

Web Based Real-Time Meteorological Data Analysis and Mapping Information System

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Abstract—In this paper, the real-time meteorological data analysis and mapping information system is proposed. This system makes real-time data and the results of analysis available through all end users. It captures the real-time meteorological data from meteorological stations, pushes these data into geodatabase and publishes the raw data and the results of analysis through server as a web mapping service that can be accepted by any desktop and web applications. One of contributions of the proposed system is executing the real-time analysis and mapping operations whenever the latest real-time meteorological data arrive to the system via a determined protocol from meteorological stations. This contribution allows the system to store, analyze and map each meteorological data once. Other contribution is related to mapping operations. Proposed system creates the map for certain data and for the results of analysis and renews each time when the data is changed. Due to these contributions proposed information system allows the end users to get newest meteorological information in instant. Besides, because these operations are performed on the server side, any end user can use them without the need for custom code.

Keywords—Geographical Information System, Web Based Information System, Real-Time Meteorological Data, Mapping, Statistical Analysis, Geostatistical Analysis, Krigging Interpolation Method

I. INTRODUCTION

Information technologies have gained importance today. Also Geographical Information Systems (GIS) are becoming increasingly popular. GIS are utilized to improve efficiency, decision making and communication by integrating various multiple and complex sets of information. These systems provide a framework for management, analysis and representation of geographical information. There are three major components of GIS: the data sets and models which represent the raw information, the maps and globes in which this information is placed, and the processing and manipulation techniques that can be applied [1]. GIS can be divided into five components: hardware, software, data, people, and methods. All of these components need to be in balance for the system to be successful. No one part can run without the other [2].

Meteorological information is important to everyone, each minute of the day. Independently on the location, terrain and climate, particular sections of the country, and regions of the world, people have a more immediate need for meteorological

data. Damage to life and property from severe meteorological conditions is all too common, but with improved decision support systems that incorporate the latest meteorological information technology including real-time meteorological data observations and GIS, notification, planning and recovery can be dramatically improved [3].

In the new millennium the need for instant meteorological information with the click of a mouse is not only desired, it is expected. Information renders knowledge; and knowledge spurs prudent decision making. Since the meteorological information affects every facet of our real-times from food production to energy consumption, public safety and travel, its impact is extensive [3]. The aim of this study is to help people to make more accurate and immediate decisions on the base of real-time meteorological information.

The easiest way to be informed about the current meteorological information for end users can be a web based information system through internet. But most systems are not real-time and do not have interactive map features. Analysis is commonly done before representation and the results of analysis are stored as an image in offline manner. When analysis results are represented as image, it loses interactive map features like vector data, zoom-in, zoom-out, selecting, querying, editing on map. Analysis period can be 1 day, 12 hours, 6 hours, 1 hour etc. While these systems are working offline, meteorological data changes can be sharply and the end users cannot reach latest useful information. It is possible to encounter these problems in offline systems. To solve these problems a real-time information system, which performs an analysis whenever the new raw data come, is proposed. So, end users can benefit with more accurate information and make better decisions about their related works. Proposed system can analyze various meteorological data like temperature, humidity, wind, rain, etc.

One of contributions of proposed real-time meteorological data analysis and mapping information system is the providing the real-time analysis and mapping whenever the latest real-time meteorological data arrives to the server via a determined protocol from meteorological stations. This contribution allows the system to store, analyze and map new meteorological data once. Existing information systems use the exact time intervals that are defined by system previously to initiate the analysis and mapping operations [4], [5]. According to existing methods the same meteorological data may be stored, analyzed and mapped repeatedly. Assume that an analysis period of the existing systems is 1 hour and the data of parameter X are changed once per 6 hours. In this case,

during 6 hours the data storing, analyzing and mapping operations will be executed 6 times. The first time will be executed on the base of the new data of X , but the others will be executed by using the same data of X repeatedly. As a result the same data and results of analysis may be duplicated in the database which may cause chaos during queering to analyze and map old data and results of analysis. Other deficiency of this method is unproductive use of server processor time to analyze and map the same data repeatedly.

