Final Project
Mapping areas of cold air pooling (CAP) in Rocky Mountain National Park (RMNP)

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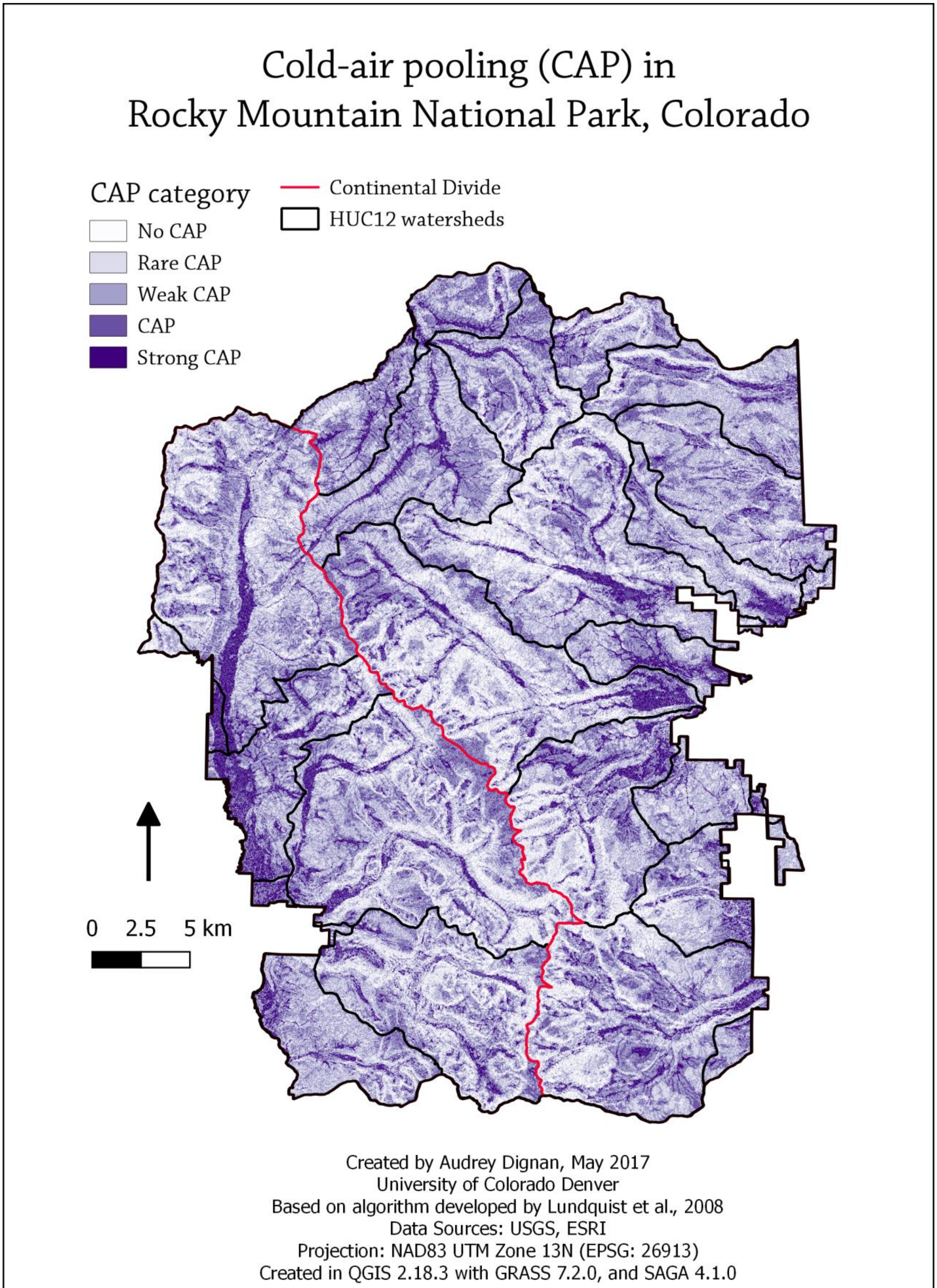
NO	Criteria	%
1.	Preliminary Concept Outline • How are cold air pools (CAPs) distributed throughout Rocky Mountain National Park?	10%
2.	Project Scope/Objective • Rocky Mountain National Park (RMNP) • Identification areas that are prone to cold-air pooling (CAP)	10%
3.	Project Results and Conclusions • 60% of the land surface area of RMNP is prone to CAP • Lessons learned • Recommendations for further analysis & future applications	20%
4.	Processes involved • Download DEM data from USGS • Process DEM in QGIS & SAGA: • Use Raster Calculator in QGIS to generate final CAP map	30%
5.	Background Research • Peer-reviewed literature on CAP formation. • Peer-reviewed literature on climate change refugia for cold-adapted alpine plants. • Software documentation for QGIS & SAGA GIS (standalone) • Online forums like StackExchange for help with specific issues	10%
6.	Report Format • Report and maps	10%
7.	Final products • Project report • Map of cold air pools in RMNP for conservation purposes	10%
	TOTAL	100%


