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An Introduction to Atmospheric and Oceanographic Data

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TABLE OF CONTENTS

PREFACE

The purpose of this NCAR Instructional Aid (IA) is to serve as a "data-primer" for students and those in other fields of research who are interested in carrying out research involving the analyses of data in the atmospheric and oceanographic sciences. This IA will describe, in very general terms, the datasets most commonly used to study the atmosphere-ocean system and the formats used for archival. The datasets include observations from conventional meteorological sources such as stations and ships, from satellites, and analyzed grids produced at operational weather forecast centers. Detailed descriptions of instruments, methodologies and relative quality is not attempted. Rather, the focus is upon the broad characteristics of the data sources and the datasets. The characteristics not only include the observed variables and their spatial and temporal extent but also common problems, data limitations and sources of error. Datasets available from NCAR are used to illustrate typical archives. A bibliography containing selected references for each chapter provide the interested reader with more details.

Atmospheric and oceanographic data are generally archived at data archiving and distribution centers. Addresses, both conventional and electronic, of several major data centers are provided. A discussion of the Internet includes how to find datasets using the World Wide Web. Finally, a list of commonly used abbreviations and acronyms is provided to familiarize newcomers with atmosphere/ocean jargon.

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Comments, Suggestions, Errors

This IA will be updated on a regular basis. We would like to hear your input concerning the text. Please send your comments to shea@ncar.ucar.edu.

1. INTRODUCTION

Data analysis is one of the foundations for research in the atmospheric and oceanographic sciences. The data are in different forms and are obtained from a variety of sources (Fig. 1.1) on different spatial and temporal scales. Some common examples include:

(i) Conventional meteorological observations may be recorded on an hourly basis, at fixed internationally agreed–upon times or once per day at several types of stations. Stations which record only once per day normally record minimum and maximum daily temperatures (T_{min} and T_{max}, respectively) and precipitation, while the other station types commonly observe a wider range of variables which may include: temperature, precipitation, surface pressure, humidity, wind speed and direction, cloud cover, snow depth, visibility, solar radiation and current weather. Measurements at various levels of the atmosphere are recorded one, two or four times per day at a relatively small number of stations at internationally agreed–upon times. These "upper air" observations are made by radiosondes or rawinsondes. The former measure temperature and humidity while the latter measure temperature, humidity and winds as functions of pressure. These upper air observations are generically referred to as "raob" data regardless of which instrument was actually used. Data over the oceans are provided by ships and by moored and drifting buoys which measure many of the same atmospheric variables as land stations. In addition, a suite of ocean measurements may be made. These can include sea temperature, salinity, dissolved oxygen, various nutrients and tracers at the surface or in vertical profiles much like atmospheric raob data. Unlike land–based observations, these ships and drifting buoys are (generally) moving and each report can come from a different geographic location.

(ii) Irregularly spaced observational data are frequently interpolated to regularly or near–regularly spaced arrays (grids) using computer–based analysis algorithms. These analyses produce a global field which is depicted by a finite number of discrete points. Some algorithms are simple while others are quite complex. Many of these gridded datasets are derived by various national meteorological forecast centers because the numerical models used to make operational weather forecasts require the initial data to have some regular form. These gridded initial conditions are a best estimate of the state of the atmosphere at a particular time. Later, these gridded datasets, sometimes called 'analyzed' grids, are used by researchers to derive 'diagnostic' or value–added datasets. Diagnostic datasets contain derived physical quantities (*e.g.*, divergence, streamfunction, heat and momentum transport, Eliassen–Palm fluxes, *etc.*) which may be used to further describe the atmosphere and physical and dynamical processes.

(iii) Satellites commonly provide information on a broad range of geophysical quantities such as the vertical distribution of atmospheric temperature and moisture, clouds, winds, atmospheric gases and sea surface temperatures. The instruments on satellites detect electromagnetic energy within a specific range of wavelengths which has been reflected or emitted by the atmosphere and/or earth–ocean surface. The actual atmospheric or oceanographic quantities are derived using sophisticated retrieval algorithms. These data, which by their nature, represent spatial averages, may be available for certain regions or for the entire globe depending upon a satellite's orbit. However, these data are "asynoptic", that is, they are not measured at fixed, specified "synoptic" observing times, but may be measured at varying times.

(iv) Climate models, which may run for many hours on supercomputers, produce gridded arrays of the basic variables. Atmospheric models calculate temperature, geopotential height, humidity, winds and vertical motions at a number of different levels. Oceanographic models include ocean temperature, salinity, and horizontal and vertical motions at different depths. The data archives from the model runs are later processed to provide derived quantities. One method of using these models is to run simulations with different physical algorithms or initial conditions and compare the results to a control run. Examples include using different convection algorithms or boundary layer formulations or differing amounts of carbon dioxide.

Common Data Problems and Characteristics

No observational dataset is perfect. Conventional observational atmospheric and oceanographic datasets (Chapters 3 and 4), satellite data (Chapter 5), and analyzed datasets (Chapter 6) all have problems which are briefly discussed in subsequent chapters. Users of the data should be aware of the deficiencies within the datasets. Unfortunately, metadata (*i.e.*, information about the data) is often either unavailable or difficult to obtain. Metadata can be critical for correctly interpreting the observations or derived results.

Atmospheric and oceanographic datasets share many characteristics. They can be very large; many span limited time periods and have limited spatial extent; missing data and outliers are common; the spatial distribution of various observational networks is uneven; and, often, time series of data are not homogeneous. The datasets contain variables which are (generally) not independent in time or space; thus, most variables should be viewed within a multivariate context. Finally, the climate system in which the variables are sampled is not in equilibrium. This is because the system includes many physical and chemical processes which act over a variety of temporal and spatial scales. For some research, the fact that the climate system is not in equilibrium is not important (*e.g.*, studying cumulus convection). However, this fact should not be ignored when using data records which span long periods of time. As a specific example, it complicates the interpretation of the role of greenhouse gas warming.

Organizational Sources of Data

There are many organizations which archive and make available atmospheric and oceanographic datasets. In the U.S., NOAA* operates national data centers whose function is to collect, archive, quality assess, and disseminate data needed for national and international environmental research programs. These centers include NCDC, NGDC and NODC. Each has a specific purpose: NCDC has a large base of conventional surface and upper air data from U.S. supervised stations and a growing archive of international station data; NODC has archives containing oceanographic data from around the world; and NGDC has a large data base which contains diverse geophysical datasets including solar variability and paleoclimate data. NESDIS contains vast archives of satellite datasets. The CDIAC archives datasets of greenhouse gases (particularly carbon dioxide and methane) and atmospheric trace gases such as chlorofluorocarbons and nitrous oxide. The NSIDC archives snow, ice, cryosphere and selected climate data. NCAR has comprehensive data archives which contain data from a number of different sources and include many different data types (see Chapter 11 and Appendix F).

It is sometimes difficult to determine what datasets are available and where they are located. NCAR's Data Support Section (DSS) can assist people trying to locate data. Also, it may be possible to use software tools (*e.g.*, 'ftp', 'gopher' and the World Wide Web) to browse inventories at data centers which may contain the desired information (see Chapter 10 which discusses the Internet). A list of selected data centers which archive and disseminate atmospheric and oceanographic datasets is included in Appendix A.

In October 1994, several U.S. government organizations which are the source of various meteorological and oceanographic datasets will change names. The National Meteorological Center (NMC) will be known as the National Centers for Environmental Prediction (NCEP) and the Climate Analysis Center (CAC) will be renamed the Climate Prediction Center (CPC). In this text,

* See Appendix D for a list of acronyms.

the current names will be used because they are ubiquitous to datasets discussed herein.

This IA emphasizes archived datasets. However, environmental data including analyzed grids from NMC (see Chapter 6) are available on a real-time basis via Unidata systems. Many universities and investigators use these systems for both instructional and research purposes. Appendix A provides information on how to find out more about this program.

Layout of Text; Sample Datasets from NCAR; Acronyms

The focus of this NCAR Instructional Aid is upon introducing atmospheric and oceanographic data to people interested in pursuing research in these fields. To that end, each of the following chapters describes some general aspects of different types of datasets. The data chapters include the following information: a brief overview of the source of the data; an overview of the spatial and temporal coverage; and, some deficiencies and strengths. A bibliography containing selected references appropriate to each chapter appears at the end of the text.

For illustrative purposes, it is useful to refer to some specific examples to indicate typical time spans or data distributions. The examples have been taken from the NCAR archives and are presented in the form of tables at the end of selected chapters. Each table contains headers which describes different characteristics of each dataset. Generically, each table may have the following entries: an NCAR ID indicates NCAR's internal dataset identifier of the form 'dsnnn.n' (*e.g.*, ds234.1); AREA or REGION indicates the primary geographic location of the data; NO. STA. indicates the approximate number of stations; PERIOD specifies the time spanned by the dataset; FREQ indicates the observations are archived on an hourly, daily (D) and/or monthly (M) basis; ORDER indicates time series (T) and/or synoptic (S; all observations for one time are grouped together); VAR means the variables contained in the dataset. (T–temperature, p–pressure, z–geopotential height, h–relative and/or q–specific humidity, T_d–dew point temperature, u–east/west wind speed, v–north/south wind speed, w–vertical velocity, prc–precipitation, slp/stp–sea level or station pressure, an $*$ means many variables are recorded). VOL indicates whether the entire dataset is small (S; less than 250 megabytes [MB]), medium (M; 250–1000MB) or large (L; greater than 1000MB).

There are many acronyms and abbreviations commonly used in the atmospheric and oceanographic sciences (*i.e.*, the proverbial 'alphabet soup'). These are often perplexing to both new and veteran researchers. To help facilitate communications with colleagues, a list of some commonly used acronyms and abbreviations is provided in Appendix D.

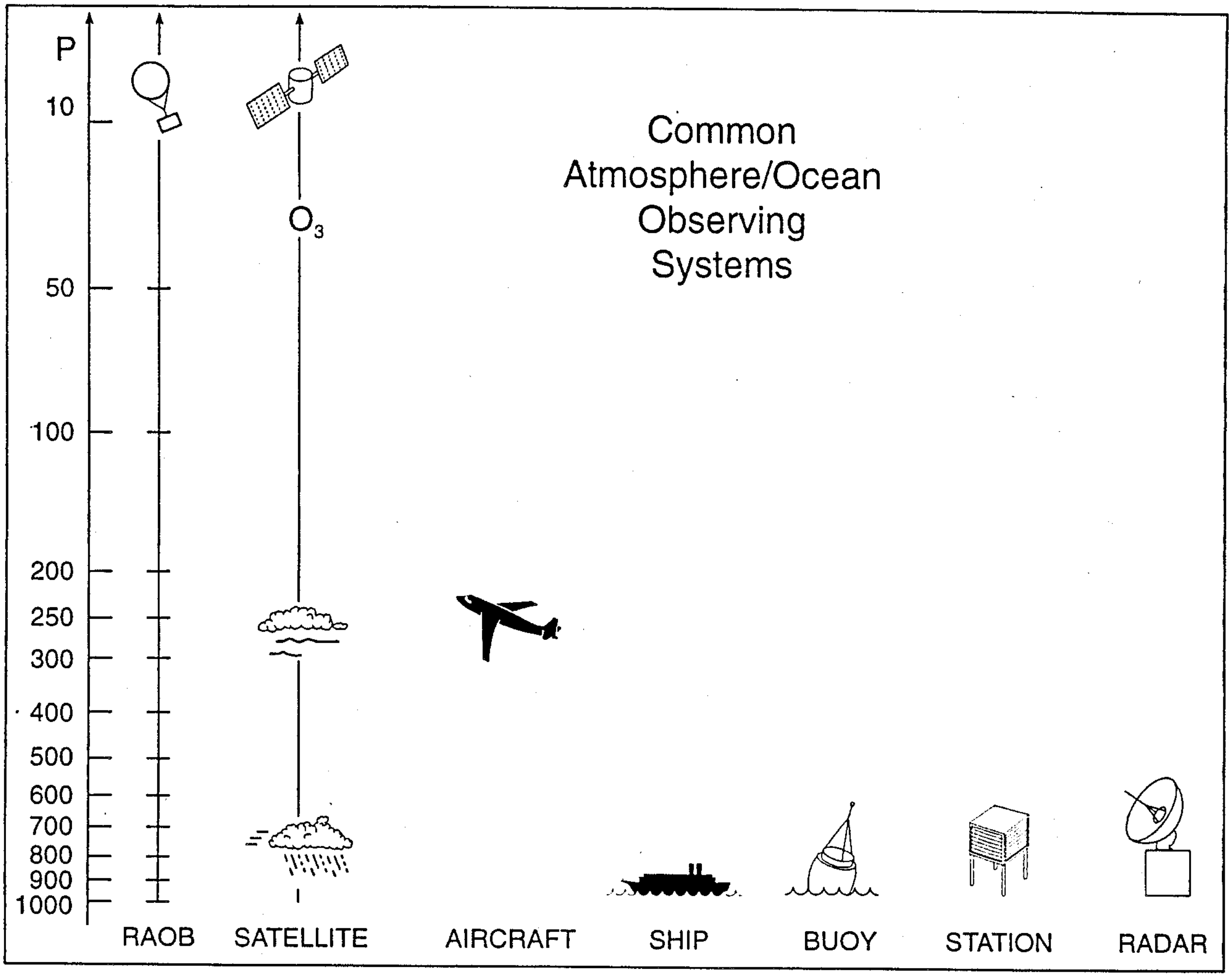


Figure 1.1 Cartoon depicting some major observing systems used by the atmospheric and oceanographic communities. Observations from raob, pibal, aircraft, and land surface stations are discussed in Chapter 3; ship, buoy and other oceanographic data are discussed in Chapter 4; and, polar-Orbiting and geostationary satellite data in Chapter 5. (Adapted, with permission, from a H. Jean Thiébaux illustration.)

2. DATA FORMATS USED FOR ATMOSPHERE/OCEAN DATASETS

Atmospheric and oceanographic data may be archived in several different computer forms: character format, native format, packed binary or in one of several "standard" scientific data formats. Users of datasets must be aware of how the data are stored. There are different methods for storing both character and numeric values. Normally, detailed descriptions of data formats are provided and, often, software to access the data is readily available.

Before providing some comments on common archived data forms, a few words about computer terminology may be in order. The smallest element of information contained in a computer is called a *bit*. Each bit may be 'on' or 'off' and is represented by a '1' or '0', respectively. Computers store both text and numbers as sequences of bits. A sequence of 8–bits is called a *byte* and is often (but not always) used to describe a "character" of text (*e.g.*, 'a', 'q', ';', '+', '6' *etc.*). An ordered sequence of bytes is called a *word*. Generally, computer workstations and supercomputers used by the atmospheric and oceanographic scientists have word lengths of 32– or 64–bits, respectively. If the bytes refer to characters, then a 32–bit word could contain 4 characters, while a 64–bit word could contain 8 characters. A computer word used for storing floating point numeric values consists of three segments: a sign bit, a characteristic (biased exponent) and a mantissa. An integer is represented by two segments: a sign bit and a sequence of bits. A 32–bit word can store floating point numbers with six–to–seven decimal place precision while a 64–bit word can store numbers with thirteen–to–fourteen decimal place precision. Workstations which normally operate with 32–bit words can also use and store numeric data in 64–bit mode by using type declaration statements in FORTRAN (double precision) and C (double and long int). Most computers internally use numbers where the most significant bits are ordered from left to right (called "big–endian" form). Some computers (primarily DEC) store data in "little–endian" form which means the byte order within words is reversed. This characteristic of computer hardware architecture can cause some difficulty when using binary data. However, software is often available to transform the data into a more convenient form.

In the early years of computers, the size of a dataset was often described in terms of the number of 7– or 9–track computer tapes that were required to archive the data. Today, there are a variety of storage media available and the sizes of datasets are typically described in terms of kilo–bytes (KB)*, mega–bytes (MB), giga–bytes (GB) and tera–bytes (TB). Table 1.1 summarizes these dataset size descriptors. (Note: a reasonably full 9–track tape holds about 130MB.)

* Note: a kilo–byte of computer memory refers to 1024 bytes.

Table 1.1
Commonly used file size descriptors

Name	Size	
kilo–bytes (KB)	1000 bytes (B)	10^3 B
mega–bytes (MB)	1000 KB	10^6 B
giga–bytes (GB)	1000 MB	10^9 B
tera–bytes (TB)	1000 GB	10^{12} B

Character format: This is often the most convenient form for the user. The most commonly used character set is that based upon the ASCII standard. The other character set which may be encountered is EBCDIC which is an IBM standard. ASCII and EBCDIC are 8–bit character sets. Conversion from one character set to another may be accomplished using various software "tools" (*i.e.*, computer software; "filters" in UNIX jargon). The advantage of using character data is that it may be read directly by a human being or through standard computer input or output statements provided in the FORTRAN and C programming languages. Character formats are convenient for 'small' datasets that must be used on a variety of machines. However, the number of computer instructions needed to read character data is considerable and character data take up relatively large amounts of space on computer external media such as discs or tapes. For example, the numbers '9', '679.43', -0.123456E+05 require 1, 6 and 13 bytes, respectively, in ASCII. As will later be explained, these numbers can be archived much more concisely using 'packed–binary' representation.

Native Format: Computers from different manufacturers may use different schemes for the representation of both characters and numbers. The internal format used by a particular computer is called its native format. As previously described, characters are generally stored in ASCII although some machines use EBCDIC. Numeric values often use a standard IEEE format or vendor specific representations (*e.g.*, Cray, DEC). Reading and writing data in native format can be very fast because no data conversions need to be performed. In addition, no precision is lost. (This can be very important in some numerical models or matrix inversion problems.) However, reading one machine's native format on another computer which uses a different native format can be slow because a conversion algorithm must be used. One additional drawback is that each numeric value archived in native form requires the full word length of the machine (*i.e.*, 32 or 64 bits). Thus each value is stored with full machine precision even if it uses more bits than necessary for the known accuracy of the values (*e.g.*, 12.1°C stored as 12.1357°C).

Packed Binary: Because atmospheric and oceanographic datasets can be quite large, it is desirable to optimize the amount of information that can be archived on external media. This optimization of information using a minimum number of bits is called packed binary. It is an efficient method for archiving data and is independent of machine representation. Packing data values means expressing integer and, most often, floating point values in sequences of bits sufficient to capture the required precision of the data. For example, the floating point number "3.1" requires 32- or 64-bits in native format or 24-bits (three ASCII or EBCDIC characters) in character format. However, in packed binary it requires only five bits. (Appendix C gives an example of packing and unpacking a number.) Obviously, significant reductions in storage space can be realized.

These packed binary numbers are sequentially stored and, subsequently, retrieved from a bit stream*. Although software must be used to perform the conversion of the bit groups to a machine's internal format, it is often considerably faster than converting character data. One additional benefit of packed binary is that it means data can be electronically transmitted more efficiently owing to smaller volume.

Scientific Data Formats

There are a number of "standard" scientific data formats. Documentation and software necessary to implement these formats are generally available via computer networks (see Appendix B). Architecture independent standard formats commonly used for atmospheric and oceanographic datasets include:

- GRIB (GRId in Binary) is a WMO standard data format which is an efficient method for transmitting and archiving large volumes of two-dimensional meteorological and oceanographic data. It is the standard used by two of the world's largest operational meteorological centers (NMC and ECMWF). This is a good example of a packed binary format.

- CDF (Common Data Format) was initially developed by NASA Goddard about 1980 as an interface and a toolkit for archival and access to multidimensional data on a VAX using VMS FORTRAN. Over the years it has evolved into a machine-independent standard and is often

* NCAR has FORTRAN and C routines, called 'gbytes' and 'sbytes' that will unpack and pack the bit streams. The software and documentation may be obtained from NCAR via anonymous ftp (see Chapters 10 and 11). Most vendors also provide software that provide bit level access for manipulation of bit stream data.

used by different NASA groups for storing space and earth science data.

- netCDF (network CDF) is an interface for scientific data access. It was developed by Unidata (UCAR) around 1986, using CDF as a starting point. Unidata rewrote the CDF library to provide machine-independent archival and access. Strangely, netCDF is not compatible with the NASA CDF and no translation software currently exists. (At the time of this publication, NASA is working on a new CDF which should be compatible with netCDF.) netCDF emphasizes a single common interface to data, implemented on top of an architecture independent representation. Access to data with netCDF files is determined by user written software. Access can be random or sequential.

- HDF (Hierarchical Data Format) is a general, extensible scientific data exchange format defined by NCSA. HDF emphasizes a single common format for the data, on which many interfaces can be built. A netCDF interface to HDF is provided but there is no support for mixing HDF and netCDF structures. In other words, HDF can read HDF and netCDF but can only write in HDF. HDF is often used to archive and transmit raster images.

- BUFR is a WMO standard data format for the representation of meteorological and oceanographic data. Although it could be used for *any* type of data, its primary function is to represent observational data (*e.g.*, from stations, raobs and ships). It was designed to reduce redundancy for efficient transmission over the GTS and to reduce the computer time required to decode the information.

Why are there so many 'standards'? The answer is partly historical and partly practical. Historically, many agencies developed their own internal format standards for data archival prior to working with other organizations. When other groups requested data, the originating agency sent them in their own format (of course!). Soon several groups were using the data in a particular format and it became a "de-facto" standard. On a practical level, the development of any data archiving and exchange format involves trade-offs among various features: compactness, simplicity, ease of communications, portability, sortability, ease-of-use, *etc.* Thus, some formats are better for archival and transmission and others for accessibility. For example, netCDF requires field widths to be a multiple of 8 bits, while GRIB has no such restriction. A data type which can be represented most efficiently by 9 bits will require almost twice the disk space in netCDF as it will in GRIB. However, an advantage of netCDF is that it is a self describing format and a rich set of data descriptors (metadata) can be attached to each data file. These descriptors may include multi-dimensional grid definitions, scaling factors, units of the values, titles, comments, *etc.* With data files structured in netCDF and with appropriate netCDF software the data may be quickly accessed without concern or knowledge of the internal format. To a lesser degree, GRIB is a self describing format. For example, the first section of a GRIB record contains the number of bytes in the whole GRIB message. Then each subsequent section contains the number of bytes in that section. Binary sections also indicate the number of bits that each value takes up. GRIB is used by the world's largest operational meteorological centers (NMC and ECMWF) for gridded data because it allows the data to be efficiently packed and thus moved from one site to another. A table which lists specific attributes about several standards including how to find out more about them is in Appendix B.

Which standard format is best? There is no universally correct answer. Most people would choose the standard with which they are most familiar (human nature!). The real answer depends on the application of the data. Comparisons among these formats in different application environments can result in widely differing performances. Careful testing of each format under typical application scenarios would be required prior to choosing a particular standard.

Another often asked question is: "Why not use a commercial relational data base product?". The problem lies in the 'complex' nature of scientific data. Generally, scientific data are multidimensional and/or hierarchical and they are available in a wide variety of data formats. Commercial relational systems are best designed to meet the needs of business, banking and consumer services. These databases are structured to give detailed access to relatively few well defined data structures. They can not easily accommodate the changing and varied needs of science. In addition, these packages are quite inefficient for accessing the volume of data required for research in the atmospheric and oceanographic sciences. In the future, the emerging object-oriented databases may be better able to address the needs of the scientific community.

3. CONVENTIONAL METEOROLOGICAL STATION DATA

Surface Observations

The term 'surface observation' refers to observations made near the surface. Temperature and humidity instruments are generally located in instrument shelters about 2.0 meters above the ground (Fig. 3.1). The shelters are meant to protect the instruments from exposure to direct sunshine, precipitation and condensation while at the same time providing adequate ventilation. Historically, the design of these shelters has varied from country–to–country and shelters within countries have evolved over time. In some instances, the shelters or the instruments introduced systematic biases. An example of a systematic error is a thermometer which consistently measures temperatures too high or low. Precipitation measurements are made by a variety of devices and methods. The most common method is to measure the water depth within a container. The accuracy of the measurements can be affected by both the intensity of the precipitation and, in particular, the wind speed. Also, it should be noted that precipitation observations often show considerable spatial variation, even at nearby locations, especially in showery weather and in areas where topography influences local conditions.

Most countries have several 'classes' of observing stations making surface measurements. In practice there is considerable overlap in the tasks required of each class. For example, the U.S. classifications include first order, second order or air–way, and co–operative stations. The differences are in the variables measured and the frequency of the observations. A first order station operates 24 hours–a–day and is maintained by a NWS trained and certified staff. The observations made at these stations span a wide number of variables and usually include: temperature, precipitation, surface pressure, humidity, wind speed and direction, cloud cover, snow depth, visibility, solar radiation and current weather. The observations are taken frequently, either on an hourly basis or at specific times (*e.g.*, 00, 06, 12, 18 UTC). Second order stations are maintained by a trained staff who are supervised by NWS personal. The majority are operated by the FAA to provide weather observations in support of aircraft operations. These stations record observations at airports which include many, but not necessarily all, of the variables measured at first order stations. The frequency of observation can be hourly but may be less. Co–operative ("co–op") stations are stations operated by of the NWS Co–op Observing Program. This program consists of approximately 7,750 stations manned by volunteers who regularly report observations. Typically, the measured variables at co–op stations include only temperature and precipitation and the observations are made much less frequently. In fact, many stations just record the temperature extremes (T_{min} and T_{max}) and precipitation once per day. Since some of the co-op stations are affiliated with agricultural interests they may also record soil temperature, soil moisture and evaporation. The precipitation reported by co-op stations is not necessarily the amount which occurred on a specific calendar day. Rather, it is a 24-hour precipitation amount. For example, it could be the total precipitation from 0500 on one day to 0500 the next day. At stations which record only once per day the reported precipitation may be less than actually occurred due to evaporation from the measuring container, especially in dry climates.

One major advantage of surface station observations is that they span the longest time periods and are, therefore, often used in climate studies. However, there are many limitations associated with these observations of which researchers should be aware. These include outliers, inhomogeneities, missing data, spatial-temporal sampling problems, different instrument types, instrument bias, *etc.* Inhomogeneities in observational data may result from changes in a station's geographic location, elevation, observing times, instruments, averaging techniques, surrounding environment, observers, *etc.* Station location and elevation changes are generally recorded and may (possibly) be accounted for, but, in general, information on other sources of inhomogeneities (*i.e.*, metadata) is often not available. Even if metadata are available, a complicated process must be used to account for the various factors. Since the metadata are often site specific it can be labor intensive to incorporate the information correctly.

A time series of December sea-level pressures from Bombay, India spanning 1920 to 1993 illustrates a commonly encountered inhomogeneity (Fig. 3.2). A discontinuity is clearly evident around 1960. No documentation is available and neither the location nor the elevation have changed. However, many countries reprocess data at decadal intervals and it is possible that the averaging procedure changed. Another possibility is that beginning in 1960 the observations were taken at different times. In any event, some procedure should be used to adjust for the discontinuity.

Instrument quality varies from country-to-country. Surface temperatures can be recorded to within 0.5°C. Precipitation is often recorded to the nearest millimeter (mm). However, the recorded precipitation amounts (both rain and snow) are often underestimated due to winds, evaporation and equipment design. Underestimates typically range from only a few percent to 50% in some extreme cases. On a global basis it is estimated that precipitation amounts are underestimated by about 15%. Figure 3.3 illustrates the corrected and uncorrected annual precipitation for the former USSR and the USA.

The spatial distribution of stations making surface observations over the mid-latitudes of the northern hemisphere is uneven but adequate for many research projects interested in studying large-scale phenomena. However, over much of the tropics and the southern hemisphere the number of stations are far fewer. Figure 3.4 illustrates a sample spatial distribution of stations currently reporting *daily* maximum and minimum temperatures and precipitation over the GTS. (The data are from NCAR ds512.0 .) It must be emphasized that the number and the spatial distribution of stations has varied considerably with time. In the early years (1880s onward) observations are generally from European and North American stations. The tropics and the southern hemisphere have had considerably fewer stations which persists to the present time. Thus there are large spatial and temporal gaps in the surface station coverage.

Many countries have established national *climatological reference stations* to maintain a high-quality basis for studying climate change. These reference stations are chosen based upon length of record, location and the quality of the observations. In some instances, the climate records have been adjusted after careful analysis. These adjustments may include comparisons with nearby stations, correcting for differing observation times over the period of record, and other adjustment procedures. In the U.S., this is called the Historical Climatology Network (ds565.0). It consists of 1200 stations which span 1880–1987 (update in progress). This dataset is continually being updated. It is a product of a joint effort between NCDC and CDIAC.

Climatologies and Gridded Data of Surface Variables

Climatologies for several surface variables are available. These climatologies, which are available on grids with different resolutions, represent the 'average' of a quantity over a particular time period. They are available in digital form as station files or gridded fields and in printed form as contoured maps or tables. Measures of climate variability and covariability (*e.g.*, variances, covariances, correlations, standard deviations, anomalies, percentiles, spectra, empirical orthogonal functions, extremes, *etc.*) are available less often. These statistical quantities are used for many purposes including agricultural planning and validation of climate models. Some examples of climatologies include the monthly mean temperature, precipitation and sea level pressure over the globe for a 30-year period, or the probability of precipitation occurring on any particular day of the year at a particular location.

As part of the daily operation procedures at meteorological centers (*e.g.*, NMC and ECMWF), gridded analyses of a number of different variables are produced. These grids are generated at a number of levels including near the surface. A detailed description of gridded analyses is presented in Chapter 6. At NMC and NSIDC, gridded analyses of snow cover over the globe and the Northern Hemisphere are generated. These are available from NCAR.

Upper Air Observations

"Upper air" observations began in the 1940s. However, large numbers of these observations only became available starting with the International Geophysical Year (IGY; 1957–58). Today a small number of stations make upper air observations up to four times per day at internationally agreed-upon times. These upper air observations are made by radiosondes or rawinsondes. A radiosonde is an expendable balloon-borne instrument which measures pressure, temperature and humidity and relays the information to an observing station where the data are recorded after corrections are made for instrument response time. A rawinsonde is a radiosonde whose three dimensional position is measured by one of several position tracking methods. In the past, a reflector was tracked by radar or radio-theodolite to estimate wind speed and direction. These days, rawinsondes are tracked using the Omega or Loran location finding systems. In the future, they may be tracked by the GPS. These upper air observations are referred to as "raob" data, regardless of which instrument was actually used.

The height of each report is derived by integrating the "hydrostatic equation":

$$\frac{\partial p}{\partial z} = -\rho g \tag{1}$$

where

p = pressure (hPa)

z = height (m)

ρ = air density (kg m^{-3})

g = gravity (m s^{-2})

This equation expresses a mechanical balance between the downward force of gravity acting upon the mass of the atmosphere and a pressure gradient force acting upward. The hydrostatic equation may be integrated using the humidities, temperatures and pressures measured by the raob to provide the height of the observations to a high degree of accuracy. Only in cases of severe thunderstorms and some other small-scale systems will the accuracy of this relationship be seriously compromised.

The wind speeds and directions at the pressure levels are estimated from the horizontal displacement of the balloon using: (i) the heights calculated from the hydrostatic equation, (ii) measured azimuth and elevation angles of the balloon or other location indicators, and (iii) trigonometric relationships.

The words "height" and "geopotential height" (Z) are sometimes carelessly interchanged. However, they are subtly different. Height (or altitude) refers to the absolute distance above sea–level. Geopotential height is what is actually reported in raob observations. The geopotential height is closely related to altitude but accounts for variations of gravity within latitude and height. It is defined by the following relationship

$$Z = \frac{1}{g_0}\int_0^z g dz \tag{2}$$

where g_0 is a constant approximating the value of gravity at sea level. In the past, this value has been taken as 9.8 ms^{-2}, but in 1993 (in the US) this changed to 9.80665 ms^{-2} which is the standard value of gravity at 45° latitude used by WMO to calibrate barometers. (In fact, this differs from the real value at 45° latitude which is 9.80616 ms^{-2}). The geopotential height is proportional to the potential energy of a unit mass relative to sea level. Clearly, if $g = g_0$ there is no numerical difference between z and Z. Since $g \simeq g_0$ in the lower atmosphere the two quantities are numerically interchangeable for most meteorological purposes. However, in the upper stratosphere and higher, the differences can be significant.

The data from raobs are recorded at numerous constant pressure levels as they rise through the atmosphere*. The levels most commonly reported are *mandatory* levels and *significant* levels. A mandatory level is a level reported by raobs from all countries. Originally, the mandatory levels were 1000, 850, 700, 500, 400, 300, 200, 150, 100 and 50 hPa+. Currently, the mandatory levels include the original mandatory levels plus 925, 250, 70, 30, 20 and 10 hPa. International transmission codes have specific blocks reserved for data at these levels. Significant levels are levels where there are abrupt changes in the temperature or humidity profiles. (Sometimes, significant levels based upon abrupt changes in wind speed or direction are reported.) Significant levels provide additional information and can be quite useful to weather forecasting offices. Besides mandatory and significant levels some raob reports regularly include data at 975, 950, 900, 800, 750, 650, 600 and 550 hPa. A typical sounding is presented in Table 3.2.

The spatial distribution of raob stations (Fig. 3.5) is considerably less dense than the distribu-

* The mean ascent rate of a raob is ~5 m/sec. Thus, it took about 1.7 hours to rise from the surface the 10 hPa level of Table 3.2 .