Another contribution is related to mapping operations. Existing information systems create a map once in the exact time intervals in different formats like jpeg, png, etc. and publish it through web as picture. So, existing systems do not take into consideration are there the new data or not at the input of system, they simply repeat the same analysis routines in the exact time intervals on the base last received data. As an example, let us consider an assumption in previous paragraph. In that case, the existing systems will create and publish the same map 6 times, although the data will be changed only one time during 6 hours. Proposed method creates the map of data and analysis results and renews each time when the data are changed.

II. RELATED WORKS

There are many studies related to real-time data analysis information systems.

D. Burke and P. Dodd propose the Aggregated Real-Time Feeds in ArcGIS [6]. Their methodology uses simple batch scripting with a handful of public domain command line utilities to download and preprocess the feed data. The scripts then use ArcSDE command line functions to push these data to the database. The scripts also incorporate logic to track the process, making sure they run as expected. Scripts run every 5 minutes, 30 minutes, once an hour, or once a day depending on the appropriate need. After the data is pushed into ArcSDE, ArcGIS Server services are authored and served.

O. Ozdilek and D. Z. Seker propose a web based application for real-time GIS [4]. Their objective is to create a weather processing system by integrating weather data with different structures collected from different sources in various formats, in a web based real-time GIS. The key different of their study is using the Scalable Vector Graphics (SVG). In their study, SVG Map Server Component is programmed to generate SVG images from the database and add them basic interactivity that can be triggered by programmed UI elements in JavaScript or other script languages. Map server component is a set of PHP scripts capable of reaching constructed database structure and generating SVG images from the data stored in database. Map Server generates maps on the web pages on the fly.

R. A. Mcpherson and others propose Statewide Monitoring of the Mesoscale Environment [5]: A Technical Update on the Oklahoma Mesonet. Their study also includes a full implementation and detail from data collect to demonstration. Established as a multipurpose network, the Oklahoma Mesonet operates more than 110 surface observing stations that send data every 5 min to an operations center for data quality

assurance, product generation, and dissemination. Quality-assured data are available within 5 min of the observation time. Since 1994, the Oklahoma Mesonet has collected 3.5 billion weather and soil observations and produced millions of decision-making products.

Existing meteorological information systems have important deficiencies. For example, some of them do not use a real-time data processing, others do not use a web system and use only desktop clients, the third group of existing studies does not use geostatistical analysis, many existing systems use only published static images for results and etc. So these systems are not fully appropriate for a decision making system application. Proposed in this study system offers a web based and real-time analysis applications.

III. REAL-TIME METEOROLOGICAL DATA ANALYSIS AND MAPPING INFORMATION SYSTEM

This study aims to fill the vacuum in the area of decision making on bases of the real-time meteorological data and the results of analysis while system is collecting the data measured continuously by the meteorological stations. Proposed architecture to capture, preprocess, analyze, publish and represent the real-time meteorological data is shown in Fig.1. Proposed architecture consists of five modules:

- 1) Data Preprocess Module;
- 2) Analysis Module;
- 3) Publishing Module;
- 4) User Interface Module;
- 5) Control Module.

Proposed architecture realizes the procedure which captures the new raw data come from meteorological stations and initiates preprocess, analysis, publish and representation operations. Mentioned procedure consists of four steps:

- 1) Transform, preprocess and store raw data (Data Preprocess Module);
- 2) Analysis routines (Analysis Module);
- 3) Publishing a map document as XML services (Publishing Module);
- 4) Creating the web application to represent a map for end users (User Interface Module).

Control Module consists of only Real-Time Data Controller (Block 3) which organizes above mentioned procedure to work whole system in synchronization and represents the raw data and results of analysis to end users in real-time through internet. Control Module controls the raw data (Block 1) which come from stations. If data are changed or the new meteorological data are come, Block 3 realizes this and initiates the transform, preprocess and store raw data step (Blocks 2 and 4). Simultaneously this module is responsible for analysis routines and initiates analysis step (Blocks 4 and 5). So, the whole system reacts to new meteorological data whenever data are changed with the help of Real-Time Data Controller.

Main architecture is a classic server client. Server includes web services, database and application server. Clients are end users which can access real-time map via their web browsers.