Cold-air pooling (CAP) in
Rocky Mountain National Park, Colorado
CAP category
No CAP
Rare CAP
Weak CAP
CAP
Strong CAP
Continental Divide
HUC12 watersheds
0 2.5 5 km
Created by Audrey Dignan, May 2017
University of Colorado Denver
Based on algorithm developed by Lundquist et al., 2008
Data Sources: USGS, ESRI
Projection: NAD83 UTM Zone 13N (EPSG: 26913)
Created in QGIS 2.18.3 with GRASS 7.2.0, and SAGA 4.1.0

FOSS4G Final Project Report

Mapping areas of cold-air pooling (CAP) in Rocky Mountain National Park (RMNP)

Preliminary Concept Outline

As the climate warms, species that have adapted to the harsh cold conditions of the alpine zone will face two options to avoid extinction: move to stay within a suitable temperature range or adapt to the new climate conditions. Given the rapid rate of warming, however, the former is the only viable option for many species. The direction of predicted range expansion depends heavily on the spatial scale of analysis. Coarse-resolution (> 1 km) spatial data shows exclusively uphill movement, but a fine spatial resolution (< 500 m) is able to show a variety of microclimates that are unresolved at coarse resolutions. Some of these microclimates are actually cooler and moister than the surrounding landscape, providing suitable habitat for alpine plants that may otherwise struggle to survive. These habitat patches, commonly known as climate change refugia, stay cool because they can become decoupled from the free atmosphere. This decoupling helps them warm at a slower rate than the surrounding landscape and retain snowpack later into the spring season. Refugia may therefore mitigate the extinction of cold-adapted species as the climate warms.

The question of how to identify refugia for conservation purposes is one that has been addressed in the literature, but no consensus has been reached. One approach is to map cold-air pools (CAPs). CAPs, which are characteristic of complex mountainous terrain, form under clear night skies in narrow valleys and local depressions. The temperature at the bottom of a CAP can be as much as 10 °C cooler than adjacent ridges, potentially providing suitable habitat for cold-adapted species.

The objective of this project is to identify areas of Rocky Mountain National Park (RMNP) as CAP-prone, ambivalent, or not prone to CAP. I will use 30-m DEMs and HUC12 watershed boundaries that are publicly available online through the USGS National Map (TNM) online download service. I will use GRASS tools to calculate flow accumulation & direction (*r.flow*), topographic index (*r.topidx*), slope (*r.slope*), and curvature (*r.slope.aspect*). Using these layers, I will develop a scoring criteria for designating pixels as prone to CAP, ambivalent, or not prone to CAP. Finally, I will design a map highlighting CAP-prone areas in RMNP using QGIS cartographical tools. This map can be used to develop conservation plans that prioritize CAPs as potential refugia.

