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GPH 473 Project Report

Introduction

This project looks at the applications of Geographic Information Systems in atmospheric science, specifically in meteorology. Developments in this area were researched and discussed. Using archived data, we produced synoptic meteorology maps for four unique times to demonstrate some of the current capabilities and limitations of using a GIS to analyze surface weather data. Additionally, we propose possible uses of such operations and other questions which may be addressed with a GIS.

Background

Synoptic meteorology looks at atmospheric conditions across a space at a single point in time, usually on a spatial scale of 1,000 - 2,500 km (about 620 - 1,500 miles) at which larger weather features such as fronts are easily visible (NWS). Data at this scale is an important component of weather forecasting, especially in the form of surface analysis charts. These maps contain plotted surface weather data, from which isobars and fronts are interpolated and drawn. These charts can be compared with charts from past hours and with information from other sources, such as Doppler radar, to get an idea of how the atmosphere is behaving (Hopkins).

While there is specialized meteorology software available for such tasks, it is also possible to employ a GIS. Its use does not require as advanced a background in meteorology and it allows for the easy combination of weather, forecast, and climate information with other geographic knowledge. For example, the National Weather Service Storm Prediction Center makes available quality-controlled severe weather report data and offers instructions on importing it into ArcMap for users “with little or no experience with ArcGIS” (Smith “Instructions”, 2). In ArcMap, the reports could be easily queried for specific events and combined with information such as nearby populations or dollar amounts of damage (Smith “GIS”, 2). A GIS can be useful even for professional meteorologists. Papers presented at the 87th annual meeting of the American Meteorological Society proposed GIS applications ranging from verification of NWS Storm Warnings to combining datasets for a more holistic view of a developing hurricane (AMS). Geographic visualization tools, such as Google Earth, are also becoming more recognized for the greater geographic awareness they offer forecasters. As shown below, the National Weather surface offers KML/KMZ formatted weather data which can be easily viewed in Google Earth (see Figure 1), though such visualization tools do not offer the depth of analysis possible in a GIS.

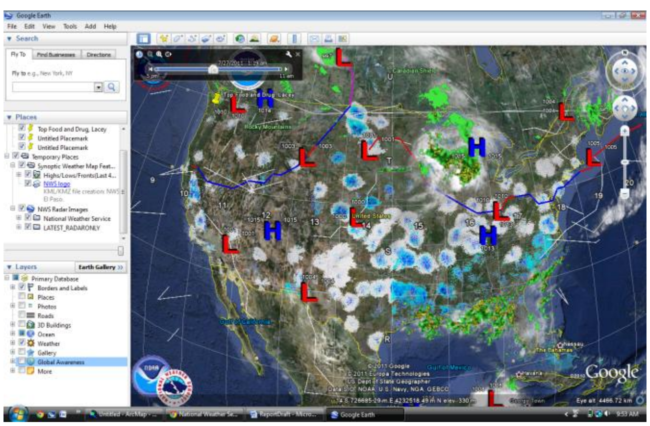


Figure 1: Synoptic features and a base reflectivity radar composite for July 27, 2011 from NWS shown in Google Earth.

There are still many complications with using GIS in atmospheric science. While atmospheric data comes from point locations, it is assumed that features such as temperature and air pressure are continuous across space, and not just in two dimensions. Atmospheric scientists generally treat their data four-dimensionally, employing three spatial dimensions plus time (Nativi et al., 13). According to a report by COST 719, a research group within the European Science Foundation which is dedicated to GIS in meteorology and climatology, one of the biggest issues preventing wider use of GIS in meteorology is the significant time component of weather, though other issues also discourage the wider use of GIS for processing weather data (Tveito et al., 12). Not only is the data modeled differently than in a GIS, but it is also stored differently, not in Database Management Systems but in Data Interchange Formats. As this traditional way of managing atmospheric data seems to be very effective, the main focus of developing GIS with regard to atmospheric data concerns interoperability with these established structures and data types (Nativi, 15).