\+ The unit "hPa" which stands for hecto-Pascal is favored over "millibar" (mb) which is the historically used unit for atmospheric pressure. Either is acceptable in journals. Millibar or mb will be frequently encountered in text books, articles and descriptions of dataset archives. Just remember that 1000 hPa means the same as 1000 mb.

tion of surface stations. North America and Europe have the densest reporting networks. Large spatial gaps south of 20°N are evident. The time period spanned by these data records is generally shorter than that of surface stations. The earliest raob data start in the 1940s but large numbers of reporting stations only began in the late 1950s, about the time of the IGY (1957–58).

Some sources of error for raob data are similar to those for surface observations (*e.g.*, calibration error). The homogeneity of raob observations away from the surface are less affected by small changes in the location or by changing environment of the station. As with surface observations, metadata are scarce. The measurement of humidity has been particularly suspect. Humidity measurements at low temperatures (*e.g.*, -40°C) are of questionable reliability. Over the U.S. humidities less than 20% were often not recorded and high humidities ($\sim$95%) which occur in clouds could not be measured. Table 3.1 lists a chronology of changes in the radiosonde since 1943 and figure 3.6 illustrates the effect upon relative humidity measurements of various instrument and sounding changes.

The pressure instrument is accurate to about $\pm$1–2 hPa. Temperatures are accurate to $\pm$0.5°C up to about 20 km. Relative humidity accuracy is a few percent, except at very low temperatures and at very low or very high humidities. The geopotential height is quite accurate. However, systematic biases in the temperature or humidity measurements can introduce large errors in the estimate of geopotential height. For example, a systematic error of 0.5°C in the temperature instrument could lead to an error of 25 meters or so in the 200 hPa geopotential height.

Mean Year–Month Statistics for Raob Data

NCAR has computed mean year–month statistics (*i.e.*, the average of a variable or quantity of the span of one month in a particular year) for a number of raob stations at mandatory levels. This includes not only the mean temperature, wind speed, geopotential height and humidity, but also quantities such as sensible heat transport, momentum transport and eddy quantities. These are contained in NCAR dataset ds391.0.

Other Sources of Upper Air Data

Other common sources of upper air data are aircraft reports (AIREP), pilot–balloon (PIBAL) observations and data derived from satellites (see Chapter 5). An AIREP is code used to transmit aircraft observations to an operational meteorological center. These reports can be particularly useful to forecast centers when they come from locations over the oceans where there are few station observations. A PIBAL is a balloon which is visually tracked while ascending in order to measure upper level winds. It is used to support aircraft operations. No temperature or humidity measurements are made.

Table 3.1*
Chronology of changes in U.S. radiosondes

Date	Change
1943	Lithium chloride humidity element replaced hair hygrometer.
1943	Dark ceramic resistance sensor replaced glass-tube electrolytic temperature element.
1948	Relative humidity computed using saturation relative to water instead of ice
1948	Change observing times from 2300, 1100 UTC to 0300, 1500 UTC.
1949	Smaller temperature sensor to reduce response time.
1950	Correction for solar radiation introduced (until 1960).
1957	Change observing times from 0300, 1500 UTC to 0000, 1200 UTC.
1960	Introduced white-coated temperature elements.
1965	Carbon humidity element, began reporting low humidities.
1972	Redesigned humidity ducts to reduce solar effects.
1973	Stopped reporting relative humidity below 20%.
1980	New carbon hygristors, new relative humidity transfer equation.
1988	Precalibrated hygristor replaced type requiring preflight calibration.
1988	New VIZ sonde with new humidity duct.
late-1980's	New Space Data Division (SDD) manufactured radiosonde at some stations. Differences between VIZ and SDD noted.
1993	Relative humidity to be reported over broader range, values <20% and up to 98% (instead of 95%) in cloud.
1993	Gravitational constant used to define geopotential height from geopotential changed from 9.8 to 9.80665 m s^{-2}.

*From Trenberth, K.E., 1994: Atmospheric Circulation Climate Changes. *Clim. Change*, in preparation.

Table 3.2
Typical Raob Report (NMC decode)

p (hPa)	Z (m)	T (°C)	T_D[1] (°C)	DIR	SPD (kts)
1005.0	99999.0	10.6	1.2	25.0	19.0
1000.0	131.0	10.4	1.4	999.0	999.0
962.0	99999.0	8.6	0.3	999.0	999.0
925.0	99999.0	7.6	2.5	270.0	40.0
858.0	99999.0	2.6	0.0	999.0	999.0
850.0	1467.0	2.4	0.0	265.0	46.0
841.0	99999.0	2.6	0.0	999.0	999.0
817.0	99999.0	3.2	11.0	999.0	999.0
800.0	99999.0	2.2	5.0	999.0	999.0
788.0	99999.0	3.2	9.0	999.0	999.0
750.0	99999.0	0.6	14.0	999.0	999.0
700.0	3032.0	-1.5	12.0	265.0	44.0
634.0	99999.0	-5.5	23.0	999.0	999.0
600.0	99999.0	-6.3	32.0	999.0	999.0
572.0	99999.0	-9.3	11.0	999.0	999.0
546.0	99999.0	-11.1	14.0	999.0	999.0
500.0	5640.0	-16.1	21.0	250.0	60.0
480.0	99999.0	-18.7	3.3	999.0	999.0
400.0	7290.0	-27.1	9.0	255.0	59.0
336.0	99999.0	-37.3	7.0	999.0	999.0
300.0	9290.0	-43.5	9.0	255.0	58.0
291.0	99999.0	-45.1	10.0	999.0	999.0
250.0	10490.0	-52.9	8.0	260.0	64.0
245.0	99999.0	-52.9	10.0	999.0	999.0
200.0	11900.0	-63.1	13.0	255.0	64.0
174.0	99999.0	-68.3	12.0	999.0	999.0
150.0	13660.0	-58.3	20.0	255.0	32.0
100.0	16210.0	-59.9	31.0	270.0	17.0
75.4	99999.0	-59.5	31.0	999.0	999.0
70.0	18440.0	-59.5	31.0	275.0	25.0
55.0	99999.0	-59.5	31.0	999.0	999.0
50.0	20540.0	-59.3	31.0	270.0	16.0
30.0	23750.0	-59.1	31.0	245.0	15.0
26.0	99999.0	-60.3	31.0	999.0	999.0
20.0	26280.0	-60.7	31.0	265.0	10.0
10.0	30610.0	-58.7	31.0	290.0	33.0

Note: 99999.0 and 999.0 represent missing data.

[1]Some form of humidity is reported. These include: relative humidity (%), specific humidity (q) or dew-point depression (T_D).

Table 3.3
Some NCAR Datasets Containing Hourly Data

NCAR ID	AREA	NO. STA.	PERIOD	FREQ	VARIABLES	VOL
ds359.0	USA	32	5/1992-pres	hrly	u,v,w	M
ds470.0	USA	300	1938–92	hrly–3hr	*	L
ds472.0	USA/Canada	5900	1976–92	hrly	*	L
ds505.0	USA	3000	1948–92	hrly	precip	M
ds521.0	USA	255	1969–76	hrly–3hr	*	M

Table 3.4
Some datasets containing daily/monthly T_{min}, T_{max}, Precipitation

NCAR ID	AREA	NO. STA.	PERIOD	TYPE	ORDER	VOL
ds463.0	Global	7,500	1967-80	D	S	L
ds467.0	Global	10,000	1899-1972	D	T	L
ds469.0	Canada	95	1963–72	D	T	S
ds473.0	Antarctica		1980–91	D		S
ds473.5	Greenland		1987–91	D		S
ds483.0	Malaysia	111	1951–85	D	T	S
	Thailand	52	1951–85	D	T	S
ds508.0	USA	137	1881–1985	D	TS	S
ds510.0	USA	11,000	1888–1992	D	T	L
	Pacific Is.					
	Caribbean					
ds512.0	Global	7500	1979–7/93	MD	TS	M
ds516.0	Canada	780	1874–1989	D	T	L
ds518.0	Japan	100+	1951–89	D	T	S
ds522.0	USA	372	1888–1976	D	T	S
	Canada	127	1874–1979	D	T	
ds523.0	Australia	10,000	1939–82	D	T	M
ds524.0	Russia	223	1880–1989	D	T	S
ds565.0	USA	1200	1880–1987	M	T	M
		138	1880–1987	D	T	M
ds582.0	Antarctica	47	1980–89	MD	T	S

Table 3.5
NCAR Datasets containing Precipitation only

NCAR ID	AREA	NO. STA.	PERIOD	TYPE	ORDER	VOL
ds482.0	Australia	14000	1932-82	DM	T	M
ds482.1	Australia	191	1840-1990	DM	T	S
ds484.0	Pacific	200+	1971-93	D	T	S
ds485.0	China	180	1951-82	D	T	M
ds517.0	Brazil	2300	1910-74	D	T	S

Table 3.6
NCAR Datasets containing Monthly Mean
Sfc. Temperature (T), Precipitation(P), Sea Level and/or Station Pressure (SLP/STP)

NCAR ID	Region	No. of Stations	Standard T	Standard P	Parameters SLP	Parameters STP	Max. Period
ds570.0	Global	4400	x	x	x	x	1731–pres
ds571.0	Africa	1000	–	x	–	–	1880–1973
ds572.0	S. America	680	–	x	–	–	1891–1983
ds574.0	USA	3900	x	x	–	–	1941–1980
ds575.0	India	4000	–	x	–	–	1901–1970
ds576.0	Canada	3900	x	x	–	–	1831–1982
ds577.0	Australia	10000	–	x	–	–	1831–1982
ds578.0	China	90	–	x	–	–	1951–1980
ds578.1	China	160	x	x	–	–	1951–1990

Table 3.7
Some Gridded Snow Cover Datasets at NCAR

NCAR ID	Source	Region	Base Period	Freq
ds082.0	NMC	Global	1979–94	wkly
ds315.0	NSIDC	NHem	1966–91	wkly, monly

Table 3.8
Gridded Global Precipitation Climatologies

NCAR ID	Source	Grid	Region	Nominal Period	Interannual Variability
ds207.0	RAND (Moeller)	4°- 5°	global		no
ds236.0	Legates/Willmott	0.5°	global		no
ds238.0	DOE	4°- 5°	land	1951–89	anomalies
ds701.5	Spencer	2.5°	ocean	1979–92	no
ds290.0	Shea (NCAR)	2.5°	global	1950–79	st. dev.
ds768.0	Cogley/Briggs	1°	global		st. dev.
ds865.0	Jaeger	4°- 5°	global		no

Table 3.9
Gridded Global Surface Temperature Climatologies

NCAR ID	Source	Grid	Region	Nominal Period	Interannual Variability
ds205.0	Crutcher and	5°	No Hem	1931–64	no
	Taljaard		So Hem		no
ds215.0	Jones	5°	global	1851–1990	yes
ds217.0	Oort(GFDL)	2.5°- 5°	global	1958–73	yes
ds236.0	Legates	0.5°	global	1920–80	no
ds290.0	Shea(NCAR)	2.5°	global	1950–79	yes

Table 3.10
NCAR Datasets containing Large Amounts of "Raob" Data

NCAR ID	AREA	PERIOD	FREQ; ORDER	VAR	VOL
ds353.0	Global	1962–72	D; S	T,p,T_d,rh,u,v,z	L
ds353.4	Global	1974–pres	D; S	T,p,T_d,rh,u,v,z	L
ds390.0	Global*	1948–pres	D; T	T,p,T_d,rh,u,v,z	L
ds390.1	U.S. control	1948–pres	D; T	T,p,T_d,rh,u,v,z	L
ds390.5	Global	1943–74	D; T	T,p,T_d,u,v,z	L
ds391.0	Global*	1948–pres	M; T	T,p,T_d,u,v,z derived quan	M

*Spotty outside U.S.

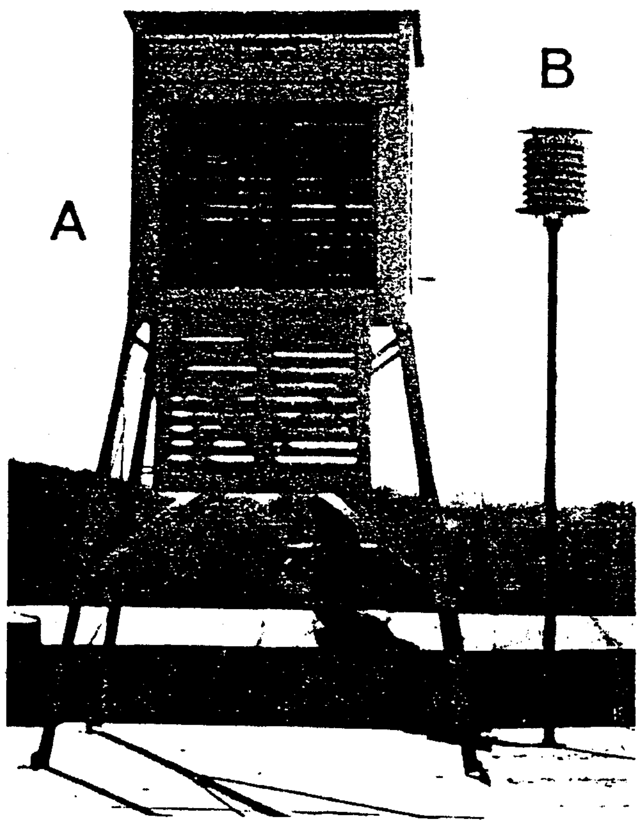


Figure 3.1 (a) The standard NWS Cotton Range Shelter, and (b) a Maximum–Minimum Temperature System (MMTS). (From Quayle *et. al.*, 1991)

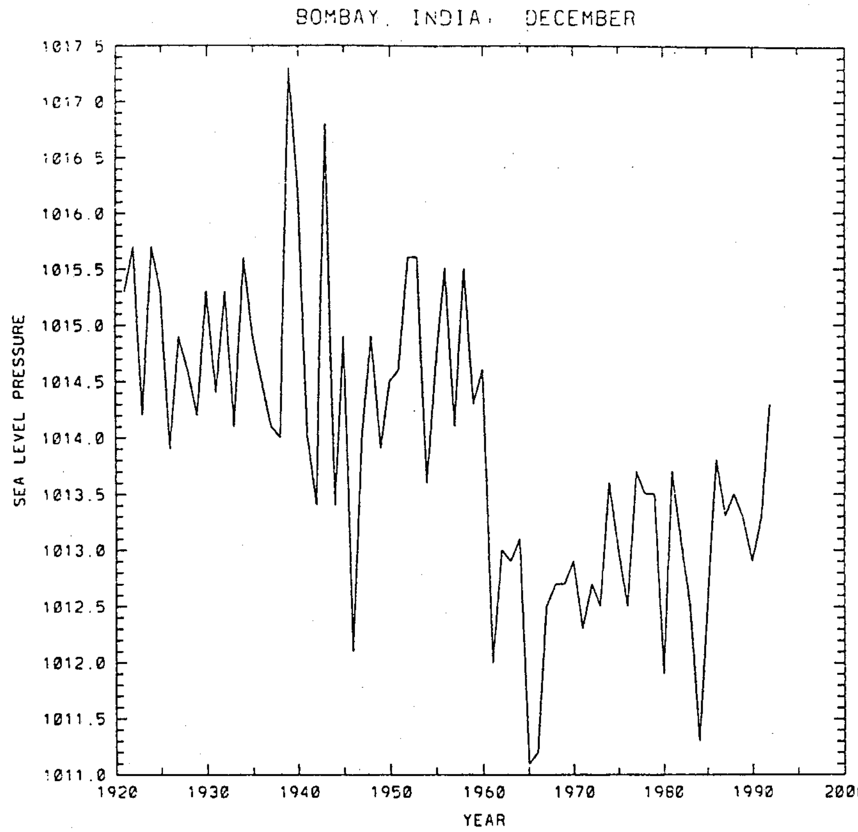


Figure 3.2 A time series of December sea level pressure at Bombay, India. Note the discontinuity around 1960.

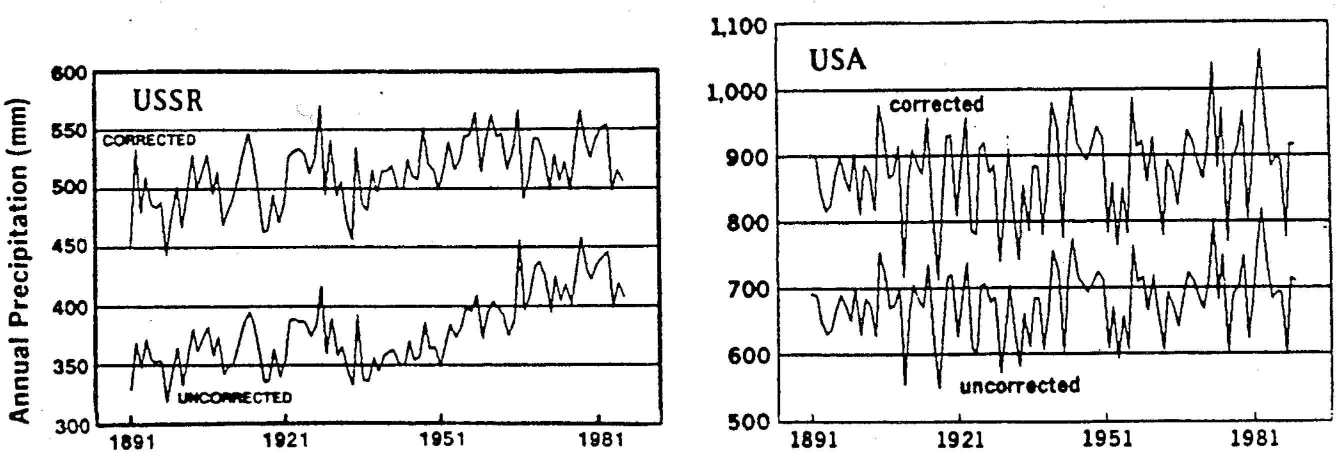


Figure 3.3 Annual corrected and uncorrected rainfall for the former USSR, 1891–1985 and the USA. From Groisman (1991b).

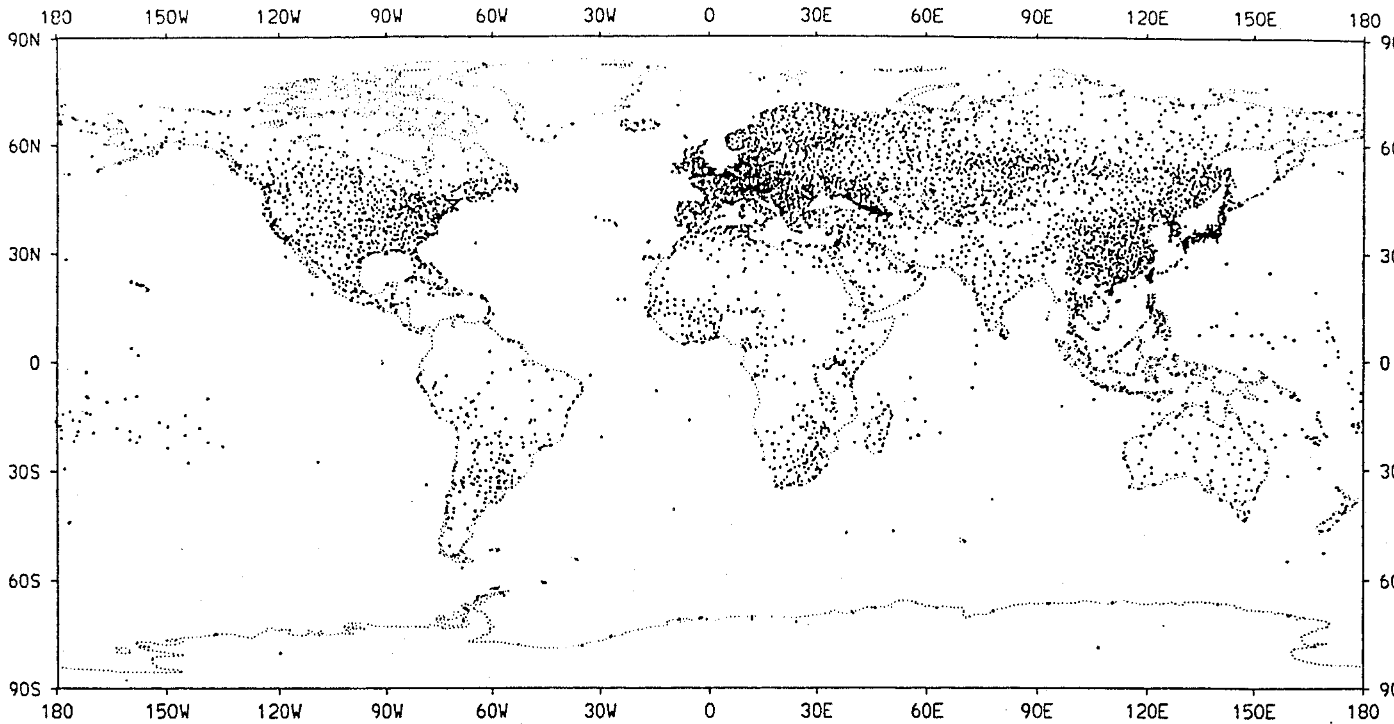


Figure 3.4 Distribution of surface stations reporting over the GTS on particular day in 1993.

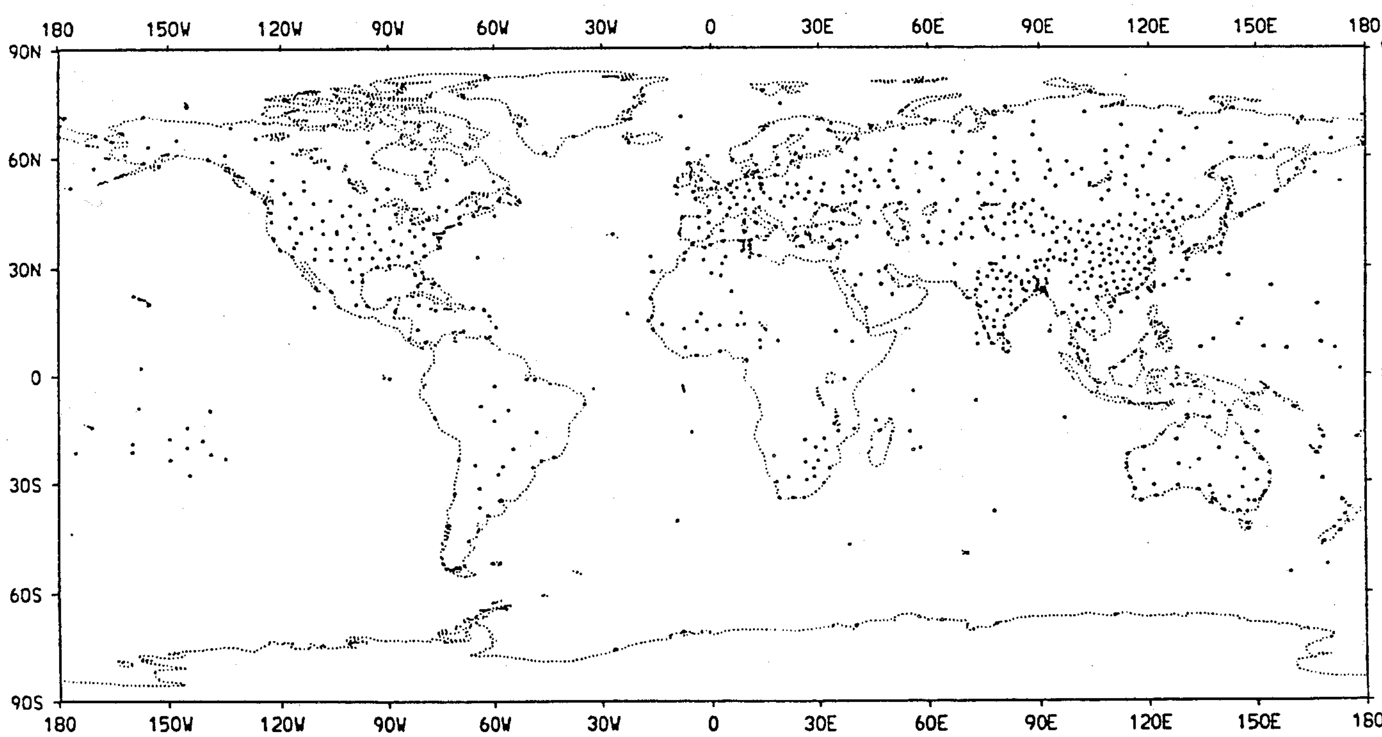
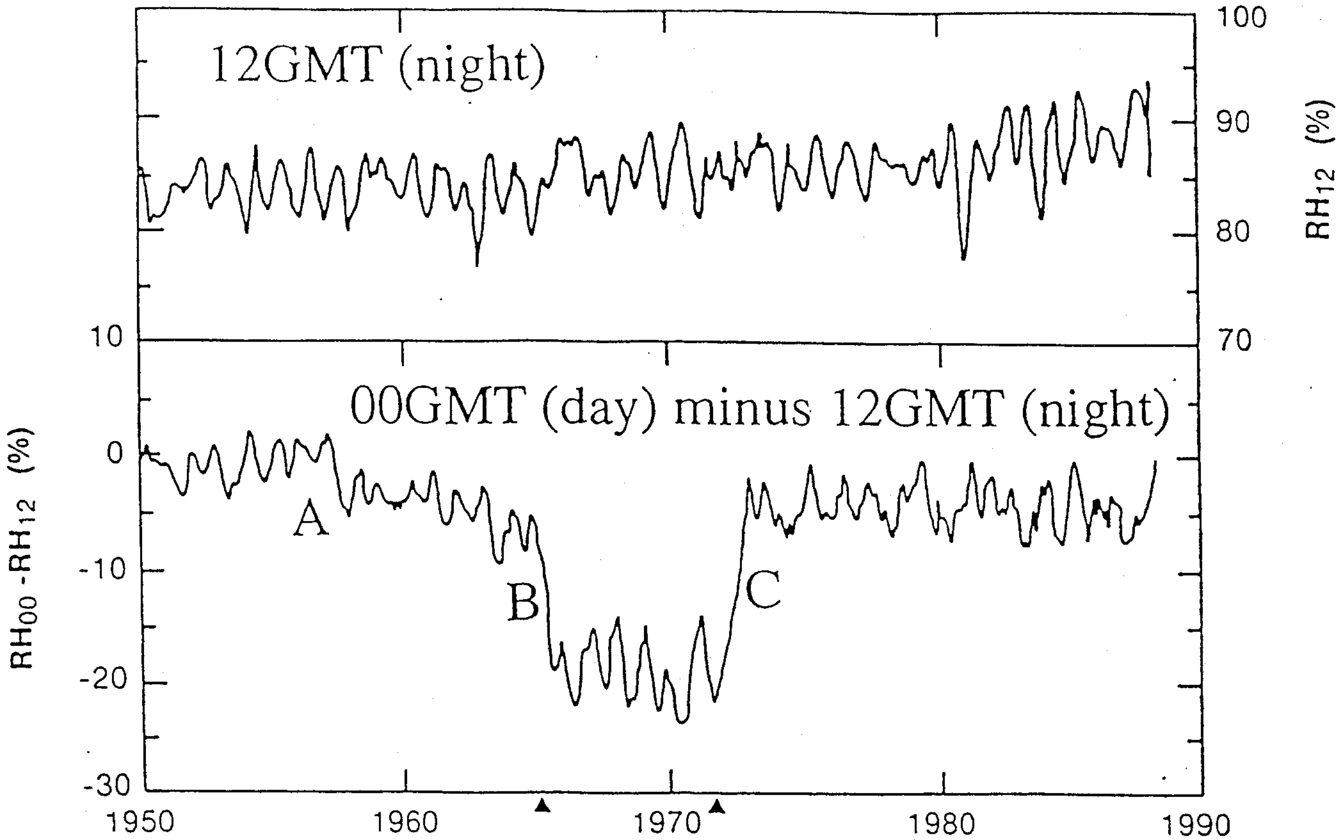


Figure 3.5 Distribution of raob upper air stations at a particular synoptic time in 1993.



A 1957 Sounding times changed from (03,15) to (00,12)

B 1965 Carbon hygristors and new housing introduced.
Solar heating of housing lowered reported daytime relative humidity.

C 1973 Housing improved to avoid solar heating.

Figure 3.6 Heterogeneities in daytime 850 hPa relative humidities over Hilo, Hawaii. From Elliot and Gaffen (1991).

4. OCEANOGRAPHIC DATA

There is a broad range of oceanographic data types. This chapter will focus on the data that defines the physical characteristics of the ocean-atmosphere boundary layer and the subsurface distribution of sea water properties. Upper atmosphere observations taken from ocean islands or ships can be considered conventional meteorological observations and are discussed in chapter 3.

Oceanographic data are collected using both *in situ* methods and remote sensing. The most obvious remote sensing platforms are satellites, but scientific aircraft, some special buoys, and even some ships use instruments (*e.g.*, radiometers) to remotely sample the ocean surface. Some of the primary remote sensing instruments and resulting oceanographic data are: radiometers which estimate sea surface temperatures (SSTs), scatterometers which measure wave disturbances and yield surface wind speeds and directions, and high precision altimeters that measure ocean surface deformation. The surface deformation is used to estimate sea surface slopes and ocean currents. Satellite data are a major asset for oceanographic research. *In situ* sampling from ships and buoys does not, in general, yield sufficient spatial or temporal data resolution over the vast ocean regions that cover more than 70% of the planet. Carefully calibrated and adjusted satellite data, sometimes blended with *in situ* observations as a data processing procedure, provide our best assessment of global ocean conditions.

Useful *in situ* ocean observations come from different sources, with varying degrees of quality. The highest quality data are collected during scientific research programs, by instrumented buoys (both moored and free drifting), by ships specifically designed to collect environmental data, and by coastal or island stations that function in a manner similar to standard land stations. Lower quality data, but nevertheless quite valuable, are regularly collected aboard merchant ships as they traverse shipping routes, and by fishing fleet vessels during commercial fishing operations.

Scientific research programs collect the widest variety of *in situ* data. Typical ship board activities will collect sea surface data (SST, salinity, wave height, wave direction, *etc.*), near–surface meteorological conditions (air temperature, wind speed, wind direction, dew point temperature, barometric pressure, cloudiness, *etc.*), and, often, subsurface sea water characteristics (*e.g.*, vertical profiles of temperature, salinity, dissolved nutrients, dissolved gases, anthropogenic tracers, ocean currents, and ocean bottom depth). Some research programs also deploy surface drifting buoys whose locations are monitored by satellite. These provide buoy trajectories (that approximate surface ocean circulation), and usually a few other geophysical variables (*e.g.*, SST, barometric pressure, *etc.*). To a lesser extent, some free drifting buoys are located below the ocean surface. These buoys are tracked acoustically or they periodically rise to the surface for satellite tracking. Buoys of this type are used to monitor subsurface oceanic flow as well as subsurface sea water properties. Moored surface buoys with subsurface instruments below are also used by science programs. The surface instrumentation collects many types of data relevant to ocean-atmosphere boundary layer processes, while the subsurface instruments normally focus on water temperature, salinity, pressure, and ocean currents.

The sampling periods for scientific research programs are often short relative to the needs of climate studies. Some long term environmental monitoring is carried out by NOAA's National Data Buoy Center (NDBC). The NDBC maintains an array of approximately 50 moored surface buoys primarily located in the Atlantic and Pacific coastal waters of the United States, but also include areas off the Hawaiian Islands and Alaska, in the Gulf of Mexico and the Great Lakes. The deployment of this array began in the mid-1970's and is ongoing. Essentially, these buoys represent a quasi-permanent array of ocean observing stations. Weather observing ships were used beginning in 1945. These ships remained positioned at assigned locations serving as weather and ocean/atmosphere observing stations. However, as automated instrumentation and buoy technology improved the deployment of weather ships has dramatically decreased. Although the weather ships did some profile sampling of subsurface ocean properties, the primary focus was on the ocean surface and meteorological conditions. The NDBC buoy array also samples surface and near–surface conditions such as SST, wind speed and direction, air temperature, barometric pressure, and wave data.

One scientific program that is contributing important data for climate studies is called TOGA/Tropical Atmosphere Ocean (TAO). A smaller program began about 1980 and has evolved and expanded into the present day TOGA/TAO which covers the equatorial belt of the Pacific Ocean with surface and subsurface instrumentation fixed to 30-50 moored buoys (Fig. 4.1). In near real time mode, data from these instruments are collected by satellite and are used for global weather and ocean condition forecasts. During periodic instrument service and repair, these data are also collected in a delayed mode. Following post sampling calibration of the instruments, the delayed mode data are quality checked and corrected. Both the near real time and delayed mode data are important for monitoring typical ocean conditions such as El Niño.

Data collected on merchant and fishing vessels are a large source for surface oceanographic data. Typically these data are gathered at synoptic weather observing times aboard ships that are in transit. Mariners have done this through history, of course, with widely varying methods and degrees of accuracy. The typical measurements are wind speed and direction, barometric pressure, air temperature, SST, and local weather conditions. In the earliest times, these data were recorded by hand in logbooks. Some historical logbook data have been digitized and now the earliest digital records are from the early 1800's. Modern vessels use automated systems whereby the data are collected digitally and transmitted via satellite to land–based collection agencies. These data provide critical information for present day weather and ocean–condition forecasting. Nevertheless, significant amounts of data are still only recorded in logbooks. Several data archival programs are in progress to digitize more logbook data. Given the vast regions of the ocean, and the relatively sparse sampling that occurs, almost any available data are considered useful.