Project Area

This project will focus on Rocky Mountain National Park (RMNP), located in northern Colorado (approximately 40.224 to 40.534 latitude, -105.482 to -105.864 longitude). It covers 1,075 square kilometers of the Southern Rocky Mountains and ranges in elevation from 2,396 to 4,346 meters above sea level, making it one of the highest national parks in the continental United States. The Continental Divide runs north to south, and the headwaters of the Colorado River are located in the park's northwestern area. The climatic and topographic diversity has created a diverse array of ecosystems, from alpine tundra to montane forest. The tree line in RMNP varies between 3,400 to 4,000 meters. The alpine zone above tree line is comprised of herbaceous meadows, fell fields, and talus slopes, dominated by grasses, sedges, and willows.

Project Results and Conclusions

Cold-air pooling in RMNP

According to this model, approximately 60% of the land surface area in RMNP experiences CAP (weak CAP: 37.43%, CAP: 16.66%, strong CAP: 5.38%; Figure 1). Only 8.65% of the landscape never experiences CAP, which likely represents points located on ridges or peaks.

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+-----------------------------------------------------------------------------+
|                         Category Information                          |  %  |
|                 #|description                                        |cover|
|-----------------------------------------------------------------------------|
|        0-0.015686|from  to . . . . . . . . . . . . . . . . . . . . . .|  8.65|
|0.988235-1.003922|from  to . . . . . . . . . . . . . . . . . . . . . .| 31.88|
|1.992157-2.007843|from  to . . . . . . . . . . . . . . . . . . . . . .| 37.43|
|2.996078-3.011765|from  to . . . . . . . . . . . . . . . . . . . . . .| 16.66|
|        3.984314-4|from  to . . . . . . . . . . . . . . . . . . . . . .|  5.38|
|-----------------------------------------------------------------------------|
|TOTAL                                                                  |100.00|
+-----------------------------------------------------------------------------+
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Figure 1: Raster statistics showing percent cover of CAP areas in RMNP. This is the output from the GRASS command "r.report".

Lessons learned

The primary thing I learned was the flexibility of open source GIS software and the depth of the support community! While working on this project, I used four different standalone GIS software programs – QGIS, SAGA, Whitebox GAT, and ArcGIS – and three of those were open source. This project was primarily completed in QGIS due to my familiarity with the program that I gained during this course. The only time I opened ArcGIS was to convert a data layer from an ESRI-specific file type to a more universal one (.shp or .tif). SAGA and Whitebox GAT were each used to fill in some gaps in analysis that were missing from the QGIS tools.

As much as I like QGIS, it definitely has its limitations, and I learned a few of them during this project. The main one that I kept running into was the amount of memory & CPU that tools were using up. There were several times when I had to shut down the entire program and restart my computer. In particular, I had many problems with the SAGA tools, which seemed to be better suited for topographical & morphological analysis than the QGIS tools & GRASS

