phase two of the Tactical Environmental Support System (TESS 2). Each of these independently developed systems adopted unique and specific data management and display methodologies. Consolidation of these climatologies on a single system, such as phase three of TESS (TESS(3)), would necessitate duplicative software functionality or major software revision. For example, since data have been stored in uniquely formatted operating system files, a unique file access routine is needed for each climatology file. Furthermore, each of the existing climatology data files is configured for a specific application program. Access to these files is unavailable except through the applicable program. Similar redundancy, specificity and revision problems exist for the current display software.

## C. PROPOSED SOLUTION

Development of a Climate Information System (CIS) is proposed as an effective means of meeting the above climatic data needs. A CIS is a combination of software and computer workstation hardware which provides localized access to on-line climatic data sets. A CIS generally couples climatic data with other social, economic, engineering or military information in order to help planners make weather-affected decisions.

The proposed system is called CLIMA-TV which is an acronym for CLIMAtology-TeleVideo and is intended to convey the visual and interactive nature of the CIS. The CLIMA-TV CIS uses compact computer media to reduce climatic data storage space requirements. Compared to the manual methods used with hard copy and microfilm, CLIMA-TV saves time and labor by automating all data retrieval and display. Unlike the specialized data file formats used in the IREPS, ICAPS and TESS 2 computer systems described above, CLIMA-TV employs a more generalized approach to data organization through the use of a commercial software Data Base Management System (DBMS). The DBMS simplifies access to differing data types and insulates CLIMA-TV users (including software developers) from the need to know the physical format and file structure of the data they wish to use. The data access generalizations supported by the DBMS greatly reduce the amount of specialized software which must be written during CIS development. Treinish and Gough (1987b) and Jurkevics et al. (1990) provide an overview of the generalized versus specific approaches to data management.

CLIMA-TV uses computer graphics to improve data comprehensibility by remapping data to common scales and projections and by supporting overlay and animation. CLIMA-TV provides new tools for the application of climatology to naval operations. CLIMA-TV assists naval operational planning and provides a quality check of observed data. CLIMA-TV reduces the time and effort required to locate and analyze climatic data.

## D. THESIS GOALS

The primary goal of this thesis is to develop a prototype CIS; a working computer system designed to manage and display climatic data in support of naval operations. Attainment of this goal requires development of original computer software, data acquisition, data processing and composition of system documentation. The CLIMA-TV CIS design rationale and implementation methodology are described and the capabilities of CLIMA-TV are tested with sample data sets. The CLIMA-TV techniques are intended for application to such naval systems as TESS(3) and the Naval Environmental Operational Nowcasting System (NEONS). TESS is a computer system for oceanographic and meteorological support of naval operations. The NEONS supports research and development of improved environmental data management techniques.

A supplemental goal is to develop the CLIMA-TV in adherence to government and computer industry standards, thereby establishing a portable system. Portability, in this context, means that the data management and display techniques employed by CLIMA-TV minimize the changes required to use them on a variety of hardware hosts. The software and documentation must meet Department of Defense (DOD) specifications. The CLIMA-TV approach minimizes the development of unique software by using commercial software whenever feasible. This approach conforms with the TESS(3) procurement contract which stipulated the use commercial products.

Another supporting goal is the acquisition or development of the required climatic data sets as specified by CNOC. Although inclusion of all such data sets in CLIMA-TV is beyond the scope of this project, this document consolidates various statements of need for climatic data; identifies data sources when possible; provides the tools needed to later include these data sets; and describes the sample data sets hosted by the prototype system. This thesis is planned to be a reference for future automated climatology developments in support of naval operations.

The following sections summarize the evolution of the major components needed for development of a CIS which meets these goals. These components are: an extensive data base, automated data management and trained interpreters of those data.

# II. CLIMATOLOGY AS APPLIED TO NAVAL OPERATIONS

## A. CLIMATOLOGY OVERVIEW

Weather is real, but climate is a human invention. The concept of climatology derives from an assumption that no matter how the earth's weather fluctuates, it must have an average. Climatology is a statistical construct which allows one to determine that the average weather for the last 12,000 years differs significantly from the previous 12,000, when North America was glaciated. The nature of such changes is still questionable despite recently fortified studies of climatic change. Did one climate change to another for some physical reason? Are these millenary periods simply fluctuations within an even longer term climate? Or is it possible that the weather may never converge to an average? Perhaps the Earth's climate is a chaotic system which never settles into an equilibrium (Gleick, 1987).

Nevertheless, the utility of climatology is unaffected by its artificiality and uncertainty. The growing number of climatological applications is evidence of this conclusion. The prime function of climatology continues to be the delineation of local, regional and global climates. Such climate delineations are important in climatic change research. However, whenever plans and decisions are made which are based on climatology there is a need to consider the social, economic and environmental effects of climate as well as the climatic properties themselves. Only then can the costs and benefits of the alternative actions be estimated.

The atmospheric and oceanographic properties which define the climate are called climatic elements. The elements more commonly considered to be important are temperature, humidity, wind, pressure, precipitation, cloud and radiation (Guttman, 1989). Climatic factors are the physical conditions which affect the climatic elements, e.g., latitude and elevation.

The ancient Greeks divided the world into three climatic zones; torrid, intermediate and frigid. During the more than 2,000 years since then, the trend has been to define the climate at increasing resolutions of time and space (Griffiths, 1976). Circa 1900, Koppen derived a climatic classification scheme using 25 main climatic types and 14 subdivisions which could be paired in many combinations. Yet even Koppen's highly flexible system, shown in Figure 1, falls short of current needs for site specific climatic information.

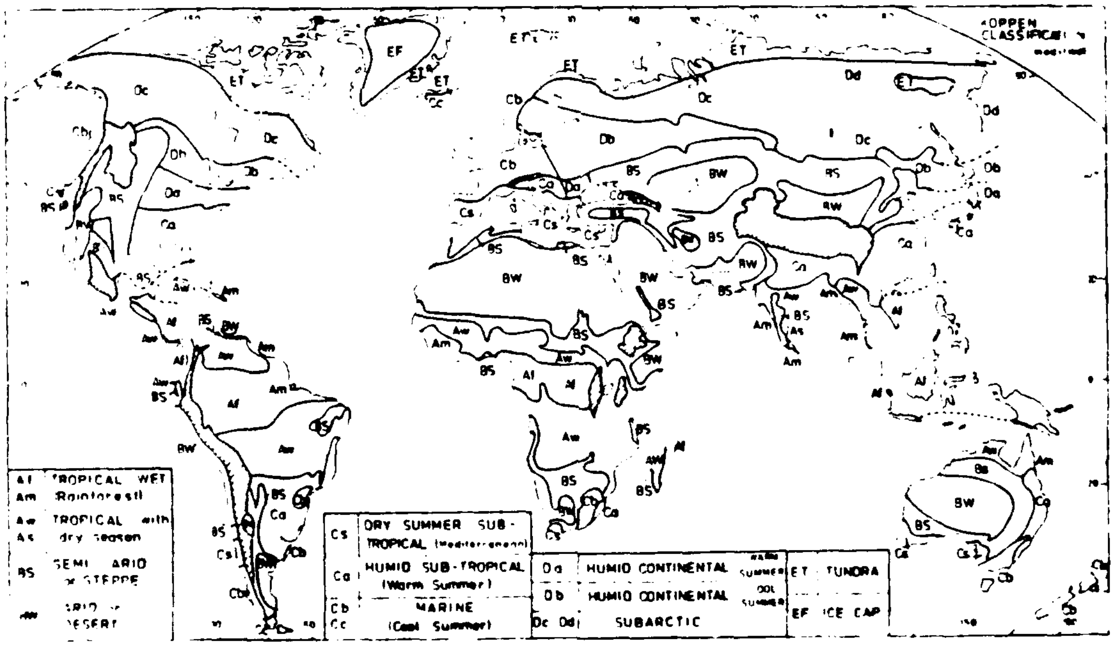


Figure 1. Koppen Climate Classification Scheme. The division of the continents into climatic types is shown (from Boucher, 1975).

The climate of a locality is the synthesis of the day-to-day values of the ambient meteorological elements. This synthesis should be more than simple averaging, although means are the most popular statistics in climatology (World Meteorological Organization (WMO), 1983). Guttman (1989) states that climatic specifications should also include the range, variability and duration of the climatic variables. Frequency distributions and contingency tables, therefore, are required for a complete statistical description of a climatic element.

Climatic data are usually expressed in terms of a calendar month or season and are determined over a period long enough to ensure representativity. The WMO (1983) directs that a 30 year period be used for means and the total period of record for extremes. The 30-year period was a compromise adopted primarily to monitor climatic change. In some other applications, 30-year means are inferior to statistics based on shorter time periods. Kunkel and Court (1990) cite evidence which suggests means for shorter averaging periods (5-15 years) are the preferable indicators of the general weather conditions to be expected in the coming year. Thus, the planning needed by the Navy can be supported with short period statistics.

Kunkel and Court (1990) review the ongoing debate over the applicability of commonly used climatic statistics. Writing on behalf of the American Association of State Climatologists, the authors recommend:

1) The term "normal" should describe 30-year climatic means.

2) For averaging periods other than 30 years, the median should be used as a better measure of central tendency for variables which have a non-Gaussian distribution (e.g., total precipitation). The mean should be used for those variables with quasi-Gaussian distributions (e.g., temperature).

3) Additional averaging periods other than 30 years should be used to provide flexibility in answering climatic queries. Periods of 11 and 21 years are suggested. These periods reflect the clustering of research results around 10 and 20 years and the odd value is used to simplify the calculation of the median for non-Gaussian distributions. Also, decade-like time periods (e.g., 1980-1990) cover 11 years.

4) A measure of variability should be included with the mean or median. Suggested statistics are the 10 and 90 percentiles for non-Gaussian distributions and the standard deviation for quasi-Gaussian distributions.

5) Climatic extremes should be provided for homogeneous data sets (e.g., constant instrument location and measurement practices).

## B. MILITARY OPERATIONS

While describing the application of climatology to military operations, Griffiths (1976) stresses three points. First, pure climatology does not give the type of information required. In fact, classical climatological data are always insufficient and sometimes misleading. Second, the planning information supplied by applied climatology should not be used as a short-range operational forecast. Third, close co-operation between the military planner and climatologist is always necessary to ensure that the planner understands the preceding two limitations of climatology.

Weather which is suitable for one type of operation may be unsuitable for another operation. For example, heavy fog may cancel an air strafing attack but provides cover to a commando raid. Griffiths (1976) lists several types of military operations and the corresponding information which the planner must consider while arranging the operation. The broad scope of climatic effects on military operations precludes more than a summary here.

Aircraft operations. Safe flight operations require minimum visibility and ceiling conditions. Strong winds and precipitation further restrict flights. The planner must know how frequently an airfield can be used.

Tactical ground support. The planner uses climatology to indicate the fraction of the day that air support can be expected. Both the airfield and the support area must have suitable conditions concurrently.

Strategic bombing. The weather requirements for strategic bombing are more flexible unless visual bombing is required. Planning a visual bombing raid requires study of secondary targets which may be attacked if the primary one is obscured. Similar considerations apply to aerial reconnaissance.

Amphibious assault. In addition to the ground support listed above, sea conditions are important. The surf, tides, temperature, visibility and winds all affect the initial landing and the subsequent resupply.

Airborne assault. Wind conditions are critical to paradrop, helicopter and glider operations. Cloud cover, precipitation and visibility can also limit the period these operations are feasible.

Overland resupply. Soil trafficability must be considered for overland passage. The variable water content of the soil depends on precipitation amounts, evaporation and soil drainage.

Chemical warfare. Dispersion of smoke and gases depends on atmospheric stability and boundary layer winds. Humidity also affects many agents. For incendiaries to be most effective the surface must be dry. Microclimate is more important in chemical warfare than other operations.

Bivouac. Soldiers are often denied shelter. Attention must be given to the effects of exposure, including chill factors and heat exhaustion. In designing equipment, climatic means lose their importance and extreme values must be considered.

Finally, the planner must know about all hazards, such as hurricanes, which occur in the theater of operations. Such infrequent yet devastating events can wipe out armies, fleets and installations.

