TRANSMAP: An integrated, real time environmental monitoring and forecasting system for highways and waterways in RI

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16. Abstract

This report summarizes the work accomplished during the first year of a three-year project to develop a state of the art, integrated environmental monitoring and modeling system to provide data and information to support the operation, management, and evaluation of various land and marine based transportation systems in RI. The system, called TRANSMAP (Transportation Mapping and Analysis Program) is an extension of existing systems for environmental monitoring and modeling designed by University of Rhode Island (URI) scientists for marine (COASTMAP) and highway (ROADMAP) applications and commercially available systems. TRANSMAP features an open architecture, industry standard software tools and modules, an embedded geographic information system (GIS), standardized data handling protocols, an environmental data analysis and presentation system, and access for linkage to models and management tools. The first year project objectives are to: (1) develop an integrated system for monitoring and forecasting of environmental conditions on Rhode Island highways and waterways in support of the Rhode Island Department of Transportation (RIDOT) and the transportation community, (2) implement, test, and evaluate the performance of this system for land and water based measurement sites, (3) transfer the data products and forecasts to interested URI Transportation Center researchers, RIDOT operations staff, major transportation user groups, and the public, and (4) begin the process of transferring the system for commercialization by private industry. The basic framework of TRANSMAP has been constructed and the system is operational with access to a variety of existing, real time meteorological and marine measurement systems having been implemented. A thermal energy balance model that provides real time forecasts of the temperature profile in the roadbed has been developed and incorporated within TRANSMAP. A hazardous chemical spill model that predicts the zone of concern for an evaporative plume from land-based spills of hazardous chemicals have been developed and integrated within TRANSMAP. Testing and evaluation of the thermal energy model are now in progress. Tools have also been developed to access data from GIS databases and to display these as overlays on the system base map. The report concludes with a summary of planned activities to further develop, refine, and implement TRANSMAP and its associated web based access.

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Environmental data is critical for effective operation, management, and evaluation of various land and marine transportation systems. For landside systems this data is typically used to assist in road maintenance (snow plowing) and treatment (salting/deicing) in winter, traffic control and planning, responding to accidental releases of material in transport (chemical or petroleum spills) and in evaluating the performance of various transportation systems (e.g., roadbed material monitoring). For marine operations the data is typically provided to vessel operators and pilots to assist in the safe navigation of people and bulk and containerized cargo. The land-based systems, typically known as road weather information systems (RWIS), were first introduced in the early 1970s with applications principally to monitor roads and airports (USDOT 1998). Utilizing advances in communications and computer technology, RWIS rapidly evolved from stand alone weather monitoring stations, with local data recording, to fully integrated, real time weather and pavement monitoring systems. Today's RWIS typically include an extensive network of weather and pavement sensing systems (5 to 50). These are connected to a base station server that collects, archives, displays, and distributes the data. Communications between the sensors, base station, and user can be by telephone, cell phone, radio and satellite telemetry, or the Internet. Data loggers at the sensor sites can also record data. Atmospheric parameters normally measured include wind speed and direction, wind gusts, atmospheric pressure, air temperature, relative humidity, precipitation, solar radiation, and visibility. The road condition parameters measured include road surface and subsurface temperatures, wet/dry road conditions, freezing point, presence of snow and its depth, and conductivity of runoff water. In the current generation of RWIS these data are integrated with thermal road surface mapping data, pavement ice forecasting models (based on a real time energy balance model) and salt optimization routines to provide integrated real time winter highway maintenance management systems.

These systems have undergone extensive evaluation by the US Department of Transportation (USDOT), Federal Highway Administration (FHWA) as part of the Advanced Transportation Management Technologies, Demonstration Project No. 105 (USDOT 1998). Numerous commercial companies (SSI, Vaisala Inc., Coastal Climate, Aanderaa A/S, and others) provide fully integrated systems or key sensors for such systems. The Rhode Island Department of Transportation (RIDOT) installed eight Surface Systems Inc. (SSI) road weather and pavement monitoring stations and the associated base station in 1998. The base station is located at the RIDOT maintenance center in Providence, RI. System sensors (weather and pavement) are located at the following sites throughout the state: Intersection of Rte 91 and 78 in Westerly, Intersection of Rte 146 and 95 in Providence, Rte 95 at the Civic Center exit in Providence, Intersection of Rte 102 and 95 in North Kingstown, Rte 101 at Jerimoth Hill in Foster, Intersection of Main Road and Rte 24 in Portsmouth, Rte 138 at the eastern end of Newport Bridge in Newport, and at the Block Island DOT facility. The locations of the sensors are shown in Figure 1. The system includes weather and pavement sensors and measures wind speed and direction, air temperature, dew point, relative humidity, precipitation, pavement surface and 40 cm depth temperature, runoff conductivity, snow presence and amount, and dry/wet road conditions. This system is fully operational and currently being used for assistance in deploying highway snow removal equipment and de-icing chemicals. The data is not currently distributed to the public.

On the marine side, the National Research Council (1999) recent study on Applying Advanced Information Systems to Ports and Waterways Management has identified accurate, real time information about harbors and waterway conditions including, tides, water depths, currents, and weather as one of the most urgent needs of mariners. In response to this need NOAA has developed and deployed a variety of real time sensing systems to assist the marine transportation community (Parker, 1998). Data is currently available from the NOAA/ National Ocean Survey's National Water Level Observation Network (NWLON) of real time water level sensors and the Physical Oceanographic Real Time Systems (PORTS). The NWLON typically provides sea surface elevation data while PORTS provides data on the sea surface elevation, wind speed and direction, air temperature, barometric pressure, and currents (surface, bottom, or profile). The PORTS data is typically accessible to ship captains and pilots via telemetry or the Internet. PORTS systems have been installed by NOAA in high traffic areas including New York /New Jersey Harbor, Galveston Bay, Tampa Bay, and San Francisco Bay. There is currently a NOAA real time sea surface elevation gauge (NWLON station) located in Newport. The data is available via the Internet (http://www.co-ops.nos.noaa.gov/d_ports.html). Rhode Island Department of Environmental Management (RI DEM) implemented a PORTS system for Rhode Island, with real time environmental monitoring stations in Narragansett Bay, during the summer of 2000. Measurements include the following: surface elevation, currents (obtained from an upward looking ADCP (acoustic Doppler current profiler)), and surface temperature and salinity in the Providence River; sea surface elevation and meteorological parameters (wind speed/direction, air temperature, atmospheric pressure) at Newport; meteorological parameters and ADCP currents at Fall River; meteorological parameters and visibility (upbay) at Prudence Island; and meteorological parameters and ADCP currents at Quonset Point. Data from all these real time observation stations are available via the NOAA PORTS web site (http://www.co-ops.nos.noaa.gov/nbports/nbports.html). Data are also available directly from the PORTS Narragansett Bay system server located at DEM offices in Providence, RI. In addition real time water quality monitoring systems (salinity, temperature, dissolved oxygen, sea surface elevation and meteorological parameters) are currently in operation or planned for various locations in the bay under the Narragansett Bay Network. The Rhode Island Department of Environmental Management, NOAA, and the Narragansett Bay EMPACT program, led by the Narragansett Bay Commission, sponsor this network. The current operational stations are shown in Figure 1. The data is accessible via http://www.gso.uri.edu/~dkester/nbay/index.htm.

A review of the commercially available RWISs shows that individual companies that market such systems have developed them independently. The instrumentation, sensors, data handling procedures, communication protocols, and the software to visualize and display the data and support the integrated system of models (ice forecasting, road salting optimization) and management support modules are proprietary. The user must rely on the supplier for any changes in the system or to integrate other sensors into the system. The RWIS generally have base maps (fixed or pre-determined views) and very limited or no geographic information system (GIS) functionality. As an example, overlaying data on vegetation cover or aquifers locations at risk from an accidental chemical spill from a tanker truck would require the supplier to design, develop, and install customized software for that particular application. Extension of the system to new areas or the addition of new models or management modules must also be performed by the system developer. The systems also do not allow the user to perform any independent analysis of the data. Even when data analysis modules are included the user is unable to modify or customize them for their application. Often the developer installs the systems and the user is never given the administrative password and hence can't access their own data nor export the data to other software. These constraints, closed architecture and limited functionality, substantially limit the utility of the systems. In most cases the RWISs also don't take advantage of the newest development in software systems and tools. As an example, distribution of the data products via the Internet, through web servers, is just now being offered and only by a few suppliers.

The NOAA PORTS system has been specifically established to support marine transportation for the major harbors and ports in the US. The presentation of data is standard for all PORTS systems and is given either in terms of the most recent observations or recent tabulated time series data in graphic form. Historical data is not maintained or available from the NOAA PORTS system. The access, via the web site, does not allow for integration with models, nowcasting/forecasting tools or management support systems, data analysis modules, or incorporation of GIS functionality.

To provide a closer integration of environmental monitoring systems and models Spaulding et al (1998) developed COASTMAP, an integrated environmental modeling and monitoring system designed for application to estuarine and coastal seas. The system was developed with funding from the University of Rhode Island, Ocean Technology Center (OTC) (industry sponsored) and the URI Sea Grant program. The integrated system is PC based and consists of environmental monitoring stations, a geographic information system, data processing and analysis tools and environmental now-casting and forecasting models. COASTMAP allows the user to collect, manipulate, display, and archive environmental data through embedded environmental data management tools (e.g., time series analysis including filtering, power spectral analysis, and harmonic analysis) and a geographic information system. Data collection can be either by use of conventional instrumentation or through a real time monitoring systems using radio/satellite telemetry, cell phone, or web based communications. The system currently includes a suite of environmental models (three-dimensional hydrodynamics and particle based pollutant transport) to predict the dynamics in the operational area and to integrate real time data into the models to allow predictions of environmental conditions. COASTMAP operates on a personal computer with a Windows based user interface. It is controlled by pull down menus and makes extensive use of color graphics to display model predictions (e.g., animations, plots, 3-D perspective views) and the results of data analysis. The software is designed using a geographically oriented shell based architecture making applications to any geographic area simple and fast. Spaulding et al. (1998) report the application of COASTMAP to real time monitoring of currents and meteorological data and modeling of the circulation and pollutant transport for Greenwich Bay.

As part of the technology transfer component of the URI OTC projects, under which COASTMAP's development was funded, Applied Science Associates Inc. (ASA), Narragansett, RI obtained non-exclusive rights to market and distribute COASTMAP from the University. ASA has extensively modified and improved COASTMAP and marketed the system worldwide. They have recently installed COASTMAP for Mexican waters, as a real time water level monitoring system for west (Pacific) and east (Gulf of Mexico) coasts. In addition ASA, working with a RWIS supplier, re-configured their extensively modified version of COASTMAP to operate as the server and data analysis and display system for a RWIS for the state of New Jersey. The system was set up for a section of Rte 80 in northern New Jersey. The system was selected for its open architecture, embedded GIS, data analysis and presentation modules, and ability to incorporate models and data management tools (ASA, 2000). The system, renamed ROADMAP, can monitor weather and pavement conditions (air/road and freezing temperature, wind speed and direction, atmospheric pressure, solar radiation, relative humidity, precipitation, snow fall, visibility, runoff conductivity, etc.) at selected locations. Data is transmitted by cell phone, Internet, radio, satellite telemetry, or telephone from sensor to base station. The monitoring system output includes presentation of the real time status of all variables at all monitoring stations, an alarm notification based on pre-set weather conditions, a historical archive and associated environmental statistics at each site, and displays of forecasts of weather conditions at each site based on the National Weather Service forecasts. The system can be accessed via the Internet and provides all or selected portions of the data.

The broad goal of the present project is to develop a fully integrated real time monitoring and modeling system to provide environmental and pavement condition data for highways and waterways in Rhode Island. The system, called TRANSMAP (Transportation Mapping and Analysis Program) is an extension of the existing COASTMAP and ROADMAP systems. It features an open architecture, industry standard software tools and modules, an embedded GIS, standardized data handling protocols, an environmental data analysis and presentation system, and access for linking of models and management tools. The principal users of the system are anticipated to be transportation system managers who are responsible for collecting and analyzing real time environmental information in support of decision making for road treatment (deicing), ferry and associated terminal operations, shipping, environmental protection (oil and chemical spills, combined sewer releases), and recreational boating. Integration of weather information from both land and sea stations will substantially augment the available meteorological data bases for coastal regions and help to better understand the spatial and temporal structure of the wind and air temperature fields. The specific objectives of the project are to (1) develop an integrated system for monitoring and forecasting of environmental conditions on Rhode Island highways and waterways in support of the Rhode Island Department of Transportation and the transportation community, (2) implement, test, and evaluate the performance of this system for land and water based stations in Rhode Island, (3) transfer the data products and forecasts to interested RIDOT operations staff, major transportation user groups, and the public, and (4) transfer the system for commercialization by private industry.

