For Crying “Drought” Loud

New Mexico Supercomputing Challenge Final Report

Team: 2

Cottonwood Classical and Del Norte High School

Team Members:

Ayvree Urrea ayvreeurrea@gmail.com

Kiara Onomoto kiaraonomoto@gmail.com

Violet Kelly kellyviolet1111@gmail.com

Sponsor Teacher:

Karen Glennon

Mentor:

Flora Coleman

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Executive Summary:

Drought in the Rio Grande River has and will continue to worsen as the years go on. According to research completed by Williams et al. as a result of climate change "...2000-2021 was the driest 22-yr period since at least 800 [CE]" [1]. This type of drought is dangerous due to the widespread effect on wildlife, crops, and general livelihood. Water is a resource that is important to the prosperity of not only human species, but also animals and crops as well. The rain that we get during monsoon season is not enough to relieve drought. We have also seen that drought is occurring more often, for longer periods, and sooner in the year. Through our project we researched the effects of drought in New Mexico specifically. We have found that methods such as optimizing federal reservoirs to more than one entity, redefining dams in a way that is more infrastructurally beneficial to its environment, and redistributing water sources, can lead to a healthier river that can withstand dryness and be drought-resistant. As the Rio Grande river has changed in the last 100 years, its systems of irrigation and water distribution should change as well. We believe that these solutions can save the amount of water supply in the Rio Grande, as well as use it in more impactful ways that can save the drying environment around the river. Our project focused on visualizing drought as it relates to the Palmer Drought Severity Index in different divisions of New Mexico monthly from the years 1895-2022. This visualization has allowed us to draw conclusions based on patterns of past drought conditions as it relates to seasonal and monthly data. We created a map of New Mexico using the eight divisions of New Mexico with a gradient that shows where drought is more severe and what months of the year this happens.

Problem:

The Rio Grande River, which flows through New Mexico, has been facing severe drought due to climate change and needs a better distribution of water plan. In addition, New Mexico needs to have additional options for water resources. In Las Cruces specifically, the Rio Grande didn't flow until March and was dry by September last year, completely disrupting the irrigation season which normally lasts from February to October. Since many cities in New Mexico reside along the Rio Grande River, this drought has a widespread effect on wildlife, crops, and livelihood. In Las Cruces, water is diverted and drained according to "water rights" which accounts for three-quarters of the state's surface and groundwater even though this only makes up 2.4% of New Mexico's Gross Domestic Product. Due to this distribution of water, New Mexican residents suffer not only by not being able to enjoy the pleasures of living by the water, but wildlife and nature suffer as well. Last year, Albuquerque also experienced a dry river on a 5-mile stretch of the Rio Grande for the first time in 40 years which means that drying events are taking place earlier and farther north than normal. Although rain alleviates drought, the Rio Grande is a snow-melt-driven system, and this is not enough to reverse long-term drought conditions. Water resources need to be reconsidered and redistributed to prepare for the nearing endemic state of drought in the Rio Grande River.

Objectives:

Our objectives were to create a code utilizing pycharm which could not only visualize drought as it already occurs in the Rio Grande and New Mexico, but also make predictions as to what patterns this drought will continue to follow. Specifically, we wanted to investigate how climate change may affect the future drought that we may face and the problems this could cause for our community. Finally, we wanted to discuss possible mitigation practices to the effect of drought or relief possibilities.

To start our project, we wanted to investigate possible measurements of drought. These include the Palmer Drought Severity Index which is a measurement of the duration and intensity of long term drought patterns and the Standardized Precipitation Evapotranspiration index which takes into account precipitation and potential evapotranspiration. We decided to use the Palmer Drought Severity Index because it could be best used to look at the historical aspect of drought without variables related to human impacts like irrigation or snowfall. This will be used to make predictions regarding drought in the future as it relates to historical patterns. To garner accurate results, we gathered New Mexico precipitation data from the past few years from NASA Worldview. In order to best accurately display drought in different areas of NM, we used the eight divisions of New Mexico's weather divisions which was obtained through the National Centers for Environmental Information. This has monthly PDSI historical division data from 1895-2022 and helps us to understand/visualize drought patterns for specific months of the year and areas of New Mexico. We also discussed possible strategies to mitigate drought such as water redistribution and reprioritization.

