OCS Report
MMS 98-0043

Meteorology of the Northeastern Gulf of Mexico

Interim Report

MMS U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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ABSTRACT

During this two-year study entitled *"Meteorology of the Northeastern Gulf of Mexico"* meteorological data for the 1995-1997 period from all available sources (National Weather Service, National Data Buoy Center, stations funded by Minerals Management Service, and other private sources) spanning the region of the Northeastern Gulf of Mexico (NEGM) were collected. Estimates of the temporal/frequency contents and spatial scales of variation from these wind measurements will be prepared. Humidity air and sea-surface temperature measurements for the same period throughout the NEGM will also be analyzed and maps of the mean and variance fields, and estimate the temporal and spatial scales of variation will be prepared. Calculations of mean and variance fields of surface wind stress and heat flux over the NEGM will be made and maps prepared of the quantities to estimate wind curl and vertical vorticity means and variability after effects of sea breezes are removed via filtering techniques. These data will be used to study winter cyclogenesis and cold frontal passage in the NEGM. Assessments will be made of frontal passage and the modification of air masses affect the local fields of temperature, humidity, pressure and other relevant meteorological parameters. The transport of water and latent heat across water-land boundaries or coastlines will be estimated along with the properties of the atmospheric boundary layer. Temporal and spatial variation scales were analyzed as functions of atmospheric and climatological types. Prognostic meteorological model output will also be archived for the same period to supplement the observational data base for the NEGM region. A computer-based "expert" software system will be developed that would allow rapid, real-time access to the information developed in this study and aid in interpretation of current and forecast meteorological conditions.

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Several persons contributed substantially to the writing of this report, but all participants made contributions to the ideas, results, and accomplishments to date of the study. Below we recognize those who made significant contributions to the study (in no particular order):

Mark Yocke -- ENVIRON
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1. INTRODUCTION

BACKGROUND

There is renewed interest in oil and gas extraction activities in the Northeastern Gulf of Mexico (NEGOM). While indications are that the resources to be recovered are likely to be natural gas rather than oil, the threat of an oil spill in the NEGOM from these activities remains a great concern. The National Environmental Policy Act mandates multidisciplinary environmental assessments of Outer Continental Shelf activities to address spill concerns. Such assessments could benefit from an meteorological database, especially in regards to oceanographic studies, oil spill trajectory estimates, air quality/plume dispersion calculations, and operational meteorological forecasts in the NEGOM.

The Minerals Management Service (MMS) contracted with ENVIRON International Corporation (ENVIRON) and its team to conduct a meteorological study of the NEGOM and to assemble such a database. ENVIRON's team is composed of Sonoma Technology Inc., AeroVironment Environmental Services, Evans Hamilton Inc., and Dr. S.A. Hsu of Louisiana State University.

While the research conducted for this study will result in a database useable for ongoing and future MMS studies in the NEGM, the meteorological and oceanographic science communities should benefit as well as our understanding of atmospheric-oceanic interactions in this area are improved. We also hold the view that the vitally important database product from this study may be used as a type of "handbook" to be utilized in the future by planners and analysts in the case of new industrial activities in the area, as well as on the occasion of monitoring and predicting conditions associated with non-routine or accidental hazardous events.

Knowledge acquired through the variety of analyses to be performed in this study will improve understanding of wind field patterns and sea breeze structures, atmospheric boundary layer behavior and structures, wind stress patterns on the sea surface and effects on ocean currents, cold air outbreaks, and boundary layer moisture fluxes across the land-sea interface. Further, this database will be useful for several ongoing and proposed oceanographic studies in the NEGOM. One such study is the 1996-97 "Northeastern Gulf of Mexico Inner Shelf Circulation Study" program, designed to provide for analyses of sea surface currents in the same area. It is intended that the raw data and analysis products from the current study will be used to reconcile wind and stress patterns with trajectory data from "Northeastern Gulf of Mexico Inner Shelf Circulation Study" drifters and supply valuable information concerning the state of the atmosphere for any period of interest during that study.

STUDY OBJECTIVES

The objectives of this study include the following:

1) To collect wind data from all available sources (National Weather Service, National Data Buoy Center, stations funded by Minerals Management Service, and other private sources) spanning the NEGOM, and estimate the temporal/frequency contents and spatial scales of variation from these measurements;

2) To collect humidity, air and sea-surface temperature measurements throughout the NEGOM from these same institutions, prepare maps of the mean and variance fields, and estimate the temporal and spatial scales of variation;

3) To calculate mean and variance fields of surface wind stress and heat flux over the NEGOM and prepare maps of these quantities, to estimate wind curl and vertical vorticity means and variability with and without effects of sea breezes (i.e. with and without filtering techniques), and to use these data to the maximum extent possible to study winter cyclogenesis and cold frontal passage in the NEGOM;

4) To assess how frontal passage and the modification of air masses affect the local fields of temperature, humidity, pressure and other relevant meteorological parameters;

5) To estimate the transport of water and latent heat across water-land boundaries or coastlines and the properties of the atmospheric boundary layer, and to evaluate the temporal and spatial variation scales analyzed as functions of atmospheric and climatological forcing;

6) To develop an "expert" software system to allow the users of the NEGOM meteorological data base simple access and display capabilities.

The study performance period extends across 24 months. It is broken into two phases; a field study and ancillary data collection effort is conducted in the first twelve months, followed by data reduction, analysis, interpretations, synthesis, and report preparation for the remaining twelve months. The study area is defined to be enclosed within the latitudes of 28°-32°N and the longitudes 82°-90°W.

The main technical tasks in this program are:

Task 1 -- Data Acquisition, Archival, and Relational Data Base Design
Task 2 -- Data Reduction, Statistical Analysis, and Synthesis
Task 3 -- Development of an "Expert" Software System

This interim report describes the efforts and results generated to date just beyond the half way point in the study. The next chapters report on the activities of and results from these three main tasks.

2. FIELD WORK AND DATABASE DEVELOPMENT

OVERVIEW

During 1997, the study team conducted a survey of available measurement and modeling databases to compile into the MMS NEGOM meteorological database. The survey revealed that the only routine measurement data available can be obtained from the National Climatic Data Center (NCDC) and the National Data Buoy Center (NDBC) and from monitoring on Breton Island. Activities necessary to procure, reduce, and analyze gridded modeling data were considered to be out of scope for the current effort, and are described in an add-on proposal. The survey also included a review of available oil-spill trajectory models.

Mr. Dick Davis of the NCDC was contacted on February 20, 1997 in order to establish an agreement for NCDC to be the final repository of the MMS NEGOM meteorological database. Mr. Davis asked that we provide him with a letter explaining the goals of the project, the agency funding the study, the project management staff, and a description of the data structures that would make up the final database. This letter was sent to Mr. Davis on February 28, 1997.

In late 1997, the MMS NEGOM meteorological database was created using all 1995-96 surface and upper air data in the NEGOM study area, purchased from the NCDC, and C-MAN and buoy data freely downloaded from the NDBC web site. The database was created using Microsoft® Access on the AeroVironment Environmental Services, Inc. (AVES) PC-based computer network. An intermediate copy of the database was placed on the AVES Internet File Transfer Protocol (FTP) site, and downloaded by ENVIRON for the purpose of developing systems and programs to generate statistical and diagnostic analyses.

The NEGOM database was then updated once 1997 surface, upper air, buoy, and C-MAN data became available in early 1998. Later, it was discovered that meteorological data from the New Orleans International Airport and the New Orleans Naval Air Station, which are within the area of interest, were not included in the NCDC data set. Subsequently, these data were purchased from NCDC. Five-minute surface meteorological data from Breton Island spanning the period of 1996-97 has just recently been provided by Louisiana State University. The draft final 1995-97 NEGOM database, without the Breton Island data, was again placed on the AVES FTP site for downloading by the data analysis contractor in May 1998.

FIELD WORK

Potential Routine Observational Data Sources

The following government agencies, and private companies were contacted for monitored meteorological data collected within the study area (28°N to 32°N, 82°W to 90°W) and for the years 1995, 1996, and 1997:

- National Climatic Data Center (NCDC), Mr. Al Chen, (704) 271-4800.
- National Data Buoy Center (NDBC), Internet home page.
- USGS Center for Coastal Geology, Internet home page.
- Breton Island (National Park Service), Dr. Shu, LSU
- Shell Oil Company, Mike Vogel, (713) 245-7454
- Chevron, Cort Cooper, (510) 842-9119
- Marathon, Ken Schaudt, (713) 296-3149
- Conoco, Mr. David Peters, (713) 293-1248
- Exxon, John Heideman, (713) 965-7587
- Mobil, Walt Springs, (214) 851-8346
- Freeport-McMoran, Walt Groce, (800) 535-7904
- Amoco, Dave Driver, (713) 212-7289
- Texaco, Tom Mitchell, (713) 432-3346
- ORYX (Sun), Kirdes Schubert, (214) 715-4606
- British Petroleum, Gale Baxter, (713) 560-3423
- U.S. Navy, Office of Naval Research
- U.S. Navy, Fleet Numerical, Naval Oceanographic Office
- NWS Cooperative Data
- Southern Regional Climate Center, John Grymes, (504) 388-2912
- Neptune Sciences, Inc., Marshall Earle, (504) 643-9362
- Evans-Hamilton, Incorporated, Doug Evans, (301) 762-8070
- Ocean Weather, Vince Cardone, (203) 661-3091
- University of Alabama – Dauphin Island Campus
- Pennsylvania State University

Only the NCDC, NDBC, and LSU were able to provide meteorological data for the study region for the period of interest. The data specifically obtained are described later.

Large-Scale/Gridded Databases

Large-scale observational databases (i.e., satellite and special study) and gridded numerical model output have not yet been requested or received for this study. An add-on to the current scope of work has been proposed to obtain a 1996-97 gridded meteorological database, and to include these raw data and additional parameters derived from them to the MMS NEGOM database. As part of the current scope, however, a survey was conducted to determine what gridded data were available, and their characteristics. The following is a summary of the search findings:

- **U.S. Navy Operational Global Atmospheric Prediction System (NOGAPS)**, operated by Fleet Numerical in Monterey (Dennis Laws). Model data are derived and archived on a 2.5° grid (240 km), which is much greater than our requirement for data resolution at or less than 100 km. Data are available for 1995 and 1996 in GRIB format, which is frequently used in storing meteorological model data. Mr. Laws has stated that he can provide a program for decoding the data, but that it is written in C and would require a Unix workstation or similar 32-bit computer.

- **U.S. Air Force Relocatable Window Model** (RWM), operated at Offutt Air Force Base (Gordon Brooks). Only about 15 days of data were saved from 1995 and 1996, mainly for periods characterized by winter or severe weather that provided interesting case study. Output for this data are in graphic format, though it appears that they could customize it for whatever our purposes or needs might be.

- A search was conducted using the NOAAServer, which accesses available information from a very large collection of databases, including all of those compiled and maintained by NOAA. The search for "surface meteorology" for 1995-1996 in the Gulf of Mexico area yielded the information contained in Attachment 2-1. Data sets that seem promising are presented in bold face. Note that any of the databases included in this list with the words "preview" below them are essentially available on-line. The data can either be downloaded directly in netCDF format (which can be decoded using software available on the Internet) or it can be viewed graphically with a fairly good graphics program which allows for defining the area viewed, thus defining the resolution.

  A few brief comments regarding this list:

  - The VORTEX-95 data covers a period from 4/1/95 through 6/30/95.
  - The GCIP/ESOP-95 data covers a period from 4/1/95 through 9/30/95. Data are essentially contours of observable data.
  - The NMC Real-time Marine Data contains many interesting parameters, including wind stress parameters. However, they are monthly averages.
  - Tom Ross at NCDC was contacted regarding the NMC North American Surface Analyses, which looked promising based on the description. However, the Surface Analyses are based mainly on the observable surface data. A good data archive at www.arl.noaa.gov/ss/transport/archives.html has archived data from a number of models. Unfortunately, the best grid resolution for 1995/1996 data is about 180 km for the NGM model. The Eta model grid size is about 80 km, but is only available for 1997. All data from this site is in GRIB format. The RAMS archive referenced on this Web page, while using a 15 km grid size, only applies to a small area around the state of Maryland for 1997.

- The NCEP/NCAR Reanalysis Surface Data (Attachment 2-2) contains many parameters, including many standard parameters such as pressure, temperature, humidity, etc. Daily data are available back into the 1950's and are easily obtained using NOAAServer. Similarly, the more interesting parameters, including most derived data and wind data, are available for 1997. All of the Reanalysis data, including upper air data, can be obtained on-line. Unfortunately, these data also appear to have been created using a larger (2.5°, 240 km) grid size.

- **NOAA Regional Spectral Model (RSM)** (Henry Juang). This model uses a definable grid size that can basically be set at whatever one requires (40 km is typically used). There are no archived data for this model. However, Mr. Juang indicated that the model could be provided to government agencies to be run for specific study periods. Again, a workstation with Fortran would be necessary to run this model.

- **U.S. Navy Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS)**. It has not been possible to connect with anyone regarding this model, but the Internet page on this model indicates that the model is available for outside use. See Attachment 2-3 for the Web page describing the COAMPS model. This model can be run on a grid with resolution as low as one meter. Again, a workstation with Fortran would be necessary to run the model.

- **Eta Model Archives.** Purdue has archived Eta modeled data in graphical format back through the beginning of 1995. This includes surface and upper air data, but unfortunately does not include surface wind data. These data can be found at wxp.eas.purdue.edu/archive/index.html. Grid size for the ETA model is typically 80 km.

- **Satellite Imagery** from the USGS Center for Coastal Geology. Satellite images of the Eastern Gulf of Mexico start in December 1996 and are available on the Internet. Images prior to December 1996 are likely available, but have not yet been processed. This imagery includes sea surface temperature, reflectance, and altimetry. The URL for the home page is http://coastal.er.usgs.gov/east_gulf/.

Table 2-1 summarizes the above discussions of available gridded analyses and model output.

Table 2-1
Summary of large-scale model and observational databases, and typical data resolution

Model/data	Grid size	Comments
Navy Relocatable	240 km	
Window Model	50 km	Limited number of days during 1995, 1996
GCIP/ESOP-95	NA	Contours of observed data
NMC Real-time Marine Data	180 km	Monthly averages
NGM Model	180 km	
ETA Model NCEP/NCAR	80 km	1997 only. Data available for 1995, 1996 in graphical format from Purdue, though surface winds not included
Reanalysis	240 km	
Regional Spectral Model	Definable	User-run model
COAMPS	Definable	User-run model
Eastern Gulf of Mexico Satellite Imagery	NA	Likely available by request for 1995, 1996

Oil Spill Trajectory Modeling

A survey of the oil spill models available from government agencies and private sources was made. It was found that a number of models are available, as well as models developed by the U.S. Navy for predicting the drift of persons lost at sea which may also be of interest. The following "primer" is intended to familiarize meteorologists with the features, inputs and applications of oil spill trajectory and fate models as they apply to the coastal and offshore regions of the Gulf of Mexico. Consequently discussion of such oil spill modeling issues as ice coverage and enclosed water body (i.e., lake) boundary conditions and dynamics are not included.

Most commonly used oil spill trajectory and fate models in use today are based on Geographic Information Systems (GIS). Most of these have been adapted for use on 386/486/Pentium desktop PCS. There are a wide variety of commercially available models for determining oil spill trajectories and probabilities of impacts; fate of oil spills (natural or chemically induced degradation and decomposition); transport of dissolved and sinking fractions as well as floating plumes; guiding response and containment efforts; and predictions of impacts, costs, wildlife moralities, and mitigation on sensitive ecological areas. All of the available models may be validated and calibrated with "real-time" observational input. Basic components of an oil spill transport models include the following:

1. **GIS Data Base -** This normally consists of relevant geographic data, such as coastal boundaries, country, state, and county boundaries, harbor or coastal ecological features and variable offshore bathymetry compiled into a GIS database, which is often stored in digital

form in a format such as Workstation ArcInfo, AutoCad, dBASE4, and QuattroPro. Quite often offshore bathymetry is available only on hardcopy (charts) and must be digitized, however such agencies as NOAA, the Defense Mapping Agency, or commercial sources have these data for most of the Gulf region in an already digitized form. Several commercial data bases are available on CD-ROM (such as the Digital Chart of the World and the World Vector Shoreline) which are easily interfaced with a GIS database. These come in two formats generally, raster based maps and vector based maps. Raster based maps have generally high quality but vector based maps are more flexible and adaptable to generating grid systems.

2. **Grid System -** This is a geo-referenced, GIS generated, curvi-linear grid system on which to base numerical modeling. Rectilinear grids are easy to interpret, construct and adapt to modeling computations. However, in complicated coastal areas or islands, a boundary conforming grid may be preferable. Such grids are readily generated, the user identifies key grid nodes, and an integrated grid generating module constructs the grid - which can be subsequently modified to increase the density of grids, for instance.

3. **Hydrodynamic Model -** A hydrodynamic model simulates dynamic forces which would act on a spill. The most important of these is wind (determined from a representative wind time series), but also includes (for various applications) tides (particularly for marine applications), river flow, and marine density distributions. Wind and tide information can be obtained from NOAA coastal meteorological sources and offshore meteorological buoy and from NOAA tidal station records. River flow data may be obtained from the U.S. Geological Survey. A number of commercial climatological data bases (including wind time series) are available on CD-ROM which are easily interfaced with oil spill hydrodynamic models. In coastal embayments and estuaries, the type of tide cycle (such as semi-diurnal) must be modeled often several times to establish a steady state from which a data set for a representative tidal cycle may be developed. To predict the fate or degradation of an oil spill specialized transport models are available which require the input of other environmental parameters such as air temperature, barometric pressure and water temperature.