There are many ancillary oceanographic data types that are important. Sea level, sea ice concentration, and ocean bottom topography are a few examples. These are briefly discussed at the end of this chapter.

Table 4.1 shows a list of selected oceanographic datasets that are available at NCAR. This selection of data will be used as example in the subsequent discussion. This is not a comprehensive list of all available data. Many federal agencies and other research institutes have important data not shown in Table 4.1. Some organizations which archive oceanographic data are listed in Appendix A.

Ocean-Atmosphere Boundary Layer Data

Data that define the physical conditions at the ocean-atmosphere boundary are of interest to many scientists. Atmospheric-oceanic forcing is studied over a broad range of temporal and spatial scales. Generally, temporal periods span seconds to centuries and spatial coverages range from centimeters to thousands of kilometers. The existing data are generally inadequate to address a broad range of research topics. On a global scale, the data are marginally adequate for problems focused on long term monthly variations. As necessary spatial and temporal requirements of a particular scientific investigation decrease, it becomes more likely that data will exist to study the problem.

Efforts have been made to collect datasets suitable for global studies of ocean-atmosphere climate. One such project has resulted in the Comprehensive Ocean Atmosphere Data Set (COADS). COADS is a cooperative effort between four groups; NCAR, the Environmental Research Laboratory (ERL) of NOAA, the National Climatic Data Center (NCDC), and the Cooperative Institute for Research in Environmental Sciences (CIRES). The goal of the COADS project is to collect near–surface oceanographic data from many sources and merge them together to form the most complete data base possible. The primary sources included in COADS are: surface observations from merchant ships operated by many different countries, observations taken from oceanographic research vessels and some fishing fleet data, data from moored ocean buoys and coastal stations operated by the NDBC, moored buoy data from the TOGA/TAO experiment, the global drifting buoy data from the Marine Environmental Data Service (MEDS) of Canada, and drifting buoy and manned stations on Arctic sea ice. Efforts to extend and improve the data quality in COADS are continuing. Presently, COADS is the "best" available global set of marine surface data covering the 1854-1992 time period. The COADS is contained within the NCAR dataset ds540.0 (see Table 4.1). It contains 2° box statistical summaries of various observed variables and derived quantities on a year–month basis. These are presented in Table 4.2 .

As with land stations, the spatial distribution of ocean observations has changed significantly with time. Figure 4.2 depicts the number of 2° boxes with at least *one* observation for January from 1880 to 1979. This is summer in the southern hemisphere and represents the season with the best spatial distribution of observations. During the southern hemisphere winter (*e.g.*, July), the number of 2° boxes with observations in high southern latitudes drops significantly. Indeed, if more than one observation (say, 5) is required to reduce sampling errors, the number of usable 2° boxes drops significantly in both the tropics and the southern latitudes (Fig. 4.3).

A dataset similar, but not identical, to COADS is the Meteorological Office Marine Data Bank (MDB) developed at the Hadley Centre, Meteorological Office, Bracknell, United Kingdom. COADS and MDB have many data in common but also each contains unique information. Long range plans are in place to blend COADS and MDB together. Climate research based on the MDB and COADS has contributed significantly to our understanding of climatic variations and of sampling biases that exist in these datasets that span many decades and numerous changes in sampling methods and technology. The quality of some climate change and climate variability estimates rely heavily on datasets like COADS and MDB. Improvements in these datasets are important for improved climate studies.

Satellite data are now being used to help define the surface boundary layer conditions. For example, AVHRR data are commonly used to augment *in situ* SST observations in order to provide more complete (both spatially and temporally) estimates. These are called the blended SST analyses. In a similar fashion, scatterometer data from ERS-1 are used to improve estimates of wind over the oceans.

Subsurface Observations

In order to understand oceanic circulation, it is necessary to know the internal distribution of water mass (*e.g.*, density) within the ocean. The distribution of ocean water density is defined by the water temperature, salinity, and pressure or depth. Measurements of these water properties are generally made with vertical profiling instruments lowered from research ships. These measure how assorted ocean properties vary as a function of depth. The most common is the temperature–depth profile. One of the first instruments developed specifically to measure this was the mechanical bathythermograph (MBT). This instrument is suspended from a cable and lowered from a stationary or slowly moving ship. Changes in water temperature are detected using xylene in a thin copper tube while pressure, which is closely related to depth, is sensed by a flexible diaphragm. The combined response of these sensors is recorded by a stylus scribing a mark on a gold plated glass slide. Following recovery of the MBT, the glass slide is removed and the scribed curve is read with a viewer containing depth and temperature grid scales. Sampling with this instrument is typically limited to the upper 100-200 meters depth. MBT measurements were prevalent for about three decades beginning in 1940. In the 1960's a new instrument, the expendable bathythermograph (XBT), was developed and superseded the MBT. Again the XBT was specifically designed to measure temperature–depth profiles, but it uses much different technology. Temperature is estimated by a temperature sensitive thermistor in the weighted nose of a small ($\approx$ 30 cm) torpedo shaped housing. The disposable XBT housing is dropped into the ocean. Freely uncoiling conductive wire maintains a connection with an on board recording device (a strip chart recorder or computer) so that temperature changes detected by the thermistor can be transmitted. The XBT descends through the sea water at an approximately constant rate, so depth is proportional to the time interval during the descent. After the full length of conductive wire is uncoiled, the XBT breaks free, ending the data collection. Nominally, most XBTs sample to a depth of about 400 meters but some XBTs are designed for deeper sampling (750 meters or more). When rapid sampling of large areas is required, specially designed XBTs may be deployed from low flying aircraft. XBTs are still commonly used because they are inexpensive and quite simple to use. Programs that arrange for deployment of XBTs from merchant vessels, while en route between ports, have been used successfully to collect much additional data at low cost.

The first systematic sampling ($\sim$ 1900) of the ocean's subsurface properties was done using self–closing sample bottles (*e.g.*, Nansen and Niskin bottles) and calibrated thermometers on cables lowered from stationary ships. This sampling method, broadly called ocean station data, provides temperature and depth data at each location. The sample depths range from the surface to the maximum ocean depth. Not only is the depth of sampling greater than the BT technologies, but the recovery of water samples from discrete depths allows for laboratory determination of other ocean water properties. Primarily those properties have been salinity, nutrients (dissolved nitrates, nitrites, phosphates, and silicates), and dissolved oxygen. In this sampling scheme, ocean depth is determined by a thermometric technique whereby temperature differences between two thermometers (one vacuum sealed and protected from the ocean water pressure and the other exposed to the pressure) are used to estimate sample depth. Beginning in the mid-1960s, electronic instrumentation was introduced for use in conjunction with standard ocean station procedures. These instruments are called STDs or CTDs for the measurements of salinity or conductivity, temperature and depth (pressure). These instruments provide high resolution vertical profiles of temperature, salinity, and depth. In some cases, the high resolution data are augmented with water analyzed from sample bottles. Today the majority of ocean station data is obtained using CTD technology.

The temperature, salinity, and depth measurements from ocean stations are often used to calculate water density and, if data from several stations are available, a first order estimate of subsurface ocean current speeds can be made using the principles of geostrophic flow. The individual properties are also mapped and contoured in horizontal and vertical sections to describe water mass movements. The motivation for these types of studies is to develop an understanding of the general ocean circulation.

In recent years, water samples have been used to measure other ocean water properties. Dissolved gases, such as co_2 and n_2o, are measured to improve our understanding of ocean-atmosphere exchanges of these compounds. Dissolved anthropogenic constituents such as helium-3, tritium, freon-11, and freon-12 are used as water parcel time stamps. Because constituents like these have known decay properties, the amount of time when a 'water-parcel' was last in contact with the atmosphere may be approximated. These estimates provide time–history information on the slow–moving deep–ocean circulation and improve the understanding of water mass ventilation (*i.e.*, water reaching the surface). There are numerous other ocean measurements that are made in support of biological and geological research that are not covered in this text.

The National Oceanographic Data Center (NODC) of NOAA is the primary source of ocean profile data. They have separate archives of MBT, XBT, ocean stations from bottle samples (SD), and both low and high vertical resolution CTD/STD stations. These historical archives typically have data within 2-3 years of the current date. The most recent data are often held by the groups who carry out the collection so that they can study the information prior to public release. Large field programs like the World Ocean Circulation Experiment (WOCE) and TOGA have archive centers responsible for collecting all data from many different ocean cruises. Following a reasonable amount of time, normally about two years, the data are submitted to NODC which provides data selection and data distribution services to all users. As part of ongoing data projects NCAR has the NODC archive (ds542.0). Smaller ocean station datasets include: Reid's selected deep ocean stations (ds543.0), Jenkin's tritium and helium-3 observations (ds544.0), Stalcup's observation from a warm core ring (ds545.0), Levitus' stations at standard levels (ds285.0), and Gordon's Southern Ocean stations (ds285.1). As a typical example, a vertical cross section of ocean temperatures from Europe to North America (fig. 4.4) was prepared using Reid's dataset.

In ocean regions of particular interest (*e.g.*, the Gulf Stream, the Kuroshio Current, the Antarctic Circumpolar Current) moored instrumented arrays are sometimes used to monitor oceanic flow and water properties. These arrays tend to be maintained for several years or less. The time series of observations have limited value for large spatial studies, but they do provide excellent data for energetic studies of ocean currents and calibration/comparison data for co-located ocean station survey data. Unfortunately, placing instruments in the deep ocean (to depths of 5000 meters or more) is technically challenging and expensive. Therefore, these available records are few, but quite important to our understanding of ocean flow. One good source for ocean current data is the School of Oceanography at Oregon State University, Corvallis, Oregon. NODC also has current meter time series data holdings.

Analyses

Analyses refer to gridded fields of properties derived from observed data, such as described in the previous sections. The majority of ocean analyses are for the sea surface. The reason for this is that most *in situ* ocean observations and satellite remote measurements apply only to the surface. Furthermore, understanding interactions between the ocean and atmosphere near the surface has long been recognized as important for better weather forecasting and has therefore received research emphasis. Analyses can be as simple as the interpolation of observed data onto a uniform grid. More complicated methods are used to develop grids during operational weather center forecasting procedures. Those procedures use real-time observed data in conjunction with previous output model grids and sophisticated data assimilation schemes (see Chapter 6).

Researchers involved in ocean-atmosphere comparative studies, and those who want an initial look at data often prefer analyzed grids because they are convenient to use. However, users should understand how the grids were produced and use them with appropriate caution. Some concerns might include: how noisy (spatial and temporal) were the original observations, what quality control and interpolation procedures were used. Ultimately, the question that remains for a user is "Have the procedures used to derive the gridded products adversely affected my scientific inferences?". Thorough metadata are critical to help scientists in answering this question.

Analyzed data span a full range of spatial and temporal scales. However, for most basic ocean research, gridded analyses that cover large portions of ocean basins with temporal resolutions ranging from several realizations per day to decades may be adequate. Analyses with higher temporal and/or finer spatial resolutions are often desired, but the lack of *in situ* observations, satellite remote sensing resolution scales, and operations weather center procedures preclude the development of these products.

Gridded climatologies, annual means, and monthly analyses provide first order estimates of ocean properties. The quality of these analyses generally varies with the density of the observational network used to derive them. Typically, the observational density, and thus the quality, is best over the northern hemisphere poleward of 20°N and is poorest over the southern oceans. Prior to the establishment of the TAO array, large areas of the tropical Pacific also had poor coverage. For most major oceanic variables (*e.g.*, wind speed and direction, SST, atmospheric pressure, air temperature, humidity) these analyses are available on 2°x 2° (latitude x longitude) grids. Other variables (*e.g.*, wave height and direction, cloud information, salinity, precipitation, sea ice limits, *etc.*) are more poorly represented. Derived quantities like heat fluxes, radiation fluxes, and momentum fluxes are also not as good as desired. Nevertheless, in certain regions where adequate sampling is available, reasonable estimates are available and have proved useful in climate research. Examples of datasets archived at NCAR that fall into this category include: Trenberth's global wind stress climatology based on ECMWF analyses (ds110.1; see Chapter 6), Hellerman's monthly global wind stress (ds232.0), Shea's global monthly SST climatology (ds289.0), Legates' global air temperature and precipitation monthly climatology (ds236.0), Esbensen's global wind stress and heat budget climatology (ds209.0), and Oberhuber's global climatological atlas based on COADS (ds541.0).

Sub-surface analyses are very important for oceanographic research, especially for large scale comparative studies and model initialization and verification. Several sub-basin scale analyses have been made (NCAR datasets ds286.0, ds278.0, ds544.0, and ds285.1). One global dataset which is particularly popular was developed by Sydney Levitus, then at GFDL and now at NODC. He derived annual, seasonal, and monthly analyses from the NODC station data archive. These multi-level global ocean analyses, on a 1° grid, provide analyzed temperature, salinity, and dissolved oxygen data. This dataset is available from both NODC and from NCAR (ds285.0). Levitus is developing a new world ocean atlas scheduled for public release in late 1994. This atlas will incorporate much new data and many old data that have recently become available. Analyzed grids at 1° resolution for temperature, salinity, dissolved oxygen and nutrients (no_3, sio_2, pho_4) are all part of the atlas.

In support of tropical Pacific Ocean studies and associated coupled ocean–atmosphere studies, NMC now makes available the first operational sub-surface ocean analyses. Using observational data from ships and the TOGA/TAO moored buoys, an ocean model produces analyzed grids of sea surface temperature and ocean current velocity on a weekly basis for the tropical Pacific Ocean (ds277.1). Analyses like these are presently only possible in regions with adequate subsurface *in situ* measurements. These analyses represent a new frontier for ocean science and should improve with time and experience.

When the research focus changes from mean conditions to long term trends or interannual variability, datasets spanning long time periods are required. Typically, gridded monthly time series, often called year-month time series (12 monthly grids per year), are needed for this type of research. The COADS provides a long year-month history by statistically summarizing *in situ* data in 2°x 2° areas, for all available data, for the period 1854-1992. The variables summarized are those commonly taken at synoptic hours on board ships (*e.g.*, wind speed and direction, SST, air temperature, atmospheric pressure, relative humidity, and cloud type). In general, these summaries are of higher quality and provide better global coverage in the more recent years. SST is the most frequently analyzed variable. Important improvements have been made in these analyses beginning in 1970 by incorporating sea-ice edge location and using optimum interpolation methods to estimate various quantities in data sparce regions. In these recent analyses, the SST interpolation is constrained to correctly match the freezing temperature of sea water at the sea ice edge location. This greatly improves the representation of SST in high latitude regions which often lack sufficient *in situ* observations. Another advancement in SST analyses became possible in 1980 with the availability of satellite AVHRR data. To date, our best available SST analyses are derived using *in situ* observations as ground truth, in combination with AVHRR data to provide patterns to fill data sparse regions, and realistic sea ice edge specification (also obtained from satellite measurements) to constrain the analyses at high latitudes. Reynolds and Stokes, from NMC, are responsible for many of these developments and the resulting analyses are available from NCAR (ds277.0). Confidence in these techniques has advanced to the point that weekly 1°x 1°global SST grids are now available in near real time.

These analyses improve our ability to monitor changes in SST (*e.g.*, the El Niño and La Niña phenomena).

Many other analyses that fully or partially rely on satellites are available. Several have been mentioned here, but the interested reader is referred to the monthly publication, *Climate Diagnostic Bulletin, U.S Dept. of Commerce, NOAA, National Weather Service, National Meteorological Center.* In that publication, analyses are graphically displayed and brief discussions are often presented. Monthly sea level displacement from the mean is derived using the European Space Agency ERS-1 satellite altimeter and tide gauge data from islands in the Pacific Ocean. Global ocean dynamic topography, which reflects relative ocean circulation, is derived on a two week or monthly basis using the TOPEX/POSEIDON satellite altimeter data with a set of ocean tidal and geoid models. Other promising developments include tropical rainfall analyses based on outgoing long–wave radiation measurements and surface wind speed and directions as determined by scatterometer measurements taken from satellites. Developing ocean analyses such as these have potentially important benefits.

Analyses, done as part of operational weather center forecasting procedures, have proven to be valuable research datasets (see Chapter 6). These analyses offer relatively high temporal and spatial resolution. Major centers (*e.g.*, NMC and ECMWF) now provide analyses at intervals as often as four times per day at many atmospheric levels including the surface boundary layer for many variables including SST (Fig. 4.5), air temperature, pressure, winds, humidity, fluxes, and precipitation. A wide variety of real time ocean and atmospheric observations are used in each analysis. The data are subjected to consistency checks with previous analyses. Grids of this type became available from NMC in 1976, but it was not until 1979, during FGGE (see Chapter 8), that global analyses first became viable. Even though 18 years of data are available it is not suitable for long term trend evaluation. During this time period there have been significant developments (improvements) in numerical techniques and computational coding of model dynamics. These developments have led to model changes that cause changes in the analyzed grid products not related to climate changes. The problem is how to separate changes resulting from changing procedures from real climate change. To address this problem four "reanalysis" projects are underway. Chapter 6 presents more details on this project.

Sea–Ice, Sea Level, Topography Data

The previous sections identify some important types of ocean data, however there are often other data types required for oceanographic research. The global ocean bottom topography*

* A complete listing of topography datasets at NCAR appears in Chapter 9.

and geographical limits of the ocean basin are defined with ocean bathymetry datasets. A 1° resolution set from Scripps Institute of Oceanography and the Rand Corporation (ds750.1) gives a good representation at low resolution while the ETOPO5 (Earth Topography 5 minute) dataset from the National Geophysical Data Center (ds759.1) presents ocean depth and land elevation at a 5'x5' resolution. Other higher resolution datasets, for limited regions are available from the Defense Mapping Agency, Department of Defense. The mean position and the variability of sea ice limits are also important for some oceanographic studies. To fill this requirement NCAR provides some basic datasets identified as ds233.0, ds234.0 and ds270.2 in Table 4.1. These datasets are derived from higher resolution archives at the National Ice Center (formerly the U.S Navy Joint Ice Center) and the NSIDC. Under certain circumstances (*e.g.*, coastal salinity studies) the freshwater flux into the coastal ocean is required. NCAR has a small archive of selected world river flow rates (ds552.0). Other river flow data are available from U.S Geological Survey (see Appendix A). A small selection of historical sea level time series data is available at NCAR. The records from 1800-1987 are available in ds252.0. More modern and comprehensive records can be obtained from the WOCE Sea Level Data Center at the University of Hawaii (see Appendix A).

Table 4.1
Selected NCAR Oceanographic Datasets

NCAR ID	Description	Size (MB)	Max. Period
ds110.1	Trenberth, Global Wind Stress Climatology Based on ECMWF	174	1980-89
ds209.0	Esbensen, Global wind stress and heat budget climatology	9	
ds209.1	Weare, Tropical Pacific Ocean yr-mo heat budget	23	1957-79
ds209.2	Isemer and Hasse, Bunker Climate Atlas of the North Atlantic	25	
ds209.3	Hastenrath, Heat budget atlas for the tropical Atlantic	5	
ds230.0	OBrien, FSU trop. Pacific & Indian Ocean. yr-mon wind str.	20	1961-92
ds231.0	Wyrtki, Tropical Pacific yr-mon surface wind stress	9	1947-73
ds231.1	Harrison, Climatological mean wind stress, global ocean	19	
ds232.0	Hellerman, GFDL Monthly Global wind stress	3	
ds236.0	Legates, Global air temp. and precip., monthly climatology	84	
ds250.0	Pacific hourly, daily, and monthly sea level heights	51	1901-87
ds251.0	EPOCS, Equatorial Pacific Ocean Climate Studies datasets	94	1950-79
ds252.0	PSMSL Permanent Service Mean Sea Level station data	24	1800-1987
ds253.0	Air and Surface water co_2 and n_2o, obs., global ocean	2	1977-90
ds254.0	Najjar, Global ocean nutrient grids (po_4, no_3, sio_2), 1x1	45	
ds255.0	Hansen, AOML EPOCS drifting buoy position and SST	9	1979-84
ds256.0	MEDS, Global surface drifting buoy dataset	1267	1978-92
ds256.1	PMEL/TOGA-TOA Atlas moored buoys, EPOCS moored buoys	42	1980-91
ds256.2	Colony, Arctic SLP and T. from Ice Buoys, 2 x daily	251	1979-90
ds257.0	MEDS, Canadian West and East Coast sst and salinity	10	1914-85
ds258.0	Scripps pier & west coast temp. and salinity	3	1916-90
ds259.0	Ship Improved METeorological (IMET) data, May-Nov, Knorr	4	1992
ds271.0	Oort and Yi, Global yr-mon SST grids from COADS	393	1880-79
ds272.0	Sadler, Tropical Marine Climate Atlas, sst, slp, wind stress	10	
ds274.0	Rasmussen, Tropical Pacific yr-mo sst, wind, t-air	204	1946-76
ds277.0	Reynolds & Stokes, NMC yr-mo, weekly, and climate SST	23	1970-94
ds277.1	Leetmaa, NMC, wkly, trop. Pacific, subsurf. U, V, and T	520	1991-94
ds278.0	Bauer, Global ocean near surface monthly and annual climatology	70	
ds279.0	Samuels & Cox, GFDL Dataset Atlas for Oceanographic Model.	165	
ds280.0	Meehl, Global long-term mean ocean surface currents	.2	
ds285.0	Levitus, Clim. Atlas of the World Ocean, grids and obs.	401	1900-78
ds285.1	Southern Ocean Atlas, gridded (1x2) and observed stations	25	1900-75
ds286.0	Fukumori, The Hydrography of the North Atlantic Ocean...	18	
ds287.0	GFDL MOM Model Climatological Datasets	310	
ds289.0	Shea et. al (1992), Global Monthly SST Climatology (2°; via ftp)	1	
ds289.1	Bottomley's Global Ocean Surface Temperature Atlas	68	
ds474.0	Colony, Russian Ice Stations Meteorological Obs., 6-hrly	10	1950-90
ds533.0	USSR Marine Ship Archive, surface marine obs.	2510	1888-1991

Table 4.1 (continued)
Selected NCAR Oceanographic Datasets

NCAR ID	Description	Size (MB)	Max. Period
ds535.0	Observations from Ocean Weather Ships	470	1941-91
ds541.0	Oberhuber, An atlas based on COADS, global, climatology	75	
ds542.0	NODC XBT, MBT, SBT, SD, and STD/CTD station data archive	2763	1900-92
ds543.0	J.L. Reid, Selected deep ocean stations (7000 obs)	18	1900-87
ds544.0	Jenkins, Tritium and helium-3 from TTO-NAS and NATS	.3	1981
ds545.0	Hydrographic Data from Warm Core Ring 82-B, Stalcup et. al.	9	1982
ds545.1	Gulf Stream Anatomy Hydrographic Survey - Fall 1988, Rossby	4	1988
ds552.0	UNESCO selected river flow rates	2	1800-1972
ds726.0	Atlas, SEASAT scatterometer derived wind stress, dealiased	200	1978
ds726.1	Chelton, SEASAT scatterometer derived wind stress	1	1978
ds727.1	Fu and Zlotnicki, JPL GEOSAT Gridded Data Track File	520	1986-88
ds744.0	ESA ERS-1 satellite scatterometer data.	7900	1991-1993
	Ocean Depth and Land Elevation		
ds750.1	Scripps/RAND Corp. global land elevation / ocean depth	1	
ds759.1	ETOPO5 5 minute gridded world elevation / ocean depth	57	
ds754.0	Global 10 minute Elevation Dataset from the Navy	56	
	Comprehensive Ocean Atmosphere Dataset (COADS)		
	global ocean surface data from ships and buoys		
ds540.0	CMR, Compressed Marine Reports, 72 million obs.	1723	1854-1979
ds540.0	LMRF, Long Marine Reports, 41 million obs.	2564	1980-92
ds540.1	MSTG, Monthly Summary Statistics, in 2x2 squares	1578	1854-1992
	Datasets from Operational Atmospheric Analyses		
ds082.1	NMC 2.5x2.5 Global Grids, surface subset, 2xdaily	2945	1976-94
	NMC 2.5x2.5 Global Grids, yr-mon grids	93	1976-94
ds084.5	NMC Med. Range Forecast Model Flux Archive, 4xdaily	20547	1990-94
ds240.0	U.S. Navy Fleet Numerical Oceanography Center	8123	1961-91
ds110.0	ECMWF 2.5x2.5 Global Grids, near surface subset	663	1980-89
ds111.1	ECMWF/TOGA Adv. Oper. Dataset, 4xdaily, 1x1 resol.	27600	1985-94
ds111.2	ECMWF/TOGA Basic 2.5x2.5 Analysis, 2xdaily	14400	1985-95
ds108.0	Australian National Meteorological Research Centre	1720	1972-89
	Sea Ice		
ds233.0	Walsh, Arctic Monthly Sea Ice Concentration	5	1953-88
ds234.0	Ropelewski, Antarctic Monthly Ice Area	1	1973-90
ds270.2	Alexander and Mobley, Monthly Average SST+Ice-Pack Limits	2	

Table 4.2
COADS: Variables and Derived Quantities
Slutz *et al*, 1985

#	β	Observed Variable
1	S	sea surface temperature
2	A	air temperature
3	W	scalar wind
4	U	vector wind eastward component
5	V	vector wind northward component
6	P	sea level pressure
7	C	total cloudiness
8	Q	specific humidity
		Derived
9	R	relative humidity
10	D	$S - A$ = sea-air temperature difference
11	E	$(S - A)W$ = sea-air temperature difference*wind magnitude
12	F	$Q_s - Q$ = (saturation Q at S) $-Q$
13	G	$FW = (Q_s - Q)W$ (evaporation parameter)
14	X	WU
15	Y	WV (14-15 are wind stress parameters)
16	I	UA
17	J	VA
18	K	UQ
19	L	VQ (16-19 are sensible and latent heat transport parameters)

#	α	Statistic
1	d	mean day-of-month of observations
2	h	hour statistic of observations
3	x	mean longitude of observations
4	y	mean latitude of observations
5	n	number of observations
6	m	mean
7	s	standard deviation
8	0	0/6 sextile (the minimum)
9	1	1/6 sextile (a robust estimate of $m-1s$)
10	2	2/6 sextile
11	3	3/6 sextile (the median)
12	4	4/6 sextile
13	5	5/6 sextile (a robust estimate of $m+1s$)
14	6	6/6 sextile (the maximum)

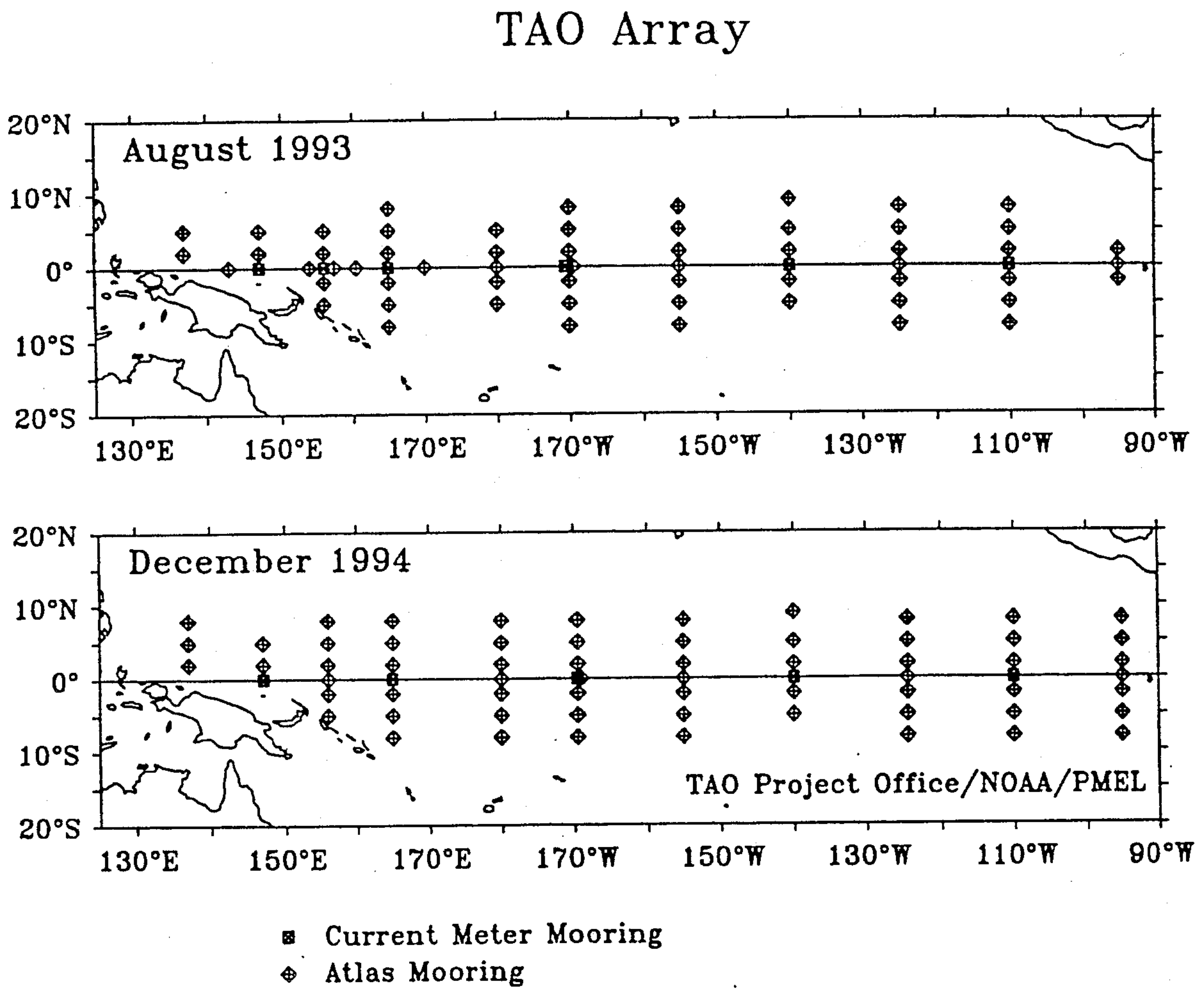


Figure 4.1 The TOGA/TAO array buoys in August 1993 and the final configuration in December 1994. (From McPhaden, 1993)

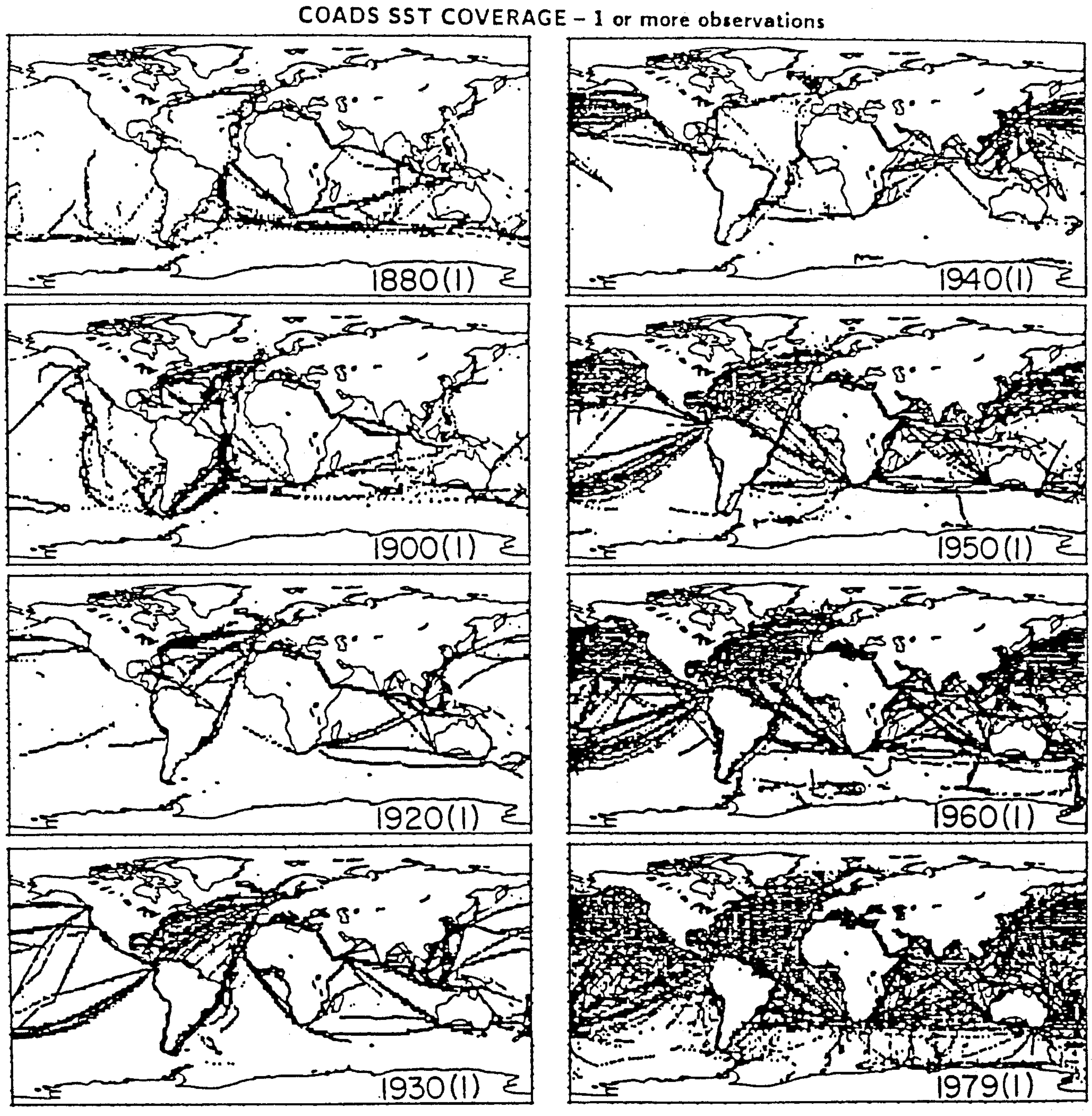


Figure 4.2 The distribution of 2° boxes that contained at least one observation for various Januaries from 1880 to 1979. (From Trenberth *et al*, 1992)