In 2003 a collaborative effort between ESRI and scientific groups to develop an Atmospheric Data Model for GIS began (Wilhelmi et al., 4), but it may be many years before any major developments are seen. Because the physical environment, such as water bodies and mountains, has a well documented effect on weather, and weather affects many human features such as energy, agriculture, and recreation, there are potentially great benefits to successfully incorporating the results of atmospheric analysis in a GIS. The model suggested by the above collaborative effort would contain many thematic layers with unique data types, accuracies, and symbolizations, such as a layer stack for radar raster series, another for polygon shaped weather events, and another for multipoint climate data (14). Few advances seem to be made on some of the troublesome temporal issues, though (30).

Analyzing climate or weather conditions in one point in time is a much more realistic application of GIS currently. When initially researching possible projects, one of our original group members came across an article on the internet that showed meteorology students producing weather maps with a GIS (Shipley, 3) . This seems to be a common exercise in the few GIS classes that have a meteorology focus. Since our group did not originally want to do a climate project but still desired to work with atmospheric phenomenon, producing synoptic meteorology maps appeared to be a good fit. By definition they are spatial in nature and analyze the weather at a single moment in time. While these maps are not conventionally produced this way, we wanted to explore how a GIS could be put to the task as part of an investigation into the applications of GIS in atmospheric science.

Methodology

We obtained our station point data from the National Climatic Data Center, which describes itself as the "world's largest active archive of weather data." It is part of the U.S. Department of Commerce, the National Oceanic and Atmospheric Administration (NOAA), and the National Environmental Satellite, Data and Information Service (NESDIS). While there are many sources, public and private, of different types of weather data, NCDC was the only provider of hourly station data for the U.S, which is necessary for making a synoptic weather map. The hourly data, which we accessed at http://www.ncdc.noaa.gov/oa/climate/climatedata.html#hourly, is available through a GIS map interface and a web order form.

We decided to make one map for each season, which should give a variety of weather patterns in the data. We chose a day roughly in the middle of each meteorological season (defined in terms of weather rather than astronomy): January 15, April 15, July 15, and October 15. We selected 2010 for the year assuming that the class may be more interested in seeing an analysis of weather events they can recall. We originally chose 6 am as a time, the flaws in which became quickly apparent, as 6am occurs at different moments across the US. Since NCDC provides time information in UTM, simplifying the selection of simultaneous data, we changed our choice to 6 UTC.

Collecting and uploading the data to a database was the most laborious part of the project. Data had to be requested individually for each day for each state, requiring a minimum of 192 separate orders. Once ordered, it took anywhere from a few hours to almost a week for the data to appear online if it did at all. Sometimes the website would not recognize that the user was from a ".edu" domain. Each text file had to be individually saved, and then the headers had to be removed for processing.

Once we were able to get Access to import one flatfile correctly, we wondered if there was an easier way to import all the files. Some old Access VBA code was modified for Access 2007 on the web, the version being used, and tested. When it seemed to work, it was modified to look through the whole folder of files and import each one. Because the data and the related station information were in two different files, different macros were designed for observation data and station data. Once the data was in Access, some queries were written to clean up the data and make it easier to use. The tables were then exported to an excel sheet because Access did not run on all the machines being used.

There are private companies who collect and distribute weather station information for a fee; as we do not have access to these resources, we compiled the data on our own. However, professional forecasters or atmospheric scientists would likely have better access to pre-compiled station data, especially for current information. In general, it is easier to obtain current weather information than archived information, which is mainly handled by NCDC; as we learned, pulling archived readings from NCDC can be inefficient and time-consuming without ordering an entire dataset on CD

Discussion

Using ArcCatalog, we then imported the data tables and created a shapefile of observation points, using GCS NAD 1983 as the spatial reference based on information from NCDC's station metadata. A coordinate system was created to match a polar stereographic system often used in weather mapping and composite satellite images (NOAAPORT). The default standard parallel was maintained, but the central meridian was shifted from -105 degrees to -100, as this gave a better presentation of the coterminous United States.

There is an internationally agreed-upon model used for plotting station information on synoptic maps. First, the barometric pressure needed to be converted into a shorthand form, which was done with a calculation in a new field in the attribute table. Then formatting tags were used to arrange the field values around each point. The wind direction was symbolized by converting the wind speed, originally in miles/hour, into knots and grouping the speeds by rounding to the nearest five knots. The wind barbs were already provided in ESRI's Weather style, and they were rotated according to the value in the wind direction field. However, we were not able to include cloud cover information in the symbolization or add symbols for current weather in the labels, and little advice on how to do so could be found online. A station model template would be a useful inclusion in future atmospheric GIS models.

