An Approach for Producing Long Term Statistics Based on Weather Radar Data

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Abstract – **Weather radar data are valuable because of small spatial and temporal resolution and strong correlation with precipitation. The aim of this research is to analyse occurrence frequency of reflectivity higher than certain threshold over particular territory. The frequency is measured inside a raster generated for horizontal cross section at particular altitude. Several parameters are found to be changeable: spatial resolution, time period, attitude, reflectivity threshold and minimal cloud size. The developed method for statistics generation is accurate and efficient in order to provide rapid analysis of large amount of radar data. The method can identify single clouds and remove clouds that are irrelevant for the analysis due to their small size. The statistic obtained by the developed method could be used as a foundation for further analysis of precipitation frequency or storm occurrence in different areas.**

Keywords – **Metrological data, Weather radar reflectivity, Geospatial statistics, Spatial data conversion, Flood fill.**

I. INTRODUCTION

Nowadays, climate changes gain focus and incorporate large number of researchers in science and technology. The researches analyze meteorological data in order to create fundament for further analysis, decision making, improving quality of human life, etc. Beside qualified meteorologist, these studies demands multidisciplinary approach which shall include scientist form computer science domain and use information system to generate, store, manipulate and analyze data required for research. Generating statistics based on meteorological data collected during certain period of time is very important source of information for climate changes. Data used in the most of the meteorological data statistics deal with certain piece of the Earth. This requires using some more or less complex geographical information system (GIS). Furthermore, analysis of this type of data can be time consuming due to large amount of data collected during a relatively long period of time.

There are a large number of software tools that provide support for data analysis. They usually implement different kind of statistical analysis: mathematic, scientific, economic etc. But, small number of software tool are dedicated to spatial analytics, and even a smaller number of them support georeferenced data. Most of these analytic tools are incorporated as component in larger software systems like ArcGIS [1], Quantum GIS [2] and SAGA GIS [3]. All these systems provide different type of analysis suited for raster and vector data.

Meteorological data statistics require analysis of large amount of data. Data can have various types of sources, like portable devices, meteorological stations, weather radar and satellites. Frequently data from various sources are integrated to provide better insight for climate changes research. In this paper we will focus on meteorological data collected by weather radar. In particular we will address reflectivity as the most common weather radar data type. It can be used for different type of weather analysis, like estimation of precipitation and severe storms.

The goal of the paper is to create statistics for a certain geographical space based on weather radar data. The statistics is represented as a raster grid that can be displayed over the terrain. This grid is regular in particular spatial reference system in Cartesian coordinates. In contrast, radar scan create 3D regular grid of points in spherical coordinate system with center at radar location. Thus, data transformation form spherical to Cartesian grid must be performed before a statistical analysis take place. This fact makes standard geospatial statistic tools inapplicable for weather radar data processing. The basic data type that weather radar produces is reflectivity of water content in atmosphere.

Radar reflectivity can be used for creating the cloud model in geographical space. It is commonly used to detect prediction of storms and analysis of precipitation that cloud can produce. In temperate continental climate reflectivity is used to predict and analyze hazardous events like hailstorms and heavy rain storms, which can help in preventing floods. Beside, the statistical data generated from reflectivity can offer additional information for analysis of precipitation amount in certain areas, which is important for different domains, but primarily agriculture and forestry. The correlation between reflectivity and precipitation is high in meteorology. In this article we address the problem of crating the long term statistics over the particular area. The statistics is created based on reflectivity at certain altitude, which is useful for mentioned domain analysis. The result of this research is a GIS tool. The tool is made flexible to generate statistics tailored for different application. This is achieved by

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selection of several parameters such as altitude, area of interest, raster resolution, time period and temporal resolution.

This research is involved creating statistics about of occurrence frequency of reflectivity greater than certain threshold. In simple terms, higher values of reflectivity indicated greater precipitation. According to that generating the map of occurrence frequency for these values will result in raster map which correlate with precipitation inside the particular region during certain period of time. Statistic is created based on reflectivity raster at selected altitude. We designed accurate and efficient algorithm that create this raster using bilinear interpolation first in vertical and than in horizontal plane. Reflectivity raster at particular altitude cannot be considered as set of independent cells. Single cells or several of them cannot be considered as a cloud that can affect precipitation event. It can be the reflection of airplane, flock of birds or some errors. Beside, some analysis requires clouds which area of a cross section is greater that certain threshold.