## C. EVOLUTION OF NAVAL CLIMATOLOGY

The detailed description of Bates and Fuller (1986) is summarized here. In 1838 the Navy Depot of Charts and Instruments began taking meteorological observations every three hours around the clock. Lt. Matthew F. Maury, upon taking command of the depot in July of 1842, found that the resultant collection of naval logs was destined for the scrap bin. By combining this old data with new information coming from the fleet, Maury was able to issue charts showing optimal sailing tracks for the North Atlantic and parts of the South Atlantic and North Pacific. Maury's charts were tested in 1848 when they were used by the barque *W.H.D.C. Wright* during a cruise from Chesapeake Bay to Rio de Janeiro and back. Southbound, she took 38 days; returning, she took 37 days. In contrast, a typical one-way passage was 55 days. This and similar successes gave Maury the cooperation of the U.S. Merchant Marine and by late 1851 more than a thousand ships had provided meteorological logs. In 1860 Maury's office produced a six-part global series of track, trade wind, pilot, thermal, whale, storm and rain charts supplemented by eight volumes of sailing directions. The mass of climatic data and publications had begun to grow.

The Depot eventually became the Naval Hydrographic Office and by 1895 it could no longer keep up with the data flow from its 3,118 cooperating observers. The new hydrographer, Commander Charles P. Sigsbee, suggested that Herman Hollerith's new system for electrical counting and averaging of census data be applied to this flood of raw weather data. In 1897, a Hydrographic Office publication described a method for placing each daily set of weather observations on a single punched card, permitting the data to be recalled for either synoptic or climatological purposes. This is the first known instance of machine-processed meteorological data.

President Theodore Roosevelt abolished the Hydrographic Office's Division of Marine Meteorology in 1904. A naval meteorological capability reappeared thirteen years later during World War I. The need for officers qualified to interpret weather reports was met by a new postgraduate level aerology course taught at Harvard's Blue Hill Meteorological Observatory. This harbinger began the weather-specific training of naval officers which continues today at the Naval Postgraduate School (NPS), Monterey.

In 1979, the Naval Ocean Systems Command placed Hewlett-Packard model 9845 desktop computers aboard some 20 ships. The application software on these computers included a climatology of electromagnetic propagation conditions. Computerized climatology had gone to sea.

The preceding discussion recounts the progression of naval climatology which led to the need as well as the opportunity to produce a CIS like CLIMA-TV. The following section describes the enabling technologies used to implement such a CIS.

# III. CLIMATE INFORMATION SYSTEM TECHNOLOGIES

## A. CLIMATE INFORMATION SYSTEM OVERVIEW

During the period of electronic computation of climatic data which began almost 90 years ago, climatologies were published by the hundreds. As the mass of climatic data stored in archives, tape vaults and on library shelves grew, the original problem of data availability was replaced by one of data accessibility. The desired data had to be located, extracted and forwarded to the user. Turn-around time for data requests at central repositories, such as the National Climatic Data Center (NCDC) ranges from several days to several weeks. Such a response is acceptable when considering a climatic problem with a time scale which is orders of magnitude larger than the delay. However, in military operations the data used in decision-making often is needed immediately. This need can be met either by distributing access (via remote terminals) to an automated, central climatology data bank, or by distributing the data bank itself to a local CIS. The National Aeronautics and Space Administration (NASA) Climate Data System (NCDS) described below is an example of the former method. However, the remote access approach is subject to communication bottlenecks or interruptions which may be unacceptable to some users of climatologies. Military planners must also consider the possible destruction of central repositories. Therefore, military users of climate data are better served by redundant, distributed data archives installed on CIS's at various locations.

The choice between the central site and the distributed CIS approaches did not exist until this decade. Although a sufficiently comprehensive data base has existed since the turn of the century and computationally sufficient computers have been available for 35 years, it was the personal computer revolution of the 1980's which made possible the CIS and the provision of local access to climatic data. The dramatic reductions in the cost and size of computer hardware and the productivity gains provided by the commercial software industry now make it feasible to install a CIS aboard every naval ship and at every naval facility having a need for climatic data. Recently deployed naval computer systems such as TESS; the Automated Tropical Cyclone Forecasting (ATCF) System; and the Geophysical Fleet Mission Program Library (GFMPL) System have included some CIS attributes.

## B. DATA BASE MANAGEMENT SYSTEMS

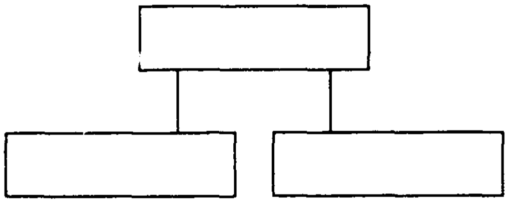
A Data Base Management System (DBMS) is software which controls the organization, storage, retrieval, security and integrity of data in a data base. The DBMS accepts requests for data from an application program and instructs the operating system to transfer the appropriate data. Changing an information system is easier when a DBMS is used.

With a DBMS, a computer programmer is no longer concerned about the file structure or about how to access any single value within a record; the DBMS handles this (WMO, 1983). The user need only identify the desired piece of information. The advantage of a DBMS grows with the number and complexity of programs accessing the data. Without a DBMS, much of each application program must involve reading data files rather than concentrating on calculating new data and generating reports.

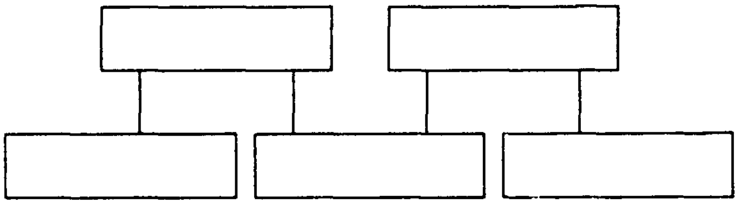
Since CIS development is primarily a data base problem, the success of the CIS design will largely depend on making the correct choice of data management software. Descollonges (1989) describes three categories of data management software: hierarchical, network and relational. Dawson (1989) adds another category, object-oriented data bases, which currently are more important in research and development than as a commercial products.

These DBMS categories are derived from the differing methods used to organize data into record types and the way record types are related to each other. The hierarchical, network and relational data base structures are schematically represented in Figure 2.

(a) Hierarchical data base



(b) Network data base



(c) Relational data base

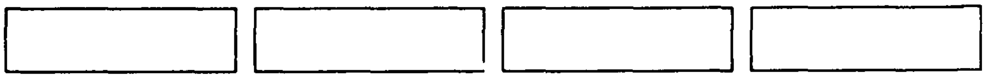


Figure 2. Schematic of Data Base Structures. The hierarchical, network and relational data bases are shown.

Hierarchical data bases link records together like an organization chart. A record has only one owner in what is called a "one to many" structure. In other words, each subsidiary record is linked to only one higher level record. Hierarchical records need not be divided into fields. Connections between files do not depend on the data in the files. All links are defined during the creation of the data base and are fixed for the life of the data base.

The network data base lets any record or file be related to any other record or file. A record can have multiple owners in what is called a "many to many" structure. All links are predefined and fixed as in hierarchical systems.

Relational data bases organize data into spreadsheet-like tables which must have unique rows and their fields must be single valued. The relational model is a logical concept. The data may not actually be in tables, it just looks that way. Knowledge of the storage addresses or ordering of the rows is unnecessary to access the data. A Relational DBMS (RDBMS) does not link records together physically as do the network and hierarchical systems. Instead, implicit links result when records have a common field, such as WMO station number, which allows matching. This method is more flexible for ad hoc queries but is generally slower than the other two approaches. RDBMS's often use indexing to accelerate the process of accessing the fields used for matching. The relational data base model was developed in the early 1970s by Edgar F. Codd, has become the most important data base technology and is the state of the art in the commercial data base field (Dawson, 1989 and Descollonges, 1989).

There are numerous vendors of RDBMS software. For computers using UNIX based operating systems, Oracle has the largest installed base with a 38% market share. Informix is next in popularity (25%) and is the RDBMS included with the TESS 2 computer. Other widely available RDBMS's include RTI (13%), Unify (7%) and Progress (4%). The remaining 13% of the market is split by various vendors including Ingres, Sybase and Empress.

Regardless of vendor, most commercial RDBMS's use the Structured Query Language (SQL) interface for data manipulation. SQL uses English-like commands to query the data base. SQL is standard promulgated by the American National Standards Institute (ANSI) and the International Standards Organization (ISO). Standard SQL provides a consistent means for defining, maintaining and accessing a relational data base. Thus, an application program using an SQL interface to the data base is portable to computer systems which may use different DBMS software.

The CLIMA-TV design specifies a RDBMS because its advantages include easy queries and ease of developing or modifying applications. Because they have become industry standards, SQL and RDBMS's promote data distribution among a variety of computer hosts.

CLIMA-TV uses the Empress RDBMS because it is used on both of the CLIMA-TV computer hosts, i.e., TESS(3) and NEONS. Empress was chosen for these two systems because, at the time development began, only Empress supported binary data streams (bitstreams) of arbitrary length. This feature, called the bulk attribute type, allows data to be packed without regard for byte boundaries, thus reducing storage space and data input/output time. This is particularly useful for storing bitmap graphic images and other arbitrary sequences of data values. Other RDBMS vendors have since released products which also include variable length bitstreams.

A disadvantage of RDBMS's has been their cost. However, commercial competition has driven down the price of RDBMS's and it is no longer economical to develop custom data management software for a CIS. For example, the current price of the Empress RDBMS for the Hewlett-Packard model 835 computer is $14,000, about enough money to pay the salary of a skilled computer programmer for three months. The version of Empress for International Business Machines (IBM) personal computers (PC) is $1,250.

Another disadvantage of commercial RDBMS's was the computational overhead associated with their general application design and the requirement to unpack the data retrieved from files. This drawback now has been overcome by the declining cost of increased processor speeds.

## C. OTHER CIS APPROACHES

### 1. NASA Climate Data System

The NCDS is being developed by the National Space Science Data Center (NSSDC) at NASA's Goddard Space Flight Center (Smith et al., 1983; Treinish, 1984; Reph et al., 1986). Closs et al. (1989) describe the NCDS as a centralized system available to remote users via a modem connection. The user can obtain a description of any archived NCDS data set and can also access directly an online subset of these data. Archived data which are not online can be ordered on tape, or in some cases these data may be placed temporarily online. The NCDS utility software lets the user browse, select, manipulate and display the online data. The user can produce output products in several forms, such as subset tapes, graphics, data listings and statistical summaries. There are five subsystems in the NCDS: Catalog, Inventory, Data Access, Data Manipulation and Graphics. The NCDS is implemented on a VAX computer from Digital Equipment Corporation (DEC).

The Catalog subsystem is used to find data sets of interest. It provides key information about each data set in a standard format so that the user can compare and access pertinent data sets. The descriptions include the characteristics, processing status, availability and point of contact. Catalog describes data sets held by other systems and archive centers in addition to those data sets held at NCDS.

The Inventory subsystem describes only data sets actually held in the NCDS library. It describes the data set contents at a lower level than Catalog by providing specific information about the data volume and physical location. The NCDS system software uses Inventory to locate and retrieve user requested data.

The Data Access subsystem accesses the NCDS tape library data sets. This may involve transferring data to disk files or copying the data to tape for delivery to the user. The Data Access subsystem prompts the user to specify the data set name, time interval and latitude/longitude (if applicable) of the data of interest.

The Data Manipulation subsystem lets users browse the data or transfer (down-load) data for further analysis. Inherent in the browse feature are data listing and subsetting capabilities.

The Graphics subsystem produces graphical representations of NCDS data including histograms, vector and scatter plots, pseudo color images and contour plots on various map projections. Output is provided for many terminal and plotter types.

Additional NCDS software components include the following commercial products. The Graphics subsystem uses a graphics package from

Template Graphics Company. Statistical analysis is supported by the PROTRAN software product. The Inventory subsystem uses the Oracle RDBMS to help the user find out what data sets are available.

The climatic data sets are not themselves managed by Oracle. Treinish and Goucher (1990) argue that commercial DBMS's do not provide an effective management approach because such systems are oriented toward business rather than scientific applications. The authors cited inadequate performance of RDBMS's and the lack of multidimensional and hierarchical data structures in the relational model as their reason for developing a unique data structure known as the NSSDC Common Data Format (CDF). The NCDS online data sets all have been converted from their original formats to CDF.