4. **Oil Spill Transport Model -** Both deterministic and probabilistic oil spill transport models are used to model the surface trajectory of floating oil spills and the subsurface transport (and resurfacing) of dissolved or sinking constituents. For modeling purposes crude oil or petroleum products are generally divided into four components (based on their physical/chemical/toxicological characteristics); two aromatic fractions considered toxic to organisms, a volatile relatively insoluble fraction, and a non-volatile insoluble (residual) fraction. Physical inputs required include chemical spilled, type of spill (catastrophic or instantaneous release or chronic discharge over a period of time), amount spilled, time of spill and location of spill. For oil spills, the deterministic models are able to provide weathering predictions and the extent of shoreline oiling. Probabilistic or stochastic models require observed or recorded seasonal sets of weather input so as to predict most likely trajectories, providing the time and locations of impacts under given conditions. They can

also provide the relative likelihood of oiling on a given open ocean or coastal location. Several models are also available that incorporate toxicological data and known ecological data to predict environmental impacts of oil spills such as fish or bird kills.

Based on an Internet review, the two most widely used oil spill trajectory models are Oilmap by Applied Science Associates, Inc. (ASA) and the Oil spill Information Service (OSIS) by BMT Marine Information Systems Limited (BMT). These two model packages are comparable, and are briefly described below.

Oilmap (http://www.appsci.com/oilmapww.htm)

OILMAP is a PC (DOS/Windows) based oil spill model system suitable for use in oil spill response and contingency planning. OILMAP provides rapid predictions of the movement of spilled oil. It includes simple graphical procedures for entering both wind and hydrodynamic data and specifying the spill scenario. The GIS is interactive and allows the user to enter, or import from external GIS sources, a variety of geographic data such as response resources, environmentally sensitive areas, and key coastal features.

OILMAP has numerous options which allow the system to meet the user's specific needs. These include:

- Predicting the weathering of spilled oil;
- Modeling the subsurface transport of spilled oil;
- Predicting the probability of key areas being impacted from a given site;
- Assessing the vulnerability of key sites to oiling;
- Back tracking the model to determine the likely spill site position;
- Over flight update facility;
- Boom-Oil interaction;
- Performing risk assessments for important resources;
- Developing Coastal Planning and Management Data Bases using the interactive GIS;
- Provision of customized management vessel traffic support system;
- Provision of customized resource and cost management system
- Assisting in search and rescue operations

OILMAP is delivered with an oil spill trajectory & fates model, and interactive GIS and environmental data tools. The oil spill model predicts the surface trajectory of spilled oil for either instantaneous or continuous release spills. The model includes algorithms for oil spreading, evaporation, emulsification, entrainment, oil-shoreline interaction, and oil-ice interaction are included in the model. The oil's distribution and mass balance with time are predicted for the type of oil spilled. The user can update the model predictions to agree with observed oil locations through the addition of GIS polygons. Boom may also be added to implement simple booming strategies. The user may also alter drift rates and drift angles so that the model may be used to predict the trajectory of other floating objects (e.g., for search and rescue work). A variety of graphically based tools are included which allow the user to:

- specify spill scenarios;
- display spill trajectories;
- grid any area within the geographic location for model operation;
- input wind time series;
- generate steady current fields;
- generate tidal current fields;
- enter and edit oil types in the oil library;
- enter data into OILMAP's Geographic Information System (GIS);
- display GIS resources impacted by the oil trajectory;

The GIS uses the Microsoft Access Database to store information for each GIS object. This database may be developed externally using the Microsoft Access tools or manipulated directly from within OILMAP. In addition to text information, each object may be attached to other files such as bitmaps (BMP, TIF, PCX etc.), text files, word processor files, or even video (AVI) files. By clicking on a GIS object, these files may be directly viewed from OILMAP. The GIS engine also supports display of ARCVIEW/ARCINFO shape files directly, as well as OILMAP Native GIS formats, and provides import tools for MAPINFO (MIF/MID) export formats.

Stochastic Mode - This model generates multiple stochastic simulations for user selectable spill locations using statistical or historical wind time series. The model can be run to determine most likely spill paths for spills on a monthly, seasonal, or annual basis. This model is frequently used for contingency planning and risk assessment.

Receptor Mode - The receptor mode performs reverse trajectory calculations from user selectable locations. Calculations can be used to identify probable release locations of spills given current oil locations, or principal avenues of vulnerability for important resources.

Subsurface Transport - This module contains all the weathering algorithms described in the fates and trajectory model, but also predicts the subsurface transport of entrained/dissolved oil.

OSIS (http://www.bmtmis.com/bmtmis/Products/Osis/osis.htm)

The Oil Spill Information System (OSIS) is capable of modeling both the physical transport and spreading of the oil spill, and the physicochemical weathering processes that the oil undergoes in the marine environment. The models are run within a GIS/electronic charting based application with built-in oceanography, weather, oil types and geographical databases.

OSIS has also been extensively validated using trial spills. These are licensed by the UK Government and involve the dumping of several tons of oil at sea to study its movement and weathering. Furthermore, OSIS has been validated against actual spill incidents, most recently with its use for the 'Sea Empress' oil spill.

The following list summarizes features provided as standard in the system;

- Full oil spill trajectory, spreading, weathering and beach impact models;
- Integrated GIS with continuous co-ordinate tracking and distance/bearing measurement;
- Ability to model developed spills by defining the spill extents;
- Ability to backtrack spills to identify sources;
- Batch mode model runs with recording of results for later replay;
- Graphical entry of weather forecast with import facility;
- Status panel display of oil spill parameters;
- Integrated units system allowing complete user set-up of preferred units;
- Ability to move spill on-screen to accommodate observations during an incident;
- Comprehensive results facilities including graphs of oil properties, spill reports and spreadsheets (all using Microsoft applications e.g. Word, Excel);
- Resource Damage Assessment to identify oiled resources;
- Full color printout and screen copy facilities;
- Full on-line help system as well as professionally written system manual;
- Unique Easyspill® system for non-experienced users and emergency.

As with OILMAP, OSIS has stochastic, receptor, and subsurface modeling capabilities.

The above two software packages appear to be the most comprehensive and ready for use "off the shelf". The following two software products were also noted, though they appear to require more site-specific adaptation than the above.

Trajectory Analysis Planner (TAP) (http://response.restoration.noaa.gov/software/tap.html)

TAP is a software package provided by NOAA. It appears to be geared more towards response preparedness than real-time trajectory plotting. Also, a specific version of TAP is created for each particular water body. The web-page indicates that, to date, versions have been created for the Delaware and San Francisco Bays.

OilSim (http://www.chc.nrc.ca/numerical/oilsim.html)

OilSim is a numerical model for simulating the propagation and fate of petrochemical spills in marine environments developed by the Canadian Hydrolics Center (CDC). OilSim uses an explicit lagrangian formulation to model advection, dispersion and evaporation of oil under the influence of winds and currents. Shoreline and weedbed interaction is modeled using environmental data from GIS systems. Hydrodynamic and wind conditions can vary both temporally and spatially.

OilSim is an integrated module of CHC's HYDA (Hydronumerical Modeling Environment) data management system, so use of HYDA would be required. CHC is part of Canada's National Research Council, and primarily provides modeling services to Canadian firms. However, they do sell the HYDA and OilSim software in both Canada and the United States.

DATA ARCHIVING AND DATABASE STRUCTURE

Data Received

Table 2-2 lists the data obtained from NCDC sites in the study area, with the date range of valid data for each.

Table 2-2
Station data obtained from NCDC

Station ID	Station Name	Station Type	Range of	Observables
00013858	Eglin AFB/Valparais	Upper Air	95 - 97	raob
00013861	Waycross/Ware Co.	Upper Air	1/95	raob
00013889		Upper Air	95 - 97	raob
00053813	Slidell Municipal	Upper Air	95 - 97	raob
00093805	Tallahassee Regional	Upper Air	95 - 97	raob
722055	Ocala Muni (AWO8)	Land Based	95 - 97	wind, t, Td, Vsby
722120	Cross City	Land Based	95 - 6/96	wind, t, Td
722130	Waycross/Ware Co.	Land Based	95 - 96	wind, t, Td, Vsby
722135	Alma/Bacon	Land Based	95 - 97	wind, t, Td, p, Vsby
722140	Tallahassee Regional	Land Based	95 - 97	wind, t, Td, p, Vsby
722146	Gainesville Regional	Land Based	95 - 97	wind, t, Td, p, Vsby
722160	Albany Municipal	Land Based	95 - 97	wind, t, Td, p, Vsby
722166	Valdosta Regional	Land Based	95 - 97	wind, t, Td, p, Vsby
722210	Eglin AFB/Valparais	Land Based	95 - 97	wind, t, Td, p, Vsby
722215	Crestview/Bob Sikes	Land Based	95 - 97	wind, t, Td, p, Vsby
722223	Pensacola Regional	Land Based	95 - 97	wind, t, Td, p, Vsby
722225	Pensacola NAS	Land Based	95 - 97	wind, t, Td, p, Vsby
722226	Whiting Field NAS-North	Land Based	95 - 97	wind, t, Td, p, Vsby
722230	Mobile/Bates Field	Land Based	95 - 97	wind, t, Td, p, Vsby

722235	Mobile Downtown	Land Based	95 - 97	wind, t, Td, Vsby
722245	Panama City/Bay Co.	Land Based	95 - 97	wind, t,Td, Vsby
722246	Duke Field/Eglin Aux	Land Based	95 - 97	wind, t, Td, p, Vsby
722267	Troy Municipal	Land Based	95 - 97	wind, t, Td, p, Vsby
722268	Dothan Municipal	Land Based	95 - 97	wind, t, Td, Vsby
722269	Cairns AAF/Ozark	Land Based	95 - 97	wind, t, Td, p, Vsby
722275	Andalusia/OPP Airport	Land Based	95 - 97	wind, t, Td, p, Vsby
722276	Schell AHP	Land Based	95	wind, t, Td, Vsby
722307	Golden Tri	Land Based	95 - 97	wind, t, Td, Vsby
722309	Grand Isle	Land Based	95 - 97	wind, t, Td, Vsby
722310	New Orleans Int'l Airport	Land Based	95 - 97	wind, t, Td, p, Vsby
722316	New Orleans NAS	Land Based	95 - 97	wind, t, Td, p, Vsby
722348	Pine Belt Regional AWOS	Land Based	95 - 97	wind, t, Td, Vsby
747685	Gulfport-Biloxi	Land Based	95 - 97	wind, t, Td, p, Vsby
747686	Keesler AFB/Biloxi	Land Based	95 - 97	wind, t, Td, p, Vsby
747750	Tyndall AFB	Land Based	95 - 97	wind, t, Td, p, Vsby
747770	Hurlbert Field	Land Based	95 - 97	wind, t, Td, p, Vsby
747810	Moody AFB/Valdosta	Land Based	95 - 97	wind, t, Td, p, Vsby

Table 2-3 lists the data obtained from NDBC sites in the study area, with the date range of valid data for each.

Table 2-3
Station data obtained from NDBC

Station ID	Station Name	Station Type	Range of	Observables
42001	Mid Gulf	Buoy	95 - 97	wind, t, p, wave
42002	West Gulf	Buoy	95 - 97	wind, t, p, sst, wave
42003	East Gulf	Buoy	95 - 9/96	wind, t, p, sst, wave
42007	OTP	Buoy	95 - 97	wind, t, p, sst, wave
42036	West Tampa	Buoy	95 - 97	wind, t, p, sst, wave, visy
42039	Pensacola S	Buoy	95 - 97	wind, t, p, sst, wvht, dpd, apd, mwd
42040	Mobile South	Buoy	95 - 97	wind, t, p, dp, sst, wvht, dpd, apd
BURL1	Southwest Pass, LA	C-Man	95 - 97	wind, t, p
BUSL1	Bullwinkle Block 65	C-Man	8/95 - 10/96	wind, t, p, sst
CDRF1	Cedar Key, FL	C-Man	95 - 97	wind, t, p
CSBF1	Cape San Blas, FL	C-Man	95 - 97	wind, t, p, dp
DPIA1	Dauphin Island, FL	C-Man	95 - 97	wind, t, p, sst
GDIL1	Grand Isle, LA	C-Man	95 - 97	wind, t, p, sst, dp
KTNF1	Keaton Beach, FL	C-Man	95 - 97	wind, t, p

Figure 2-1 displays the locations of all measurement sites within the analysis domain. Two sites are located outside this area: buoy 42002 to the west of 91 °W, and RAOB site 13889 near Jacksonville, FL.

Data Screening and Validation

NCDC Data

Data validation was not necessary for the data received from NCDC since they perform extensive validation measures at their facilities before the data are made available to the public. The NCDC data are processed in accordance with the procedures outlined in the United States Air Force Environmental Technical Applications Center (USAFETAC) Climatic Database Users Handbook Number 4. These data go through a four step process that includes:

- Checking the data for readability and inventorying the data;
- Converting the data into the DATSAV2 format;
- Processing the data through quality control programs that identify class (systematic) and sports (intermittent) errors and developing methods for correcting the data;
- Processing the data through a series of merge programs to produce a monthly file, and then a yearly file.

NDBC Data

Data validation was not necessary for the data received from NDBC since they perform extensive validation measures at their facilities before the data are made available to the public. The NDBC data are collected by remotely operating sites (buoys and C-MAN stations). These data are used in real time, which requires real-time operational checks to eliminate gross errors. These checks include:

- Transmission parity error, range limit, and time continuity checks;
- Relational checks, such as examining the wind gust to wind speed ratio to check the quality of both measurements;
- Another check ensures that the battery voltage is adequate for barometric pressure measurements.

Once the data arrives at NDBC, stricter range and time continuity limit checks are performed. These checks include:

- Comparison of measurements from duplicate sensors to ensure that they track together;
- A man-machine mix of quality checks, such as graphical procedures that relate wind speed and spectral wave energy;
- The use of time series plots, spectral wave curves, and computerized weather maps to detect errors.

Breton Island Data

The Breton Island data have just been received from ENVIRON. It is anticipated that these data will have to be validated.

The procedures that AVES uses for data processing and validation ensure that the reported data are valid and comparable to those collected by federal, state and local air pollution agencies. These procedures meet the requirements and guidelines of the Environmental Protection Agency; e.g., Appendices A and B of 40 CFR 58; Quality Assurance Handbook for Air Pollution Measurement Systems, Volumes I and II (1994a, 1994b). The AVES data processing procedures are presented below.

Once the data is read from the original sources (9-track tapes, floppies, or 8-mm cassettes) and transferred to the AVES MicroVAX workstation, they are processed by customized FORTRAN programs that parse and index the data into the specified categories. These parsed files are then loaded into the Microsoft® Access database tables according to their categories. Various queries and screening procedures are set up in the database to identify outliers, which are flagged for review. These flagged data are reviewed by both data aides and the project manager (Level I data review).

The Level I reviewed data are output both electronically and in hard copy for further review. This second level of review (Level II) compares the data from adjacent stations for consistency (parameter-to-parameter comparisons for consistency and trends). This data review is performed by AVES personnel who are familiar with the interrelationships of air quality and meteorological parameters, and potential local influences at the sites. The Level II validated data represent the "final data" produced by AVES for this project.

Data Reformatting

The NCDC data did not contain decimal points when received. The decimal points were added back into the data in accordance with the USAFETAC Climatic Data base Users Handbook Number 4. Additionally, all missing data codes were standardized by changing them to -999.

The NDBC data was reformatted as follows:

- Missing data codes were converted to -999 to be consistent with the NCDC data;
- The data units were changed to be consistent with the NCDC units. For example, temperatures in degrees Kelvin were converted to degrees Celsius, and visibility units in miles were converted to meters.

Database Structure

The MMS NEGOM database is maintained in a secure area of the AVES computer network. The AVES computer network is PC based; the network servers use Windows NT, while Windows95 is the operating software for the individual user computers. The data is organized into ten Access tables by data type. The structure of the tables is described below:

TABLE NAME	VARIABLES
Station Information:	ID, name, type, latitude, longitude, elevation, call letters
Temperature and Pressure:	ID, date, hour, dewpoint, temperature, sea level pressure, altimeter setting
Winds:	ID, date, hour, direction, speed
Wind Gust:	ID, date, hour, gust
Sea Surface -Temperature:	ID, date, hour, sea surface temperature
Sea Surface - Wave:	ID, date, hour, significant height, dominant period, mean period
Sky Conditions:	ID, date, hour, ceiling, cloud type, cloud cover
Precipitation::	ID, date, hour, period of precipitation, precipitation
Visibility:	ID, date, hour, visibility
Upper Air:	ID, date, hour, (height, pressure, temperature, speed, direction, relative humidity) (repeat for each altitude) (standard encoding)

This structure allows for querying the data for screening, validation, and reformatting, and performing the required data analyses. Security for the NEGOM database is provided by the AVES computer network. System backups are performed daily. Copies of the daily system backups are stored off site.

Data Transfer

The AVES FTP site is set up on one of the AVES servers. The NEGOM database has been allocated a directory titled MMS within the FTP site's Private directory which has password-only access. The NEGOM participants have been given instructions for accessing this FTP site. Each participant selects a password when they enter the site for the first time. The AVES computer system manager is the only person who has access to the user names and corresponding passwords. A database status folder is included in the FTP area, which automatically documents all transactions that take place with and in the MMS FTP site. The log entries include the date, time, and user name. Log entries for file uploads and downloads include the date, time, user name, file name, and whether it was uploaded or downloaded.