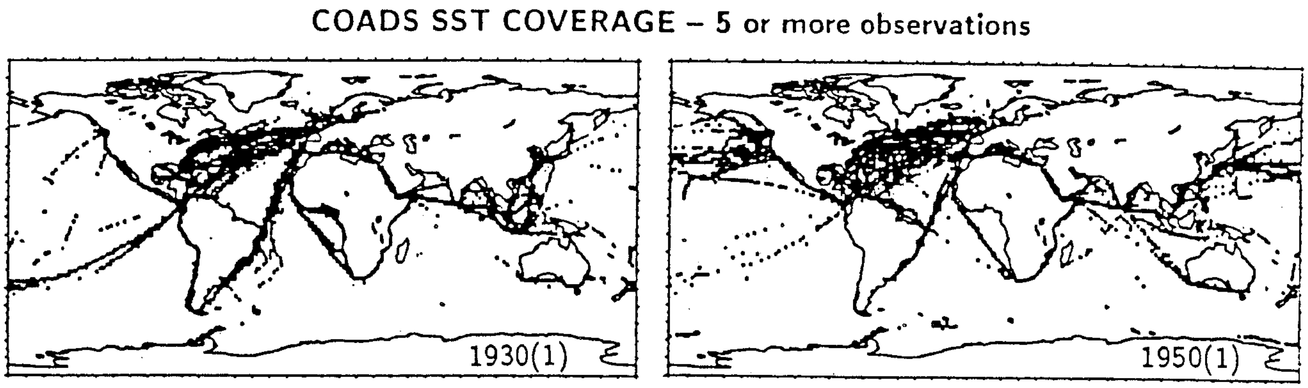


Figure 4.3 Same as Figure 2 except requiring 5 observations for years 1930 and 1950. (From Trenberth *et al*, 1992)

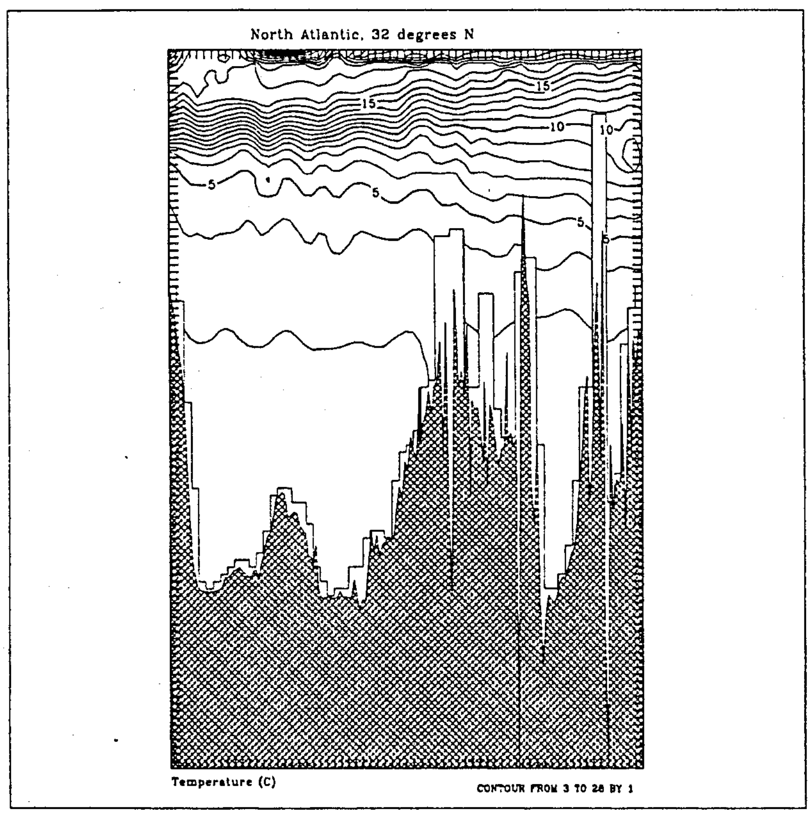


Figure 4.4 Vertical cross section of ocean temperatures from North America to Europe at 32°N. The temperature data were from Reid's selected deep ocean stations (ds543.0). The topogrphy data were from the ETOPO5 dataset (ds759.1). The contours range from 3°C to 28°C at intervals of 1°C.

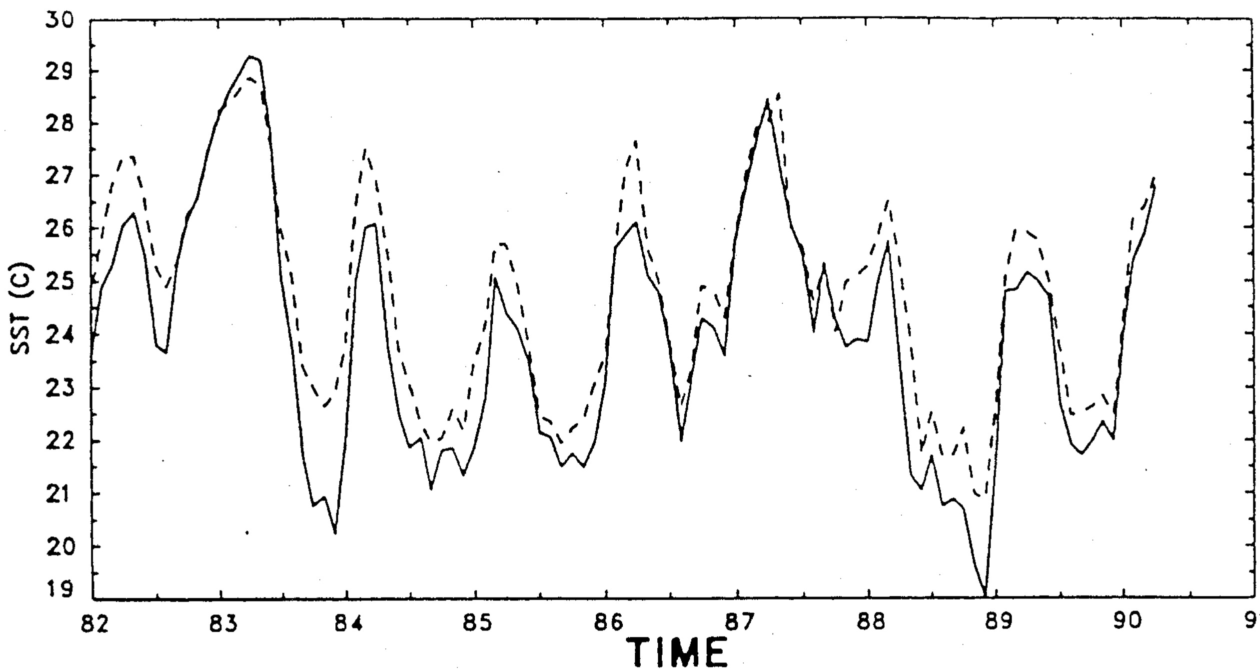


Figure 4.5 Comparison between SSTs from the CAC operational analyses at 110°W at the equator (dashed line) and a moored buoy (solid line; McPhaden and Hayes 1990). [From Shea *et al*, 1992]

5. SATELLITE DATA

The first meteorological satellite, TIROS 1, was launched on 1 April 1960. Since that initial launch, the remote sensing of the atmosphere and earth's surface by satellites has made great progress and has contributed significantly to operational weather forecasts and our understanding of the atmosphere–ocean system. For example, satellites have been useful for measuring the areal extent of the polar ice packs and continental snow cover and their seasonal and interannual variability. Prior to satellite observations, these quantities which are important components of the climate system, had been difficult to quantify.

Measurements and Orbits

Satellite instruments detect[1] radiances (*i.e.*, electromagnetic energy over a finite range of wavelengths or, equivalently, frequencies). These radiances are the result of scattering, reflection or emission by the earth/atmosphere system. Although the instruments and computer algorithms are designed to minimize unwanted information (*i.e.*, noise) the radiances received by satellite instruments contain both the desired signal and some noise. (Noise, in this discussion, means not only unwanted instrument/transmission signals but also unwanted signals from other geophysical variables.) The detected radiances are transmitted to centers which process and archive both the raw and processed data. The processing involves sophisticated 'retrieval' algorithms (*e.g.*, inversion techniques and/or statistical models) which can be used to derive estimates for a broad range of geophysical quantities. These quantities include, but are not limited to: sea surface and atmospheric temperatures, winds, water vapor, precipitation, cloud-cover, snow and/or ice cover, elements of the radiation budget, chemical components (*e.g.*, ozone [o_3], carbon dioxide [co_2], . . .) and other physical quantities of interest at various space and time scales. These estimated quantities are used for visual weather displays, as input to operational weather forecast centers and for basic scientific research.

The sources of the radiances detected by passive satellite instruments are reflected solar energy and energy absorbed and reemitted by the earth/atmosphere system. The portions of the electromagnetic spectrum which are normally used for geophysical studies are: the ultravi-

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1 Most instruments on geophysical satellites are passive rather than active devices. A passive device detects radiances while an active device is the source of the energy. Active devices have been less frequently used for geophysical satellites because they require more power which usually limits instrument lifetime.

olet (UV; $\sim$ 0.0001–0.4 μm), the visible (VIS; $\sim$ 0.4–0.74 μm), the near infrared/infrared (IR; sometimes called outgoing long wave radiation (OLR); $\sim$ 0.74–100 μm) and the microwave wavelengths ($\sim$ 100 μm and longer). The wavelengths are inversely proportional to the temperature of the emitting body. Solar energy is contained within the shorter wavelengths (0.15–4 μm) with about 9% in the UV range, 45% in the VIS range and the rest at the longer wavelengths. Various geophysical variables and chemical constituents of the atmosphere–ocean system emit radiation at the longer wavelengths due to much lower emitting temperatures. For example, the infrared and microwave wavelengths may be used to derive atmospheric and thermal information (*e.g.*, the atmosphere's vertical temperature profile and cloud top temperatures). The visible wavelength range is mainly used to monitor cloud systems and infer precipitation.

Satellites may be categorized by their orbits. The two most common categories are polar–orbiting and geostationary (Figs. 5.1 and 5.2). Generally, polar–orbiting meteorological satellites maintain sun–synchronous orbits (an orbit whose plane is fixed relative to the sun). Sun–synchronous polar orbiters generally have low orbital altitudes (*e.g.*, 850 km). At this altitude it takes about 100 minutes to encircle the globe which yields 14–15 equatorial crossings per day. Sun–synchronous orbits are designed so that a satellite passes over a particular location at the equator twice per day at the same time every day. Being in a polar orbit does not necessarily mean that the satellite passes directly over the poles. Rather, their orbits are at an angle relative to the equator. This equator–crossing angle is called the inclination angle and it is a defined by a mission's objective. Operational meteorological satellites have large inclination angles (80° to 100°) while research satellites may have smaller inclination angles (Fig. 5.3). Operational polar orbiting satellites are principally used to obtain daily cloud cover, vertical temperature and water vapor distributions and global sea surface temperature. They are also used to receive/transmit data from moving platforms (*e.g.*, drifting buoys or balloons) and determine their geographic position based upon the Doppler shift in the frequency received at the satellite.

Geostationary satellites have high altitudes (*e.g.*, 36,000 km), maintain a fixed geographic location and orbit at the same speed that the earth rotates. They make observations at 20–30 minute intervals throughout each day. This allows continuous monitoring of a particular area of the earth. The size of the area monitored is a function of instrument design and satellite altitude. However, a single geostationary satellite can monitor about 25–30% of the earth's surface. Figure 5.2 illustrates the areas covered by five geostationary satellites. Spatial resolution varies among the different satellites, ranging from 1 to 5 km (VIS) and from 5 to 8 km (IR). Geostationary satellites collect full images of VIS and IR each half hour and can do so more frequently if needed. Use of the IR allows images to be collected during the day or night. Uses of these data include locating and tracking tropical storms and deriving wind estimates which are used by operational weather forecasting models.

Both polar orbiting and geostationary satellites transmit data back to earth by radio. Polar orbiters record, and in some cases, preprocess the data prior to transmitting to earth. Geostationary satellites are always in contact with a ground station and need not record the data. Geostationary satellites provide two types of direct broadcast services: (i) a high-resolution transmission, most often used by researchers, and (ii) a low resolution transmission often called weather facsimile (WEFAX). Figures 5.4 and 5.5 provide schematics of transmission systems for each satellite type.

Satellite Data Characteristics

Unlike conventional atmospheric and oceanographic surface observations (see Chapters 3 and 4), which are site specific, irregularly spaced and of varying quality; satellite data represent spatial averages, cover wide areas and are of relatively consistent quality (if the calibration of the detecting instrument has remained stable). However, the absolute accuracy of the derived quantities is difficult to establish. Each meteorological satellite has different spatial sampling resolutions. For orbiting satellites, horizontal resolution is best along a satellite's track and is less over areas between tracks. As an example, the UARS, which is used to study the chemistry, dynamics, and energetics of the stratosphere, has a 500 km wide latitudinal swath.

One characteristic of raw satellite data is its *very* large volume. In general, NASA archives the experimental data and NOAA archives operational data. These data are available to researchers. However, the computing requirements generally preclude individual researchers from doing their own processing. Thus, the research community uses the processed datasets which are of considerably smaller volume, yet may still be quite large.

Some sources of error for satellite measurements include: space-time sampling problems, instrumentation limitations, calibration drift, aerosol loading after volcanos, difficulty in removing noise, uncertainties in location, changes in equatorial crossing times and calibration of results with other observed variables. Sometimes (*e.g.*, ERBE), the processed data are a combination of inversion methods and models which can make the data uncertainty estimates difficult to assess.

One difficult problem is how to assign various estimates to specific atmospheric altitudes. Simply stated, the problem is that the satellite instruments detect vertically integrated radiance values. Complex models exist that estimate how a particular vertical distribution of a geophysical variable emits radiation. However, there are a large number of complexities that make interpolation of a measured radiance value to specific atmospheric levels uncertain. Much work remains to be done but comparison studies with *in situ* data show that significant progress is being made.

Some Satellite Systems and Programs

TIROS and ESSA: The TIROS series (launch dates: 1960–63 for TIROS I–VIII; 1965 for TIROS IX and X) of satellites were the first to be launched specifically for atmospheric studies. There were essentially two sensors on board, an IR radiometer and a television camera. These satellites were spin-stabilized, meaning that the spin axis was fixed in space. Consequently, the instruments viewed the earth perpendicularly only once per orbit. This resulted in the use of elaborate spherical geometry to determine the latitude and longitude of the data. The later TIROS series, ESSA (1966–1969), was improved so that the spin axis was perpendicular to the orbital plane, enabling perpendicular measurements and easier rectification once per satellite rotation. The ESSA orbits were sun-synchronous.

NIMBUS: NIMBUS satellites (1964–78) were used for cloud mapping and used wide field–of–view and fixed radiometers. However, the satellites were earth stabilized (as opposed to spin stabilized) so that the axis is always perpendicular to the surface of the Earth, and they occupied polar sun-synchronous orbits at approximately 1000 km altitude.

NOAA: NOAA (1970–present) operates a system of operational weather satellites. The first five were ITOS (Improved TIROS Operational System) type satellites, carrying three main instruments; two scanning radiometers (VIS and IR) and a Vertical Temperature Profile Radiometer (VTPR). These were polar orbiters that provided information on clouds, vertical temperature profiles, water vapor, outgoing long–wave radiation (OLR), *etc.*

TIROS-N: The third generation of operational meteorological polar-orbiting satellites was started by TIROS-N. The Stratospheric Sounding Unit (SSU) was provided by the United Kingdom, France provided the data collection system and it was launched by the U.S. in 1978. The first Microwave Sounding Unit (MSU) and a High Resolution Infra-Red Sounder (HIRS) were flown on this platform.

GOES: The first Geostationary Observational and Environmental Satellite (GOES-1) was launched in May 1974. The most recent launches occurred in March 1987 (GOES-7) and April 1994 (GOES-8). These NOAA satellites are usually located at 75°W and 135°W longitudes. The combination allows coverage of almost all of North America and South America and adjacent oceans (see Fig. 5.2). Originally, the GOES series provided only VIS and IR images. However, the instruments have improved in quality over the past 20–years allowing for more comprehensive examinations of the atmosphere. For example, the more recent GOES series provide the ability to infer the vertical profiles of temperature and moisture. This information is used by operational forecast centers.

Special Purpose Earth-Orbiting Satellites: Skylab demonstrated the ability to accurately measure the sea surface height (SSHT) from space. The SSHT is useful for geophysical studies because it is a proxy for the geoid, a surface of equal gravitational attraction. The anomalies in the gravitational field provide valuable information about changes in the density structure of the Earth. It is interesting to note that "sea level" is not the same over the globe. The SSHT near Sri-Lanka is more than 180 meters lower than near New Guinea, 6800 km away (granted, these are the extremes). The success of Skylab experiments spawned the use of radar altimeters on GEOS, Seasat, Geosat, TOPEX, and ERS-1.

Earth Radiation Budget Experiment: The ERBE satellite system consisted of an Earth Radiation Budget Satellite (ERBS), NOAA 9, and NOAA 10. The instrument package includes both scanning and nonscanning radiometers designed to provide high resolution, regional scale measurements of numerous radiative quantities. These provided a basis for long-term continent-scale monitoring of the radiation budget. More specifically, they measure the amount of solar radiation at the top of the atmosphere and the radiation emitted by the earth/atmosphere system. These are of fundamental importance since they determine the sources and sinks of energy that drive the climate system.

International Satellite Cloud Climatology Project: The purpose of ISCCP is to collect and analyze satellite observed radiances to infer the global distribution of radiative properties of clouds. The goal is to improve the modeling of cloud effects on climate. It uses data from the five geostationary satellites and polar orbiters of the NOAA/TIROS-N type.

Table 5.1
Some Representative/Commonly Used NCAR Satellite Datasets

NCAR ID	SATELLITE/ EXPERIMENT	MAX. PERIOD	DESCRIPTION
ds676.0	TIROS N, NOAA	1974-pres	daily gridded VIS and IR brightnesses, OLR
ds692.0	NOAA series	1972-1979	vertical temperature profiles from 8 IR bands
ds700.0	NOAA series	1978-1992	raw global radiances from MSU, SSU, TOVS (sounders)
ds701.0	NOAA series	1979-1993	gridded mid-troposphere temperature from 53.74GHz
ds701.5	NOAA series	1979-pres	gridded precipitation from MSU channels (Spencer)
ds703.0	NOAA series	1989-1991	Polar Orbiter Global (GAC) Data
ds710.0	NIMBUS-7	1978-1986	along-orbit ozone derived from backscattered UV
ds712.0		1974-1974	reduced gridded dataset Atlantic brightnesses and IR
ds716.0	INSAT	1984-1989	India: IR and VIS VHRR 2x,8x daily
ds718.5	NOAA series	1974-1994	monthly and half-monthly OLR
ds724.0	Meteosat	1993-pres	radiances; 2500x2500 pixels; start July 93; (G Campbell)
ds725.0	ISCCP	1983-1987	geostationary US cloud cover from radiances
ds727.1	GEOSAT	1986-1988	along-orbit global ocean wind speed, wave height, SSHT
ds733.0	NIMBUS-7	1978-1987	ERBE matrix of daily/monthly radiances
ds742.0	ISCCP	1983-1994	global equal-area gridded cloud cover every 3 hours
ds744.0	ERS-1	1991-1993	along-track oceanic wind speeds and directions, SSHT

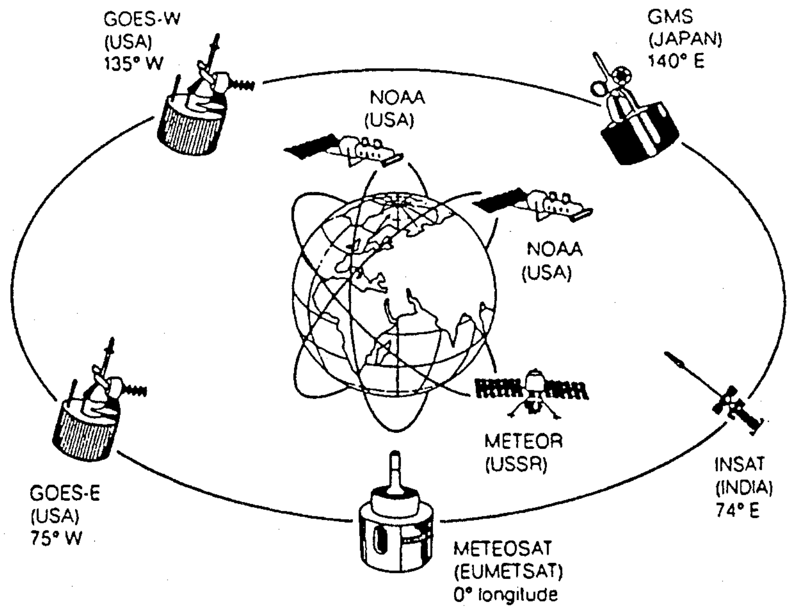

Figure 5.1 The worldwide operational meteorological satellite system. (From Hauschild *et al*, 1992)

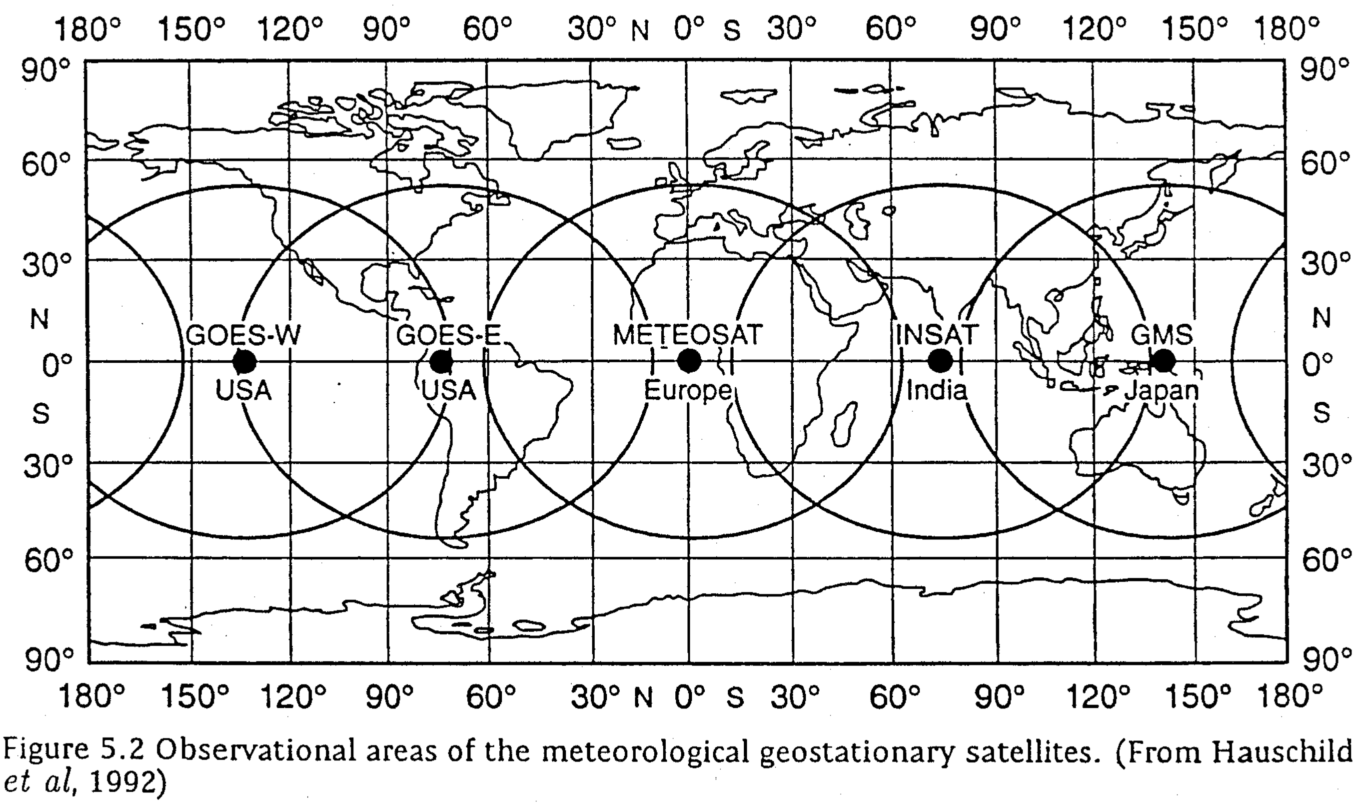

Figure 5.2 Observational areas of the meteorological geostationary satellites. (From Hauschild *et al*, 1992)

Global Coverage: UARS

- Orbital altitude 600 km, 57° inclination. Coverage ±80°, 97% surface in one day. Orbital precession results in measurement coverage of all local times in 36 days.
- Vertical: 15-60 km, 2.5 km resolution. Latitudinal: 500 km. Defined by the distance traveled in the 1 min needed to make the vertical measurement.

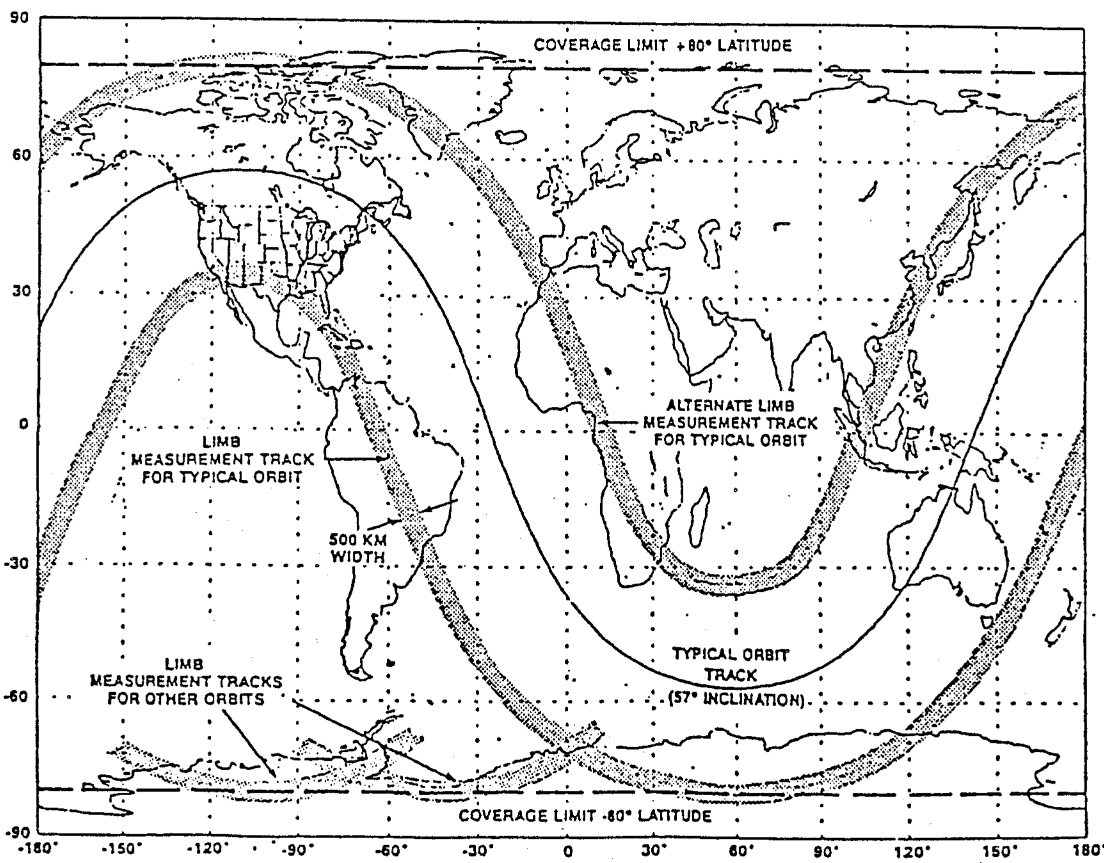

Figure 5.3 Schematic illustrating the spatial coverage of UARS, a polar–orbiting research satellite. (Courtesy of David P. Edwards, NCAR)

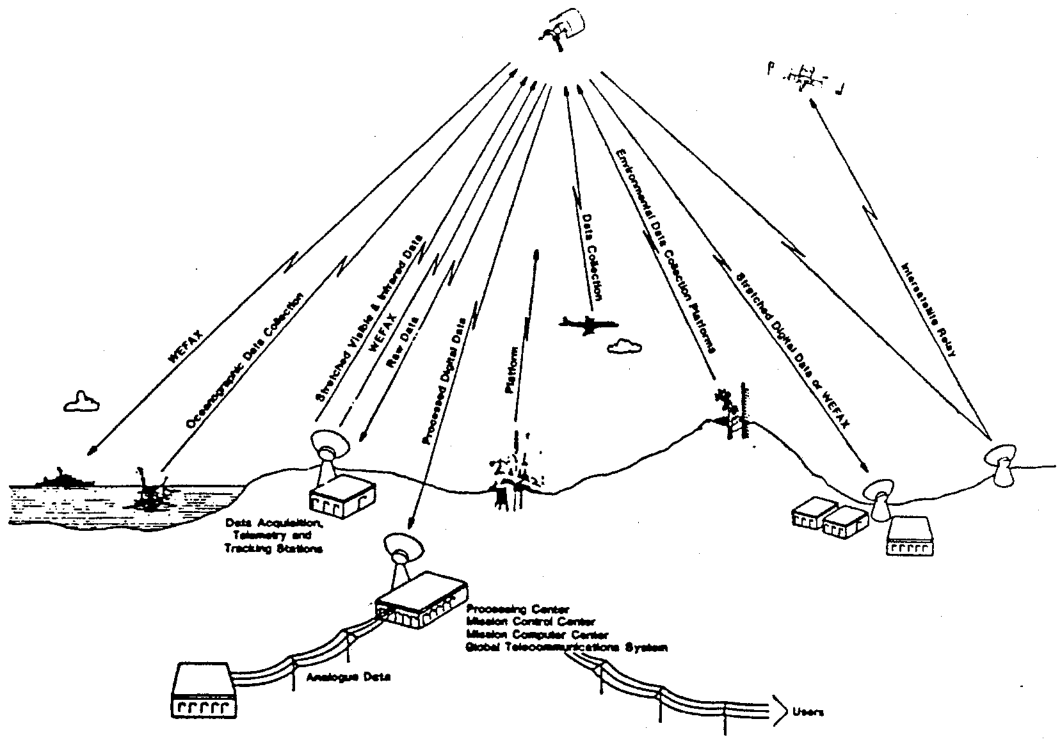

Figure 5.4 Geostationary satellite data processing system. (From WMO No. 679, Geneva, Switzerland)

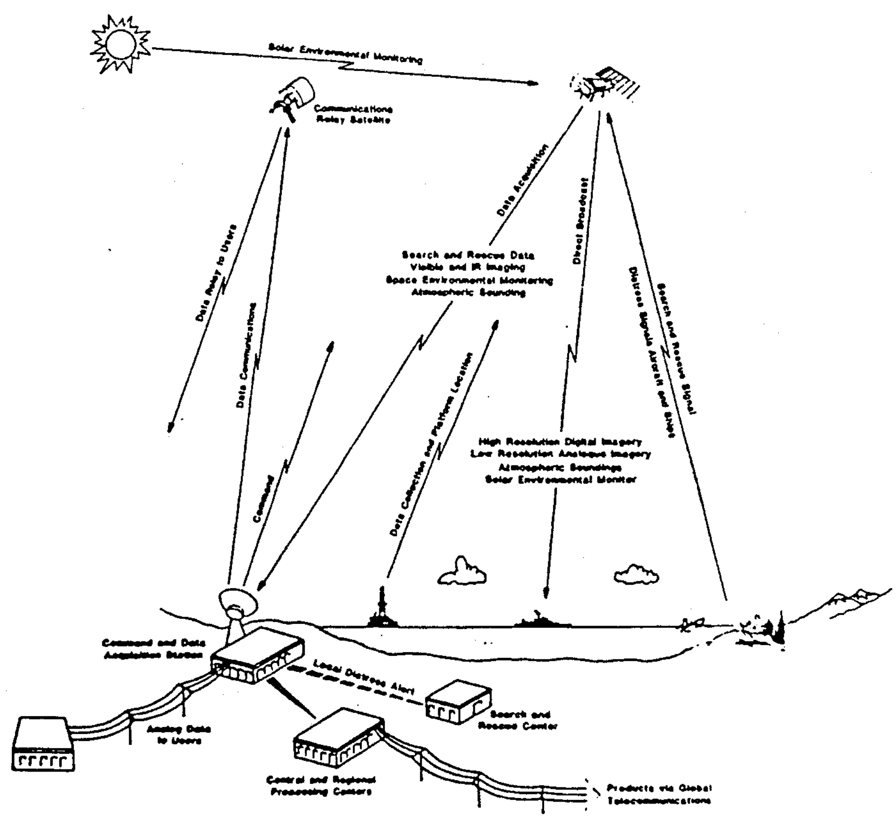

Figure 5.5 Polar-orbiting satellite data processing system. (From WMO No. 679, Geneva, Switzerland)

6. ANALYZED AND MODEL DATA

On a typical day 5,000 weather stations, 600–900 atmospheric–sounding stations (raob and pibal), 2,000 ships, 600 aircraft, several polar–orbiting satellites, five geostationary satellites and various other sources provide observations that are used by operational forecast centers to produce gridded analyses (see below for details). These gridded analyses represent a best estimate of the state of the atmosphere at a particular time. They are used as initial conditions for daily weather forecasts models and are the datasets most commonly used to analyze atmospheric quantities and processes on large spatial scales.

