Title: Modeling Real-Time Evapotranspiration, Growing Degree Days, and Soil Moisture in the State of Minnesota with Stochastic Indices and Geospatial Prediction

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Project Github repository of all code: https://github.com/casones/GIS5572/tree/main/Final
Link to Final ArcOnline MapViewer:
https://umn.maps.arcgis.com/apps/mapviewer/index.html?webmap=d6aad14ba8f043bc8aac317f941feb7b
Link to Video Overviewing Each Aspect of Your Project: https://youtu.be/HziXioaLEyI
Link to Your Lab 4 Peer Reviews: **Alex and Carl's Peer Reviews**

Abstract

This project aims to develop a stochastic index-based geospatial prediction model for the Minnesota Corn Growers Association to provide real-time updates on critical data related to corn crops. Using architecting diagrams for explanation, QAQC modeling flows and evapotranspiration/weather monitoring mathematical equations, the result is to show real time results and potential best growing times.

Problem Statement

The Minnesota Corn Growers Association is seeking a web-based solution to provide its members with real-time updates on critical data related to their corn crops. The Association requires a map of the entire state that updates daily with information on current and past growing degree days, soil moisture levels, and evapotranspiration. Additionally, the Association's developers require the ability to receive geojson results in real-time. The goal is to provide growers with the tools they need to make informed decisions about planting, irrigation, and other critical activities. The Minnesota Corn Growers Association seeks a reliable and efficient solution that can meet these requirements and help growers maximize crop yields.

Input Data

#	Title	Purpose in Analysis	Link to Source
1	Actual Evapotranspiration Raster	For measuring hydrological index for assessing variation in the Penman–Monteith equation, which combines mass transfer with the surface energy balance and is able to estimate the potential evapotranspiration rate based on meteorological data and crop physiological characteristics. (Ghiat, I et. al)	ESRI
2	Potential Evapotranspiration Raster	For measuring hydrological index for assessing variation in the Penman–Monteith equation, which combines mass transfer with the surface energy balance and is able to estimate the actual	ESRI

		evapotranspiration rate based on meteorological data and crop physiological characteristics.(Ghiat, I et. al)	
3	GLDAS Evapotranspiration 2000 - Present Raster	Historical evapotranspiration raster with bands for general reference assessment and modeling/simulation.	ESRI
4	NDAWN Daily Temperature/Soil Readings CSV	Precipice for interpolation and visualization to show variation from weather analysis and showing statistical analysis in temperature, precipitation, and soil moisture from ND readings and MN.	NDAWN
5	ISU Temperature/Precipitation Readings CSV	Same precipice for interpolation and visualization to show variation from weather analysis and showing statistical analysis in temperature, precipitation, and soil moisture.	Iowa State University
6	MN National Landcover Dataset	To show live visualization and accurate display of land use and patterns in which crops/critical areas of biophysical and deteriorating areas are inflicted by growing degree days and lack of evapotranspiration.	MN Geospatial Commons
7	MN Elevation Dataset (DEM)	To show live visualization and accurate display of land use and patterns in which crops/critical areas of biophysical and deteriorating areas are inflicted by growing degree days and lack of evapotranspiration. And in spatial juxtaposition to interpolated weather sensors and temperature.	MN Geospatial Commons