Section 2 of the report presents an overview of TRANSMAP and the associated system architecture. Initial application of TRANSMAP to Rhode Island is summarized in Section 3. Also included here is a review of the principal data sources and linkages to Geographic Information System (GIS) data sets. Implementation of TRANSMAP in Rhode Island and the status of the web-based interface are provided in Section 4. Section 5 gives a brief summary of work currently in progress (2nd year of the project) and that planned for the third year of the project. Study conclusions are given in Section 6 and references in Section 7.

2. OVERVIEW OF TRANSMAP AND SYSTEM ARCHITECTURE

TRANSMAP is a personal computer-based system and consists of environmental monitoring stations, a geographic information system, data processing and analysis tools, and environmental nowcasting and forecasting models. TRANSMAP allows the user to collect, manipulate, display, and archive environmental data through embedded environmental data management tools (e.g., time series analysis including filtering, power spectral analysis, and harmonic analysis) and a geographic information system. Data collection can be either by conventional instrumentation or through a real time monitoring system using radio/satellite telemetry, cell phone communications, or the Internet. The system also allows access to environmental models. In its present form, a thermal energy balance model and a highway contaminant (hazardous chemical) spill model can be accessed through the user interface. Each is described in additional detail below. TRANSMAP operates in WINDOWS NT, is controlled by pull down menus, and makes extensive use of color graphics to display the results of data analysis and model predictions. The software is designed using a geographically oriented, open architecture making applications to any geographic area simple and fast (Spaulding and Howlett, 1996).

To assist transportation operational and hazardous materials response teams, NOAA and EPA's Areal Locations of Hazardous Atmospheres (ALOHA) contaminant transport model has been integrated into TRANSMAP (NOAA/EPA 1999). The model supports emergency training, planning and response tactics for personnel that respond to chemical spills and accidents. Based on user supplied information ALOHA first predicts the rates at which chemical vapors escape into the atmosphere from broken pipes, leaking tanks, or evaporating puddles. The embedded database includes over 1000 common hazardous chemicals that are transported by land, rail, or water. The model then predicts how a hazardous gas cloud from the release will disperse in the atmosphere after the accidental chemical release. The model is hence ideally designed to allow the user to predict the atmospheric plumes from highway spills of many hazardous chemicals that are transported via highways and railways. The user provides a description of the spill parameters (e.g. location, contaminant type, containment vessel characteristics, and how the chemical is escaping from the container) and the current or forecasted weather conditions as input to the model. Information on the weather (temperature, wind speed and direction) is provided from TRANSMAP's database or from a weather forecast and is selected from the monitoring site closest to the spill location..

To illustrate the use of the model a hypothetical spill event is presented. A spill of methane from a tractor tailor tank (5 m diameter, 20 m length) at 13:14 PM on February 23, 2001 was simulated. The release occurred through a 10 cm circular hole in the bottom of the tank, which allowed the chemical to be released for 12 minutes before it was successfully plugged. The spill was assumed to occur at two locations on Route 1A in Narragansett, RI. Location of the spill is easily entered in TRANSMAP's GIS by clicking the cursor on the spill site or manually entering the geographic coordinates. The winds during the accident were from the east at 10 m/sec. Figure 2 shows several of the forms (atmospheric option, Figure 2a; tank size and orientation, Figure 2b) that need to be completed for this release. Also provided is ALOHA's summary of the spill event (Figure 2c). The model predicts the size and orientation of the impact zone associated with the chemical release. Predictions can be in terms of a user specified concentration (Level of Concern (LOC)) in the atmospheric plume or the Immediately Dangerous to Life or Health (IDLH) levels. A chemical's IDLH, according to the National Institute for Occupational Safety and Health (NIOSH), is an estimate of the maximum concentration in the air to which a healthy worker can be exposed without suffering permanent damage or escape impairing health effects. ALOHA predictions are automatically overlaid on the base map for the area within TRANSMAP. Subsequent modifications to the ALOHA predictions are automatically refreshed in TRANSMAP's GIS display. The embedded geographic information system in TRANSMAP allows the user to overlay other relevant information that might be useful in responding to the spill (i.e. locations of schools in the vicinity of the spill site that might need to be evacuated.). For the example selected, Figure 3 shows the model predicted area for which methane concentrations exceed the LOC (1ppm) for the two spill sources. As one can see the impact zone is predicted to encompass several schools west of the spill site for the northern most spill and none for the southern most release site.

To allow the user an ability to predict the road surface conditions, a thermal energy balance model is provided within TRANSMAP. The primary use of the model is to predict the icing of road surfaces and to provide sufficient advanced warning to allow appropriate response from road maintenance crews. The model is based on the one dimensional thermal energy equation and includes turbulent, sensible and latent heat fluxes between the road and the atmosphere and the net longwave and shortwave solar radiation fluxes at the road surface. Figure 4 shows a schematic of the solar radiation flux on the left side and the components making up the net heat flux on the right. The latent and sensible heat fluxes are dependent on the wind speed, specific temperatures and humidity of the road surface and atmosphere, and the stability of the atmosphere. The net radiation flux is dependent on solar zenith angle, ice and snow height, effects of water vapor and cloud cover, total downward solar flux consisting of direct and diffuse radiation, and surface albedo. The model is primarily based on earlier models developed by Sass (1992, 1996) and Baker and Davies (1990). Additional work by Unsworth and Monteith (1975), Savijarvi (1990), Strub and Powell (1987), Louis (1975), Korotenko (1992), and Manton (1987) provided information needed in the parameterization of the atmospheric heat flux terms. The thermal diffusion equation, with empirically parameterized flux terms at the road surface, is solved by a standard forward in time, centered in space finite difference numerical scheme. The model predicts the continuous vertical temperature profile from the road surface to depths of about two meters in the roadbed. The model also allows predictions of road icing conditions. Atmospheric data, necessary as input to the model, can be supplied either from observations in TRANSMAP'S databases or from a weather forecast model. Figure 5 shows the model predicted road surface temperature and net heat flux time series over one day (upper panel) for January 15, 2001 and the road temperature versus depth in the bed for morning, mid day, and evening periods (lower panel) and for the same day. In operation the output can be animated so that the time series of the vertical temperature profile and the heat flux and road surface temperature is displayed as a function of time. One can clearly see as the sun rises (7:30) the net heat flux is from the air to the road surface and the road surface temperature rises. This continues until early afternoon when the sun has reached its zenith angle. In the late morning (11:00) the heat flux begins to decrease. The road surface temperature however continues to increase, but at a reduced rate. By mid afternoon (14:30) the heat flux changes direction, with the heat flowing from the roadbed to the atmosphere. As a result of this heat loss the roadbed temperature continues to decline until about 19:00. After this time the temperature of the bed remains almost constant until the solar heating cycle begins the next day. At night the heat flux direction is from the road to the atmosphere and the road surface temperature reaches its minimum value early in the morning (5:00). The vertical temperature profile shows that the temperature in the upper layer of the bed varies as the surface heat flux varies, but with a phase lag. The daily temperature variations are restricted to the upper ¾ meter of the roadbed, over a typical daily cycle.

The present TRANSMAP system includes three personal computers (PC) configured to operate as servers (Figure 6). TRANSMAP may operate directly with typical monitoring systems consisting of environmental monitoring stations that relay data via radio, satellite, telephone, cellular or Internet or other communication protocol to a base station. In the present application, TRANSMAP accesses data from existing environmental monitoring systems that post data on the Internet. One PC in the TRANSMAP system is used as the communications and data storage (CDS) server. Typical operation of the CDS PC includes communications with sensors, data collection, quality control, and storage of the data for subsequent distribution or analysis. A second PC functions as a map (MAP) server and supports the operation of TRANSMAP and its embedded GIS. This server obtains data from the CDS server and is able to analyze and display this information. The MAP server also performs all model simulations and nowcasting/forecasting tasks. The third PC is configured as the web (WEB) server. This server supports the distribution of data products to a wide variety of clients (e.g., public, research community, environmental organizations). WEB obtains its data from the MAP server.

TRANSMAP is designed specifically for personal computer platforms running Microsoft Windows NT® or Windows 2000®. A minimum CPU speed of 350 MHz is recommended. TRANSMAP operation requires 256Mb of RAM memory and sufficient storage on a fixed disk to install the application and base files. Exact disk space requirements depend on the level and extent of GIS and environmental data sets included in the installation. In order to access data from external sources access to the Internet is required.

TRANSMAP utilizes a number of programming technologies to achieve high-level functionality for its various components. The graphic user interface (GUI) has been developed in Visual Basic and is tightly integrated to dynamic link libraries (DLL's) containing data analysis and handling tools developed in Visual Fortran. A variety of ActiveX controls (OCX) are utilized in the development of the GUI, with each providing a specific set of functions for the programmer. For example, ArcView geographic information system functionality is embedded in TRANSMAP through Map Objects OCX developed by, and available commercially, from ESRI. Numerical models, such as the road-bed temperature prediction model (thermal model), are coded in Fortran. Externally linked models, such as CAMEO and ALOHA, were obtained from NOAA. The source programming language for these models and their interfaces are C, FORTRAN, and Visual Basic.

3. APPLICATION OF TRANSMAP TO RHODE ISLAND

Basic Setup

The basic development of TRANSMAP, as outlined in Section 2, has been completed and initial application made to southeastern New England, with a primary focus on Rhode Island and adjacent bay and coastal waters. Figure 1 shows the location of the study area. The application has been extended beyond Rhode Island to include coastal waters since they are of principal concern to the marine transportation community. The base map shows all state boundaries and the county boundaries for Connecticut, Rhode Island, and Massachusetts. The figure also shows the locations of all interstate and state highways in the three states. Data were obtained via the Internet either from the Rhode Island Geographic Information System (http://www.edc.uri.edu) or its Massachusetts counterpart (http://www.state.ma.us/mgis/massgis.htm).

The TRANSMAP system for Rhode Island has been configured in the three-server format noted in Section 2. All computers utilize Pentium III processors and are currently located in the Department of Ocean Engineering, University of Rhode Island, Narragansett, RI.

Data Sources

In the initial application of TRANSMAP to Rhode Island, access to three major, real time data collection programs or the output of predictive models have been established or are in progress. Other organizations are handling the data collection, quality control, and archiving tasks. Access to each data set is via the Internet. A brief summary of the data and its source is given below. Also noted is the status of TRANSMAP's ability to access this data.

NOAA/ PORTS

The Narragansett Bay PORTS system includes measurements of the following: surface elevation, currents (upward looking ADCP (acoustic Doppler current profiler)), and surface temperature and salinity in the Providence River; sea surface elevation and meteorological parameters (wind speed/direction, air temperature, atmospheric pressure) at Newport; meteorological parameters and ADCP currents at Fall River; meteorological parameters and visibility (upbay) at Prudence Island; and meteorological parameters and ADCP currents at Quonset Point. Data from all these real time observation stations are available via the NOAA PORTS web site (http://www.co-ops.nos.noaa.gov/d_ports.html). The station locations are shown in Figure 1.

Implementation of a direct FTP (File Transfer Protocol) connection to the NOAA/ National Ocean Service (NOS) PORTS data has been completed. All data are being routinely downloaded in real time (6 minute intervals) and stored on the system server. TRANSMAP can display the most recent measurements, or any historical measurements, from the system. Historical measurements are constructed and archived from the real time measurements retrieved from the PORTS site by TRANSMAP since they are not directly available from the PORTS web site. TRANSMAP can process the data and display contour maps of air pressure, air and water surface temperature and surface salinity, and bay and coastal water levels on the base map. TRANSMAP can also display vector plots of the wind speed/direction and the surface water currents. As examples, Figures 7 and 8 show vector maps of the wind speed and direction and water surface currents for the bay and adjacent offshore waters, respectively. The inserts on the left side of the figures provide the data at each observation station. The insert on the upper right of Figure 8 shows a schematic representation of vertical current structure at the Providence, Quonset and Fall River PORTS stations. Figure 9 shows a contour plot of the air temperature. The figure also shows the air temperature contours based on the observations. Figures 10a, b, and c show sea surface salinity, water levels, and bay surface temperature, respectively for Narragansett Bay and adjacent coastal waters. Isolines are also shown to give a sense of the spatial structure of the observations. These contours have been generated based on the observed data at the PORTS and COFS sites. Figure 11 shows the interface with PORTS. The left panel shows the FTP control, the center panel the data being retrieved and the right panel a time series of air temperature, barometric pressure, water temperature, and surface elevation for observations collected at the Newport station for January 2001.

RIDOT RWIS

The Rhode Island Department of Transportation (RIDOT) installed eight Surface Systems Inc (SSI) road weather and pavement monitoring stations and the associated base station in 1998. The base station is located at the

RIDOT maintenance center in Providence, RI. System sensors (weather and pavement) are located at the following sites throughout the state: Intersection of Rte 91 and 78 in Westerly, Intersection of Rte 146 and 95 in Providence, Rte 95 at Civic Center exit in Providence, Intersection of Rte 102 and 95 in North Kingstown, Rte 101 at Jerimoth Hill in Foster, Intersection of Main Road and Rte 24 in Portsmouth, Rte 138 at the eastern end of Newport Bridge in Newport, and at the Block Island DOT facility. The locations of the sensors are shown in Figure 1. The system includes weather and pavement sensors and measures wind speed and direction, air temperature, dew point, relative humidity, precipitation, pavement surface and 40 cm depth temperature, runoff conductivity, snow presence and amount, and dry/wet road conditions. This system is fully operational and currently being used to assist making decisions about deploying highway snow removal equipment and de-icing chemicals. The data is not currently distributed to the public.