Because the reported air pressures are adjusted to sea level, we did not need to correct for the effects of elevation on the surface pressures and could proceed to place isobars on the maps. Isobars are lines of equal pressure drawn across weather maps. We used a Kriging interpolation to show how these contours could be created in a GIS. Once the interpolation was performed using Spatial Analyst, the same tool was used to draw contours of the interpolated pressure surface in 4 millibar increments with a base contour of 1000 mb. The lines were then smoothed with the line smoothing tool and a tolerance of 200 miles, which was found through trial and error to give nicely shaped approximations. These isobars generally showed the same pressure trends as the NWS surface analysis charts though the contours were obviously differently shaped. An initial statistical analysis of the data would be useful if the interpolated surface or isobars were to be used in a more quantitative manner. We were able to do a similar analysis on our temperature data to create isotherms; unlike our air pressure data, though, the temperatures are not corrected for elevation and will show some influence from the geography. The isotherms were measured in units of five degrees with a base contour of 32 degrees Fahrenheit to show the freezing line, if present.

Many analysis charts were available through NCDC, so the 500 mb height analysis at 6 UTM were selected to help with the analysis. The charts were georeferenced against a shapefile of the United States obtained from the US Cenus. Because the images were formatted similarly, a saved set of control points was used to georeference all four charts. A similar process was performed on Nexrad Base Reflectivity composite images, which show areas of precipitation.

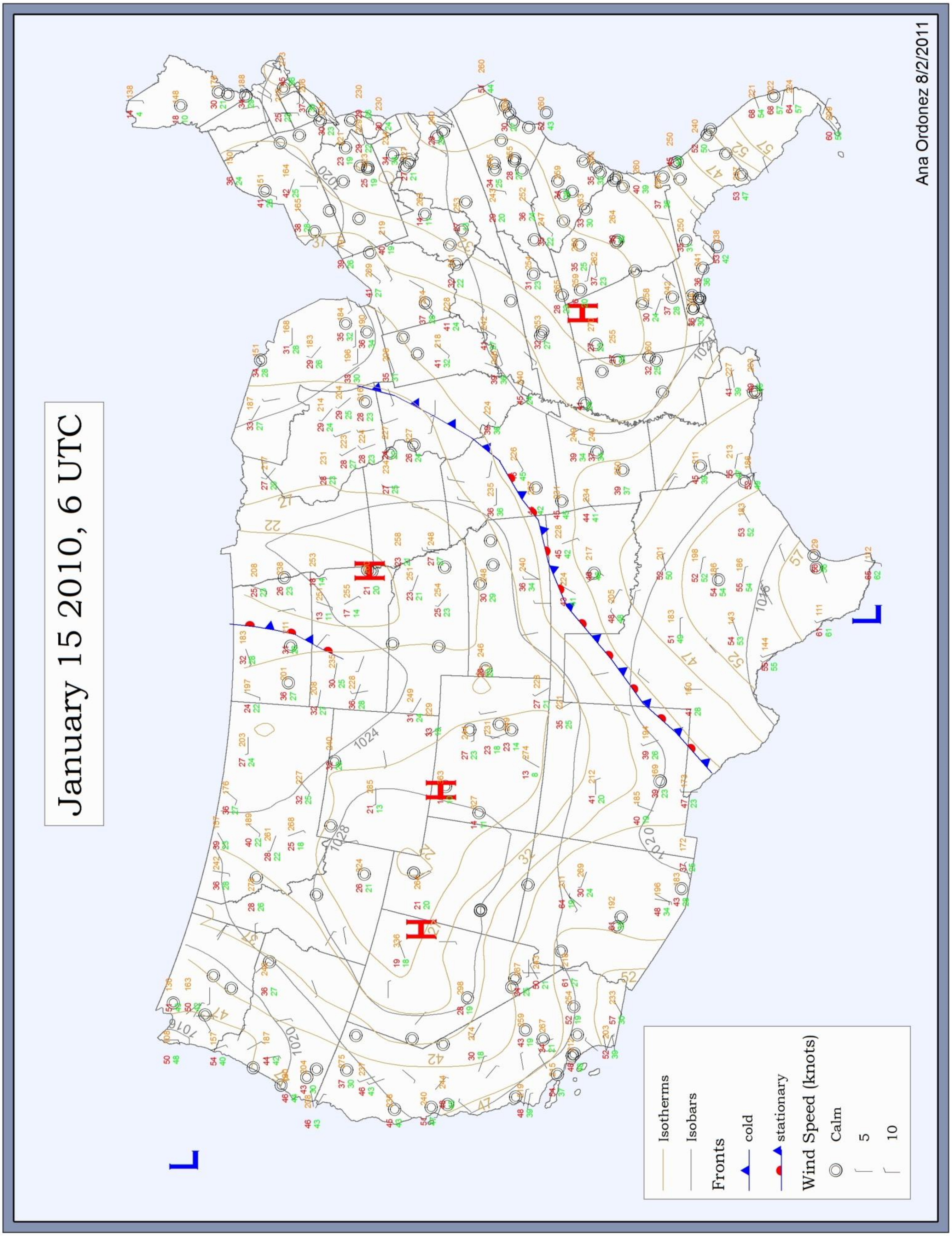
Layering the 500 mb isohypse line charts and Nexrad images over the station data enhanced the determination of pressure centers and fronts when considered with isobars and wind direction. The fronts were drawn as polylines and given the appropriate symbolization (cold, warm, occluded, etc.). Pressure centers were approximated as points for ease of visualization. All the features were drawn in feature classes stored in a personal geodatabase.