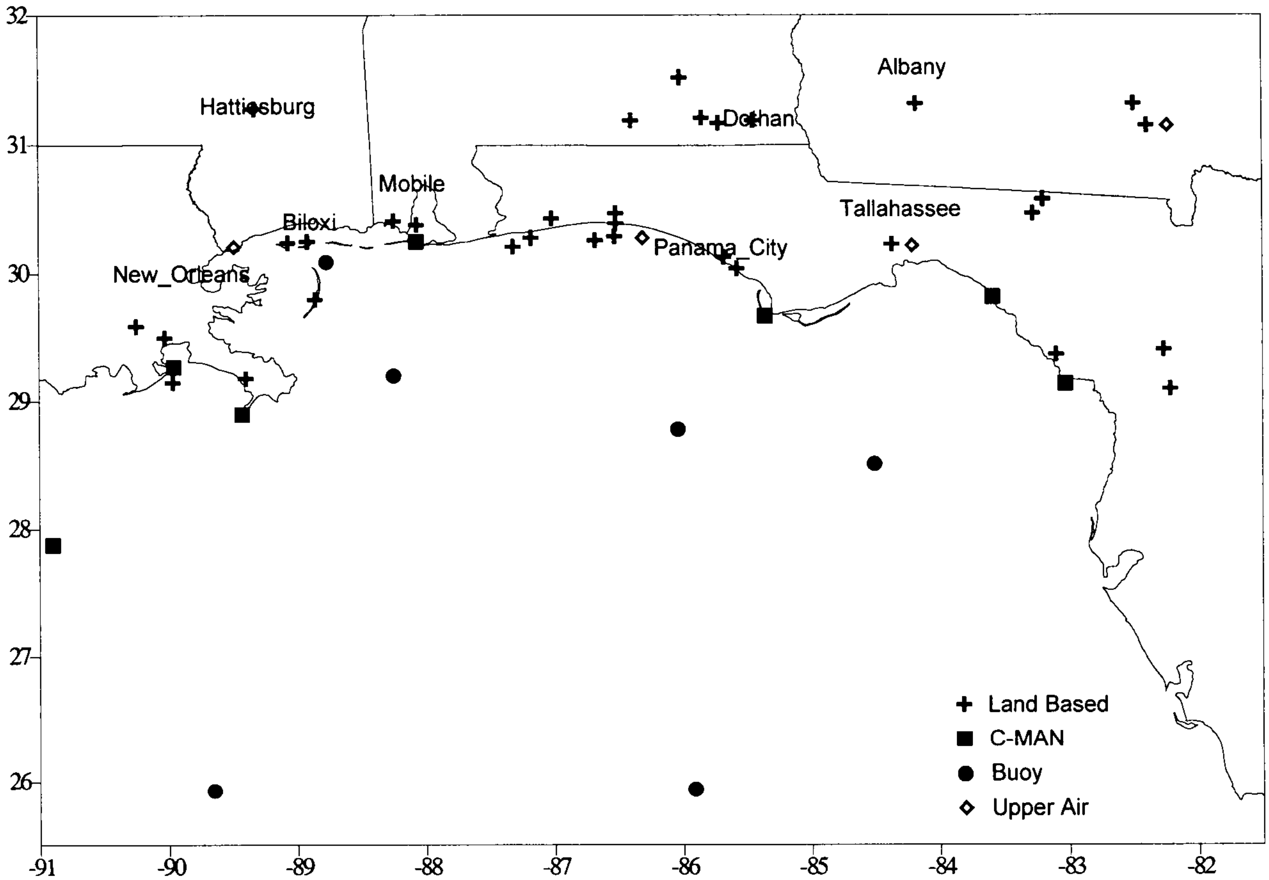

Figure 2-1. Location of land-based buoy, C-MAN, and upper air monitoring sites in the MMS NEGOM study area.
(Note: coastline may not be accurately depicted).

Search of NOAA Databases
Surface Meteorology, 1995 – 1996, Gulf of Mexico
(Attachment 2-1)

1. Reynolds SST data at NOAA/CDC
Description | Preview | Obtain

2. STORM-WAVE 6-second NWS Soundings
Description | Preview | Obtain

3. STORM-WAVE: Upper Air 5mb Sounding Composite
Description | Preview | Obtain

4. GCIP/ESOP-95: Upper Air ARM-CART Soundings
Description | Preview | Obtain

5. VORTEX-95 6-sec NWS Soundings
Description | Preview | Obtain
Office of Oceanic and Atmospheric Research, Score: 167, Map Available

6. GCIP/ESOP-95: Upper Air NWS High-Resolution (6 second) Soundings
Description | Preview | Obtain

7. VORTEX-95 10-sec CLASS Soundings
Description | Preview | Obtain

8. VORTEX-95 High Resolution Surface Composite
Description | Preview | Obtain

9. GCIP/ESOP-95: Surface USGS Reservoir Data
Description | Obtain

10. GCIP/ESOP-95: Surface Meteorological Composite (5-minute)
Description | Preview | Obtain

11. GCIP/ESOP-95: Surface Meteorological Composite (Hourly)
Description | Preview | Obtain

The GCIP/ESOP-95 Hourly Surface Composite contains data from several networks (i.e., Artais Automated Weather Observation System, Handar AWOS, and Qualimetrics AWOS, Oklahoma Mesonet, Department Of Energy Atmospheric Radiation Measurement Surface, High Plains Climate Network, Automated Surface Observing System, Wind Profiler Network, National Climatic Data Center Surface Airways Observations, and Colorado Agricultural Meteorological data) for the ESOP 95 domain. Data from these sources were merged and quality controlled to from this Surface Composite.

Pressure [Pa]
Pressure reduced to mean sea-level [Pa]
Pressure reduced to mean sea-level using [Pa]
Wind direction [Degree true]
Wind speed [m/s]
Maximum wind speed (gusts) [m/s]
Temperature/dry-bulb temperature [K]
Dew-point temperature [K]
Total precipitation/total water equivale [kg/m**2 (mm)]
Horizontal visibility [m]
Layer Height [feet]

Period of Record
  Beginning Date: 19950401
  Ending Date: 19950930

Project
  GCIP/ESOP-95 : GCIP Enhanced Seasonal Observing Period - 1995

Originating Center
  UCAR/JOSS

Storage Medium
  online
  magnetic tape

Point_of_Contact:
  Contact_Information:
    Contact_Person_Primary: Steven Williams
    Contact_Organization: UCAR/OFPS
  Contact_Organization_Primary:
    Contact_Organization: UCAR/JOSS > UCAR Joint Office for Science Support
    Contact_Person: Steven Williams
  Contact_Position: Data Specialist
  Contact_Address:
    Address_type: Mailing and physical address
    Address: P.O. BOX 3000
    City: Boulder
    State_or_Province: CO
    Postal_Code: 80307-3000

Country: USA
Contact_Voice_Telephone: 303-497-8164
Contact_Electronic_Mail_Address: INTERNET > <URL:mailto:sfw@ucar.edu>

12. GCIP/ESOP-95: Surface Precipitation Composite (Hourly)
Description | Preview | Obtain

13. GCIP/ESOP-95: Surface ABRFC Miscellaneous Precipitation Data
Description | Obtain

14. GCIP/ESOP-95: Surface USGS Stream Flow Data
Description | Obtain

15. GCIP/ESOP-95: Surface Co-operative Agency Reservoir Data
Description | Obtain

16. GCIP/ESOP-95: Surface Meteorological Composite (20-minute)
Description | Preview | Obtain

17. GCIP/ESOP-95: Surface NCDC SAO Specials Dataset
Description | Preview | Obtain

18. GCIP/ESOP-95: Surface Precipitation Composite (15-minute)
Description | Preview | Obtain

19. VORTEX-95 MAPS Surface Analyses
Description | Obtain

20. Monterey Real-time Marine data at NOAA/CDC
Description | Preview | Obtain

21. NMC Real-time Marine data at NOAA/CDC
Description | Preview | Obtain

Monthly surface marine data gathered by NOAA's National Meteorological Center (NMC), and provided courtesy of Richard W. Reynolds at NMC, become available about 1-5 days following the data month. The basic observational data are edited, using a "trimming" procedure to identify outliers with respect to climatological 3.5 sigma limits derived from 1950-79 COADS data. Two summary statistics, the mean and number of observations, are then calculated for each of 11 observed and derived variables, using COADS-compatible 2-degree latitude x 2-degree longitude boxes (cf., COADS).

ASCII files of the most recent monthly updates may be found in the ascii subdirectory; please refer to the README file in that directory for further information.

Point_of_Contact:
  Contact_Information:
    Contact_Person_Primary:
      Contact_Person: CDC Data Management
      Contact_Organization: NOAA/OAR/ERL/CDC
    Contact_Address:
      Address_Type: mailing address
      Address:
      Climate Diagnostics Center
      U.S. Dept. of Commerce
      NOAA, Code R/E/CD
      325 Broadway
      City: Boulder
      State_or_Province: CO
      Postal_Code: 80303
      Country: USA
    Contact_Voice_Telephone: (303) 492-7365
    Contact_Facsimile_Telephone: (303) 497-7013
    Contact_Electronic_Mail_<URL:mailto:cdcdata@cdc.noaa.gov>

22. VORTEX-95 NCEP 29km eta model Surface Flux
    Description | Obtain

23. GCIP/ESOP-95: Surface USGS Streamflow (PRELIMINARY)
    Description | Obtain

24. Hourly Surface Land from NCDC
    Description | Ordering information

25. Hourly Surface Landfrom NCDC (E-BUFR)
    Description | Obtain

26. NMC North American Surface Analyses
    Description | Ordering information

27. NMC Northern Hemispher Surface Analyses
    Description | Ordering information

28. COMET Case Study 002: Complete Dataset
    Description | Obtain

29. COMET Case Study 003: Complete Dataset
Description | Obtain

30. COMET Case Study 004: Complete Dataset
Description | Obtain

31. NCEP/NCAR Reanalysis Surface data at NOAA/CDC
Description | Preview | Obtain

Abstract

The NCEP/NCAR Reanalysis project is using a state-of-the-art analysis/forecast system to perform data assimilation using past data from 1958 to the present.

This document describes NCEP/NCAR Reanalysis data that is currently available on-line at CDC (this is not all of the data generated by the Reanalysis). Additional files will be periodically added.

The NCEP/NCAR Reanalysis descriptions here are subdivided into separate data sets

These are currently:

Pressure Level Data
Surface Data
Surface Flux Data
Other Flux Data
Tropopause
T62 Spectral Coefficients

Point_of_Contact:
  Contact_Information:
    Contact_Person_Primary:
      Contact_Person: CDC Data Management
      Contact_Organization: NOAA/OAR/ERL/CDC
    Contact_Address:
      Address_Type: mailing address
      Address:
      Climate Diagnostics Center
      U.S. Dept. of Commerce
      NOAA, Code R/E/CD
      325 Broadway
      City: Boulder

State_or_Province: CO
Postal_Code: 80303
Country: USA
Contact_Voice_Telephone: (303) 492-7365
Contact_Facsimile_Telephone: (303) 497-7013
Contact_Electronic_Mail_<URL:mailto:cdcdata@cdc.noaa.gov>

32. Wind Profiler Network, Surface_6
Description | Ordering information
National Climatic Data Center, Score: 139, Map Available

33. Wind Profiler Network, Surface_60
Description | Obtain
National Climatic Data Center, Score: 138, Map Available

34. NCEP/NCAR Reanalysis Surface Flux Gaussian Grid data at NOAA/CDC
Description | Preview | Obtain
Office of Oceanic and Atmospheric Research, Score: 134, Map Available

35. NCEP/NCAR Reanalysis Non-surface Gaussian Grid data at NOAA/CDC
Description | Preview | Obtain
Office of Oceanic and Atmospheric Research, Score: 130, Map Available

Gridded NCEP Meteorological Data Archives
(Attachment 2-2)

Transport Modeling & Assessment - Silver Spring, MD

Overview

The National Weather Service's National Centers for Environmental Prediction (NCEP) runs a series of computer analyses and forecasts operationally. NOAA's Air Resources Laboratory (ARL) routinely uses NCEP model data for use in air quality transport and dispersion modeling calculations. In 1989 ARL began to archive some of these datasets for future research studies. ARL has in the past, or is presently archiving the following NCEP datasets, which can be retrieved via ftp by clicking on the name of the dataset:

NOTE: Only a limited set of data (generally the last 6 months) is available via the ftp server. See long term access of data for information on obtaining data that is not available via ftp here.

- MRF archive (1991-1996)
  - MRF readme file
  - Northern Hemisphere archive grid domain map
  - Southern Hemisphere archive grid domain map
- FNL archive (1997-)
  - FNL readme file
  - FNL missing data listing
  - Northern Hemisphere archive grid domain map
  - Southern Hemisphere archive grid domain map
- NGM (Jan. 1991 - Apr. 1997)
  - NGM Readme File
  - NGM archive grid domain map
- Eta Data Assimilation System (EDAS, 1997-)
  - EDAS Readme File
  - EDAS missing data listing
  - EDAS archive grid domain map

All of theses datasets contain basic fields such as the u- and v-wind components, temperature, and humidity. However, the archives differ from each other because of the horizontal and vertical resolution, as well as in the specific fields provided by NCEP. All fields were selected by ARL according to what is most relevant for transport and dispersion studies and disk space limitations.

ARL also archives gridded data from it's own running of the RAMS mesoscale model. RAMS archives can be found at:

- Regional Atmospheric Modeling System

RAMS Readme File
RAMS archive grid domain map

Longer Term Access of Data

In addition to the availability of several months of data online, the data are also archived onto 3480 cartridge tapes and sent to the National Climatic Data Center (NCDC) for long term storage and distribution to the public.

NCDC can be reached at:

Climate Services Branch
National Climatic Data Center
151 Patton Avenue
Asheville, NC 28801

Email: orders@ncdc.noaa.gov
Phone: 704-271-4800
Fax: 704-271-4876
ftp: ftp.ncdc.noaa.gov
www: http://www.ncdc.noaa.gov

Description of COAMPS
(Attachment 2-3)

What is COAMPS?

COAMPS is a acronym for "The Coupled Ocean/Atmosphere Mesoscale Prediction System" and it represents an analysis-nowcast and short-term (up to 48 hours) forecast tool applicable for any given region of the earth. COAMPS includes an atmospheric data assimilation system comprised of data quality control, analysis, initialization, and nonhydrostatic atmospheric model components and a choice of two hydrostatic ocean models. The atmospheric component of COAMPS can be used for real-data simulations, the analysis can use global fields from the Navy Operational Global Atmospheric Prediction System (NOGAPS) or the most recent COAMPS forecast as the first-guess. Observations from aircraft, rawinsondes, ships, and satellites are blended with the first-guess fields to generate the current analysis. For the idealized experiments, the initial fields are specified using an analytic function and/or empirical data (such as a single sounding) to study the atmosphere in a more controlled and simplified setting. The atmospheric model uses nested grids to achieve high-resolution for a given area and contains parameterizations for subgrid scale mixing, cumulus parameterization, radiation, and explicit moist physics. Typical mesoscale phenomena that COAMPS has been applied to includes mountain waves, land-sea breezes, terrain-induced circulations, tropical cyclones, mesoscale convective system, coastal rainbands, and frontal systems.

The COAMPS model domain typically covers a limited area on the earth. The model grid size, usually referred to as grid resolution, can range from a few hundred kilometers (synoptic scale) down to approximately one meter when using the large-scale eddy (LES) more. The actual dimensions used depend on the scale of the phenomena the user is interested in simulating.

The model dimensions can be set so as to produce any rectilinear pattern and can also be rotated to align with any surface feature, such as the terrain or a coastline. COAMPS can be run with any number of nested grids, with the grid resolution in any mesh one-third that of the next coarser mesh.

COAMPS also contains an option to utilize either the Modular Ocean Model (MOM) or the Princeton Ocean Model (POM). In a fully-coupled mode, the atmospheric and ocean models can be integrated simultaneously so that the precipitation and the surface fluxes of heat, moisture, and momentum are exchanged across the air-ocean interface every time step. Optionally, the atmospheric model or either of the ocean models can be used as a stand-alone system.

Restriction for COAMPS usage

COAMPS is developed to support Tactical Naval operations and R&D usage. In order to get a copy of COAMPS source code, organizations other than those within the Department of Defense (DOD), are required to sign NRL's Memorandum of Agreement.

What kind of experience is needed to use COAMPS

The users should have basic knowledge of numerical weather prediction, an understanding of atmospheric science in the area of numerical weather prediction, some knowledge of UNIX operating system and Fortran 77 programming language.

Hardware and software requirement for COAMPS

COAMPS is a portable atmospheric modeling system (the ocean model coupling is under development, not for release now), that can currently be run on most of the major vendor machines such as Cray, SGI, DEC ALPHA, SUN and HP workstations. Future releases will include the ability to run on the mpp type machines.

3. METEOROLOGICAL TYPECASTING

PURPOSE

One of the goals of this project, besides the compilation and delivery of a complete three-year observational database of meteorological parameters in the NEGOM, is to augment the raw database with statistical summaries of the data and to analyze the role of synoptic-scale weather patterns in defining regional-scale forcing. Such analyses will provide valuable resources into concurrent and future oceanographic studies, as well as the likely transport of pollutant plumes from accidental releases off-shore. In light of inter- and intra-annual meteorological variability in the NEGOM, it is useful to provide statistical measures on various temporal scales, such as season, year, and data period (1995-1997), as well as stratified by meteorological regime.

The NEGOM Expert System described in Section 5 not only provides a simple interface tool to access both the raw data and the statistical summaries, but also can be used in a forecast mode to estimate likely air and water parcel trajectories based upon the three-year climatology. A sequence of probable parcel paths can be determined from statistical information generated for a particular location, season, and meteorological regime that agrees most closely with current and forecast weather patterns. Caution should be exercised in using this three year climatological data base since the period includes an "El Nino" episode.

It becomes obvious then that a systematic procedure for identifying key meteorological patterns in the NEGOM must be developed so that (1) each day in the database can be classified into a particular regime for the purpose of generating pattern-specific statistics for the meteorological parameters, and (2) so that a user of the Expert System can select one or more of these patterns to match current and forecast conditions, thereby displaying the most appropriate statistical fields. This section describes the procedure by which ten synoptic-scale weather patterns were selected to describe the range of conditions observed during the 1995-97 data period. General guidance is also provided for users of the Expert System in choosing the most appropriate pattern from common weather and forecast charts.