Access to the RIDOT Road Weather Information System (RWIS) has been a substantial, unanticipated problem in this project given the fact that the data format is proprietary to Surface Systems, Inc. (SSI), the vendor who supplied the system. SSI has not provided RIDOT with the data format. As the system is currently configured, RIDOT staff are unable to directly access or manipulate the data. SSI has been contracted to provide the necessary software to allow us to access the RIDOT weather data via the web. This software is scheduled to be installed in March 2001.

In addition to the existing stations, RIDOT is currently preparing a request for proposal to extend the current Rhode Island RWIS with an additional 12 stations. The proposed installation locations are:

1. I-95 at Roosevelt Avenue, Pawtucket
2. I-95 at Elmwood Avenue, Cranston
3. I-195 at Warren Avenue, East Providence
4. Route 114/136 at Mount Hope Bridge, Bristol
5. Coldbrook Road (on Adamsville Hill), Little Compton
6. Wrentham Road (south of Highland View Road), Cumberland
7. Route 146 at bridge 448, North Smithfield
8. Route 100 (near Zambarano Memorial Hospital)
9. I-295 at Route 6, Johnston
10. Route 102 at Route 14, Foster
11. Route 1 at Route 108, Narragansett
12. I-95 at Route 2, West Warwick

The data collected at each site will be similar to those currently in the RWIS. In addition color digital cameras are planned to show road conditions. The vendor for these additional stations is currently unknown but the supplier must ensure that the new system is fully compatible with the current system. Access to this new data set should therefore be straightforward.

While data from the RWIS is not currently available, an output window has been designed to display the most recent observations at each station (Figure 12). Selecting the appropriate tab the observations at the station of interest can be displayed. The time of the observation is given at the top of the form and data below. This includes both the meteorological parameters as well as the roadbed conditions.

COFS

A protocol has been developed to access the output of the NOAA, National Center for Environmental Prediction (NCEP), Coastal Ocean Forecast Model System (COFS) for the US east coast. These data are placed on the FTP server on a daily basis. TRANSMAP can currently download and display real -time predictions of the surface elevations, currents, salinity, and temperature for near shore waters off the Rhode Island coast and the output from the associated ETA meteorological model for these same waters and over the State of Rhode Island. Figure 1 shows the location of COFS grid points along the southern coast of Rhode Island. As an example the wind predictions for February 21, 2001 from COFS are shown in Figure 7.

NOAA, Rhode Island DEM, and Narragansett Bay Commission

The University of Rhode Island Graduate School of Oceanography has established a monitoring network for Narragansett Bay. NOAA, the Rhode Island Department of Environmental Management, and the Narragansett Bay Commission sponsor the network. Information about the network and access to data can be obtained through the network web site: http://www.gso.uri.edu/~dkester/nbay/index.htm. Measurements of salinity, temperature, and dissolved oxygen are obtained at 15 minute intervals from near surface (0.5 m below the surface) and near bottom (0.5 m above the bottom) stations at five sites: Phillipsdale on the Seekonk River, Pomham Rocks on the Providence River, Bullock Reach on the Lower Providence River, North Prudence in Upper Narragansett Bay, and South Prudence mid Narragansett Bay. System operation has been sporadic at several of the upper bay sites during the winter 2000- 2001 due to ice damage. Data from the system is not currently available in real time but is typically posted one to several weeks after being collected.

TRANSMAP can access and display this data but it is of limited value at this time since the data being collected focuses on characterization of bay water quality and has limited utility in supporting marine transportation. The other major problem is that the data is not posted to the web site in real time.

Geographic Information for Rhode Island

To provide background information to assist in the interpretation of model results or to support the use of TRANSMAP, access has been established to the Rhode Island Geographic Information System (RIGIS) (http://rigis@edc.uri.edu/rigis/, http://rigis@edc.uri.edu/riatlas/). This access allows any layers in the RIGIS to be obtained from the web site and downloaded into TRANSMAP. The process is quite simple given the fact that both TRANSMAP and RIGIS use ERSI ArcView software. To illustrate the capability, Figure 13 shows selected GIS layers of interest in transportation overlaid on the base map for Rhode Island. The layers include state and town boundaries, interstate and state roads, railroads, RIPTA routes, bridges and overpasses, lakes and ponds, and RIDOT RWIS, PORTS, URI GSO, and COFS stations. Figure 13 is simply an illustration of the capability. The user is free to select layers appropriate to the application of interest.

4. IMPLEMENTATION OF TRANSMAP

The basic TRANSMAP framework as outlined above, with access to the various data sources noted, is currently operational at Ocean Engineering, Narragansett Bay Campus, University of Rhode Island, Narragansett, RI. Completion of the initial version of the system awaits obtaining access to the RWIS data.

Project investigators have met with Mr. John Nickelson, RIDOT, Maintenance Department and Ms. Cynthia Levesque, RIDOT, Transportation Management Center to better understand their needs and how TRANSMAP output can best be configured for their operations. Mr. Nickelson is responsible for the day-to-day management and operation of the RWIS. Ms. Cynthia Lesveque serves as director of Transportation Management Center that uses road weather information, in conjunction with real time video and traffic observation reports, to assist in traffic management along major highways in Rhode Island. Once TRANSMAP's link to RWIS has been finalized and further testing performed to verify that the system operation is robust, it will be provided to the RIDOT Maintenance Department. This should occur in the spring 2001. Feedback from RIDOT users will be obtained and the system revised and upgraded. Once RIDOT is satisfied with the system operation TRANSMAP will be provided to RIDOT Transportation Management Center.

To provide the public with access to the information being collected by TRANSMAP, a web based server system is under development. The system is currently operational, in rudimentary form. The development of the web-based interface is being coordinated with a similar effort funded by the EPA EMPACT program and led by the Narragansett Bay Commission. The system allows access to a base map, GIS data on primary and secondary highways from RIGIS, and linkages to a variety of supporting web sites (e.g., PORTS, various weather sites, etc.). As an example Figure 14 shows the opening page of the web site. It displays a map of Rhode Island and shows the location of the RWIS and PORTS observation sites. The option bar to the left allows the user to learn about the background of the project, obtain current news, provides access to the data being collected and to the environmental models, and links to related web sites. Figure 15 shows the opening menu that allows the user to query historical data. In this case wind speed and direction data is being requested from the Westerly RWIS site from June 1 to June 30, 1999. The system has been demonstrated several times to members of the perspective user community to obtain initial feedback on its design and functionality. Completion of the initial version of the system has been delayed because of the delay in accessing RIDOT weather data.

5. PLANNED ACTIVITIES

The primary focus of the present report has been the work accomplished during the first year of the three-year project. The second year of the project began in September 2000. The principal tasks for the next two years of the project are:

1. *to fully implement the system and provide system installation and operational training to RIDOT (Maintenance Division and Transportation Management Center) and DEM staff and make appropriate modifications to meet their specific needs*. The initial installation can be accomplished quite quickly once the software necessary to access RWIS weather data is available. It is anticipated that the system will be installed, in its rudimentary form in spring 2001 allowing RIDOT to evaluate system performance and functionality. After this is done their input will be solicited, the system revised as appropriate, and an upgraded version installed.
2. *to implement and validate the thermal energy balance model that will allow predictions of road surface temperature using data from in-situ sensors and to evaluate model performance in nowcasting and forecasting applications*. The thermal energy balance model is currently operational using synthesized weather and roadbed (composition and thermal diffusivities) data. The next step will be to link the model to the RIDOT weather data to allow now-casting of road temperatures at RIDOT weather station sites. Once this is accomplished, the model will be extended to the forecast mode, with the ability to assimilate observed temperatures to improve the forecasts. A variety of forecasting experiments will be performed using historical data to assess the model's ability to forecast road surface temperatures 6, 12, 24, 36, and 48 hours into the future. A variety of meteorological forecasting techniques will be used to force the model. Model predictive performance will be documented for each forecast period using standard statistical measures (e.g. rms errors, relative error, and standard deviations). The model's predictive performance will be evaluated using persistence and forecast weather data (local weather forecasts available via the Internet) to specify atmospheric forcing for the model. Once model testing has been completed it will be implemented in TRANSMAP.
3. *to extend and improve the Internet/web access to the system, including the ability to animate observations and forecasts and to assist public transport groups (e.g. AAA, Rhode Island Public Transit Authority, Water Cruises) in setting up Internet access for internal and public use*. The web-based distribution system of TRANSMAP is currently operational. Implementation of the system is awaiting the connection to RWIS weather data before the initial version of the system is ready for evaluation by users. Once this link is accomplished the system will be placed in operation and feedback solicited from the users about the ability of the system to meet their needs and what improvements (i.e. additional data, data format and visualization, access to GIS data, etc.) that they feel are necessary. These improvements will be implemented to the extent that resources are available. The focus will be primarily on groups who are expected to make routine use of the system.
4. t*o test application of the ALOHA hazardous materials response model in cooperation with the Rhode Island DEM Hazardous Materials response team*. ALOHA model is currently operational within TRANSMAP but has not undergone any real testing or evaluation. It is proposed to work with the Rhode Island Department of Environmental, Hazardous Material response team to implement the system for routine use in their operation. Once the system is fully functional TRANSMAP will be installed for their use. They will be asked to evaluate its utility to support their responses to hazardous chemical spills. Their feedback on how to improve ease of operation, display of model predictions, or other areas they feel need to be improved to meet their needs will be solicited.
5. *to link TRANSMAP with a high-resolution weather forecasting model currently under development for southeastern New England.* The NOAA, National Ocean Service (NOS), National Center for Environmental Prediction (NCEP) currently provides routine nowcasts and forecasts of the weather and circulation for the east coast (shore to outer edge of the Gulf Stream, from Florida to Greenland) of the US. These forecasts are part of the Coastal Ocean Forecasting System (COFS). The weather forecasts include wind speed and direction, atmospheric pressure, air temperature, humidity, and solar radiation. These forecasts cover all of Rhode Island at a resolution of about 20 km. In a study funded by the National Ocean Partnership Program (NOPP) at Drexel University and the University of Rhode Island, NOAA National Ocean Service personnel will be developing a high-resolution (1-2 km) weather model for southeastern New England. It is proposed to link TRANSMAP with the existing NOAA/NOS weather model and then to migrate to the higher resolution model once that information becomes available, early in 2002. Access to this information will provide high resolution forecasts for the weather in Rhode Island and will also provide input to the thermal energy model discussed above. The

forecasts of road surface temperature, using local forecasts, will be compared against those using the improved NOAA weather model.

6. *to transfer the technology developed in this project to private industry for commercialization*. The final step will be to transfer the technology developed in this project, TRANSMAP, to private industry. The will be accomplished by identifying suitable industrial partners and working cooperatively with them to provide them with the software and assist them in identifying key markets for the system.

6. CONCLUSIONS

The present report demonstrates that the initial framework and the web-based access to the TRANSMAP system have been developed and the system implemented for the Rhode Island study area. Linkages to all key data sets (PORTS, COFS, and Narragansett Bay Data Network), with the exception of the RWIS, have been successfully implemented. For the PORTS and COFS data the linkages allow near real time access to the data being collected. ALOHA, a model to predict the evaporative plumes of spills of hazardous chemicals (1000 chemicals in the data base) has been implemented within the TRANSMAP structure. In addition, a thermal energy balance model has also been developed and is currently operational. This model allows the user to predict the time dependent, vertical temperature profile from the road surface to several meters depth in the roadbed. Both the chemical spill model and the thermal energy balance model can be linked to the real time weather observations or to forecasts of weather as input. This allows both models to run either in nowcast or forecast modes.

TRANSMAP allows the user to visualize the observations (e.g. air temperature, wind speed/direction, sea surface currents, bay salinity, temperature, and sea surface elevation) on a base map of the study area. This can be done either in terms of a spatial map or the time series of the observations at one location. Embedded tools also allow the spatial maps to be contoured. TRANSMAP's GIS has been linked with the RIGIS, MassGIS and Connecticut GIS databases and allows any layer in those databases to be imported into TRANSMAP and displayed over TRANSMAP's base map. The user can turn GIS layers on and off and can hence customize the display to support a particular application. This importance of this feature is clearly illustrated in the present report for the simulated methane spill on Rte 1A in Narragansett, RI. Here the user can simulate the release impact zone within minutes and then, through the use of the GIS, identify schools in the evaporative plume that need to be evacuated.