Brief History of Operational Forecasts

The first numerical weather forecast by computer was made in 1950. This forecast was based upon a simple one–level model over a limited domain. Regular or operational computer forecasts by the (then) U.S. Weather Bureau began in the mid–late fifties. Initially, very idealized models which made 24 to 48 hour forecasts of 500 hPa geopotential heights were used. These models, called equivalent barotropic models, used finite differences over a limited domain. They allowed a quantity called geostrophic vorticity (*i.e.*, the Laplacian of geopotential height) to be advected by the winds. These forecasts were useful but they could not predict the initiation or demise of this quantity. The next generation of operational models were called baroclinic models. These models were able to forecast vertical motion, in addition to vorticity and, thus, were capable of forecasting cyclogenesis (*i.e.*, the formation of cyclonic disturbances). As both computers and knowledge progressed, the operational forecast models evolved. Rather than use highly simplified models over limited areas, operational centers began using a simplified version of the Navier–Stokes equations* (sometimes called the 'primitive equations') in the 1960s. Initially, due to computer and operational constraints, these equations were used only over one hemisphere but soon they were used for global forecasts.

For a variety of reasons, many forecast centers changed from approximating the primitive equations with finite differences of data at grid points to exact differentials of spherical harmonics. They also changed from using pressure as a vertical coordinate to the 'sigma' (σ) coordinate system. This quantity represents a transformed pressure coordinate and has several advantages. (It also has a few disadvantages.) The biggest advantage is that it is easier to deal with the

* The main simplification was the use of the hydrostatic approximation.

lower boundary of the earth's surface because sigma levels approximately parallel the model's smoothed topography. Some recent model formulations use a hybrid pressure–σ coordinate system where σ is used in the troposphere and pressure in the stratosphere with a gradual transition in between.

Early hemispheric and global operational forecast models used horizontal resolutions of about 5°. Today global operational models have horizontal grids as fine as about 0.6° ("T213" Gaussian resolution in spherical harmonic jargon). The number of vertical levels used by the operational forecast models has increased significantly over time. In the early days, they included only five tropospheric levels. Currently, NMC and ECMWF use 28 and 31 levels, respectively. These levels encompass both the troposphere and the lower stratosphere.

Differences between Operational and Climate Models

The purpose of a operational forecast models is to predict the details of the weather out to, say, 10 days. Climate models also simulate the details of weather but do so for much longer time periods (*e.g.*, 10–100+ years). Generally, climate models use lower horizontal and vertical resolutions than forecast models because climate simulations at high resolutions would be prohibitively expensive. Forecast models assume specific initial conditions (see below) based upon the current state of the atmosphere–ocean system. Climate researchers (usually) are interested in the statistics of the climate simulations while users of forecast models are interested in specific realizations.

Historically, there were considerable differences between operational models and climate models. For instance, early operational models (even those using the primitive equations) did not include radiation because, over short time periods, radiation effects were thought to be small. However, radiation is of fundamental importance for climate models. Many other physical approximations also differed between the models. Currently, there is little difference in either the numerics or physics used in operational and climate models. In fact, it is now generally accepted that poor representations of physical processes are a source of systematic forecast error (so it is important to have a good model climate if you want to accurately forecast the detailed evolution of the atmosphere over several days).

The DSS has several datasets from non–NCAR climate model experiments located in ds318.0 (Table 6.3). A separate dataset (ds318.6; Table 6.4) contains three 100–year runs from the Max Plank Institute. All were part of EPA carbon dioxide studies. In addition, NCAR's Climate Modeling Section makes several simulations from the CCM2 available (see Chapter 11).

Data Assimilation and Analyzed Grids *

The process of establishing a dataset suitable for the initial conditions to an operational forecast model has been an integral part of the operational cycle since the first routine numerical forecasts. These datasets are the analyzed grids which have formed the basis for many atmospheric research studies. The procedure to develop these datasets has changed significantly over time to keep pace with model and computer improvements. Early analyzed grids were developed using a simple objective analysis method. Currently, they are produced using a four-dimensional (4-D) data assimilation system in which multivariate observed data are combined with a "first guess" using a statistically optimum scheme. The first guess is the best estimate of the current state of the atmosphere from previous analyses produced using the forecast model.

It must be emphasized that the operational analyses are performed under time constraints for weather forecasting purposes and not with the objective of providing a continuous picture of the atmosphere over time. Changes in the operational model, data handling techniques, the data available, initialization, and so on, which are implemented to improve the weather forecasts, may disrupt the continuity of the analyses. Some aspects, such as detailed analyses of the conditions at the surface of the earth, may be of less importance for weather forecasting while of great importance for diagnostic studies. Typically, the representation of orography in the operational models is greatly simplified (as it is in climate models).

The global atmospheric analyses produced as a result of four-dimensional data assimilation operationally consist of global fields of eastward and northward wind components (u, v), geopotential height (Z), temperature (T), and relative humidity (RH) or, equivalently, specific humidity (q) as a function of pressure (p), latitude and longitude. In recent times, these quantities have been analyzed on the levels of the numerical weather prediction model used in the 4-D data assimilation to provide the first guess for the analyses. Generally, these are σ levels where $\sigma = p/p_s$, and p_s is the surface pressure defined on the model surface topography. Alternatively, the model levels are a hybrid between σ and pressure coordinates, typically reverting to constant pressure above about 100 mb. Analyzed fields on standard constant pressure levels are produced by interpolation (*e.g.*, at ECMWF by using tension splines or linearly). Actually, the changes in the analysis from one synoptic observation time to the next are interpolated to update the standard pressure level fields although the details as to how this has been done have changed with time. Horizontal divergence and vertical motion (ω = vertical p-velocity) fields

* Most of this section has been taken from Trenberth and Solomon (1994) with permission.

are produced diagnostically from the analyses. Once the fields have been analyzed, they are typically initialized using a procedure called nonlinear normal mode initialization (NNMI) to bring the mass and temperature fields into a dynamical balance with the velocity fields consistent with the predominant low frequency motions in the atmosphere. Thus, analyzed gridded datasets may be "initialized" or 'uninitialized". (In some studies it is important to know which type of analyses are being used.)

In addition to the standard analyzed variables, new global fields of various quantities are becoming available from satellite data and/or from the model itself. In some cases, the satellite products may be produced as a part of the four-dimensional data assimilation process such that some elements of the model and/or analyzed fields are used. Examples of possible new products include short-wave and long-wave radiation at the top of the atmosphere and at the surface, cloudiness, precipitable water, and cloud liquid water. Fields of soil moisture, snow cover, sea surface temperature, surface wind and wind stress, and fluxes of sensible and latent heat may be produced. Some of these will have much larger model components than others. All need to be validated. More comprehensive use of the model can result in estimates of precipitation, latent heating, and other diabatic heating fields throughout the atmosphere. Because of the importance of precipitation in the hydrological cycle and in agriculture, and of diabatic heating in driving the whole atmospheric circulation, there is considerable interest in these fields. It is therefore desirable to obtain as much information as possible about these fields and use physical constraints whenever possible to try to determine them more accurately.

Reanalysis Project

As previously discussed, there are several reasons why these analyzed grids have problems that can limit their usefulness. Model numerics, physics, horizontal and vertical resolutions and other changes over time (Fig. 6.1) have introduced inhomogeneities into these analyzed grids (Fig. 6.2). To provide researchers with a relatively clean series of analyses to address a broad range of research topics, several operational and research organizations are establishing their own programs to reanalyze data for various time periods. Informally, these collective efforts may be called the Reanalysis Project. The following organizations have established reanalysis projects: NMC–NCAR, ECMWF, NASA GSFC, and the NRL (Monterey). Each will use its own unique model and data assimilation scheme to produce analyzed grids every 6 hours over assorted time spans. Table 6.1 provides a brief summary.

Unlike the model/assimilation schemes which will not change, the observational data bases used as the basis for the analysis effort will change with time. These input data bases will be similar in many respects but, will also differ in some way: *e.g.*, NMC–NCAR will use a comprehensive set of quality controlled observations including the recovery of 'lost' datasets; ECMWF will include direct assimilation of satellite radiances to improve the moisture analysis; NASA GSFC will include special satellite data; and NRL will use operationally available observations only. This heterogeneous mixture of models, assimilation methods and data will allow researchers to assess the degree of agreement among the final products which might be interpreted as a measure of reliability.

Initially, each reanalysis effort will focus on a particular time period: 1979–93 for ECMWF; 1985–89 for NRL; 1985–90 for GSFC; and, 1985–93 for NMC. These planned time periods may change. GSFC will likely extend their reanalysis to the present while NMC eventually hopes to produce analysis back to 1958. In fact, NMC has plans to establish a Climate Data Assimilation System (CDAS). The CDAS will use the same model/assimilation scheme as the in NMC reanalysis but on a seven day delay basis to capture all possible operational data. It is expected that reanalysis efforts will take place at regular intervals (say, 5 to 10 years) with newer better models and assimilation schemes.

Table 6.1
Reanalysis Project

GROUP	RESOLUTION Horizontal	Vertical	INITIAL PERIOD*
NMC–NCAR	T62	28	1985–pres
ECMWF	T106	31	1979–93
NASA GSFC	2° x 2.5°(~ R43)	20	1985–90
NRL	T79	18	1985–89

*These could change.

Table 6.2
Major Gridded Analyses Available at NCAR

NCAR ID	SOURCE	GRID	REGION	PERIOD	UPDATE	VARIABLES [*means many]	LEVELS
ds060.0	NMC	47x51	NH	1959–72	12hrly	z,t,thick	sfc,tropo,strato
ds060.1	NMC	47x51	NH	1960–77	12hrly	z	tropo (500mb)
ds061.0	NMC	47x51	NH	1964–80	12hrly	z,t	strato
ds061.5	NMC	47x51	NH	1962–72	12hrly	*	sfc,tropo,strato
ds061.6	NMC	47x51	NH	1962–63	12hrly	z,t,u,v	sfc,tropo,strato
ds062.0	NMC	47x51	NH	1967–71	12hrly	*	sfc,tropo,strato
ds063.0	NMC	47x51	NH	1963–72	12hrly	p,t,u,v,rh	sfc,tropo,strato
ds065.0	NMC	47x51	NH	1958–72	12hrly	w,z,thick	tropo
ds066.0	NMC	65x65	NH,SH	1973–pres	12hrly	*,snow	sfc,tropo,strato
ds067.0	NMC	65x65	NH,SH	1981–pres	daily	z,t	strato
ds069.0	NMC	LFM	NH	1971–91	12hrly	*	sfc,tropo,strato
ds069.5	NMC	NEST	NH	1984–90	12hrly	*	sfc,tropo
ds075.0	NMC	73x23	Trop	1968–90	12hrly	t,u,v,ff	tropo
ds080.0	NMC	144x37	NH,SH	1972–74	12hrly	z,t,u,v,rh	sfc,tropo,strato
ds082.0	NMC	145x37	NH,SH	1976–pres	12hrly	*	sfc,tropo,strato
ds082.1	NMC	145x37	NH,SH	1976–pres	12hrly	*	sfc,bound,1000
ds082.5	NMC	145x37	NH,SH	1991–pres	12hrly	*	sfc,tropo,strato
ds084.0	NMC MRF	R30	Global	1990–pres	12hrly	z,v,t,u,v,rh	tropo,strato
ds084.2	NMC	T80,T126	Global	1990–pres	6hrly	div,vort, *etc.*	18 layers
ds084.5	NMC MRF	384x190	Global	1990–pres	6hrly	flux	
ds110.0	ECMWF WMO	144x73	Global	1980–89	12hrly	z,t,u,v,w,rh	tropo
ds110.1	ECMWF	144x72	Oceans	1980–86	monthly	wind stress	sfc
ds110.3	ECMWF WMO	144x73	Global	1978–89	lt means	u,v,t,z,w,q	tropo
ds111.0	ECMWF TOGA	T106	Global	1985–pres	6hrly	u,v,w,t,z,rh	tropo,strato
ds111.1	ECMWF TOGA	N80	Global	1985–pres	6hrly	pcp,tsoil, *etc.*	sfc
ds111.2	ECMWF TOGA	144x73	Global	1985–pres	12hrly	u,v,w,t,z,rh	sfc,tropo,strato
ds111.4	ECMWF TOGA	T106	Global	1990–91	6hrly	t,w,vort,div,q	19 (model) levels
ds111.5	ECMWF TOGA	144x73	Global	1985–92	m means	u,v,w,t,z,rh	sfc,tropo,strato
ds195.0	DSS/SCD	47x51	NH	1946–94	daily	slp,tsfc,u,v,z	sfc,tropo,strato
ds195.5	DSS/SCD	72x19	NH	1946–93	daily	slp,tsfc,sst,u,v,z	sfc,tropo
ds219.0	ECMWF	72x37	Global	1979–89	yrly	u,v,w,z,t,q,+	tropo,strato
ds277.0	NMC	various	Global	1982–93	wkly	sst	sea level
ds277.1	NMC ODAS	112x81	Oceans	1991–94	wkly	u,v,t ocn/atmo	27 levels
ds302.5	ECMWF	193x97	Global	1978–79	12hrly	w	tropo,strato
ds306.0	NMC	73x37	Global	1979	12hrly	u,v,t,q	sfc, sigma
ds307.0	ECMWF FGGE	192x49	NH,SH	1978–79	12hrly	u,v,w,t,z,rh	sfc,tropo,strato
ds307.3	ECMWF FGGE	192x49	NH,SH	1979	6hrly	u,v,w,t,z,rh	sfc,tropo,strato
ds307.5	ECMWF FGGE	96x25	NH,SH	1978–79	12hrly	u,v,w,t,z,rh	sfc,tropo,strato
ds618.0	ECMWF AMEX	T106	Global	1987jan	12hrly	rh,vort,div	sfc,tropo,strato
ds673.0	NMC Nimbus-5	145x37	Global	1975		ice,pcp	sfc
ds757.0	NMC	144x72	Global			sfc elev	sfc
ds840.1	NOAA TDL	LFM	NH	1973–93	hourly	mdr	

Table 6.3

ds318.0[1]

Non-NCAR Climate Model Outputs for EPA co_2 Studies in a Common Format

GROUP	RESOLUTION Horizontal	VARIABLES Number	SIZE (MB)
UKMO	48x36	9	2.99
OSU	72x46	9	5.60
GFDL	48x40	22	7.07
GFDL Q-flux	48x40	22	7.07
GISS	36x24	25	5.24
GISS control	36x24	7	0.47
GISS Sc A	36x24	7	4.26
GISS Sc B	36x24	7	2.84
GFDL 1x co_2	48x40	22	31.65
GFDL 2x co_2	48x40	22	31.65
GFDL R30	96x80	22	27.63
CCC	96x48	6	5.73

[1]Consult NCAR's Data Support Section for details.

Table 6.4

ds318.6[1]

Non-NCAR Climate Model Output for EPA co_2 Studies
Three Max Plank Inst. 100 year runs

GROUP	RESOLUTION Horizontal	VARIABLES Number	SIZE (MB)
MPI	64x32	7+	114.7

[1]Consult NCAR's Data Support Section for details.

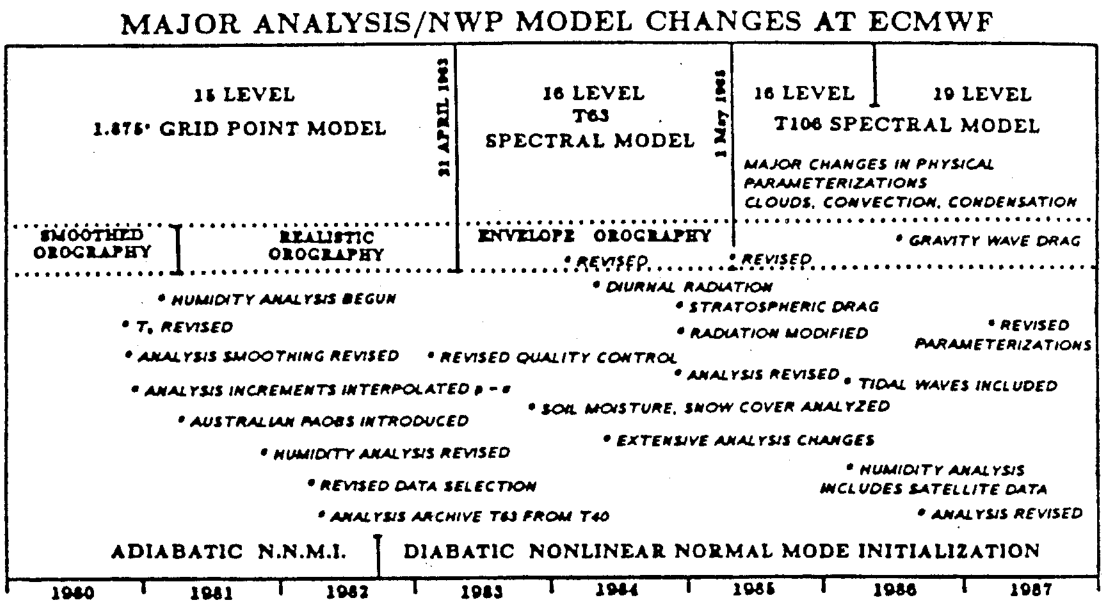

Figure 6.1 Sequence of major analysis and/or four dimensional data assimilation model changes at ECMWF from 1980–87. The numerical weather prediction model characteristics and resolution are given on top, with main analysis or assimilation changes below. (From Trenberth, 1992)

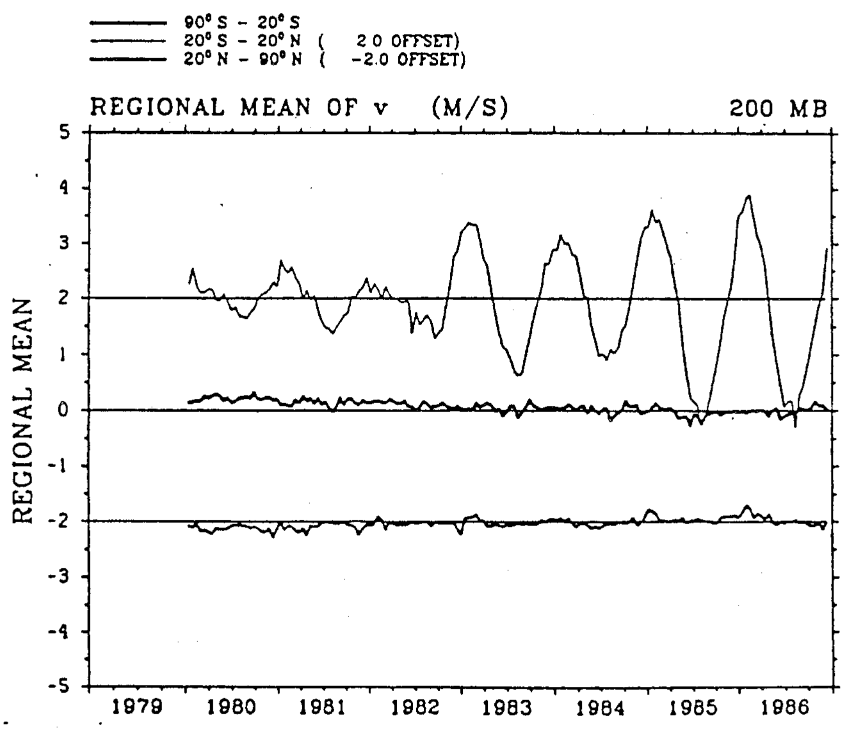

Figure 6.2 Fifteen–day averages of areal averages of v at 200 hPa. The major increase occurred when diabatic processes were introduced into the NNMI in 1982. (From Trenberth, 1992)

7. ATMOSPHERE–OCEAN COMPOSITION

The composition of the atmosphere and oceans is an important component of the climate system. From the deepest part of the ocean to the top of the atmosphere, atmospheric and oceanic composition exerts a profound influence on the atmosphere/ocean's structure and dynamical systems, and on the radiation emitted and absorbed by the atmosphere. Atmospheric composition is a primary factor in the thermal structure of the atmosphere. The climate could be changed as a result of alterations to outgoing radiative fluxes by greenhouse gases. Aerosols introduced by volcanos (*e.g.*, so_2) and humans (*e.g.*, CFCs and HFCs) can cause changes on both short and long time scales by altering the chemical makeup of the atmosphere and, thus, altering the radiative balance of the earth.

Some important atmosphere/ocean constituents include:

- Water vapor (*i.e.*, the gaseous phase of water) is a very important greenhouse gas because it strongly absorbs outgoing long–wave radiation and, of course, is essential to life itself. Atmospheric water vapor is very important in large–scale thermally driven circulations due to the release of latent heat when the water vapor condenses. Specific (or relative) humidity is a variable commonly (but poorly) observed by both conventional observations (Chapter 3) and satellites (Chapter 5) and is available on analyzed grids (Chapter 6). The distribution of water vapor is known to within ($\pm 20\%$).

- Ozone is present in abundance between 10 and 40 kilometers above the earth's surface. This region of the stratosphere contains about 90% of the world's ozone. One reason for the importance of ozone is that it absorbs dangerous ultraviolet (UV) radiation from the sun. In fact, ozone absorbs nearly all solar radiation between 0.2 and 0.3 μm. Decreases in ozone in the upper atmosphere (*e.g.*, "the ozone hole"; possibly induced by humans) allow more ultra–violet radiation to reach the surface of the earth which could alter the chemistry of the troposphere and expose plants, animals and humans to dangerous side–effects. Additionally, variations in ozone amounts, which are very sensitive to variations in solar radiation, affect the distribution of temperature and wind in the stratosphere, which could affect the dynamical interactions between the stratosphere and troposphere. It is also an important component of smog near the surface and some communities have occasional 'ozone alerts'.

- Observational records from both Mauna Loa (Hawaii) and the South Pole indicate that the amount of carbon dioxide in the atmosphere has been steadily increasing. Much of this increase is due to the burning of fossil fuels. Carbon dioxide plays an important role in greenhouse warming scenarios because it absorbs outgoing long-wave radiation and, thereby, warms the lower atmosphere.

- Salinity is a measure of the total dissolved salts in sea water. Combined sodium and chloride make up about 85% of the principal ionic constituents in sea water. Although salinity varies throughout the ocean, the relative proportion of constituents remains very nearly constant, with the exception of ocean water directly impacted by river runoff. This relationship is important and is exploited by instruments designed to determine salinity. Salinity has a major influence on the physical properties of sea water. Ocean water density is determined by temperature and salinity; and density variations affect water flow (ocean currents) much in the same way atmospheric density variations cause wind. Some other properties that are influenced by variations in salinity are: the freezing point of sea water, the speed of sound, electrical conductivity, and specific heat capacity.

- The distribution of oceanic dissolved nutrients and oxygen strongly influences the distribution of biological ecosystems in the marine environment. The primary nutrients are nitrate, nitrite, phosphate, and silicate. The many complex relationships between biological activities and nutrient distribution are beyond the scope of this report. Beyond biological considerations, the variations in large scale nutrient distributions are used as tracers to infer general ocean circulation.

- There are several minor oceanic constituents that have recently become of interest as scientists attempt to answer climate change and global warming questions. For example, knowing the distribution and changes in distribution of co_2 and n_2o are important to understanding the carbon cycle and human impacts from burning fossil fuel. Even very minor ocean trace elements such as strontium and uranium that have been embedded in marine corals over millenia are used to detect changing environmental conditions in the distant past, giving a perspective for the observed changes that have occurred in the recent decades.

Datasets, particularly those derived from satellite measurements, are providing increased knowledge of the amount and variability of many atmospheric constituents. The most common constituents measured include water vapor, ozone and those associated with greenhouse warming (*e.g.*, methane). Measurement for many other constituents are available but are limited. Currently, several projects are in progress or have been proposed to address the need for more data. Some of these include the:

WMO's Global Atmospheric Watch: The GAW program is the principal permanent operational program for monitoring the evolution of the chemical composition of the atmosphere on global and local scales.

WCRP's Stratospheric Processes and their Role in Climate: The SPARC project will make ground-based and vertical profile measurements of physical parameters in the stratosphere as well as aerosols and chemical species of fundamental importance to determine stratospheric change.

IGBP's International Global Atmospheric Chemistry Program: The IGAC makes measurements of chemical processes in the troposphere, particularly those related to the oxidizing capacity of the atmosphere.

WMO's International Global Aerosol Program: IGAP will make observations of the optical properties related to aerosols to determine the impact of aerosols on climate.

The Carbon Dioxide Information Analysis Center (CDIAC) has archives containing greenhouse gas data and operates as a World Data Center for Atmospheric Trace Gases. (See Appendix A for details on contacting CDIAC.)

Table 7.1
Some NCAR Datasets with Constituent Information

NCAR ID	MAX. PERIOD	DESCRIPTION
ds254.0		Najjar, Global ocean nutrient grids (po_4, no_3, sio_2)
ds709.0	1989–81	NASA SAMS Experiment Zonal Mean Methane + n_2o
ds710.0	1978–86	NASA Nimbus-7 Orbital Total Ozone Obs, 78Oct-86Sep
ds711.0	1970–77	NASA Nimbus-4 Total Ozone Obs, 70Apr–77May
ds765.5		GSFC Global Wetlands+Methane Emission, 1°
ds804.0	1963–69	NCC TD9518 Daily Ozone Soundings, 63Sep-69May
ds805.0	1951–75	Canadian Total Ozone Obs + Anals, daily, monthly
ds805.1	1957–76	London's Global Total Ozone Anals, monthly
ds805.2	1957–85	Canadian Ozonesondes + Total Ozone, 1957Jul-1985
ds806.0	1967–69	London's Global Ozone from OGO-4, 1967Sep-1969Jan
ds866.0		GISS Methane + Livestock Distribution, 1°
ds867.0		Matthew's GISS Methane from Rice Cultivation

8. RESEARCH PROJECT DATASETS

The meteorological and oceanographic communities are confronted with many difficulties when performing research on physical processes. One major problem is obtaining detailed information on processes over the globe (particularly, over the oceans). No single nation has the resources to document the behavior of the global climate and the natural and human potential for altering it. To address this problem, the research communities develop experiments and programs which involve many nations. These international efforts allow different nations to participate and contribute to programs of global significance. Some examples of past, ongoing and future research programs and experiments include*:

International Geophysical Year: The IGY was the first of several international geophysical programs. The IGY spanned the period 1 July 1957 through 31 December 1958. Extensive observations for a wide range of geophysics including meteorology and oceanography were made at a worldwide network of stations.

Global Atmospheric Research Program: The GARP was designed to study the dynamics and physical processes in the atmosphere with the principal objective of extending the range of useful weather forecasts and understanding the physical basis of climate. The program spanned the period 1967–1982 and involved the cooperation of many nations. The GARP was implemented as a series of major observational and experimental studies.

GARP Atlantic Tropical Experiment: GATE was the first of a series of field experiments within GARP. The purpose was to study the physical processes in the tropical atmosphere, in particular cumulus convection, and their relation to large–scale weather systems in the tropics and the general circulation of the atmosphere. Seventy countries participated during the period June through September 1974.

First GARP Global Experiment: FGGE was the principal observational and experimental component from GARP. The entire global atmosphere was studied in detail for a period of one year (December 1978 – November 1979) by a wide range of organizations. There were two Special Observing Periods (SOPs; 1 Jan to 5 March and 5 May to 5 July, 1979) during which special observing systems were mounted and many additional meteorological observations collected.

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* Some of these summaries were based upon material appearing in International Meteorological Vocabulary, WMO–No.182, 1992.

The data collected represent the most comprehensive set of meteorological variables ever assembled, and have been the basis of extensive research into atmospheric dynamics and physical processes leading to major advances in operational weather forecasting.

Tropical Ocean and Global Atmosphere Program: The TOGA Program commenced on 1 January 1985 and will be completed 31 December 1994. It is part of the WMO's World Climate Research Programme. The purpose of TOGA is to improve our knowledge of the tropical ocean/atmosphere system and its effect on the climate at higher latitudes. Critically important to the success of TOGA is the collection and archiving of data. These data will form the basis for real-time studies of the evolution of the tropical atmosphere/ocean system and the development of short-term climate prediction models.

TOGA Coupled Ocean-Atmosphere Response Experiment: The TOGA COARE field program is designed to provide data on ocean-atmosphere interactions in the western Pacific warm pool region. COARE has three components: one focused on the atmosphere, one on the ocean and one on the interface between these two systems. Some examples include studies on ocean mixing and energy exchange in this region. These data will allow researchers the opportunity to diagnose and model several aspects of the coupled ocean-atmosphere processes.

Monsoon Experiment: MONEX was part of the FGGE. It occurred in two phases: the winter of 1978–79 (Winter MONEX) and the summer of 1979 (Summer MONEX). It was part of the FGGE and was aimed at obtaining a better set of observations in the monsoon regions. (All the MONEX data is in the FGGE data sets. In fact, these are the best sources of MONEX data.)

Alpine Experiment: ALPEX was the last field experiment conducted within the framework of GARP. Data from the Alpine region have been collected and analyzed in order to understand phenomena such as lee-side cyclogenesis and the mechanisms for driving local mountain winds. The program was initiated in 1981 and is continuing. There was a special observing period in 1982.

World Climate Research Programme: The WCRP provides a framework for cooperation among nations. It has been in existence for about 10 years. Programs and experiments within the WCRP are directed toward advancing our understanding of climatic variations on a wide range of time scales, from monthly monthly-seasonal fluctuations to seasonal-interannual variations to decadal and century-scale changes.

International Geosphere-Biosphere Program: The IGBP which began in 1986 provides a framework for biological and chemical experiments which focus on understanding and prediction of changes in the earth system on time scales of decades to centuries.

World Ocean Circulation Experiment: Under the WCRP, WOCE has several objectives. These include: (i) developing models useful for predicting climate change; and (ii) collecting a comprehensive set of observations which can be used to validate the models and provide a basis for studying the long term behavior of the ocean.

Global Energy and Water Cycle Experiment: GEWEX objectives are to: (i) determine the hydrologic cycle and energy fluxes by means of global measurements of atmospheric and surface properties; (ii) model the global hydrologic cycle and its impacts on the ocean and atmosphere; and, (iii) develop the ability to predict variations of global and regional hydrologic processes and water resources and how these variations are influenced by environmental change.

Earth Observing System: EOS is the major NASA contribution to the U.S. Global Change Research Program. It consists of (i) a series of satellites whose instruments will detect a large number of geophysical variables to study processes and monitor changes on the land, ocean and atmosphere; (ii) a Data and Information System (EOSDIS) to archive and distribute data and geophysical and biological products; and (iii) a scientific research program. It is the beginning of a comprehensive, global observing system with wide–band, high spectral and spatial resolution over a long time frame. The first EOS satellite may be launched in 1998 with new satellites every 18 to 24 months and replacements every 5 years. The EOS is projected to provide a 15–year series of scientific products. In preparation for the massive amounts of data which will be archived and disseminated, a number of EOSDIS have already been established (Appendix A). EOSDIS will be a state–of–the–art information system to foster rapid and easy access for users. EOSDIS policy specifies that all data and derived products be available to all users. Researchers in the U.S. and participating countries will pay only the nominal cost of data reproduction and delivery.

Tropical Rainfall Measuring Mission: TRMM is a joint effort between the U.S. and Japan. It will test the feasibility of using active and passive microwave data, together with the visible and infrared, to derive rainfall amount and distribution between 35° north and south latitudes. In addition, some information about the vertical distribution of rain in thunderstorms will be obtained. TRMM seeks, at least, a three year dataset of monthly averaged rainfall. (As part of EOS, an additional TRMM package is proposed in order to provide a decade of continuous observations.) Data from TRMM will be used to validate climate models.