Treinish and Gough (1987a, 1987b) describe the CDF as a self-defining data structure. The CDF is, in effect, a data base system. Units of data are variables which can be described by attributes. Variables are grouped into records. A collection of records constitute a data ensemble. In addition to the data ensemble, the CDF contains a data dictionary and attribute table which contain ancillary information which completely define the data ensemble. The data dictionary specifies how each variable varies with respect to records. The attribute table defines the variable names, mnemonics, units, type (e.g., REAL*4, INTEGER*2 in the FORTRAN sense), range, resolution, display format and the organization of the individual values within the data structure. The simplest data structure is a one dimensional collection of scalars. The CDF also allows multidimensional structures, such as a two dimensional atmospheric profile of temperatures at various levels and three dimensional contour maps.

The CDF isolates the details of the data set structure. An application programmer only needs to know about the CDF operations, not the actual data storage. CDF operations are the software tools the programmer uses to create, access, fill, extract and query the data structure. These CDF operations correspond to the SQL of a commercial DBMS.

The central site, dial-in nature of the NCDS is poorly suited to most naval CIS needs. Since the CDF was developed in-house it is unsupported by standard, commercial software such as SQL. Furthermore, the argument of Treinish and Goucher (1990) against commercial DBMS's is weakened by the successful development of the NEONS. However, the NCDS data sets are a valuable data source for naval research and development. Access to the NCDS could also support some of the operational needs of naval bases, such as NEOC.

### 2. CLICOM

CLICOM is a climatic data processing system developed by the NCDC under a WMO contract (McGuirk and Llanso, 1989). CLICOM is designed primarily for use in developing countries, by personnel with little technical training. CLICOM currently is used in 37 countries, including 35 sites in the USA. CLICOM software runs on an IBM PC and manuals have been translated into Spanish and French. The user interface is a series of menus and data entry forms. The CLICOM processing functions include data entry, quality control, data management and summarization.

CLICOM organizes data into four categories: station history, data dictionary, inventory and climatology. All information is maintained by a commercial RDBMS called DataEase. The station history records contain the station names, locations and reporting practices. The data dictionary describes the data sets, variables, codes and record formats. The inventory lists the available data.

Climatic data are grouped into five types: monthly, daily, synoptic, hourly and upper air soundings. All, except upper air, are stored by station and climatic element over a specified time interval. Upper air data are grouped into one record of several parameters per sounding level.

CLICOM lacks some important CIS capabilities required for most naval applications. It is designed to manipulate a station-specific data base of historical weather data (i.e., a recent time series). CLICOM's primitive graphics provide only line and bar charts, although a graphics upgrade is underway to add contour plots, wind roses and tephigrams.

### 3. Midwestern Climate Information System

The Illinois State Water Survey developed the Midwestern Climate Information System (MICIS) in order to provide information about the current status of many weather parameters and climate-affected agricultural conditions throughout a nine-state midwestern region (Kunkel et al., 1990). A computer terminal and modem allows an MICIS subscriber to access this weather and climate information. The MICIS data base is a mix of climatic records (e.g., means and extremes) and historical weather data (e.g., time series of synoptic observations and weekly and monthly summaries). Historical data since 1948 are available for about 1500 stations. The historical data base is updated daily with the latest synoptic observations. Users can view the "current" state of the weather (past days, weeks or months) and can also compare this information with prior year, "normal" conditions or extremes. Both maps and tabular displays are available.

The MICIS is hosted on a Sun computer workstation running UNIX. All MICIS climatic data are stored on-line using a 325 MB disk. The data are stored in a MICIS-specific binary format with one station-day of five climatic elements occupying eight bytes. Data access and statistical computations are performed using FORTRAN and C programs written for MICIS. The regional and agricultural focus of MICIS has little application to Navy needs for climatic information.

### 4. Climate Analysis Center

The National Oceanographic and Atmospheric Administration (NOAA) Climate Analysis Center (CAC) maintains the Climate Assessment Data Base (CADB) as part of its climate monitoring function (Finger et al., 1985). The CADB is accessed by special software written for NOAA which locates data records by relative byte addresses. This approach allows variable length records but is intrinsically linked to an IBM operating system. Like the MICIS data base, the CADB contains both historical time series and climatological mean values. CADB coverage is global with climatic means of temperature and precipitation available for about 4000 stations. Temperature and precipitation distributions for about 1500 global synoptic stations are calculated. The CADB is the primary source used by the CAC to prepare a wide variety of climate products, such as the *Weekly Climate Bulletin* which depicts major climatic anomalies throughout the world. Many of these products are accessible via a dial-in modem system.

The CAC has developed two interactive computer systems for weather forecasting based on the climatic anomalies published in the *Monthly & Seasonal Weather Outlook* (MSWO). Lehman (1990a,b) describes these systems, which are called Quick Projections of Monthly Outcomes (QPMO) and Quick Projections for Multiple Stations (QPMU). QPMU is a multi-station version of QPMO. QPMO and QPMU use the predicted anomalies to modify climate statistics for the 500 U.S. stations contained in the data base. Alternatively, the user may elect to look at the unmodified climatic station data. The CAC systems give the outcome probability results for user specified inquiries. For example, a user may ask "How many days next month are expected to have a daily maximum temperature above X degrees?" QPMO and QPMU provide temperature and precipitation statistics for 24 monthly periods beginning on the 1st and 16th of each month.

The CAC systems can support naval operations within the U.S. which require decisions based on temperature and precipitation in the month ahead. These applications include construction and building air conditioning loads. These outputs are of minor importance to tactical operations. The existing data base includes 17 Navy and Marine Corps Air Stations. The data base could be expanded to allow broader use in Canada, Eurasia and the Mediterranean Sea. QPMO and QPMU are of limited use for oceanic, polar or southern hemisphere locations since these regions are not covered by the MSWO.

# IV. SYSTEM DESIGN

## A. DESIGN APPROACH

There is an emerging consensus regarding the design of computer workstations which host a CIS. A growing body of literature (for example, Dueck and Wells (1988), Gardiner et al. (1989) and Hibbard et al. (1990)), delineates the key requirement of following accepted industry standards so as to provide for life cycle support and upgrade paths. In particular, the use of open system architecture eliminates sole-source vendor problems. Also important is adherence to good documentation practices. This approach allows commercial hardware and software components to be used, thereby reducing application software development costs.

The above authors agree that the computer workstation used for a CIS should have a 32-bit processor with multi-tasking and multi-user capabilities. The computer should have at least ten megabytes (MB) of random access memory (RAM) and a minimum of 1 gigabyte of disk storage. A graphics display terminal is required and a high-resolution (1024x1024 or greater) color graphics terminal is the preferred configuration.

Dueck and Wells (1988), Gardiner et al. (1989) and Hibbard et al. (1990) all conclude that UNIX is the de facto standard operating system for workstations. The programming languages of choice are C and FORTRAN. The C language is tightly coupled with UNIX, thereby permitting maximum system access. FORTRAN is included to take advantage of a large amount of existing software. Graphics applications shall use the Graphical Kernel

System (GKS). GKS defines a set of drawing primitives and generic graphing commands. Other graphics standards exist (e.g., CORE and PHIGS), but GKS is now the most widely implemented. The X Windows environment is currently the most prominent user interface standard. X Windows provides window management mechanisms such as pull-down and pop-up menus, icons and buttons. X Windows operations include graphics, imagery, networking and keyboard, mouse or other device input.

## B. DESIGN LIMITATIONS

CLIMA-TV will be implemented on several naval computer systems including the TESS(3). Jarrett (1991) describes the TESS(3) CIS software design requirements. The CLIMA-TV design must be compatible with the UNIX operating system environment. As an operational product, CLIMA-TV must be documented according to current military standards, in this case DOD-STD-2167 (DOD, 1985). The climatic data bases should also be navy standards, such as those contained in the Oceanographic and Atmospheric Master Library (OAML) (U.S. Navy, 1990a). When a data requirement is unmet by the OAML data bases, the data chosen for use should be taken from naval sources whenever possible. CLIMA-TV software must be coded in a DOD approved programming language for which the necessary compiler is available for all computers expected to host the CIS.

Since a TESS(3) was not yet available, CLIMA-TV was prototyped on the NEONS which is a Hewlett-Packard (HP) model 835 computer using the HP-UX version of UNIX. The CLIMA-TV application software is coded in FORTRAN and C. The UNIX shell programming language is used to connect the various software components. CLIMA-TV uses the Empress

RDBMS for data management and the NCAR GKS graphics package for pictorial data display. Empress and NCAR graphics are more fully described in later sections below. CLIMA-TV does not use X Windows since TESS(3) does not support it. A future upgrade of TESS(3) may add X Windows.

With some graphics and user interface modifications, the CLIMA-TV prototype is portable to the TESS(3) Masscomp computer which also runs UNIX. Furthermore, the CLIMA-TV software is similarly portable to the Naval Academy's Meteorological Laboratory (MetLab) system which uses an HP 835 and several HP 370 computers (Smith and Stringer, 1990). This is an example of the flexibility of the CIS design to support naval activities.

## C. DATA REQUIREMENTS

The climatic data base specifications of CNOC were summarized in Table 1 and those requirements included the TESS(3) climatological data base needs stated in CNOC OCEN 87-01 (U.S. Navy, 1987a). Details of the TESS(3) climatic data requirements are presented in Table 2. Meeting these requirements will be an evolutionary process as successive CLIMA-TV versions include additional data. In selecting the initial CLIMA-TV data sets, emphasis was placed on meeting the TESS(3) requirements. Geographic data requirements, such as bathymetry and weapon systems requirements, such as radar frequencies, are not addressed by CLIMA-TV. Formatting these data as Empress tables should be pursued outside of this project.

Operational users at both ship and shore facilities were contacted as part of this project to assess their climatic information needs. These data requirements vary with the type of mission to be supported. Frequent uses include predeployment planning and supporting P-3 ASW operations.

TABLE 2. TESS(3) CLIMATIC DATA REQUIREMENTS. CNOC established the following requirements for TESS(3) in the requirement named OCEN 87-01 (U.S. Navy, 1987a).

1. Ocean Waves
   - a. Data Elements (for primary and secondary wave components)
     - (1) wave height
     - (2) wave direction
     - (3) wave period
   - b. Resolution
     - (1) Horizontal Spatial: 1 degree of latitude
     - (2) Vertical Spatial: surface
     - (3) Temporal: monthly
   - c. Units
     - (1) Height: meters
     - (2) Direction: tens of degrees, true
     - (3) Period: seconds
2. Ocean Fronts & Eddies
   - a. Data Elements
     - (1) ocean front location and strength classification
     - (2) ocean cold/warm core eddy frequency
   - b. Resolution
     - (1) Horizontal Spatial: 0.5 degree of latitude (fronts)<br>1.0 degree of latitude (eddies)
     - (2) Vertical Spatial: surface
     - (3) Temporal: monthly
   - c. Units
     - (1) Front location: set of latitude/longitude coordinates.
       Front class: label as strong, moderate or weak and provide a temperature gradient range.
     - (2) Eddy frequency: percent
3. Ocean Currents
   - a. Data Elements
     - (1) ocean current velocity
   - b. Resolution
     - (1) Horizontal Spatial: 1 degree of latitude
     - (2) Vertical Spatial: surface
     - (3) Temporal: monthly

TABLE 2 (continued). TESS(3) CLIMATIC DATA REQUIREMENTS.

