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Change in Snow Depth due to Increasing CO2 Concentrations in the Western US

Motivation

The primary motivation of our project is to better understand how our changing climate will impact the future of snow in the western United States. It is already well known that anthropogenic CO2 production is affecting the climate on a global scale. We know that this will and already has changed winter snowpack in the US. But we want to look at how this increase in CO2 will affect the snowpack in the future. Understanding how CO2 levels impact snow depth is crucial to the future of water resources, habitat resources, and outdoor recreation. As snowfall decreases, and rainfall increases, there will be less runoff during the summer, as there will be little snow to melt. This will greatly impact water availability that is crucial to both human and wildlife populations. Further, the outdoor recreation economy depends on the winter season for a large portion of their income, along with thousands of jobs. Climate change is expected to continue to shorten the ski season, impacting resorts, hotels, restaurants, mountain towns, parks, and the overall snow sport industry. As passionate environmentalists and avid winter sports enthusiasts, the future of winter in the western US is important to livelihoods. We want to better understand how snow depth will change with increasing CO2 concentrations so that we can personally be prepared for the future of our winters and also educate others about the potential impacts.

Methods

Our hypothesis is that CO2 concentrations doubling and quadrupling will affect Snow Water Equivalent (SWE) and the Amount Of Ice And Snow On Land Change Over Time to decrease throughout the continental United States. To test our hypothesis we used data from the current Coupled Model Intercomparison Project (CMIP6), the Climate Earth System Model (CESM), and python. Specifically, we focused on eight locations across the Western US including Steamboat, CO, Wolf Creek, CO, Taos, NM, Jackson, WY, Bozeman, MT, Ketchum, ID, Snowbird, UT, and Lake Tahoe, CA. These were chosen to pinpoint various mountain ranges, elevations, and popular recreation areas in western US.

To gather historical snowpack data, we used CMIP6 data. This data was compiled to make graphs of snow depth from the eight different locations in the western US from 2000 to 2014. In CMIP6, SND or “Snow Depth Over Land" is the variable used.We then ran a pair of 20 year projections using the CESM. These runs were fully coupled climate models looking at two different CO2 levels, a doubling and a quadrupling of CO2. For the doubling of CO2 concentration we gave the model an initial value of 569.4 ppm, and for the quadrupling of CO2 concentration we gave the model a value of 1138.8 ppm. The output of both of these models focus on the SWE & Amount Of Ice And Snow On Land Change Over Time. This model was run for the same locations as the CMIP6 model. In CESM, SNOWHLND or “Water Equivalent Snow Depth” is the variable used.

The three final data sets from the CMIP6 run and the CESM doubling and quadrupling runs were then compared to find what the impact of CO2 doubling and quadrupling would have on our environment and to better understand the impacts of anthropogenic warming.