Research:

Drought Indices:

To investigate the relationship between drought and the future of the Rio Grande, we have investigated drought indexes that have recorded historical data. We primarily researched the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Evapotranspiration Index (SPEI). The Standardized Precipitation Evapotranspiration Index utilizes both precipitation and evapotranspiration data [7]. A limitation to this method is that it needs a long base period of around 30-50 years to collect data and process accurate results. Therefore, we looked into PDSI.

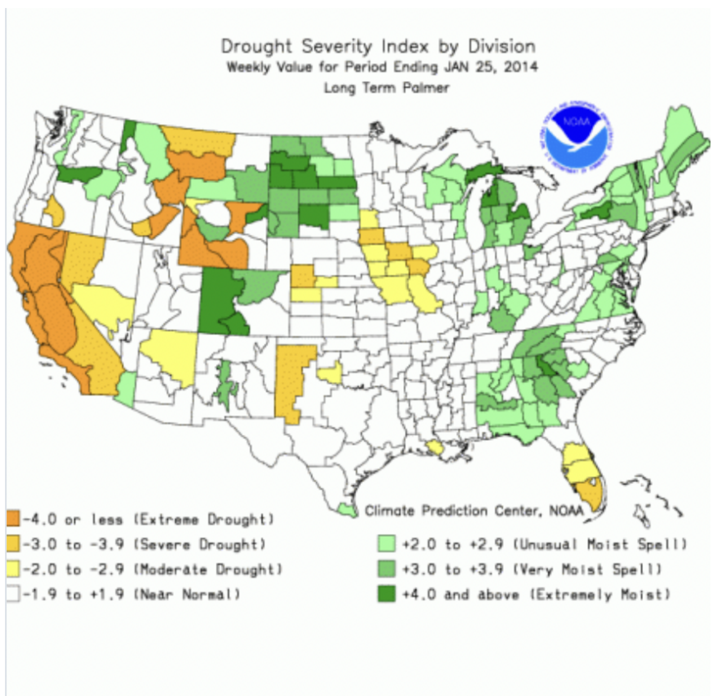

Figure 1

(https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi)

The Palmer Drought Severity Index is a historically-based drought index that contrives temperature and precipitation data from a given location. This data is then calculated into a scaled index (reference Figure 1) that generally spans from -4 (indicating severe drought) to +4 (indicating extreme moisture). This index uses and determines the water balance equation, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. It

“...uses precipitation, temperature, and available water capacity (AWC) as input data, thus the parameters of water balance can be calculated, such as runoff, recharge, evapotranspiration, and coefficient of soil moisture loss” [7]. Limitations within this index are its nonconsideration of human impacts such as irrigation, the variation of water balance components that also vary with elevation and land cover, and lastly, snowfall. In our project, we utilized this index in a way that put current conditions into a historical perspective. We have obtained monthly index data ranging from the years 1895-2022 in order to compare and validate these values with possible predictions.

Nasa Worldview:

NASA Worldview was a tool to strengthen our understanding of drought data. NASA Worldview gave a comprehensive list of data sets from varying factors that contribute to drought. Some of these factors include land surface reflectance, land surface temperature, population density, precipitation rate, radiance, and soil moisture (as seen in Figure 2). NASA Worldview allowed us to recognize how drought has its impacts on both humanity and the environment. A higher population density will more easily experience drought than a low population density. We looked into using NASA Worldview for our data but it only allowed data to be downloaded one day at a time. Considering we wanted to look at data at least a few decades in the past, this wasn’t an option for us.