After being drawn, the maps did show some seasonal variations that would be interesting to compare to the statistically “normal” weather for the days. Unfortunately, once this became apparent, we were unable to pull the normals in time (as these were also available by state from NCDC). With such data, it could be shown if any regions of the country were experiencing unusually warm or cold weather and why that might be.

However, these maps suggest that a GIS does have potential in assisting with forecasts. In terms of the proposed atmospheric data model layers, they already incorporate three successfully: a base layer of human elements (state outlines), atmospheric boundaries (the drawn fronts and interpolated contours), and weather point measurements. Importantly, the maps compare favorably with NWS surface analysis charts from the same hours.

The maps are printed on the following pages, each with a legend to clarify the symbolization. To quickly explain the station models: the red in the upper left denotes the current air temperature, the green number below it notes the current dew point temperature, and the orange number in the upper left shows the last three digits of the air pressure, in millibars, adjusted to sea level and without the decimal separating the ones and tenths digits.

Few major weather events took place on these days. On January 15 the country appears to be dominated by high pressure, although there is a storm in southern Texas. In April one can see a cold air mass (behind the cold front) moving down across the plains and Midwest, which a blob of warm, relatively moist air from the gulf occupies. This area could see thunderstorms soon, as the cold air will push up the warm air and produce tall clouds. The eastern part of the state is enjoying clear skies under high pressure. In July some distinct areas of high and low pressure can be seen, but there do not seem to be any dramatic developments. In October, especially with the radar layer turned on, the end of a large storm can be seen, with what is possibly an occlusion over the northeast as a cold front catches up to a warm front. According to a FEMA warning issued around the same time, this is likely a decaying Nor'easter storm (FEMA).