- c. Units
  - (1) Location: Latitude and longitude coordinates
  - (2) Direction: degrees true
  - (3) Speed: knots

4. Ocean Acoustics

- a. Data Elements:
  - (1) Below layer gradient
  - (2) Convergence zone ranges
  - (3) Sonic layer depth, including diurnal change in depth
  - (4) Shallow sound channel depth
  - (5) Shallow sound channel intensity (thickness & strength)
  - (6) Critical depth
  - (7) Directional ambient noise
  - (8) High frequency bottom loss

- b. Resolution
  - (1) Horizontal Spatial: 0.5 degree of latitude
  - (2) Vertical Spatial: depth below surface
  - (3) Temporal: monthly

- c. Units
  - (1) Gradients: degrees Celsius per meter
  - (2) Convergence zone ranges: kilometers
  - (3) Depths: meters
  - (4) Channel thickness: meters
  - (5) Channel strength: meters per second
  - (6) Acoustic signals: decibels

5. Upper Air Climatology

- a. Data Elements
  - (1) Sea level pressure
  - (2) Geopotential height of isobaric levels
  - (3) Air and dew point temperatures

  - (4) Wind velocity

- b. Resolution
  - (1) Horizontal Spatial: 2.5 degrees latitude
  - (2) Vertical Spatial: sea level and 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 50, and 10 mb isobaric levels.
  - (3) Temporal: monthly

- c. Units
  - (1) Pressure: millibars
  - (2) Temperature: degrees Celsius
  - (3) Height: meters
  - (4) Wind: knots/degrees true

## TABLE 2 (continued). TESS(3) CLIMATIC DATA REQUIREMENTS.

6. Visibility

a. Data Elements:
(1) Mean visibility
(2) Frequency of occurrence of restricted visibility
(0.5, 1, 3 and 5 nautical miles or less)

b. Resolution
(1) Horizontal Spatial: 1 degree latitude
(2) Vertical Spatial: surface
(3) Temporal: monthly

c. Units
(1) Mean visibility: nautical miles
(2) Restricted visibility frequency: percent

7. Sea Ice Boundaries

a. Data Elements:
(1) Sea ice edge location

b. Resolution
(1) Horizontal Spatial: 0.5 degree latitude
(2) Vertical Spatial: surface
(3) Temporal: monthly

c. Units
(1) Location: Latitude and longitude coordinates

8. Cloud Coverage

a. Data Elements: (by layer and total cloud cover)
(1) Cloud amount
(2) Cloud base height

b. Resolution
(1) Horizontal Spatial: 1 degree latitude
(2) Vertical Spatial: low, middle, high and total
(3) Temporal: monthly

c. Units
(1) Cloud amount: percent
(2) Cloud base height: hundreds of feet

Required elements as reported by users are listed in Table 3. Many of these elements overlap with the established requirements shown in Table 1 but elements not included in CNOC's list are wanted by the fleet users. Some of these elements (e.g., Electronic Warfare products), are too poorly defined to be addressed without clarification.

TABLE 3. OPERATIONAL USER REQUIREMENTS. The various climatic parameters listed below were cited by users during a survey of operational requirements conducted for this research.

Electronic Warfare products
Bathythermographs (BT's) and shallow water BT's
Upper air profiles
Maximum and minimum temperatures
Wind frequency distribution and prevailing wind velocity
Refractivity profiles
Sea ice
Wave height
Mean ocean front position
Sound speed profiles
Sonic layer depth
Ocean currents
Sea surface temperature
Biological activity
Representative radiosonde profiles
Tides
Sea state
Tropical storm tracks
Bottom contours
Surface duct cutoff frequency
Ambient noise, shipping traffic
Typical convergence zone (CZ) range, range to CZ annulus
CZ depth requirement, CZ depth excess, possible/reliable CZ
Alfa/November indices, (magnetic disturbance of communications)
Active/passive sensor data, propagation loss profiles
Low frequency bottom loss, bottom loss levels
FLIR range
Below layer gradient
Optimum VLAD, VLAD/DIFAR decision matrix
Acoustic half channel and shallow sound channel

## D. DATA BASE MANAGEMENT

The CLIMA-TV data base is managed by the Empress RDBMS which provides a SQL interface to the data. The Empress DBMS and SQL are described in Rhodinus (1987). In overview, Empress extends the standard operating system facilities for information management. Empress provides data recovery, checking and security. Empress keeps all data in relational tables.

Using SQL to access climatic data enhances the portability of the CLIMA-TV software. With SQL, Empress could be replaced by some other DBMS, without changing the application software. Although SQL calls can be made interactively, CLIMA-TV enforces a consistent query structure by placing all SQL calls within UNIX shell programs. Furthermore, CLIMA-TV does not use SQL commands embedded within applications programs coded in higher order languages such as FORTRAN or C. This approach avoids the proprietary Empress Host Language Interface and enhances the portability of the CIS.

In addition to Empress, the CIS uses the UNIX operating system to manage ASCII text files. These text files contain narrative descriptions that do not require management by Empress. These files are accessed by such UNIX tools as the **more** and **cat** commands. The UNIX operating system is described by McGilton and Morgan (1983).

## E. DATA DISPLAY

### 1. CLIMA-TV Graphics

In keeping with its emphasis on non-developmental and commercial software, the CLIMA-TV employs the National Center for

Atmospheric Research (NCAR) Graphics utilities, Version 2.0. NCAR Graphics is a collection of FORTRAN procedures tailored to display meteorological data (Clare et al., 1987). The NCAR Graphics utilities:

- produce X-Y coordinate plots.
- contour data fields on (ir)regularly spaced grids.
- produce world maps using in one of ten projections.
- produce solid color maps.
- display two-dimensional vector fields.
- draw lines in three-dimensional space.
- provide halftone (gray scale) shading.
- draw three-dimensional displays of bivariate functions.
- draw iso-surfaces from a three-dimensional array.
- draw text in various fonts.
- draw dashed lines with user-defined patterns.

Some utilities can be used together. For example, isopleths can be superimposed on map backgrounds.

NCAR Graphics conforms to the GKS standard, adopted by both ANSI and ISO. The GKS standard allows portability of graphics application programs between different host computers by providing a consistent interface to high level languages (Clarkson and Skrinde, 1985). This interface includes commands for data input and drawing, multiple workstation capability and device-independent graphics primitives. GKS can be implemented in one of twelve levels, depending on the graphical input and output capabilities. ANSI (1985) provides a full GKS description.

NCAR Graphics Version 2.0 normally implements GKS level 0A (Clare et al., 1987). The only possible output at this level is a metafile (a file of encoded graphics instructions allowing device-independent storage of the graphic image). NCAR Graphics produces a Computer Graphics Metafile (CGM), which is an ANSI and ISO standard. To produce plots on a graphics output device from a metafile, a metafile translator must be invoked. Each computer host must have its own device-specific metafile translator. To speed graphics production by avoiding these interim steps of metafile creation and translation, CLIMA-TV added a higher level GKS package which provides a direct path from GKS to the graphics output device.

Portability among computers was one reason for selecting NCAR Graphics for the CLIMA-TV. Other factors included low-cost (~$300); functionality tailored to meteorological graphics; product support from NCAR; growth path through the GKS; reliability resulting from years of extensive use and testing and an existing group of experienced users (NCAR Graphics is used at both NPS and FNOC.

CLIMA-TV is not intrinsically linked to NCAR Graphics, however. Computers hosting alternative graphics utilities, such as TESS(3), can also host the CLIMA-TV software. This rehosting would require either the direct replacement of the CLIMA-TV calls to NCAR subroutines with calls to the equivalent resident utilities, or the installation of a "translation layer" of subroutines mapping the NCAR calls to these equivalents. The latter approach was adopted during the rehosting of the TESS 2 applications software in TESS(3).

The choice of NCAR Graphics unfortunately limits some of the CLIMA-TV capabilities. For example, NCAR Graphics Version 2.0 does not provide color filled contours or land/sea discrimination, although Version 3.0 does. Since CLIMA-TV uses Version 2.0, this later shortcoming requires that isopleths of oceanic data, such as sea surface temperature, must be plotted in the same color as is the land mass. By using this approach, the solid fill land polygons mask the inappropriate sections of the isopleths. Figure 3 illustrates the NCAR Graphics capabilities in CLIMA-TV.

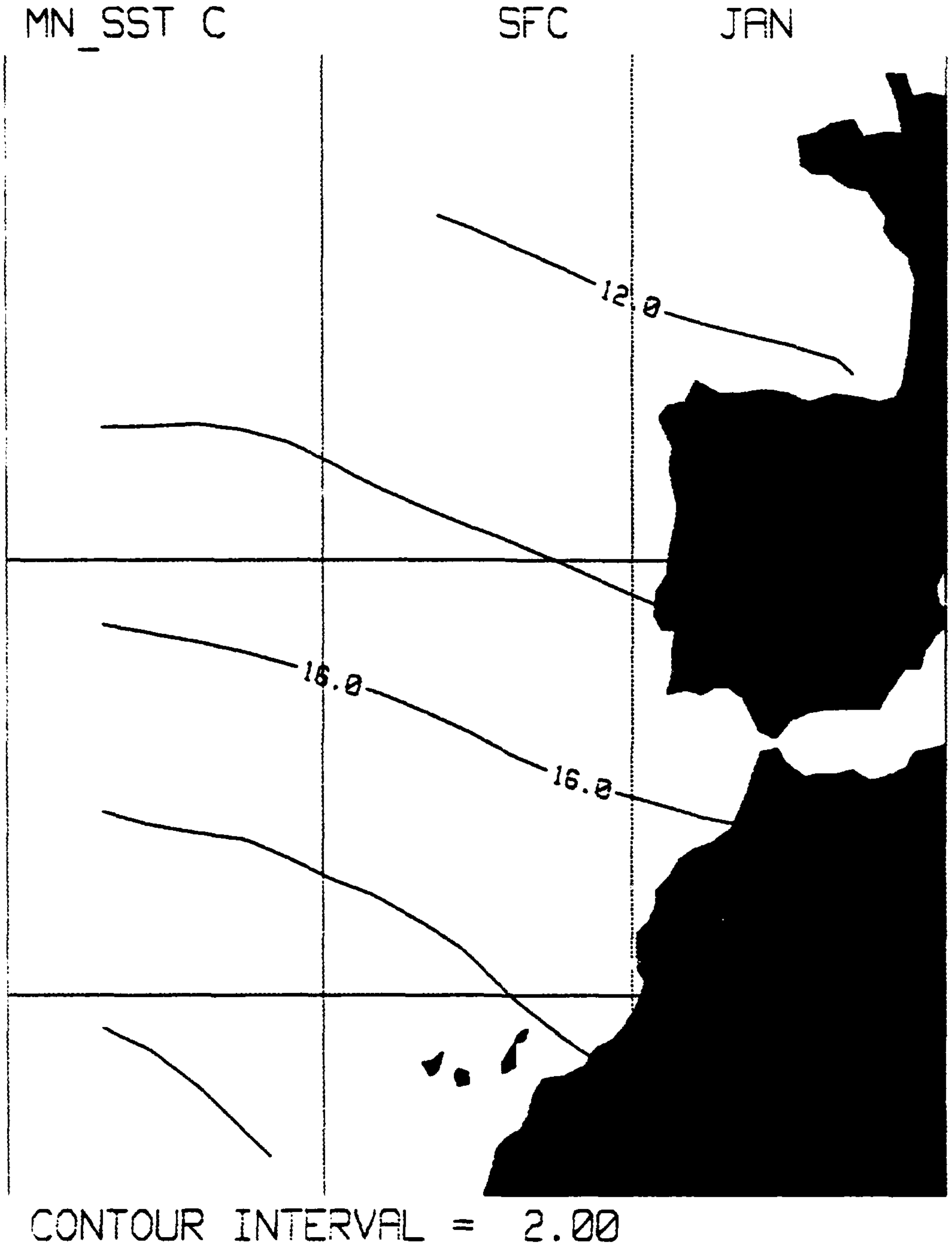


Figure 3. Sample Contour Map. The NCAR Graphics capabilities in CLIMA-TV are demonstrated. On the computer display screen, land is green and water is blue.

### 2. Color Displays

The advantages and limitations of colored displays are based on human physiology and psychology. Durrett and Trezona (1982) provide an overview of these factors. Benefits of color include: increased user interest, reduced visual search time, improved discrimination of subtle differences and emphasis of the organization of the information (Shneiderman, 1987). The disadvantages of color often result from the following conditions: using too many colors, using color irrelevantly or unnaturally, using color in highly chromatic lighting and employing color vision defective operators (Neri and Zannelli, 1984).

The CLIMA-TV CIS can benefit from color displays in several ways. The natural association of certain colors with physical conditions is used to enhance comprehension. For example, land and sea are colored green and blue respectively to emphasize the coastline and geographic regime (maritime, coastal or continental). Color also can be used to distinguish more easily between multiple fields which may be plotted on the same map background (Grotjan and Chervin, 1984). The CLIMA-TV design follows the guidelines for color use proposed by Neri and Zannelli (1984) who studied the use of color displays in Navy submarines.

Willey and Nesbitt (1986) note that observers can differentiate more colors than they can name. Therefore, the CLIMA-TV design uses only nameable colors. This reduces ambiguity when it is necessary to refer to a specific color in the user's manual or during briefings to the end users of the products. Durrett and Trezona (1982) counsel that the average user shouldn't be expected to remember more than five to seven colors. The eight studies cited by Neri and Zannelli (1984) put the upper limit for the number of colors recommended for computer displays between four and eight. Shneiderman (1987) suggests limiting the number of colors in a single alphanumeric display to four, with seven colors in the entire sequence of displays.