Upper Atmosphere Research Satellite: UARS will gather data related to the chemistry, dynamics, and energetics of the stratosphere. UARS data will be used to study energy input, stratospheric photochemistry, and upper atmospheric circulation. UARS will provide information which will be used to understand and predict how the nitrogen and chlorine cycles relate to ozone balance.

Table 8.1
Some Gridded Analyses from Research Programs at NCAR

NCAR ID	SOURCE	GRID	REGION	PERIOD	UPDATE	VARIABLES	LEVELS
ds027.0	IGY		NH	7/1957-6/59	daily		strato
ds102.0	IGY		SH	6/1957-58	daily	slp, z	sfc,500hPa
ds103.0	IGY		SH	6/1957-58	daily	z	500hPa
ds106.0	IGY		Tropics	6/1957-58	daily	slp	sfc
ds111.0	ECMWF TOGA	T106	Global	1985–pres	6hrly	u,v,w,t,z,rh	tropo,strato
ds111.1	ECMWF TOGA	N80	Global	1985–pres	6hrly	pcp,tsoil, *etc.*	sfc
ds111.2	ECMWF TOGA	144x73	Global	1985–pres	12hrly	u,v,w,t,z,rh	sfc,tropo,strato
ds111.3	ECMWF TOGA	N48, N80	Global	1985–pres	6hrly	sens+latent heat flux stress,LW,VIS	19 levels
ds111.4	ECMWF TOGA	T106	Global	1990–91	6hrly	t,w,vort,div,q	19 levels
ds111.5	ECMWF TOGA	144x73	Global	1985–92	mon	u,v,w,t,z,rh	sfc,tropo,strato
ds302.2	MONEX		Tropics	5-7/1979		u,v	tropo
ds302.4	MONEX		Tropics	5-7/1979		precip	sfc
ds302.5	ECMWF FGGE		Global	1978-79		w	tropo,strat
ds304.0	GARP DST 3		Global	5/1974-3/76			tropo,strato
ds307.0	ECMWF FGGE	192x49	NH,SH	1978–79	12hrly	u,v,w,t,z,rh	sfc,tropo,strato
ds307.1	ECMWF FGGE		Global	1-3/1979	daily		
ds307.3	ECMWF FGGE	192x49	NH,SH	1979	6hrly	u,v,w,t,z,rh	sfc,tropo,strato
ds307.5	ECMWF FGGE	96x25	NH,SH	1978–79	12hrly	u,v,w,t,z,rh	sfc,tropo,strato
ds307.7	ECMWF ALPEX		Global	spr/1982	daily		sfc,tropo,strato

9. ANCILLARY DATASETS

Some datasets contain information which is not meteorological or oceanographic but influence or interact with the climate system. Topography (sometimes called orography), vegetation soil type, wetlands, albedo, hydrological information (*e.g.*, streamflow and runoff) and solar data fit into these categories.

Topography

Topography alters the flow of the atmosphere. The lee sides (*i.e.*, the downwind side) of large mountain ranges are areas where cyclones often develop or where weak disturbances intensify (*i.e.*, cyclogenesis). In addition, topography can act as a barrier that prevents cold or warm air from penetrating certain geographic regions. For example, the Indian Peninsula is protected from bitter cold Siberian air masses during the winter season, while during summer, the topography can cause considerable variability in precipitation amounts over very short distances. Regions where winds have a component blowing toward the mountains can result in large amounts of precipitation due to orographic lifting.

The ocean bottom topography is also very significant in oceanography. The continental slopes and shelves that adjoin the continents form barriers for oceanic currents. Some eastward flowing ocean currents develop into strong western boundary currents (e.g. the Gulf Stream, and Kuroshio Current) along the continental slopes. Mid-ocean ridges form the largest relief features on earth and strongly influence deep water circulation and the distribution of deep ocean water properties. At shallow levels there are sills and constrictions that isolate deeper water in fjords and enclosed seas (*e.g.*, the Mediterranean Sea, Gulf of Mexico, and Sea of Japan). Topographic features like these greatly control the water exchanged with the open ocean and determine many characteristics of the enclosed sea. In some cases, the water that spills over the sills is traceable over much of the open ocean. For example, the Straits of Gibraltar are very shallow (the Gibraltar Sill) and restrict the flow of the very saline waters of the Mediterranean Sea into the Atlantic. The saline water is more dense and would normally flow out along the bottom, but the sill retards this flow to the extent that when the water can finally spill over the sill, it is traceable over much of the Atlantic Ocean because of its relatively high temperature and salinity.

Topographic datasets are available in a range of grid resolutions. Some are coarse (*e.g.*, 2.5°) while others are of high resolution (*e.g.*, 30 seconds). Users should be aware that those with coarser resolutions generally represent a spatial average while the high resolution grids represent point values. In some cases, however, "high-resolution" datasets are actually interpolated from those with lower resolutions. The highest resolution datasets are generally available for specific regions of the globe (*e.g.*, North America) because of the large volume of data.

Land–Surface Data

Vegetation, soil characteristics (*e.g.*, texture, color, wetness) and streamflow/runoff are important components of the climate system. Both vegetation and soil are important factors in the global radiation budget. For example, the color of vegetation and soil directly contribute to the surface albedo (*i.e.*, the ratio of radiation reflected by the surface to that incident upon it) which is central to radiation budget studies. Vegetation and other land-surface processes are major factors in the global carbon budget and biogeochemical cycles. Land–surface hydrology (*e.g.*, river/stream flow and runoff) is important both from a local and a global perspective. These can influence crops/vegetation, soil wetness and irrigation.

Land–surface datasets contain much information. Some examples include: vegetation classifications and indexes, major world ecosystems, biomass, hydrological information and soil characteristics. These datasets are difficult to evaluate and each has strengths and weaknesses. Some are derived from atlas data and, given the rapidly changing world in which we live, may not be applicable on a local basis. Some may have detailed soil types while others use very broad definitions.

Solar Data

Solar data are necessary for radiation budgets and it is possible that even small variations in energy output by the sun may influence the climate. Sunspot data have been available for centuries. One of the best known geophysical cycles is the solar sunspot cycle. This is a quasi–periodic variation with a period of about 11 years. Although satellite data have indicated that the variation of solar energy at the top of the atmosphere is small (about 0.1%, but much larger in certain wavelengths such as UV), chemical reactions such as the creation of ozone in the upper atmosphere can be very sensitive to these variations.

Table 9.1
Topography

NCAR ID	Source	Grid	Area
ds750.0	Scripps	1°	global
ds750.1	RAND	1°	global
ds754.0	U.S. Navy	10'	global
ds755.0	U.S.A.F.	1°, 30', 5'	global
ds756.1	DMA	30 sec	U.S.
ds757.0	NMC	2.5° + spectral	global
ds759.1	NGDC	5'	global

Table 9.2
Gridded Soil, Vegetation and Albedo

NCAR ID	Source	Grid	Type
ds207.0	RAND	4°- 5°	albedo
ds676.0	NESS	2.5°	albedo
ds765.0	Matthews-GISS	1°	vegetation cultivation intensity seasonal albedo
ds765.5	Matthews-GISS	1°	wetlands+vegetation % inundation methane emission soil
ds766.0	Argonne	$\frac{1}{4}, \frac{1}{6}$°NA	land usage (Landsat)
ds767.0	Wilson, H–S	1°	vegetation/color soil
ds769.0	Olson	0.5°	ecosystems (veg by carbon den)
ds770.0	Staub-Rosenw	1°	soil
	(GISS+FAO)	1°	sfc slope

Table 9.3
Datasets with Solar Information

NCAR ID	MAX. PERIOD	DESCRIPTION
ds832.0	1932–81	NOAA WDCA Magnetic Indices + Sunspots
ds834.0	1610–1993	Sunspots, 1610-1986 (from Clark + NGDC)
ds503.0	1952–76	NCDC SOLMET TD9724 Solar + Sfc Obs, daily
ds504.0		NCDC TD9734 Typical Meteorological Year, Solar + Sfc
ds730.0	1978–83	Campbell's Earth Radia Budget Exper (ERBE)
ds732.0	1984–86	Barkstrom's (ERBE)
ds733.0	1978–87	NIMBUS 7 ERBE Matrix Data, daily 1978Nov-1987Nov

10. INTERNET*

Modern communications and computers allow access to a wide variety of information (*e.g.*, data, software, documentation). The methods of communication are changing rapidly. Currently, there are several commonly used methods of electronically determining where data are located and accessing and transferring data. Most universities and research facilities have access to network resources, so this is a good way of discovering public information about scientific data.

The Internet connects many universities, government labs, commercial companies and military installations. The Internet is not a monolithic organization. Rather, it is a cooperative of local networks that have agreed–upon a defined common method of communication called a protocol. Thus, the Internet is a network of networks that functionally works as one network. The protocol used for the Internet is the "Transmission Control Protocol/Internet Protocol" or TCP/IP. This protocol (actually a set of protocols) was developed by the U.S. Department of Defense in the early–to–mid 1970s. The TCP, which usually resides within an operating system, allows full duplex, sequenced, and non–duplicated delivery of information between individual computers. The IP is used to transmit information across the Internet.

Each local network consists of a router (most often implemented as software on a workstation) which is connected to a communication line which in turn is connected to another router and so on. The routers are sometimes called gateway machines because they allow access to both a local network and other networks which use different protocols.

NCAR is an important link within the Internet. It is part of the National Science Foundation's NSFNET which is sometimes referred to as the "backbone". This network was originally developed to allow NSF's supercomputer centers to communicate with each other. Currently, NCAR is one of 16 nodes on the NSFNET backbone. (*Note*: In the near future NSFNET will be phased out in favor of a new networking infrastructure.)

The TCP/IP set of protocols supports several features including, remote logins, file transfers, and electronic mail. Some TCP/IP applications include:

Electronic Mail (e–mail): Electronic mail allows communications between individuals on different computers. It can also be used to transfer small amounts of data or software. This method

* Notation used in this chapter: anything in **boldface** is either used for emphasis or is something entered on a keypad; hopefully the two cases will not be confusing.

of communication facilitates dialog between individuals at remote sites (and even with people in the next office!).

Telnet: Telnet is a program, and a protocol, which allows the user to log on to a remote system. In general, remote hosts require the user to have an account and a password in order to log in. Some services, though, allow connection through a general user id (or even no user id); in this case, a password is usually not required, and the user is put into a restricted shell from which only certain commands are available (usually via a menu system). To connect to another machine, simply type **telnet** followed by the name of the host. For example, to connect to the USGS telnet service, you would type **telnet glis.cr.usgs.gov**.

File Transfer Protocol: The File Transfer Protocol (FTP or ftp) is the most ubiquitous method of inter-network data transfer. Almost all systems support this method. FTP is the primary utility for fast, reliable file transfers between computers on the Internet. Most systems which have public information available support "anonymous FTP". This means that no secret password is required to access this information. To access a computer using anonymous FTP, at your system prompt type **ftp** followed by the Internet name or address of the desired system. For example, to connect to the computer called ncardata.ucar.edu which contains information on datasets available at NCAR, you would type **ftp ncardata.ucar.edu**, use **anonymous** as your login and your email address as the password (if requested). Type **help** to get a list of commands which you can use to search files and obtain information. On some systems you must enter **help** followed by a command to get specific information.

Not all FTP systems accept the same commands, but a list of some useful commands includes:

ls	list files in the current directory
cd	change directory, *e.g.*, **cd wx** changes to the wx directory
binary	sets transfer mode to be appropriate for binary files
ascii	sets transfer mode to be appropriate for text/ascii files (the default)
get	retrieves a file, *e.g.*, **get readme** gets a file called readme
bye	exits FTP

Some sites are configured to prohibit outgoing FTP connections for security reasons. Users at these sites can make use of the FTP-by-mail servers which are available:

ftpmail@decwrl.dec.com	North America
ftpmail@src.doc.ic.ac.uk	United Kingdom
ftpmail@cs.uow.edu.au	Australia
ftpmail@grasp.insa-lyon.fr	France
ftpmail@ftp.uni-stuttgart.de	Germany

Send an e-mail message to the closest address, with the lines:

reply your_address@some.where	with your email address
connect ncardata.ucar.edu	for example
cd datasets/ds111.2/software	again - for example
get access_sun.f	the name of the file you want
quit	

For complete instructions, send a one-line message reading **help** *to the server.*

Archie: The "archie" service is invoked by entering **archie**, or, better yet, **xarchie** if you are on an X-Window system. It can be used for searching all FTP sites for filenames and directories matching a specified search string. Users should be aware that archie can put large demands on the network when many searches are requested.

Gopher: Using ftp requires users to know where they can access the data; they must connect to a particular Internet address, and then navigate through subdirectories. Also, if many remote users are examining or browsing a data base, a computer server can be overwhelmed. Gopher is a distributed information system developed at the University of Minnesota that allows efficient access to databases that are stored on computers all over the world. Gopher does not tie up a remote machine because it is connected only long enough to access desired information, and it is easy to use because it is strictly menu driven.

Gopher is a program executed by entering **gopher** or **xgopher** (if on a system running X-windows). It can be used to retrieve files from Gopher servers anywhere on the Internet. Gopher servers store files containing text or binary data, as well as links to other Gopher servers and gateways to other information systems and network services such as FTP.

The Gopher client presents information to the user as a series of nested menus. Some menu items may lead to files, and some may lead to other menus. The "Veronica" service allows users to search all Gopher servers for file descriptions which contain a specified keyword.

Public domain Gopher clients are available for many computers and operating systems. If one is not already installed on your system, you can obtain a client by anonymous FTP to **boombox.micro.umn.edu**, in the directory **/pub/gopher**. You can also use a remote Gopher client via a telnet session to a remote host such as **consultant.micro.umn.edu** or **gopher.uiuc.edu** (login as **gopher** unless otherwise specified).

World-Wide Web (WWW): The "Web" is a multimedia hypertext-based information system. "Hypertext-based" means that any word or image in a document can be specified as a pointer (link) to another document where more information can be found. The reader can open the second document by selecting the link.

WWW servers make use of the Hypertext Transport Protocol (HTTP or http) and are sometimes referred to as "http servers". As with Gopher, the documents can be distributed across many remote systems with different protocols. The reader need not know where the referenced documents are located, nor what protocol is necessary to access them. WWW's advantage over Gopher is that documents may be multimedia; containing formatted text as well as images, sounds, and movies.

To access the WWW, the user must run a client program, often called a **browser**. WWW browsers can access many different types of sites, including FTP, Gopher, Telnet as well as HTTP; because of this, the WWW is rapidly becoming *the* major means of access to Internet resources. The most popular WWW client is NCSA Mosaic, which runs under X-windows, Microsoft Windows and Macintosh to provide a point-and-click interface. You can retrieve copies of NCSA Mosaic in both source and executable binary form from NCSA's anonymous FTP server, **ftp.ncsa.uiuc.edu**.

Other graphical Web browsers are available for most (if not all) platforms. There are line-mode and VT100 browsers available for terminals without graphic capability. If one is not already installed on your system, you can obtain information about clients by anonymous FTP to **info.cern.ch** in the **/pub/www/src** directory. You can also use a remote WWW client via a telnet session (login as **www**) to the nearest of several hosts :

fatty.law.cornell.edu	Eastern North America
www.njit.edu	Eastern North America
www.cc.ukans.edu	Central North America
www.huji.ac.il	Israel
info.funet.fi	Finland
info.cern.ch	Switzerland

Initially, the user is connected to a "home page". When the user clicks on any highlighted word, phrase, or image, Mosaic accesses the selected document. For example, someone using Mosaic to look at NCAR's DSS catalog might click on the name of a dataset to get the desired information. Mosaic allows full exploitation of many of the features of the WWW, such as interactive forms and maps, so it is very popular; in fact, WWW servers are sometimes (incorrectly) referred to as "Mosaic servers". The documents being viewed have an address called a Uniform Resource Locator (**URL**) that is the WWW equivalent of a filename that includes information about the server. Generally, the URLs can be built based upon a knowledge of the site/server and the filename of the document as shown below:

ftp://host.name.domain/directory/[filename]	ftp site
http://host.name.domain/directory/[filename]	www server
telnet://host.name.domain	telnet site
gopher://host.name.domain	gopher server
wais://host.name.domain	wais server
news:newsgroup.name	newsgroup

For example, if a document is available at **ftp://nic.fb4.noaa.gov/pub/** it means that you could type (assuming you are on a UNIX system) **ftp nic.fb4.noaa.gov**, then log in as **anonymous**, answer the password prompt with your email address, **cd pub**, then **ls**, just to see what is in the directory, much less look at any document. If you are using a WWW browser, you could find the *Open URL* menu, enter **ftp://nic.fb4.noaa.gov/pub/** and the contents of that directory will be listed, usually with icons indicating the type of file (text, directory *etc.*). The files can also be "browsed" in place merely by clicking on the link. This is a significant advantage over FTP. This strategy also works with numeric sites, i.e. opening the URL **ftp://192.67.134.72/** works too (this is the anonymous FTP area for the NCDC). More information on building URLs is generally located under the *Help* menu in your browser.

Some FTP sites (currently including NCAR) have hypertext documents and effectively "simulate" http servers; opening these documents with a browser allows you to use the full benefits of the multimedia nature of the WWW.

The bottom line is that the more you poke around on the WWW, the more you find. Please do not abuse the WWW by accessing non-work-related images; this slows down the system for all of us.

Finding Documents and Data using Mosaic:

The simplest way to access a known URL is to go under the *File* menu and click on *Open URL*. This will create a window that has an editable field and several options. When you finish typing the URL, click on *Open*, and the "page" will open in the Mosaic window.

If you don't know a specific URL, things are slightly more complicated and potentially a **lot** more convoluted. Under the *Navigate* menu are two choices: *Internet Starting Points* and *Internet Resources Meta-Index*. If you know the geographic region or location of the item you are trying to locate, poke around in *Internet Starting Points* and get to *Web Servers Directory*, an alphabetical list of WWW servers listed by region.

Under the *Internet Resources Meta-Index* submenu are links for several methods of searching the WWW, usually from indices (lists) compiled from searches made aperiodically on WWW servers. There are also a few general indices which allow users to search information about all servers for a specified keyword. This search capability has been extended to include such Internet tools such as Gopher, FTP, archie, and finger. In particular, the *World Wide Web Worm* (under the Meta-Index submenu) or the *World Wide Web Crawler* (available at **http://www.biotech.washington.edu/WebCrawler/WebQuery.html**) are very useful and have documentation on-line.

Meteorology Frequently Asked Questions:

A very large list of meteorological and oceanographic data sources is available on the net as part of the *Meteorology Frequently Asked Questions* (**FAQ**). There are currently two parts to the meteorology FAQ (part1 and part2), which can be found at **ftp://rtfm.mit.edu/pub/usenet/news.answers/weather/data**. This is updated every two weeks, when a new copy is posted to newsgroups *sci.geo.meteorology*, *news.answers* and *sci.answers*. If you can't use FTP, send email to **mail-server@rtfm.mit.edu** with **send /pub/usenet/news.answers/weather/data/part1** as the only text in the message (leave the subject blank). Do the same for part2. Other sources for the meteorology FAQ include **ftp://vmd.cso.uiuc.edu/wx/sources.doc** and the hypertext version

http://www.cis.ohio-state.edu/hypertext/faq/usenet/weather/top.html.

Scientific Data Format Frequently Asked Questions:

More information about scientific data formats may be found in the current copy of the *Scientific Data Formats FAQ*. This can be obtained by anonymous FTP to **rtfm.mit.edu** and is called **/pub/usenet/news.answers/sci-data-formats**. If you can't use FTP, use one of the FTP-by-mail servers previously mentioned. A current hypertext version can also be obtained from **http://fits.cv.nrao.edu/traffic/scidataformats/faq.html**, from **http://www.ncsa.uiuc.edu/SDG/Software/HDF/SciDataFormatsFAQ.html**, or (for European users in particular) from **http://info.mcc.ac.uk:80/CGU/Visualisation/sdf.html**. This FAQ is also updated every two weeks, with copies posted to *sci.data.formats*, *sci.answers* and *news.answers*.

More information about the Internet, FTP, Telnet, *etc.* may be found in either of the above-mentioned FAQs.

11. DATA AVAILABLE AT NCAR AND METHODS OF ACCESS

An important function of NCAR is providing researchers with efficient, low-cost access to datasets. Several sections within NCAR have datasets which are available.

Data Support Section

NCAR's Data Support Section (DSS), which is part of NCAR's Scientific Computing Division (SCD), maintains an archive of more than 400 atmospheric, oceanographic, and geophysical datasets. It is one of the most comprehensive data archives to support atmospheric and oceanographic research. Most of the datasets originated elsewhere, and they are archived at NCAR in their original forms. These datasets can be used by researchers with access to NCAR's Mass Store System (MSS). Other users can order datasets on a variety of magnetic media or, for small datasets, by FTP. Generally, there is a nominal charge.

The types of data available from NCAR cover a very wide range of subjects, including most of the data types discussed in previous sections of this document. The data archive is organized in a decimal system similar to the library's Dewey system (see Appendix E). The datasets are grouped such that similar datasets are numerically close to one another. Appendix F has a complete list of datasets available from the DSS as of the date of this publication.

Researchers can obtain an up-to-date list of all of the DSS datasets and other information (including pricing) via anonymous FTP to **ftp ncardata.ucar.edu** , or by using a WWW browser and opening the URL named

ftp : //ncardata.ucar.edu/catalogs/.html/README.html.

Each dataset has one or more volume serial numbers (VSNs) associated with it. A VSN is a file on the MSS. It usually consists of a single file, but sometimes contains many files, separated by logical file marks. Sometimes there is only one VSN for the entire dataset; more often, there are many VSNs, for example one VSN for each month of a large, multi-year dataset. The VSNs are of the form KnnnnK or Ynnnnn, where each n represents a digit. For example, the character version of the dataset ds754.0 is in the VSN named K0240K and the MSS path would be /DSS/K0240K.

Information on a particular dataset, say ds754.0, is contained within the subdirectory 'datasets/ds754.0' . If you are using ftp, you can 'cd' to that directory; from a WWW browser, you can select the menu of datasets from the DSS home page and simply select the dataset of interest. Within each subdirectory there is a file called MASTER which provides a brief outline of the dataset contents and lists the VSNs in that dataset. In addition, FORTRAN routines and, occasionally, inventories for each VSN are available.

The DSS staff provides assistance and expertise to help researchers locate data appropriate to their needs. Questions may be sent via email to **datahelp@ncar.ucar.edu**. [see Appendix A]

Climate Analysis Section

The Climate Analysis Section (CAS) of NCAR's Climate and Global Dynamics Division (CGD) attempts to increase the understanding of the atmosphere by exploring aspects of climate through development and analysis of observational and assimilated data sets and by using the datasets for empirical studies, diagnostic analyses, and model validation. An important central ongoing thrust relates to datasets and includes acquisition of data; evaluation, improvement, and restructuring of datasets; development of climatologies; and use of datasets in diagnostic studies.

The CAS archive includes a variety of datasets (generally) archived as T42 Gaussian grids. These have been reformatted from equally spaced grids at various resolutions to a common grid to facilitate comparisons. (The DSS is the original source of the equally spaced grids.) The datasets include climatologies, monthly means, gridded satellite data and analyzed data. Of particular interest are sets of ECMWF and NMC daily global analyses which are available at various spectral resolutions determined two or four times per day. The datasets have been subject to considerable quality control and have been used as the basis for calculating monthly averages of the basic state variables and deriving value-added diagnostic quantities on a T42 Gaussian grid. The size of the archive with monthly quantities is much smaller and more manageable than the original daily archive. They are archived in the format used by the NCAR Community Climate Model. However, software exists that can be used to interpolate the data to arbitrary grid arrangements. Information about these datasets has been cataloged and can be obtained by using e-mail, gopher or the Web. Specifically:

(i) For email access, the user should send mail to **casmail@isis.cgd.ucar.edu** with a subject of 'help'. This will result in a help file being sent to the user.

(ii) The catalog may be accessed via gopher, either directly or through the World Wide Web (see [iii]). The CGD gopher is located at **isis.cgd.ucar.edu**, from that menu one can directly move to the CAS Catalog.

(iii) For those with access to a WWW client, the CAS home page is at **http://www.cgd.ucar.edu/cas**. The home page has a link to the CGD gopher mentioned above.

Climate Modeling Section

Research in the Climate Modeling Section (CMS) encompasses a variety of modeling studies of the physical mechanisms governing the global climate system. In particular, the CMS developed the Community Climate Model (CCM2*) and has made a number of control integrations available for general use (Table 11.5). These include simulations with different spectral resolutions than the one at which the model was developed (T42); simulations with observed sea-surface temperatures; and, a simulation with the optional Biosphere-Atmosphere Transfer Scheme (often referred to as "BATS"). Details may be found under the NCAR gopher or in the NCAR Technical Note by Williamson (1993). These datasets can be used by researchers with access to NCAR's Mass Store System (MSS).

Datasets produced by atmospheric and oceanographic models can be quite large. The dataset size is a function of horizontal and vertical resolution and how many and how often variables are saved. A typical ten year integration of the CCM2 at T42 horizontal resolution with daily averaged data archived consists of about 55GB. Figure 11.1 illustrates a typical data reduction path one might follow to produce results.

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* FORTRAN code for CCM2 may be obtained via anonymous ftp (**ftp ftp.ucar.edu**; **cd ccm**; **binary**; **get ccm2.tar**; get other files also).

Table 11.1
CAS Archive: ECMWF

SOURCE:	derived from ds111.0
TITLE:	ECMWF TOGA Advanced Operational Analysis
TITLE:	Upper-air Dataset
GRIDS:	T42 truncation from Spherical Harmonics
LEVELS:	1000mb 850mb 700mb 500mb 400mb 300mb 250mb
LEVELS:	200mb 150mb 100mb 70mb 50mb 30mb 10mb
LEVELS:	As of Jan 01, 1992, There is also a 925 mb level
VARIABLES:	Z T U V W RH Q Psfc
DATES:	January 1, 1985 - December 31, 1993
HOURS:	00,06,12,18
FILES:	/TRENBERT/CTEC/ET42yymmdd, with yy=year, mm=month, and dd=first day on volume. dd takes the values: 01,04,07,10,13,16,19,22,25,28 and sometimes 31
MEANS:	Monthly means are available for the same period
SOURCE:	derived from ds111.2
TITLE:	ECMWF TOGA Advanced Operational Analysis
TITLE:	Upper-air Dataset
GRIDS:	T42 truncation from 2.5 Gridded data
LEVELS:	1000mb 850mb 700mb 500mb 400mb 300mb 250mb
LEVELS:	200mb 150mb 100mb 70mb 50mb 30mb 10mb
VARIABLES:	Z T U V W RH, Q, Psfc, Land-Sea-Ice Flags
DATES:	January 1, 1985 - December 31, 1993
HOURS:	00,12
FILES:	/TRENBERT/CTGAN/U/ET42yymmdd,with yy=year, mm=month, and dd=first day on volume. dd takes the values: 01,06,11,16,21,26, and sometimes 31
MEANS:	Monthly means are available for the same period
SOURCE:	derived from ds111.2
TITLE:	ECMWF TOGA Advanced Operational Analysis
GRIDS:	T42 truncation from 2.5 gridded
LEVELS:	SURFACE
VARIABLES:	PHIS Psfc Tsfc Pmsl U10 V10 T2 T_D2 Land-Sea-Ice Flags (U10, T2 refer to U at 10 meters and T at 2 meters)
DATES:	January 1, 1985 - December 31, 1993
HOURS:	00,12
FILES:	/TRENBERT/CTGAN/S/ET42yymm,with yy=year, mm=month
MEANS:	Monthly means are available for the same period

Table 11.1 (continued)
CAS Archive: ECMWF

SOURCE:	derived from ds110.0
TITLE:	ECMWF WMO Archive
TITLE:	Upper-air Dataset
GRIDS:	T42 and R15 truncation from 2.5 degree Gridded
LEVELS:	1000mb 850mb 700mb 500mb 300mb 200mb 100mb
VARIABLES:	Z T U V W RH Q
SURFACE FIELDS:	PHIS, Psfc, Land-Sea-Ice Flags
DATES:	December 1, 1978 - December 31, 1989 Missing December of 1979
HOURS:	00,12
FILES:	/TRENBERT/CTGAN/Etttyymm, where ttt is either T42 or R15 to indicate truncation, yy is year, mm is month, and for T42 datasets an A or B is appended to indicate the first 15 days or the month, or the remainder, EG. ET428501A
MEANS:	Monthly means are available for the same period

Table 11.2
CAS Archive: NMC

SOURCE:	derived from ds082.0
TITLE:	NMC (Msg data filled with ECMWF data, DS111.0)
TITLE:	Initialized (The fill-in data is uninitialized)
GRIDS:	T42 truncation from 2.5 degree regular
LEVELS:	1000mb, 850mb, 700mb, 500mb, 400mb, 300mb, 250mb,
LEVELS:	200mb, 150mb, 100mb, 70mb, 50mb
VARIABLES:	Z T U V RH Q PHIS Psfc Land-Sea-Ice Flags
DATES:	January 1, 1987 - Feb 28, 1994
HOURS:	00,12
FILES:	/TRENBERT/CTNMC/NT42yymmP, with yy=year, mm=month, and P either A (for days 1-15) or B (for the remainder of the month)
MEANS:	Monthly means are available for the same period

Table 11.3
CAS Archive: Satellite

Mission	Time Period
ERBE	1985-89
ISCCP	March 1983 - June 1991
MICROWAVE SOUNDING UNIT	1982 - 93
NIMBUS 7 CMATRIX	April 1979 - March 1985
NIMBUS 7 ERBE	November 1978 - October 1987
NOAA OLR	June 1973 - April 1993
SSM/I	1985–91

Table 11.4
CAS Archive: Surface/Climatologies

Derived from NCAR ID	Variable and Source
ds277.0	SST: CAC monthly 1979 - 1993
ds289.0	SST: Shea, Trenberth, Reynolds Climatology
ds865.0	Prc: Jaeger (Nominal period 1931-1965)
ds236.0	Prc: Legates (Nominal period 1920-1980)
ds290.0	Prc: Shea (Nominal period 1950-1979)
ds205.0	Tsfc: Crutcher (Nominal period 1950-1964)
ds236.0	Tsfc: Legates (Nominal period 1920-1980)
ds290.0	Tsfc: Shea (Nominal period 1950-1979)
ds217.0	Tsfc: Oort (Nominal Period 1963-1973)
ds110.1	Wind Stress: Trenberth

Table 11.5
CCM2: Control Integrations

Run	Resolution	Time (yrs)	Comment
Standard	T42	20	Case 388
	T42	10	Case 414
	R15, T21, T31	10	
	T63, T106	4	
BATS	T42	10	
AMIP	T42	1979-88	Obs. SST

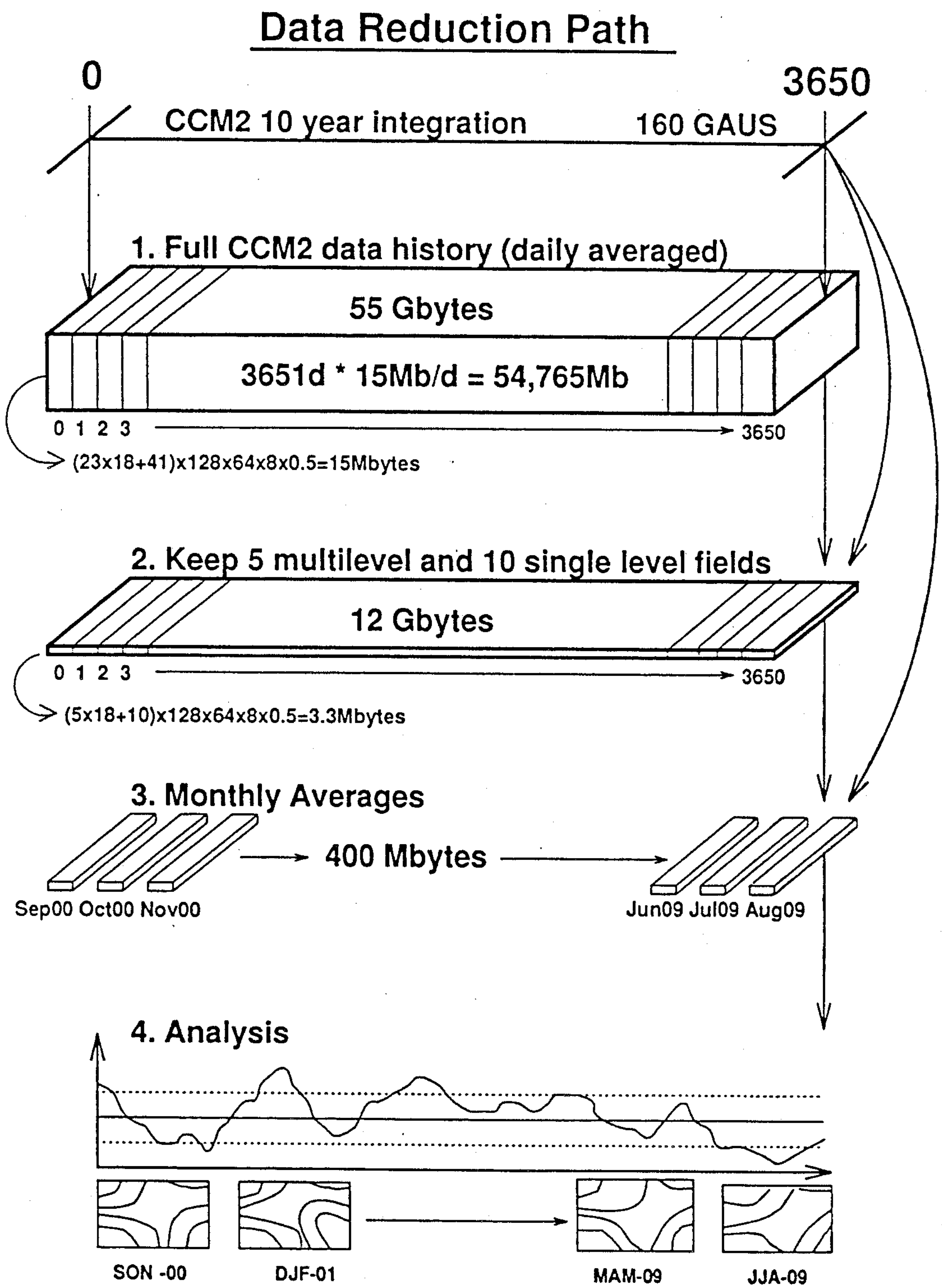

Figure 11.1 Schematic illustrating the size of CCM2 daily averaged datasets at T42 resolution and the data reduction paths one might follow. (Courtesy of Lawrence Buja, NCAR)

12. SUMMARY

A brief tour of data commonly used for research in the atmospheric and oceanographic sciences has been provided. The manner in which data area stored and accessed are described including how to determine where desired data are located. General sources of error for each data source have been outlined. Several rules researchers should apply when using *any* dataset include:

- Determine the strong and weak points of the dataset.
- What problems may be encountered and how can they be handled?
- Given the accuracy of the measurements what conclusions can be substantiated?
- What impacts have changes in instrumentation, observing practices, algorithms and/or methodologies had on the data?