IDENTIFICATION OF METEOROLOGICAL CATEGORIES

The selection of weather regimes began with a review of eight synoptic weather types previously developed by Muller and Wax (1977) for New Orleans and coastal Louisiana. A preliminary classification was performed for the year 1994 using these weather types. From this analysis, it was determined that the eight weather types needed to be refined to more specifically address surface wind and pressure gradient patterns in the NEGOM. Specifically, the following changes were made:

- The Coastal Return classification was separated into two regimes dominated by high pressure over or off-shore of the eastern U.S. -- Eastern Continental High and Bermuda High;
- The Pacific High and Gulf Return classifications were combined into one regime based on a low pressure system over the Midwest U.S. -- Midwest Low;
- The Frontal Overrunning classification was separated into two regimes dominated by low pressure over the eastern U.S. -- Eastern Low and Gulf Front East/West;
- The Gulf Front classification was separated into two regimes dominated by high pressure over the Gulf -- Gulf High and No Gradient (the difference being defined in terms of the location and breadth of the central highest pressure).

The names of the remaining original classifications were changed to be more descriptive in terms of the dominant system defining each regime. These changes resulted in a set of ten final synoptic patterns.

Two project team members independently reviewed NWS daily weather maps for each day of the three year NEGOM database, and assigned each day to a specific classification based on pressure contour maps and wind flow patterns at 1200 UTC (0600 CST). After reconciliation of the two independent reviews, the criteria or "rules" defining each of the ten regimes were amended and solidified. The review determined that ten synoptic surface patterns would adequately represent the various surface conditions in the Northeast Gulf provided that an accurate and comprehensive description of each was available to future users of the Expert System. Examples of these ten synoptic patterns are shown in the attached figures (3-1 through 3-10). Basically the critical variable in determining these patterns are the orientation of the isobars, and hence wind direction.

In order to properly classify each synoptic category, it is important to follow the criteria that describe the synoptic feature, the most important of which is the isobar orientation. The criteria for each synoptic feature are described below and are included, in brief, in the figure captions and in a decision chart shown in Figure 3-11. In general, these guidelines distinguish between the position and orientation of synoptic high and low pressure systems that influence the wind flow in the Northeast Gulf region.

Midwest Continental High (Figure 3-1): A high-pressure system is generally centered west of the Mississippi River and north of the Texas/Mexico border. In the Northeast Gulf the isobars under this pattern are orientated from the northeast to the southwest. Winds in the Northeast Gulf under this pattern are from the north by northwest with anti-cyclonic curvature following the flow.

Eastern Continental High (Figure 3-2): A high pressure system is generally centered east of the Mississippi River and west of the eastern seaboard and from just north of the Northeast Gulf Coast to the US/Canada border. In the Northeast Gulf the isobars under this pattern are orientated from the east to the west. Winds in the Northeast Gulf under this pattern are from the northeast with anti-cyclonic curvature following the flow.

Bermuda High (Figure 3-3): A high-pressure system is generally centered in the Atlantic Ocean from Florida to Maine. In the Northeast Gulf the isobars under this pattern are orientated from the south to the north or from the southeast to the northwest. Winds in the Northeast Gulf are from the east by southeast under this synoptic pattern, with anti-cyclonic curvature following the flow. This pattern often coexists with a **Midwest Low**. If this is the case, the user must decide which pattern is closest to the Northeast Gulf and select that pattern.

Midwest Low (Figure 3-4): A low-pressure system is generally located east of the Rockies with or without a north/south orientated front located west of New Orleans. In the Northeast Gulf the isobars under this pattern are orientated from the south to the north. Winds in the Northeast Gulf under this synoptic pattern are from the southeast with cyclonic curvature following the flow. This pattern often coexists with a **Bermuda High**. If this is the case, the user must decide which pattern is closest to the Northeast Gulf and select that pattern.

Gulf Front or Trough N/S (Figure 3-5): A north/south-orientated front or trough exists between New Orleans and Tampa. Winds in the Northeast Gulf to the west of the front are northwesterly and winds to the east of the front are southeasterly under this pattern. This pattern may often be accompanied by other patterns such as the **Midwest Low** or **Bermuda High**. If the winds on both sides of the front are from the same direction (indicating a weak front or trough), and the wind directions are consistent with the other accompanying pattern, then the **Gulf Front or Trough N/S** pattern should be ignored and the other accompanying pattern should be chosen.

Gulf Front or Trough E/W (Figure 3-6): An east/west-orientated front or trough is located in the Northeast Gulf region within 50 km of the coastline. Winds are northerly on the northern side of the front and southerly on the southern side of the front. Other patterns may often coexist with this pattern. If the winds on both sides of the front are from the same direction (indicating a weak front or trough), and the wind directions are consistent with the other observed synoptic pattern, then the **Gulf Front or Trough E/W** pattern should be ignored and the other accompanying pattern should be chosen.

East Coast Low (Figure 3-7): A low-pressure system is generally located east of the Mississippi River with east/west-orientated isobars over the Northeast Gulf region and no front over the Northeast Gulf. Winds in the Northeast Gulf are westerly under this synoptic pattern with cyclonic curvature following the flow.

Gulf High (Figure 3-8): High surface pressure is centered in the Gulf, south of the Northeast Gulf Coast from Florida to Texas, and usually associated with a weak pressure gradient. Winds in the Northeast Gulf have a southerly component under this pattern, and are generally weak and anti-cyclonic.

No Gradient (Figure 3-9): No other patterns are present and no surface pressure gradient is evident in the Northeast Gulf region. Winds in the Northeast Gulf are calm or light and variable under this pattern.

Hurricane, Tropical Storm, or Depression (Figure 3-10): A hurricane, tropical storm or tropical depression exists in the Gulf region. Winds in the Northeast Gulf are variable.

When choosing a synoptic pattern the user should use the wind observations as a guideline. For example, if the user suspects that an eastern continental high is present, but the winds in the Gulf are not northerly, as expected, but from a significantly different direction, then the user should attempt to find another category appropriate to the wind direction and pressure pattern. If, however, the user suspects that the synoptic category is an eastern continental high and northerly winds are observed, then the user should choose the Eastern Continental High with confidence.

As mentioned above in the synoptic pattern description, there are times when more than one pattern may be present, in which case the user must choose the feature that has the greater influence on the winds in the Northeast Gulf. For example, an east/west-orientated front may exist over the Northeast Gulf region with a strong continental high located east of the Mississippi and to the north of the Gulf. If the high pressure system dominates the pressure pattern and the wind flow, and if the front has little influence on the wind (i.e., no wind shift across the frontal boundary), it is appropriate to classify the pattern as the Eastern Continental High and not the Gulf Front or Trough E/W.

At times it may be difficult to decide which pattern is having a greater influence on the winds in the northeast Gulf. Under these circumstances the user should choose the upstream feature (generally the feature to the west) rather than the downstream feature (generally to the east). For example, if the Midwest Low and the Bermuda High are simultaneously observed and both appear to be having an equal influence on the winds in the northeast Gulf, then the user should choose the upstream Midwest Low rather than the Bermuda High.

After categorization of the synoptic condition the user may wish to estimate transport times. The estimation of transport times requires an estimation of wind speeds over the northeast Gulf. Because the wind speeds cannot be estimated from the synoptic patterns, the surface pressure gradients may be used. Guidelines for wind speeds based on the surface pressure gradients have been estimated using geostrophic balance and a logarithmic vertical wind profile, and are shown in the Table 3-1. For example, with a surface pressure gradient of 4 mb per 400 km, the surface wind speed at 10 meters over the water will be about 10 m/sec. Likewise, a surface pressure gradient of 4 mb per 800 km would result in a 10 meter wind speed of about 5 m/sec.

Table 3-1.
Relationship between isobar spacing and 10-m geographic wind speed.

Distance (km) between 4 mb isobar contours	Wind Speed (m/sec)
200	20
400	10
600	7
800	5
1000	4
1500	3
2000	2

DAILY TYPECASTING FOR 1995-1997

Results of synoptic typecasting for each day of the three year period 1995-97 are shown in Table 3-2. Cumulative days for each of the ten categories are given for each season and for the entire year. Overall, daily synoptic meteorology is found to be dominated during this period by the three high pressure categories (Midwest, eastern and Bermuda high), followed in order by no-gradient, the frontal categories, and finally by the various lows (Midwest, eastern, and tropical). The daily assignments were used in the calculation of statistics by meteorological category, season, and year.

Table 3-2.
Frequency of occurrence (days) for each synoptic category by season and year.

Period	MCH	ECH	BH	MLOW	GFNS	GFEW	ELOW	GH	NG	TS
Spring 95	20	23	18	4	11	2	2	5	4	1
Summer 95	10	24	30	0	5	0	1	5	14	2
Fall 95	7	32	11	1	7	4	1	5	15	9
Winter 95	21	34	15	1	7	3	2	2	5	2
1995	58	113	74	6	30	9	6	17	38	14
Spring 96	14	18	26	1	9	4	4	8	6	1
Summer 96	9	24	25	0	6	3	0	5	19	0
Fall 96	4	23	18	2	3	7	3	12	20	0
Winter 96	9	37	18	0	7	6	2	5	7	1
1996	36	102	87	3	25	20	9	30	52	2

Spring 97	12	27	16	3	12	4	1	7	8	0
Summer 97	4	28	14	2	8	6	4	17	8	0
Fall 97	6	21	6	0	6	11	5	2	31	4
Winter 97	20	32	7	4	10	6	6	1	6	0
1997	42	108	43	9	36	27	16	27	53	4

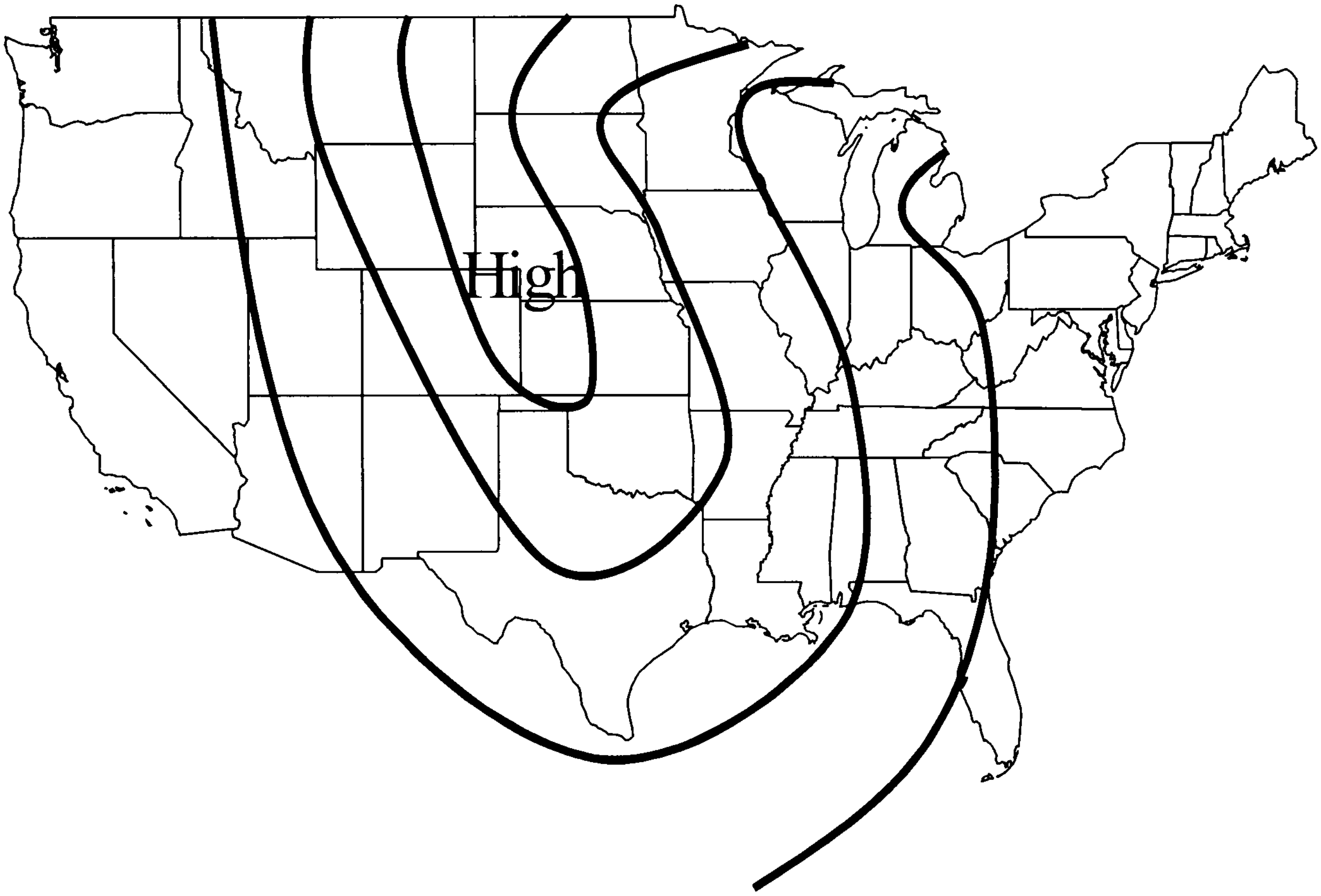

Figure 3-1. Midwest Continental High (MCH), high pressure generally centered west of the Mississippi River and north of the Texas/Mexico border. In the Northeast Gulf the isobars are approximately orientated northeast to southwest and winds are from the north by northwest.

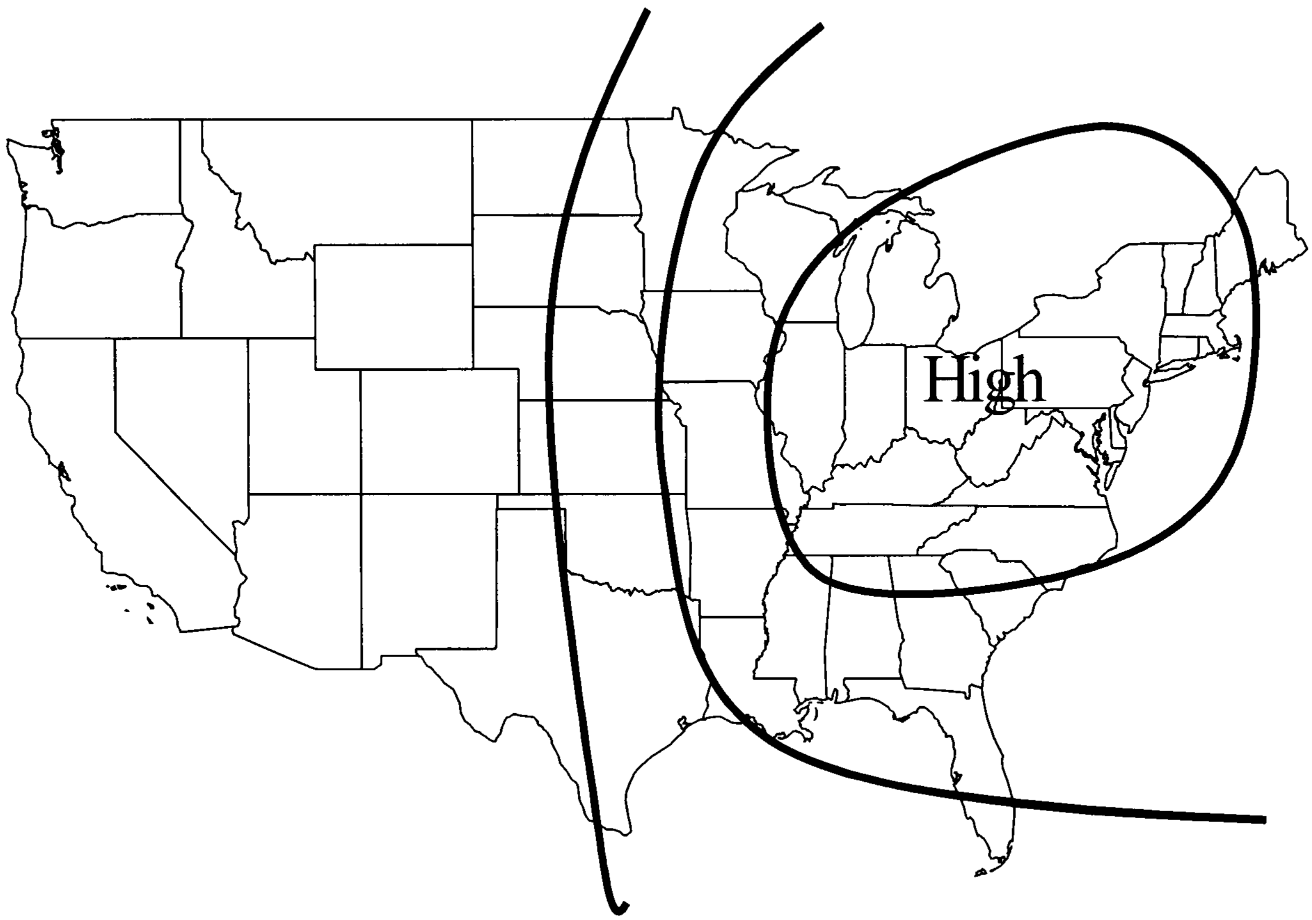

Figure 3-2. Eastern Continental High (ECH), high pressure generally centered east of the Mississippi River and west of the eastern seaboard and from just north of the Gulf Coast to the US/Canada border. In the Northeast Gulf the isobars are approximately orientated east to west and winds are from the northeast.