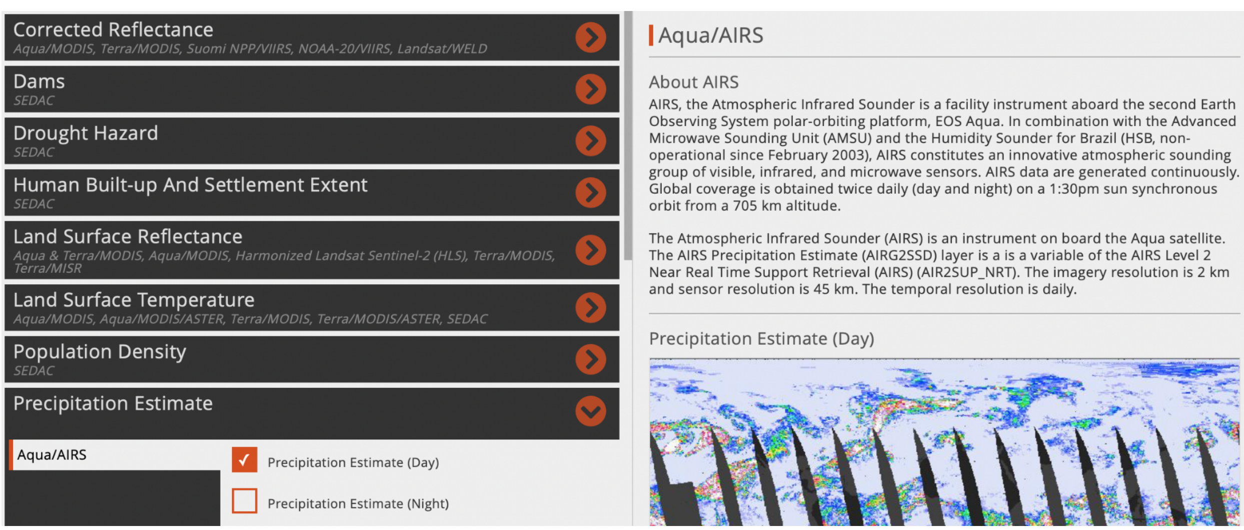

Figure 2

(https://worldview.earthdata.nasa.gov/?v=-122.84927811493296,27.101252117697136,-90.03298740584484,43.6461320168624&l=Reference_Labels_15m(hidden),Reference_Features_15m(hidden),Coastlines_15m,AIRS_Precipitation_Day,VIIRS_NOAA20_CorrectedReflectance_TrueColor(hidden),VIIRS_SNPP_CorrectedReflectance_TrueColor(hidden),MODIS_Aqua_CorrectedReflectance_TrueColor(hidden),MODIS_Terra_CorrectedReflectance_TrueColor&lg=true&s=-106.1084,34.4213&t=2023-01-21-T06%3A24%3A22Z)

Climate Divisions:

To accurately display drought in different areas of NM, we are using the eight divisions of New Mexico's weather divisions. These divisions include as shown in Figure 3: Central Valley (5), Central Highlands (6), Northeastern Plains (3), Southeastern Plains (7), Northwestern Plateau (1), Northern Mountains (2), Southern Desert (8), Southwestern Mountains (4). We obtained this division index from the National Centers for Environmental Information (NCEI). It presents historical division data of monthly PDSI from 1895-2022 [6]. We used this in our project to understand where drought may be the most severe in New Mexico as well as which months of the year this continually occurs in. These patterns have helped us understand drought and also enable us to make predictions about what will happen in the future if these patterns do continue.

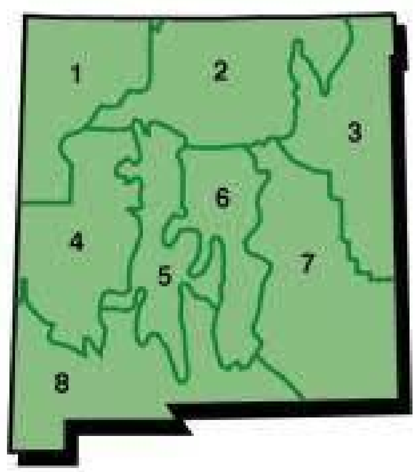

Figure 3

Water Prioritization:

As aforementioned, humans can affect drought just as much as nature. Both in population (how many people need water) but also in management. What is the most effective way to allocate our water resources? The three largest sectors that this gets broken into are industrial, domestic, and agricultural. The industrial sector will use water for production of goods. A caveat of supplying the industrial sector with water is that it will most likely become contaminated after use. Water purification is a process that requires a lot of time and energy. The domestic sector covers an individual's use of water. For example, showering, laundering clothing, running the dishwasher, and drinking. This sector's allocation will depend on the population of the state or county. Finally, the agricultural sector, where water is used to water crops or give to animals. This sector is especially important in New Mexico considering our relatively large production of pecans, peppers, and corn. Our climate is naturally dry so most plants require artificial watering in order to thrive.

During droughts, water has to be allocated precisely in order to fulfill the needs of each main sector. In addition to our drought predictions, we thought it would be interesting to explore the relationship between humans, economy, and nature. In a future project, it would be interesting to create an algorithm which would calculate the most beneficial use of a certain amount of water. Figure 4 shows the average separation of each sector.