Frequency raster generation process is time consuming knowing that that radar generates one dataset at least every 10 minutes. Thus our solution is designed to be efficient and shorten the processing time. To achieve this we design processing method with high performance. It is based on efficient flood fill algorithm in order to separate the area of cloud with reflectivity above the threshold. However, processing time depend on several factors: area and time interval of interest and spatial resolution.

The result of research is presented in following sections. Next section addresses related tools and system that provide geospatial raster data analysis. Third section explains the research problem and software tool as a result of the study. The last section presents main conclusion about the results and possibilities for a future work.

II. Related Work

Creating statistics from data collected by measurement of natural phenomena can offer new perspective to scientist. Therefore, software tools that support data statistics are common and heterogeneous. This paper addresses problem of geospatial statistics based on weather radar data. General purpose GIS frequently implement component that can perform different type of geospatial analysis. ArcGIS [1], Quantum GIS [2] and SAGA GIS [3] are widespread system used for manipulating with spatial data. All of them can perform some kind of geospatial analysis and support visualization of radar data. But, except ArcGIS other two do not perform analysis based on weather radar data. The one component of ArcGIS can perform short time analysis of precipitation from radar data [4].

Except GIS, radar management systems usually have a lot of tools for processing radar data. All these systems crate 2D products based on radar data. The processing is done for each cell of the raster grid, and creates a result that can be used for estimating some weather conditions. These systems are not designed to perform long term analysis, but primarily for nowcasting. But, they implement necessary conversion from original spherical data grid to regular Cartesian data grid. Such systems are Rainbow 5 [5] and IRIS software [6]. The complex system used in USA for tracking weather and nowcasting implements some complex techniques for radar data processing and generating useful products as result of some kind of short term analysis. Some of them, like TITAN [7], include algorithms for identification of a cloud in order to analyze their motion and changes over time. Identification of the cloud is necessary for our research to single out errors and clouds irrelevant according to the purpose of analysis. All this facts indicate that custom tool should be designed to fulfill requirements for a long term geospatial analysis address in previous section of this paper.

III. Long Term Statistics based on Weather Radar Data

Meteorological data are important for various domains of life, like climate changes, agriculture, forestry, urban planning and medicine. There are numerous different sources of meteorological data, such as sensors on the ground, weather radars and satellites. This research addresses statistics based on precipitation data. All three type of sources mentioned before can be used for precipitation analysis. But each of them has different constraints. Network of precipitation sensors is installed in larger cities and it is not dense enough to generate coverage over the whole area of interest. The weather radar measures reflectivity of the clouds, over the large area. Precipitation can be calculated form reflectivity based on well known Z-R relation. But, this is can be used only for clouds that produce rain, which requires other sources to confirm that. However, considering long term statistics it can show trends about precipitation. The main advantage of radars is relatively small spatial resolution, below 1km. The drawbacks of the last type of sources, satellites, are expenses for data generation and large spatial resolution of the grid.

The goal of this research is to generate map of precipitation trends during a certain longer period of time. The result should be relatively precise raster map with resolution near 1km. Besides, map should be generated for a larger area inside the territory of Republic of Serbia. This was main reasons to use radar as data sources. The radars, also, have good temporal resolution inside the area of interest, which is less than 10 minutes. Knowing that, the trends of precipitation for each cell in raster map should be defined. Single value of reflectivity at particular altitude from each radar measurement is used to analyze trends. If this value is upper than certain threshold, the output raster cell is incremented. Therefore, this simple measure of trends does not use Z-R relation and avoid assumption that higher reflectivity produce heavier precipitation, even where the cloud does not produce any. The final result is raster map that contain occurrence frequency of reflectivity higher than particular threshold in certain period of time. This value can be considered as the frequency of precipitation events at particular square area on the ground.

This frequency of precipitation should be good foundation for further analysis of the scientist from other domains. Several parameters are observed to be important according to their needs: time interval, spatial resolution, altitude, reflectivity threshold, and minimal size of cloud. All parameters can be adjusted in tool we developed. The purpose of analysis (amount of precipitation, storm risk etc.) affects the altitude at which reflectivity data should be analyzed. It defines altitude of CAPPI (Constant Altitude Plan Parallel Indicator) radar product that must be generated for precipitation analysis, which is addressed in the next subsection. CAPPI product is raster map of reflectivity at certain altitude. Minimal size of cloud is defined as important criteria, because it can avoid problem that are consequence of reflection from airplane, flock of birds or some radar errors. Besides, for some domain only the larger clouds should be included in creating statistics. Minimal cloud size is represented as minimal area of the cloud cross section on certain altitude. Inspection of this parameter requires identification of the cloud at the cross section, which is complex problem that will be address later in the paper.