CLIMA-TV uses black and the six colors suggested by Neri and Zannelli (1984); red, yellow, green, cyan, blue and white. These six colors are recommended for the following reasons. They are well spaced throughout the visible spectrum and are thus easier to differentiate than a set of hues grouped in one or two spectral locations. Four of the colors are opponent-color pairs (red/green and yellow/blue). These pairs maximize color contrast. While sophisticated color monitors may support up to 4096 colors, the primary hues of red, blue and green are supported by even the most inexpensive color displays (Durrett and Trezona, 1982). The portability of the CLIMA-TV design thus is improved.

The CLIMA-TV color palette has drawbacks, however. Willey and Nesbitt (1986) note that single primary colors (red, green and blue) are single points of failure (places where one transistor or wire can cause one color channel to vanish). Durrett and Trezona (1982) insist that opponent-color combinations should always be avoided in textual and graphic displays. This is because yellow on a blue field and red on a green field produce the sensation of shadows on the display and afterimages with color reversal. Shneiderman (1987) notes another troublesome color pairing. Pure red and blue seem to vibrate when used together. Red and blue are on opposite ends of the spectrum and the eye muscles strain to simultaneously focus for both colors. The selection of color combinations is made more difficult for a transportable system like CLIMA-TV. Each color appears differently on monitors of various manufacture and careful tests with various combinations is necessary (Shneiderman, 1987). This trial and error approach was used in the development of a paleoclimatology animation system at the University of Wisconsin, Center for Climatic Research (P. J. Behling, personal communication and Behling, 1988).

## F. DATA SOURCES

Data bases come in many forms, although most scientists think of and use digital data bases. Unfortunately, a great amount of climatic data is available only as hard copy tables and atlases. A few climatic narratives and tables were digitized for this project with a Dest PC Scan Plus optical scanner connected to a word processor. The time required and the high error rate associated with scanning printed climatologies made the conversion from paper media to digital data too laborious to pursue extensively. Therefore, existing digital data sets are used to create most of the initial CLIMA-TV data base. The various sources of these climatic data sets are identified below. Once the digital data sets were located and acquired, the data had to be installed as Empress tables or UNIX files. The software development required to create, access and display the CLIMA-TV data base represents a large part of the work expended on this project.

### 1. National Climatic Data Center

NCDC is part of NOAA and is the nation's main repository of climatic data with over 280 data sets, 210 million paper records and 1 million microfiche. Total archives contain about 100 terabytes of data and are increasing by 14 terabytes per year. Other NOAA data centers are the National Oceanographic Data Center and the National Geophysical Data Center.

These centers are part of the World Data Center system, which provides environmental data globally.

Located with the NCDC in Asheville, NC is the Naval Oceanography Command Detachment (NOCD), which is the Navy liaison to the NCDC. NOAA (1988) describes NCDC products, media and ordering information. The majority of digital data sets included in CLIMA-TV were obtained from NCDC via NOCD. Many NCDC data sets also are available through the NCDS described in the preceding section.

Several commercial vendors, including EarthInfo (Boulder, CO) and WeatherDisc Associates (Seattle, WA), market selected NCDC data sets on Compact Disk-Read Only Memory (CD-ROM). These vendors do not quality check or change the NCDC data sets during the media transfer. The access software provided with these CD-ROM's is for MS-DOS personal computers rather than UNIX systems. For these reasons, CLIMA-TV uses the original NCDC data sets on tape rather than the CD-ROM versions. General Microsystems (Bellevue, WA) sells a CD-ROM device driver which is compatible with the TESS(3) computer.

### 2. Fleet Numerical Oceanography Center

FNOC maintains the Climatology Master Tape Data Set (CLIMASTER) which is described in the FNOC Products Manual (U.S. Navy, 1987b) and in the FNOC Computer User Guide (U.S. Navy, 1990b). CLIMASTER contains monthly, seasonal and annual climatic summaries. FNOC also has several non-summarized time series of observations, called historic data sets, which are not considered for CLIMA-TV. CLIMASTER data are used as first-guess fields in analysis models and as input to assessment models. For example, the ocean temperature and salinity climatologies support various acoustic products. The CLIMASTER data sets are typically formatted as hemispheric, polar stereographic grid fields of 63x63 points with a spatial resolution of 381 kilometers at 60 degrees latitude. There are several regional scale climatologies with resolutions ranging from 40 to 60 kilometers. The FNOC climatic data sets are:

**Bauer-Robinson.** Monthly temperatures and salinities from the ocean surface to the bottom on a one degree grid.

**Expanded Ocean Thermal Structure.** Monthly temperature, first and second temperature derivatives and primary layer depth from the surface to 400 meters at fixed and variable levels. North and south hemispheric grids.

**Deep Ocean Temperature.** Monthly ocean temperature at fixed depths from 400 to 5000 meters. North and south hemispheric grids.

**General Digital Environmental Model.** Seasonal temperature and salinity at 30 levels between the surface and 5000 meters. Spherical 0.5 degree grid for the North Atlantic, North Pacific and Mediterranean Sea.

**Typical Expendable Bathythermograph Profile.** Monthly temperature profile representing a "typical" sounding. Spherical 0.5 degree grid for the North Atlantic, North Pacific and Mediterranean Sea.

**Salinity.** Monthly salinity as determined by the Geophysical Fluid Dynamics Laboratory from the surface to 5000 meters at fixed depths. North and south hemispheric grids.

**Verti-Clim Temperature.** Typical temperature profiles for the southern hemisphere.

**Optimum Path Aircraft Routing System.** Monthly wind components and air temperature at standard isobaric levels on a global spherical grid. Original data provided by NCAR.

### 3. Naval Oceanographic Office

The Naval Oceanographic Office (NAVOCEANO) created an environmental data base during the development of TESS 2. These data sets are described in U.S. Navy (1986a, 1986b and 1990a) and are rehosted on TESS(3) in their original UNIX file formats. This data base now is accessible only through special purpose application software and transferring the data sets to the Empress DBMS is a high priority of the TESS project. The CLIMA-TV provides an established schema for this transfer. The NAVOCEANO TESS 2 climatic data sets are:

**Historical Ocean Profiles.** Seasonal ocean temperature and salinity profiles at standard depths. Monthly temperature profiles deemed to be most "typical" of a predefined ocean province.

**Bottom Depth.** Ocean depth in decameters on a five minute geographic grid.

**Bottom Loss.** Acoustic bottom loss in decibels for both high and low audio frequencies. Spatial resolution is 5 and 10 minutes, respectively.

**Ambient Noise.** Seasonal wind and shipping noise at fixed audio frequencies. Spatial resolution is 2 degrees in the Mediterranean Sea and 5 degrees elsewhere.

**Optical Water Type.** Optical water type expressed as an index between 1 and 5 on a 2 degree grid.

**Volume-scattering Coefficients.** Seasonal integrated column strengths of acoustic scattering at fixed audio frequencies. Grid is 5 minutes square.

**Tidal Constituents.** Tidal constituents included are amplitude, phase lag and angular speed. Tidal data is for 6,000 stations.

**Atmospheric Duct Statistics.** Monthly, diurnal statistics of surface, elevated and evaporation ducts. Frequency of occurrence, mean duct height and surface wind speed are included.

**Wind Speed.** Monthly median wind speed on a 1 degree grid of the Northern Hemisphere below 64 degrees.

NAVOCEANO also produced a data set of mean ocean frontal positions and strengths as part of the Geophysical Fleet Mission Program Library. This data set is a digitization of Defense Mapping Agency Map 5104. The data are not now part of TESS 2 or TESS(3).

### 4. Institute of Naval Oceanography

The Institute of Naval Oceanography (INO) is installing two NCAR climatic data sets in an Empress data base. Lai (1990) describes these sets which include:

**Levitus.** Annual temperature, salinity and oxygen profiles for 33 levels on a one degree grid. Seasonal temperature and salinity profiles for 24 levels on a one degree grid also are included.

**Hellerman.** Monthly and seasonal ocean surface wind stress on a two degree grid.

# V. INITIAL DATA BASE CONTENTS

The installation of climatic data in the CLIMA-TV data base is an ongoing effort. The initial data base is arbitrarily limited to selected data sets which are chosen to demonstrate the capabilities of CLIMA-TV to handle different data types. The CIS design eases the addition of updated and new data sets. The following data sets were obtained from various sources and installed in the initial CLIMA-TV data base. Table 4 recaps the TESS(3) climatic data requirements and shows how these have been addressed by CLIMA-TV, either by providing the data or by identifying candidate data sets for meeting the remaining TESS(3) requirements.

## A. MARINE CLIMATIC ATLAS

The U. S. Navy Marine Climatic Atlas of the World (1974-81) is a primary reference for naval users of climatic data. This nine volume series is based on historical marine observations collected aboard the ships of many nations over more than 120 years. NOCD plotted these climatic data for each 5-degree quadrangle onto a Miller cylindrical map projection of the world. The maps were then analyzed and manually adjusted for continuity and consistency. Where the 5-degree resolution was inadequate, 1- and 2-degree resolution maps of individual ocean basins were referenced. Ocean analyses were based solely on marine observations. Isopleths of the means and standard deviations were drawn on the charts and then the maps were digitized.

TABLE 4. STATUS OF TESS(3) REQUIREMENTS FOR CLIMATIC DATA. The status of the TESS(3) climatic data requirements is described as met, partly met or unmet.

1. Ocean Waves (primary and secondary wave components)

   a. Data Elements

| | |
|---|---|
| (1) wave height | partly |
| (2) wave direction | unmet |
| (3) wave period | unmet |

   b. Status
   CLIMA-TV provides monthly mean and standard deviation of primary wave height only. No source found for unmet requirements.

2. Ocean Fronts & Eddies

   a. Data Elements

| | |
|---|---|
| (1) ocean front location and strength classification | partly |
| (2) ocean cold/warm core eddy frequency | unmet |

   b. Status
   Data set of annual front locations and strengths obtained from NAVOCEANO. No source found for unmet requirements.

3. Ocean Currents

   a. Data Elements

| | |
|---|---|
| (1) ocean current velocity | unmet |

   b. Status
   FNOC data set of monthly mean u and v components of surface currents for northern hemisphere available from FNOC.

4. Ocean Acoustics

   a. Data Elements:

| | |
|---|---|
| (1) Below layer gradient | met |
| (2) Convergence zone ranges | unmet |
| (3) Sonic layer depth | partly |
| (4) Shallow sound channel depth | unmet |
| (5) Shallow sound channel intensity | partly |
| (6) Critical depth | unmet |
| (7) Directional ambient noise | unmet |
| (8) High frequency bottom loss | unmet |

## TABLE 4 (continued). STATUS OF TESS(3) REQUIREMENTS FOR CLIMATIC DATA.

b. Status
CLIMA-TV provides means of convergence zone, below layer gradient, shallow sound channel magnitude and sonic layer depth. Diurnal variations not provided. FNOC or NAVOCEANO data sets may satisfy unmet requirements.

5. Upper Air Climatology

a. Data Elements

| | | |
|---|---|---|
| (1) | Sea level pressure (SLP) | met |
| (2) | Geopotential height of isobaric levels | met |
| (3) | Air and dew point temperatures | met |
| (4) | Wind velocity | met |

b. Status
SLP for oceanic areas only. Other parameters on global, 2.5 degree grid for 13 standard isobaric levels. Monthly means and standard deviations.

6. Visibility

a. Data Elements:

| | | |
|---|---|---|
| (1) | Mean visibility | unmet |
| (2) | Frequency of occurrence of restricted visibility (0.5, 1, 3 and 5 nautical miles or less) | partly |

b. Status
NOARL data set gives frequency of visibility < 2 nautical miles for 2.5 degree grid between 70S-70N. No source found for unmet requirements.

7. Sea Ice Boundaries

a. Data Elements:

| | | |
|---|---|---|
| (1) | Sea ice edge location | unmet |

b. Status
No source identified.

8. Cloud Coverage

a. Data Elements: (by layer and total cloud cover)

| | | |
|---|---|---|
| (1) | Cloud amount | met |
| (2) | Cloud base height | unmet |

b. Status
Mean cloud amount for low, mid, high and total cloud. No source found for unmet requirement.