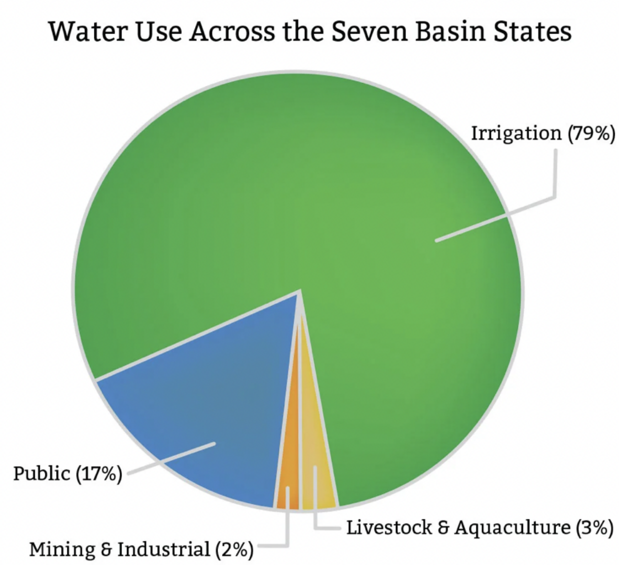

Figure 4

(https://learn.genetics.utah.edu/content/earth/waterallocation)

Predictions and Probability

One of the objectives of this project was to be able to predict future drought, thus identifying how severely climate change will affect our weather patterns. Our hypothesis is that as the Earth experiences this positive feedback loop of growing warming and warming. Drought will also become more and more severe. The increased temperature will directly cause an increase in evaporation (decrease in soil moisture). This rapid evaporation will severely dry out soil, so when it does rain, the soil won't be able to soak up the water. We will instead probably experience an increase in flash flooding. We predict that drought will continue to intensify and therefore we must begin to find solutions now.

Probability goes hand in hand with predictions. Most predictions have a likelihood, a probability. We researched how to incorporate probability formulas and concepts into this project. This would also eliminate any misleading or false information by stating "this is our predicted rate of precipitation with a likelihood of …" We researched independent events, mutually exclusive events, conditional probability, and how to calculated expected value. This general knowledge of probability allows us to accurately integrate the topic into our code.

Python and Pycharm

Objective: Creating a model that computationally predicts future droughts, in order to identify possible solutions in water distribution.

Overview:

In our program, we wanted to create a model that visually represented New Mexico and its historical data pertaining to droughts. This would then allow us to then transition to the idea of predicting droughts and the impacts it has on surrounding environments. To start this, we analyzed historical data of PDSI in different divisions of New Mexico to find patterns and the relationships that are present with this large array of data.

Obtaining and converting data:

In our research, we were able to find PDSI drought data from NCEI databases that provided files of monthly drought conditions in the contiguous United States. We then converted this data into our program and found a way to simplify and understand this abundant data in order to only focus on New Mexico drought data. Then we had to dissect and understand the format of the series of ten digits.

Finally, we used shapefiles also acquired from NCEI databases to create a visual of New Mexico in our program. This allowed us to create a structure and shape of the state, as well as display the eight climate divisions.

0503051926	1.10	-0.20	-0.40	-0.91	-1.07	-1.28	-0.72	-1.05	-1.05	-1.12	0.28	0.40
0503051927	0.25	0.48	1.18	1.66	-1.30	1.34	2.02	2.95	-0.14	-0.59	-0.72	-0.70
0503051928	-0.92	-0.93	-0.97	-1.34	0.71	2.95	4.26	4.09	3.35	3.81	4.02	3.30
0503051929	2.68	2.61	1.86	2.48	2.16	1.51	1.67	1.91	2.84	3.55	3.86	3.22
0503051930	2.82	2.16	1.49	1.09	2.33	2.11	2.38	3.61	3.02	3.82	4.45	3.84
0503051931	3.17	3.37	3.52	-0.15	-0.58	-1.05	-1.80	-1.77	-2.47	-2.74	-2.57	-2.39
0503051932	-2.24	-2.15	-2.11	-1.39	-2.28	-1.85	-1.49	-1.66	-2.12	-2.15	-2.46	-2.24
0503051933	-2.43	-2.52	-2.66	-1.57	-1.19	-2.38	-2.71	2.36	2.44	-0.72	-1.21	-0.90
0503051934	-1.25	0.70	-0.58	-1.50	-3.18	-3.67	-4.94	-5.21	-5.06	-5.35	-5.13	-4.93
0503051935	-4.85	-4.50	-4.67	-4.01	-2.20	-1.30	-2.26	-2.93	-2.22	-2.48	-2.26	-2.29
0503051936	-2.21	-2.22	-2.50	-2.59	-2.47	-3.41	-4.14	-4.31	-3.64	-3.30	-3.47	-3.13
0503051937	-2.93	-2.78	-2.48	-2.86	-3.80	-3.50	-4.43	-4.93	-4.44	-4.30	-4.07	-3.44
0503051938	-3.29	-3.15	-2.91	0.58	1.17	-0.47	-0.27	-0.62	-0.12	-0.87	-0.86	-0.79