The principal focus of the project, in the near term, is to establish routine and reliable access to the RWIS data via the web. SSI engineers have been contracted and are scheduled to install the web-based access to RWIS in March 2001. Once this access is fully operational, the beta version of TRANSMAP and its web-based extension can be completed and the system installed for use by the RIDOT Maintenance Division and eventually for the RIDOT Transportation Management Center. Additional improvements are planned over the next two years to test, verify, and extend the thermal energy balance model to real time now-casting and forecasting, to provide operational training to system users, to progressively improve the features and user interface in response to user feedback, to test and validate the ALOHA model and facilitate its use in real response situations, to provide a real time link to a high resolution (1-2 km) meteorological model for Rhode Island and its coastal waters, that is currently in development, and to transfer the system to private industry for commercialization.

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LIST OF FIGURES

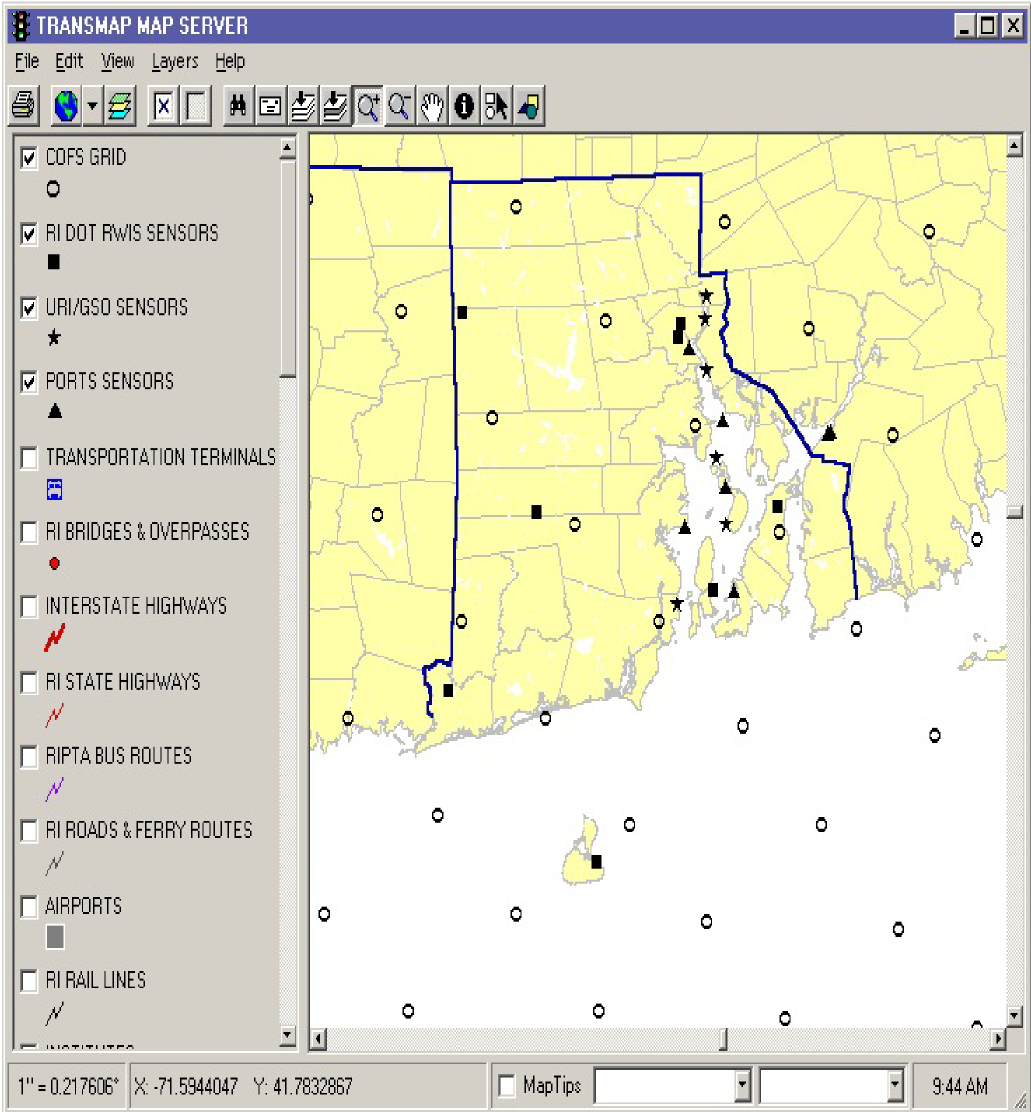

FIGURE 1 Southeastern New England study area for TRANSMAP. The locations of the NOAA/PORTS, RIDOT Road Weather Information System (RI RWIS), URI GSO and COFS sites are shown. Town/county boundaries are shown for Connecticut, Massachusetts, and Rhode Island.

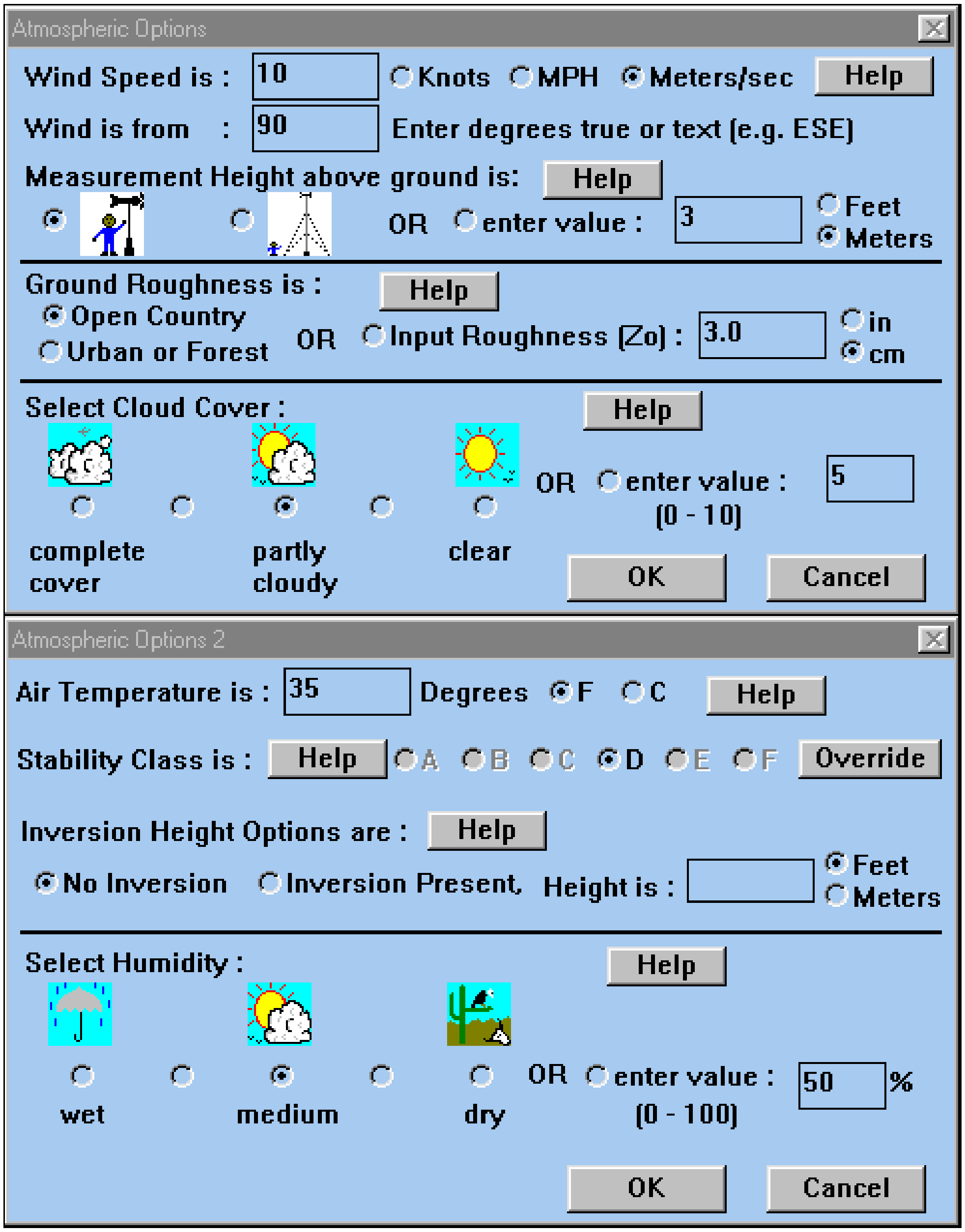

FIGURE 2a Input for ALOHA describing atmospheric options.

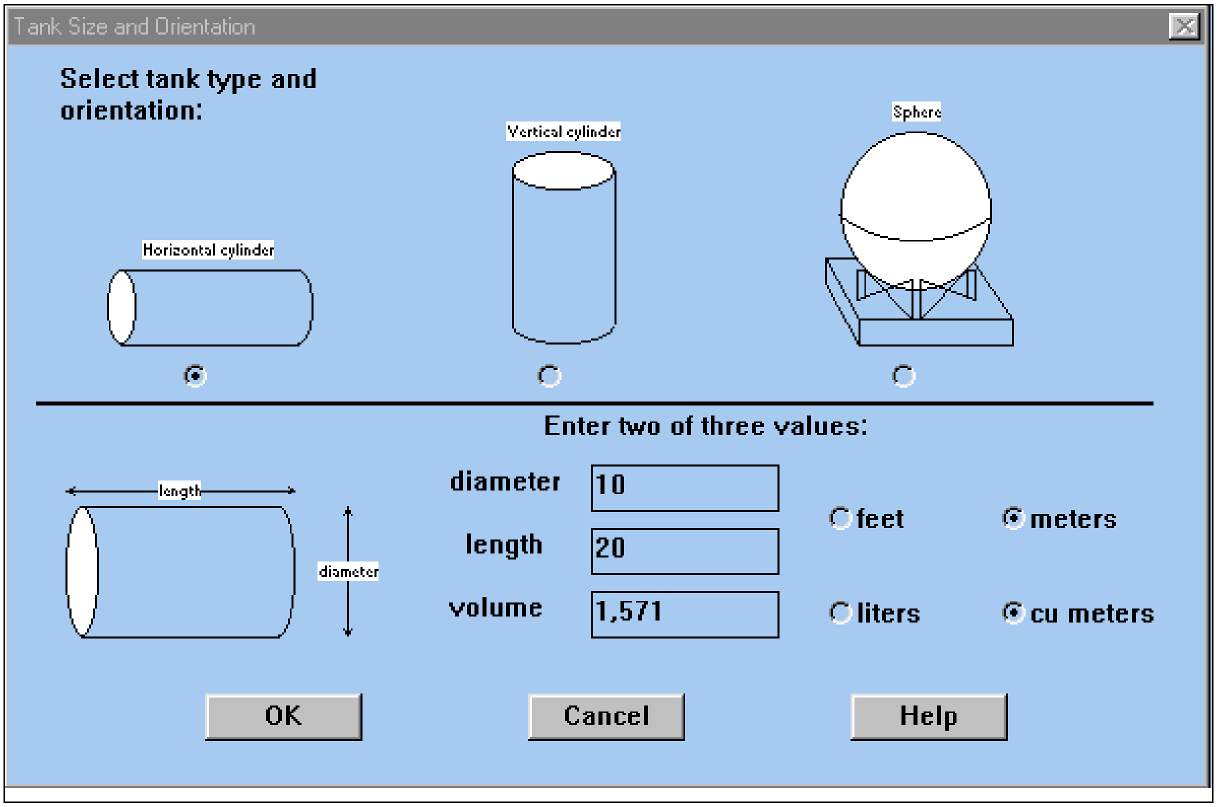

FIGURE 2b Input form for ALOHA describing tank size and orientation.

```
ALOHA 5.2.3 - [Text Summary]
File  Edit  SiteData  SetUp  Display  Sharing
SITE DATA INFORMATION:
  Location: NARRAGANSETT, RHODE ISLAND
  Building Air Exchanges Per Hour: 1.62 (sheltered single storied)
  Time: February 23, 2001  1314 hours EST (using computer's clock)

CHEMICAL INFORMATION:
  Chemical Name: METHANE       Molecular Weight: 16.04 kg/kmol
  TLV-TWA: -unavail-           IDLH: -unavail-
  Footprint Level of Concern: 1 ppm
  Boiling Point: -161.49° C
  Vapor Pressure at Ambient Temperature: greater than 1 atm
  Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
  Wind: 10 meters/sec from 90° true at 3 meters
  No Inversion Height
  Stability Class: D           Air Temperature: 35° F
  Relative Humidity: 50%       Ground Roughness: open country
  Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
  Leak from hole in horizontal cylindrical tank
  Tank Diameter: 5 meters      Tank Length: 20 meters
  Tank Volume: 393 cubic meters
  Tank contains gas only
  Internal Temperature: 35° F
  Internal Press: 10 atmospheres
  Chemical Mass in Tank: 3.16 tons
  Circular Opening Diameter: 10 centimeters
  Release Duration: 12 minutes
  Max Computed Release Rate: 522 kilograms/min
  Max Average Sustained Release Rate: 475 kilograms/min
     (averaged over a minute or more)
  Total Amount Released: 2,424 kilograms

FOOTPRINT INFORMATION:
  Dispersion Module: Gaussian
  User-specified LOC: 1 ppm
  Max Threat Zone for LOC:  greater than 10 km

TIME DEPENDENT INFORMATION:
  Concentration Estimates at the point:
  Downwind:       1 meters
```

FIGURE 2c Summary information for the methane spill on Rte 1A, Narragansett, RI on February 23, 2001.