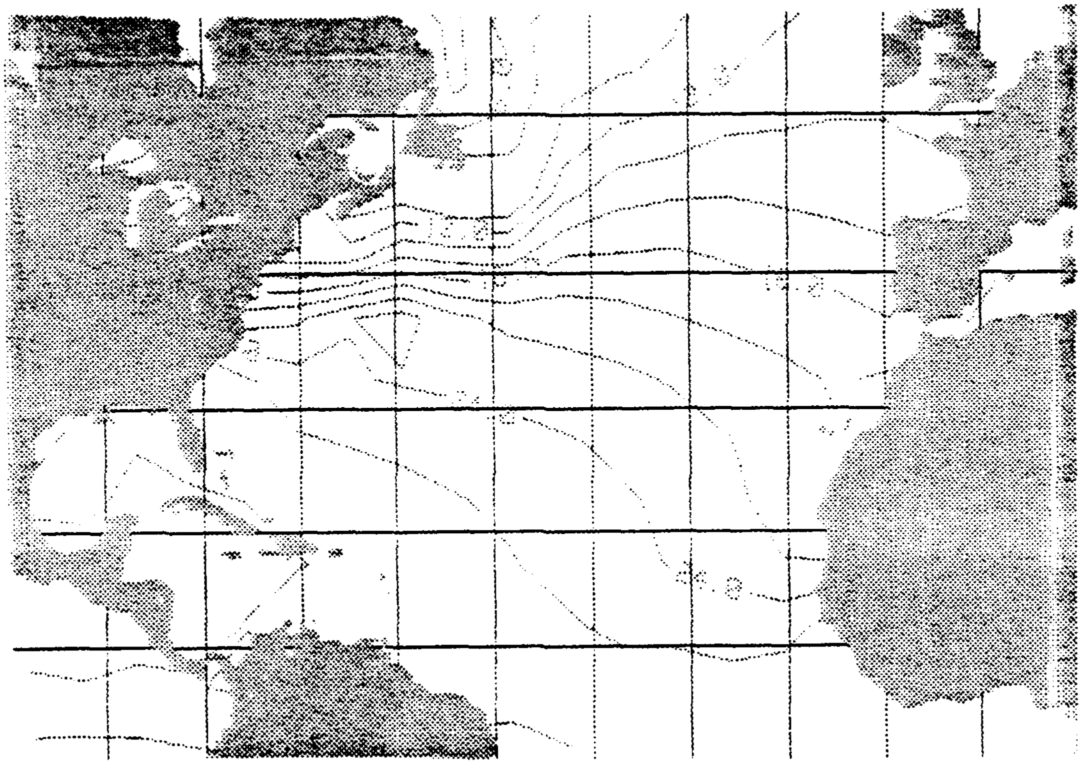
A subset of the digitized maps is a product known as the Pilot Charts - Sums of Global Atlas Marsden Squares (TD-9757), described in NOAA (1988). This global data file presents monthly observation counts for eight-point wind roses; means and standard deviations for wind speed, pressure, air, wet bulb, dew point and sea surface temperatures, air-sea temperature difference and wave height; and gale and superstructure icing frequencies. The number of observations used to compute each statistic also is included. Summarized data are available for both 1-degree and 5-degree Marsden subsquares. CLIMA-TV uses only the 5-degree data due to disk storage limitations. The period of record summarized varied during the period January 1850 through December 1970, depending on the ocean basin. The statistics contained in this data set were computed from all ship observations within a 5-degree quadrangle over the entire period of available data.

Tapes containing the Pilot Charts data were acquired from NOCD and the data were transferred to the CLIMA-TV data base. Figure 4 shows a sample CLIMA-TV contour map of the mean June sea surface temperature and the corresponding map from the Marine Climatic Atlas. The loss of detail in the CLIMA-TV product is due to the 5 degree spacing of the data and the inadequacy of the NCAR contouring software.

Both the CLIMA-TV and Navy Atlas maps are subject to misinterpretation if the possible consequences of the data processing procedure are not considered (U.S. Navy, 1981). Specifically:

1. Stationarity (no significant trends in the data) must be assumed where different areas contain data from different periods of record.

(a) CLIMA-TV contour map of mean June SST.



(b) Mean June SST from the Marine Climatic Atlas.

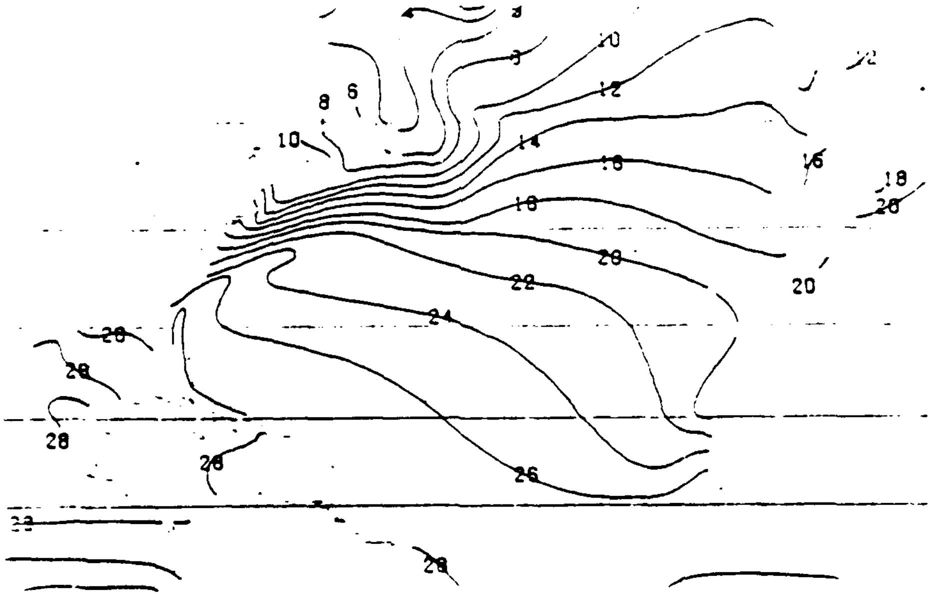


Figure 4. Comparison of Mean June Sea Surface Temperature (SST). Charts for (a) CLIMA-TV and (b) the Marine Climatic Atlas (U.S. Navy, 1981) are shown. The contour interval is 2 degrees Celsius in both charts.

The authors of the Marine Climatic Atlas concluded that there were no operationally significant trends. Operationally significant accuracies for most climatic applications were considered to be:

| | |
|---|---|
| Temperature | ± 1°C |
| Pressure | ± 1 mb |
| Wind Speed | ± 3 kts or 10%, whichever is greater |
| Wave Height | ± 0.5 m |

2. Inhomogeneity among various data sources was empirically adjusted or inhomogeneous data sets were deleted.

3. The temporal variation of observations within a month was ignored. Thus, if all data from one area were clustered at the beginning of the month, while data from another area were clustered at month's end, a bias could result.

4. Data were grouped by 5-degree quadrangles. Due to the convergence of the meridians at the poles, the area within a 5-degree quadrangle varies with latitude. The area also varies in coastal zones. This presents a special problem for the standard deviations since they represent both the point variability (for each point within the quadrangle) and the areal variability (caused by gradients of the variables across the areas).

5. The centroid of the quadrangle is the assumed locus of the parameter being analyzed. Spatially derived errors result should the observations be concentrated in a corner of the quadrangle.

Since the mean ice limit approximates the minus 2 degree Celsius sea temperature, this threshold was adopted for the Marine Climatic Atlas as the boundary for the wave height and air-sea temperature difference analyses. To ensure that the air-sea temperature charts agree with the mean air and mean sea surface temperature charts, the analyses were graphically derived. This restricted the resolution to 2 degrees Celsius which was the contour interval of the charts. The wave height charts show the higher of the sea or swell. Combined sea and swell wave heights may be significantly higher.

Despite these limitations and problems, the Marine Climatic Atlas authors conclude that the charts compare well with the only long-term point climatological data available over the oceans - the Ocean Weather Station (OWS) data set. The OWS network of semi-fixed location ships has collected data for over three decades beginning in the 1950's. Means and standard deviations computed for the OWS's were compared to those values interpolated from the 5-degree charts. Results show that the means are in close agreement, but the standard deviations vary considerably from point-source values, depending upon geography and climate.

Quayle (1974) made an independent comparison of OWS and transient ship weather reports. He investigated the suspicion that climatologies derived from transient ship observations may be biased toward good weather. Ships may avoid bad weather when possible, thus decreasing the amount of bad-weather data. Conversely, the authors of the Marine Climatic Atlas suggest that ships may slow down in foul weather, thus taking more observations and increasing the data sample. Quayle (1974) concluded that the fair weather bias was a consistent phenomenon but it is of relatively little importance (except for precipitation) when dealing with routine climatological records. Other influences on the overall quality of ship observations, such as instrument inaccuracies and observer experience/subjectivity, are dominant.

A qualitative review of some of the Pilot Chart parameters as summarized in the Marine Climatic Atlas is listed below:

* Air Temperature - Considered to be generally reliable. However, observed temperatures on sunny days in the tropics appear consistently high due to poor instrument exposure.

* Sea Surface Temperature - The varying measurement methods tend to decrease the reliability of the individual values. Gradients and relative values are considered reliable.

* Sea Level Pressure - One of the least accurate parameters because of instrument, coding and conversion errors. The large scale patterns and gradients are relatively accurate.

* Wave Height - Extremely subjective estimates which depend of the observer's experience and the size of the ship. Transient ships tend to report lower wave heights relative to reference measurements.

## B. CLOUD CLIMATOLOGY

The naval requirement for a global climatology of low, mid, high and total cloud amount is listed in CNOC OCEN 87-01 (U. S. Navy, 1987a). The scientific importance of an accurate cloud climatology is clear since clouds are the predominant influence on the Earth's radiation budget (Hughes, 1984). Militarily, clouds reduce the efficacy of aircraft and satellite surveillance, interrupt the beam path of electro-optical systems and affect flight and other operations. Snow (1988) describes the importance of cloudiness to military planners.

Hughes (1984) reviewed the cloud climatologies then available and concluded "there is, at present, no unique and/or generally agreed on global cloud climatology." The magnitude of cloud amount varies more among the climatologies reviewed than the geographical pattern. There is general agreement about the location of cloud amount maxima and minima. The areas of most disagreement between the climatologies were the oceanic and polar regions, precisely the areas of most interest to the Navy.

Like other cloud climatologies derived from surface observations, the Marine Climatic Atlas of the World (1974-81) shows little of the spatial detail revealed by recent satellite cloud climatologies. The Navy atlas itself cautions that the low cloud data contained therein is of poor quality and quantity. Isopleths of the percent frequency of low and total cloud amount exceeding specified thresholds are shown in the Navy atlas. These thresholds differ between some ocean basins. For example, the North Pacific cloud climatology presents the percent frequency of total (low) cloud amount $\leq 2/8$ ($\geq 5/8$). The South Pacific climatology gives the percent frequency of total (low) cloud amount $\leq 2/10$ ($\geq 6/10$). Conversion between the okta and tenths scale of surface cloud observations is arbitrary. These spatial resolution and conversion problems weaken the existing naval cloud climatology and indicate the Navy needs another global cloud climatology.

This widely shared requirement for an accurate, quantitative, global cloud climatology resulted in the establishment of the International Satellite Cloud Climatology Project (ISCCP) discussed by Schiffer and Rossow (1983, 1985). ISCCP data collection began in July 1983. Upon completion of the on-going data processing, the ISCCP will produce a five year time series of global cloud amount, cloud height, cloud-top temperature and other properties such as radiances. At that time, the ISCCP will likely be the most accurate global cloud observation data set. Presently, 38 months of processed cloud climatology data are available from the National Environmental Satellite, Data and Information Service (Kidwell, 1990).

Since completion of the ISCCP five-year global cloud climatology appears to be years away, an interim climatology is needed. One candidate is the RTNEPH (Real-Time Nephanalysis) Climatic Database described in the RTNEPH Users Handbook (U. S. Air Force, 1986) and Bunting et al. (1983). In contrast to the ISCCP's planned five-year, low resolution (-250 km) archive, the Air Force's nephanalysis is the only continuing, high resolution (-46 km) global cloud archive in existence (Henderson-Sellers, 1986). While RTNEPH is primarily a time series of global cloud analyses beginning on 1 January 1984, the subset histogram database provides the number of occurrences of each LMHT/A (low/middle/high cloud types and amounts/total cloud amount) code value by month and 3-hour synoptic time. The histogram database will eventually contain 8 years of data. A global cloud climatology could be derived directly from the RTNEPH time series or more easily from these histogram summaries. However, this effort is not trivial since there are 48 9-track, 6250-bpi tapes per year of RTNEPH histogram data, according to the RTNEPH Users Handbook. Hughes and Henderson-Sellers (1985) describe the derivation of a one-year climatology using the Air Force's 3D-nephanalysis (3D-NEPH) data set which preceded the RTNEPH. Hughes and Henderson-Sellers (1985) conclude that the 3D-NEPH archive (and presumably the newer RTNEPH data set also) offers a potentially useful cloud climatology, with certain regional exceptions.

