Formulating a Hydrologic Cycle Model for the Arkansas-Red Basin River by Monitoring Precipitation Trends

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WHY?

An understanding of the tight interrelationships between the energy, carbon and water cycles is needed to understand how energy production and may affect water cycle processes through climate change. One important consequence energy production is the emission of carbon dioxide from fossil fuel combustion. Changes in carbon and nitrogen levels in an ecosystem may result in variability in the growth rate of vegetation, which affects the evapotranspiration rate and soil moisture. Land-use changes and vegetation patterns can dramatically affect the recharge of groundwater and stream-flow, and possibly result in causing changes in basin-scale precipitation patterns.
Improving understanding of the function of regional water cycles is the goal of the Department of Energy's (DOE) Water Cycle Pilot Study.

The goal of this research is to develop accurate hydrological models, which are mathematical descriptions of the physical processes that control the regional water budget. Water cycle models are critical for determining freshwater availability, which have been limited by inadequate understanding of water cycle details important on both river basin and global scales. The study area for the DOE Water Cycle Pilot Study is the Atmospheric Radiation Experiment's (ARM) Cloud and Radiation Test-bed (CART) site, which is a substantial subset of the Arkansas-Red River Basin (ARB). A small subset of this domain, the Walnut River Watershed domain (40 km x 80 km), is under particular scrutiny by Water Cycle Pilot Study investigators.

WHAT?

The goal of the present study is to develop a detailed climatology of precipitation over the ARM CART site and Walnut River Watershed. To achieve this goal, precipitation trends measured by meteorological radar were used to develop statistical surveys of precipitation over the ARM CART on an hourly, daily, and monthly basis. Data from the National Weather Service's (NWS) Weather Surveillance Radar-1988 Doppler (WSR-88D) network were used in the study. These radar systems continuously record data that can be used to estimate the rate of precipitation and the accumulated rainfall over ARM CART Site. The radar-measured precipitation is adjusted by the Arkansas Red River Basin Forecast Center using information from a surface rain gauge network. These calibrated precipitation estimates are used in this study.

Precipitation estimates for the ARM CART site and Walnut River Watershed were extracted from the files containing estimates for the entire Arkansas Red River Basin. These data were subsequently analyzed to develop a statistical climatology of the precipitation patterns for use by Water Cycle Pilot Study investigators.

HOW?

A seminal tool in this research is MATLAB, a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

MATLAB was used to write programs to access and evaluate precipitation data archived at the ARM External Data Center. The origin of the data is the National Atmospheric and Oceanic Administration's Arkansas Red River Basin Forecast Center (ABRFC). Stage II data products are produced by ABRFC by merging radar precipitation estimates (Stage I) with ground truth data provided by rain gages. Stage III data is a mosaic of all the Stage II precipitation estimates within the Arkansas-Red River Forecast Center (ABRFC) area. The Stage III data files encompass 15 WSR-88D radars and approximately 500 rain gages. The Stage III data are retrieved and archived by the ARM External Data Center in NetCDF format (a self-describing file format). To develop the necessary software, files for the year 2000 were used.

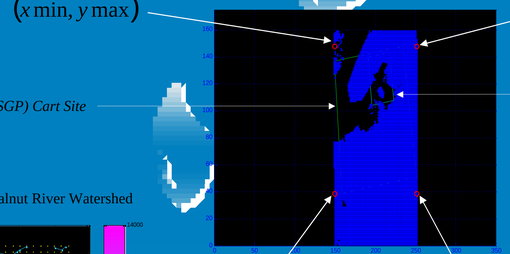
The one-hour precipitation files furnished by the ARM are available in the Hydrologic Rainfall Analysis Project (HRAP) coordinate system. This coordinate system is based on a polar stereographic map projection with a standard longitude of 105 West. It was necessary to develop an algorithm to convert the HRAP coordinates to the conventional latitude and longitude coordinate system.

The next step was to find the latitude/ longitude boundaries for the ARM (SGP) Cart site and the Walnut River Watershed. The latitude/ longitude boundaries for the Walnut River Watershed were supplied by the Environmental Protection Agency (EPA). Once the coordinate transformations and data parsing were complete, a program that graphically represents daily precipitation values for the ARB, ARM site, and the Walnut River Watershed was formulated.