Results

CMIP 6 Data

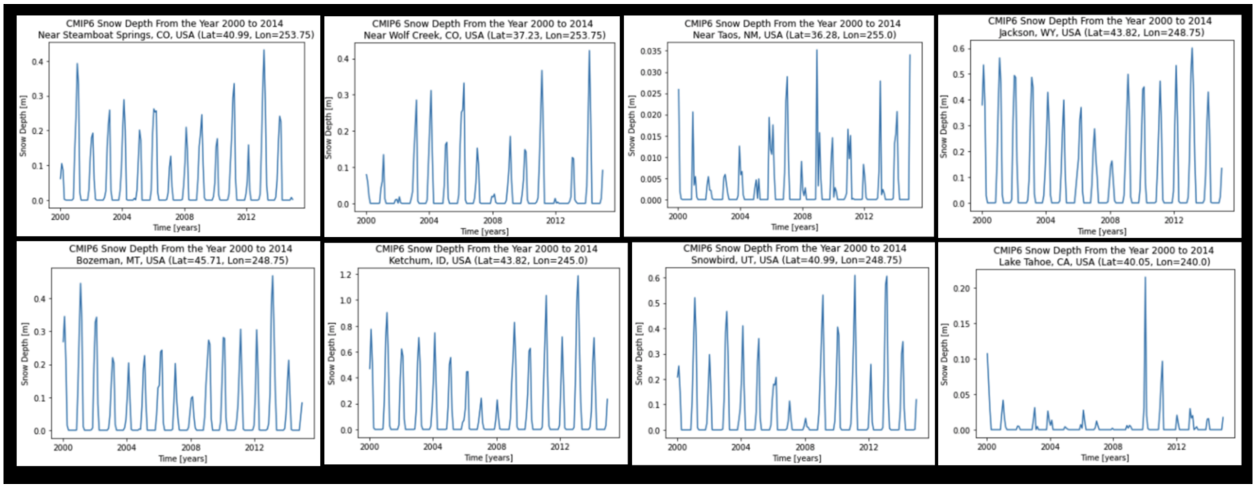

Figure 1. CMIP6 snow depth from 2000-2014 at Steamboat, CO, Wolf Creek, CO, Taos, NM, Jackson, WY, Bozeman, MT, Ketchum, ID, Snowbird, UT, and Lake Tahoe, CA

Figure 1. from the CMIP6 data shows the variability in snow depth from the years 2000-2014 in the eight locations we focused on. There is no general trend in any of the figures as it is too short of a time period to see any major changes. We are using these graphs not to show the general trend of historical snow depth, but rather to exemplify the natural variability present in the system. These graphs were used to compare with the CESM data and confirm that doubling and quadrupling will have an impact on snow depth.

CESM Data: Doubling and Quadrupling of CO2 Concentrations Over 20 Years

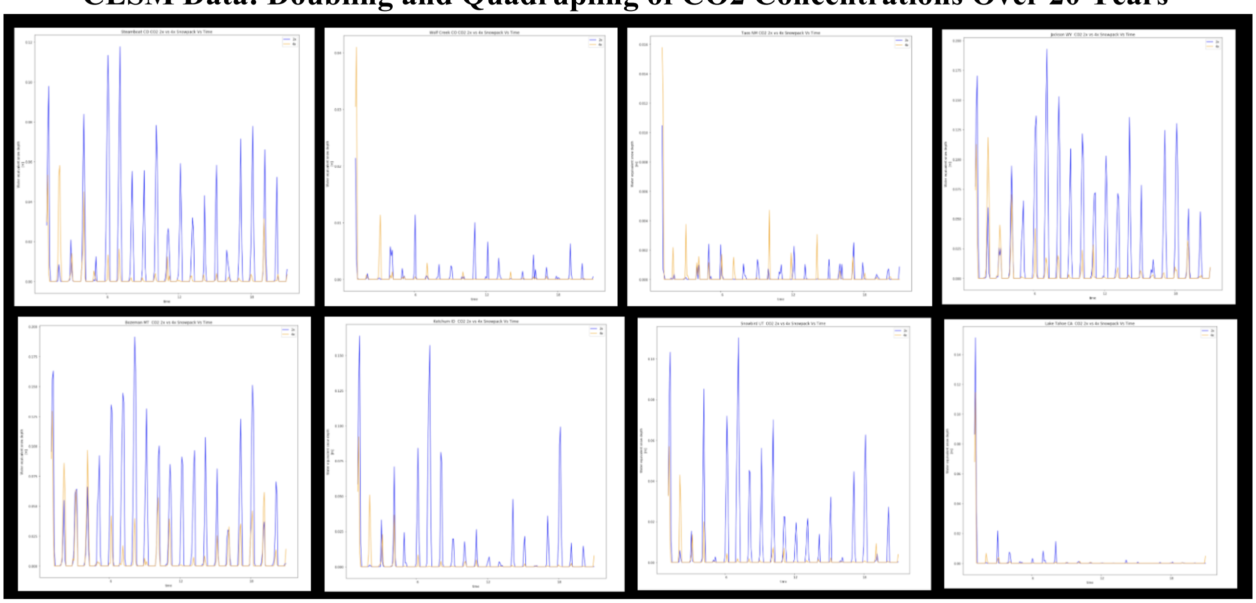

Figure 2. SWE over the next 20 years with doubling (purple) and quadrupling (yellow) of CO2 for the eight locations.

Figures 2.1 - 2.8 represent the change in snow depth over the next 20 years with the doubling and quadrupling of CO2 for the eight different locations we focused on. Snow depth is measured through snow water equivalent (SWE). Overall, these trends highlight a quick decrease of SWE over time, with the quadrupling of CO2 being much more abrupt than doubling.