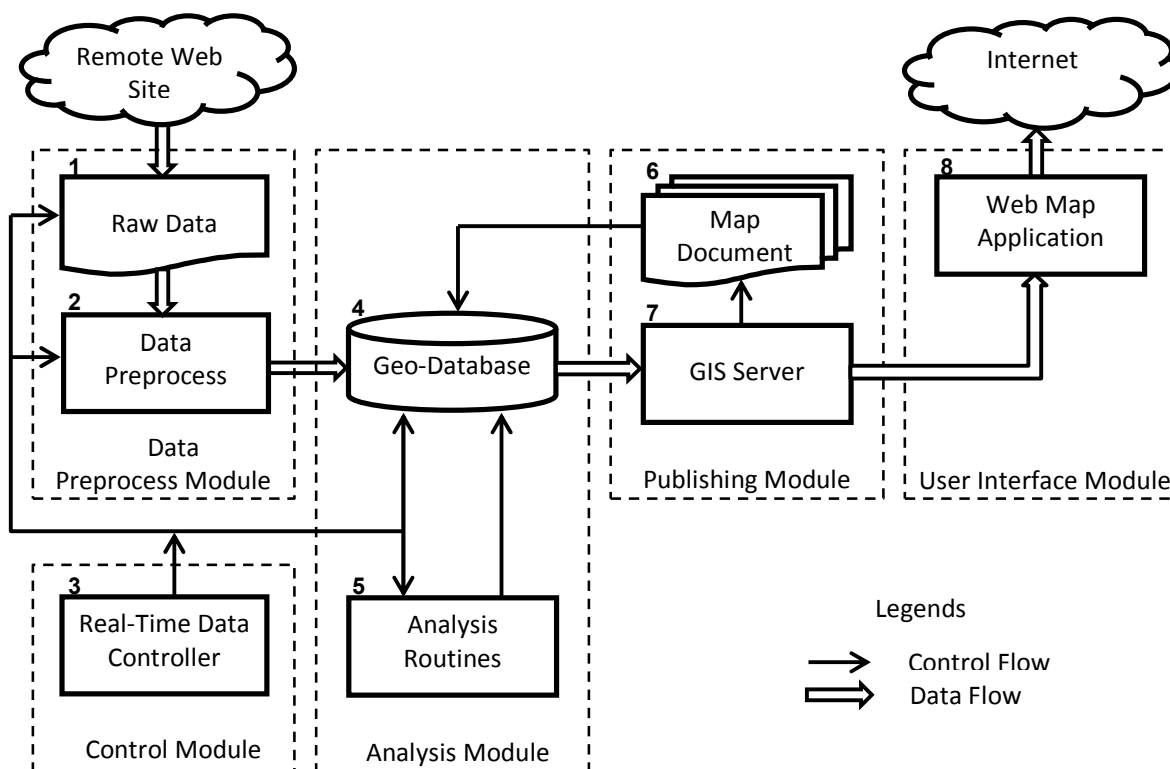


Fig.1. Architecture of real-time meteorological data analysis and mapping information system

A. Transform, preprocess and store raw data (Data Process Module)

Meteorological stations continuously produce meteorological data. These raw data can be transferred from stations to server in several ways. For example, they can be transmitted as file via web service, FTP, socket and transmitted file can be in XML, text, excel, and other formats (Block 1). This file includes latest metrological data which will be analyzed and represented to end users. The fields of the record are separated with a special character.

First, the records of the latest file are transformed to store in spatial database. After reading the raw data from a file, it is need to treat these data as a geographical object. Transform raw data to a geographical feature is need for mapping, analyzing and all other operations in spatial domain (Block 2). All raw data are transformed to the point features (because all stations are as point in spatial domain) and are stored in Geodatabase (Block 4).

B. Analysis routines (Analysis Module)

Geodatabase is a storage mechanism for spatial and attribute data that contains specific storage structures for features, collection of features, attributes, relationships between attributes and relationships between features. Received raw data are stored in a Geodatabase (Block 4) to query, analyze and benefit its advantages [7].

The geodatabase structure includes two tables. One of them is used for historical purpose to store all received data. This

table may also be used for statistical purpose. Second table is used for temporary storing the last arrived data. Two tables are used to increase the performance of the system. Besides, there is also a background layer for the map that will be served to end users in geodatabase. For example, a layer may include a background with country boundaries.