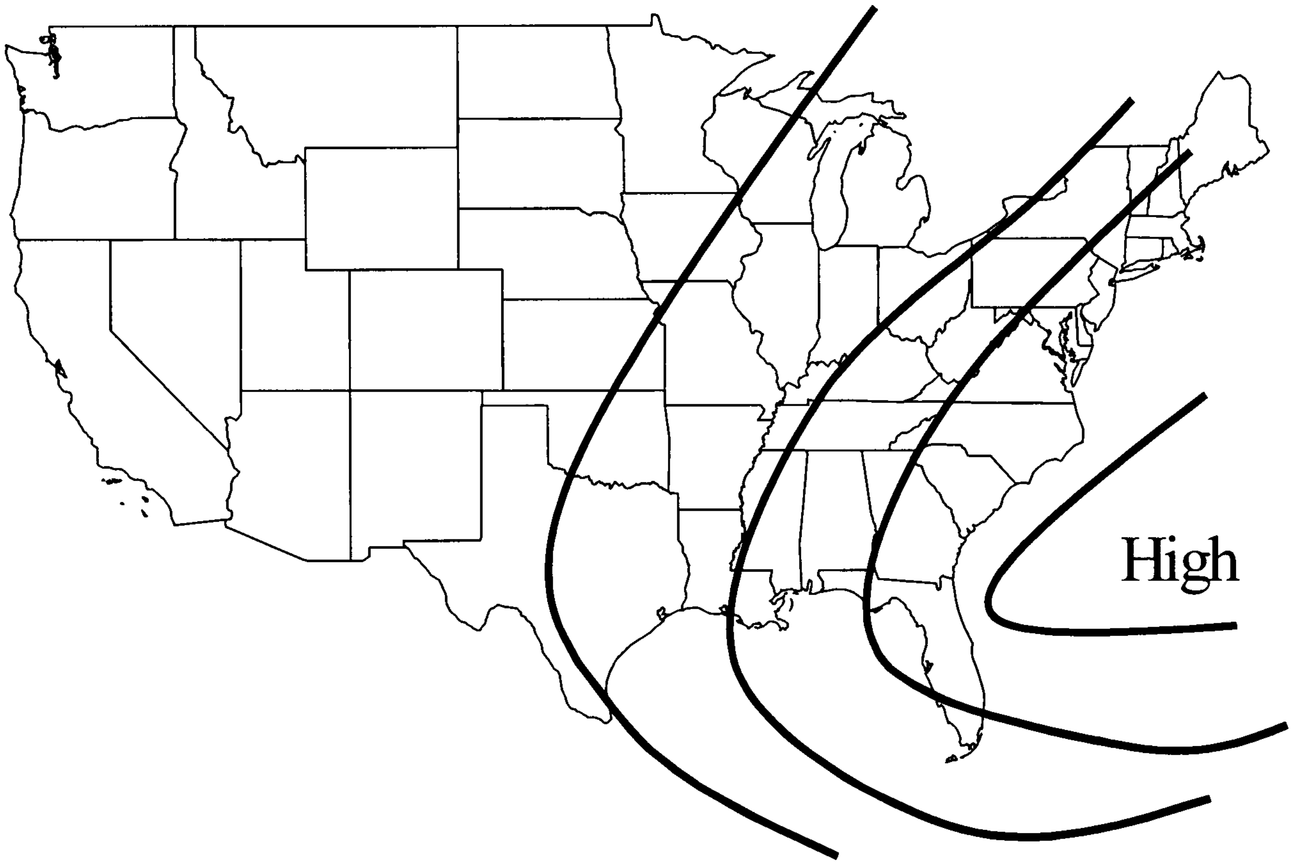

Figure 3-3. Bermuda High (BH), high pressure generally centered in the Atlantic Ocean from Florida to Maine. In the Northeast Gulf the isobars are approximately orientated southeast to northwest or south to north and winds are from the southeast.

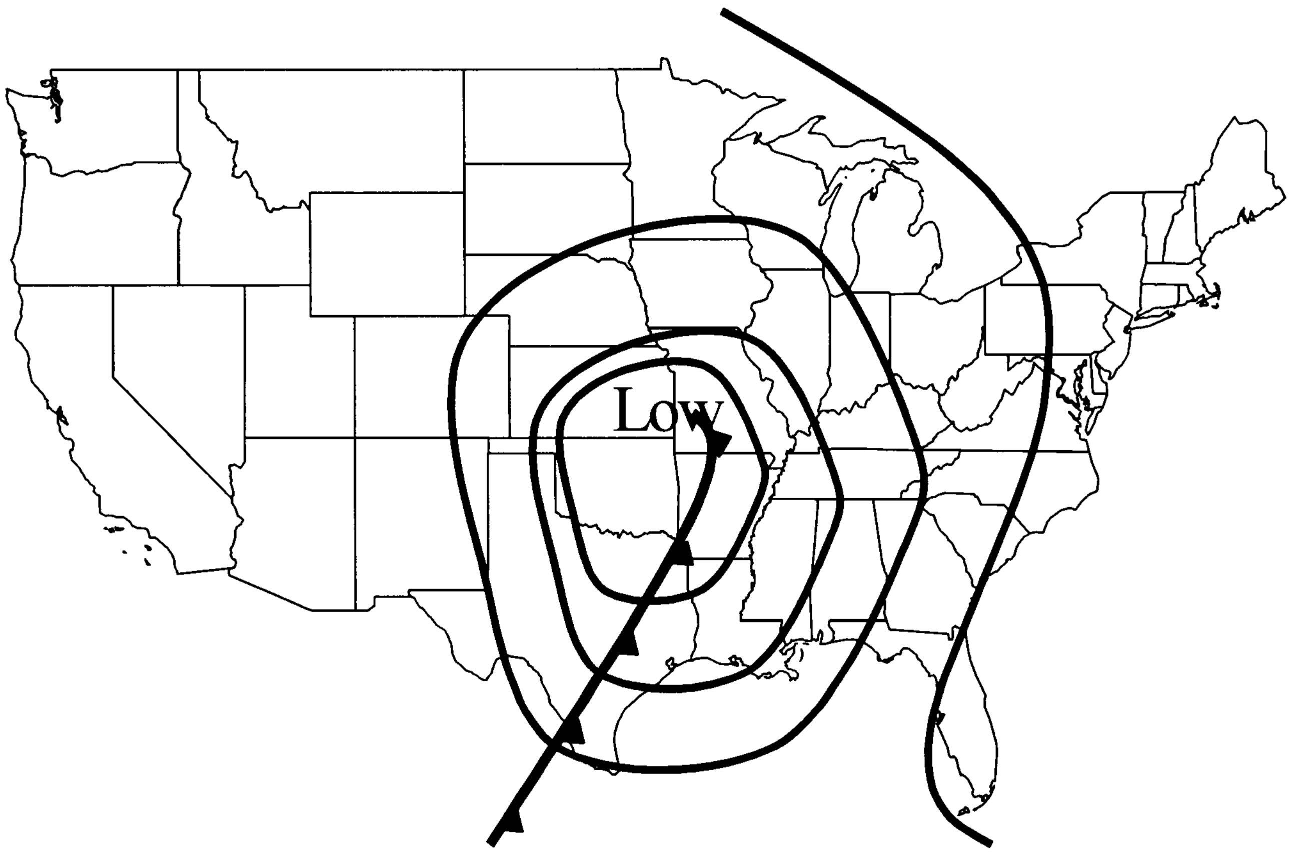

Figure 3-4. Midwest Low (MLOW), low centered east of the Rockies with or without a north/south-orientated front west of New Orleans. In the Northeast Gulf the isobars are orientated south to north and the wind has a southerly component.

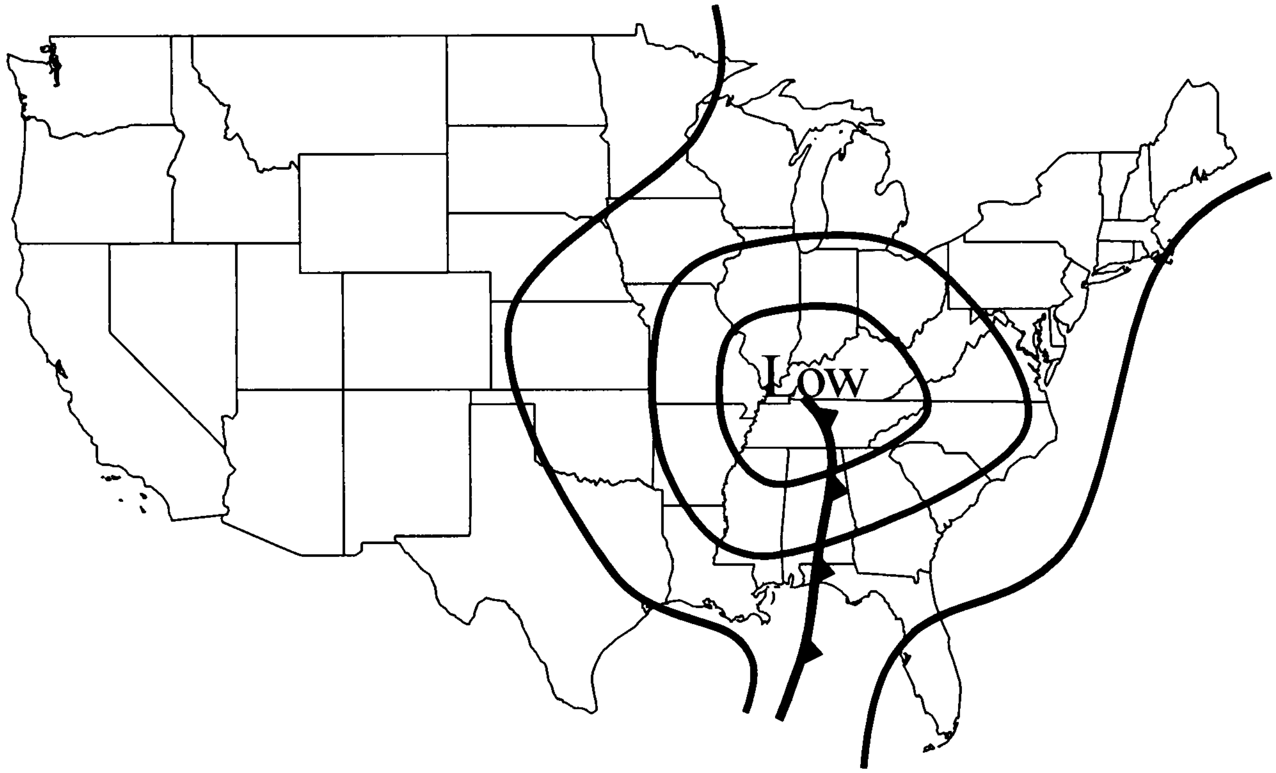

Figure 3-5. Gulf front or trough N/S (GFNS), north/south-orientated front or trough between New Orleans and Tampa. In the Northeast Gulf winds to the west of the front are northwesterly and winds to the east of the front are southeasterly.

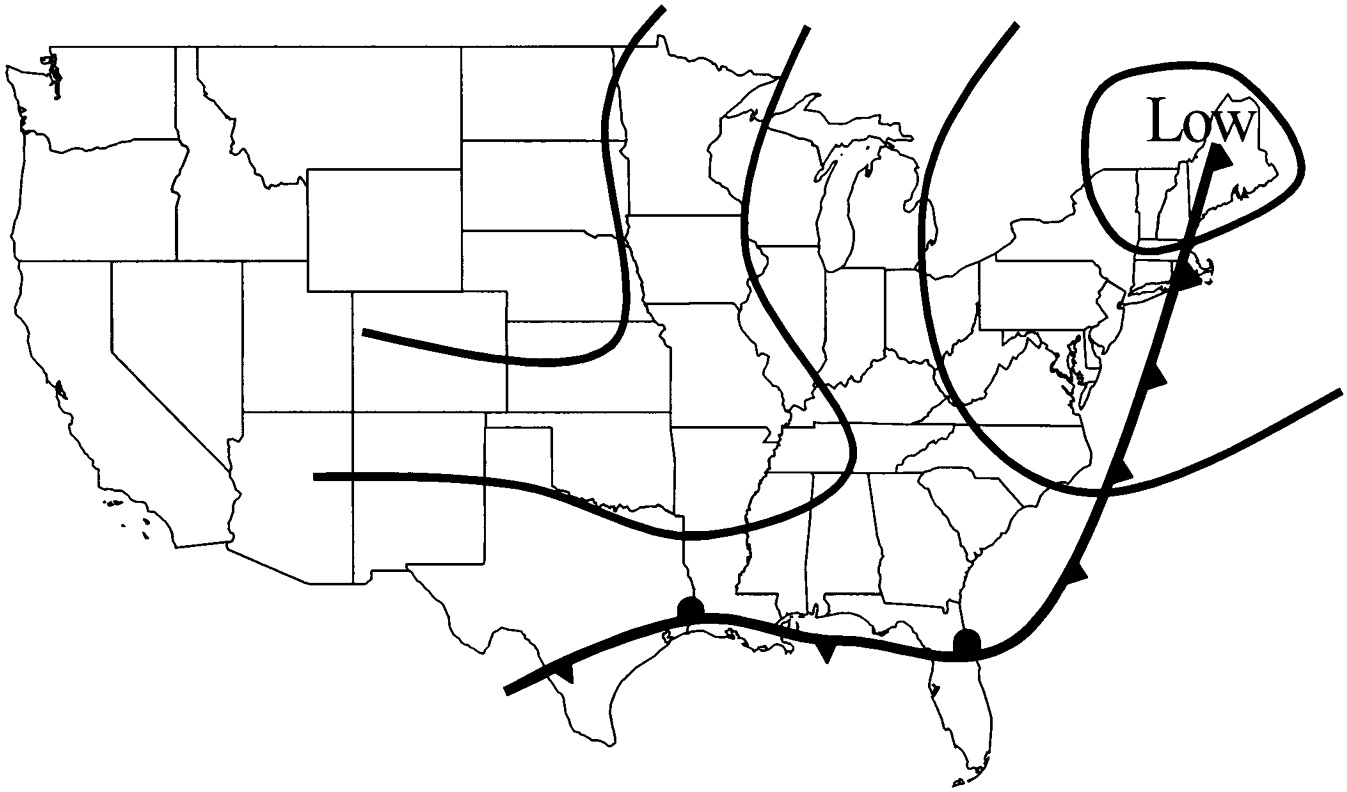

Figure 3-6. Gulf front or trough E/W (GFEW), east/west-orientated front or trough located in the Gulf region. In the Northeast Gulf winds are northerly on the northern side of the front and southerly on the southern side of the front. The wind directions are highly variable.

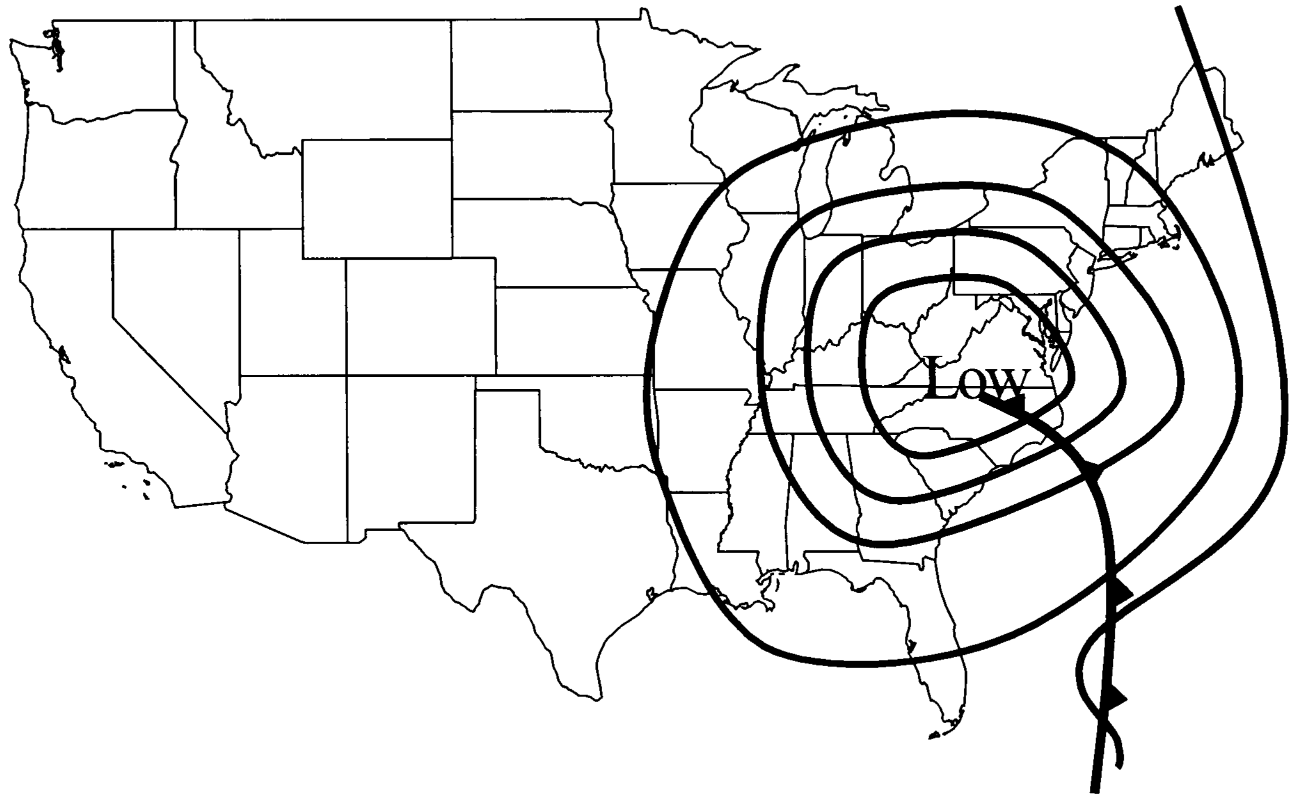

Figure 3-7. East Coast Low (ELOW), low pressure system east of the Mississippi River with west/east-orientated isobars over the Gulf region and no front over the Gulf. In the Northeast Gulf the wind has a westerly component.