Figure 5

Nested Dictionary:

In our program, we implemented a nested dictionary to separate the vast amount of data by state, climate division, month, and year. We chose to use a nested dictionary in our program because of its ability to comprehend and reiterate data in a limited amount of time. This would then help us have the ability to find certain points of drought data in a given year, month, and climate division. In figure 6 and 7, it shows the structure of our nested dictionary and our ability to print certain divisions and months, in order to analyze specific points.

```
def create_dictionary(input_data):
    """
    Create a dictionary using the divisions in New Mexico
    """

    division_names = ['NORTHWESTERN PLATEAU', 'NORTHERN MOUNTAINS',
                      'NORTHEASTERN PLAINS', 'SOUTHWESTERN MOUNTAINS',
                      'CENTRAL VALLEY', 'CENTRAL HIGHLANDS',
                      'SOUTHEASTERN PLAINS', 'SOUTHERN DESERT']

    month_names = ['Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun',
                   'Jul', 'Aug', 'Sep', 'Oct', 'Nov', 'Dec']

    data_dictionary = {}
```

Figure 6

```
print(len(nm_dictionary['CENTRAL VALLEY']['Jan']))
print(nm_dictionary['CENTRAL VALLEY']['Jan'])
```

Figure 7

Visual Gradient:

One of the vital parts of our program was the representation of the drought data in a visual setting using shapefiles, PDSI drought data, and the nested dictionary. One of our main goals for this program was to be able to represent the change of drought over time in these eight climate divisions. The graph displays the shape of New Mexico and the borders of the climate divisions. It then uses a color gradient to show the difference in drought in varying shades of oranges. The darkest orange represents a drier climate condition compared to lighter shades of orange which show wetter and more sustaining conditions. With the implementation of the nested dictionary, we are able to show different time frames throughout a given year. This has allowed us to compare the varying months in years spanning from 1895 to 2022 (figure 8 and figure 9)