The objectives of data analysis routines are to allow the end users to set queries and to retrieve useful information to satisfy the specific requirements of decision makers, and an important function of the analysis is the ability to predict what will occur at a location, at another point in time and under certain conditions. The most important analytical process of the GIS is the provision of capabilities for spatial analysis functions that are responsible for the manipulation and analysis of the spatial data.

Currently, the analytical capabilities of GIS related to the structure of the database (raster or vector) are used, and the proposed prototype uses the raster GIS structure because that raster family is determined to have greater analytical power. System provides the user with two kinds of analytical capabilities as introduced in the following sections: statistical analysis and geostatistical (spatial) analysis routines [8].

Analysis module is initiated by event of new arrived data. This module analyses the last arrived point features and its value on the geodatabase. Meteorological data needs interpolation for suitable analysis. The input of the analysis module is the point data or layer which is converted to the last read spatial objects on the geodatabase. The output of the analysis module is a raster file. This file will be last layer

which will be added to the map. In order to represent the map in understandable form raster file is colored.

1) Statistical Analysis

Statistical analysis can be useful for end users (Block 5). Daily maximum, minimum, average values are statistical analysis samples. It can easily calculate without need of spatial information of stations. Almost all web sites about weather give information to end users like current temperature, average temperature, minimal and maximal temperature.

2) Geostatistical Analysis

Geostatistical Analysis (Block 5) provides a cost-effective, logical solution for analyzing a variety of data sets that would otherwise cost an enormous amount of time and money to accomplish. Identifying variation in natural phenomena to assessing possible environmental risks is very important for end users.

In natural resources the point field sampling is often used for spatially oriented projects and interpolation methods are implemented to predict the values in an unsampled location and to generate maps. The mapping and spatial analysis often requires converting the field measurements into continuous space. Therefore the point data sets must be converted to a continuous form using an interpolation method [9], [10].

This step is the most time consuming step. The interpolation is needed to calculate the values for all coordinates on the base of the raw data getting from specific coordinates. There are a lot of interpolation methods for geostatistical analysis.

C. Publishing a map document as XML services (Publishing Module)

SOA (Service-Oriented Architecture) based architecture is used to integrate other platforms like mobile, desktop and other web platforms. This map is also serviced for applications corresponding to standards of Open Geospatial Consortium, Inc (OGC).

A map document, which includes a country layer for background, latest received data layer and analysis results layer is created. Map document file (in mxd format) will be served as representation and it will contain the references about what kinds of data will be represented. Three layers will be represented for end users in proposed system. The first of them is a layer pointed to the meteorological stations from where the points and their values were arrived. The second is

the background layer used to allow the end users to see and understand the map in more clear and visible form. This layer contains the information like the countries and their boundaries, cities and their boundaries, etc. And the last layer is a raster data which are created in the result of geostatistical analysis and will be used by end users for decision making. This layer represents the interpolation at the result of geostatistical analysis.

Representation the map as service: In order to be accessible from web and other sources and also from mobile, desktop and other web environments the map document it is necessary to convert it as service form. For this purpose GIS server products are used. As input the map document file (in mxd format) is used. As output the different standard formats like XML, SOAP, REST, etc. are offered.

D. Creating web applications to represent a map for end users (User Interface Module)

As final step it is necessary to serve and represent a map prepared in previous step. To this end, a web application was developed which takes map service and converts it as raster images. Web application represents the maps and layers, handles error management, prints maps and does other functionalities. As a result, the end users (clients) can use real-time map.

IV. SIMULATION RESULTS

Here the simulation steps and results of the proposed architecture are given and analyzed.

A. Simulation platform

For simulation a Virtual Machine with following platform is used:

- Windows Server 2003;
- Microsoft.Net Framework 3.5;
- MS SQL Express 2005;
- ArcGIS Server 9.3;
- ArcSDE;
- Intel Core 2 Duo 2.55 GHz, 1 GB RAM.

B. Simulation data

Proposed architecture was implemented on the base of meteorological data for Ankara city of Turkey. Table 1 gives the main information about meteorological stations of this region.