A. Generating Reflectivity Raster for Further Analysis

Precipitation is strongly correlated with reflectivity measured by weather radar. Frequency of precipitation is estimated based on CAPPI at particular height. CAPPI should be created efficiently because generating statistics for certain period of time may demand processing hundred or thousand of radar scans. Weather radar used for creating statistics perform 3D scan, which creates regular 3D grid in spherical coordinate system whose center is radar location. CAPPI is regular 2D grid on plane in Cartesian system which coincides with Earth surface. It can be, also, considered as a raster map.

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Input:
A: input matrix of reflectivity values (size cx x cy)
minRefl: minimal value of reflectivity inside one cloud
minPix: minimal pixel count of one cloud

Input-output:
B: input-output matrix (size cx x cy)

Declare:
TEMP: Intermediate matrix with cloud positions (size cx x cy)
index: index used to mark the current cloud in intermediate matrix TEMP
countPix: count of pixels inside a cloud, returned by the flood fill algorithm

InitializeMatrix(TEMP, 0)

index = 0
for i = 1 to cx do
   for j = 1 to cy do
      if A[i,j] >= minRefl and TEMP[i,j] = 0 then
         index = index + 1
         countPix = FloodFill(A, TEMP, cx, cy, index)
         if countPix < minPix then
            countPix = FloodFill(A, TEMP, cx, cy, -index)
         end if
      end if
   end for
end for