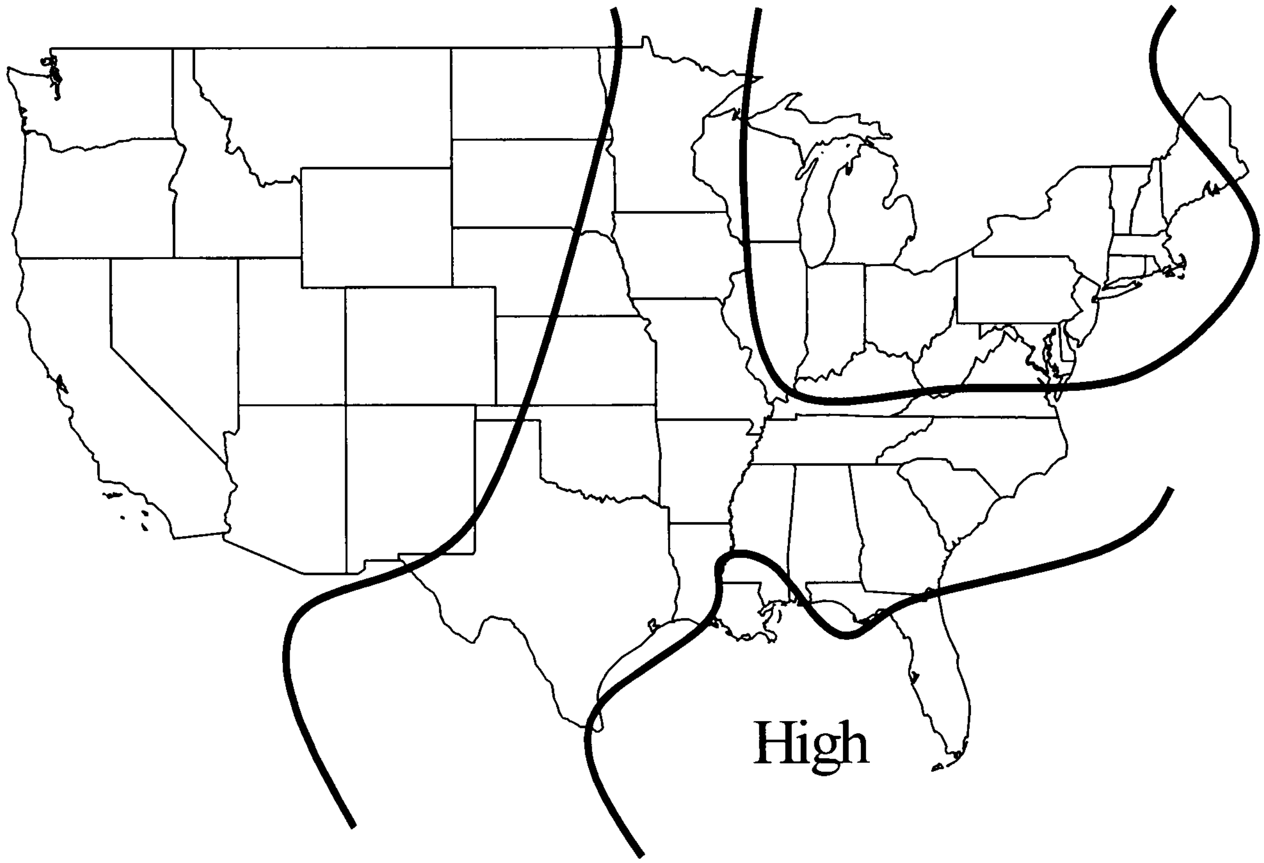

Figure 3-8. Gulf High (GH), high surface pressure centered in the Gulf, south of the Northeast Gulf from Florida to Texas. In the Northeast Gulf winds have a southerly component.

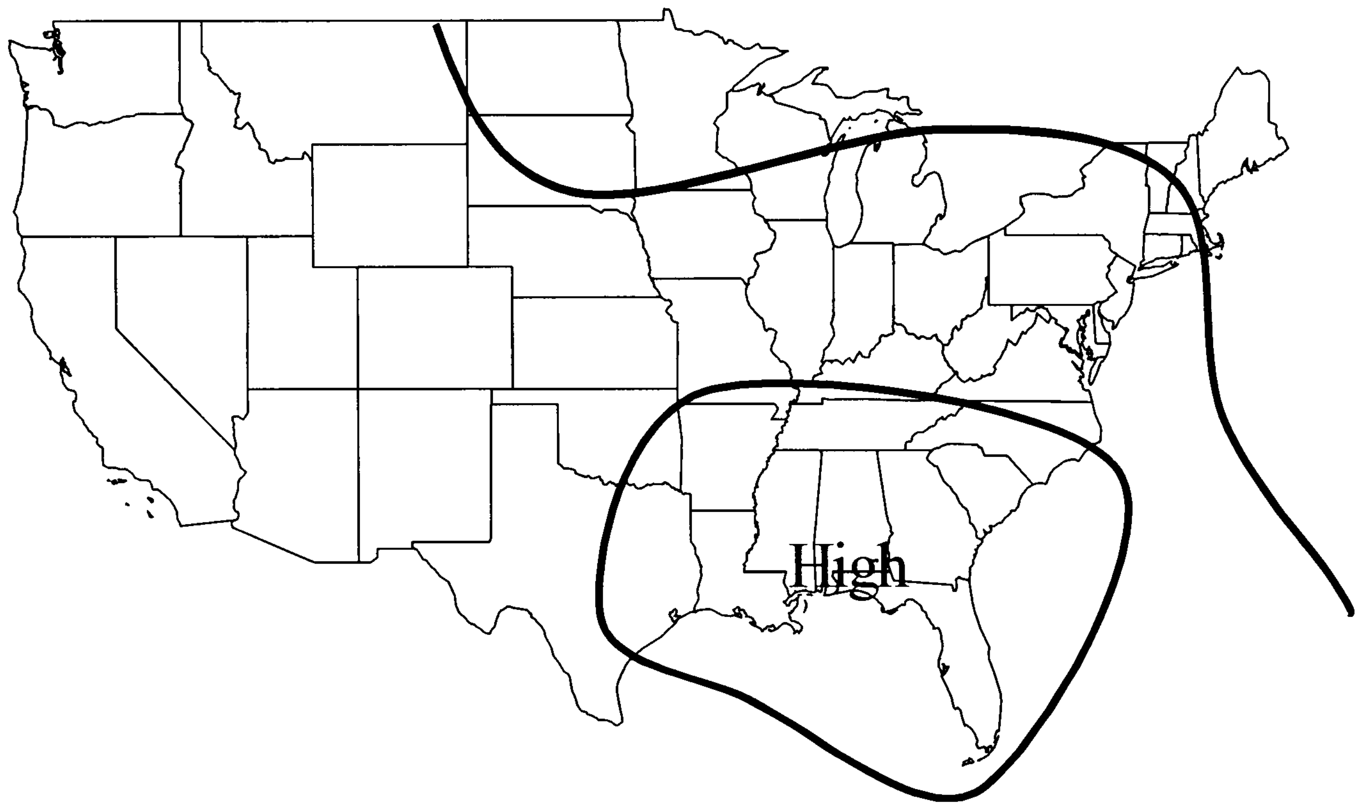

Figure 3-9. No Gradient (NOGRAD), no surface pressure gradient in the Gulf region. In the Northeast Gulf winds are calm or light and variable.

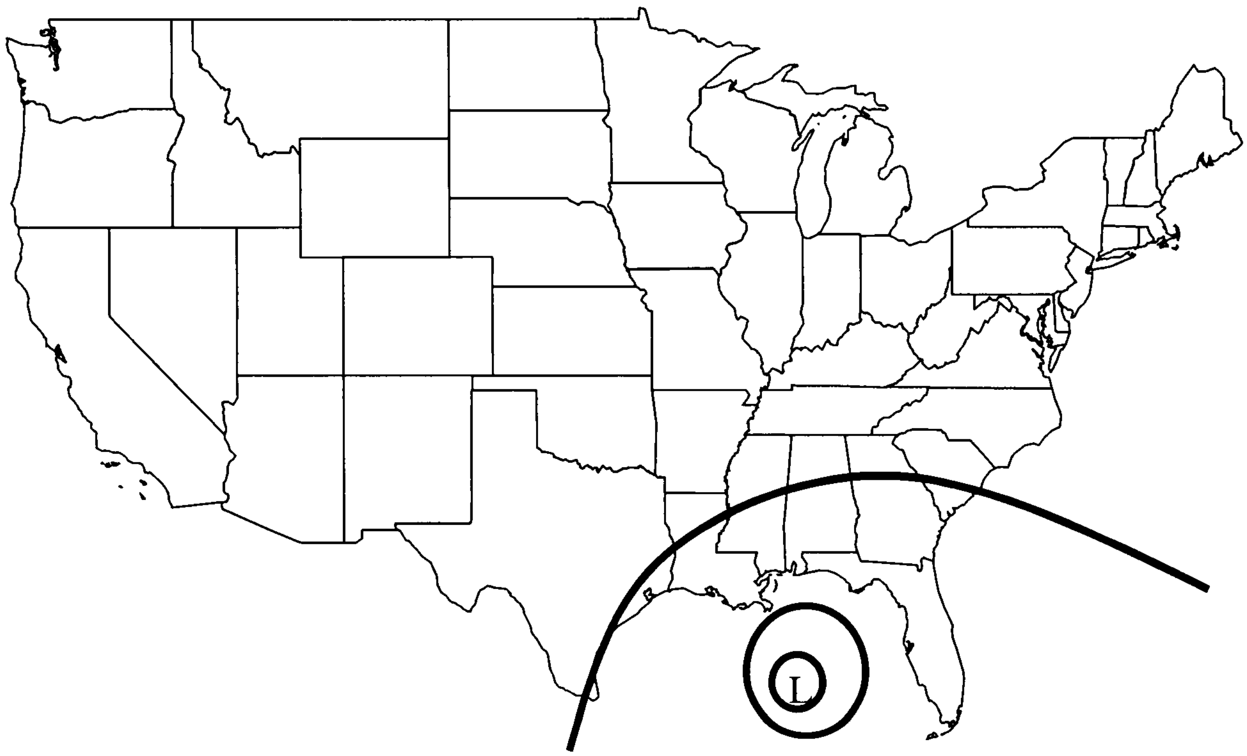

Figure 3-10. Hurricane, Tropical Storm, or Depression (TS), a tropical storm in the Gulf region. In the Northeast Gulf winds are variable.

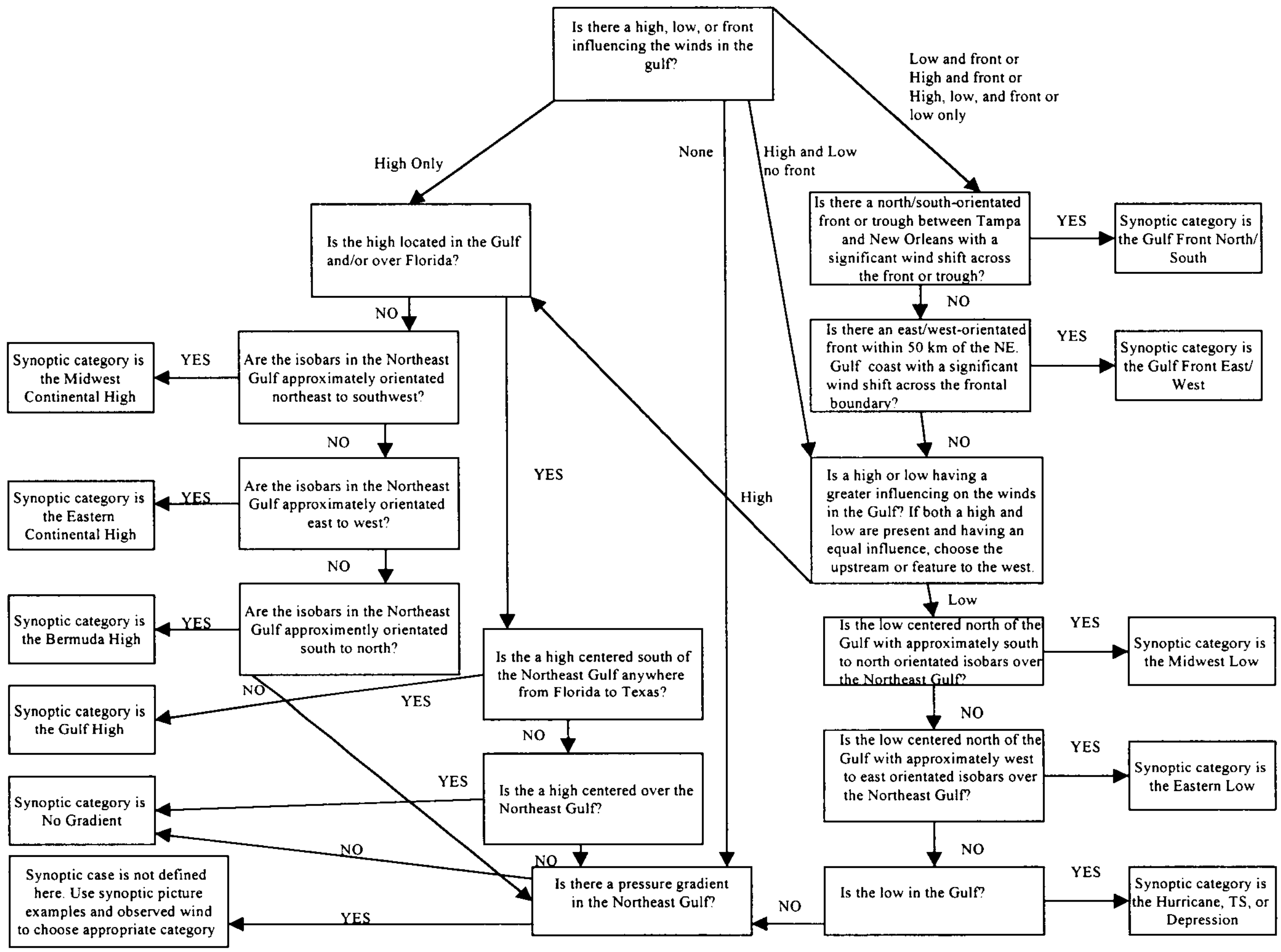

Figure 3-11. Decision tree flowchart describing the general methodology to select a synoptic category.

4. METEOROLOGICAL DATA REDUCTION/ANALYSIS AND SYNTHESIS

OVERVIEW

Besides the compilation of a historical three-year observational database, the MMS requires various analyses of directly measured and derived quantities to be provided that may be useful to multi-disciplinary scientific studies, forecasters, and engineers. These analysis products are to be synthesized with the raw database.

The following general tasks have been performed:

- Means and variances, stratified by season, meteorological regime, year, and total data period (1995-97) have been determined for directly measured quantities such as winds, temperature (air and/or sea, depending on the site), humidity, and pressure.

- Means and variances, stratified by season, meteorological regime, year, and total data period (1995-97) have been determined for quantities derived from directly measured parameters (where data allow); these include heat flux, boundary layer depth, boundary layer stability, moisture and latent heat flux across the land-sea boundary, stress, stress curl, and Ekman pumping velocity.

- Time series of winds and temperature for all marine sites and selected coastal stations have been generated for the entire data period. All time series data have been reduced and analyzed using accepted, state-of-the-art time series techniques, including the calculation of frequency spectra and autocorrelation functions. These same analysis techniques have been applied to filtered versions of the raw time series that remove significant tidal modes such as sea breeze circulations.

- Using all available data, distribution maps have been prepared for mean and variance wind patterns, mean and variance wind stress, mean and variance air and sea surface temperature, and mean and variance humidity. Distribution maps are stratified by season, meteorological category, year, and total data period.

- Vertical vorticity and wind stress curl have been estimated, mapped, and interpreted under different thermal stratification conditions.

- Bulk formulae have been utilized to estimate surface layer water and latent heat transport across the sea-land boundary; statistics of these fluxes have been calculated for various temporal and meteorological regime stratifications.

- The basic properties and stability associated with the atmospheric boundary layer have been estimated using theoretical relationships (bulk parameterization); statistics of these parameters have been developed for various stratifications (season, meteorological category, etc.) that allow for their variations to be determined as a function of atmospheric forcing.

To date, all analyses have been based on diagnostic approaches to meet the objectives of this study. This has included the computation of wind stress, heat flux, boundary layer parameters, and even humidity (where not measured), as well as measures of the variability of these parameters (e.g., means and standard deviation, etc.). These efforts have been limited by the available data since some necessary parameters are only available at a few sites. For example, many of the diagnostic calculations listed above have hinged on meteorological data taken at buoy and C-MAN stations located in the NEGOM. The locations of these sites are presented in Figure 2-1. The derivations of certain parameters require measurements of variables that are not always reported by Buoy or C-Man stations. The methodology to derive these quantities using alternative approaches is described later in this section.

Meteorological models offer significant advantages over diagnostic or objective analyses made from the available measurement network. Primarily, the modeled hydrodynamic fields are generated on a finer spatial (and in some cases time) scales than available from a monitoring network. In the case that it is necessary to extrapolate analyses beyond the spatial limits of the monitoring network, or to interpolate analyses to finer scales within the network, the mass- and energy-consistent hydrodynamic fields generated by numerical models allow for high precision and remove much of the guesswork. This is particularly true in the vertical, where modeled fields allow for much more spatial and temporal detail in the vertical than available from measurements. Moreover, the theoretical expressions employed by meteorological models automate the estimation of key parameters that will be useful in this study, particularly in defining the structures and variations of the atmospheric boundary layer, heat and mass fluxes, and sea breeze circulations.

We have requested from MMS an add-on to the current project to assemble daily NWS Eta forecast model fields for the study period and compile these fields into the NEGOM database. These model fields will be synthesized to improve the estimates of various derived quantities, properties of the boundary layer, variations arising from various atmospheric forcings, and provide a climatology of winter cyclogenesis, cold frontal passage, and development and seasonal variations of sea breeze circulations.

In Section 5, we describe how graphical and tabular summaries have been prepared in a "look-up" format that describe the averaged meteorological conditions for each weather type. These presentations are designed so that investigators can determine the dominant synoptic weather pattern currently affecting or forecasted to affect weather conditions in the region, and then determine the climatologically-averaged transport conditions that accompany such patterns.