<u>Station ID</u>	<u>X Coordinate</u>	<u>Y Coordinate</u>	<u>T (°C)</u>	<u>H (%)</u>	<u>W (km/h)</u>	<u>Date and Time</u>
17130	# 39.943	# 32.856	# 16	# 35	# 6	# 14.04.2010 11:00:00
17134	# 39.794	# 32.805	# 14.1	# 43	# 10	# 14.04.2010 11:00:00
17664	# 39.780	# 32.718	# 13.5	# 42	# 17	# 14.04.2010 11:00:00
17679	# 40.188	# 31.350	# 15	# 47	# 8	# 14.04.2010 11:00:00
17680	# 40.164	# 31.921	# 15.3	# 46	# 4	# 14.04.2010 11:00:00
17711	# 39.916	# 33.242	# 16.9	# 70	# 10	# 14.04.2010 11:00:00
17728	# 39.584	# 32.146	# 15.8	# 46	# 6	# 14.04.2010 11:00:00
17144	# 38.938	# 33.538	# 12.7	# 63	# 8	# 14.04.2010 11:00:00

Table 1. Stations information

Station ID	Station Name	X Coordinate	Y Coordinate	Height
17130	Ankara	39.943	32.856	891
17134	Golbasi	39.794	32.805	1115
17664	KizilciHamam	39.780	32.718	1033
17679	Nallihan	40.188	31.350	650
17680	Beypazari	40.164	31.921	682
17711	Elmadag	39.916	33.242	1130
17728	Polatli	39.584	32.146	886
17144	Sereflikochisar	38.938	33.538	921

Table 2. Latest hourly meteorological data

Station ID	Year	Month	Day	Hour	Temperature T (°C)	Humidity H (%)	Wind W (km/h)
17130	2010	4	14	11	16	35	6
17134	2010	4	14	11	14.1	43	10
17664	2010	4	14	11	13.5	42	17
17679	2010	4	14	11	15	47	8
17680	2010	4	14	11	15.3	46	4
17711	2010	4	14	11	16.9	70	10
17728	2010	4	14	11	15.8	46	6
17144	2010	4	14	11	12.7	63	8
...

Simulation data from meteorological stations in Table 1 were obtained from State Meteorological Department of Turkey. Data examples are given in Table 2.

It is assumed that these data are arrived to the system (Block 1, Fig.1) as a text file in CSV (Comma Separated Values) format. Above is an example of a piece of this file:

CSV file includes fields from Table 1 and Table 2. Fields in CSV file are separated by a special character (in this case by #).

C. Geodatabase tables

Before pushing the received data in CSV file to geodatabase, two tables are prepared. The first table is called as Latest

Received Data and stores the latest received data. The second table is called as Historical Data and stores all data including the latest received data. This is done in order to improve the database performance by shortening the query time of the latest received data. For this aim the above described tables with point feature classes are constructed including appropriate fields in ArcCatalog. These tables have the same format. An example geodatabase table is given in Table 3.

Table 3. Geodatabase tables format

Station ID	X Coordinate	Y Coordinate	Date Time	Values of Parameters	Shape
xxx	xxx	xxx	xxx	xxx	xxx

Table 4. Historical Data (or Latest Received Data)

Station ID	X Coordinate	Y Coordinate	Date Time	T (°C)	H (%)	W (km/h)	Shape
17130	39.943	32.856	14.04.2010 11:00:00	16	35	6	Point
17134	39.794	32.805	14.04.2010 11:00:00	14.1	43	10	Point
17664	39.780	32.718	14.04.2010 11:00:00	13.5	42	17	Point
17679	40.188	31.350	14.04.2010 11:00:00	15	47	8	Point
17680	40.164	31.921	14.04.2010 11:00:00	15.3	46	4	Point
17711	39.916	33.242	14.04.2010 11:00:00	16.9	70	10	Point
17728	39.584	32.146	14.04.2010 11:00:00	15.8	46	6	Point
17144	38.938	33.538	14.04.2010 11:00:00	12.7	63	8	Point

Next, the data from CSV file are pushed to the designed tables of geodatabase (Block 4) by Block 2, Fig.1. Block 2 reads a CSV file line by line, converts them to the point features by ArcObjects API and pushes to geodatabase by using developed code. An example for Historical Data (or Latest Received Data) table is given in Table 4.

D. Statistical analysis

A statistical analysis is executed on the base of Table 4 (Block 5, Fig.1). The results of this analysis such as daily maximum, minimum and average values related with each of parameters such as temperature, humidity, etc. will be stored in Table 5 of geodatabase. Example Table 5 for temperature statistical analysis results is given below.