January 15 2010, 6 UTC
Isotherms
Isobars
Fronts
cold
stationary
Wind Speed (knots)
Calm
5
10
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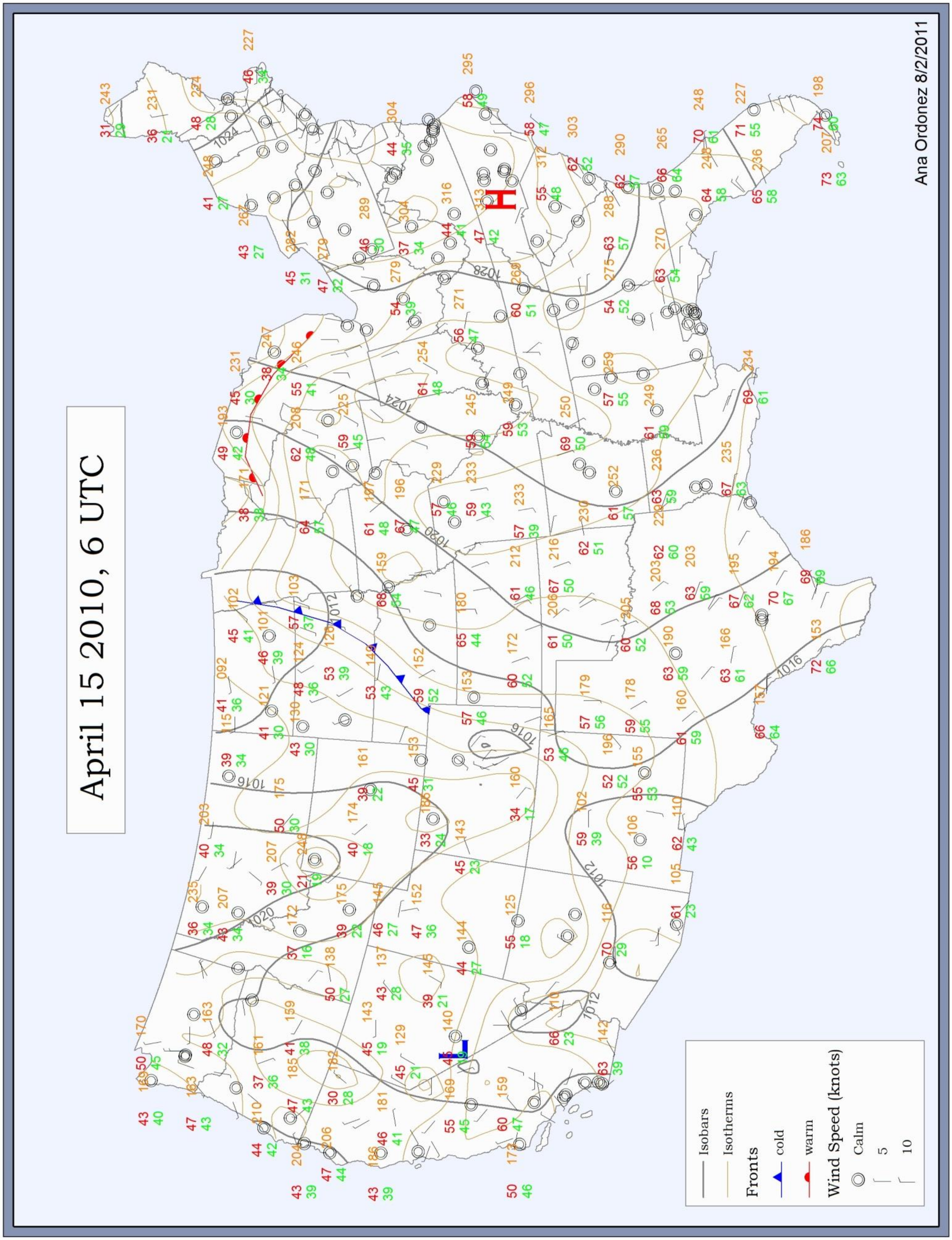