ISSUES ASSOCIATED WITH DERIVED QUANTITIES

One of the thrusts of the subject study, besides the compilation and statistical analysis of directly measured meteorological parameters in the northeast Gulf of Mexico, is to determine and analyze spatial and temporal patterns of several derived quantities (i.e., stress, fluxes, and boundary layer parameters). As described above, the calculation of derived quantities is often difficult for the Gulf due to the sparsity of necessary measurement data, particularly any parameters dependent upon humidity or spatial gradients of winds. Some parameters can be grossly calculated but may not lend themselves to a substantive level of analysis due to data sparsity and complexities associated with mid-gulf versus shoreline measurements; in particular, the determination of vorticity and stress curl are problematic.

This sub-section presents a review of the specific problem areas, and closes with our final diagnostic approach of applying parametric relationships to the existing surface observation database. A more detailed discussion of these issues is presented in a memorandum to Lugo-Fernandez (Emery, 1998). The importance of obtaining archived gridded prognostic meteorological model fields is also stressed; these are regarded as a highly valuable resource to provide the data coverage and variables needed for an adequate assessment of derived parameters.

Humidity-based Parameters

Most derived quantities that characterize the boundary layer depend on surface-level humidity measurements. The number of data buoys measuring dew point in the northeastern Gulf has recently been increased in the last half of 1997. Nevertheless, humidity data are routinely available from only a single buoy in the Gulf of Mexico for the database years of 1995-97. It is therefore essential to identify available methodologies from which to derive either humidity or, alternatively, related boundary layer parameters directly. We have previously identified three possible resources (Emery, 1998): (1) satellite soundings of moisture, (2) recently developed empirical relationships between surface layer temperature and moisture fluxes, and (3) archived NWS Eta prognostic meteorological model fields.

In order to utilize satellite data, potentially significant additional resources would be needed to procure vertical sounder archives and process the data for the 3 year database. In return, a rather high spatial (20 km), but low temporal (6-hourly), resolution surface humidity database could be developed for much of the northeastern Gulf. While prognostic model archives do include analysis and forecast fields, only the 3-hourly analysis fields would be valuable to this particular study. The fields are available on a 40 km grid in a Lambert Conformal projection, with coverage across the entirety of North America and surrounding oceans (extending across the northern half of Mexico). This database should supply ample coverage across the northern Gulf of Mexico. The major drawback to this source of information is the enormity of the data volume; as with the satellite data described above, this approach would require significant additional resources to procure the Eta archives and process the data for the 1996-97 MMS database. The obvious advantages of utilizing this information source would far surpass the limited usefulness of a simple surface observation dataset.

Hsu (1998) presents a compelling relationship between air and sea-surface temperature differences and the Bowen ratio (the ratio of sensible to latent heat flux from the surface) in the Gulf of Mexico during unstable conditions. Based upon theoretical considerations, the air-sea temperature difference can be linked to the latent heat flux to some extent. Using data from Buoy 42040 during a cold air outbreak in December 1996, Hsu finds a linear correlation between the air-sea temperature difference and the air-sea mixing ratio difference with a high correlation coefficient of 0.98; these findings are then extended to a non-linear relationship between air-sea temperature difference and the Bowen ratio under unstable conditions and seems to also work reasonably well under neutral and weekly stable conditions. This relationship was extended to additional buoy data from four sites between 1993 and 1997. Different coefficients are derived for near shore areas as well, based on data from the Dolphin Island C-MAN site.

Once the Bowen ratio is known, surface humidity may be calculated, and heat fluxes, surface layer stability, and boundary layer depth can be determined at each site containing air and sea-surface temperature data. This approach, therefore, is limited to estimations of humidity based on available hourly buoy temperature data at each site, and will not improve the spatial or temporal resolution beyond those of the temperature observations. Nevertheless, we have pursued the latest developments of Hsu (1998) in relating sea-air temperature differences to the Bowen ratio. This appears to be a promising technique to derive boundary layer quantities that would otherwise require knowledge of humidity at each measurements site.

Wind-based Parameters

We have previously identified several problems associated with determining some of the derived quantities from the wind observations. Particularly, we have investigated the feasibility of using pressure measurements at buoys and C-MAN sites to define a rhombus from which the pressure Laplacian may be calculated, from which geostrophic vorticity and stress curl can be derived. Originally, only two rhomboids could be defined that had a sufficient number of measurement sites to calculate these quantities. This problem was remedied in part by procuring data from three additional buoys located along the 28°N parallel.

A Laplacian, being a second-order spatial derivative, requires a rhomboidal configuration of at least 5 measurement sites. A simple differencing formula suggested by Hsu (1992) was initially planned to be used in this project; however, its simplicity rests in the assumption that the various sites are fairly equally spaced, and that the sites are aligned orthogonally. In the current study, the distances between sites are quite variable for the few highly non-orthogonal rhomboids that can be constructed. To understand the sensitivity of the rhomboid approach to which differencing technique is used, vorticity was calculated using the formula initially chosen (Hsu, 1992), and then with a revised formula to account for the large disparity among inter-site distances (although it still did not account for the non-orthogonality in each rhombus). An example of the results are shown in Table 4-1 for a particular time for two rhomboids. Note that both the Laplacian and vorticity values change by an order of magnitude, and the signs flip, denoting a change from cyclonic to anticyclonic vorticity.

Table 4-1.
Example of Laplacian and vorticity calculations using two differencing methodologies at 1200 LST, July 14, 1996.

Rhombus centered on site	Initial Laplacian	Revised Laplacian	Initial Vorticity	Revised Vorticity
42007	5.4×10^{-8}	-2.8×10^{-8}	6.1×10^{-4}	-2.7×10^{-4}
42040	4.8×10^{-10}	-1.7×10^{-9}	5.4×10^{-6}	-2.0×10^{-5}

Furthermore, there is no consistent "scale" of the derived quantities among each rhombus. For example, one rhombus may characterize the scale of vorticity across 40,000 km^2, whereas another might extend over several more orders of magnitude, while containing a portion of the first area. The fact that the vorticity from the smaller rhombus is consistently higher than the vorticity from the larger rhombus indicates that rhombus scale is playing a role in the calculations. Similar differences were noted in the seasonal and annual averages. However, for the seasonal calculations, an additional problem of data availability arose. For the two years worth of hourly pressure data currently available in-house, only 10-25% of the total number of hours contained sufficient data at all sites to calculate the two-dimensional spatial gradients.

A simplification to the rhombus methodology was also presented in the analyses of Hsu (1992), in which it was determined that an equally robust metric could be based on simply the temperature (pressure) difference between a single shoreline site and a deep water buoy (i.e., a transect methodology). This stems from the fact that in the winter season, the along-shore component of temperature difference is quite small compared to the large temperature differences orthogonal to the shore, especially between deep water and the shoreline. It was realized that a similar analysis can be carried out for the current study of the northeastern gulf, however, transects would need to be developed that run orthogonal to the gulf shelf break both east and west of the Desoto Canyon area due to its influence on atmospheric baroclinicity. It was also suggested that transects be developed to characterize outer gulf and near-shore vorticity separately. The transects methodology was fully adopted in lieu of the use of fully two-dimensional rhomboids in calculating Laplacian fields; we have worked closely with Dr. Hsu in developing the most appropriate transects as a function of sub-surface topography and data availability.

Hence, it appears that while Laplacian calculations can be made from the buoy data alone, the quality of the results will remain highly uncertain and dependent upon the methodology employed. Also, spatial and temporal coverage will be greatly limited. It becomes obvious from these tests, then, that an improved set of wind information on a more regular grid would be a valuable component of the northeastern Gulf database, certainly in regards to the reconciliation of stress estimates with currents and transport patterns of LATEX drifters in 1996-97.

The prognostic meteorological model fields being archived by NOAA (as described above) also offer a very attractive source of surface (and aloft) wind data. Additionally, the Eta archive apparently offers vorticity fields as well; this would drastically simplify the development of the various derived quantities dependent on surface wind and pressure patterns. Prognostic modeling databases offer a source of wind and thermodynamic data that contain consistent temporal coverage as well as possessing consistent spatial scale on a regular orthogonal grid.

DIAGNOSTIC METHODOLOGY

The first and most critical step in the process of calculating the various derived parameters was to ensure that all over-water sites possessed hourly humidity data when sufficient temperature and pressure data were available. This step draws from the relationships developed by Hsu (1998) that link air-sea temperature differences to the Bowen ratio. Once Bowen ratio is known, it is a rather simple matter to determine humidity parameters. Two basic humidity measures are calculated in this way: specific humidity is calculated since it is needed for other derivations such as heat flux; and dewpoint temperature is needed to fill in missing humidity values for buoy and C-MAN sites in the raw observational database.

At over-water sites without humidity measurements, the Bowen ratio is first calculated for all hours with valid air and sea-surface temperature (T and T_s in °C, respectively):

$$B = a\left(T_s - T\right)^b$$

where the constants $a = 0.077$, $b = 0.70$ for buoy sites, and $a = 0.087$, $b = 0.74$ for C-MAN sites (as determined by Hsu, 1998). The ambient specific humidity q_a can be determined from a relationship defining surface latent heat flux as a function of moisture and temperature differences between the sea and air surface:

$$q_a = q_s + \frac{T - T_s + 0.01z}{2500B} \qquad (g/g)$$

where z is measurement probe height (5 m for buoys 42039, 42040, and 42036, and 10 m for all other buoys and C-MAN sites). The sea-surface specific humidity is assumed to be saturated, and is therefore a function of ambient pressure p (mb) and sea-surface temperature only:

$$q_s = 0.62\frac{e_s}{p}, \qquad e_s = 6.1\times 10^{\left(\frac{7.5\,T_s}{257.2 + T_s}\right)}$$

Specific humidity must be determined as well for all land sites that report dewpoint T_d (°C), using equations similar to above:

$$q_a = 0.62\frac{e}{p}, \qquad e = 6.1\times 10^{\left(\frac{7.5\,T_d}{257.2 + T_d}\right)}$$

The horizontal moisture flux orthogonal to the coastline F_q is determined at selected coastal sites based on the north-south component of the observed wind v (m/s) and the water vapor concentration c_w (kg/m^3):

$$F_q = v \cdot c_w \qquad (kg\,m^{-2}s^{-1})$$

where

$$c_w = 1.2\,q_a\left(\frac{273\,p}{1013.25\,T}\right)$$

The 1.2 factor in the equation above represents a standard atmospheric density, which is used throughout these analyses wherever density appears. The range of this value is not large under most circumstances, and is relatively small compared to the uncertainty associated with the assumptions necessarily made in these analyses. The horizontal latent heat flux F_h (J/kg) is calculated from F_q by simply multiplying the latter by the latent heat of vaporization (2.5×10^6 J/kg).

The total surface heat flux H is only determined for conditions in which the sea surface is warmer than the ambient air temperature. The equation utilizes the Bowen ratio previously calculated, and therefore heat flux is only determined for over-water sites:

$$H = 1.2\,c_p\,c_T\,V\left(T_s - T\right)\left(1 + \frac{0.07}{B}\right) \qquad (Wm^{-2})$$

where c_p is the specific heat of dry air at constant pressure (1004 J K^{-1} kg^{-1}), c_T is the bulk heat transfer coefficient under convective conditions (taken from Hsu [1997]), and V is total wind speed (m/s). From this, the convective boundary layer depth may be estimated using an empirical relationship developed by Hsu (1997):

$$CBL = 369 + 6004\left(\overline{w'\theta_v'}\right) \qquad (m)$$

where

$$\overline{w'\theta_v'} = \frac{H}{1.2\, c_p} \qquad (m\, K/s)$$

There are a number of parameters to represent the stability regime of the surface boundary layer. We have decided to use the bulk Richardson number since it can be directly determined from wind speed and surface-to-probe gradients in temperature:

$$R_b = \frac{g\,z}{V^2 T_s}\left(T_s - T\right)$$

where g is the gravitational acceleration constant (9.8 m/s^2) and T_s must be expressed in units of K in the denominator.

Calculation of wind stress requires the knowledge of a drag coefficient. Since the focus of the current study is on wind stress on the ocean surface, we have limited the calculation of wind stress to over-water stations. As pointed out by Hsu (1995), it is difficult to define the drag coefficient, or alternatively the friction velocity u^*, because they depend on more unknown variables than there are equations to interrelate them. Therefore, Hsu developed a parameterization for the over-water drag coefficient C_d based on wave information that is routinely available from buoy sites. Effectively, the significant wave height H_s (m) and the dominant wave period T_p (s) are used as surrogates for a space- and time-variable surface roughness length. The resulting equation is:

$$C_d = \left\{\frac{0.4}{11 - \ln\left[\dfrac{H_s}{\left(\dfrac{g T_p}{2\pi V}\right)^{2.6}}\right]}\right\}^2$$

The vertical component of the wind stress tensor can then be determined for all over-water stations from the following relationship:

$$\tau = 1.2\, C_d\, V^2$$

The wind stress curl may be determined by combining the horizontal components of the vertical stress with the geostrophic vorticity equation. Evaluating vorticity requires the calculation of a pressure (or temperature) Laplacian, and as discussed above, this second-order two-dimensional spatial derivative requires at least five data points. We have elected to evaluate the vorticity using a transect method, which reduces the number of data points to three, aligned along a direction that usually yields the largest gradient (i.e., orthogonal to the gulf shore line). This approach maximizes the total number of possible configurations as well as the coverage of stress curl estimates over the Gulf.

Hsu (1992) utilized a Laplacian of temperature to diagnose geostrophic vorticity during wintertime cold-air outbreaks over the central and western Gulf. Since our focus is more broad in determining stress curl for all seasons of the two-year database, we have elected to use pressure so that diurnal temperature tides at land sites are not introduced (although a slight diurnal pressure wave of usually less than 1-2 mb is typically present). The large land-based temperature variation over the day is often sufficient to cause a semi-diurnal reversal in the geostrophic vorticity for all scales of transects. We do not see this when using pressure.

Transects are defined by three sites that are roughly equally spaced along a consistent direction. In this way, the one-dimensional pressure Laplacian may be simplified using pressure from the three sites and an average separation distance D (m):

$$\nabla^2 p = \frac{1}{D^2}\left(p_1 + p_2 - 2p_0\right)$$

where p_1 and p_2 are pressures (Pa) at the transect endpoints, and p_0 is the pressure at the central (usually coastal) site. The wind stress curl is then determined from

$$\nabla \times \tau = \frac{C_d V_0}{f} \nabla^2 p$$

Here, the drag coefficient is taken from the buoy site defining the deep water endpoint of the transect, or the nearest buoy to the transect if no data are available. The total wind speed V_0 (m/s) is taken from the central site in the transect, and the Coriolis parameter f is set to 7.3×10^{-5} s^{-1}, which represents the value at 30°N. From the stress curl, it is a simple matter of deriving the Ekman pumping velocity:

$$W_e = \frac{\nabla \times \tau}{\rho_w f}$$

assuming the density of water ρ_w is 1000 kg/m^3.

Transect Definitions

Several transects were defined for the calculation of pressure Laplacian. The general rules in developing these were: (1) three sites define a transect, one in the outer Gulf, one near shore, and one inland; (2) the spacing between each of the three sites should be fairly uniform; and (3) the three sites should form a straight line orthogonal to the shoreline. Two sets of transects were defined, coastal and deep water, with the central point of the former located on or near the coast (typically C-MAN sites) and the Gulf point located near the shelf break, and the central point of the latter at the shelf break and the Gulf point at a "deep water" buoy. Many more transects were defined than were feasible when calculating actual hourly pressure Laplacian values, because some of the land based endpoint sites contained significant data gaps. Since no viable alternatives were found, these transects were dropped from the analysis. Figure 4-1 and 4-2 present the locations of the deep water and coastal transects, respectively. Note that in the figures, dashed lines represent original transect definitions that had to be dropped due to data sparsity. Table 4-2 provides a listing of stations defining each transect in these analyses, by station ID.

Table 4-2.
List of deep and coastal transects, and site IDs that define each.

Transect ID	Outer Water Site	Coastal Site	Inland Site
Deep Water			
1D	42001	42040	722267
2D	42003	42039	722267
3D	42003	42036	722135
Coastal			
1C	BUSL1	GDIL1	747685
2C	BUSL1	BURL1	42007
3C	42040	722225	722275
4C	42039	722210	722267
5C	42039	722245	722269
6C	42039	CSBF1	722140
7C	42036	CSBF1	722269
8C	42036	KTNF1	722135
9C	42036	CDRF1	722146

STATISTICAL ANALYSES

Statistical Data Summaries

Statistical summaries (sample mean, sample variance) for routine and derived meteorological parameters were prepared for each surface observing site listed in Table 2-2 and Table 2-3. Data were organized into five tables:

1. By site
2. By site and meteorological type
3. By site and season (winter = December-February; spring = March-May; summer=June-August; fall=September-November)

4. By site and meteorological type and season

5. By site and season and year

Summary statistics were computed from the data in each cell in each of the above five tables for the following parameters:

- temperature (C)[1]
- barometric sea-level pressure (mb)
- relative humidity (%)
- wind speed (m/s)
- magnitude of u and v components of the wind vector (m/s)
- wind direction (degrees from north)
- sea surface temperature (C)[1]
- surface heat flux (W/m^2)[1]
- convective PBL depth (m)[1]
- bulk Richardson number[1]
- horizontal moisture flux across the land-sea boundary[2]
- horizontal latent heat flux across the land-sea boundary[2]
- wind stress[3]
- stress curl[4]
- Ekman pumping[4]

Notes:

[1] Only sites with sea surface temperature (buoy and C-MAN)
[2] Coastal sites only
[3] Buoy sites only
[4] Transects only

Also tabulated are the number of non-missing values used in the statistical calculations, and number of possible values (based on hourly sampling). The number of possible hourly values was computed as twenty-four times the number of days in the table cell. Thus, for the first table (by site), the number of possible values in the 1996-1997 data period was 17,544.