Table 5. Statistical analysis results of daily temperature

Station ID	X Coordinate	Y Coordinate	Daily maximum T (°C)	Daily minimum T (°C)	Daily average T (°C)
17130	39.943	32.856	21	10	16
17134	39.794	32.805	19	11	14
17664	39.780	32.718	23	13	15
17679	40.188	31.350	22	15	18
17680	40.164	31.921	21	13	16
17711	39.916	33.242	19	10	16
17728	39.584	32.146	21	11	15
17144	38.938	33.538	18	12	15

E. Map document

A map document (Block 6, Fig.1) should be prepared manually once. Map document is prepared using ArcMap and includes three layers. An example of map document is given in Fig.2. It contains three layers:

1) Latest received data layer;

2) Geostatistical analysis results layer;

3) Country background layer.

The same map documents are prepared for daily maximum, minimum and average values related with each of parameters such as temperature, humidity, etc.

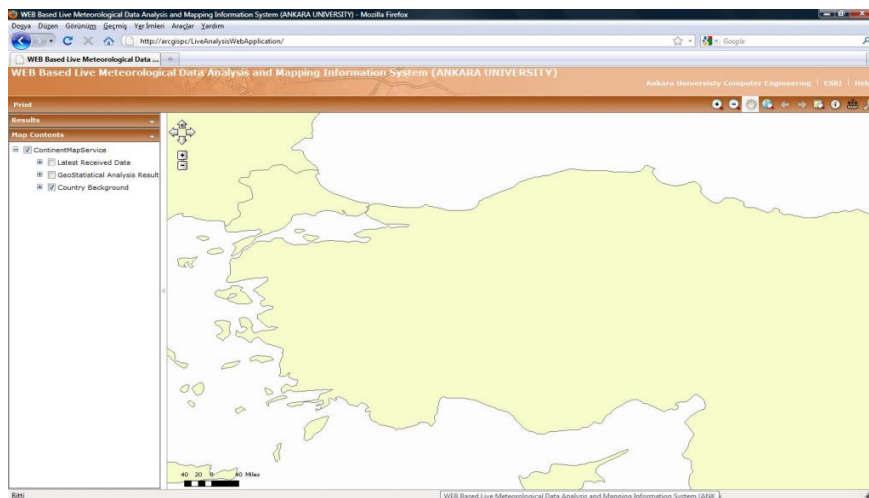


Fig.2. Map document

F. Geostatistical analysis

Next, the geostatistical analysis is executed (Block 5, Fig.1). In order to obtain the desired output, an interpolation technique should be used. Many interpolation techniques were implemented, however, the best results were obtained by using Kriging method [11], [12], [13]. Geostatistical analysis is done by ArcGIS Geostatistical Kriging function which is called by developed code with following input parameters: 1) input point features (for example, the latest received data); 2) Z value field (for example, temperature value field); 3) output surface raster (for example, any raster file); 4) Kriging

method (for example, ordinary or universal); 5) Semivariogram model (for example, circular, etc.). There are other input parameters which are defined by default. Circular semivariogram gives the best results for representation. The output created by the interpolation techniques is a raster data. Raster data are colored by selecting appropriate color ramp, for example, yellow-red ramp for temperature. An example of output raster data is given in Fig.3.

New raw data or new results of analysis force the output raster data to be changed, consequently, the map document, which contains geostatistical analysis result defined by output raster data, is also changed. Proposed system is fed with

meteorological real-time data and it processes, analyzes and maps on the server side.