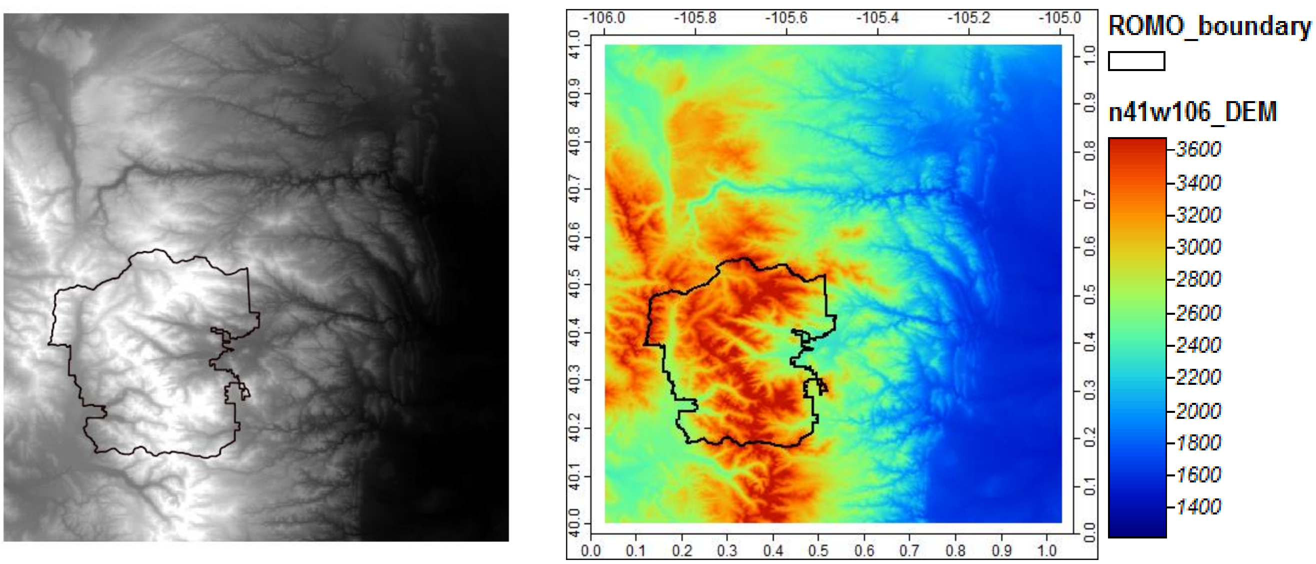

Figure 2: A DEM raster as rendered by QGIS (left) and SAGA (right). RMNP boundary shown in black. The SAGA export also automatically included its legend! (far right)

commands. One SAGA tool wouldn't run at all because it couldn't find the .dll directory. According to a StackExchange response about the issue, QGIS has a compatibility problem with some of the SAGA tools, and this particular user recommended running the tool in the standalone SAGA software. This is why SAGA was included on the list above, and I'm glad I came across that recommendation because I really enjoyed exploring the standalone software. I was impressed with how beautifully the DEM file was rendered (Figure 2).

Finally, I learned that the secondary topographical analyses (meaning they use primary topographical analyses like slope or aspect in their calculations) of curvature and Topographic Position Index (TPI) are complicated and not at all intuitive. They are also not well-explained in the software documentation or anywhere else online. For example, the GRASS command to compute curvature, r.slope.aspect, includes both profile and tangential curvature, but only includes limited information about what these outputs show. In addition, the authors of my primary reference for this project, Lundquist et al. (2008), mention the importance of the user-defined radius in the curvature calculation, but there's no way to adjust the neighborhood radius in the GRASS command. The GRASS tools related to curvature and TPI can be improved and should be the focus of future development.

Recommendations for further analysis and future applications

This project could be strengthened by comparing the theoretical output map to measured land surface temperature (LST). There are two primary ways to do this: (1) use remotely sensed satellite data like LANDSAT, or (2) take measurements in the field. While the former would certainly be less time-consuming and labor-intensive, a major obstacle exists: the spatial resolution of most remotely-sensed LST is too coarse to resolve the complexity of the landscape at scales relevant to CAP processes. In fact, the data is often too coarse many other disciplines that deal with fine-scale processes, including climatology, hydrography, and biogeochemistry. For example, the LANDSAT 30-year normals products have a spatial resolution of 800 meters.

Another approach to obtaining high-resolution temperature data might be to take measurements in the field. These data could then be used to "ground-truth" the locations of CAP vs. non-CAP areas. A network of data loggers can be distributed across the landscape for several months, programmed to record temperature on an hourly basis. Lundquist et al. (2008) used this approach to validate their automated algorithm and found that their algorithm correctly identified 14 out of 17 sites (82%) within the Loch Vale area of RMNP. At approximately $20 per piece, Maxim High-Resolution Thermochron iButtons offer high-resolution temperature recording (±0.2°C) at an accessible price (Lundquist & Lott, 2008).