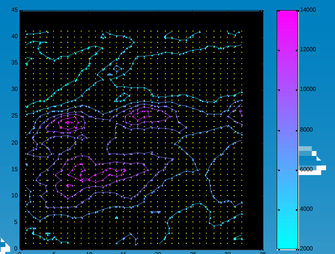
Abstract

Water is the source of all life on earth. The distribution of water, however, is quite varied; many locations have plenty of it while others have very little. Moreover, the total amount of the earth's water does not change. The circulation and conservation of earth's water is called the "hydrologic cycle". Forming a hydrologic cycle model is crucial to understanding the interrelationships between climate change, the variability in the growth rate of vegetation, and how water cycle processes are affected by fossil fuel combustion. Many factors must be considered when developing a hydrologic model. One of the most important factors is precipitation. In the present study, precipitation climatology for a subset of the Arkansas-Red Basin River (ABR) was developed using data from meteorological radar and rain gauges. This domain is under study by DOE's Water Cycle Pilot Study. Using computational software (MATLAB), a program was created to parse precipitation data files from the Arkansas Red River Basin so as to create matrices containing data for the ARM (SGP) Cart site and the Walnut River Watershed. These data were subject to statistical and graphical analysis. These codes will be used in the future to compile long term statistics (years).

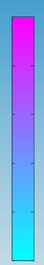
159 x 335 Arkansas-Red Basin River Matrix outlining boundaries for the ARM SGP site and Walnut River Watershed



One day of data for the Walnut River Watershed



One day of data for ARM Cart Site



One day of data for Arkansas-Red Basin River

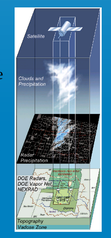
Background

The Earth System Science Division (ESSD) of the Brookhaven National Laboratory supports DOE activities through basic and applied research in atmospheric science, ecology, marine science, and. ESSD efforts are focused on developing the means of evaluating and resolving environmental problems associated with energy production and use.

ESSD also conducts basic research and devises technologies to increase the understanding of global climate change. A recent project proposed by ESSD is the Water Cycle Pilot Study. This study proposes to gain a better understanding of the interrelationships between climate change and precipitation patterns through hydrologic cycle modeling.

Results

The precipitation amounts over the Arkansas Red River Basin area (graph to the right) are used to extract those precipitation values present in the ARM (SGP) Cart site and in the Walnut River Watershed. The MATLAB figures below show the daily precipitation in each of the three boundaries. The uppermost graph displays the precipitation with in the maximum and minimum points of the ARM (SGP) site. These values were used to develop the bottom graph, a matrix of the ARM site. The same procedure was carried out for the Walnut River Watershed (graph on left). Each data point represents the amount of rainfall/precipitation that fell in that area in that time period. Therefore, contour plotting was necessary to analyze where the precipitation was concentrated. The color map displays the flux in height across each boundary, giving a spatial view of height comparisons. The contour plots show a representation of how currents and fronts participate in the distribution of rainfall. The plots also enabled us to target which hours, days, months, etc. were of importance to model.



Discussion and Conclusions

Precipitation trends in the ABR, ARM (SGP) Cart Site, and Walnut River Watershed have been successfully analyzed. The purpose of mapping out these three boundaries in a graphical and computational method has been achieved. Statistical analysis using the mean, standard deviation of each gridded point, and further analysis will reveal the character of these trends. Then, a hydrologic model will determine the basin-scale water cycle variability on seasonal and decadal time scales.

The optimal observation of the data for hydrologic cycle modeling is to find a day or month in which the precipitation is uniform. Trends in the precipitation amounts within each data file inhibited the likelihood of consistency in precipitation heights.
This hydrologic cycle model will help answer questions such as:

- *What are the underlying causes of variation in the water cycle on both global and regional scales, and to what extent is this variation induced by human activity?*
- *To what extent are variations in the global and regional water cycle predictable?*
- *How will variability and changes in the cycling of water through terrestrial and freshwater ecosystems be linked to variability and changes in the cycling of carbon, nitrogen, and other nutrients at global and regional scales?*

To extend this analysis, monthly and yearly precipitation trends will be monitored focusing on statistical averaging and deviation variance.

References

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Acknowledgments

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