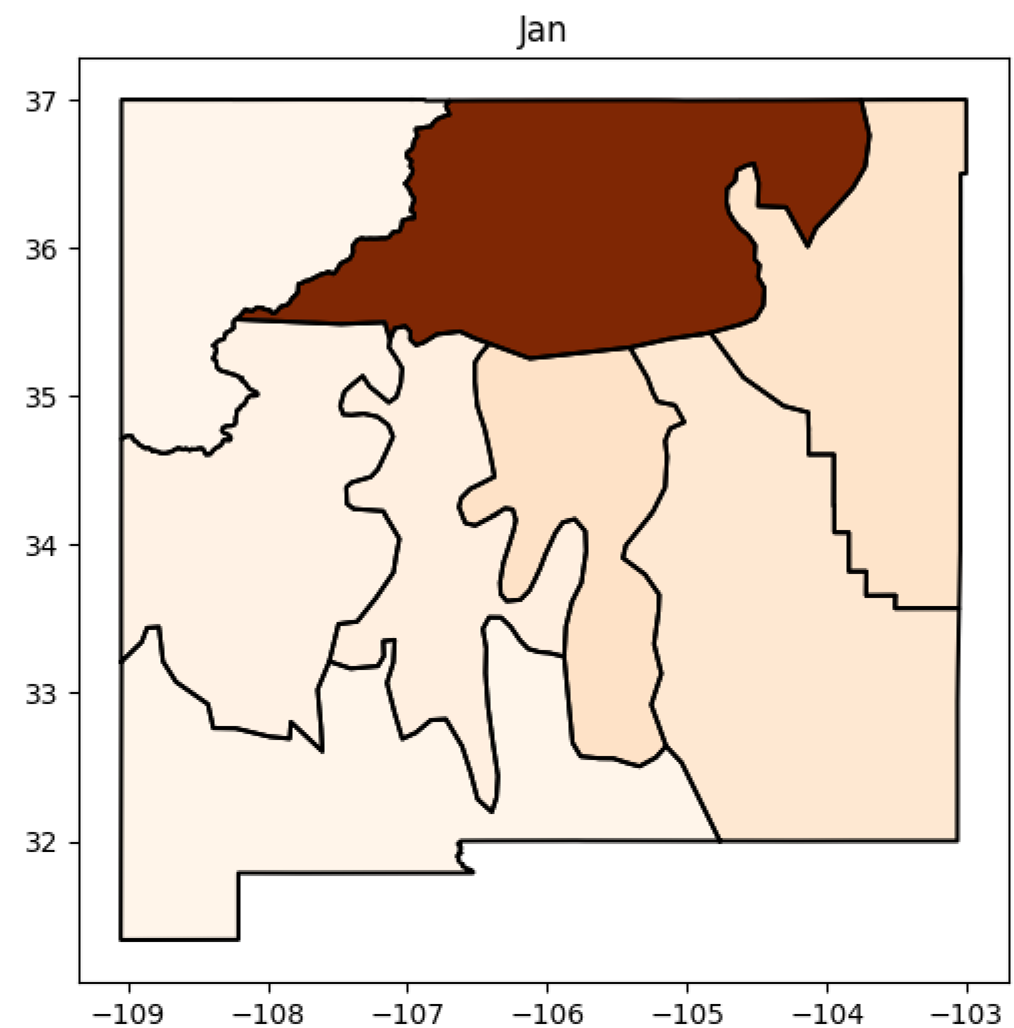

Figure 8

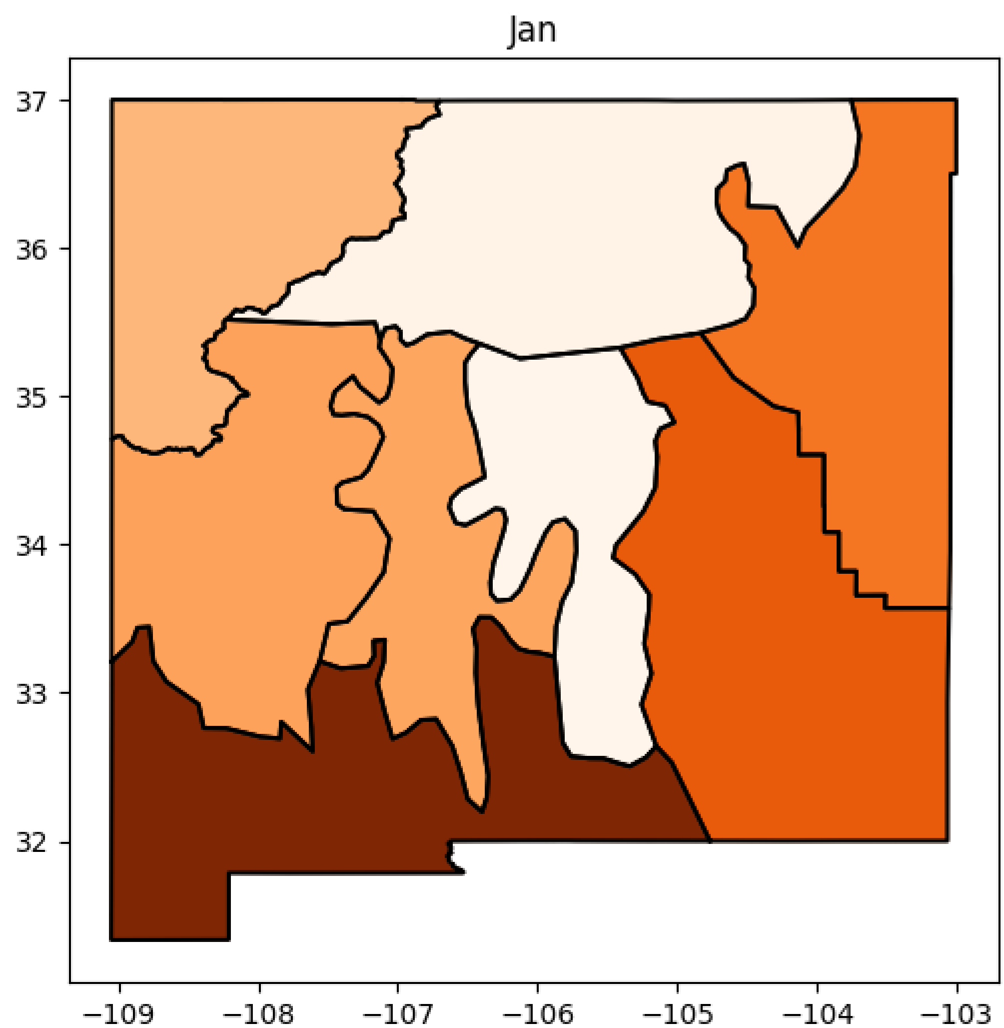

Figure 9

Tables and Graphs:

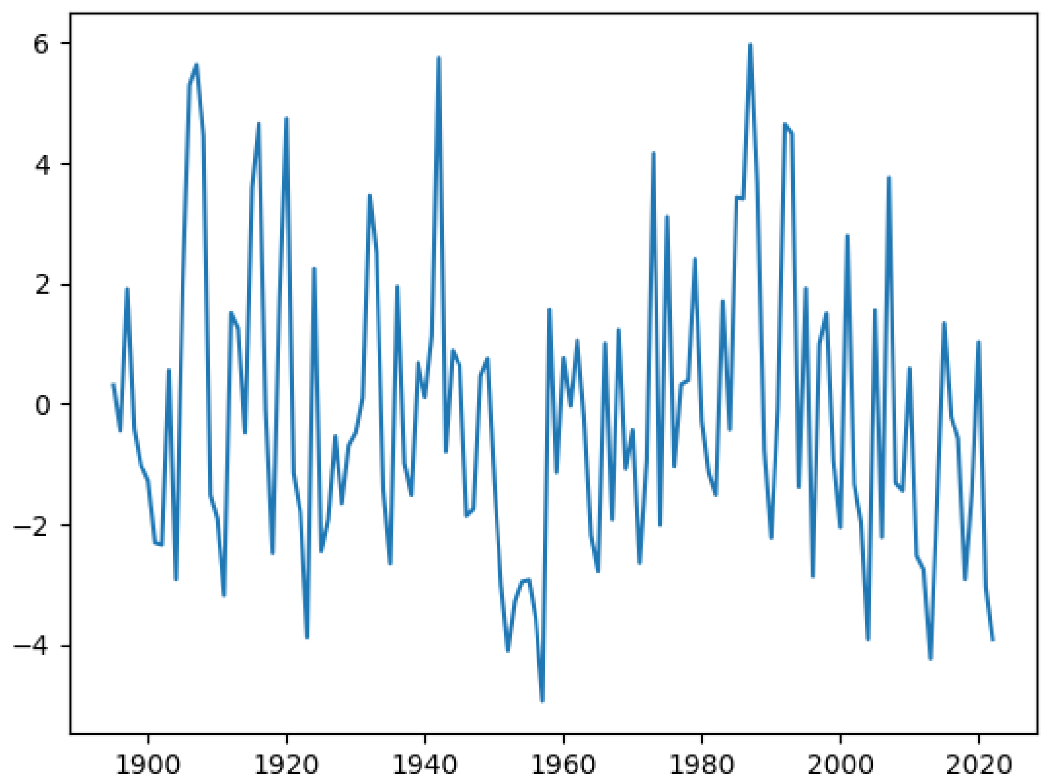

Figure 10

In Figure 10, the x-axis depicts year and the y-axis depicts the precipitation rate. The data represents each plot of PDSI monthly data between the years 1895 to 2022.

Results:

This year our results were mostly visual and pattern related. We used our code to use historical PDSI data to model drought in the eight divisions of New Mexico. A gradient is used in order to see where drought is more severe and the code runs through all 12 months of a specific year. Through running our code we found some patterns for specific years. An observation was that in 1895 drought was present in central NM (division 5). As compared to 2022 drought was more stagnant in the SW of NM in 2022, and drought was shown to vary in 1895 with there being no drought in most of NM from December 1895-March 1896. In 1950 drought was harsh on the east of New Mexico, and in 1990 there was consistent drought in divisions 2 and 3. In 2000 drought conditions were severe in October, November, and December. In 2010 drought started in the west and gradually moved up the state while Division 5 stayed impacted by drought. In 2015 drought stayed present in the northeast side and in 2018 the summer was not impacted by drought while the winter was. In 2020 Drought was harsh in the Southwest and there was consistent drought in division 5 of 2021 while there was no drought in division 1. Finally, in 2022 there was consistent drought in the Southwest. As we can see from these observations, drought has remained an issue in various areas of New Mexico throughout the years. Some of the most damaged areas are central NM and the northwestern plateau.