April 15 2010, 6 UTC
Isobars
Isotherms
Fronts
cold
warm
Wind Speed (knots)
Calm
5
10
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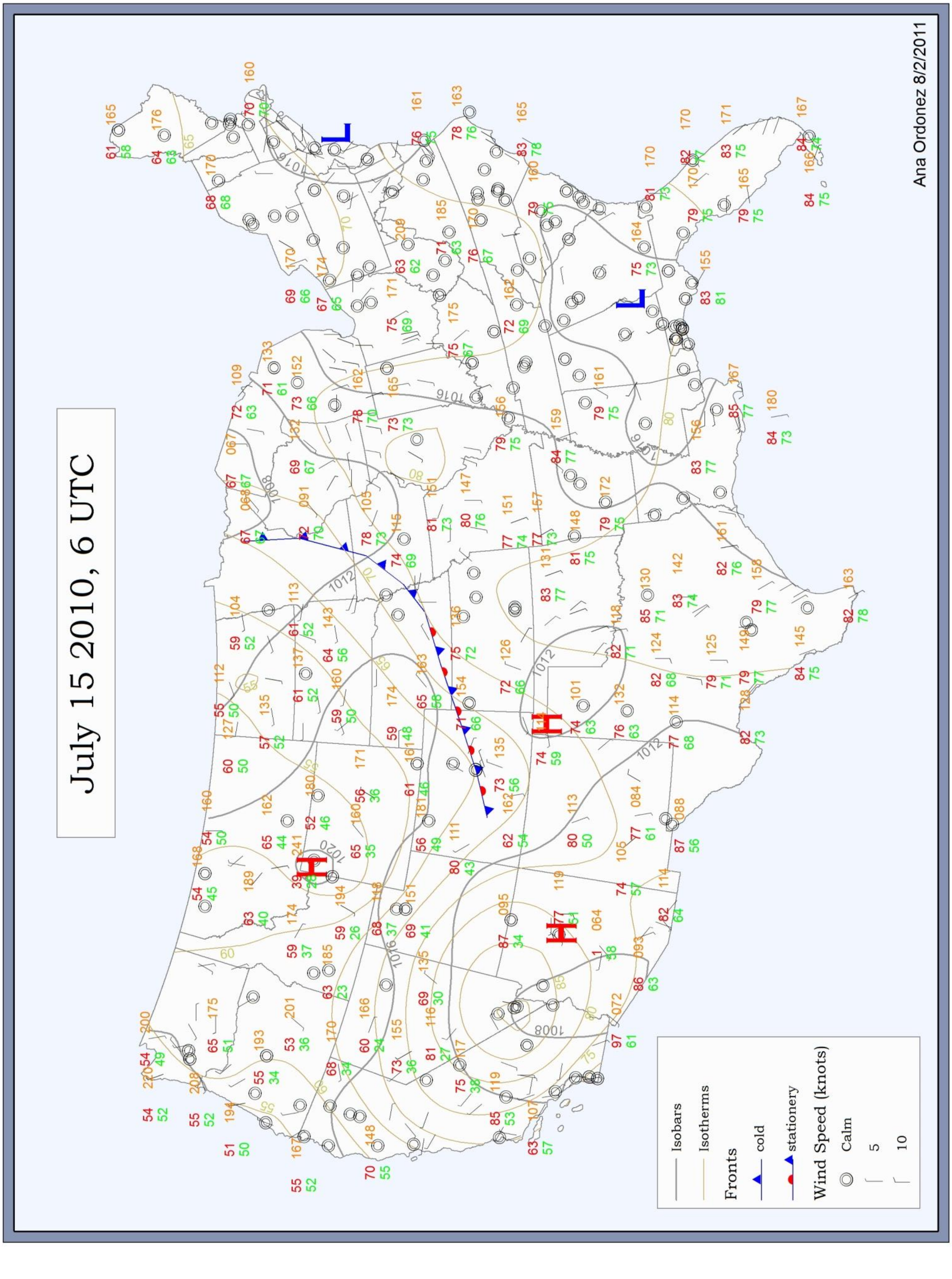