A future application of this project is to compare current and historic distribution of cold-adapted alpine plants. Some questions to be addressed include: Do plants utilize CAP-prone areas? If not, are there significant landscape barriers (e.g. high ridge) that might prevent them from inhabiting CAP-prone areas? Are there sufficient CAP areas at and above treeline?

The CAP map can also be used to analyze future projections of suitable habitat for cold-dependent fauna, such as the American pika. The pika makes its home in talus fields at or above tree line and is one of the only mammals that spends its entire adult life in the alpine zone. The rapid increase in atmospheric air temperature puts the thermally-sensitive pika at risk of extinction. Some questions to be addressed include: Can CAP-prone areas provide suitable habitat for pika? Are there enough talus fields and herbaceous alpine meadows in CAP-prone areas to support pika? Does pika habitat tend to occur in CAP-prone or non-CAP areas?

Processes and Procedures Involved

- Download 30-m DEM data from the USGS National Map (TNM) online download service (https://viewer.nationalmap.gov/basic/)
- Project in NAD83 UTM Zone 13N
- Process DEM in QGIS:
  - Slope
  - Tangential Curvature
- Process DEM in SAGA:
  - Standardized Height (SH) - Relative Heights and Slope Positions tool
- Reclassify slope raster in QGIS:
  - 0-14.999° = 2
  - 15-29.999° = 1
  - 30-90° = 0
- Use Raster Calculator in QGIS to generate final CAP map (per Lundquist et al., 2008):
  - (Reclassified Slope) + (Tangential Curvature < 0) + (Standardized Height < -76.1243*Slope + 2283.73)
- Clip final raster to RMNP boundary shapefile

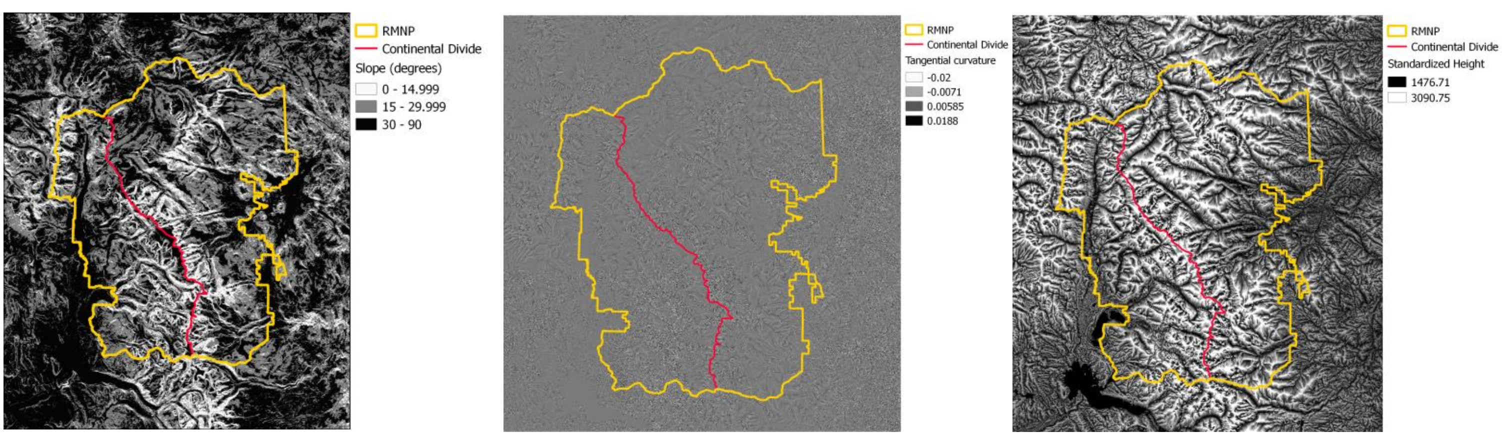

Figure 3: Raster layers used to create CAP map: Slope, reclassified into categories (left); Tangential curvature (center); and Standardized Height (right).

References

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