In summary: "Know thy data!".

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Appendix A
Some Atmospheric and Oceanographic Data Centers

NCAR/SCD Data Support Section P.O. 3000 Boulder, CO 80307 (URL) http://www.ucar.edu/ NCAR Discipline: Comprehensive atmospheric-oceanic archives	(303) 497-1219 voice (303) 497-1298 fax (attn: Data Support) (Internet) datahelp@ncar.ucar.edu (FTP) ncardata.ucar.edu
National Climatic Data Center Climate Services Branch Federal Building Asheville, NC 28801 (URL) http://www.ncdc.noaa.gov/ NCDC Discipline: Conventional station and ocean data	(704) 271-4800 voice (704) 259-0876 fax (Internet) orders@ncdc.noaa.gov (FTP) 192.67.134.72 /pub/data/inventories
Carbon Dioxide Inf Analysis Center Oak Ridge National Laboratory P.O. Box 2008 Oak Ridge, TN 37831-6335 (URL): http://jupiter.esd.ornl.gov/programs/cdiac/cdiac.html CDIAC Discipline: Greenhouse and Trace gases	(615) 574-0390 voice (615) 574-2232 fax (Internet): cdp@ornl.gov (FTP) cdiac.esd.ornl.gov /pub
National Oceanographic Data Center User Services Branch NOAA/NESDIS E/OC21 1825 Connecticut Avenue, NW Washington, DC 20235 (URL) http://www.nodc.noaa.gov/ NODC Discipline: Ocean data	(202) 606-4549 voice (202) 606-4586 fax (Internet) services@nodc.noaa.gov (FTP) esdim1.nodc.noaa.gov
National Geophysical Data Center NOAA, Mail Code E/GC, Dept 945 325 Broadway Boulder, CO 80303-3328 (URL) http://www.ngdc.noaa.gov/ngdc.html NGDC Discipline: Wide range of geophysical data	(303) 497-6826/6761 voice (303) 497-6513 fax (Internet) info@ngdc.noaa.gov (FTP) ftp.ngdc.noaa.gov
NSIDC DAAC User Services National Snow and Ice Data Center CIRES, Campus Box 449 University of Colorado Boulder, CO 80309-0449 (URL) NSIDC Discipline: Snow and ice, cryosphere, climate	(303) 492-6199 voice (303) 492-2468 fax (Internet) nsidc@eos.nasa.gov (FTP)

Appendix A (continued)
Some Atmospheric and Oceanographic Data Centers

WOCE Data Information Unit College of Marine Studies University of Delaware Lewes, DE 19958 (URL) http://www.cms.udel.edu/ WOCE DIU Discipline: info on all WOCE data & DACs	(302) 645-4278 voice (302) 645-4007 fax (Internet) woce.diu@delocn.udel.edu (Telnet) delocn.udel.edu (username:INFO)
TOGA COARE UCAR/TCIPO P.O. Box 3000 Boulder, CO 80307-3000 (URL) http://www.coare.ucar.edu/ TOGA/COARE Discipline:	(303) 497-8697 (303) 497-8634 fax (Internet) kippes@ncar.ucar.edu (FTP) tcdm.coare.ucar.edu
Coordinated Request & User Support Office National Space Science Data Center c/o World Data Center-A-R&S (outside USA) Code 633.4 NASA/Goddard Space Flight Center Greenbelt, MD 20771 (URL) http://www.gsfc.nasa.gov/nssdc/nssdc_home.html NSSDC Discipline:	(301) 286-6695 voice (301) 286-1771 fax (Internet) request@nssdca.gsfc.nasa.gov (FTP) nssdca.gsfc.nasa.gov
ASF DAAC User Services Alaska SAR Facility University of Alaska PO Box 757320 Fairbanks, AK 99775-7320 (URL) ASF Discipline: Polar processes, SAR products	(907) 474-7487 voice (907) 474-7290 fax (Internet) asf@eos.nasa.gov (FTP)
EDC DAAC User Services U.S. Geological Survey EROS Data Center Sioux Falls, SD 57198 (URL) EDC Discipline: Land processes	(605) 594-6116 voice (605) 594-6589 fax (Internet) edc@eos.nasa.gov (FTP)

Appendix A (continued)
Some Atmospheric and Oceanographic Data Centers

Goddard DAAC User Services NASA Goddard Space Flight Center Code 902.2 Greenbelt, MD 20771 (URL) GSFC Discipline: Upper atmosphere, global biosphere, atmospheric dynamics, geophysics	(301) 286-5033 voice (301) 286-1775 fax (Internet) gsfc@eos.nasa.gov (FTP)
Langley DAAC User Services NASA Langley Research Center Mail Stop 157B Hampton, VA 23681-0001 (URL) http://eosdis.larc.nasa.gov/ LaRC Discipline: Radiation budget, clouds, aerosol, tropospheric chemistry	(804) 864-8656 voice (804) 864-8807 fax (Internet) userservices@eosdis.larc.nasa.gov (Telnet) eosdis.larc.nasa.gov -l ims (passwd larcims)
Marshall DAAC User Services NASA Marshall Space Flight Center Building 4492 Huntsville, AL 35812 (URL) MSFC Discipline: Hydrologic cycle	(205) 544-6329 voice (205) 544-5147 fax (Internet) msfc@eos.nasa.gov (FTP)
JPL DAAC User Services Jet Propulsion Laboratory Mail Stop 300-320 4800 Oak Grove Drive Pasadena, CA 91109 (URL) http://seazar.jpl.nasa.gov/ JPL Discipline: Physical oceanography	(818) 354-0151 voice (818) 393-2718 fax (Internet) jpl@eos.nasa.gov (FTP) ftppodaac.jpl.nasa.gov
ORNL DAAC User Services Oak Ridge National Laboratory PO Box 2008, Mail Stop 6490 Oak Ridge, TN 37831-6490 (URL) ORNL Discipline: Biogeochemical dynamics	(615) 241-3952 voice (615) 574-4665 fax (Internet) ornl@eos.nasa.gov (FTP)
SEDAC User Services CIESIN SEDAC 2250 Pierce Road University Center, MI 48710 (URL) CIESIN Discipline: Human dimensions of global change	(517) 797-2727 voice (517) 797-2622 fax (Internet) ciesin.info@ciesin.org (Gopher) gopher.ciesin.org

Appendix A (continued)
Some Atmospheric and Oceanographic Data Centers

Canadian Centre for Climate Modelling and Analysis (CCC) P. O. Box 1700, MS 3339 Victoria, B. C. CANADA V8W 2Y2 (URL) CCC Discipline: Model data, CMC Global analyses, climate data	(604) 363-8241 voice (604) 363-8247 fax (Internet) slambert@uvic.bc.doe.ca (FTP) none
National Ice Center 4301 Suitland Road Washington, D.C. 20395-5180 (URL) NIC Discipline: Sea Ice	(301) 763-5972 voice (301) 763-4621 fax (Omnet) D.BENNER/Omnet
National Meteorological Center Transition Project Office W/NMC04 5200 Auth Road Camp Springs, MD 20746 (URL) http://www.noaa.gov/nws/nws_nmc.html NMC Discipline: atmospheric and oceanic data	(301) 763-8005 voice (301) 763-8545 fax (Internet) (FTP) 140.90.50.22 /pub/nws/nmc
Unidata User Support Section P.O. 3000 Boulder, CO 80307 (URL) http://www.unidataucar.edu/ UCAR Discipline: Real time environmental data	(303) 497-8644 voice (303) 497-8690 fax (Internet) support@unidata.ucar.edu (FTP) unidata.ucar.edu

Appendix B
Features of Common Scientific Data Formats; Access Information

Table B.1

Comparison of three scientific-data-management systems*

Feature	CDF	HDF	netCDF
Languages supported	C, Fortran	C, Fortran	C, Fortran, C^{++}
Inherent data types	char, short, int, float, double, string,	byte, short, long, float, double	byte, char, short, long, float, double
User-definable types	no	yes	no
Data-conversion method	XDR, native	XDR, native	XDR
Maximum array dimension	10	unlimited	32
Extended array dimension	yes	yes	yes
Hyperset access	yes	yes	yes
User-definable attributes	yes	yes	yes
Attribute types	any	any	any
Named dimensions	no	yes	yes
Array-index ordering	row, column	row, column	row, column
Shareability	yes	yes	yes
Compression	no	yes	no
Supporting tools	yes	many	ncdump, ncgen, a few others

* Adapted from: "Software for Portable Scientific Data Management," 1993: Brown *et al*, Computers in Physics **7**: 304-308

GRIB is not a "tool" for scientific data management. It is designed for efficient archival and transmission of two dimensional gridded arrays. It is a flat file format which is "quasi-self-describing" (*i.e.*, a table look–up procedure is used). Access would be sequential. It is used for archival by the world's largest operational meteorological centers (NMC and ECMWF).

Appendix B.2

More CDF, netCDF, HDF, GRIB information

Format	ftp	URL
CDF	nssdca.gsfc.nasa.gov cd cdf.dir	
netCDF	unidata.ucar.edu cd pub/netcdf	http://www.unidata.ucar.edu/packages/netcdf
HDF	ftp.ncsa.uiuc.edu cd HDF	http://hdf.ncsa.uiuc.edu:8001/
GRIB (NMC)	ncardata.ucar.edu cd datasets/ds084.5 get format_grib	ftp://ncardata.ucar.edu/datasets/ds085.5/format_grib
GRIB (ECMWF)	ncardata.ucar.edu cd datasets/ds111.2	

APPENDIX C

Example of packing and unpacking a value

Two similar methods are used to create a packed binary value. The first method uses three elements: a sign bit (*e.g.*, 0 for a positive number and 1 for a negative number), a reference value (sometimes called an 'offset') and a scaling constant. The second method uses only a reference value and a scaling constant. The basic idea is to create a number which is a non-negative scaled difference from a reference value. To design an optimized packed binary format requires knowledge of the precision and range of possible data values. Thus, most packed binary data sets are custom designed. As a simple example, consider values from numerical computations or from measurements which have the range -99.0 to 100.0 and where the desired precision is tenths. Then, the reference value might be 100 and the scale factor could be 10. Table C.1 illustrates the steps to pack (left hand column) and unpack (right hand column) a number. Appendix C.2 provides a table which indicates the number of binary digits required to represent a decimal integer.

Table C.1
Example of packing and unpacking a value

Packing		Unpacking	
value to be packed	−13.4	value to be unpacked	866
add reference value	−13.4 + 100.	unscale	866/10
store as real	86.6	store as real	86.6
scale value	86.6 ∗ 10.	subtract reference	100. − 86.6
resulting positive integer	866	value	13.4
sign bit	1	sign bit	−13.4

Appendix C: Table C.2: Decimal/Binary Position Table*

Largest Decimal Integer	Decimal Digits Required	Number of Binary Digits	Largest Decimal Fraction
1		1	.5
3		2	.75
7		3	.875
15	1	4	.937 5
31		5	.968 75
63		6	.984 375
127	2	7	.992 187 5
255		8	.996 093 75
511		9	.998 046 875
1 023	3	10	.999 023 437 5
2 047		11	.999 511 718 75
4 095		12	.999 755 859 375
8 191		13	.999 877 929 687 5
16 383	4	14	.999 938 964 843 75
32 767		15	.999 969 482 421 875
65 535		16	.999 984 741 210 937 5
131 071	5	17	.999 992 370 605 468 75
262 143		18	.999 996 185 302 734 375
524 287		19	.999 998 092 651 367 187 5
1 048 575	6	20	.999 999 046 325 683 593 75
2 097 151		21	.999 999 523 162 841 796 875
4 194 303		22	.999 999 761 581 420 898 437 5
8 388 607		23	.999 999 880 790 710 449 218 75
16 777 215	7	24	.999 999 940 395 355 244 609 375
33 554 431		25	.999 999 970 197 677 612 304 687 5
67 108 863		26	.999 999 985 098 838 806 152 343 75
134 217 727	8	27	.999 999 992 549 419 403 076 171 875
268 435 455		28	.999 999 996 274 709 701 538 085 937 5
536 870 911		29	.999 999 998 137 354 850 769 042 968 75
1 073 741 823	9	30	.999 999 999 068 677 425 384 521 484 375
2 147 483 647		31	.999 999 999 534 338 712 692 260 742 187 5
4 294 967 295		32	.999 999 999 767 169 356 346 130 371 093 75
8 589 934 591		33	.999 999 999 883 584 678 173 065 185 546 875
17 179 869 183	10	34	.999 999 999 941 972 339 086 532 592 773 437 5
34 359 738 367		35	.999 999 999 970 896 169 543 266 296 386 718 75
68 719 476 735		36	.999 999 999 985 448 034 771 633 148 193 359 375
137 438 953 471	11	37	.999 999 999 992 724 042 385 816 574 096 679 687 5
274 877 906 943		38	.999 999 999 996 362 021 192 908 287 048 339 843 75
549 755 813 887		39	.999 999 999 998 181 010 596 454 143 524 169 921 875
1 099 511 627 775	12	40	.999 999 999 999 090 505 298 227 071 762 084 960 937 5
2 199 023 255 551		41	.999 999 999 999 545 252 649 113 535 881 042 480 468 75
4 398 046 511 103		42	.999 999 999 999 772 626 324 556 767 940 521 240 234 375
8 796 093 022 207		43	.999 999 999 999 886 313 162 278 383 970 260 620 117 187 5
17 592 186 044 415	13	44	.999 999 999 999 943 156 581 139 191 985 130 310 058 593 75
35 184 372 088 831		45	.999 999 999 999 971 578 290 569 595 992 565 155 029 296 875
70 368 744 177 663		46	.999 999 999 999 985 789 145 284 797 996 282 577 514 648 437 5
140 737 488 355 327	14	47	.999 999 999 999 992 894 572 642 398 998 141 288 757 324 218 75

*From *Fortran*, J. Adams, NCAR, 1972

Appendix D: Acronyms and Abbreviations

AFGWC	U.S. Air Force Global Weather Center
AGCM	Atmospheric General Circulation Model
AMIP	Atmospheric Model Intercomparison Project
AMS	American Meteorological Society
AMSU	Advanced Microwave Sounding Unit
ASCII	American Standard Code for Information Interchange
ATMOS	Atmospheric Trace Molecular Spectroscopy
ATS	Advanced Technology Satellite
ATSR	Along-track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
BATS	Biosphere–Atmosphere Transfer Scheme (NCAR)
BCD	Binary Coded Decimal
BMRC	Bureau of Meteorology Research Centre (Australia)
BUFR	Binary Universal Form for the Representation of data
BUV	Backscatter Ultraviolet Radiometer
CAC	Climate Analysis Center (now CPC)
CCC	Canadian Centre for Climate Modelling and Analysis
CCM	Community Climate Model; CCM2 is the most recent version
CERN	European Laboratory for Particle Physics
CDAS	Climate Data Assimilation Scheme
CDC	Control Data Corporation
CDF	Common Data Format
CDIAC	Carbon Dioxide Information Analysis Center
CD-ROM	Compact Disc–Read–Only Memory
CEDAR	Coupled Energetics and Dynamics of Atmospheric Regions
CERES	Clouds and the Earth's Radiant Energy System
CFC	chlorofluorocarbons
CHAMMP	Computer Hardware, Advanced Mathematics, and Model Physics
CIRES	Cooperative Institute for Research in Environmental Science (UC - Boulder)
CLIMAP	Climate Mapping and Prediction
CMC	Canadian Meteorological Centre
CNES	Centre Nationale d'Etudes Spatiales (French National Center for Space Studies)
COADS	Comprehensive Ocean-Atmosphere Data Set
COLA	Center for Ocean–Land–Atmosphere Studies
CPC	Climate Prediction Center (formerly CAC)
CPP	Cloud Photopolarimeter
CRI	Climate Research Institute (Oklahoma State University)
DAAC	Distributed Active Archive Center
DIS	Data and Information System
DMA	U.S. Defense Mapping Agency
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DPC	Display Code (from CDC)
DSS	Data Support Section (of NCAR)
EBCDIC	Extended Binary Coded Data Interchange Code (from IBM)
ECMWF	European Centre for Medium-Range Weather Forecasting
EDIS	Environmental Data and Information Service
EDS	Environmental Data Service

Appendix D: Acronyms and Abbreviations (cont.)	
EM	Electromagnetic Radiation (from x-rays to visible light to TV to LW)
ENSO	El Niño–Southern Oscillation
EOF	Empirical Orthogonal Functions (Principal Components)
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
EPA	U.S. Environmental Protection Agency
ERB	Earth Radiation Budget
ERS	European Remote Sensing
ERBE	Earth Radiation Budget Experiment
ERL	Environmental Research Laboratory (NOAA)
ESA	European Space Agency
ESSA	U.S. Environmental Science Services Agency (forerunner of NOAA)
ESAER	European Space Agency's Earth Resources Satellite
ESMR	Electronically Scanning Microwave Radiometer
ESSA	Environmental Science Service Administration
ETAC	U.S. Air Force Environmental Technical Applications Center
FAA	U.S. Federal Aviation Administration
FAQ	Frequently Asked Question
FCDS	U.S. Navy Fleet Consolidated Data Set
FGGE	First GARP Global Experiment
FGGE SOP	FGGE Special Observing Period
FNOC	U.S. Navy Fleet Numerical Oceanographic Center
FNWC	U.S. Navy Fleet Numerical Weather Center
FORTRAN	FORmula TRANslation (a computer language)
FSL	Forecast Systems Laboratory of ERL (NOAA)
FTP	File Transfer Protocol
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GCDIS	Global Change Data Information System
GCIP	GEWEX Continental-Scale International Project
GCM	General (or Global) Circulation Model
GCRP	Global Change Research Program
GDAAC	Goddard Distributed Active Archive Center
GEOS	Geodynamics Experimental Ocean Satellite (launched 9 Apr 1975)
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GISS	GSFC Institute for Space Studies
GMS	Geostationary Meteorological Satellite
GMT	Grenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
GOF	Global Ocean Flux
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
GTS	Global Telecommunications System
GWE	Global Weather Experiment
HAO	High Altitude Observatory (NCAR)

Appendix D: Acronyms and Abbreviations (cont.)

HDF	Hierarchical Data Format
HIRS	High Resolution Infra-Red Sounder
HPCC	High Performance Computing and Communications
html	Hypertext Markup Language
IEOS	International Earth Observing System
http	Hypertext Transport Protocol
IBM	International Business Machines
IDCS	Image Dissector Camera System
IEEE	The Institute of Electrical and Electronics Engineers
IGBP	International Geosphere–Biosphere Program
IGY	International Geophysical Year (1 July 1957 – 31 December 1958)
INSAT	Indian Satellite
IO	Input/Output
IP	Internet Protocol
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared Radiation
IRIS	Infrared Interferometer Spectrometer
IRTM	Infrared Thermal Mapper
ISAMS	Improved Stratospheric and Mesospheric Sounder
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land Surface Climatology Project
ISWS	Illinois State Water Survey
ITCZ	Intertropical Convergence Zone
ITOS	Improved TIROS Operational System
ITPR	Infrared Temperature Profile Radiometer
JAWS	Joint Airport Weather Studies Project
JMA	Japan Meteorological Agency
JPL	Jet Propulsion Laboratory (California Institute of Technology)
LAN	Local Area Network
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkley Laboratory
LDGO	Lamont-Doherty Geological Observatory
LLL	Lawrence Livermore National Laboratories
LLNL	Lawrence Livermore National Laboratories
LW	Longwave radiation
MBT	Mechanical Bathythermograph
MIT	Massachusetts Institute of Technology
MMTS	Maximum–Minimum Temperature System
MONEX	Monsoon Experiment
MOS	Model Output Statistics
MPI	Max Plank Institute (Hamburg, Germany)
MRIR	Medium Resolution Infrared Radiometer
MSL	Mean Sea Level
MSU	Microwave Sounding Unit
NASA	U.S. National Space and Aeronautics Administration
NBS	U.S. National Bureau of Standards
NCAR	U.S. National Center for Atmospheric Research

	Appendix D: Acronyms and Abbreviations (cont.)
NCC	U.S. National Climatic Center (now NCDC)
NCDC	U.S. National Climatic Data Center
NCDS	NASA Climate Data System
NCEP	National Centers for Environmental Prediction (formerly NMC)
NCSA	National Center for Supercomputing Applications
NDBC	National Data Bouy Center
NESDIS	U.S. National Environmental Satellite, Data, and Information Service
NESS	U.S. National Environmental Satellite Service
NGDC	U.S. National Geophysical Data Center
NGSDC	U.S. National Geophysical and Solar-Terrestrial Data Center
netCDF	Network Common Data Format
NH	Northern Hemisphere
NHC	U.S. National Hurricane Center
NHEML	U.S. National Hurricane Experimental Meteorological Laboratory
NHRE	U.S. National Hail Research Experiment
NMC	U.S. National Meteorological Center (now NCEP)
NNMI	Nonlinear Normal Mode Initialization
NOAA	U.S. National Oceanic and Atmospheric Administration
NODC	U.S. National Oceanographic Data Center
NOO	U.S. National Oceanographic Office
NORDA	U.S. Naval Ocean Research and Development Activity
NOS	U.S. National Ocean Survey
NRL	U.S. Naval Research Laboratory
NSBF	U.S. National Scientific Balloon Facility (NCAR-ATD)
NSF	U.S. National Science Foundation
NSFNET	National Science Foundation Network
NSIDC	U.S. National Snow and Ice Data Center
NSSDC	U.S. National Space Science Data Center
NSSFC	U.S. National Severe Storms Forecast Center
NSSL	U.S. National Severe Storms Laboratory
NTIS	U.S. National Technical Information Service
NUC	U.S. National Underseas Research Center
NWP	Numerical Weather Experiment
NWRC	U.S. National Weather Records Center
NWS	U.S. National Weather Service
ODAS	Oceanic Data Assimilation System
OGCM	Ocean General Circulation Model
OKCS	Oklahoma Climatological Survey
OLR	Outgoing Longwave Radiation
ORNL	Oak Ridge National Laboratory
OSU	Oregon State University
PAM	Portable Automated Mesonetwork
PDS	Planetary Data System
PLDS	Planetary Land Data System
PRC	Precipitation
Psfc	Surface Pressure
RAOB	Radiosonde or Rawindsonde Observation

Appendix D: Acronyms and Abbreviations (cont.)

RH	Relative Humidity
RNMI	Royal Netherlands Meteorological Institute
SAGE	Stratospheric Aerosol and Gas Experiment
SAM	Stratospheric Aerosol Measurement
SAR	Synthetic Aperture Radar
SASS	Seasat A Scatterometer System
SATOBS	Satellite Observations
SCD	Scientific Computing Division (of NCAR)
SCRIPPS	Scripps Oceanographic Institute (University of California at San Diego)
SFC	Surface
SH	Southern Hemisphere
SIRS	Satellite Infrared Spectrometer
SLP	Pressure at (what would be) Sea Level
SMM	Solar Maximum Mission
SMMR	Scanning Multichannel Microwave Radiometer
SO	Southern Oscillation
SOI	Southern Oscillation Index
SR	Scanning Radiometer
SSHT	Sea Surface Height (above some reference ellipsoid)
SSI	Spectral Statistical Interpolation
SSM/I	Special Sensor Microwave/Imager
SST	Sea Surface Temperature
SSU	Stratospheric Sounding Unit
SW	Short Wave
TAO	Tropical Atmosphere Ocean
TCP/IP	Transmission Control Protocol/Internet Protocol
TDL	Techniques Development Laboratory
TIROS	Television Infrared Observing Satellite
TOGA	Tropical Oceans Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment
TOS	TIROS Observational System
TOVS	Tiros Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
Tsfc	Surface Temperature
UAOB	Upper Air Observation
UARS	Upper Atmosphere Research Satellite
UCAR	University Corporation for Atmospheric Research
UK	United Kindom
UKMO	UK Meteorological Office
UNIDATA	A corporation, not a data type
URL	Uniform Resource Locator (Mosaic)
USAF	U.S. Air Force
USBCF	U.S. Bureau of Commercial Fisheries
USCGS	U.S. Coast and Geodetic Survey
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey

Appendix D: Acronyms and Abbreviations (cont.)	
USWB	U.S. Weather Bureau
UTC	Universal Time Coordinate
UV	Ultraviolet Radiation
VHRR	Very High Resolution Radiometer
VIS	the visible part of the EM spectrum
VTPR	Vertical Temperature Profile Radiometer
WDC	World Data Center
WEFAX	Weather Facsimile
WHOI	Woods Hole Oceanographic Institute
WMO	World Meteorological Organization (Geneva, Switzerland)
WOCE	World Ocean Circulation Experiment
WODC	World Ozone Data Center
WWW	World Wide Web
XBT	Expendable Bathythermograph
XDR	External Data Representation

Table E
Numbering System Used by Data Support Section

Range	General Description
000-009	general information
010-039	various northern hemisphere daily gridded analyses
060-069	nmc northern hemisphere daily gridded analyses
070-079	nmc daily tropical grids
080-084	nmc daily global grids
085-089	monthly mean grids
100-109	southern hemisphere (and tropical) daily gridded analyses
110-119	ecmwf (and u.s.s.r.) daily global grids
180-192	stratospheric grids
193-195	time series grids
196-199	special climatological analyses
200-239	climatological and monthly mean grids
240-249	u.s. navy daily hemispheric and global grids
250-269	oceanographic observations and analyses
270-299	climatological and monthly mean grids
300-349	special meteorological analyses
350-369	upper air observations
360-369	aircraft observations
370-389	special meteorological observations
390-409	time series raobs
430-439	mean monthly raobs
460-479	surface synoptic observations
480-508	surface hourly and precipitation
509-524	surface summary of day
525-529	climatological
530-549	ship data
550-559	streamflow
560-589	mean monthly surface data
600-629	meteorological projects or experiments
670-673	satellite data
674-680	mesoscale brightness
681-704	miscellaneous satellite
705-711	satellite observed ozone data
712-749	miscellaneous satellite
750-799	geophysical data
800-802	miscellaneous
803-807	ozone data
808-839	miscellaneous
840-849	radar data
850-899	miscellaneous data
900-909	station library information
950-959	paleoclimatology
990-999	special sets supporting ncar scientists

Appendix F
NCAR Data Support Section Dataset Titles: August 1994

DS001.0	General Routines
DS010.0	NCAR N.Hem Sea Level Press, daily monthly seasonal 1899-con
DS010.1	Trenberth's N.Hem Sea Level Press, monthly (from DSS sets)
DS011.0	M.I.T. N.Hem Sea Level Press, daily 1939Jul-1944Nov
DS012.0	U.S.S.R. N.Hem Sea Level Press, daily 1880-1979
DS015.0	NMC N.Hem Sea Level Press + 700mb Ht, daily 1947-1967Aug
DS018.0	U.S. Navy N.Hem Sea Level Press + 500mb Ht, daily 1945Nov-con
DS018.1	Pazan's U.S. Navy N.Hem Sea Level Press, daily (from DSS sets)
DS020.0	U.K. N.Hem 500mb Ht, daily 1949-1961Jan
DS020.1	U.K. N.Hem Sea Level Press + 500mb Ht, daily 1945-1946
DS024.0	NCAR N.Hem 300mb Ht, daily 1958Feb-1959Mar
DS025.0	Univ Wisconsin N.Hem 300mb Ht, daily 1950-1958Mar
DS026.0	ESSPO N.Hem Tropo Anals, daily 1955Apr-1960Mar (ds018.0 +gap)
DS027.0	IGY N.Hem Strato Anals, daily 1957Jul-1959Jun
DS035.0	U.S. AFGWC N.Hem Tropo Anals, daily 1959Apr-1965
DS036.0	U.S. AFGWC N.Hem Dewpoint + Nephanals, daily 1963-1972
DS037.0	U.S. AFGWC N.Hem Boundary Layer Anals, 1973 (April)
DS038.0	U.S. AFGWC Global Multi-layer Nephanals, 1971-1979 (irreg)
DS038.5	U.S. AFGWC Global Multi-layer Nephanals, 1979 (repacked by DSS)
DS060.0	NMC B-3 47x51 N.Hem Tropo Anals, daily 1959-1972
DS060.1	Gelhard's NMC B-3 47x51 N.Hem 500mb Gap Fillers, 1960-1977
DS061.0	NMC 47x51 N.Hem Strato Anals, daily 1964-1980
DS061.1	Madden's Global Wave Anals, daily 1964-1986 (from DSS sets)
DS061.5	NMC B-3 47x51 N.Hem Anals, daily 1962Mar-1972
DS061.6	NMC B-3 47x51 N.Hem Anals, daily 1962-1963 (DSS subset)
DS062.0	NMC B-3 47x51 N.Hem Forecasts, daily 1967Nov-1971 (DSS subset)
DS063.0	NMC B-3 47x51 N.Hem Anals, daily 1963Aug-1972 (DSS subset)
DS065.0	NMC B-3 47x51 N.Hem Vert Motion Anals, daily 1958Oct-1972
DS066.0	NMC 65x65 N.Hem Tropo Anals, daily 1973-con (+ 47x51 by DSS)
DS067.0	NMC 65x65 N. + S.Hem Strato Anals, daily 1981Jun-con
DS067.1	Gelman's CAC 65x65 N. + S.Hem Anals, daily 1978Sep-con
DS069.0	NMC LFM N.America Tropo Anals, daily 1971Oct-con
DS069.5	NMC NGM N.America Tropo Anals, daily 1984Oct-con
DS075.0	NMC Tropical Anals, daily 1968-1985
DS080.0	NMC Global Tropo Anals, daily 1972Nov-1974Sep (from Flattery)
DS081.0	NMC Global Tropo Anals, daily 1974Dec-1976Jun (from Flattery)
DS082.0	NMC Global Tropo Anals, daily 1976Jul-con
DS082.1	NMC Global Boundary Layer Anals, daily 1976Jul-con (DSS subset
DS082.5	NMC Global Tropo Anals, daily 1991Jan-Jun (DSS CD-ROM)
DS084.0	NMC MRF Global 10 Day Forecasts, daily 1990-con
DS084.2	NMC Global T80 Sigma Analyses, daily 1990Sep-con (from Kistler)
DS084.5	NMC MRF Global Flux, daily 1990Mar-con
DS085.0	N.Hemis 47x51 Tropo Anals, monthly 1955Apr-con (DSS built)

Appendix F: (continued)