Prior to undertaking the extensive data processing required to reduce the RTNEPH or 3D-NEPH data sets to a multi-year climatology, it is important to consider the shortcomings of these data. The Air Force nephanalysis is an operational product and although the data are archived, they are not primarily intended to form a climatology (Hughes and

Henderson-Sellers, 1985). Changes in the input data and processing techniques employed, subjective "bogussing" and degraded or missing data all contribute to the heterogeneity of the data. Normalizing these temporal inconsistencies in 3D-NEPH is impeded by a lack of documentation (Stowe, 1984).

Both 3D- and RTNEPH combine traditional surface cloud observations and high resolution satellite information. Surface observers frequently overestimate the cloud amount because they see the sides as well as the bases of the clouds (see Figure 5). Satellites observe the cloud tops because of their high orbits. The mixing of surface and satellite observations hinders data interpretation, especially of the variability statistics, and indicates that improved methods of data integration are required (Hughes and Henderson-Sellers, 1985). The lack of an accepted conversion between satellite-derived cloud amount percentages and the okta and tenths scale of surface observations (Hughes, 1984) affects the Air Force nephanalyses, just as the naval atlases are affected by the conversion problem described above.

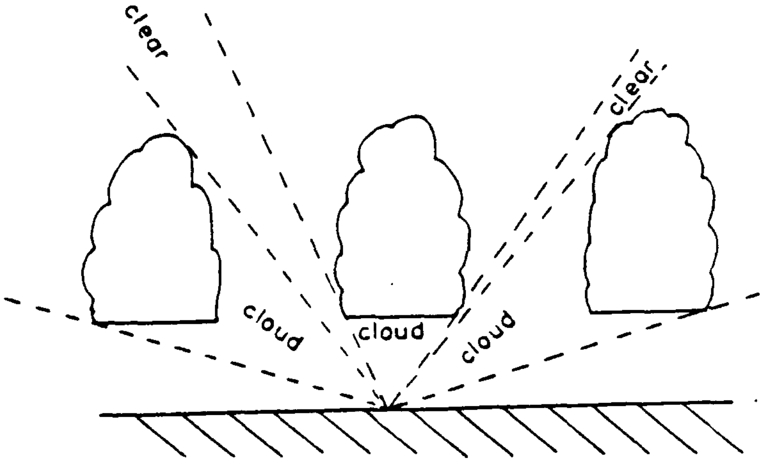


Figure 5. Surface Cloud Observations. Surface observers see the sides as well as the bases of the clouds (from Hughes, 1984).

The NASA Nimbus-7 Global Cloud Climatology (N7GCC) described by Hwang et al. (1988) avoids the preceding RTNEPH/3D-NEPH problems. This six-year (April 1979 to March 1985) climatology has been completed, validated (Stowe et al., 1988) and distributed. The N7GCC is a homogeneous set of continuous measurements from the Temperature Humidity Infrared Radiometer (THIR) and the Total Ozone Mapping Spectrometer (TOMS) on the Nimbus-7 satellite. Data processing, conversion and integration problems thus are obviated.

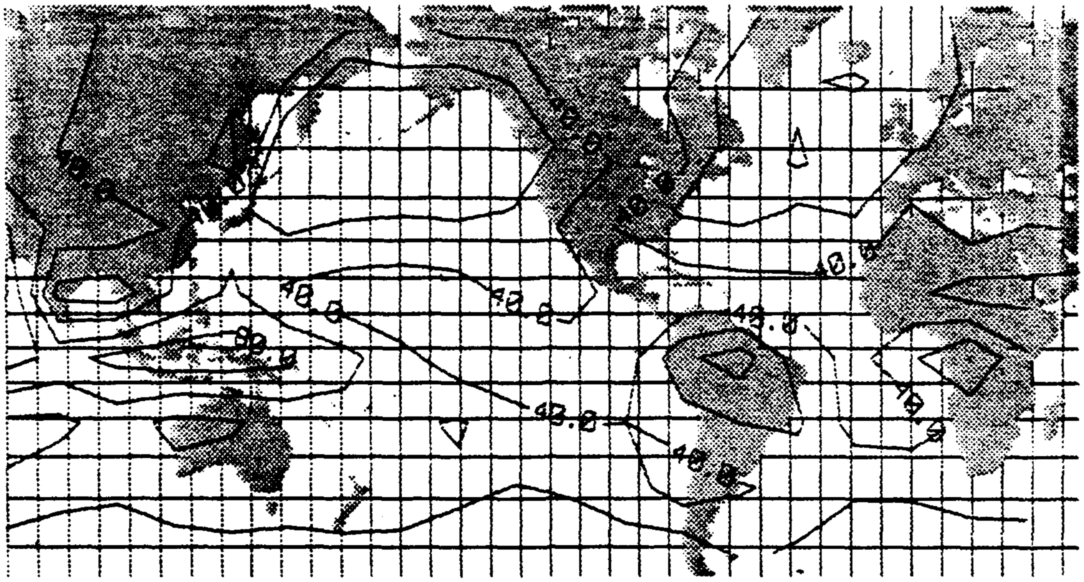
The N7GCC data set resulted from the improved processing of the Nimbus 7 THIR Earth Radiation Budget (ERB) experiment data. Stowe (1984) compared these THIR CLOUDS ERB (CLE) data to the 3D-NEPH data. These were the only two digital, global cloud type and amount data sets known to Stowe (1984) prior to the initiation of the ISCCP. Stowe (1984) found that the Air Force nephanalysis agreed better with the cloud interpretations of meteorological analysts than did CLE, except for high cloud amount. Random errors for 3D-NEPH cloud amounts were 10-25%, somewhat less than those in CLE. The 3D-NEPH systematic errors were smaller than CLE by about a factor of 2. The THIR/CLE errors were subsequently reduced (Hwang et al., 1988) by reprocessing the data using concurrent Air Force surface temperature information and TOMS reflectance. The resulting climatology product, known as Cloud MATRIX (CMATRIX), is described by Wellemeyer (1986) and Hwang et al., (1988).

The CMATRIX data set contains daily and monthly ERB target area (approximately 500 km by 500 km) cloud and radiance statistics. One year of CMATRIX data fits on a 9-track, 6250-bpi tape. The CMATRIX parameters include daytime and nighttime (approximately local noon and local midnight at the equator) values of total cloud amount, cloud amount in high, middle and low altitude categories, cirrus and "deep-convective" cloud amount (daytime only) and radiances of cloud and clear scenes. CMATRIX also includes the variances of cloud amount and radiance in space (for daily data) and time (for monthly data), correlative surface temperature and snow-ice coverage for each target area (Hwang et al., 1988). In addition to the target area statistics, CMATRIX provides global, hemispheric and zonal (4.5 degrees of latitude) averages of many of the above parameters.

The evaluation of candidate cloud climatologies summarized above, lead to the inclusion of the CMATRIX data set in the initial version of CLIMA-TV. CMATRIX was selected because of the length of the period of record (six years), the homogeneity and immediate availability of the data and the minimal data processing required to create a six-year climatological average of the monthly statistics provided by NASA.

The six CMATRIX tapes were acquired from the National Space Science Data Center, Goddard Space Flight Center, Greenbelt, MD. The monthly means were averaged to yield a six-year mean for each month and parameter. A subset of the resulting mean monthly statistics was placed in the CLIMA-TV data base. Figure 6 compares a CLIMA-TV contour map of mean January total cloud amount and the corresponding map from Berlyand and Strokina (1980). This comparison echoes the conclusion of Hughes (1984) that the magnitude of cloud amount varies more than the geographical pattern. Figure 6 shows general agreement about the location of cloud amount minima and maxima while also showing about a 20% difference in cloud amount.

(a) CLIMA-TV contour map of mean total cloud amount for January.



(b) January mean total cloud from Berlyand and Strokina (1980).

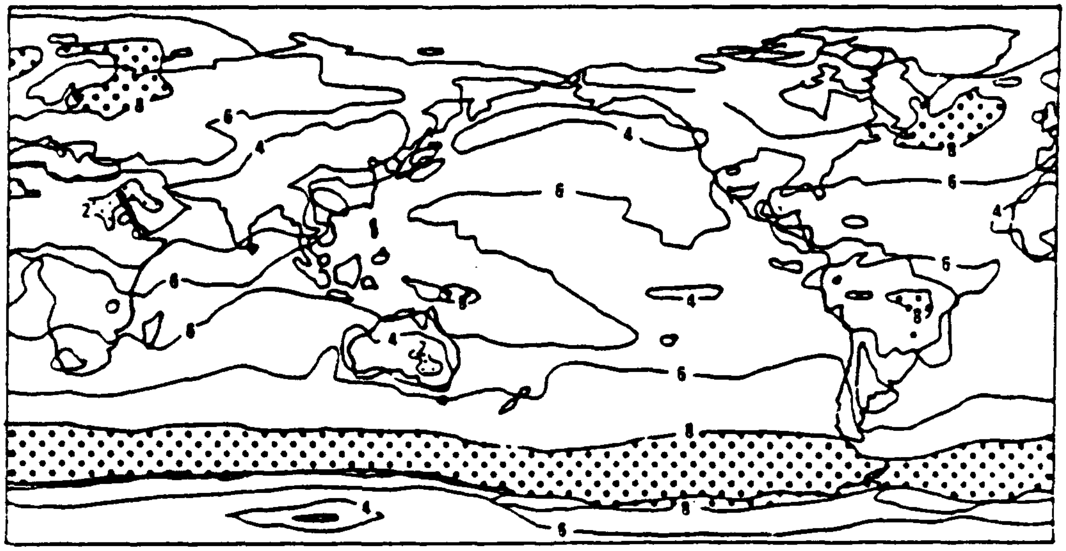


Figure 6. Comparison of Mean January Total Cloud Amount. Charts for (a) CLIMA-TV and (b) Berlyand and Strokina (1980) are shown. The contour interval is 20% in both figures.

Future cloud climatologies, such as the ISCCP or the nascent U. S. Air Force Climatology of Cloud Statistics described by Boehm (1987), eventually may replace the Nimbus-7 CMATRIX data. Such an upgrade is eased by the Empress DBMS since the applications software can remain unchanged when new data tables are created.

## C. UPPER AIR ATLAS

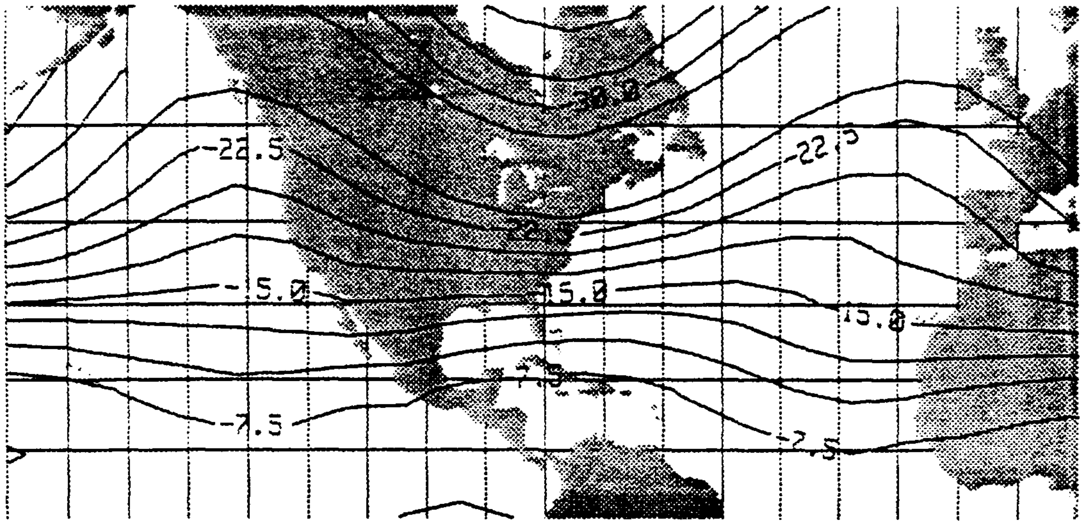
This data set provides gridded fields of monthly means and standard deviations of wind, temperature, dew point, density and height fields as analyzed by the European Center for Medium-Range Weather Forecasting (ECMWF). Wind rose frequencies and speeds are also included. The six year period of record was 1980 through 1985. The spherical grid has a spacing of 2.5 degrees, which provides a resolution of about 100 km in the middle latitudes. Global data are provided for 13 standard isobaric surfaces (1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50 and 30 mb). This data set was developed during publication of a joint services Upper Air Atlas (U. S. Navy, 1989b).