Conclusion:

Through this project we were able to gain a better understanding of drought in New Mexico and possible mitigation strategies. Our code helped us to view PDSI through many years of the past utilizing the eight divisions of New Mexico. Through this information, we were able to find patterns with drought and discover areas of New Mexico where drought is consistently worsened. We have found that methods such as optimizing federal reservoirs to more than one entity, redefining dams in a way that is more infrastructurally beneficial to its environment, and redistributing water sources, can lead to a healthier river that can withstand dryness and be drought-resistant. As we continue, we would like to make predictions of drought in the future with the assumption that drought patterns will continue as seen. Our hypothesis is that as the Earth experiences this positive feedback loop of growing warming and warming. Drought will also become more and more severe. Since drought is an issue that is consistent at the least it is exceptionally important that we start developing strategies to mitigate the problems caused to the community, wildlife, and crops.

Significant Achievements:

The most significant achievement that we had as a team this year was time management and organization. Since all three members of our team are seniors we had to learn how to better manage our time and prioritize our tasks for the challenge while also handling the workload in school and at our jobs. It was an incredibly busy and stressful year so we had to make sure that we had all the deadlines for the challenge set in our calendar. In addition, we had to make sure that our communication was always kept up with one another as we go to different schools. We set times to meet during the week that would work with all of our schedules and we made a commitment to work on our tasks on our own time separate from those meetings as well. We effectively set up a plan to research our project, do the code for our project, and also complete all of our big tasks such as the proposal, interim, evaluation, and final report. As a team of three, we did a great job staying organized and following through with the tasks we embarked on.

Ayvree Urrea:

The most significant achievement that I had this year was staying organized and appreciative amidst an incredibly stressful season of life. I have felt very overwhelmed this year with extracurriculars, sports, school, and work. However, I also wanted to get the most out of every experience with it being my last year in most of my activities. This year I have taken the time to appreciate all that I have learned through my years in the challenge. Some of those things being presenting skills, organizational skills, researching skills, and coding skills. I am very proud of the comfortability I have grown to have with presenting as I have gone through with evaluation and expo every year. I have gained many coding skills in python especially understanding matrices, functions, loops, and if/and statements. I have also become a more knowledgeable researcher in order to find the information needed and utilize it. Most importantly, I have gained confidence in my capacity to take a problem I see in the world and actually make changes- computationally or otherwise- that will help mitigate the problem. This is a skill I will forever take with me in college and beyond.

Kiara Onomoto:

The most significant achievement that I had this year was expanding my skills in communication with my team members and mentor, as well as being able to be the sole programmer on my team. Throughout my time participating in the Supercomputing Challenge, I have felt that my ability to communicate has grown significantly to what it is today. Being from a team that is divided into two schools, and having to communicate with a mentor who also has a busy schedule, this year has taught me the importance of communication. As I have participated in this program, I found it to be important to be a dependable team member. This meant that I had greatly accepted the role of communicator between my team and mentor. This year, I felt I have achieved this by organizing the availability of meetings and keeping track of deadlines. Furthermore, my skills in programming in Python have greatly benefited this year with my dedication to stepping out of my comfort zone to being the sole programmer that fully understood and could comprehend new skills that were taught to us by our mentor. These skills will greatly impact my future endeavors.

Violet Kelly:

My most significant achievement this year was integrating myself into the community of Supercomputing and learning how to present code to an in-person audience. This only being my second year in the challenge, this was the first time I got to go out to Socorro and immerse myself in the Supercomputing culture. I learned a lot through both experience and the lessons we were taught. It was also really inspiring to see everyone who was also competing in the challenge. I also got the opportunity to present our code to professional scientists, which was terrifying at first, but after the shock of nerves I became more comfortable presenting to incredibly intelligent strangers. I feel that one presentation had really prepared me or at least gotten me comfortable with the skill of public speaking that I will no doubt have to utlize in college. The question portion also helped me understand how I can better communicate my ideas to others in a way that is clear and concise. Alongside this, I've learned how to communicate my passion to others. I am passionate about mitigating the effects of climate change and educating others on the reality we are facing. This coding project was a great way for me to investigate an issue that I was naturally motivated to study and share.

Acknowledgments:

Karen Glennon, Retired Teacher

Patty Meyer, Retired teacher

Flora Coleman, Sandia National Laboratories

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