Data Flow Diagram(s) for System

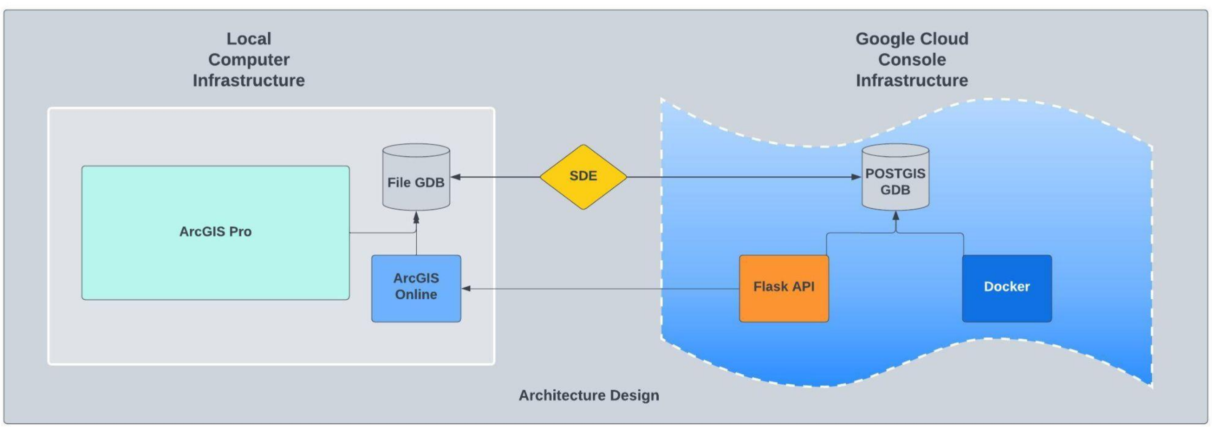
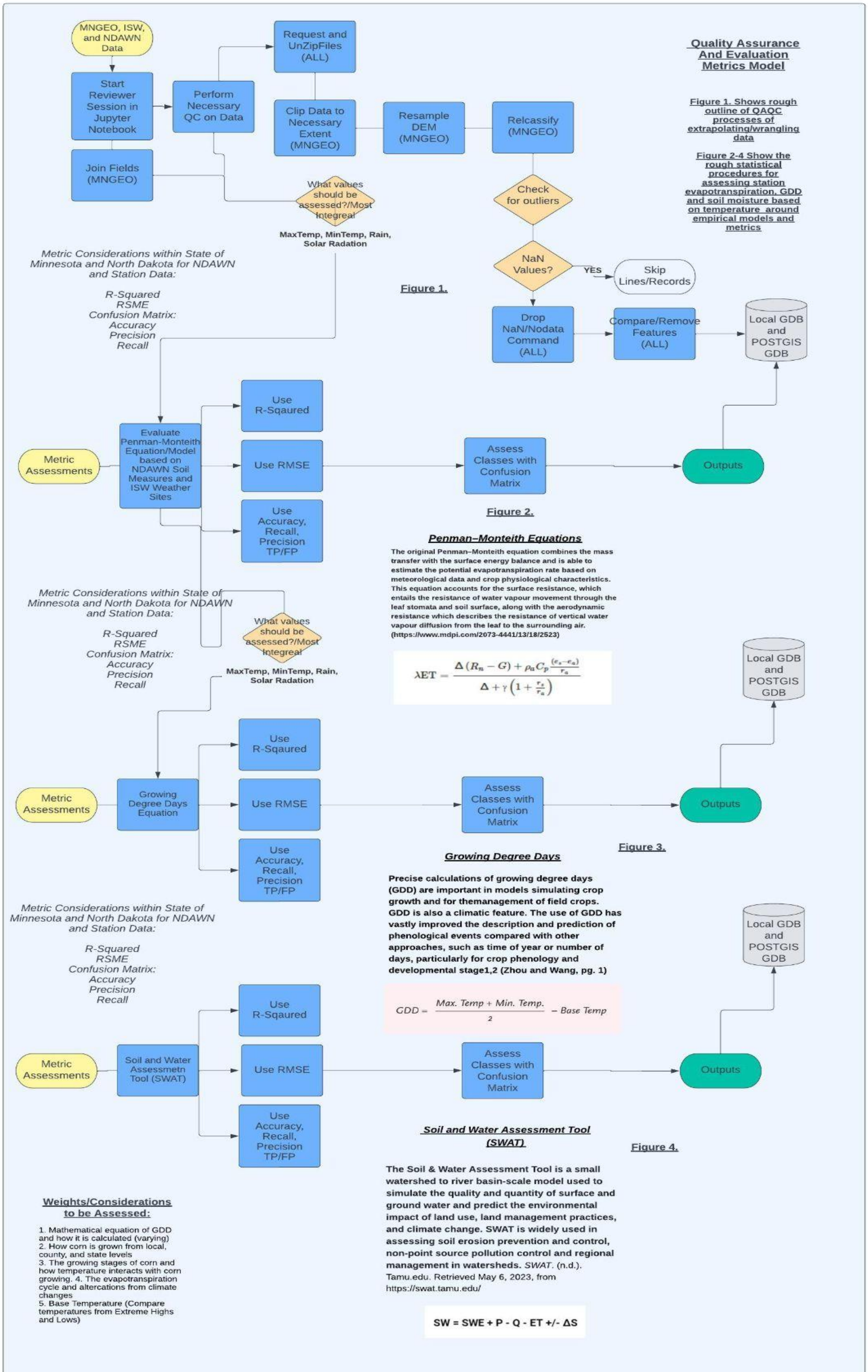


Figure 1.
Structural diagram displaying the interrelationships between architectures of local computer systems and Google Cloud Console systems with their interconnections between the Spatial Data Engine (SDE) and being served onto ArcGIS Online via Flask API.