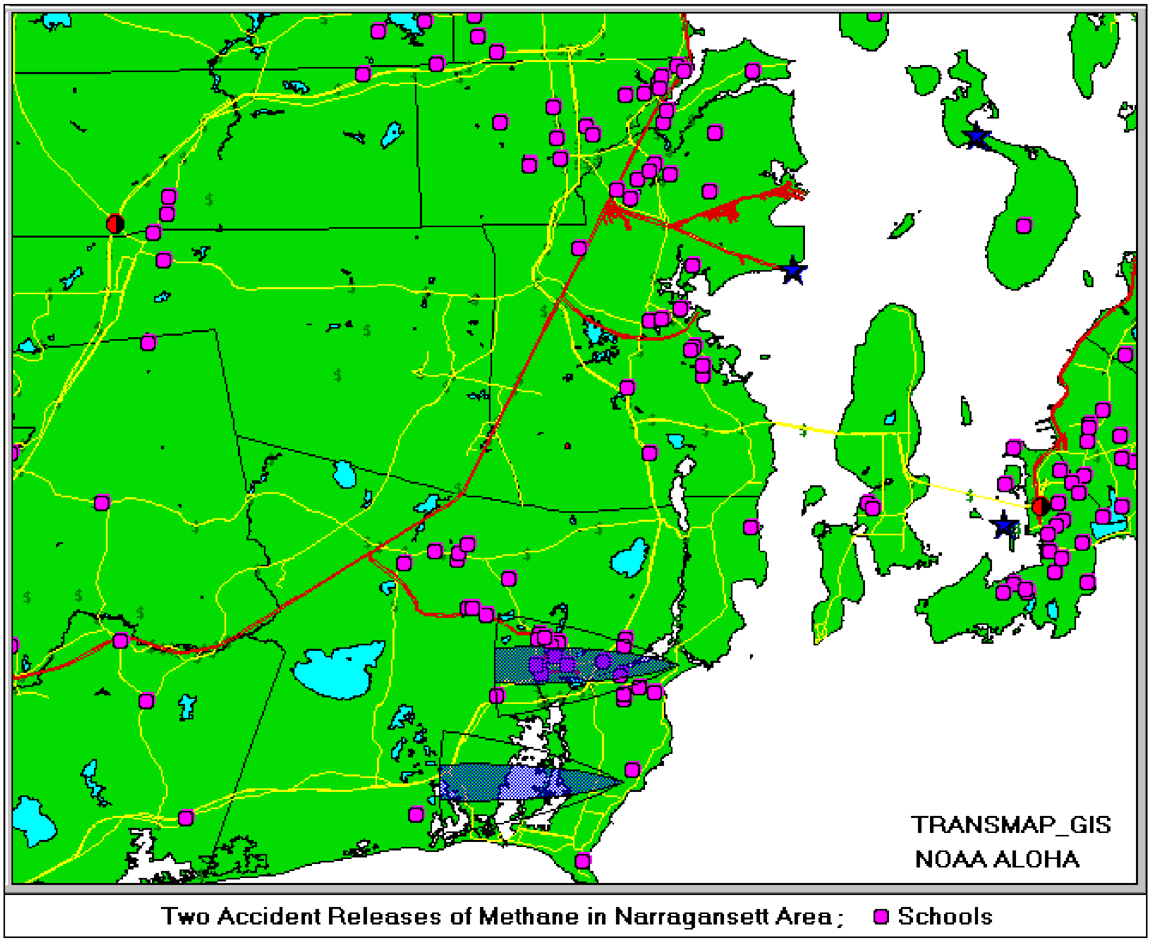

FIGURE 3 ALOHA predicted impact zones (Level of Concern, 1 ppm) for the spill summarized in Figure 2. The predictions have been overlaid on TRANSMAP's base map. Also shown are the locations of principal highways, town boundaries, water bodies, and schools. All data are from RIGIS.

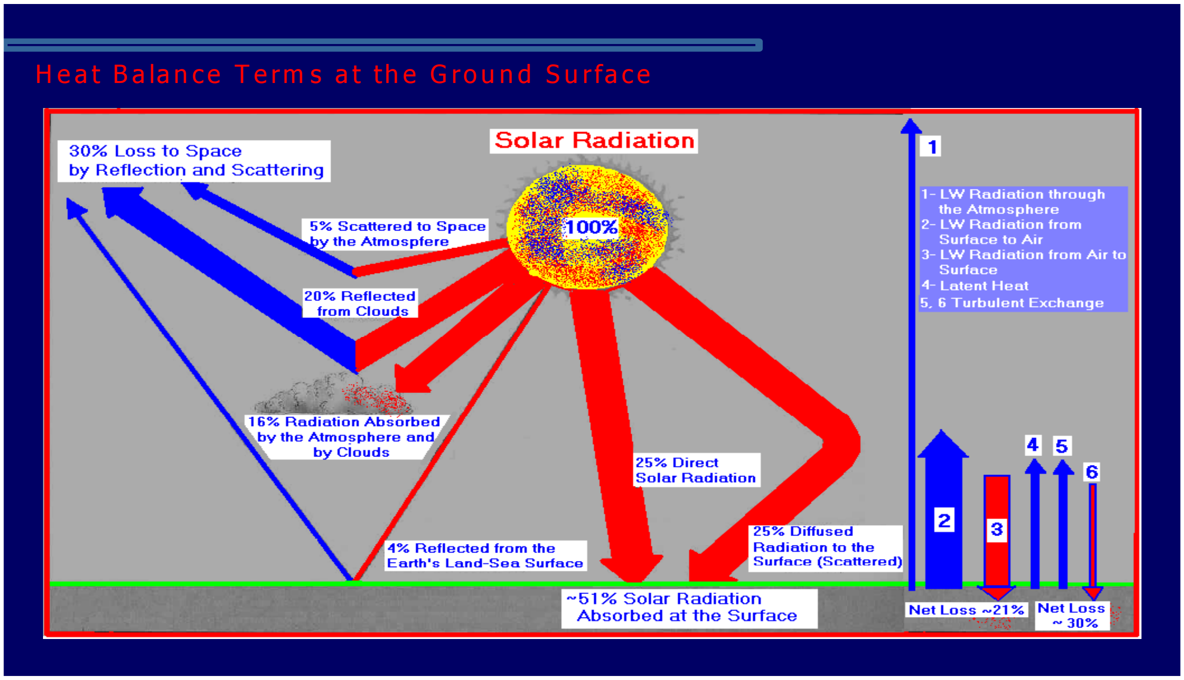

FIGURE 4 Schematic of solar radiation and heat flux terms for the thermal energy balance model.

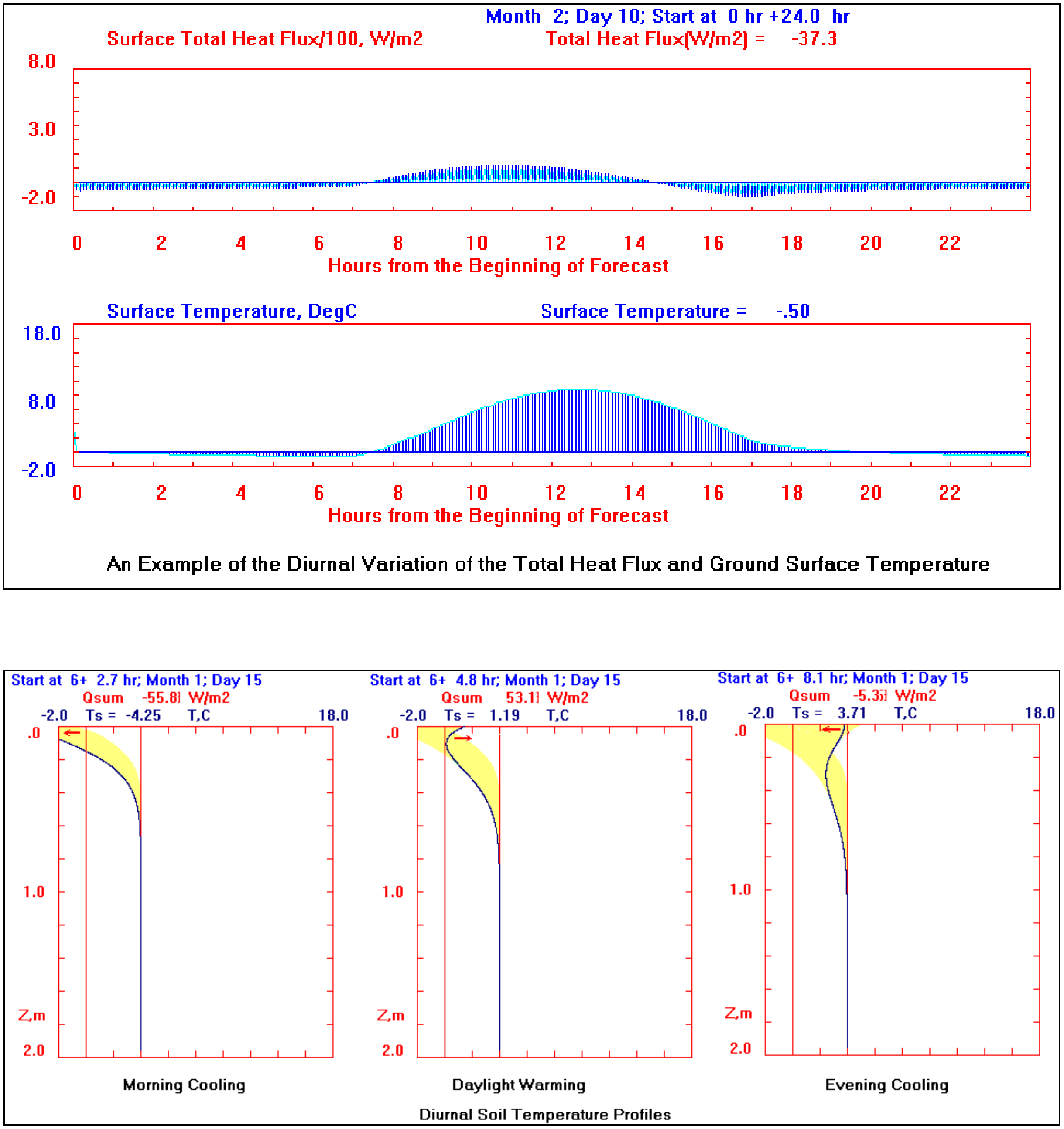

FIGURE 5 Thermal energy balance model output. The upper panel shows the time series of the net heat flux between the road surface and the atmosphere and the road surface temperature over one day. The dark lines in the lower panel show the vertical temperature profile in the roadbed for the morning cooling, daylight warming, and evening cooling periods.

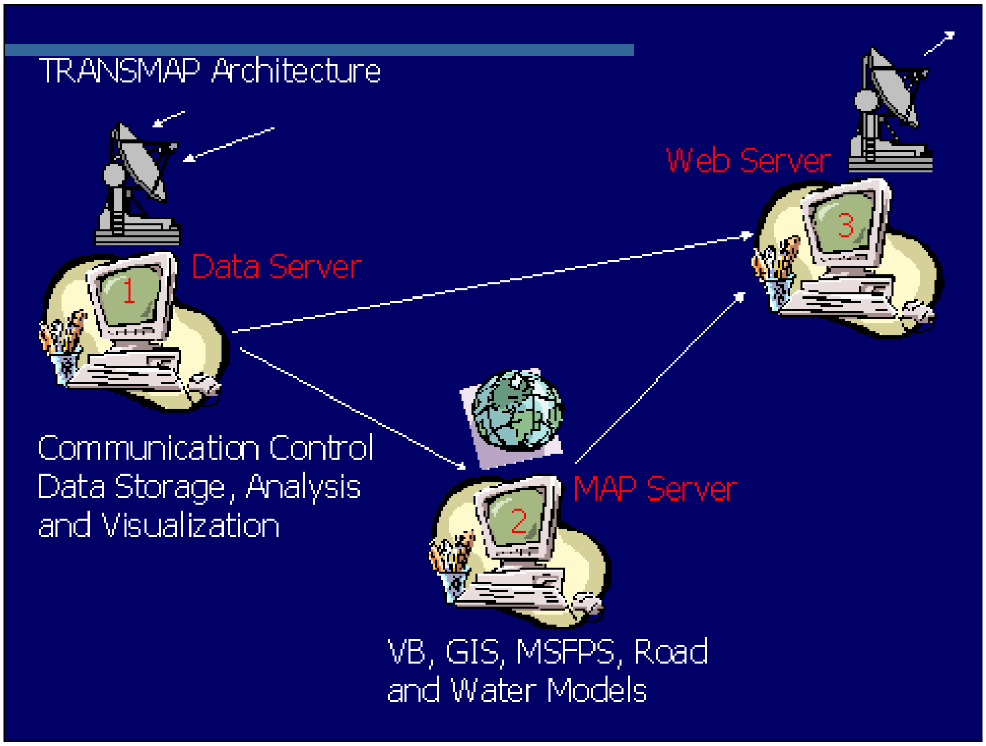

FIGURE 6 TRANSMAP system architecture for a three server system (data, web, and map).