July 15 2010, 6 UTC
Isobars
Isotherms
Fronts
cold
stationary
Wind Speed (knots)
Calm
5
10
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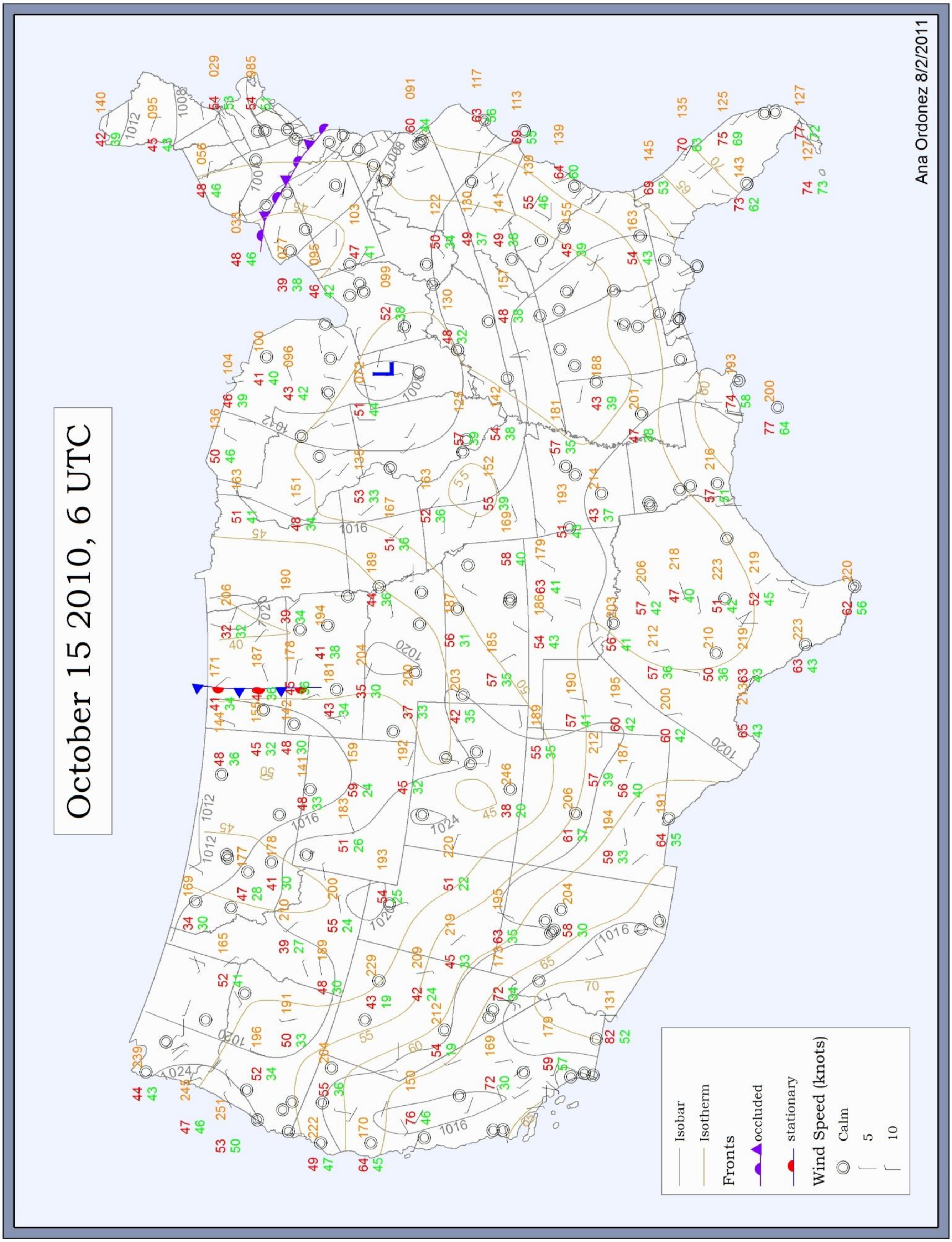
October 15 2010, 6 UTC
Isobar
Isotherm
Fronts
occluded
stationary
Wind Speed (knots)
Calm
5
10
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Conclusion

Had we mapped weather for consecutive days instead of days in different months, we would have been able to take much greater advantages of the tools offered by a GIS. It can be relatively straightforward to bring surface data into the system for analysis, and we can imagine applications such as tracking the movement of fronts and air masses or looking for trends in the locations of pressure centers over many days or a season. If we were to have studied weather among different times of year, it would have been better for use to pull climate normals instead of hourly readings, which are not a good sample of the typical weather for a given day.

While geographic information systems are used by the National Weather Service in applications such as issuing weather warnings, they do not seem to have gained much use in the actual process of forecasting. Optimally, a system would allow for modeling of the interaction of the surface with other layers of the atmosphere and even the ocean, though such a structure will not likely be seen for years. As our project shows, it is very possible to employ a GIS for synoptic weather mapping, and in this environment it would also be possible to link the weather to other elements of geography. Our experience also suggests that very effective advancements in the near future would be better access to the data already publicly available and greater availability of data in GIS compatible formats.

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