CESM Data: Linear Trend of Snow Depth over 20 years

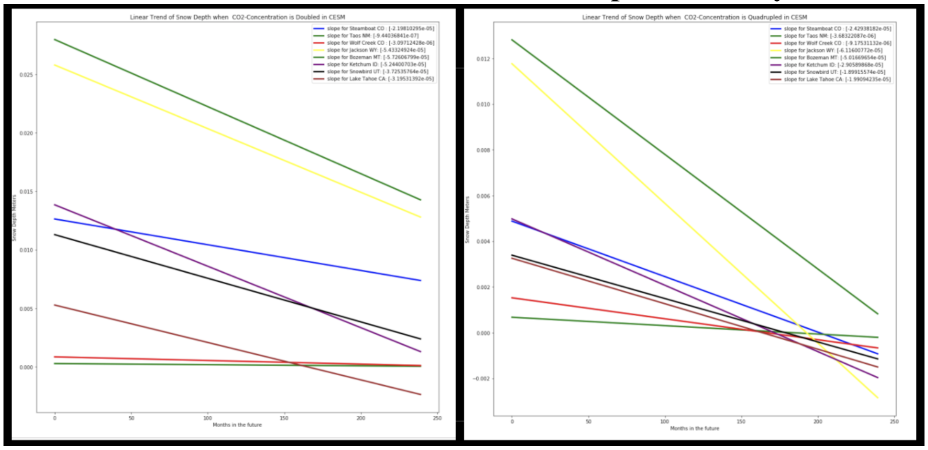

Figure 3. The linear trends of snow depth for the eight locations over a 20 year period when CO_2 concentrations are doubled (left) and quadrupled (right) in CESM.

Figures 3.1 and **3.2** represent the linear trend of snow depth when CO_2 is doubled and quadrupled for the eight locations over the next 20 years. For both runs, doubling and quadrupling of CO_2, there is an overall downward trend in snow depth with time. The decreasing trend for quadrupling of CO_2 is much more severe than the doubling trend over time.

Discussion

When we created these plots showing the trend of the snowpack depth with increased CO_2 concentration, we can clearly see that the trend in all of the locations we chose is negative. This means that no matter the location in the Western U.S., there is likely to be a decrease in SWE as CO_2 concentrations increase. The severity of the decrease in SWE is very variable between locations (with the smallest magnitude slope being 9.4e-7 m/month near Taos, NM with a doubling of CO_2 and the largest magnitude being 5.7e-5 m/month near Bozeman, MT with a doubling of CO_2) is significantly variable, as expected, but it is very interesting to see how the impacts of a doubling versus a quadrupling of CO_2 affect each location.

The most interesting of these variations is between the doubling and quadrupling of CO_2 concentrations in locations like Ketchum, ID where the slope of the change in SWE per month decreases as the CO_2 concentration goes from 2x to 4x. Despite this interesting change it may be explained simply. It would make sense that the slope decreases because as more years go without accumulating a significant snowpack the slope of the linear trend line would decrease (if many years go with 0m SWE the linear trend would have a slope very close to 0m/month). Even based simply off of these trend lines, we see that there would be a SWE of 0m for many locations after about 13 years of a quadrupling of CO_2 concentration. In contrast, when looking at the trend lines with a doubling of CO_2, we see that Lake Tahoe, CA is the only location that clearly passes a SWE of 0m.

Summary

In summary, by running these models, we can clearly see that there is an inverse relationship between the increasing concentration of CO_2 and SWE in the Western U.S. This lines up well with our hypothesis that doubling and quadrupling CO_2 concentrations would decrease SWE and snow coverage across the Western US. With the current CO_2 concentration at roughly 411 ppm, this study shows that drastically increasing the concentration to 569.4 ppm or 1138.8 ppm over the next 20 years would decrease SWE. While doubling does appear to be a better situation than quadrupling, any increase in CO_2 concentration will have negative effects on SWE and in turn impact snow sports, water resources, and the entire outdoor economy.

If the world reaches situations similar to what we have modeled, the world will likely change dramatically. In relation to outdoor winter recreation, water resources, and the economic impacts of tourism, all of these things will suffer. Snow sports will be forced to find new locations farther towards the poles where significant snowpack will still accumulate in the winter or ski resorts will be forced to create more manmade snowpack. By having to use more water to create snow, water resources will take a large hit. This coupled with a smaller snowpack (which stores most of the water resources that sustain humans and the environment) will absolutely alter how humans will have to think about water usage. If winter sport recreationists are forced to find new locations that continue to have significant snowpack over the winters, the towns that currently rely on tourism related to winter sports will suffer heavily.

All in all, the implications of such a dramatically changing snowpack will alter the world as we know it.

References

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