UpdateMatrix(B, TEMP)
```

Fig. 1. Algorithm for identification of cloud areas (based on reflectivity raster) which reflectivity is higher than particular threshold and size larger than particular minimal area

Process of creating CAPPI raster must incorporate Earth curvature, because radar range is 250km. It must, also, include curvature of radar ray due to refraction of the atmosphere.

We design method that creates CAPPI raster in two steps. The first step is creating 2D regular grid in polar coordinates at particular altitude. Points in polar grid are at same azimuth as the point on spherical grid. Value of each point in the polar grid is calculated using bilinear interpolation on four nearest points in vertical plane at particular azimuth. Earth curvature and ray refraction are incorporated in this step.

Second step is conversion from polar grid to Cartesian grid. Conversion is performed for each point in destination grid separately. Method calculates azimuth and distance of particular point in resulting grid. Based on this information four nearest points in polar grid are computed. These points are used in computation of the resulting value based on bilinear interpolation.

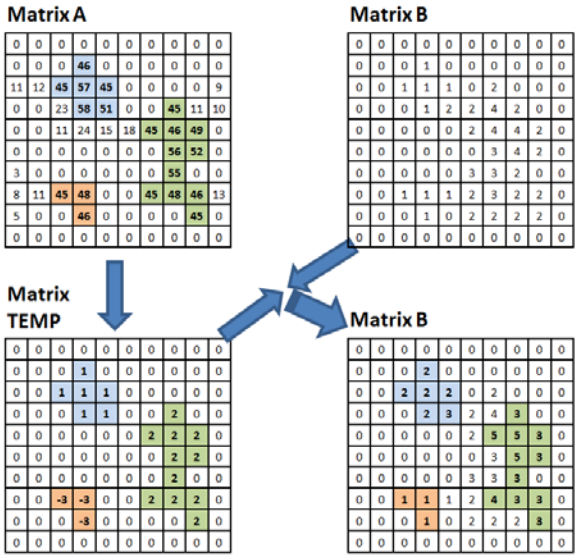

Fig. 2. Illustration of extraction of areas of interest inside cloud and creation of output statistic matrix

Described method generates highly accurate result which is achieved using nearest neighbor interpolation in both steps of processing. Besides, method is efficient thanks to two step calculation.

B. Generating Statistics from Reflectivity Raster

Based on two-dimensional reflectivity matrices (rasters) for specified altitude, obtained from weather radar in regular points in time, the developed procedure determines an output matrix (raster) of the same size as input matrices. Each element of the output matrix represents an occurrence frequency of reflectivity higher than particular threshold that is located inside the clouds of area size greater than particular minimal area size.

The foundation of the developed procedure is an algorithm for processing one two-dimensional matrix of reflectivity. The pseudo-code of the developed algorithm is given in Fig. 1. Based on the input matrix of reflectivity A, an algorithm fills an intermediate matrix TEMP of the same dimensions. Matrix TEMP elements represent position of clouds in matrix A that satisfy specified constraints: reflectivity inside the cloud must be greater than specified minimal value and cloud area size must be greater than specified minimal area. The second constraint translates into the following simple condition: number of matrix A elements (pixels) included by the cloud must be greater than specified minimal pixel count. In order to mark cloud positions in matrix TEMP, efficient flood fill algorithm [8] is implemented. The cloud elements with reflectivity greater that defined threshold are labeled by the positive integer value. If the resulting cloud area size (after applying flood fill algorithm) is not greater than specified minimal area, flood fill algorithm is reapplied to mark the cloud position as invalid. Labeling invalid positions by the negative integer value (instead by zero) enables the algorithm to skip these elements onwards thus significantly reducing calculation time. After determination of the intermediate matrix TEMP, elements of the output matrix B that correspond to valid cloud elements in matrix TEMP are incremented. To illustrate how the developed algorithm works, the simplified example is shown in Fig. 2.

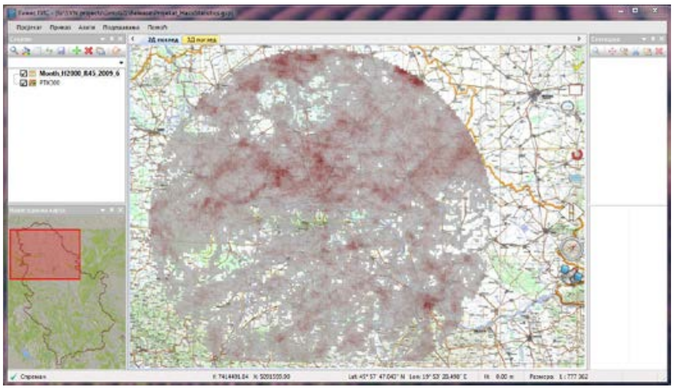

Fig. 3. Visualization of occurrence frequency of larger reflectivity values created by developed geospatial statistics tool

The developed algorithm for processing one matrix of reflectivity is iteratively applied for every two-dimensional matrix of reflectivity in the specified time period. Each iteration updates values in the output matrix B. The final version matrix B as a result of the whole processing is saved u standard ASC raster format. An example of raster generated by described software tool visualized with KP GIS [9], general purpose GIS developed to support climate changes researches, is shown in Fig 3.

IV. Conclusion

Meteorological data analysis is in focus of current researches and will be important in future researches. Analysis techniques are various and depend on data sources. Most of techniques have spatial and temporal component. This research is devoted to creating long term statistics based on weather radar data. Radar data are useful for generating statistics because of good spatial resolution (in order of 1km) and temporal resolution (less than 10min.). There is lot of tool specialized to create statistics, but they are not designed to generate statistics based on radar data. The main reason is data grid formed during radar 3D scan. Resulting grid is regular in spherical coordinate system centered at radar location. Therefore crating raster as a result of geospatial statistics based on such data requires custom processing methods.

The goal of the research is creating a geospatial statistic of occurrence frequency of higher degree of reflectivity inside clouds during longer time period. The result is raster layer in form of frequency map for certain region and selected period of time. Reflectivity is measured on horizontal cross section at certain altitude. The analysis of scientists needs reveled which parameters should be adjustable. These are: spatial resolution, time period, attitude, reflectivity threshold and minimal cloud size. Last parameter is defined as minimal area that cloud occupy on the cross section at certain altitude to be included in analysis. This way small clouds or effects of some natural phenomena inside radar scan should be discarded as irrelevant for analysis. All this parameter are included in the software tools developed as a result of this research, and all can be selected by the weather analyst.

The tool implements a method which extracts data relevant for statistic generation. Method accurately and efficiently creates raster of reflectivity at a particular altitude. It use two steps, first result in a regular grid in polar coordinate and second result in rasterize this polar grid. Both steps use bilinear interpolation. Reflectivity raster is further processed to identify clouds inside raster and discard smaller ones. High performance of processing is achieved by efficient implementation of the flood fill algorithm. Efficiency of the method is very important because generating statistic demands analysis of several thousands of radar scans.

The fact that reflectivity is strongly correlated with precipitation induce that created raster map could be considered as occurrence frequency of some precipitation level. It can be used for analysis of the precipitation in some area during certain periods of time. This can be useful in agriculture, forestry, flood and storm analysis. Requirements form specialist in domain interested for this kind of analysis will probably define further research topic.

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