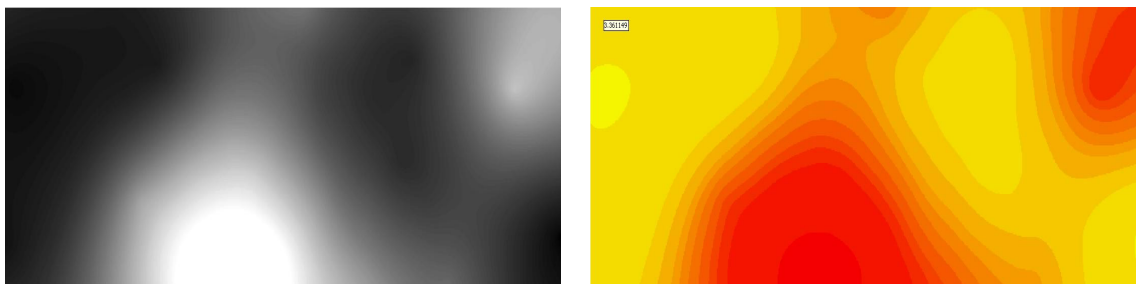


Fig.3. Gray scale and colored raster data

G. Map service

A new map service is created on ArcGIS Server (Block 7). This is realized once. Later the system will automatically repeat these operations depending on new arrived data and provide publishing the latest data. So, the previously prepared map document is published by the map service prepared by Block 7. ArcGIS Server publishes the map document in suitable international standards. Finally, the map document is converted to XML service.

H. Web map application

To visualize the XML service, an ASP.NET web site is prepared with C# that receives map service and represents it as appropriate format for end users. End users can manipulate published map by using layers at left side of screen. Upper tools bar provides standard map functions like zoom in, zoom out, information, etc. The main displayed map on the center of screen reacts to the new received and analyzed map. An example of web map application is shown in Fig.4.

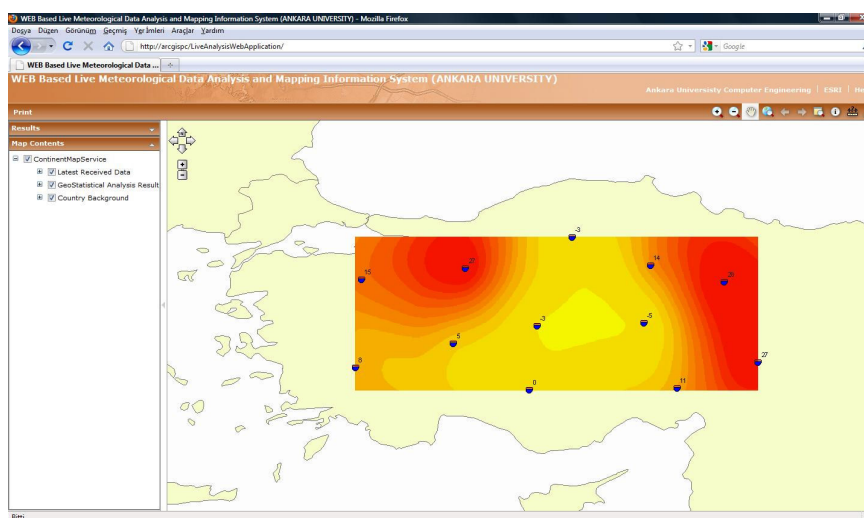


Fig.4. Web map application

I. Real-time data control

In Sections 4.1-4.8 a working principle of proposed system was given in detail, module by module. In this section the Real-Time Data Controller (Block 3, Fig.1) is explained. It is central module in proposed architecture. It controls all modules to work synchronously and represents the meteorological data to end users in real-time. First, it controls raw data which come from stations. If data are changed or new meteorological data are come Real-Time Data Controller realizes this and initializes the transform and store raw data step (Block 3). Simultaneously it is responsible for analysis routines and initialize analysis step. So all system reacts to the new data whenever data are changed with the help of real-time

data controller and end users can see latest map. C# and ArcObjects are used to implement control module.

J. Simulation results

The simulation results are given in Table 8. Proposed architecture was implemented for various numbers of stations using different interpolation techniques. Obtained results were evaluated on the base of processing time and the suitability of raster data.

Processing time is a period between the new data arrival and map publishing moments. This time period is increased by increasing the station numbers. Besides, for the same number of stations this time is changed depending on the interpolation techniques.

The suitability of raster data is defined by degree of appropriateness of the obtained map to the real situation. This was checked by comparing with maps obtained using other methods.

So, the best results of processing time and the suitability of raster data were getting using the spherical and circular Krigging interpolation techniques for any number of stations.

V. CONCLUSION

In this study, we have realized a dynamic architecture that executes the full procedure to get raw data, to analyze these data statistically, to analyze the raw data and results of statistical analysis geostatistically and publish the results as map in real-time.