DS085.1	N.Hemis 72x19 Tropo Anals, monthly 1947Apr-con (DSS built)
DS086.0	CAC Global Anals, monthly 1978Oct-con
DS087.0	Gelman's 72x19 N.+ S.Hem Strato Anals, monthly 1978oct-1988dec
DS100.0	NOTOS S.Hem Sea Level Press, daily 1951-1958
DS102.0	NOTOS IGY S.Hem Sea Level Press + 500mb Ht, daily 1957Jun-1958
DS103.0	Jenne's IGY S.Hem 500mb Ht, daily 1957Jun-1958
DS106.0	German IGY Tropical Sea Level Press, daily 1957Jun-1958
DS107.0	S.African S.Hem Tropo Anals, daily 1977Aug-1981Mar
DS108.0	Australian S.Hem Tropo Anals, daily 1972Apr-con
DS108.3	Trenberth's S.Hem 500mb Ht, 1968Jun-1977Aug
DS109.0	New Zealand Area Sea Level Press, daily 1957Jun-1978Feb
DS110.0	ECMWF WMO Global Tropo Anals, daily 1980-1989
DS110.1	Trenberth's Global Ocean Wind Stress Anals, monthly 1980-1986
DS110.3	Trenberth's ECMWF WMO Global Tropo 5 + 10 Year Mean Analyses
DS111.0	ECMWF TOGA Global Advanced Oper Spectral Anals, daily 1985-con
DS111.1	ECMWF TOGA Global Sfc Anals, daily 1985-con
DS111.2	ECMWF TOGA Global Sfc + Upper Air Anals, daily 1985-con
DS111.3	ECMWF TOGA Global Supplementary Fields, 1985-con
DS111.4	ECMWF TOGA Global Hybrid Tropo Anals, daily 1990jul-1991jun
DS111.5	ECMWF TOGA Global Tropo Anals, monthly 1985jan-con (DSS built)
DS112.0	U.S.S.R. Various Global + Hempheric Anals, 1880-1985
DS188.0	Labitzke's N.Hem Strato Anals, 1964Nov-1985
DS190.0	NCC W.N.Hem Rocket Strato Anals, wkly Jan,Apr,Jul,Oct 1964-66
DS190.3	Gelman's NMC N.Hem Strato Anals, wkly 1976Jul-1977Apr
DS191.0	Newell's N.Hem Strato Anals, wkly 1972Jan-1973Jun
DS195.0	N.Hem 47x51 Time Series Tropo Anals, 1899-con (DSS built)
DS195.1	N.Hem 72x19 Time Series Tropo Anals, 1946-con (DSS built)
DS195.5	U. Washington/NCAR CDROM N.Hem Time Series Anals, 1946-1989Jun
DS196.0	Jenne's N.Hem 500mb Ht, 15-day 1962Oct-1971 (from NMC B-3)
DS200.0	Jenne's S.Hem Climatology, monthly 1950-1966
DS201.0	Australian S.Hem Climatology, monthly 1973-1982
DS205.0	Jenne's N.Hem Climatology, monthly 1950-1964
DS206.0	Van de Boogard's Climate Anals, Jan + July
DS207.0	Rand's Global Climatology, Jan Apr Jul Oct
DS208.0	Sadler's Tropical Wind Climatology, 1960-1973
DS208.1	Sadler's Tropical 250mb Wind Anals, monthly 1966-1973
DS209.0	Oregon St. CRI Global Ocean Heat Flux + Wind Stress, monthly
DS209.1	Weare's Tropical Pacific Heat Budget, monthly 1957-1976
DS209.2	Bunker Climate Atlas of the N.Atlantic Ocean
DS209.3	Hastenrath's Tropical Atlantic Heat Budget, monthly
DS210.0	Labitzke's N.Hem Strato Climatology, 1951-1971
DS210.1	Labitzke's N.Hem Strato Anals, 1957-1988 + Sunspots 1951-1972
DS212.0	Solot's N.Hem Sea Level Press + 500mb Ht, monthly 1899-1939

Appendix F: (continued)

DS213.0	U.S.S.R. N.Hem Sfc Temp Anoms, monthly 1891-1972
DS213.1	U.S.S.R. N.Hem Sfc Temp Anals, monthly 1891-1981
DS215.0	U.K. Global Sfc Temps, monthly 1851-1990Apr
DS217.0	GFDL Atmospheric Circulation Anals, monthly 1958May-1973Apr
DS218.0	CAC Global Tropo Climate Diagnostics, 1978Oct-1985Sep
DS218.1	Chellia's CAC Global Tropo Climate Diagnostics, 1979-1988
DS219.0	Masutani's ECMWF Global Tropo Climate Anals, 1979Mar-1989Feb
DS220.0	U.S.A.F. ETAC Global Tropo + Strato Anals, monthly 1956-1960
DS222.0	Walsh's Arctic Sfc Temp Anals, monthly 1946-1975
DS230.0	OBrien's Pacific + Indian Ocean Wind Stress, monthly 1961-1989
DS231.0	Wyrtki's NORPAX Pacific Wind Stress, monthly 1947-1973
DS232.0	Hellerman's GFDL Global Ocean Wind Stress Anals, monthly
DS232.1	Harrison's Climatological Mean Wind Global Wind Stress
DS233.0	Walsh's Arctic Ice Anals, monthly 1953-1988
DS234.0	Ropelewski's CAC Antarctic Ice Anals, monthly 1973-1990Mar
DS235.0	U.S.S.R. N.Hem Sfc Press + Precip Anoms, monthly 1873-1979
DS236.0	Legates+Willmott's Global Air Temp + Precip Anals, monthly
DS237.0	Willmott's Terrestrial Water Budget, monthly
DS238.0	Diaz' Global Precip Anals, monthly 1851-1989
DS239.0	Rudolf's WCRP Global Precip Prelim Anals, monthly 1987-1988
DS240.0	U.S. Navy FNOC N.Hem Sea Sfc Temp Anals, daily 1961Nov-con
DS240.1	U.S. Navy FNOC N.Hem Sfc Anals, daily 1969Sep-con
DS240.5	U.S. Navy FNOC S.Hem Sea Sfc Temp Anals, daily 1974Aug-con
DS240.6	U.S. Navy FNOC S.Hem Tropo Anals, daily 1974Aug-con
DS241.0	U.S. Navy FNOC Anals (all types), daily 1990May-con
DS242.0	U.S. Navy FNOC Global + Tropical Anals, daily 1973Jul-1984Jul
DS250.0	Pacific Sea Level Ht Station Obs, daily 1901-1987
DS251.0	Equatorial Pacific Ocean Climate Anals, monthly 1950-1979
DS252.0	U.K. Global Perm Service Mean Sea Level (PSMSL) Obs, 1872-1987
DS253.0	CDIAC Sfc Water + Atmospheric CO2 + N2O Obs, 1977-1990
DS254.0	Najjar's NODC PO4, NO3, + SIO2 Nutrient Ocean Anals
DS255.0	Hansen's NODC EPOCS Drifting Buoy Obs, daily 1979-1984
DS256.0	Canadian MEDS Drifting Buoy Obs, daily 1980-1990
DS256.1	PMEL ATLAS + EPOCS Buoy Obs for TOGA/COADS, daily 1980-1989
DS256.2	NSIDC Univ Wash. PSC ARGOS Buoy Obs, 1987Jan-Jun,Oct-Dec
DS257.0	Canadian MEDS W. + E. Coast Seawater data, daily 1914-1985
DS258.0	Scripps Pier + W.Coast Seawater Temp + Salin, daily 1916-1990
DS259.0	Woods Hole Improved METeorological (IMET) Marine Obs, 1992
DS270.0	Washington+Thiel's Global Sea Sfc Temp Climatology
DS270.2	Rand's Global Sea Sfc Temp + Ice Climatology
DS271.0	GFDL COADS Global Sea Sfc Temp Anals, monthly 1870-1979

Appendix F: (continued)

DS272.0	Sadler's Tropical Marine Climatic Atlas, monthly 1900-1979
DS273.0	Fletcher's Sea Sfc Anals, monthly 1946-1978May
DS274.0	Rasmussen's Pacific Sea Sfc Temp + Wind, monthly 1946-1976
DS275.0	Sette's Pacific Sea Sfc Temp Anals, monthly 1949-1962
DS276.0	U.K. Sea Sfc Temp Anals, monthly 1854-1968, (by Lawes)
DS277.0	Reynolds' NMC CAC Sea Sfc Temp Anals, monthly 1970-1990Jun
DS277.1	NMC ODAS Pacific Sub Sea Sfc Temp + Current, 1991-1993, wkly
DS278.0	Bauer+Robinson's Sea Water Temp Climatology, 1969-1981
DS279.0	Samuels+Cox' GFDL Global Oceanographic Data Set Atlas
DS280.0	Noo's Global Ocean Sfc Currents, seasonal 1901-1978
DS281.0	NCDC U.S. Navy TD9757 Marine Climatic Atlas, monthly 1850-1970
DS283.0	Hansen+Lebedeff's Global Sfc Temp Anals, monthly 1880-1987
DS285.0	Levitus' Climatological Atlas of the World Ocean, 1900-1978Mar
DS285.1	NODC Southern Ocean Atlas Obs + Anal
DS286.0	M.I.T. Hydrography of N.Atlantic, 1981Jun-1985Apr (by Fukumori
DS287.0	GFDL MOM Climatological Ocean Initialization Anals
DS289.0	Shea + Trenberth's Global Monthly Sea Sfc Temp Climatology
DS289.1	Global Ocean Sfc Temp Atlas (GOSTA)
DS290.0	Shea's Climatology Atlas, 1950-1979 (from DSS sets)
DS292.0	Warren's Global Climatological Cloud Data, 1930-1983Nov
DS292.1	Warren's Global Climatological Cloud Data, by Sfc Obs 1982-91
DS295.0	Baker's Global Ocean Soundings, (empty,reserved)
DS302.0	Krishnamurti's Tropical 200mb Wind, summers 1967 + 1972
DS302.1	Krishnamurti's GATE Tropical 300mb-200mb Wind, summer 1974
DS302.2	Krishnamurti's MONEX Tropical Tropo Wind Anals, spring 1979
DS302.3	Krishnamurti's Tropical Tropo Wind Anals, monthly 1965-1974
DS302.4	Krishnamurti's MONEX Region Precip Anals, 1979May-Jul
DS302.5	Krishnamurti's ECMWF FGGE IIIb Vert Velocity Anals, 1978-1979
DS303.0	NCAR GCM Model Output, 1968Jan
DS304.0	GARP DST III Global Tropo + Strato Anals, some 1974May-1976Mar
DS305.0	Shea's N.Hem Selected Blocking Cases, 1962Dec-1977Feb
DS306.0	NMC Error Anals, 1979Mar-Apr
DS307.0	ECMWF FGGE Global Anals, daily 1978Dec-1979Nov
DS307.1	ECMWF FGGE IIIB Spectral Anals, daily 1979Jan-Mar
DS307.3	ECMWF FGGE TD101 Global Reanals, SOP1+2 1979
DS307.5	ECMWF FGGE Global Anals, daily 1978Dec-1979Nov (DSS subset)
DS307.7	ECMWF FGGE Global Anals for ALPEX, spring 1982
DS307.9	ECMWF FGGE T63 Tropo, Sfc + Tendency Anals, daily 1979
DS308.0	GFDL Global Anals for FGGE, SOP1+2 + 1978Dec-1979Nov
DS309.0	Goddard's IIIb Anals for FGGE, SOP1+2 1979
DS310.0	GATE Anals by Ooyama, Chu, + Esbensen, 1974Aug-Sep
DS312.0	NMC Global Anals + Spectral Anals for FGGE, 1979Jan-Mar,Jun
DS315.0	Dewey+Heim's Snow Cover, wkly monthly 1966Nov-1988

Appendix F: (continued)

DS318.0	GISS + GFDL Climate Model Outputs for EPA CO2 Studies
DS318.1	GFDL Climate Model Outputs for CO2 Studies
DS318.2	UK Climate Model Outputs for CO2 Studies
DS318.6	German Climate Model Tropo Anals for EPA CO2 studies
DS353.0	NMC B-3 ADP Global Upper Air Data Obs, daily 1962Mar-1972
DS353.1	NMC ADP Global Upper Air Obs (Mixed), daily 1985-con
DS353.2	NMC Global Upper Air + Sfc Obs for GATE, 1974Jun-Sep
DS353.3	NMC DST II data for GARP, 1974May-1976May
DS353.4	NMC ADP Global Upper Air Obs Subsets, daily 1973-con
DS354.0	Swedish Level IIb Upper Air + Sfc Obs for FGGE, 1978Nov-1979
DS354.1	ECMWF DST IIb Upper Air + Sfc Obs for ALPEX, spring 1982
DS355.0	U.S.A.F. Global Upper Air Obs, daily 1966Jul-1969Aug
DS358.0	Ptarmigan Dropsondes, irreg 1950-1961
DS359.0	NOAA FSL Wind Profiler Obs, hourly 1992May-con
DS360.0	U.S.A.F. ETAC DATSAV TD57 Global Aircraft Obs, 1976-1985
DS361.0	Australian Aircraft Obs, daily 1971Dec-1989
DS365.0	Sadler's Global Aircraft Obs, daily 1960-1973
DS368.0	NASA GASP Aircraft Obs, 1975Mar-1979Jul
DS381.0	Kennedy's ALPEX Aircraft Obs, spring 1982
DS383.0	FSU's BOMEX Raobs, daily 1969May-Sep
DS385.0	Fankhauser's N.America Severe Storms Cases (8), spring 1966-67
DS388.0	GATE Global Upper Air + Sfc Obs, 1974Jun-Sep
DS388.1	CEDDA GATE Global Upper Air + Sfc Obs, 1974Jun-Sep
DS389.0	Portable Automated Mesonet (PAM) Obs, 1977Apr-1982Nov
DS390.0	Global TD56 Time Series Raobs, daily 1948-con
DS390.1	U.S. Control TD56 Time Series Raobs, daily 1948-con
DS390.2	General Inventory (TD54) of Time Series Raobs
DS390.3	India Time Series Raobs, 1951-1978Jun
DS390.4	U.S.A.F. TD9014 Raobs, daily 1948-1965
DS390.5	U.S.A.F. TDF54 Time Series Raobs, daily 1943Jan-1974Dec
DS391.0	Monthly Time Series Raobs, 1948-con
DS392.0	Shea's Strato Zonal Wind + Temp Profiles, monthly 1953-1988
DS398.0	M.I.T. Raobs, daily 1958May-1963Apr (thru Kung,Univ Missouri)
DS400.0	Ascension Island Raobs, 1968-1977Mar
DS402.0	U.S.S.R. Raobs, 1961-1970
DS430.0	Global (spotty non-U.S.) Monthly Mean Raobs, 1950-con
DS460.0	U.S.A.F. ETAC TD9600 Sfc Obs, 1967Feb-Apr + 1976Aug
DS462.0	U.S.A.F. AFGWC, Sfc Obs, 1967Dec
DS462.1	U.S. AFGWC Global Sfc Obs, 1975Apr-May
DS462.2	U.S. AFGWC Global Sfc Obs for SESAME, few days 1977Apr-Sep
DS463.0	NCDC U.S.A.F. DATSAV TD9685 Global Sfc Obs, daily 1967-1980
DS464.0	NMC ADP Global Sfc Obs, daily Jul1976-con
DS465.0	U.S. Navy SPOT Global Sfc + Upper Air Obs, daily 1972Apr-1978

Appendix F: (continued)

DS465.1	U.S. Navy SPOT Global Sfc + Upper Air Obs, daily 1972Apr-cont
DS466.0	Sadler's Pacific Island Precip, monthly 1965-1972
DS467.0	NCC TD13 Global Sfc Obs, daily 1899-1970
DS467.1	U.S.A.F. DATSAV TD13 Global Sfc Obs, daily 1949-1970
DS468.0	NCC TD9685+TD9686 Global Sfc Obs Gap Filler, 1975Sep
DS468.1	U.S.A.F. DATSAV Global Sfc Obs Gap Filler, 1975Sep
DS469.0	Canadian Sfc Obs, daily 1963Sep-1972
DS470.0	NCDC TD14+TD3280 U.S. Control Sfc Airway Hourly Obs, 1938-1989
DS472.0	TDL U.S. + Canada Sfc Hourly Obs, daily 1976Dec-1989Nov
DS473.0	Univ Wisconsin Antarctic Sfc Obs, daily 1980-1991Oct
DS473.5	Univ Wisconsin Greenland Sfc Obs, daily 1987-1991Oct
DS474.0	Univ Washington Russian Ice Station Obs, daily 1950-1990
DS480.0	India Precip, daily monthly 1901-1970
DS480.1	Kanpur,India Precip, daily 1975-1984
DS481.0	India Precip, wkly 1979-1985
DS482.0	Australia Precip, daily monthly 1939-1982
DS482.1	Australia Precip, daily monthly 1840Jan-1990Dec
DS483.0	Malaysia,Thailand + Indonesia Sfc Obs, daily 1951-1985
DS484.0	Shafer's Pacific Rainfall Data, daily 1971Jan-1993Jul
DS485.0	China Precip, daily 1951-1982
DS490.0	Garcia+Hamilton's Batavia (Djakarta) Press Obs, hrly 1866-1944
DS491.0	Denver,CO + Buckley U.S.A.F. Sfc Obs, hrly 1948-1972
DS501.0	Boulder,CO Sfc Obs (precip + max-min temps), daily 1897-1976
DS501.5	Boulder,CO Sfc Wind Obs, cases 1969
DS503.0	NCDC SOLMET TD9724 Solar + Sfc Obs, daily 1952-1976
DS504.0	NCDC TD9734 Typical Meteorological Year, Solar + Sfc
DS505.0	NCDC TD3240 U.S. Control Coop Hourly Precip, daily 1948-1988
DS508.0	Amos Eddy's U.S. Sfc Anals, daily 1881-1985
DS509.0	NCDC TD3210 U.S. 1st Order Summary of Day, 1884(1948)-1987Jul
DS510.0	NCC TD3200 U.S. Control Summary of Day, 1890(1948)-1988
DS510.1	NCC U.S. Pan Evaporation, daily 1948-1978
DS510.2	Texas Sfc Obs, daily monthly 1900-1973
DS510.4	NCC U.S. Summary of Day, various stations 1890-1970
DS511.0	CDIAC U.S. HCN Temp + Precip Obs, daily 1880-1987
DS512.0	CAC Global CEAS Summary of Day/Month Obs, 1979-1989Jun
DS513.0	May's Global Sfc Temp Climate Anals, daily 1979-1989Jun
DS514.0	China Summary of Day (for FGGE?), 1979May-Sep
DS515.0	GATE ASECNA Africa Precip, daily 1974
DS516.0	Canada Summary of Day, 1950-1979
DS517.0	Brazil Precip, daily 1910-1974 (thru Geisler)
DS518.0	Japan Summary of Day, 1951-1989
DS520.0	NMC U.S. WBAN-3 Summary of Day, 1948-1963
DS520.1	NCC U.S. WBAN Sfc Obs, 1948-1978

Appendix F: (continued)

DS521.0	U.S. Summary of Day + 3 and 6-hrly 1969-1976
DS522.0	Shea's Summary of Day Collection (from DSS sets)
DS523.0	Australia Summary of Day + Sfc Obs, 1939(1957)-1982
DS524.0	Russian Summary of Day, 1880(1935)-1989
DS528.0	Vecchia's Upper Midwest U.S. Station Means, monthly
DS530.0	Antarctica Whaling Ship Obs (empty,reserved)
DS533.0	U.S.S.R. Sfc Ship Obs, 1888-1989
DS535.0	NCC TD1129+TD1116 Time Series Perm Ship Sfc Obs, 1945-1987
DS536.0	Pazan's NORPAX TD11 Sfc Ship Obs
DS540.0	COADS Global Marine Obs, 1850-1979
DS540.1	COADS Global Marine Statistics, 1850-1987
DS540.2	COADS Release 1a
DS541.0	Oberhuber's COADS Atlas
DS542.0	NODC Oceanographic Expendable Bathythermograph (XBT),1966-1987
DS542.1	NODC Oceanographic Mechanical Bathythermograph (MBT),1941-1980
DS542.2	NODC Oceanographic Station Data (OSD), 1900-1990
DS542.3	NODC Compressed (Low-resolution) CTD/STD CO22, 1969-1990
DS542.4	NODC Selected Level Expendable Bathythermograph (SBT) Data
DS543.0	Reid's NODC Deep Ocean Station Obs, 1900-1987
DS544.0	Woods Hole N.Atlantic TTO, 1981 (from Woods Hole)
DS545.0	Woods Hole Hydrographic Data from Warm Core Ring 1982-B
DS545.1	URI Gulf Stream Crest Anatomy Hydrograhic Survey - Fall 1988
DS546.0	Woods Hole Position Lotus Current Meter, 1982-1983
DS552.0	UNESCO Flow Rates of Selected World Rivers, monthly 1800-1972
DS565.0	U.S. Historical Climatology Net (HCN) Temp + Precip, 1880-1987
DS565.1	CDIAC U.S. Historical Sunshine Obs, 1891-1984
DS569.0	U.S. DOE Global Monthly Station Temp + Precip, 1738-1980
DS570.0	World Monthly Sfc Station Climatology, 1738-1988
DS570.1	World Weather Records, 1961-1970, 1971-1980
DS570.2	NCDC U.S. Monthly Sfc Station Climatology, 1961-1970
DS570.3	CAC TD9643 U.S. Station Temp + Precip, monthly 1981-1983
DS571.0	Nicholson's Africa Precip, monthly 1901-1975
DS572.0	Harnack's S.American Precip, monthly 1891-1983
DS573.0	CAC Ctrl.Pacific Island Precip, monthly 19 -1980 (thru Shea)
DS574.0	U.S. Sfc Monthly Station Normals, 1941-1980
DS575.0	India Monthly Station Precip, 1901-1970
DS576.0	Canadian Monthly Station Temp + Precip (thru Shea)
DS577.0	Shea's Australia Monthly Station Precip, 19 -1983 (from DS483
DS578.0	China Monthly Station Precip, 1951-1980 (thru Shukla)
DS579.0	Mongolia Summary of Month, 1936-1983
DS580.0	Malaysian ASEAN Climatic Atlas, 19 -1975 (thru Krishnamurti)
DS582.0	Univ Wisconsin Antarctica Sfc Obs, monthly 1980-1989
DS600.0	GARP Global Upper Air + Sfc Obs, pre-GARP 1970Jun

Appendix F: (continued)

DS602.0	Line Island Experiment Sfc + Upper Air Obs, 1967Mar-Apr
DS602.1	Line Island Experiment Aircraft Obs, 1967Mar-Apr
DS603.0	NCAR Natl Hail Research Experiment Raobs, 1972-1978 summers
DS605.0	MONEX Monsoon-77, Somalia Pibals; Indian + U.S.S.R. Ships
DS605.2	Winter Monsoon Experiment (WMONEX), 1978Dec
DS605.5	Summer Monsoon Experiment (SMONEX), 1979May-Jul
DS610.0	FGGE Dropwindsondes, 1978Dec-1979Jul (thru Shea)
DS611.0	ALPEX Dropwindsondes, spring 1982 (thru Julian)
DS615.0	TWERLE S.Hem Drifting Balloon Data, 75Jun13-76Aug09 (thru Shea
DS617.0	Hildebrand's HAPEX King Air Flux + Soundings, 1986May-Jul
DS618.0	ECMWF AMEX Global Tropo + Strato Anals, daily 1987Jan
DS670.0	NESS Global Brightness Anals, 1967-1972Aug
DS671.0	NESS NOAA-1 Longwave Anals, 1971Apr-Jul
DS672.0	Sadler's Equatorial Nephanals, daily 1965Feb-1973Jul
DS672.5	Sadler's N.Pacific Nephanals, monthly 1965Feb-1978Feb
DS673.0	NMC Nimbus-5 Sea Ice + Rain Rate (ESMR) data, 1975Jan-Feb
DS674.0	Bristor's NESS ESSA-7 Brightness, 1968-1969Mar
DS676.0	NESS Visual + Infrared Brightness Anals SRVIS+SRIR, 1974-1989
DS676.1	Weickmann's NESS Infrared Brightness Anals, 5-day 1974-1986
DS677.0	NESS ITOS Visual + Infrared Brightness Anals SRVIS+SRIR, 1973
DS678.0	NESS TIROS-M Visual + Infrared Brightness Anals, 1973Oct
DS679.0	Rodger's Nimbus-5 Selective Chopper Radiometer (SCR) 1972-1974
DS680.0	VonderHaar's Nimbus-3 Minimum Albedo Anals, 1969Apr-1970Feb
DS681.0	EDIS TIROS-N 1024 Mosaic Data for FGGE, 1979Jan-Jun
DS685.0	Kleespies' Nimbus-3 Infrared Spectrometer (SIRSA+B), 1969-1971
DS686.0	EDIS TIROS-N Operational Vert Sounder (TOVS) Obs, 1979-1980
DS691.0	NESS NOAA Vert Temp Profile Radiometer (VTPR) Obs, 1974Sep
DS692.0	NESS NOAA Vert Temp Profile Radiometer (VTPR) Obs, 1972-1979
DS695.0	Koenig's NESDIS Subtarget Radiance Obs, 1978Nov
DS698.0	NESS NOAA Polar Orbiter Global Area Coverage (GAC), 1981-1982
DS700.0	NESS NOAA Polar Orbiter Obs (TBM), 1978Oct-1989
DS701.0	NASA Global Tropo Temp Anals from MSU data, 1979-1991Jan
DS701.5	Spencer's Global Oceanic Precip Anals, 1979-1992Apr
DS703.0	NOAA Polar Orbiter Global (GAC) Data, 1989Jan-1991Dec
DS709.0	NASA SAMS Experiment Zonal Mean Methane + N2O, 1979-1981
DS710.0	NASA Nimbus-7 Orbital Total Ozone Obs, 1978Oct-1986Sep
DS710.5	Campbell's Nimbus-7 THIR, CMATRIX, 1979Apr-1985Mar
DS711.0	NASA Nimbus-4 Total Ozone Obs, 1970Apr-1977May
DS712.0	E.Smith's SMS Hourly Brightness Data for GATE, 1974Jun-Aug
DS716.0	India INSAT Visual + Infrared Images, 1984Apr-1989Mar
DS718.0	Arkin's GOES 1/2 Monthly Temp Distrib Histograms, 1982-1989Oct
DS718.5	Arkin's 1/2 Monthly Outgo LW Radia, 1974Jun-1990
DS719.0	Arkin's Monthly Tropical Wind + Outgo LW Radia (OLR) 1968-1984

Appendix F: (continued)

DS720.0	NESS GOES Wind data, 1974Oct-1984Feb
DS725.0	Campbell's Internat'l Satell Cloud Climat Proj B1, 1983-1987
DS725.1	Campbell's Internat'l Satell Cloud Climat Proj (ISCCP) CX
DS726.0	GFDL SEASAT Scatterometer Derived Winds, 1978Jul-Oct
DS726.1	Chelton's SEASAT Wind Stress Anals, 1978Jul-Oct
DS727.0	NODC GEOSAT Altimeter Wind + Wave Data, 1985Mar-1986Sep
DS727.1	JPL GEOSAT Sea Level Ht Anals, 1986Nov-1988
DS728.0	NOAA GPCP Precip, pentad estimates
DS729.0	Chang's SSM/I Precip, monthly estimates
DS730.0	Campbell's Earth Radia Budget Exper (ERBE), 1978Nov-1983Oct
DS732.0	Barkstrom's Earth Radia Budget Exper (ERBE), 1984Nov-1986Oct
DS733.0	NIMBUS 7 ERBE Matrix Data, daily 1978Nov-1987Nov
DS740.0	Naegele's NOAA Highly Reflective Cloud (HRC) Anals, 1971-1987
DS740.1	NOAA Highly Reflective Cloud (HRC) Anals, monthly 1971-1985
DS742.0	NASA Internat'l Satell Cloud Climat Proj (ISCCP) C1, 1983-1987
DS742.1	NASA Internat'l Satell Cloud Climat Proj (ISCCP) C2, 1983-1991
DS742.3	NASA Internat'l Satell Cloud Climat Proj (ISCCP) B3, 1987-1988
DS743.0	Japan GMS Satell Data (ISCCP) B1, 1983-con
DS744.0	ESA ERS-1 Scatterometer wind data, 1991nov-1993aug
DS750.0	Scripps Global Elevation + Depth Data
DS750.1	Rand's Global Elevation + Depth Data (derived from Scripps)
DS754.0	U.S. Navy Global Elevation Data, 10-Min (1984Dec)
DS755.0	U.S.A.F. Global Average Elevation Data, 1°, 30-Min, 5-Min
DS756.0	Defense Mapping Agency (DMA) Global Elevations (empty,reserved
DS756.1	Defense Mapping Agency (DMA) U.S. 30-Sec Elevations
DS756.5	USGS Selected 3-sec Elevations (CO, HI, Great Plains)
DS757.0	NMC Global Elevation Data, 2.5°+ Spectral
DS759.0	Synthetic Bathymetric Profiling System (SYNBAPS) Depths, 5-Min
DS759.1	NGDC ETOPO5 Global Ocean Depth + Land Elevation, 5-Min
DS760.0	Berkovsky+Bertoni U.S.A.F. AFCRL Global Elevation Data, 1-Deg
DS761.0	S.African Area Elevation Data, 1-Min
DS762.0	USGS Land Use and Land Cover, 200m
DS765.0	Matthew's GISS Global Vegetation, Land-use, + Albedo, 1°
DS765.5	Matthew's GSFC Global Wetlands + Methane Emission, 1°
DS766.0	Argonne Land-use + Deposition Data, 0.2°
DS767.0	Wilson, Henderson-Sellers' Global Vegetation + Soils, 1°
DS768.0	Cogley+Briggs' Global Precip Climatology + Topography, 1°
DS769.0	Olson's CDIAC World Ecosystems by Carbon Vegetation, 30-Min
DS770.0	Staub+Rosenweig's GISS Soil + Sfc Slope, 1°
DS780.0	NCAR Continental Outline Data
DS800.0	French EOLE S.Hem Balloon Obs, 1971Aug-1972 (thru NASA)
DS800.1	FGGE Constant Level Balloon Obs, 1979Jan-Jul (thru Shea)
DS800.2	French MONEX Low-level Drifting Balloon Obs, 1979 (thru Cadet)

Appendix F: (continued)

DS801.0	Japan AMTEX Obs, daily 1974-1975 Feb-Mar
DS804.0	NCC TD9518 Daily Ozone Soundings, 1963Sep-1969May
DS805.0	Canadian Total Ozone Obs + Anals, daily monthly 1951May-1975
DS805.1	London's Global Total Ozone Anals, monthly 1957Jul-1976
DS805.2	Canadian Ozonesondes + Total Ozone, 1957Jul-1985
DS806.0	London's Global Ozone from OGO-4, 1967Sep-1969Jan
DS808.0	NSSFC Severe Local Storms Log (SELSLOG), 1955-1972Jun
DS812.0	Oklahoma City KTVY Tower Obs, 1976Oct-1977Nov
DS814.0	Feiber's Global 500mb + 300mb Vorticity Indices, 1946-1979Feb
DS816.0	Batelle's Wind Energy Summaries, various stations
DS820.0	Lau's N.Hem Circulation Statistics, winters 1965-1976
DS820.1	White's N.Hem Circulation Statistics, summers 1966-1977
DS824.0	NCDC Global Tropical Cyclone Position Data, 1886-1991
DS824.1	NCDC Revised Global Tropical Cyclone Position Data, 1877-1992
DS830.0	U.S.C.G.S. Geomagnetic Data for 3 stations, 1947-1969
DS832.0	NOAA WDCA Magnetic Indices + Sunspots, 1932-1981Jun
DS834.0	Sunspots, 1610-1986 (from Clark + NGDC)
DS836.0	Jack Eddy's Compilation of Auroral Observation Catalogues
DS839.0	Incoherent Scatter Database (CEDAR), 1969-con
DS840.0	NMC TDL Manually Digitized Radar (MDR), 1973Nov-1977Sep
DS840.1	NMC TDL Manually Digitized Radar (MDR), hrly 1973Nov-1989
DS845.1	GATE Ship Radar, 1974Jun-Sep
DS845.2	GATE Ship Radar / Quadra Full Resolution, 1974Jun-Sep
DS850.0	U.S. Army Panama Meteorological + Biological Data, 1965-1970
DS855.0	NCC TD5850 Global Rocketsondes 1969-1988
DS856.0	NCC Rocketsondes, monthly 1961-1972
DS860.0	U.S.A.F. TD9703 AFCRL Atmospheric Lines for Radiation Calcs
DS861.0	Earth Insolation for 1.1 &Million Years (from Belgium)
DS862.0	CLIMAP Climatic Boundary Conditions for 18,000 years BP
DS863.0	Duffy+Imbrie's SPECMAP Ocean Cores with 400,000 years BP
DS865.0	Limpert's GSFC Precip Temp + Derived Soil Moisture Anals
DS866.0	GISS Methane + Livestock Distribution, 1°
DS867.0	Matthew's GISS Methane from Rice Cultivation
DS870.0	Sacramento Peak 9.1cm Solar Anals, 1964-1973Jul (from Stanford
DS875.0	GATE Aircraft Obs, 1974Jun-Sep
DS880.0	GATE Commercial Aircraft Obs, 1974Jun-Sep
DS885.0	NCDC TD9658 U.S. Palmer Drought Indices, monthly 1931-1982
DS885.1	NCDC TD9640 U.S. Palmer Drought Indices, monthly 1895-1987
DS887.0	Lethbridge's Thunderstorm Indices
DS888.0	World Weather Disk Data (parts selected by DSS)
DS890.0	Los Angeles Pollution (empty,reserved)
DS891.0	U.S.S.R. Various Anals + Obs, 1891-1986
DS900.0	U.S.A.F. AFGWC Station (Sfc + Upper Air) Library (1990Aug)
DS900.1	NCDC WBAN Station Library
DS901.0	NCC COOP Station Library for Summary of Day + Hourly Precip
DS902.0	NCAR ADP Upper Air Station History (DSS built)
DS950.0	Univ Arizona Tree Ring Data
DS998.0	Van Loon's Climate Research (collected by Spangler)