Spatial Interpolation Procedure

Meteorological data for the study region are available at a very limited number of irregularly spaced observing locations. A spatial interpolation procedure was employed to estimate values of temperature, sea surface temperature, relative humidity, wind speed/direction, and wind stress over a regularly spaced array of grid nodes consisting of 19 nodes in the east-west direction and 13 nodes in the north-south direction. The grid was equally spaced in a latitude-longitude coordinate system with east-west and north-south spacings of 0.5 degrees each (approximately 900 km by 700 km). Given the sparse coverage of data sites, spatial interpolation was performed via a Kriging algorithm in which the interpolation weights applied to each data point are calculated from a variogram model describing the spatial variability in the data. This results in a very flexible interpolation procedure well suited to sparse data sets. A linear model was used for the variogram with scale factor C = 6.67 and length parameter A = 4.12. The variogram was assumed to be isotropic with no nugget effect. "Ordinary" Kriging was used (i.e., no drift was specified). Calculations were carried out with a PC-based spatial mapping software package (*Surfer* 6.0, Golden Software Inc.). A data completeness criterion of 50% of all possible hours (assuming measurements made every hour) was applied: any sites not meeting this criterion were excluded from the spatial interpolation.

A typical example of gridded mean winds is shown in Figure 4-3.

Time Series Analysis Methods

Time series of hourly scalar wind speed, magnitude of the north-south wind component, and surface temperature observations collected at sixteen marine, coastal, and inland locations listed in Table 4-3 were analyzed for their statistical behavior.

Table 4-3.
Surface meteorological data sites used in the time series analysis for the 1995-1997 data period.

Site	Location	% Non-Missing Values (based on wind speed)
Buoy 42001	Mid Gulf	89
Buoy 42002	West Gulf	92
Buoy 42007	OTP	99
Buoy 42036	West Tampa	76
Buoy 42039	Pensacola S	99
Buoy 42040	Mobile South	99
Land Based 722210	Eglin AFB/Valparais	85
Land Based 722225	Pensacola NAS	94
Land Based 747686	Keesler AFB/Biloxi	88
Land Based 747750	Tyndall AFB	89
C-MAN Buoy BURL1	Southwest Pass, LA	96
C-MAN Buoy CDRF1	Cedar Key, FL	99
C-MAN Buoy DPIA1	Dauphin Island, FL	96
C-MAN Buoy GDIL1	Grand Isle, LA	99
C-MAN Buoy KTNF1	Keaton Beach, FL	99
BRETON	Breton Island	69

Since the time series analysis methods used here assume complete data, missing values were first filled in with means computed for the season and hour corresponding to the time of each missing observation. Assuming normally distributed data, this procedure avoids introduction of biases in the mean diurnal pattern. Furthermore, for sparse, randomly occurring missing values, biases in spectral analyses should be minimal. Therefore, sites in Table 4-3 represent locations with data completeness of at least 70 percent; Sites with more extensive missing data were not included in the analysis although this requirement was relaxed somewhat at the buoy sites to avoid loosing data from these critical locations.

Autocorrelation functions and periodograms were computed for both the raw time series and a filtered series in which the 24-hour diurnal cycle has been removed using a Buys-Ballot filter. The Buys-Ballot filter simply subtracts the mean diurnal cycle from the raw time series. In other words, a time series consisting of a repeated sequence of 24 values corresponding to the mean for each hour of the day is subtracted from the raw time series to create the filtered series.

Autocorrelations for lags n=1,2,..., N/2 hours where N is the length of the time series were computed and plotted using the S-PLUS *acf* function.

Smoothed periodograms were computed using the S-PLUS *spectrum* function. This function first removes any trend from the raw time series (using a least squares fit) and rescales to a zero mean. A split cosine data taper of ten percent is then applied to each end of the detrended series. A mixed radix fast Fourier transform algorithm is then applied to the series to estimate the raw periodogram which is smoothed by applying a sequence of running averages (a sequence of two modified Daniell windows of length 25 and 27). The smoothed periodogram is expressed in decibels.

An example of the type of plots generated in the time series analyses is shown in Figure 4-4.

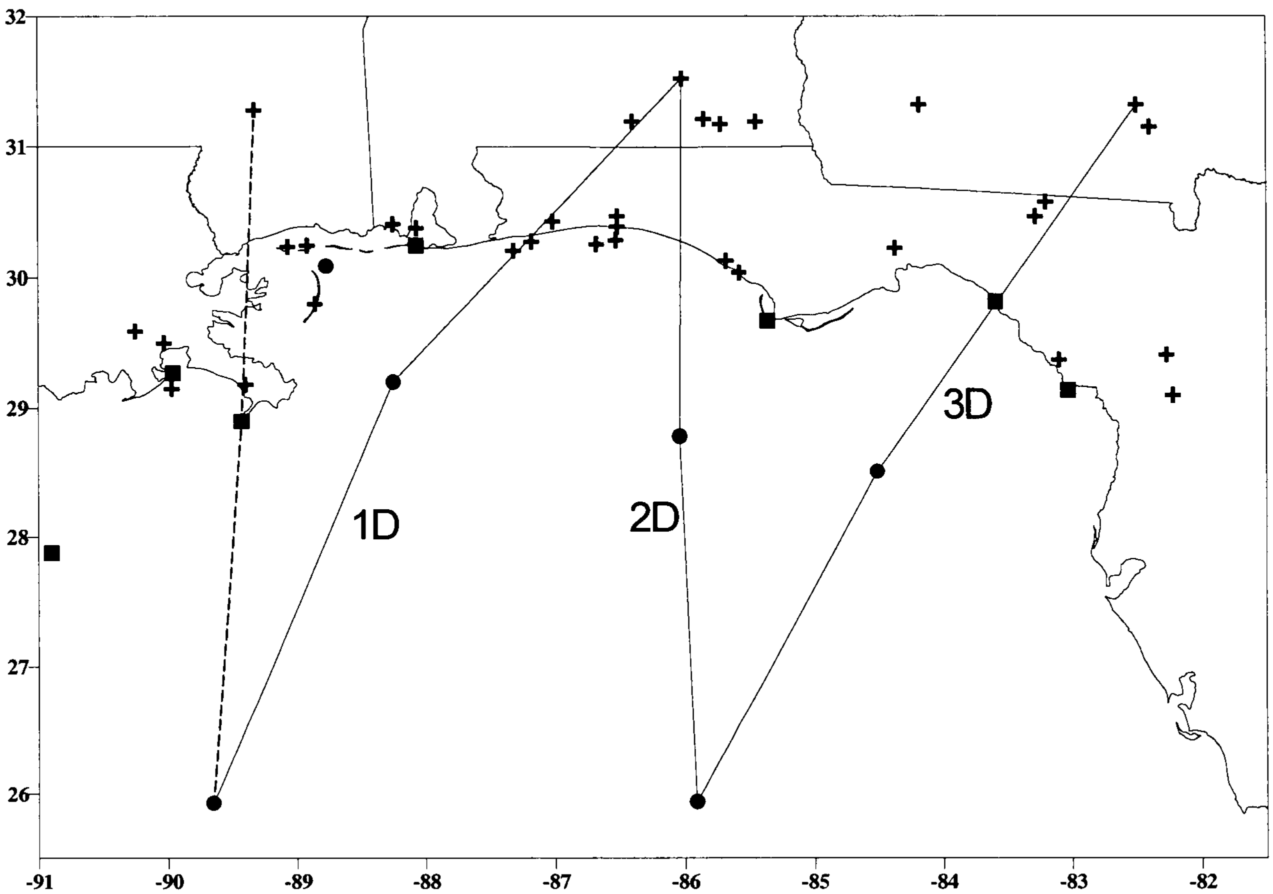

Figure 4-1. Location of deep water transects in the NEGOM. Dashed line represents original definition that was dropped from the analysis due to lack of observation data.

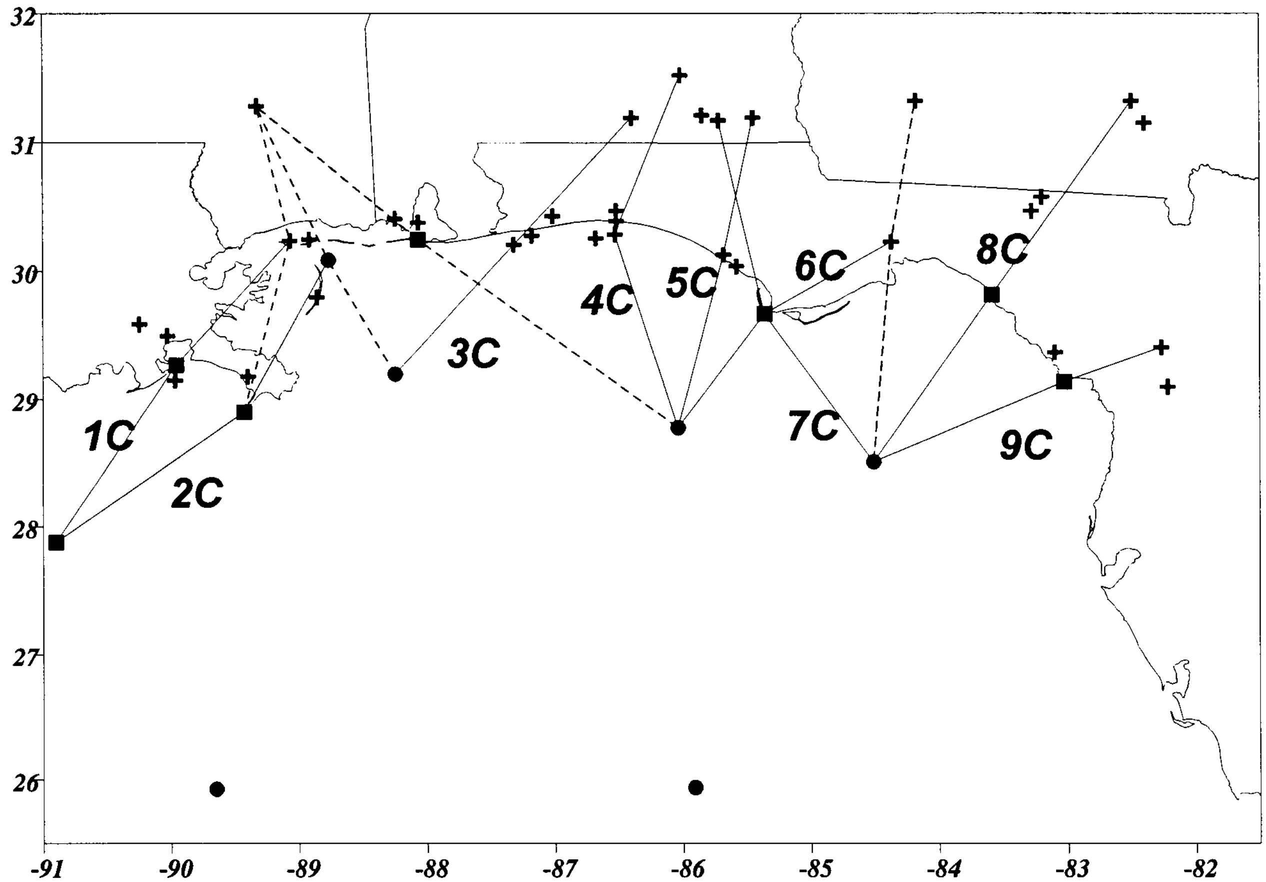

Figure 4-2. Location of coastal water transects in the NEGOM. Dashed line represents original definition that was dropped from the analysis due to lack of observation data.

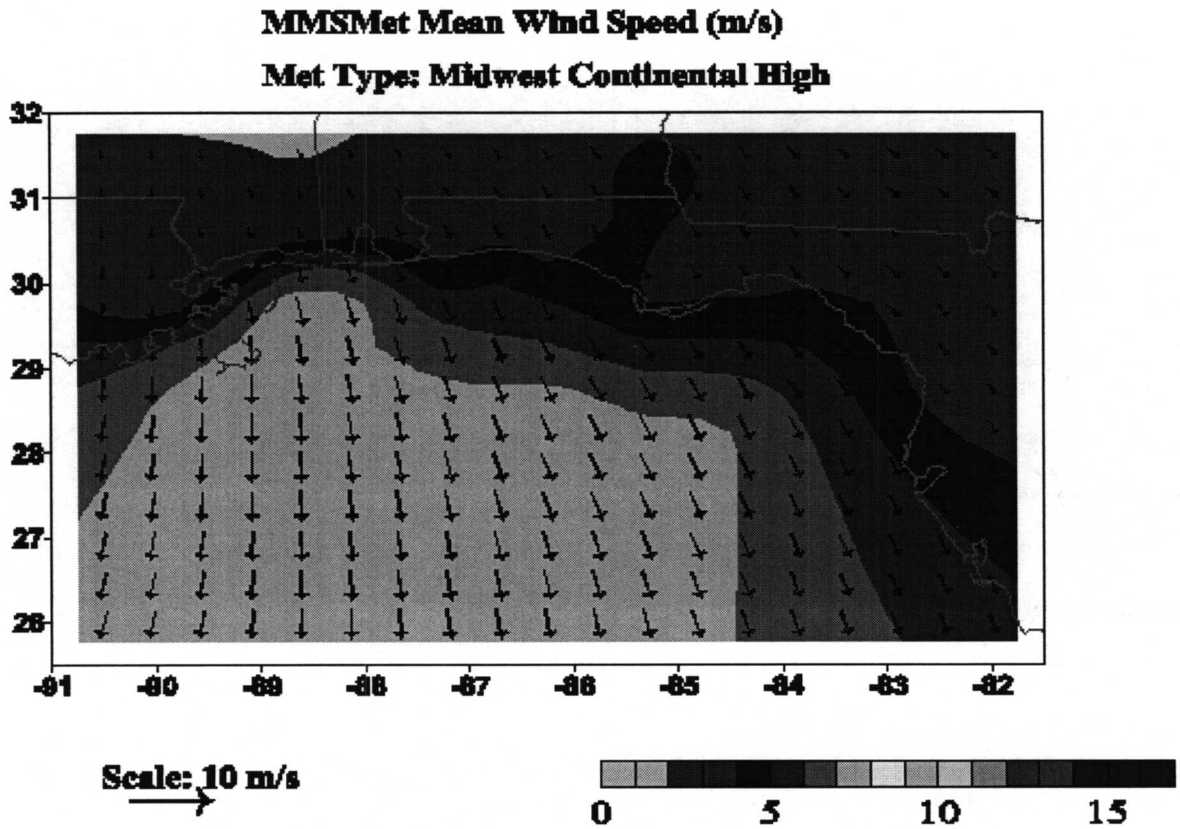

Figure 4-3. Example of gridded mean winds (vectors and contoured speed) for the Midwest Continental High category over the entire data period..

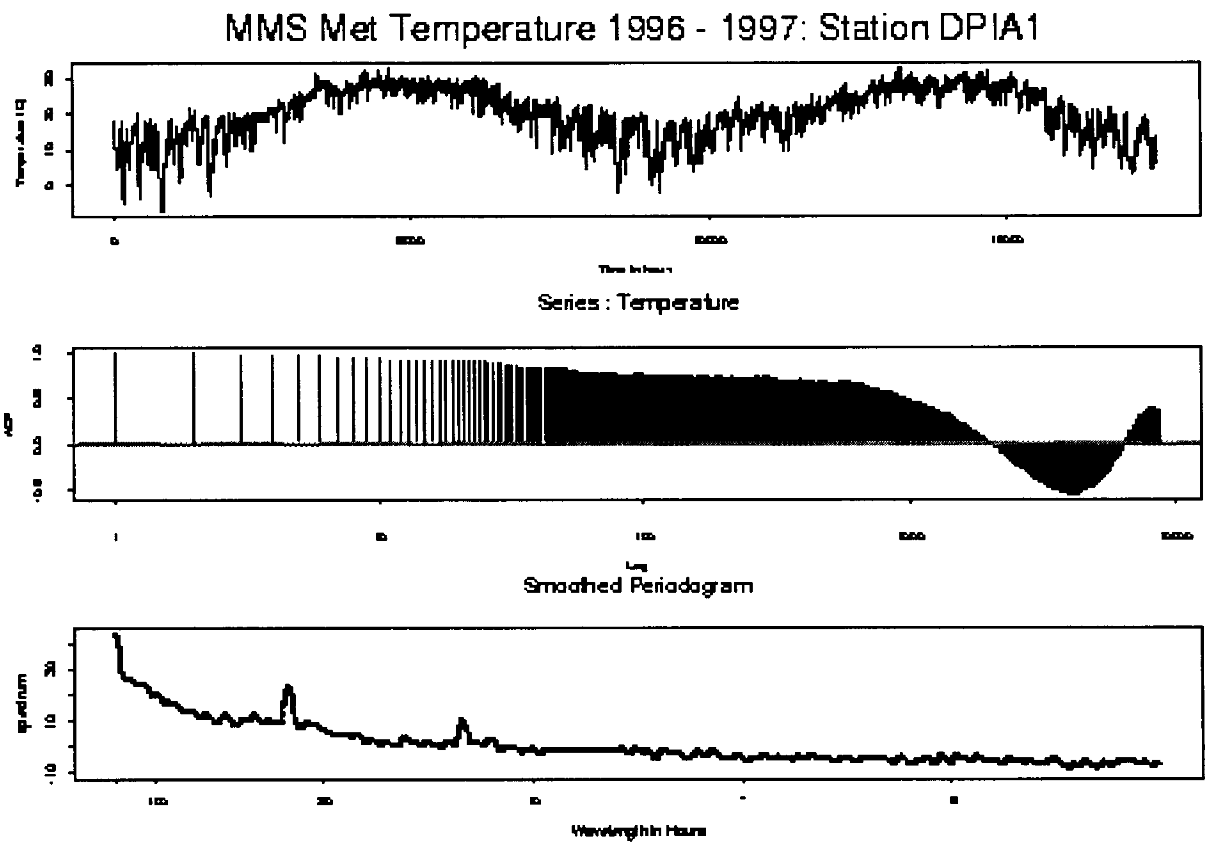

Figure 4-4. Example of time series plots of temperature for the Dauphin Island C-MAN site.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.