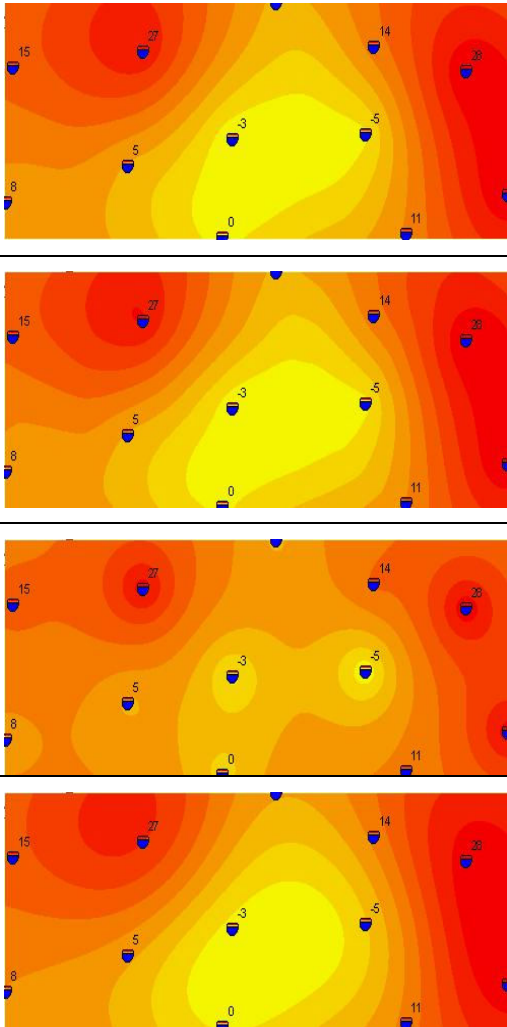
Ease of use and efficiency were achieved using ArcGIS products. Although a virtual machine is used for development

and testing, its performance acceptable for a real-time map system. Whole system can react to the new data during 10 seconds. The geostatistical analysis routines cover a large portion of this time. Krigging interpolation method gives the best result. The speed of proposed real-time analysis automation system is acceptable according to real-time data analysis applications.

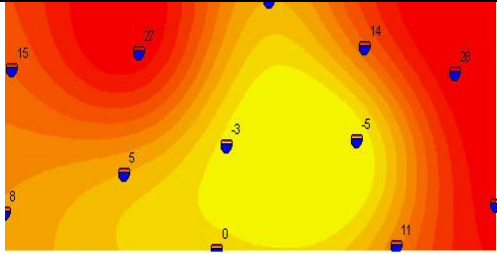
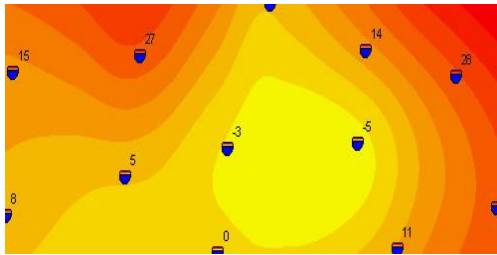
During each analysis period, ArcGIS Server needs to be stopped for a short time and started again for writing the analysis results. Although a user do not aware of this situation, it can be thought as a disadvantage of this system. Solving this situation is the subject of future works.

Creating the user interactive version of proposed system, where the analysis and mapping operations will be done according to the user's requests, is the subject of another future work.

Table 8. Simulation results

Interpolation Methods		Station Number	Time, s	Raster Data
Krigging	Spherical (Ordinary)	12	5.15	
		50	5.78	
		100	6.13	
		200	7.50	
	Circular (Ordinary)	12	5.29	
		50	6.20	
		100	7.18	
		200	8.00	
	Exponential (Ordinary)	12	5.85	
		50	6.01	
		100	6.38	
		200	7.63	
	Gaussian (Ordinary)	12	5.50	
		50	5.94	
		100	6.24	
		200	7.86	
Linear (Ordinary)	12	5.67		

		50	5.99	
		100	6.29	
		200	6.90	
	Linear Drift (Universal)	12	$\cong 10$	
	Quadratic Drift (Universal)	12	$\cong 11$	
IDW		12	$\cong 5$	
Global Polynomial		12	$\cong 5$	
Local Polynomial		12	$\cong 5$	
Radial Basis Functions		12	$\cong 5$	

				
Spline		12	$\cong 6$	

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