Quality Assurance And Evaluation Metrics Model
Figure 1. Shows rough outline of QAQC processes of extrapolating/wrangling data
Figure 2-4 Show the rough statistical procedures for assessing station evapotranspiration, GDD and soil moisture based on temperature around empirical models and metrics
MNGEO, ISW, and NDAWN Data
Start Reviewer Session in Jupyter Notebook
Join Fields (MNGEO)
Perform Necessary QC on Data
Request and UnZipFiles (ALL)
Clip Data to Necessary Extent (MNGEO)
Resample DEM (MNGEO)
Relcassify (MNGEO)
What values should be assessed?/Most Integreal
MaxTemp, MinTemp, Rain, Solar Radiation
Check for outliers
NaN Values?
YES
Skip Lines/Records
Drop NaN/Nodata Command (ALL)
Compare/Remove Features (ALL)
Local GDB and POSTGIS GDB
Figure 1.
Metric Considerations within State of Minnesota and North Dakota for NDAWN and Station Data:
R-Squared
RSME
Confusion Matrix:
Accuracy
Precision
Recall
Metric Assessments
Evaluate Penman-Monteith Equation/Model based on NDAWN Soil Measures and ISW Weather Sites
Use R-Sqaured
Use RMSE
Use Accuracy, Recall, Precision TP/FP
Assess Classes with Confusion Matrix
Outputs
Figure 2.
Penman–Monteith Equations
The original Penman–Monteith equation combines the mass transfer with the surface energy balance and is able to estimate the potential evapotranspiration rate based on meteorological data and crop physiological characteristics. This equation accounts for the surface resistance, which entails the resistance of water vapour movement through the leaf stomata and soil surface, along with the aerodynamic resistance which describes the resistance of vertical water vapour diffusion from the leaf to the surrounding air. (https://www.mdpi.com/2073-4441/13/18/2523)
$$\lambda ET = \frac{\Delta (R_n - G) + \rho_a C_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a}\right)}$$
Metric Considerations within State of Minnesota and North Dakota for NDAWN and Station Data:
R-Squared
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Confusion Matrix:
Accuracy
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What values should be assessed?/Most Integreal
MaxTemp, MinTemp, Rain, Solar Radiation
Local GDB and POSTGIS GDB
Metric Assessments
Growing Degree Days Equation
Use R-Sqaured
Use RMSE
Use Accuracy, Recall, Precision TP/FP
Assess Classes with Confusion Matrix
Outputs
Figure 3.
Growing Degree Days
Precise calculations of growing degree days (GDD) are important in models simulating crop growth and for themanagement of field crops. GDD is also a climatic feature. The use of GDD has vastly improved the description and prediction of phenological events compared with other approaches, such as time of year or number of days, particularly for crop phenology and developmental stage1,2 (Zhou and Wang, pg. 1)
$$GDD = \frac{Max.\ Temp + Min.\ Temp.}{2} - Base\ Temp$$
Metric Considerations within State of Minnesota and North Dakota for NDAWN and Station Data:
R-Squared
RSME
Confusion Matrix:
Accuracy
Precision
Recall
Local GDB and POSTGIS GDB
Metric Assessments
Soil and Water Assessmetn Tool (SWAT)
Use R-Sqaured
Use RMSE
Use Accuracy, Recall, Precision TP/FP
Assess Classes with Confusion Matrix
Outputs
Soil and Water Assessment Tool (SWAT)
Figure 4.
The Soil & Water Assessment Tool is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds. SWAT. (n.d.). Tamu.edu. Retrieved May 6, 2023, from https://swat.tamu.edu/
$$SW = SWE + P - Q - ET +/- \Delta S$$
Weights/Considerations to be Assessed:
1. Mathematical equation of GDD and how it is calculated (varying)
2. How corn is grown from local, county, and state levels
3. The growing stages of corn and how temperature interacts with corn growing. 4. The evapotranspiration cycle and altercations from climate changes
5. Base Temperature (Compare temperatures from Extreme Highs and Lows)

Figure 2.
QAQC data flow diagram the necessary procedures for correcting data and ensuring quality for the stations, DEM and landcover data being wrangled from the APIs for MNGEO, NDAWN and Iowa State University. Including listing and describing the empirical models and metrics used for each required product (evapotranspiration, GDD, and soil moisture) and their entailments for weights assessed.