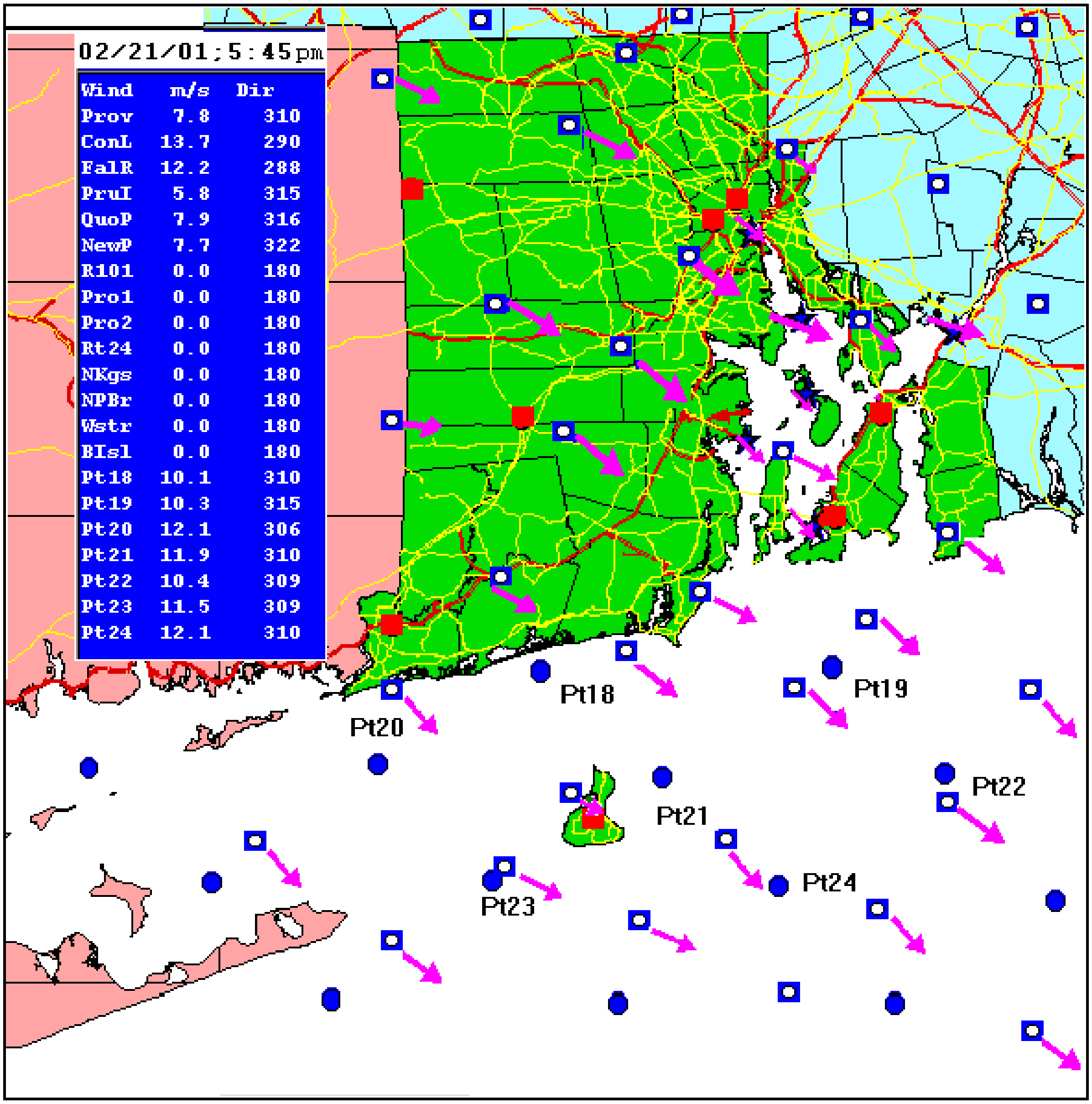

FIGURE 7 Wind speed and direction for Rhode Island, Narragansett Bay and coastal waters based on PORTS and COFS data on February 21, 2001 at 5:45 PM. The insert on the left shows the observed wind speed and direction at each station.

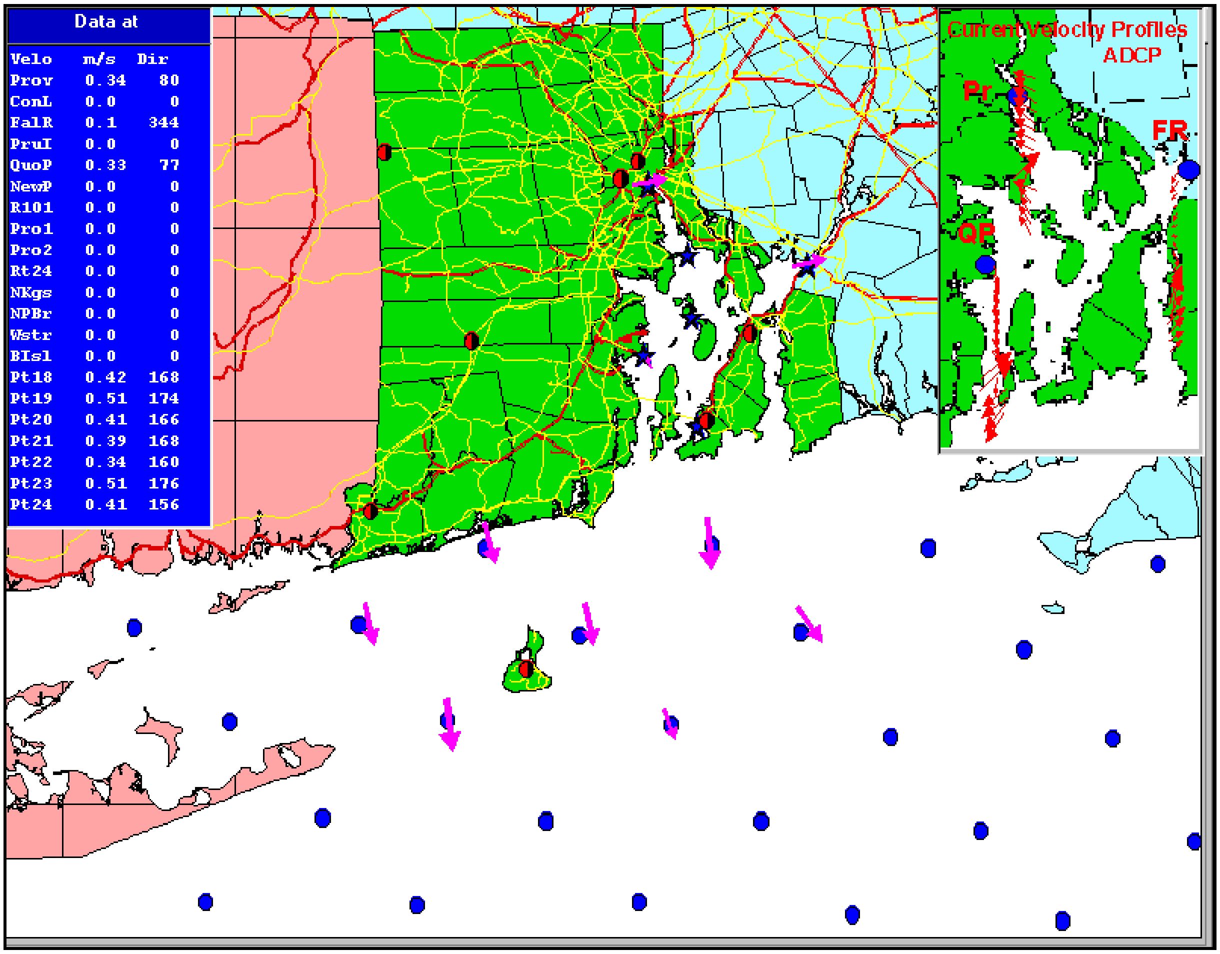

FIGURE 8 Surface velocity vectors derived from PORTS and COFS on February 22, 2001 at 1 PM for Narragansett Bay and nearby coastal waters. The upper right insert shows a schematic representation of the currents as a function of depth from the ADCP current meters from the Providence, Fall River, and Quonset Stations. The upper left insert gives the surface current speed and direction for all stations shown.

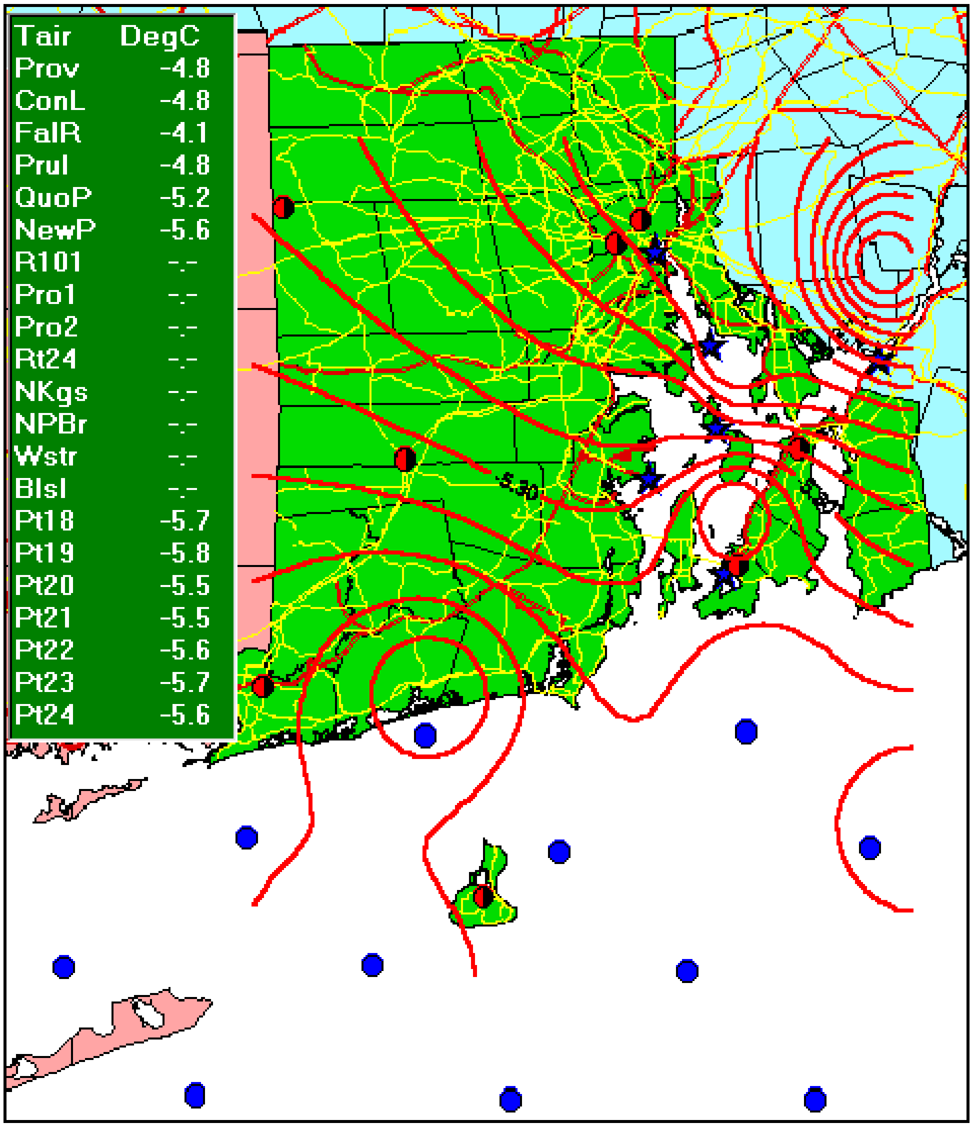

FIGURE 9 Air temperatures for Rhode Island, Narragansett Bay and nearby coastal waters for February 22, 2001, 4:30 PM. Also shown are air temperature isolines based on the PORTS and COFS data. The upper left insert gives a summary of the measurements at each station.