NOCD provided the Upper Air Atlas data. The means and standard deviations of the wind components in the original data set were converted to means and standard deviations of wind speeds and mean wind directions. Figure 7 compares a mean 500 mb temperature map from CLIMA-TV to the corresponding map from the Upper Air Atlas. The close agreement results from contouring the same data set for both charts.

## D. GENERAL ACOUSTIC CONDITIONS

This data set provides gridded fields of monthly means of convergence zone index , below layer gradient (BLG), shallow sound channel magnitude

(a) CLIMA-TV contour map of mean 500 mb temperature for January.



(b) January mean 500 mb temperature from the Upper Air Atlas.

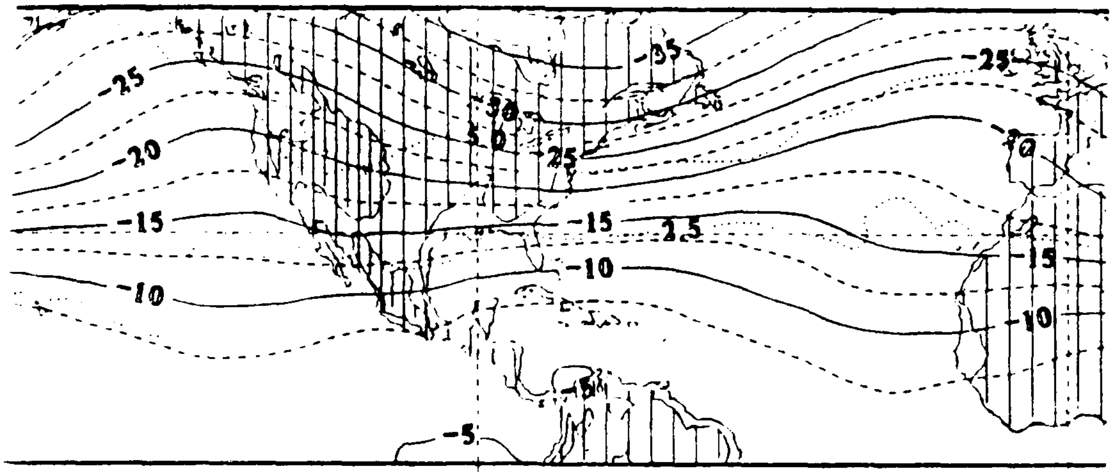


Figure 7. Comparison of Mean January 500 Millibar (mb) Air Temperature. Charts are shown for (a) CLIMA-TV and (b) the Upper Air Atlas (U. S. Navy, 1989b), a joint U.S. Navy & U.S. Air Force climatic study from which the CLIMA-TV upper air data set was produced. Figure 7b also shows the standard deviation of the 500 mb air temperature as dotted lines. The contour interval is 2.5 degrees Celsius in both charts.

(SSC) and sonic layer depth (SLD). The spherical grid mesh is 2.5 degrees. The data were computed using FNOC climatic fields as input to the FNOC General Acoustic Conditions (GAC) Depiction System. The GAC system and the four parameters listed above are detailed in the GAC Users Guide (U.S. Navy, 1989c).

In overview, the GAC products indicate the horizontal variation of acoustic conditions for a user specified region and time. The GAC system can assess a total of 15 acoustic parameters, although only four currently are included in CLIMA-TV. The BLG is the temperature gradient across the 100 foot layer immediately below the SLD. The SLD is the depth at which the maximum sound speed occurs in the layer above the thermocline. The SLD has an arbitrary maximum value of 1000 feet. The SSC is the difference between the sound speed at the shallow sound channel axis depth and the sound speed at the top or bottom of the shallow sound channel, whichever is less. Convergence zones (CZ) are regions at or near the ocean surface in which sound ray focusing occurs, resulting in high sound levels. The convergence zone usage index has three legal values with the following interpretations: 0 - No CZ; 2 - Probable CZ; 3 - Reliable CZ.

## E. RAWINSONDE CLIMATOLOGY

This digital data base was developed by NCAR utilizing monthly reports provided by stations in the WMO network to the NCDC. The NCAR data set is a time series of monthly mean values of height, air temperature, dew point, wind direction and wind speed for the surface and the mandatory 850, 700, 500, 300, 200, 150, 100, 50 and 30 millibar levels. Not all levels are available for every station. The period of record varies for each station between January, 1950 and December, 1986. These means combine reports from all synoptic observation times. The original data set was quality controlled and digitized as described in Jenne and Crutcher (1976).

The NCDC periodically updates this data base. The current data set is listed in NOAA (1988) and was obtained on magnetic tape from the NODC as the product called "NCAR World Monthly Weather Records." Alternatively, the data are available on CD-ROM from WeatherDisc Associates (see WeatherDisc Associates, (1989)) as the data set called the "NCAR World Monthly Weather Records-Upper Air (TD-9648)."

The monthly means from the tape files were combined and averaged over the period of record to create an ensemble mean for each month and station. The resulting data set contains mean monthly pressure or height, temperature, dew point, wind direction and wind speed for 880 selected stations around the world. The number of years in the averaging period also is provided for each pressure level.

## F. WMO STATION DESCRIPTIONS

These data describe the WMO and other stations, including moored buoys, which send meteorological reports. The station name, location, WMO number, call letters and political subregion are listed and certain observational practices are defined. This data set aids data access and the labeling of output. The Master Station Catalog (U.S. Air Force, 1989) describes this data set.

## G. SURFACE OBSERVATIONS

These monthly and annual station summaries provide information which is equivalent to the tables published in the Station Climatic Summaries

(U.S. Navy, 1979). Included data are means and extremes for temperature, precipitation and snowfall; and means for relative humidity, vapor pressure, dew point temperature, pressure altitude, wind velocity and sky cover. The mean number of days with thunderstorms; fog; temperatures > 90F, > 75F, < 40F and < 32F; precipitation ≥ .01 inch and ≥ 0.5 inch; and snowfall ≥ 0.1 inch and ≥ 1.5 inches also are provided. This data set is known as the Summary of Meteorological Observations, Surface (SMOS).

## H. NARRATIVE CLIMATOLOGIES

There are two types of narrative climatologies, those copied from the Air Force's Situation Climatic Briefs (SCB) (U.S. Air Force, 1985) and those copied from the Navy's SCS. Each is a narrative description of the climate in a country or region. The SCS narratives characterize the general climate of a station; provide a seasonal and monthly climatic overview; and describe the climatic extremes. The seasonal SCB narratives provide a general climatic overview, flying weather, reconnaissance weather, terminal weather at a specific airport, exposure weather, tubular summary of temperature and precipitation at that station, paradrop weather and astronomical data.

# VI. CONCLUSION

## A. SUMMARY OF RESULTS

A prototype CIS, called CLIMA-TV, was developed and demonstrated using various climatic data sets. These data sets occupy about 70 megabytes of disk storage. This research project showed the ability of a UNIX workstation and RDBMS to improve climatological support. Most CIS requirements are met by commercial hardware and software. The use of such industry standards as SQL and GKS reduces the development effort while enhancing portability. The inadequacy of the NCAR Graphics automatic contouring was demonstrated by comparison of the CLIMA-TV graphic output to the smoothed analyses published in atlases.

A large effort associated with the CLIMA-TV development was data capture, i.e., the acquisition of climatic data sets and their installation in the RDBMS. Adherence to a logical data base schema is a prerequisite to unifying the disparate data elements acquired for inclusion in the data base.

CLIMA-TV is in use on NEONS where the upper air and marine climatic atlas data sets support Special Sensor Microwave Imager (SSMI) data analysis. CLIMA-TV also provides application software for transition to TESS(3) and porting this software to TESS(3) has begun.

## B. REMAINING ISSUES

Remaining problems center on data acquisition, ingest and storage. Time requirements and error rates associated with scanning printed climatologies make the conversion from paper media to digital data too labor intensive to pursue extensively, even with up-to-date document scanners.

The data volumes of existing digital data sets requires massive on-line storage. CLIMA-TV needs large capacity hard disks, erasable-optical disks or CD-ROM media to provide the necessary storage for all required data sets. CLIMA-TV also needs an improved contouring capability. Despite these issues, CLIMA-TV is a more efficient means of locating climatic information than is manually searching through hard copy publications.

# APPENDIX A

## ACRONYMS

| | |
|---|---|
| 3D-NEPH | 3D-Nephanalysis |
| ANSI | American National Standards Institute |
| ASW | Anti-Submarine Warfare |
| ATCF | Automated Tropical Cyclone Forecasting |
| BLG | Below Layer Gradient |
| BT | Bathythermograph |
| CAC | Climate Analysis Center |
| CADB | Climate Assessment Data Base |
| CDF | Common Data Format |
| CD-ROM | Compact Disk-Read Only Memory |
| CGM | Computer Graphics Metafile |
| CIS | Climate Information System |
| CLE | Clouds ERB |
| CLIMASTER | Climatology Master Tape Data Set |
| CLIMA-TV | CLIMAtology-TeleVideo |
| CMATRIX | Cloud Matrix |
| CNOC | Commander, Naval Oceanography Command |
| CZ | Convergence Zone |
| DBMS | Data Base Management System |
| DEC | Digital Equipment Corporation |
| DOD | Department of Defense |
| ECMWF | European Center for Medium-Range Weather Forecasting |
| ERB | Earth Radiation Budget |
| FNOC | Fleet Numerical Oceanography Center |
| GAC | General Acoustic Conditions |
| GFMPL | Geophysical Fleet Mission Program Library |
| GKS | Graphical Kernel System |
| HP | Hewlett-Packard |
| IBM | International Business Machines |
| ICAPS | Integrated Carrier ASW Prediction System |
| INO | Institute of Naval Oceanography |
| IREPS | Integrated Refractive Effects Prediction System |
| ISCCP | International Satellite Cloud Climatology Project |
| ISO | International Standards Organization |
| MB | Megabytes |
| MB | Millibar |
| MICIS | Midwestern Climate Information System |
| MSWO | Monthly and Seasonal Weather Outlook |
| N7GCC | Nimbus-7 Global Cloud Climatology |
| NASA | National Aeronautics and Space Administration |

## ACRONYMS (CONTINUED)

| | |
|---|---|
| NAVOCEANO | Naval Oceanographic Office |
| NCAR | National Center for Atmospheric Research |
| NCDC | National Climatic Data Center |
| NCDS | NASA Climate Data System |
| NEOC | Naval Eastern Oceanography Command |
| NEONS | Naval Environmental Operational Nowcasting System |
| NOAA | National Oceanographic and Atmospheric Administration |
| NOCD | Naval Oceanography Command Detachment |
| NPS | Naval Postgraduate School |
| NSSDC | National Space Science Data Center |
| OAML | Oceanographic and Atmospheric Master Library |
| OWS | Ocean Weather Station |
| PC | Personal Computers |
| QPMO | Quick Projections of Monthly Outcomes |
| QPMU | Quick Projections for Multiple Stations |
| RAM | Random Access Memory |
| RDBMS | Relational DBMS |
| RTNEPH | Real-Time Nephanalysis |
| SCB | Situation Climatic Brief |
| SCS | Station Climatic Summary |
| SLD | Sonic Layer Depth |
| SMOS | Summary of Meteorological Observations, Surface |
| SQL | Structured Query Language |
| SSC | Shallow Sound Channel |
| SSMI | Special Sensor Microwave Imager |
| SST | Sea Surface Temperature |
| TESS | Tactical Environmental Support System |
| TESS 2 | Tactical Environmental Support System, phase two |
| TESS(3) | Tactical Environmental Support System, phase three |
| THIR | Temperature Humidity Infrared Radiometer |
| TOMS | Total Ozone Mapping Spectrometer |
| WMO | World Meteorological Organization |

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