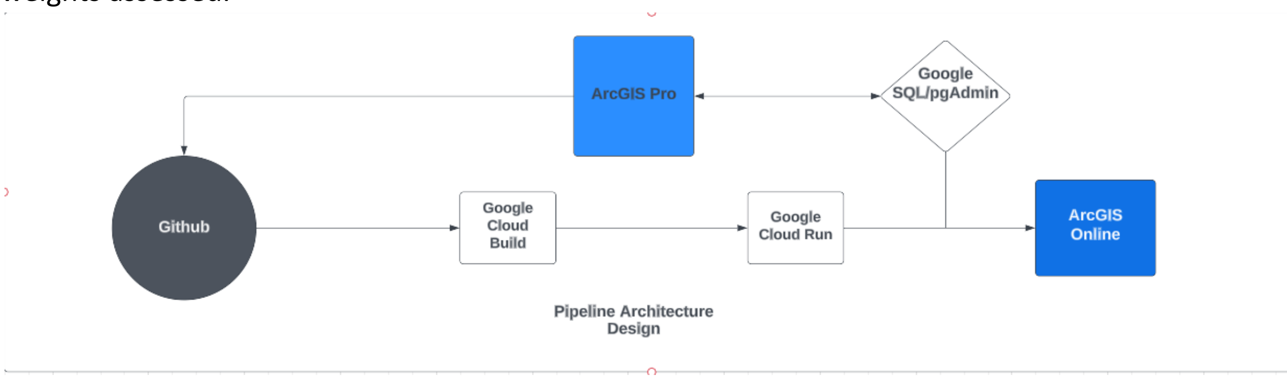

Figure 3.
Structured diagram/architecture depicting the flow of our pipeline utils python file being served from Github through Google Cloud Servers and to ArcGIS Online and the Jupyter Notebook from ArcGIS Pro.

Model Comparison

#	Model Name	Evaluation Metric 1	Evaluation Metric 2	Add more Eval metrics as needed	Rank Score of Model
1	Penman-Monteith Equation/ Model	R-Squared	RMSE	Confusion Matrix?	1
2	Growing Degree Days	R-Squared	RMSE	Confusion Matrix?	1
3	SWAT Assessment	R-Squared	RMSE	Confusion Matrix?	1

Penman-Monteith Equation/Model

This model is based on the Penman-Monteith equation and is used to estimate evapotranspiration (ET), which represents the rate of water loss from a standardized grass crop under optimal growing conditions. The equation combines physical principles and empirical relationships to estimate ET based on weather data, such as temperature, humidity, wind speed, and solar radiation. The equation is as follows:

$$\lambda \mathrm{ET} = \frac{\Delta(R_n - G) + \rho_a C_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

Growing Degree Days Equation/Model

The Growing degree days (GDD) are a measure of heat accumulation used in agriculture to predict plant growth and development. GDD models calculate the cumulative effect of daily temperatures above a base temperature threshold. The commonly used equation for calculating GDD is GDD = (Tmax + Tmin)/2 - Tbase.

Soil Water Assessment Tool (SWAT)

Soil moisture simulation models estimate the water content of soil over time based on factors such as precipitation, temperature, vegetation, and soil properties. The commonly used model is the Soil Water Assessment Tool (SWAT), which uses the soil water balance equation to simulate soil moisture dynamics. The equation is expressed as: SW = SWE + P - Q - ET +/- ΔS.

Recommendation for Decision-making

Based on the preferences of the stakeholders/clients and what's required, all the models are optimal for decision making analysis and performance. The most integral for decision making, if crops for corn were not taken into account holistically, would probably be evapotranspiration which dictates many variables on complex formulae and mineral/hydration considerations.

Reflection

What did you learn? What would you do differently if you did this again?

Alex: What I learned from this project and throughout the semester building the pipelines, learning the elevation metrics and architectures is that there is a certain amount of formulation when it comes to client and project management development. Besides understanding the intricacies of coding, metrics, and the interrelations of how to serve your product on ArcGIS Online from Github I learned the importance of the SRS. While delivering a polished product and trying to communicate with stakeholders/considering the facets/complexities of evapotranspiration, GDD, and soil moisture as a whole.

As regards to the class and if I was to do this differently, I would have had more concentration on what data sources would be most optimal and how to best wrangle them or do a change detection comparison with imagery. Then showing anomalies from different periods in time to show variation in crops, including how crops are planted differently with soil levels, nutrients etc, since this is more generalized and small scale and not larger size considerations and entailments are factored in.

Carl: Throughout working on this project and the lab assignments this semester, I've been able to build on the skills and knowledge I gained in ArcGIS I. Before enrolling in this series of courses, I had very minimal coding experience and only a basic understanding of statistics. My GIS experience mainly consisted of performing general GUI geospatial analysis tasks. I now have a better understanding of automating GIS processes through pipelines, more complex geospatial statistics, model evaluation, and general architecture of GIS data-intensive applications. I may be more confident in some of these areas than others, but I feel that I've built a solid foundation of understanding that I intend to build from as I continue through the MGIS program.

Regarding what I would do differently if I were to do this again, I would spend more time on the data wrangling step of this project. We were able to successfully pull data from an API, perform some analysis, generate some statistics, and display it online, but the extent of the data, both spatially and contextually, doesn't completely satisfy the original user statement. This is a project that I feel like I could do better after I take more courses in coding, database management, and statistics. That being said, what we were able to accomplish is something I would not have been able to do before taking this course.

References

Ghiat, I., Mackey, H. R., & Al-Ansari, T. (2021). A review of evapotranspiration measurement models, techniques and methods for open and closed agricultural field applications. Water, 13(18), 2523. https://doi.org/10.3390/w13182523

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Appendix

[Original SRS Sheet from Lab 1.1]