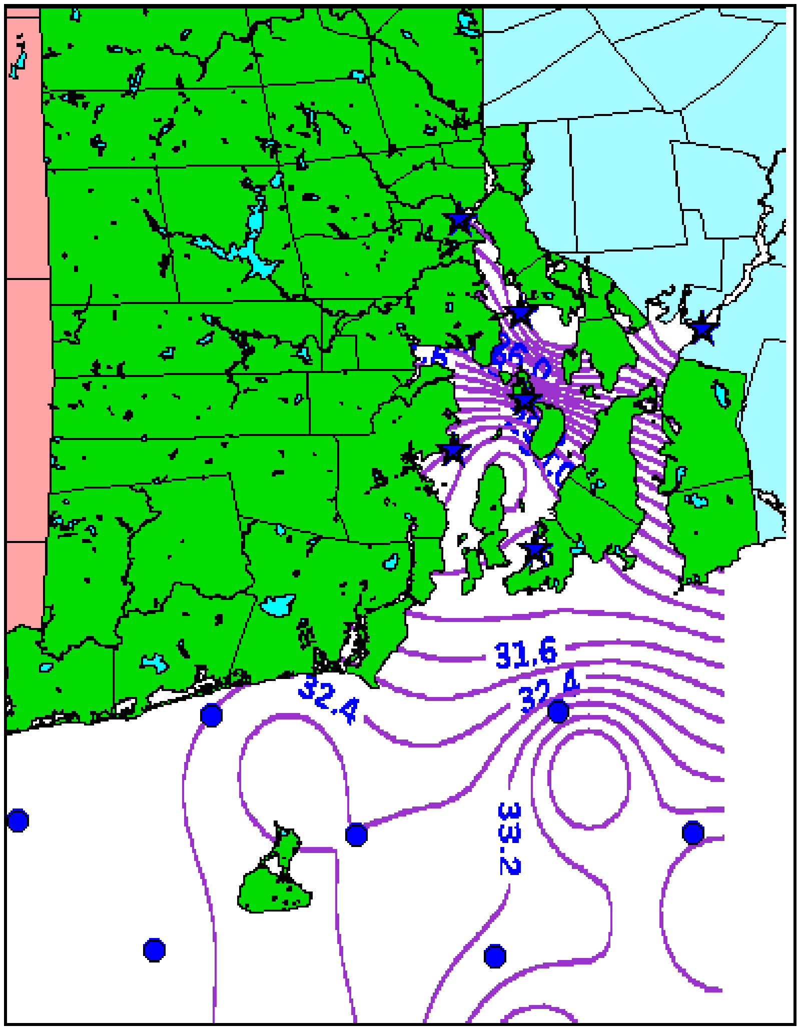

FIGURE 10a Contours of sea surface salinity for Narragansett Bay and coastal waters based on PORTS and COFS data on February 21, 2001, 6 PM.

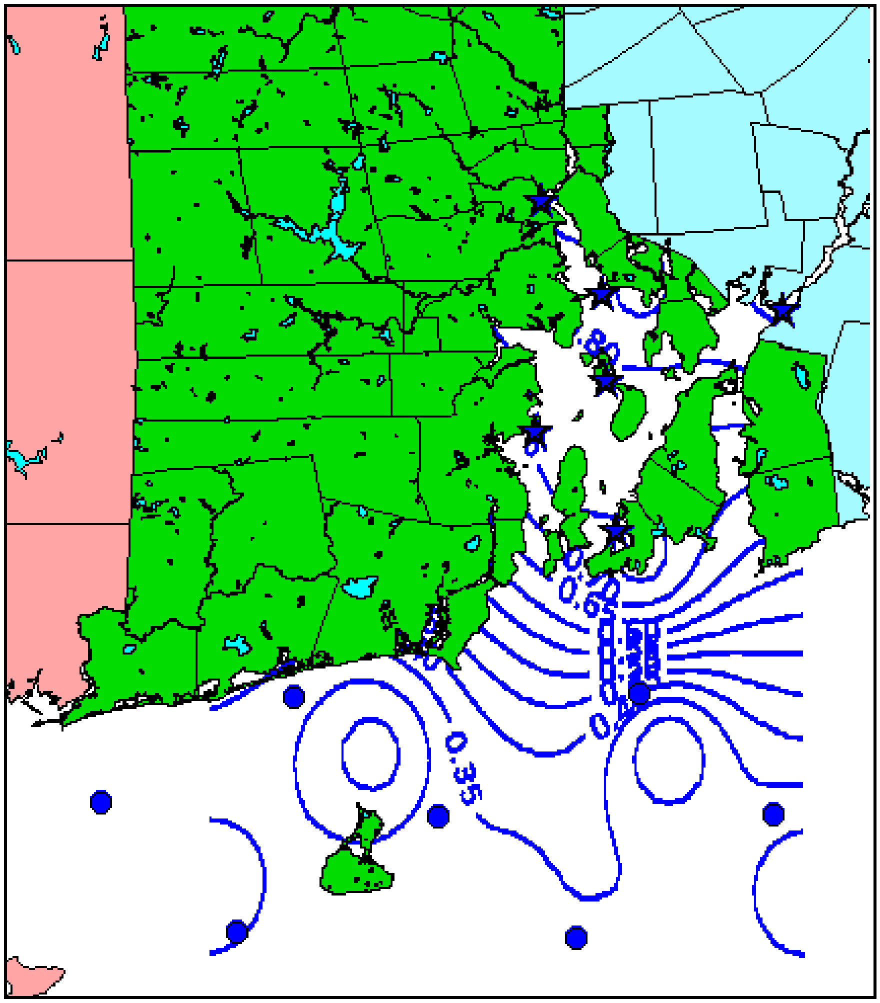

FIGURE 10b Contours of water level for Narragansett Bay and coastal waters based on PORTS and COFS data on February 21, 2001, 6 PM.

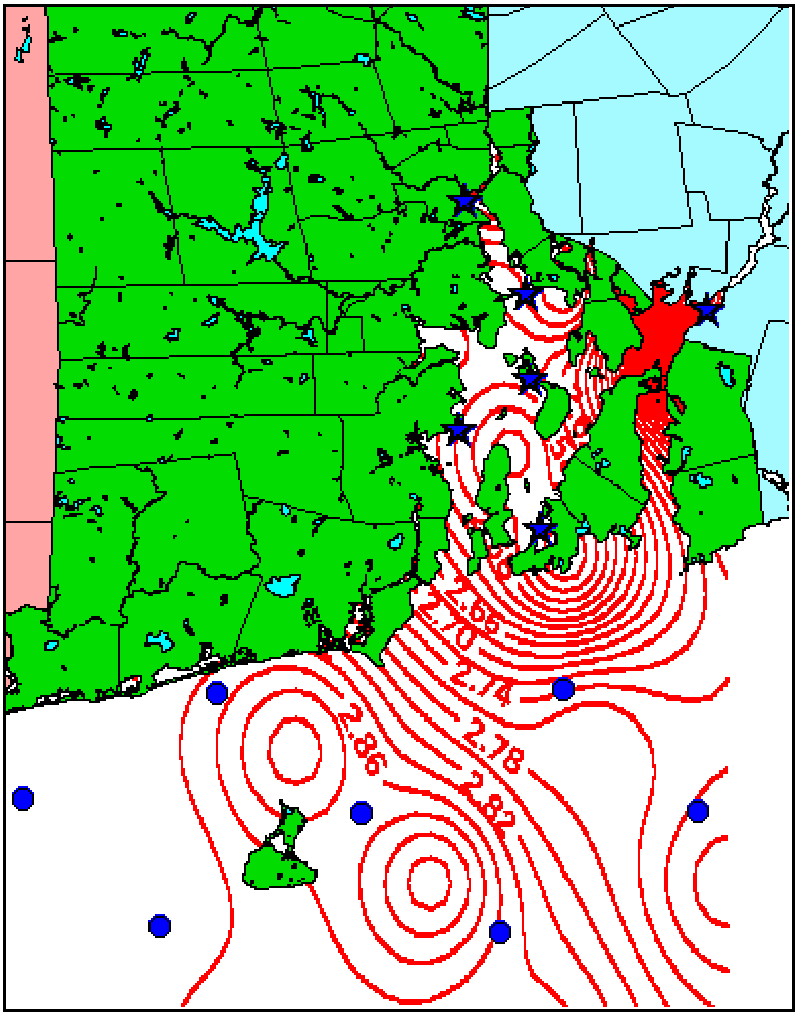

FIGURE 10c Contours of sea surface temperature for Narragansett Bay and coastal waters based on PORTS and COFS data on February 21, 2001, 6 PM.

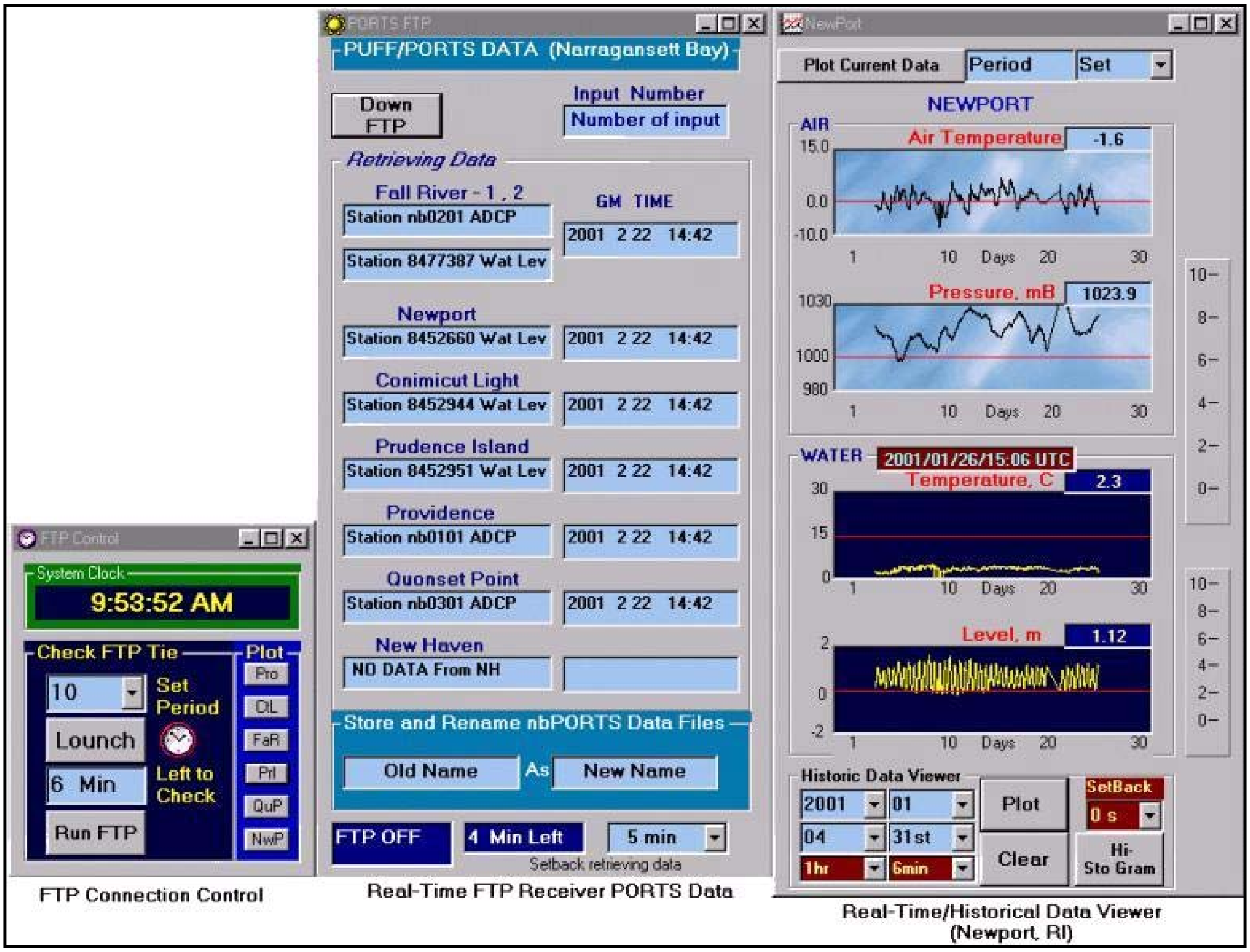

FIGURE 11 TRANSMAP interface to PORTS real time data collection. The left most panel shows the FTP control, the center panel the current being retrieved at each site and associated time, and the right panel a time series of the air temperature, barometric pressure, water temperature, and water level for observations at Newport for January 2001.

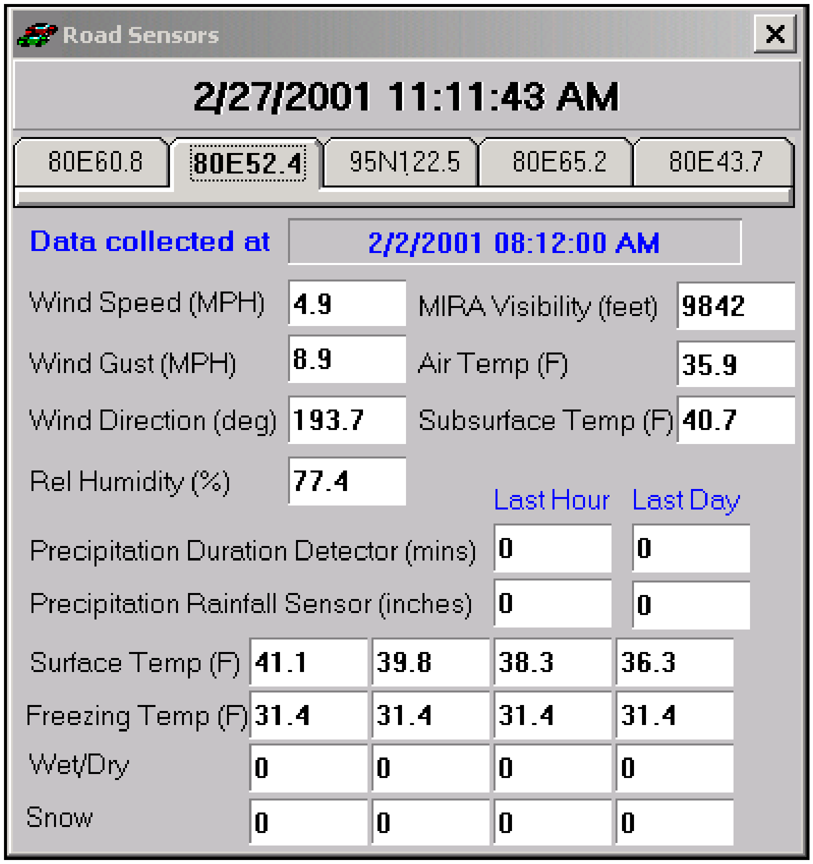

FIGURE 12 TRANSMAP current summary of road weather conditions for each station in the network.

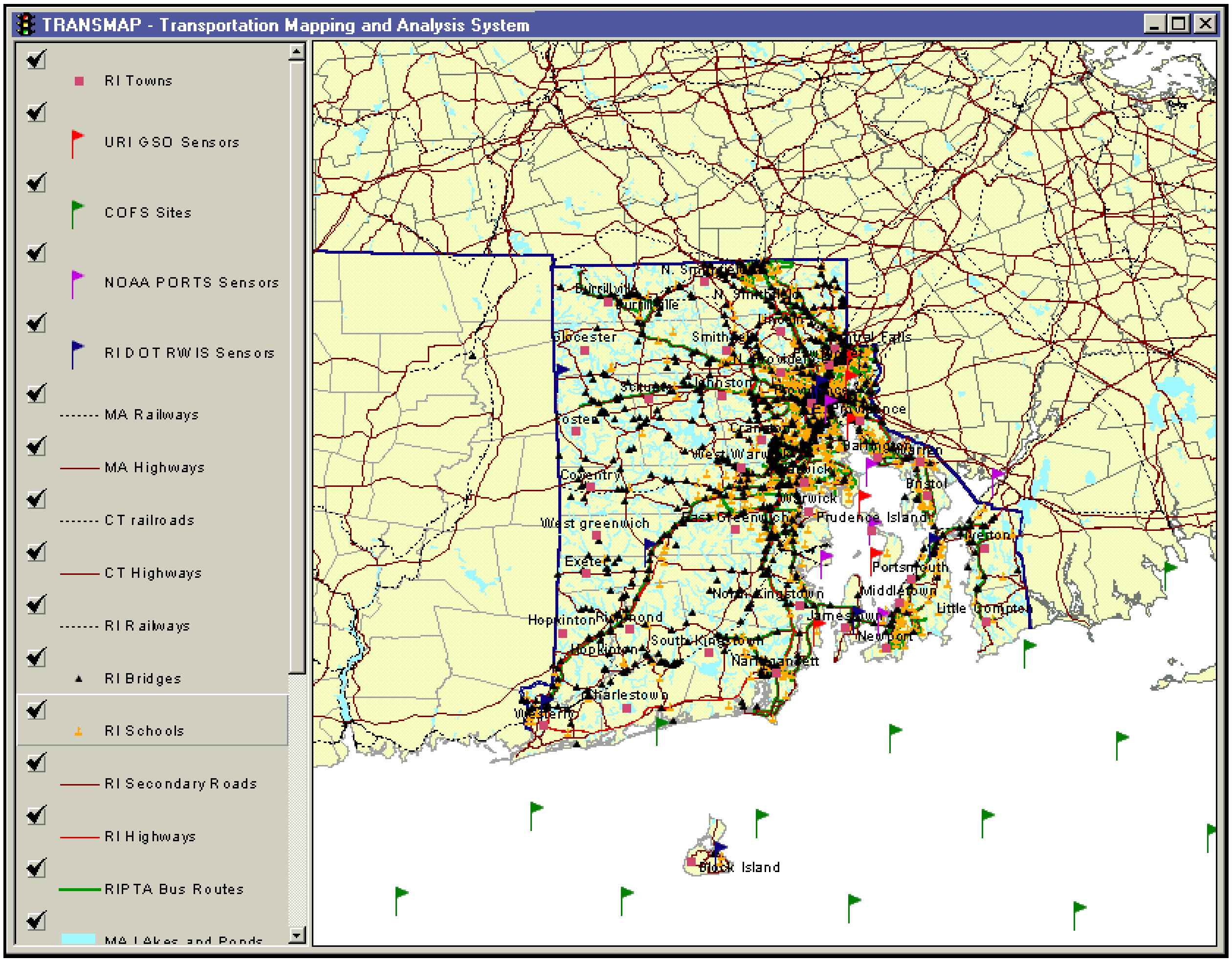

FIGURE 13 GIS data overlaid on the study area base map. Data include state and town boundaries, Rhode Island town names, interstate and state roads, railroads, RIPTA routes, lakes and ponds, bridges and overpasses, Rhode Island schools, and the location of the RWIS, COFS, URI GSO, and PORTS sampling stations. The insert at the left provides the legend for all GIS data. Data were obtained from Connecticut GIS, MassGIS and RIGIS.

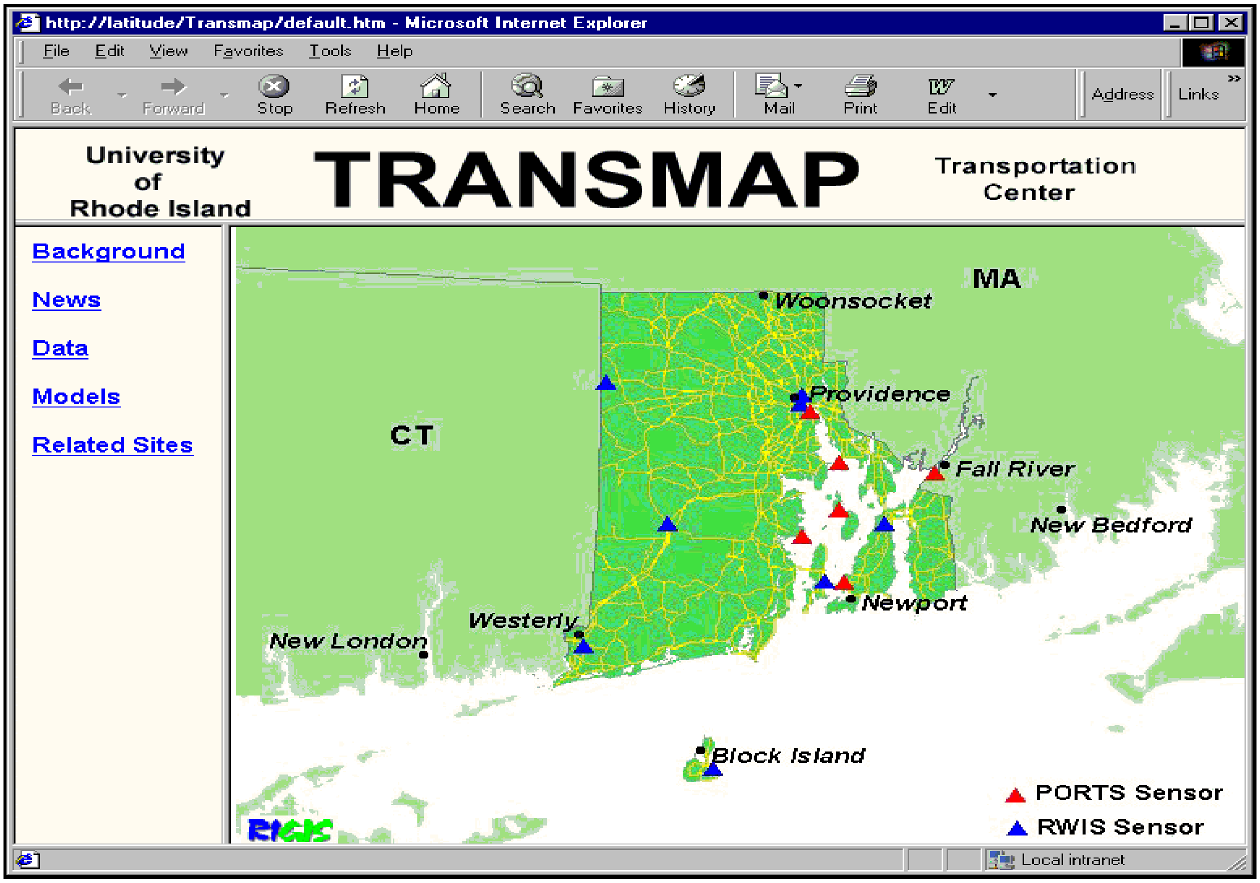

FIGURE 14 Introductory page for web based interface to TRANSMAP. The locations of the PORTS and RWIS sensors are also shown.

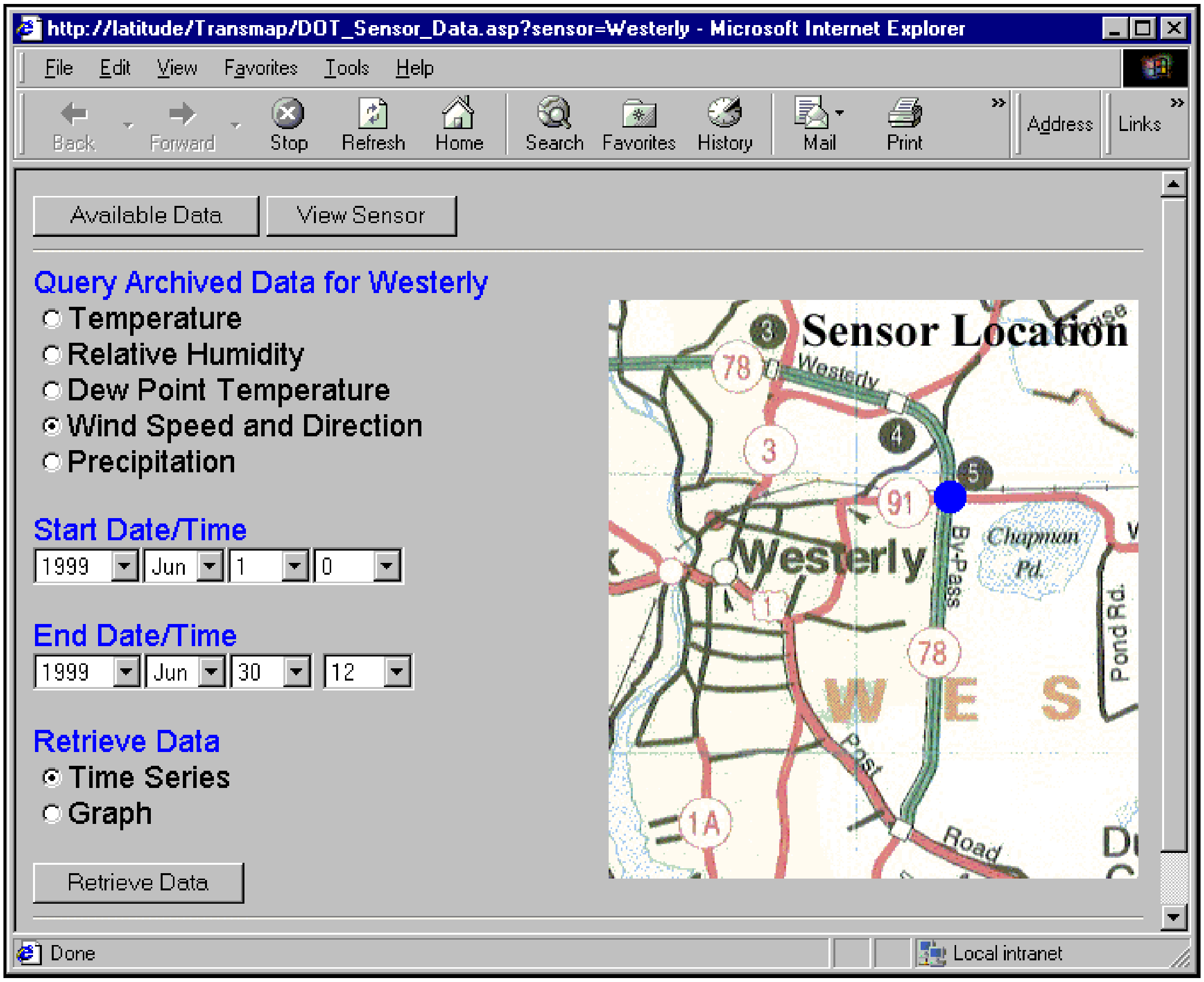

FIGURE 15 Form for accessing historical RWIS meteorological data for the Westerly RWIS site, for a user selected time period.